Reference 1

federal register

Friday
December 14, 1990

Part II

Environmental Protection Agency

40 CFR Part 300
Hazard Ranking System; Final Rule

Reference 2

United States
Environmental Protection
Agency

Office of Emergency and
Remedial Response
Washington DC 20460

EPA/540/G-91/013
September 1991

EPA

Guidance for Performing Preliminary Assessments Under CERCLA

Reference 3

Dallas Central Appraisal District

Commercial Account #26241500010010000

Location Owner Legal Desc Value Improvements Land Exemptions Estimated Taxes Building Footprint History

Location (Current 2019)

Address: 1111 S SHILOH RD
Market Area: 0
Mapsco: 29-A (DALLAS)

DCAD Property Map

View Photo

2018 Appraisal Notice

Electronic Documents (ENS)

Print Homestead Exemption Form

Owner (Current 2019)

REALM MANAGEMENT LLC
1301 S SHILOH RD
GARLAND, TEXAS 750428004

Multi-Owner (Current 2019)

Owner Name	Ownership %
REALM MANAGEMENT LLC	100%

Legal Desc (Current 2019)

1: GLOBE UNION
2: BLK A LT 1 ACS 9.408
3:
4: INT201600294401 DD10182016 CO-DC
5: 2415000100100 2CG24150001
Deed Transfer Date: 12/6/2016

Value

2018 Certified Values	
Improvement:	$970,560
Land:	+ $1,229,440
Market Value:	=$2,200,000
Tax Agent: REAL ESTATE TAX CONSULT	
Revaluation Year:	2018
Previous Revaluation Year:	2017

Improvements (Current 2019)

#	Desc: STORAGE WAREHOUSE	Total Area: 168,034 sqft	Year Built: 1970
1	Construction	Depreciation	Appraisal Method

03 001

	Construction: C-MASONRY, BLOCK, TILT-WALL **Foundation (Area):** CONCRETE SLAB (168,034 sqft) **Net Lease Area :** 225,504 sqft **# Stories:** 1 **# Units:** 0 **Basement (Area):** NONE **Heat:** CENTRAL HEAT **A/C:** CENTRAL A/C	**Physical:** 60% **Functional:** + 0% **External:** + 0% **Total:** = 60% **Quality:** AVERAGE **Condition:** GOOD	INCOME

#	**Desc:** STORAGE WAREHOUSE	**Total Area:** 33,200 sqft	**Year Built:** 1969

	Construction	**Depreciation**	**Appraisal Method**
2	**Construction:** C-MASONRY, BLOCK, TILT-WALL **Foundation (Area):** CONCRETE SLAB (33,200 sqft) **Net Lease Area :** 0 sqft **# Stories:** 1 **# Units:** 0 **Basement (Area):** UNASSIGNED **Heat:** CENTRAL HEAT **A/C:** CENTRAL A/C	**Physical:** 60% **Functional:** + 0% **External:** + 0% **Total:** = 60% **Quality:** AVERAGE **Condition:** GOOD	INCOME

#	**Desc:** STORAGE WAREHOUSE	**Total Area:** 18,518 sqft	**Year Built:** 1977

	Construction	**Depreciation**	**Appraisal Method**
3	**Construction:** S-PRE-ENGINEERED STEEL BLDGS **Foundation (Area):** CONCRETE SLAB (18,518 sqft) **Net Lease Area :** 0 sqft **# Stories:** 1 **# Units:** 0 **Basement (Area):** UNASSIGNED **Heat:** CENTRAL HEAT **A/C:** CENTRAL A/C	**Physical:** 60% **Functional:** + 0% **External:** + 0% **Total:** = 60% **Quality:** GOOD **Condition:** GOOD	INCOME

#	**Desc:** STORAGE WAREHOUSE	**Total Area:** 1,952 sqft	**Year Built:** 1983

	Construction	**Depreciation**	**Appraisal Method**
4	**Construction:** C-MASONRY, BLOCK, TILT-WALL **Foundation (Area):** CONCRETE SLAB (1,952 sqft) **Net Lease Area :** 0 sqft **# Stories:** 1 **# Units:** 0 **Basement (Area):** UNASSIGNED **Heat:** CENTRAL HEAT **A/C:** CENTRAL A/C	**Physical:** 59% **Functional:** + 0% **External:** + 0% **Total:** = 59% **Quality:** AVERAGE **Condition:** GOOD	INCOME

#	**Desc:** STORAGE WAREHOUSE	**Total Area:** 3,800 sqft	**Year Built:** 1970

5	**Construction**	**Depreciation**	**Appraisal Method**

03 002

Construction: S-PRE-ENGINEERED STEEL BLDGS **Foundation (Area):** CONCRETE SLAB (3,800 sqft) **Net Lease Area :** 0 sqft **# Stories:** 1 **# Units:** 0 **Basement (Area):** UNASSIGNED **Heat:** CENTRAL HEAT **A/C:** CENTRAL A/C	**Physical:** 60% **Functional:** + 0% **External:** + 0% **Total:** = 60% **Quality:** AVERAGE **Condition:** GOOD	INCOME

03 003

Land (2018 Certified Values)

#	State Code	Zoning	Frontage (ft)	Depth (ft)	Area	Pricing Method	Unit Price	Market Adjustment	Adjusted Price	Ag Land
1	COMMERCIAL IMPROVEMENTS	MEDIUM INDUSTRIAL DISTRICT	0	0	409,812.0000 SQUARE FEET	STANDARD	$3.00	0%	$1,229,436	N

*** All Exemption information reflects 2018 Certified Values. ***

Exemptions (2018 Certified Values)

No Exemptions

Estimated Taxes (2018 Certified Values)

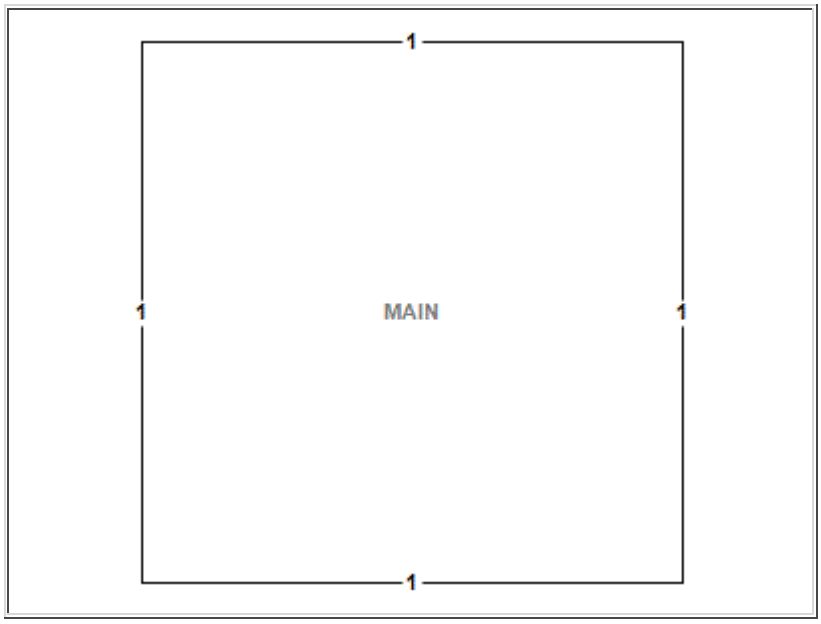
	City	School	County and School Equalization	College	Hospital	Special District
Taxing Jurisdiction	GARLAND	GARLAND ISD	DALLAS COUNTY	DALLAS CO COMMUNITY COLLEGE	PARKLAND HOSPITAL	UNASSIGNED
Tax Rate per $100	$0.7046	$1.46	$0.2531	$0.124	$0.2794	N/A
Taxable Value	$2,200,000	$2,200,000	$2,200,000	$2,200,000	$2,200,000	$0
Estimated Taxes	$15,501.20	$32,120.00	$5,568.20	$2,728.00	$6,146.80	N/A
Tax Ceiling					N/A	N/A
					Total Estimated Taxes:	**$62,064.20**

DO NOT PAY TAXES BASED ON THESE ESTIMATED TAXES. You will receive an **official tax bill** from the appropriate agency when they are prepared. Please note that if there is an Over65 or Disabled Person **Tax Ceiling** displayed above, **it is NOT reflected** in the Total Estimated Taxes calculation provided. Taxes are collected by the agency sending you the **official** tax bill. To see a listing of agencies that collect taxes for your property. **Click Here**

The estimated taxes are provided as a courtesy and should not be relied upon in making financial or other decisions. The Dallas Central Appraisal District (DCAD) does not control the tax rate nor the amount of the taxes, as that is the responsibility of each Taxing Jurisdiction. Questions about your taxes should be directed to the appropriate taxing jurisdiction. We cannot assist you in these matters. These tax estimates are calculated by using the most current certified taxable value multiplied by the most current tax rate. **It does not take into account other special or unique tax scenarios, like a tax ceiling, etc.**. If you wish to calculate taxes yourself, you may use the Tax Calculator to assist you.

Building Footprint (Current 2019)

03 004



History

History

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03 005

Dallas Central Appraisal District

This website is for informational purposes only. Title research should be performed at the appropriate County Clerks office. This is not deemed a legal document.

Account History #26241500010010000

Owner Legal Desc Market Value Taxable Value Exemptions

Owner / Legal Description

Year	Owner	Legal Description
2018	REALM MANAGEMENT LLC 1301 S SHILOH RD GARLAND, TEXAS 750428004	**1:** GLOBE UNION **2:** BLK A LT 1 ACS 9.408 **3:** **4:** INT201600294401 DD10182016 CO-DC **5:** 2415000100100 2CG24150001 Deed Transfer Date: 12/6/2016
2017	REALM MANAGEMENT LLC 1301 S SHILOH RD GARLAND, TEXAS 750428004	**1:** GLOBE UNION **2:** BLK A LT 1 ACS 9.408 **3:** **4:** INT201600294401 DD10182016 CO-DC **5:** 2415000100100 2CG24150001 Deed Transfer Date: 12/6/2016
2016	RALHAN DINESH & MANEE 2141 TEAL COURT LEWISVILLE, TEXAS 750777664	**1:** GLOBE UNION **2:** BLK A LT 1 ACS 9.408 **3:** **4:** INT201300117004 DD03272013 CO-DC **5:** 2415000100100 2CG24150001 Deed Transfer Date: 4/16/2013
2015	RALHAN DINESH & MANEE 2141 TEAL COURT LEWISVILLE, TEXAS 750777664	**1:** GLOBE UNION **2:** BLK A LT 1 ACS 9.408 **3:** **4:** INT201300117004 DD03272013 CO-DC **5:** 2415000100100 2CG24150001 Deed Transfer Date: 4/16/2013
2014	RALHAN DINESH & MANEE 2141 TEAL COURT LEWISVILLE, TEXAS 750777664	**1:** GLOBE UNION **2:** BLK A LT 1 ACS 9.408 **3:** **4:** INT201300117004 DD03272013 CO-DC **5:** 2415000100100 2CG24150001 Deed Transfer Date: 4/16/2013
2013	RALHAN DINESH & MANEE 2141 TEAL COURT LEWISVILLE, TEXAS 750777664	**1:** GLOBE UNION **2:** BLK A LT 1 ACS 9.408 **3:** **4:** INT201300117004 DD03272013 CO-DC **5:** 2415000100100 2CG24150001 Deed Transfer Date: 4/16/2013
2012	GRAND SIX LLC 917 MILITARY PKWY MESQUITE, TEXAS 751494122	**1:** GLOBE UNION **2:** BLK A LT 1 ACS 9.408 **3:** **4:** INT201100113460 DD05032011 CO-DC **5:** 2415000100100 2CG24150001

03 006

		Deed Transfer Date: 5/4/2011
2011	GRAND SIX LLC 917 MILITARY PKWY MESQUITE, TEXAS 751494122	**1:** GLOBE UNION **2:** BLK A LT 1 ACS 9.408 **3:** **4:** INT201100113460 DD05032011 CO-DC **5:** 2415000100100 2CG24150001 Deed Transfer Date: 5/4/2011
2010	BELL RODERICK L 1111 S SHILOH RD GARLAND, TEXAS 750428047	**1:** GLOBE UNION **2:** BLK A LT 1 ACS 9.408 **3:** **4:** VOL98211/0766 DD102698 CO-DALLAS **5:** 2415000100100 32624150001 Deed Transfer Date: 10/27/1998
2009	BELL RODERICK L 1111 S SHILOH RD GARLAND, TEXAS 750428047	**1:** GLOBE UNION **2:** BLK A LT 1 ACS 9.408 **3:** **4:** VOL98211/0766 DD102698 CO-DALLAS **5:** 2415000100100 32624150001 Deed Transfer Date: 10/27/1998
2008	BELL RODERICK L 1111 S SHILOH RD GARLAND, TEXAS 750428047	**1:** GLOBE UNION **2:** BLK A LT 1 ACS 9.408 **3:** **4:** VOL98211/0766 DD102698 CO-DALLAS **5:** 2415000100100 32624150001 Deed Transfer Date: 10/27/1998
2007	BELL RODERICK L 1111 S SHILOH RD GARLAND, TEXAS 750428047	**1:** GLOBE UNION **2:** BLK A LT 1 ACS 9.408 **3:** **4:** VOL98211/0766 DD102698 CO-DALLAS **5:** 2415000100100 32624150001 Deed Transfer Date: 10/27/1998
2006	BELL RODERICK L 1111 S SHILOH RD GARLAND, TEXAS 750428047	**1:** GLOBE UNION **2:** BLK A LT 1 ACS 9.408 **3:** **4:** VOL98211/0766 DD102698 CO-DALLAS **5:** 2415000100100 32624150001 Deed Transfer Date: 10/27/1998
2005	BELL RODERICK L 1111 S SHILOH RD GARLAND, TEXAS 750428047	**1:** GLOBE UNION **2:** BLK A LT 1 ACS 9.408 **3:** **4:** VOL98211/0766 DD102698 CO-DALLAS **5:** 2415000100100 32624150001 Deed Transfer Date: 10/27/1998
2004	BELL RODERICK L 1111 S SHILOH RD GARLAND, TEXAS 750428047	**1:** GLOBE UNION **2:** BLK A LT 1 ACS 9.408 **3:** **4:** VOL98211/0766 DD102698 CO-DALLAS **5:** 2415000100100 32624150001 Deed Transfer Date: 10/27/1998
2003	BELL RODERICK L 1111 S SHILOH RD GARLAND, TEXAS 750428047	**1:** GLOBE UNION **2:** BLK A LT 1 ACS 9.408 **3:** **4:** VOL98211/0766 DD102698 CO-DALLAS

03 007

		5: 2415000100100 32624150001 Deed Transfer Date: 10/27/1998
2002	BELL RODERICK L 1111 S SHILOH RD GARLAND, TEXAS 750428047 UNASSIGNED	**1:** GLOBE UNION **2:** BLK A LT 1 ACS 9.408 **3:** **4:** VOL98211/0766 DD102698 CO-DALLAS **5:** 2415000100100 32624150001 Deed Transfer Date: 1/1/1900
2001	BELL RODERICK L 1111 S SHILOH RD GARLAND, TEXAS 750428047 UNASSIGNED	**1:** GLOBE UNION **2:** BLK A LT 1 ACS 9.408 **3:** **4:** VOL98211/0766 DD102698 CO-DALLAS **5:** 2415000100100 32624150001 Deed Transfer Date: 1/1/1900
2000	BELL RODERICK L 1111 S SHILOH RD GARLAND, TEXAS 750428047 UNASSIGNED	**1:** GLOBE UNION **2:** BLK A LT 1 ACS 9.408 **3:** **4:** VOL98211/0766 DD102698 CO-DALLAS **5:** 2415000100100 32624150001 Deed Transfer Date: 1/1/1900
1999	BELL RODERICK L 1111 S SHILOH RD GARLAND, TEXAS 750428047 UNASSIGNED	**1:** GLOBE UNION **2:** BLK A LT 1 ACS 9.408 **3:** **4:** VOL98211/0766 DD102698 CO-DALLAS **5:** 2415000100100 32624150001 Deed Transfer Date: 1/1/1900

03 008

REPORT: JABR529D — DALLAS COUNTY APPRAISAL DISTRICT — PAGE 69495

DATE 08/19/84 — 1982 REAL PROPERTY TAX ROLL FOR: DALLAS COUNTY

DCAD ACCOUNT NUMBER / JURISDICTION ACCT NUM / TAXPAYER NAME/ADDRESS	SPTB CODE / ACREAGE	LOCATION OF PROPERTY / LEGAL DESCRIPTION OF PROPERTY	ENTITY CODES CITY / CNTY / ISD	COLL / HOSP / SPDS	EXEMPTIONS TYPE / SPLIT PCT	AMOUNT	TAX CEILING AMT / AGRIC USE CODE / AGRIC ADJ VALUE	LAND VALUE / IMPROVE VALUE / MARKET VALUE / TAXABLE VALUE
JOURNAL ENTRIES: 26240500070050000 / 26240500070050000	000 000	000 1705 FREEMONT	DR	CG	DO			$5,000
ACKLIN ANTHONY	C1 110	GLENFIELD ADDN		DC	PH			$0
2009 BERWICK		BLK 7 LT 0005						$5,000
DALLAS TX 75203		VOL82168 PG2465		GS				$5,000
		4803850700500	32624050007					
JOURNAL ENTRIES: 26240500070060000 / 26240500070060000	000 000	000 1709 FREEMONT	DR	CG	DO			$6,000
LOPEZ JUAN	A1 111	GLENFIELD ADDN		DC	PH			$17,320
1709 FREEMONT		LT 0006						$23,320
GARLAND TX 75040		00007		GS				$23,320
		4803850700600	32624050007					
JOURNAL ENTRIES: 26240500070070000 / 26240500070070000	000 000	000 1713 FREEMONT	DR	CG	DO			$6,000
EDWARDS R A	A1 111	GLENFIELD ADDN		DC	PH			$17,320
819 W GARLAND AVE		LT 0007						$23,320
GARLAND TX 75040		00007		GS				$23,320
		4803850700700	32624050007					
JOURNAL ENTRIES: 26240500070080000 / 26240500070080000	000 000	000 1717 FREEMONT	DR	CG	DO			$6,000
EDWARDS R A	A1 111	GLENFIELD ADDN		DC	PH			$32,450
819 W GARLAND AVE		LT 0008						$38,450
GARLAND TX 75040		00007		GS				$38,450
		4803850700800	32624050007					
JOURNAL ENTRIES: 26241500010010000 / 26241500010010000	000 000	000 1111 SHILOH	RD	CG	DO			$409,810
JOHNSON CONTROLS INC	F1 411	GLOBE UNION		DC	PH			$2,944,720
P O BOX 591		LT 0001						$3,354,530
MILWAUKEE WI 52301		A		GS				$3,354,530
		4810780100100	32624150001					

REPORT: JABP860D — DALLAS CENTRAL APPRAISAL DISTRICT — PAGE 65681

DATE 07/25/91 — REAL PROPERTY TAX ROLL FOR DALLAS COUNTY

DCAD ACCOUNT NUMBER / JURISDICTION ACCT NUM / TAXPAYER NAME/ADDRESS	SPTB CODE / ACREAGE	LOCATION OF PROPERTY / LEGAL DESCRIPTION OF PROPERTY	ENTITY CODES: CITY / CNTY / ISD	CODES: COLL / HOSP / SPDS	EXEMPTIONS: TYPE / AMOUNT / SPLIT PCT	TAX CEILING AMT / AGRIC USE CODE / AGRIC ADJ VALUE / AG LAND MKT VALUE	LAND VALUE / IMPROVE VALUE / MARKET VALUE / TAXABLE VALUE
26240500070050000 26240500070050000 ACKLIN ANTHONY 2009 BERWICK DALLAS TX 75203	C11 110	1705 FREMONT GLENFIELD ADDN BLK 7 LT 5 VOL82168 PG2465 CO-DALLAS 2405000700500 32624050007	DR DC GS	CG PH	DO		6,500 0 6,500 6,500
26240500070060000 26240500070060000 CHINSKE FRED L 2909 WANDA WAY SEAGOVILLE TX 75159	A11 111	1709 FREEMONT GLENFIELD ADDN BLK 7 LOT 6 VOL89242/1918 EX120889 CO-DALLAS 2405000700600 32624050007	DR DC GS	CG PH	DO		6,500 22,150 28,650 28,650
26240500070070000 26240500070070000 GARLAND GENERAL AGENCY 819 W MAIN ST GARLAND TX 75040	A11 111	1713 FREMONT GLENFIELD ADDN BLK 7 LOT 7 VOL87100/3432 EX042086 CO-DALLAS 2405000700700 32624050007	DR DC GS	CG PH	DO		6,500 21,650 28,150 28,150
26240500070080000 26240500070080000 GARLAND GENERAL AGENCY 819 W MAIN ST GARLAND TX 75040	A11 111	1717 FREEMONT GLENFIELD ADDN BLK 7 LOT 8 VOL87100/3432 EX042086 CO-DALLAS 2405000700800 32624050007	DR DC GS	CG PH	DO		6,500 29,760 36,260 36,260
26241500010010000 26241500010010000 JOHNSON CONTROLS BATTERY GROUP INC P O BOX 591 MILWAUKEE WI 53201	F20 421	1111 S SHILOH GLOBE UNION BLK A LOT 1 VOL90249/0076 EX122090 CO-DALLAS 2415000100100 32624150001	RD DC GS	CG PH	DO		1,229,440 3,428,380 4,657,820 4,657,820

REPORT NO JABP860D-001 — D A L L A S C E N T R A L A P P R A I S A L D I S T R I C T — PAGE 57,349
REPORT DATE 07/22/1999 — REAL PROPERTY TAX ROLL FOR DALLAS COUNTY
REAL PROPERTY TAX-YEAR: 1999

DCAD ACCOUNT NUMBER / JURIS ACCOUNT NUMBER / TAXPAYER NAME / TAXPAYER ADDRESS	LOCATION OF PROPERTY / LEGAL DESCRIPTION OF PROPERTY / SPTB CODE / REVAL YR	PROP CLASS / PR REVAL YR	ACREAGE	CITY COLL / CNTY HOSP / ISD SPDS / SPLIT PCT	MULTI OWNER EXEMPTIONS TYPE	AMOUNT	OWNER PCT / TAX CEIL DATE / AG USE CODE / AG ADJ VAL / AG LND MKT VAL	TAX CEIL AMT / DEFER CAP AMT / CAP VAL LOSS	LAND VALUE / IMPV VALUE / MKT VALUE / CPD HS VAL / TXBL VALUE
26240500070080000 26240500070080000 GARLAND GENERAL AGENCY 819 MAIN ST GARLAND TX 75040-6220	1717 FREEMONT GLENFIELD BLK 7 LOT 8 VOL97100/3432 EX042086 CO-DALLAS 2405000700800 All 1999	DR 32624050007 111 1997		CG DO DC PH GS		1 0 0 0 0 0 0 0 0 0	100 0 0 	00.00 00.00 00.00 0 0 0 0	8,500 34,440 42,940 0 0 0 42,940
26241500010010000 26241500010010000 BELL RODERICK L 1111 S SHILOH RD GARLAND 75042-8047	1111 S SHILOH GLOBE UNION BLK A LT 1 ACS 9.408 VOL98211/0766 DD102698 CO-DALLAS 2415000100100 F20 1999	RD 32624150001 421 1998		CG DO DC PH GS		1 0 0 0 0 0 0 0 0 0	100 0 0 	00.00 00.00 00.00 0 0 0 0	532,760 920,240 1,453,000 0 0 0 1,453,000
26242500010010000 26242500010010000 REED JACKIE 1415 DAIRY RD GARLAND TX 75040-8007	901 RICHARD GLYNNHILL ESTATES BLK 1 LOT 1 VOL94176/0340 DD090294 CO-DALLAS 2425000100100 All 1999	DR 32624250001 111 1997		CG DO DC PH GS		1 0 0 0 0 0 0 0 0 0	100 0 0 	00.00 00.00 00.00 0 0 0 0	8,000 26,700 34,700 0 0 0 34,700
26242500010020000 26242500010020000 TORRES RAMON ALFONSO & EVA 905 RICHARD DR GARLAND TX 75040-7404	905 RICHARD GLYNNHILL ESTATES BLK 1 LOT 2 VOL97113/3386 DD050197 CO-DALLAS 2425000100200 All 1999	DR 32624250001 111 1997		CG DO DC PH GS	HSTD 6,918	1 0 0 0 0 0 0 0 0 0	100 0 0 	00.00 00.00 00.00 0 0 0 0	8,000 26,590 34,590 0 0 0 27,672
26242500010030000 26242500010030000 MALCOLM NETTIE 913 RICHARD DR GARLAND 75040-7404	913 RICHARD GLYNNHILL ESTATES BLK 1 LOT 3 VOL98185/6881 DD022996 CO-DALLAS 2425000100300 All 1999	DR 32624250001 111 1997		CG DO DC PH GS		1 0 0 0 0 0 0 0 0 0	100 0 0 	00.00 00.00 00.00 0 0 0 0	8,000 64,260 72,260 0 0 0 72,260
26242500010040000 26242500010040000 CASTILLO TONY S 917 RICHARD DR GARLAND 75040-7404	917 RICHARD GLYNNHILL ESTATES LT 0004 0001 VOL 86052 PG 2195 4803870100400 All 1999	DR CO-DALLAS 32624250001 111 1997		CG DO DC PH GS	HSTD 6,942	1 0 0 0 0 0 0 0 0 0	100 0 0 	00.00 00.00 00.00 0 0 0 0	8,000 26,710 34,710 0 0 0 27,768

Market Value

Year	Improvement	Land	Total Market	Homestead Capped
2018	$970,560	$1,229,440	$2,200,000	N/A
2017	$970,560	$1,229,440	$2,200,000	N/A
2016	$1,435,420	$819,620	$2,255,040	N/A
2015	$1,435,420	$819,620	$2,255,040	N/A
2014	$882,700	$819,620	$1,702,320	N/A
2013	$882,700	$819,620	$1,702,320	N/A
2012	$882,700	$819,620	$1,702,320	N/A
2011	$1,806,840	$819,620	$2,626,460	N/A
2010	$1,806,840	$819,620	$2,626,460	N/A
2009	$1,806,840	$819,620	$2,626,460	N/A
2008	$1,806,840	$819,620	$2,626,460	N/A
2007	$1,440,550	$819,620	$2,260,170	N/A
2006	$1,686,430	$573,740	$2,260,170	N/A
2005	$1,626,260	$573,740	$2,200,000	N/A
2004	$1,626,260	$573,740	$2,200,000	N/A
2003	$1,626,260	$573,740	$2,200,000	N/A
2002	$425,260	$573,740	$999,000	N/A
2001	$392,240	$532,760	$925,000	N/A
2000	$392,240	$532,760	$925,000	N/A
1999	$920,240	$532,760	$1,453,000	N/A

Taxable Value

Year	City	ISD	County	College	Hospital	Special District
2018	$2,200,000	$2,200,000	$2,200,000	$2,200,000	$2,200,000	$0
2017	$2,200,000	$2,200,000	$2,200,000	$2,200,000	$2,200,000	$0
2016	$2,255,040	$2,255,040	$2,255,040	$2,255,040	$2,255,040	$0
2015	$2,255,040	$2,255,040	$2,255,040	$2,255,040	$2,255,040	$0
2014	$1,702,320	$1,702,320	$1,702,320	$1,702,320	$1,702,320	$0
2013	$1,702,320	$1,702,320	$1,702,320	$1,702,320	$1,702,320	$0
2012	$1,702,320	$1,702,320	$1,702,320	$1,702,320	$1,702,320	$0
2011	$2,626,460	$2,626,460	$2,626,460	$2,626,460	$2,626,460	$0
2010	$2,626,460	$2,626,460	$2,626,460	$2,626,460	$2,626,460	$0
2009	$2,626,460	$2,626,460	$2,626,460	$2,626,460	$2,626,460	$0
2008	$2,626,460	$2,626,460	$2,626,460	$2,626,460	$2,626,460	$0
2007	$2,260,170	$2,260,170	$2,260,170	$2,260,170	$2,260,170	$0
2006	$2,260,170	$2,260,170	$2,260,170	$2,260,170	$2,260,170	$0
2005	$2,200,000	$2,200,000	$2,200,000	$2,200,000	$2,200,000	$0
2004	$2,200,000	$2,200,000	$2,200,000	$2,200,000	$2,200,000	$0
2003	$2,200,000	$2,200,000	$2,200,000	$2,200,000	$2,200,000	$0
2002	$999,000	$999,000	$999,000	$999,000	$999,000	$0
2001	$925,000	$925,000	$925,000	$925,000	$925,000	$0

03 012

2000	$925,000	$925,000	$925,000	$925,000	$925,000	$0
1999	$1,453,000	$1,453,000	$1,453,000	$1,453,000	$1,453,000	$0

Exemptions

2018	No Exemptions
2017	No Exemptions
2016	No Exemptions
2015	No Exemptions
2014	No Exemptions
2013	No Exemptions
2012	No Exemptions
2011	No Exemptions
2010	No Exemptions
2009	No Exemptions
2008	No Exemptions
2007	No Exemptions
2006	No Exemptions
2005	No Exemptions
2004	No Exemptions
2003	No Exemptions
2002	No Exemptions
2001	No Exemptions
2000	No Exemptions
1999	No Exemptions

Exemption Details History

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03 013

Dallas Central Appraisal District

Business Personal Property Account #99200108500013600

Location Owner Value Exemptions Estimated Taxes History

Property Location (Current 2019)

Address: 1111 S SHILOH RD
Suite: AADVA
Mapsco: 29-A (DALLAS)

DCAD Property Map

View Photo

2018 Appraisal Notice

Electronic Documents (ENS)

FILE YOUR BPP RENDITION ON-LINE

Owner (Current 2019)

AADVANCED WATERMANAGEMENT INC
1111 S SHILOH RD
GARLAND, TEXAS 750428047

DBA: AADVANCED WATER MANAGEMENT INC

Value

2018 Certified Values

Total: $19,490

Exemptions (2018 Certified Values)

No Exemptions

Estimated Taxes (2018 Certified Values)

	City	School	County and School Equalization	College	Hospital	Special District
Taxing Jurisdiction	GARLAND	GARLAND ISD	DALLAS COUNTY	DALLAS CO COMMUNITY COLLEGE	PARKLAND HOSPITAL	UNASSIGNED
Tax Rate per $100	$0.7046	$1.46	$0.2531	$0.124	$0.2794	N/A
Taxable Value	$19,490	$19,490	$19,490	$19,490	$19,490	$0
Estimated Taxes	$137.33	$284.55	$49.33	$24.17	$54.46	N/A
Tax Ceiling					N/A	N/A
					Total Estimated Taxes:	**$549.83**

03 014

DO NOT PAY TAXES BASED ON THESE ESTIMATED TAXES. You will receive an **official tax bill** from the appropriate agency when they are prepared. Please note that if there is an Over65 or Disabled Person **Tax Ceiling** displayed above, **it is NOT reflected** in the Total Estimated Taxes calculation provided. Taxes are collected by the agency sending you the **official** tax bill. To see a listing of agencies that collect taxes for your property. **Click Here**

The estimated taxes are provided as a courtesy and should not be relied upon in making financial or other decisions. The Dallas Central Appraisal District (DCAD) does not control the tax rate nor the amount of the taxes, as that is the responsibility of each Taxing Jurisdiction. Questions about your taxes should be directed to the appropriate taxing jurisdiction. We cannot assist you in these matters. These tax estimates are calculated by using the most current certified taxable value multiplied by the most current tax rate. **It does not take into account other special or unique tax scenarios, like a tax ceiling, etc.**. If you wish to calculate taxes yourself, you may use the Tax Calculator to assist you.

History

History

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03 015

This website is for informational purposes only. Title research should be performed at the appropriate County Clerks office. This is not deemed a legal document.

Account History #99200108500013600

Owner Legal Desc Market Value Taxable Value Exemptions

Owner / Legal Description

Year	Legal Owner	Doing Business As (DBA)
2018	AADVANCED WATERMANAGEMENT INC 1111 S SHILOH RD GARLAND, TEXAS 750428047	**1:** AADVANCED WATER MANAGEMENT INC **2:** **3:** **4:** **5:** Deed Transfer Date:
2017	AADVANCED WATERMANAGEMENT INC STE 2 2179 S SHILOH RD GARLAND, TEXAS 750411352	**1:** AADVANCED WATER MANAGEMENT INC **2:** **3:** **4:** **5:** Deed Transfer Date:
2016	AADVANCED WATERMANAGEMENT INC STE 2 2179 S SHILOH RD GARLAND, TEXAS 750411352	**1:** AADVANCED WATER MANAGEMENT INC **2:** **3:** **4:** **5:** Deed Transfer Date:
2015	AADVANCED WATERMANAGEMENT INC STE 2 2179 S SHILOH RD GARLAND, TEXAS 750411352	**1:** AADVANCED WATER MANAGEMENT INC **2:** **3:** **4:** **5:** Deed Transfer Date:
2014	AADVANCED WATERMANAGEMENT INC STE 2 2179 S SHILOH RD GARLAND, TEXAS 750411352	**1:** AADVANCED WATER MANAGEMENT INC **2:** **3:** **4:** **5:** Deed Transfer Date:
2013	AADVANCED WATERMANAGEMENT INC STE 2 2179 S SHILOH RD GARLAND, TEXAS 750411352	**1:** AADVANCED WATER MANAGEMENT INC **2:** **3:** **4:** **5:** Deed Transfer Date:
2012	AADVANCED WATERMANAGEMENT INC STE 2 2179 S SHILOH RD GARLAND, TEXAS 750411352	**1:** AADVANCED WATER MANAGEMENT INC **2:** **3:** **4:** **5:**

03 016

		Deed Transfer Date:
2011	AADVANCED WATERMANAGEMENT INC STE 2 2179 S SHILOH RD GARLAND, TEXAS 750411352	**1:** AADVANCED WATER MANAGEMENT INC **2:** **3:** **4:** **5:** Deed Transfer Date:
2010	AADVANCED WATERMANAGEMENT INC 1111 S SHILOH RD GARLAND, TEXAS 750428047	**1:** AADVANCED WATER MANAGEMENT INC **2:** **3:** **4:** **5:** Deed Transfer Date:
2009	AADVANCED WATERMANAGEMENT INC 1111 S SHILOH RD GARLAND, TEXAS 750428047	**1:** AADVANCED WATER MANAGEMENT INC **2:** **3:** **4:** **5:** Deed Transfer Date:
2008	AADVANCED WATERMANAGEMENT INC 1111 S SHILOH RD GARLAND, TEXAS 750428047	**1:** AADVANCED WATER MANAGEMENT INC **2:** **3:** **4:** **5:** Deed Transfer Date:
2007	AADVANCED WATER MANAGEMENT INC 1111 S SHILOH RD GARLAND, TEXAS 750428047	**1:** AADVANCED WATER MANAGEMENT INC **2:** **3:** **4:** **5:** Deed Transfer Date:
2006	AADVANCED WATER MANAGEMENT INC 1111 S SHILOH RD GARLAND, TEXAS 750428047	**1:** AADVANCED WATER MANAGEMENT INC **2:** **3:** **4:** **5:** Deed Transfer Date:
2005	AADVANCED WATER MANAGEMENT INC 1111 S SHILOH RD GARLAND, TEXAS 750428047	**1:** AADVANCED WATER MANAGEMENT INC **2:** **3:** **4:** **5:** Deed Transfer Date:
2004	AADVANCED WATER MANAGEMENT INC 1111 S SHILOH RD GARLAND, TEXAS 750428047	**1:** AADVANCED WATER MANAGEMENT INC **2:** **3:** **4:** **5:** Deed Transfer Date:
2003	AADVANCED WATER MANAGEMENT INC 1111 S SHILOH RD GARLAND, TEXAS 750428047	**1:** AADVANCED WATER MANAGEMENT INC **2:** **3:** **4:**

03 017

		5: Deed Transfer Date:
2002	AADVANCED WATER 1111 S SHILOH RD GARLAND, TEXAS 750428047 UNASSIGNED	**1:** AADVANCED WATER MANAGEMENT INC **2:** **3:** **4:** **5:** Deed Transfer Date:
2001	AADVANCED WATER 1111 S SHILOH RD GARLAND, TEXAS 750428047 UNASSIGNED	**1:** AADVANCED WATER MANAGEMENT INC **2:** **3:** **4:** **5:** Deed Transfer Date:

03 018

Market Value

Year	Improvement	Land	Total Market	Homestead Capped
2018	$19,490	$0	$19,490	N/A
2017	$19,490	$0	$19,490	N/A
2016	$19,490	$0	$19,490	N/A
2015	$19,490	$0	$19,490	N/A
2014	$19,490	$0	$19,490	N/A
2013	$19,490	$0	$19,490	N/A
2012	$19,490	$0	$19,490	N/A
2011	$19,490	$0	$19,490	N/A
2010	$19,490	$0	$19,490	N/A
2009	$17,500	$0	$17,500	N/A
2008	$17,500	$0	$17,500	N/A
2007	$17,500	$0	$17,500	N/A
2006	$17,500	$0	$17,500	N/A
2005	$17,500	$0	$17,500	N/A
2004	$17,500	$0	$17,500	N/A
2003	$17,500	$0	$17,500	N/A
2002	$14,000	$0	$14,000	N/A
2001	$12,000	$0	$12,000	N/A

Taxable Value

Year	City	ISD	County	College	Hospital	Special District
2018	$19,490	$19,490	$19,490	$19,490	$19,490	$0
2017	$19,490	$19,490	$19,490	$19,490	$19,490	$0
2016	$19,490	$19,490	$19,490	$19,490	$19,490	$0
2015	$19,490	$19,490	$19,490	$19,490	$19,490	$0
2014	$19,490	$19,490	$19,490	$19,490	$19,490	$0
2013	$19,490	$19,490	$19,490	$19,490	$19,490	$0
2012	$19,490	$19,490	$19,490	$19,490	$19,490	$0
2011	$19,490	$19,490	$19,490	$19,490	$19,490	$0
2010	$19,490	$19,490	$19,490	$19,490	$19,490	$0
2009	$17,500	$17,500	$17,500	$17,500	$17,500	$0
2008	$17,500	$17,500	$17,500	$17,500	$17,500	$0
2007	$17,500	$17,500	$17,500	$17,500	$17,500	$0
2006	$17,500	$17,500	$17,500	$17,500	$17,500	$0
2005	$17,500	$17,500	$17,500	$17,500	$17,500	$0
2004	$17,500	$17,500	$17,500	$17,500	$17,500	$0
2003	$17,500	$17,500	$17,500	$17,500	$17,500	$0
2002	$14,000	$14,000	$14,000	$14,000	$14,000	$0
2001	$12,000	$12,000	$12,000	$12,000	$12,000	$0

03 019

Exemptions

2018	No Exemptions
2017	No Exemptions
2016	No Exemptions
2015	No Exemptions
2014	No Exemptions
2013	No Exemptions
2012	No Exemptions
2011	No Exemptions
2010	No Exemptions
2009	No Exemptions
2008	No Exemptions
2007	No Exemptions
2006	No Exemptions
2005	No Exemptions
2004	No Exemptions
2003	No Exemptions
2002	No Exemptions
2001	No Exemptions

Exemption Details History

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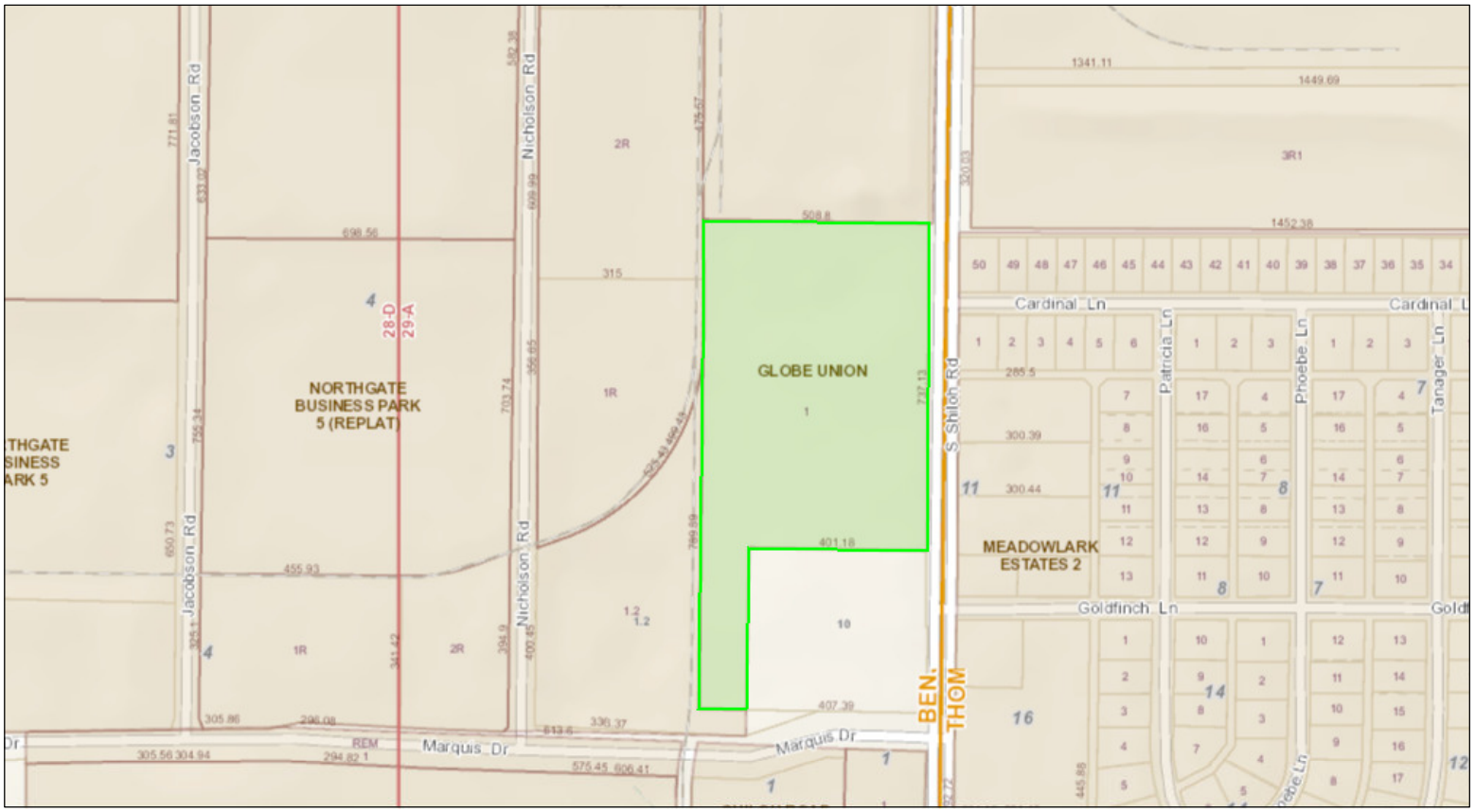
03 020

Former Globe Union

DCAD ID: 26241500010010000

Date of copy: 2/28/2019



This product is for informational purposes only and may not have been prepared for or be suitable for legal, engineering, or surveying purposes. It does not represent an on-the-ground survey and represents only the approximate relative location of property boundaries.

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W E
S

Dallas Central Appraisal District
2949 N Stemmons Freeway
Dallas, TX 75247-6195
(214) 631-1342
www.dallascad.org

1 inch equals 376 feet

0 210 420 840 ft

0 62.5 125 250 m

DCAD, NCTCOG, USGS, Esri,Inc

Commercial Account #650415245101000000

Location Owner Legal Desc Value Improvements Land Exemptions Estimated Taxes Building Footprint History

Location (Current 2019)

Address: 1305 S SHILOH RD
Market Area: 0
Mapsco: 29-A (DALLAS)

DCAD Property Map

View Photo

2018 Appraisal Notice

Electronic Documents (ENS)

Print Homestead Exemption Form

Owner (Current 2019)

REALM MANAGEMENT LLC
1301 S SHILOH RD
GARLAND, TEXAS 750428004

Multi-Owner (Current 2019)

Owner Name	Ownership %
REALM MANAGEMENT LLC	100%

Legal Desc (Current 2019)

1: BENJAMIN DYE ABST 415 PG 245
2: TR 10 ACS 2.7186
3:
4: INT201600294401 DD10182016 CO-DC
5: 0415245101000 2CG04152451
Deed Transfer Date: 12/6/2016

Value

2018 Certified Values	
Improvement:	$188,200
Land:	+ $355,270
Market Value:	=$543,470
Revaluation Year:	2017
Previous Revaluation Year:	2016

Improvements (Current 2019)

#	**Desc:** AUTOMOTIVE SERVICE	**Total Area:** 4,800 sqft	**Year Built:** 1960
	Construction	**Depreciation**	**Appraisal Method**
1	**Construction:** S-PRE-ENGINEERED STEEL BLDGS **Foundation (Area):** CONCRETE SLAB (4,800 sqft)	**Physical:** 60% **Functional:** + 0% **External:** + 0%	INCOME

03 022

Net Lease Area : 4,800 sqft **# Stories:** 1 **# Units:** 0 **Basement (Area):** NONE **Heat:** CENTRAL PARTIAL **A/C:** CENTRAL PARTIAL		**Total:** = 75% **Quality:** AVERAGE **Condition:** GOOD	

03 023

Land (2018 Certified Values)

#	State Code	Zoning	Frontage (ft)	Depth (ft)	Area	Pricing Method	Unit Price	Market Adjustment	Adjusted Price	Ag Land
1	COMMERCIAL IMPROVEMENTS	MEDIUM INDUSTRIAL DISTRICT	0	0	118,422.0000 SQUARE FEET	STANDARD	$3.00	0%	$355,266	N

*** All Exemption information reflects 2018 Certified Values. ***

Exemptions (2018 Certified Values)

No Exemptions

Estimated Taxes (2018 Certified Values)

	City	School	County and School Equalization	College	Hospital	Special District
Taxing Jurisdiction	GARLAND	GARLAND ISD	DALLAS COUNTY	DALLAS CO COMMUNITY COLLEGE	PARKLAND HOSPITAL	UNASSIGNED
Tax Rate per $100	$0.7046	$1.46	$0.2531	$0.124	$0.2794	N/A
Taxable Value	$543,470	$543,470	$543,470	$543,470	$543,470	$0
Estimated Taxes	$3,829.29	$7,934.66	$1,375.52	$673.90	$1,518.46	N/A
Tax Ceiling					N/A	N/A
					Total Estimated Taxes:	**$15,331.83**

DO NOT PAY TAXES BASED ON THESE ESTIMATED TAXES. You will receive an **official tax bill** from the appropriate agency when they are prepared. Please note that if there is an Over65 or Disabled Person **Tax Ceiling** displayed above, **it is NOT reflected** in the Total Estimated Taxes calculation provided. Taxes are collected by the agency sending you the **official** tax bill. To see a listing of agencies that collect taxes for your property. **Click Here**

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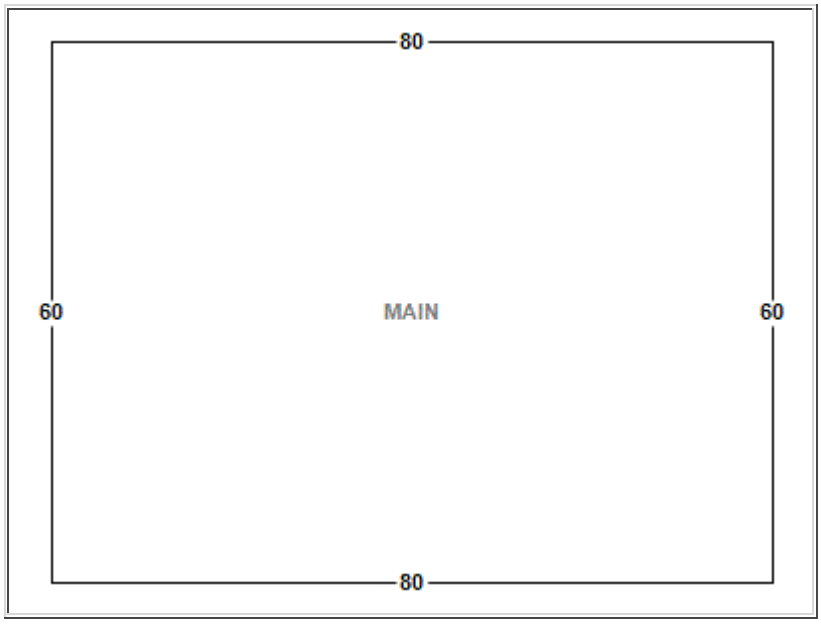
Building Footprint (Current 2019)

03 024



History

History

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03 025

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Account History #650415245101000000

Owner Legal Desc Market Value Taxable Value Exemptions

Owner / Legal Description

Year	Owner	Legal Description
2018	REALM MANAGEMENT LLC 1301 S SHILOH RD GARLAND, TEXAS 750428004	**1:** BENJAMIN DYE ABST 415 PG 245 **2:** TR 10 ACS 2.7186 **3:** **4:** INT201600294401 DD10182016 CO-DC **5:** 0415245101000 2CG04152451 Deed Transfer Date: 12/6/2016
2017	REALM MANAGEMENT LLC 1301 S SHILOH RD GARLAND, TEXAS 750428004	**1:** BENJAMIN DYE ABST 415 PG 245 **2:** TR 10 ACS 2.7186 **3:** **4:** INT201600294401 DD10182016 CO-DC **5:** 0415245101000 2CG04152451 Deed Transfer Date: 12/6/2016
2016	RALHAN DINESH & MANEE 2141 TEAL COURT LEWISVILLE, TEXAS 750777664	**1:** BENJAMIN DYE ABST 415 PG 245 **2:** TR 10 ACS 2.7186 **3:** **4:** INT201300117004 DD03272013 CO-DC **5:** 0415245101000 2CG04152451 Deed Transfer Date: 4/16/2013
2015	RALHAN DINESH & MANEE 2141 TEAL COURT LEWISVILLE, TEXAS 750777664	**1:** BENJAMIN DYE ABST 415 PG 245 **2:** TR 10 ACS 2.7186 **3:** **4:** INT201300117004 DD03272013 CO-DC **5:** 0415245101000 2CG04152451 Deed Transfer Date: 4/16/2013
2014	RALHAN DINESH & MANEE 2141 TEAL COURT LEWISVILLE, TEXAS 750777664	**1:** BENJAMIN DYE ABST 415 PG 245 **2:** TR 10 ACS 2.7186 **3:** **4:** INT201300117004 DD03272013 CO-DC **5:** 0415245101000 2CG04152451 Deed Transfer Date: 4/16/2013
2013	RALHAN DINESH & MANEE 2141 TEAL COURT LEWISVILLE, TEXAS 750777664	**1:** BENJAMIN DYE ABST 415 PG 245 **2:** TR 10 ACS 2.7186 **3:** **4:** INT201300117004 DD03272013 CO-DC **5:** 0415245101000 2CG04152451 Deed Transfer Date: 4/16/2013
2012	GRAND SIX LLC 917 MILITARY PKWY MESQUITE, TEXAS 751494122	**1:** BENJAMIN DYE ABST 415 PG 245 **2:** TR 10 ACS 2.7186 **3:** **4:** INT201100113460 DD05032011 CO-DC **5:** 0415245101000 2CG04152451

03 026

		Deed Transfer Date: 5/4/2011
2011	GRAND SIX LLC 917 MILITARY PKWY MESQUITE, TEXAS 751494122	**1:** BENJAMIN DYE ABST 415 PG 245 **2:** TR 10 ACS 2.7186 **3:** **4:** INT201100113460 DD05032011 CO-DC **5:** 0415245101000 2CG04152451 Deed Transfer Date: 5/4/2011
2010	BELL RODERICK L 1111 S SHILOH RD GARLAND, TEXAS 750428047	**1:** BENJAMIN DYE ABST 415 PG 245 **2:** TR 10 ACS 2.7186 **3:** **4:** VOL98211/0766 DD102698 CO-DALLAS **5:** 0415245101000 32604152451 Deed Transfer Date: 10/27/1998
2009	BELL RODERICK L 1111 S SHILOH RD GARLAND, TEXAS 750428047	**1:** BENJAMIN DYE ABST 415 PG 245 **2:** TR 10 ACS 2.7186 **3:** **4:** VOL98211/0766 DD102698 CO-DALLAS **5:** 0415245101000 32604152451 Deed Transfer Date: 10/27/1998
2008	BELL RODERICK L 1111 S SHILOH RD GARLAND, TEXAS 750428047	**1:** BENJAMIN DYE ABST 415 PG 245 **2:** TR 10 ACS 2.7186 **3:** **4:** VOL98211/0766 DD102698 CO-DALLAS **5:** 0415245101000 32604152451 Deed Transfer Date: 10/27/1998
2007	BELL RODERICK L 1111 S SHILOH RD GARLAND, TEXAS 750428047	**1:** BENJAMIN DYE ABST 415 PG 245 **2:** TR 10 ACS 2.7186 **3:** **4:** VOL98211/0766 DD102698 CO-DALLAS **5:** 0415245101000 32604152451 Deed Transfer Date: 10/27/1998
2006	BELL RODERICK L 1111 S SHILOH RD GARLAND, TEXAS 750428047	**1:** BENJAMIN DYE ABST 415 PG 245 **2:** TR 10 ACS 2.7186 **3:** **4:** VOL98211/0766 DD102698 CO-DALLAS **5:** 0415245101000 32604152451 Deed Transfer Date: 10/27/1998
2005	BELL RODERICK L 1111 S SHILOH RD GARLAND, TEXAS 750428047	**1:** BENJAMIN DYE ABST 415 PG 245 **2:** TR 10 ACS 2.7186 **3:** **4:** VOL98211/0766 DD102698 CO-DALLAS **5:** 0415245101000 32604152451 Deed Transfer Date: 10/27/1998
2004	BELL RODERICK L 1111 S SHILOH RD GARLAND, TEXAS 750428047	**1:** BENJAMIN DYE ABST 415 PG 245 **2:** TR 10 ACS 2.7186 **3:** **4:** VOL98211/0766 DD102698 CO-DALLAS **5:** 0415245101000 32604152451 Deed Transfer Date: 10/27/1998
2003	BELL RODERICK L 1111 S SHILOH RD GARLAND, TEXAS 750428047	**1:** BENJAMIN DYE ABST 415 PG 245 **2:** TR 10 ACS 2.7186 **3:** **4:** VOL98211/0766 DD102698 CO-DALLAS

03 027

		5: 0415245101000 32604152451 Deed Transfer Date: 10/27/1998
2002	BELL RODERICK L 1111 S SHILOH RD GARLAND, TEXAS 750428047 UNASSIGNED	**1:** BENJAMIN DYE ABST 415 PG 245 **2:** TR 10 ACS 2.7186 **3:** **4:** VOL98211/0766 DD102698 CO-DALLAS **5:** 0415245101000 32604152451 Deed Transfer Date: 1/1/1900
2001	BELL RODERICK L 1111 S SHILOH RD GARLAND, TEXAS 750428047 UNASSIGNED	**1:** BENJAMIN DYE ABST 415 PG 245 **2:** TR 10 ACS 2.7186 **3:** **4:** VOL98211/0766 DD102698 CO-DALLAS **5:** 0415245101000 32604152451 Deed Transfer Date: 1/1/1900
2000	BELL RODERICK L 1111 S SHILOH RD GARLAND, TEXAS 750428047 UNASSIGNED	**1:** BENJAMIN DYE ABST 415 PG 245 **2:** TR 10 ACS 2.7186 **3:** **4:** VOL98211/0766 DD102698 CO-DALLAS **5:** 0415245101000 32604152451 Deed Transfer Date: 1/1/1900
1999	BELL RODERICK L 1111 S SHILOH RD GARLAND, TEXAS 750428047 UNASSIGNED	**1:** BENJAMIN DYE ABST 415 PG 245 **2:** TR 10 ACS 2.7186 **3:** **4:** VOL98211/0766 DD102698 CO-DALLAS **5:** 0415245101000 32604152451 Deed Transfer Date: 1/1/1900

03 028

REPORT: JABR529D — DALLAS COUNTY APPRAISAL DISTRICT — PAGE 2847

DATE 08/19/84 — 1982 REAL PROPERTY TAX ROLL FOR: DALLAS COUNTY

DCAD ACCOUNT NUMBER / JURISDICTION ACCT NUM / TAXPAYER NAME/ADDRESS	SPTB CODE / ACREAGE	LOCATION OF PROPERTY / LEGAL DESCRIPTION OF PROPERTY	ENTITY CODES: CITY CNTY ISD / COLL HOSP SPDS	EXEMPTIONS: TYPE AMOUNT SPLIT PCT	TAX CEILING AMT / AGRIC USE CODE / AGRIC ADJ VALUE	LAND VALUE / IMPROVE VALUE / MARKET VALUE / TAXABLE VALUE
JOURNAL ENTRIES: 000 000 000						
65041524510050000			CG	DO		$5,349,500
65041524510050000						$0
LTV ELECTRO SYSTEMS INC	C1 410	BEN J DYE SUR	DC	PH		$5,349,500
P O BOX 6118	2,453.900	ABST 0415				
DALLAS TX		S-1	GS			$5,349,500
75223		6102450100500 36504152451				
JOURNAL ENTRIES: 000 000 000						
65041524510080000		SHILOH RD	CG	DO		$55,760
65041524510080000						$0
CARROLL MALCOLM W	C1 410	BEN J DYE SUR	DC	PH		$55,760
2900 WEST KINGSLEY ROAD		ABST 0415				
GARLAND TX		S-1	GS			$55,760
75041		6102450100800 36504152451				
JOURNAL ENTRIES: 000 000 000						
65041524510090000			CG	DO		$1,628,930
65041524510090000						$0
SEARS ROEBUCK & CO	C1 410	BEN J DYE SUR	DC	PH		$1,628,930
1000 BELLEVIEW 568SW		ABST 0415				
DALLAS TX		S-1	GS			$1,628,930
75295		24.93 ACS.				
		6102450100900 36504152451				
JOURNAL ENTRIES: 000 000 000						
65041524510100000		1305 SHILOH RD	CG	DO		$136,340
65041524510100000						$270,820
JOHNSON CONTROLS INC	F1 411	BEN J DYE SUR	DC	PH		$407,160
P O BOX 591		ABST 0415				
MILWAUKEE WI		TRS 10 & 11	GS			$407,160
52301		6102450101000 36504152451				

REPORT: JABP860D — DALLAS CENTRAL APPRAISAL DISTRICT — PAGE 647

DATE 07/25/91 — REAL PROPERTY TAX ROLL FOR DALLAS COUNTY

DCAD ACCOUNT NUMBER / JURISDICTION ACCT NUM / TAXPAYER NAME/ADDRESS	SPTB CODE / ACREAGE	LOCATION OF PROPERTY / LEGAL DESCRIPTION OF PROPERTY	ENTITY CODES CITY / CNTY / ISD	COLL / HOSP / SPDS	EXEMPTIONS TYPE / AMOUNT / SPLIT PCT	TAX CEILING AMT / AGRIC USE CODE / AGRIC ADJ VALUE / AG LAND MKT VALUE	LAND VALUE / IMPROVE VALUE / MARKET VALUE / TAXABLE VALUE
65041424000010000 65041424000010000 RICHARDSON I S D 400 S GREENVILLE AVE RICHARDSON TX 75080	F10 411	450 ABRAMS RD 75081 ABSTRACT 414 TR 1 00000000000 36504142000	CR DC RS	DO PH	TOTALLY EXEMPT		14,910 5,810 20,720 0
65041524510050000 65041524510050000 LTV ELECTRO SYSTEMS INC P O BOX 660248 DALLAS TX 75266	F10 411	1200 S JUPITER RD B DYE SURV ABST 415 PG 245 TR 5 ACS 33.9793 S-1 VOL83135/0596 CO-DALLAS 04152451005OO 32604152451	CG DC GS	DO PH			3,700,320 248,810 3,949,130 3,949,130
65041524510090000 65041524510090000 SEARS ROEBUCK & CO D/970 BSC 41-38 SEARS TOWER CHICAGO IL 60684	C12 410	90415 W MILLER RD ABST 0415 PG 245 TR 9 ACS 22.643 041524510090O 32604152451	CG DC GS	DO PH			2,367,190 0 2,367,190 2,367,190
65041524510100000 65041524510100000 JOHNSON CONTROLS BZTTERY GROUP INC P O BOX 591 MILWAUKEE WI 53201	F20 421	1305 S SHILOH RD ABST 0415 PG 245 TRS 10 & 11 ACS 1.47 VOL90249/0076 EX122190 CO-DALLAS 041524510100O 36504152451	CG DC GS	DO PH			409,030 262,100 671,130 671,130
65041524510120000 65041524510120000 SEARS ROEBUCK & CO D/970 BSC 41-38 SEARS TOWER CHICAGO IL 60684	C12 410	99999 W MILLER RD ABST 0415 PG 245 ACS 15.65 CO-DALLAS 610245010120O 36504152451	CG DC GS	DO PH			1,636,110 0 1,636,110 1,636,110

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DCAD ACCOUNT NUMBER / JURIS ACCOUNT NUMBER / TAXPAYER NAME / TAXPAYER ADDRESS	LOCATION OF PROPERTY / LEGAL DESCRIPTION OF PROPERTY / SPTB CODE PROP CLASS ACREAGE / REVAL YR PR REVAL YR SPLIT PCT	CITY COLL / CNTY HOSP / ISD SPDS	MULTI OWNER / EXEMPTIONS TYPE AMOUNT	OWNER PCT / TAX CEIL DATE / AG USE CODE / AG ADJ VAL / AG LND MKT VAL	TAX CEIL AMT / DEFER CAP AMT / CAP VAL LOSS	LAND VALUE / IMPV VALUE / MKT VALUE / CPD HS VAL / TXBL VALUE
65041424010020200 RICHARDSON CITY OF PO BOX 830129 RICHARDSON TX 75083-0129	500 HIGHLAND BLVD CR DO WILLIAM H DYE ABST 414 PG 240 TR 2.2 ACS 0.251 CALC DC PH ALSO ON HIGHLAND ADDN 2 & 3 CO-DALLAS RS 0414240100202 34204142401 C12 410 .251 1999		1 TOTAL EXEMPT CI 0 0 0 0 0 0 0 0	1 100 0 0 0 0 0 0 0 0	00.00 00.00 00.00 0 0 0 0 0	1,260 0 1,260 0 0 0 0 0
65041424010020300 RICHARDSON CITY OF PO BOX 830129 RICHARDSON TX 75083-0129	400 SPRING VALLEY RD CR DO WILLIAM H DYE ABST 414 PG 240 TR 2.3 ACS 0.78 CALC DC PH ALSO HIGHLAND 2-4 & HIGHLAND ESTS CO-DALLAS RS 0414240100203 34204142401 C12 410 .780 1999		1 TOTAL EXEMPT CI 0 0 0 0 0 0 0 0	1 100 0 0 0 0 0 0 0 0	00.00 00.00 00.00 0 0 0 0 0	3,900 0 3,900 0 0 0 0 0
65041424010020400 RICHARDSON CITY OF PO BOX 830129 RICHARDSON TX 75083-0129	400 CENTENNIAL BLVD CR DO WILLIAM H DYE ABST 414 PG 240 TR 2.4 ACS 0.725 CALC DC PH ALSO ON HIGHLAND EST 2 & REGION10 CO-DALLAS RS 0414240100204 34204142401 C12 410 .725 1999		1 TOTAL EXEMPT CI 0 0 0 0 0 0 0 0	1 100 0 0 0 0 0 0 0 0	00.00 00.00 00.00 0 0 0 0 0	3,630 0 3,630 0 0 0 0 0
65041524510050000 65041524510050000 LTV ELECTRO SYSTEMS INC COMPLEX PROPERTY ADVISORS 1705 W NORTHWEST HWY #220 GRAPEVINE TX 76051	1200 S JUPITER RD CG DO BENJAMIN DYE ABST 415 PG 245 TR 5 ACS 14.1712 CALC DC PH VOL83135/0596 CO-DALLAS 0415245100500 32604152451 GS F10 411 1999 1998		1 0 0 0 0 0 0 0 0	1 100 0 0 0 0 0 0 0 0	00.00 00.00 00.00 0 0 0 0 0	617,300 132,410 749,710 0 0 0 0 749,710
65041524510050200 65041524510050200 LTV ELECTRO SYSTEMS INC % COMPLEX PROP ADV CORP 1705 W NORTHWEST HWY #220 GRAPEVINE TX 76051	1900 S JUPITER RD CG DO BENJAMIN DYE ABST 415 PG 245 TR 5.2 ACS 19.8081 CALC DC PH VOL83135/0596 CO-DALLAS 0415245100502 32604152451 GS C12 410 1999		1 0 0 0 0 0 0 0 0	1 100 0 0 0 0 0 0 0 0	00.00 00.00 00.00 0 0 0 0 0	862,840 0 862,840 0 0 0 0 862,840
65041524510090000 65041524510090000 SEARS ROEBUCK & CO D768TAX B2 135A 3333 BEVERLY RD HOFFMAN ESTATES IL 60192-3322	2701 W MILLER RD CG DO BENJAMIN DYE ABST 415 PG 245 TR 9 ACS 14.5524 DC PH VOL68194/1835 DD090568 CO-DALLAS 0415245100900 32604152451 GS C12 410 1999 1998		1 0 0 0 0 0 0 0 0	1 100 0 0 0 0 0 0 0 0	00.00 00.00 00.00 0 0 0 0 0	950,860 0 950,860 0 0 0 0 950,860
65041524510100000 65041524510100000 BELL RODERICK L 1111 S SHILOH RD GARLAND TX 75042-8047	1305 S SHILOH RD CG DO BENJAMIN DYE ABST 415 PG 245 TR 10 ACS 2.7186 DC PH VOL98211/0766 DD102698 CO-DALLAS 0415245101000 32604152451 GS F10 411 1999		1 0 0 0 0 0 0 0 0	1 100 0 0 0 0 0 0 0 0	00.00 00.00 00.00 0 0 0 0 0	236,840 38,280 275,120 0 0 0 0 275,120

Market Value

Year	Improvement	Land	Total Market	Homestead Capped
2018	$188,200	$355,270	$543,470	N/A
2017	$188,200	$355,270	$543,470	N/A
2016	$60,820	$236,840	$297,660	N/A
2015	$60,820	$236,840	$297,660	N/A
2014	$60,820	$236,840	$297,660	N/A
2013	$60,820	$236,840	$297,660	N/A
2012	$60,820	$236,840	$297,660	N/A
2011	$60,820	$236,840	$297,660	N/A
2010	$60,820	$236,840	$297,660	N/A
2009	$60,820	$236,840	$297,660	N/A
2008	$60,820	$236,840	$297,660	N/A
2007	$60,820	$236,840	$297,660	N/A
2006	$60,820	$236,840	$297,660	N/A
2005	$60,820	$236,840	$297,660	N/A
2004	$60,820	$236,840	$297,660	N/A
2003	$60,820	$236,840	$297,660	N/A
2002	$60,820	$236,840	$297,660	N/A
2001	$38,280	$236,840	$275,120	N/A
2000	$38,280	$236,840	$275,120	N/A
1999	$38,280	$236,840	$275,120	N/A

Taxable Value

Year	City	ISD	County	College	Hospital	Special District
2018	$543,470	$543,470	$543,470	$543,470	$543,470	$0
2017	$543,470	$543,470	$543,470	$543,470	$543,470	$0
2016	$297,660	$297,660	$297,660	$297,660	$297,660	$0
2015	$297,660	$297,660	$297,660	$297,660	$297,660	$0
2014	$297,660	$297,660	$297,660	$297,660	$297,660	$0
2013	$297,660	$297,660	$297,660	$297,660	$297,660	$0
2012	$297,660	$297,660	$297,660	$297,660	$297,660	$0
2011	$297,660	$297,660	$297,660	$297,660	$297,660	$0
2010	$297,660	$297,660	$297,660	$297,660	$297,660	$0
2009	$297,660	$297,660	$297,660	$297,660	$297,660	$0
2008	$297,660	$297,660	$297,660	$297,660	$297,660	$0
2007	$297,660	$297,660	$297,660	$297,660	$297,660	$0
2006	$297,660	$297,660	$297,660	$297,660	$297,660	$0
2005	$297,660	$297,660	$297,660	$297,660	$297,660	$0
2004	$297,660	$297,660	$297,660	$297,660	$297,660	$0
2003	$297,660	$297,660	$297,660	$297,660	$297,660	$0
2002	$297,660	$297,660	$297,660	$297,660	$297,660	$0
2001	$275,120	$275,120	$275,120	$275,120	$275,120	$0

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2000	$275,120	$275,120	$275,120	$275,120	$275,120	$0
1999	$275,120	$275,120	$275,120	$275,120	$275,120	$0

Exemptions

2018	No Exemptions
2017	No Exemptions
2016	No Exemptions
2015	No Exemptions
2014	No Exemptions
2013	No Exemptions
2012	No Exemptions
2011	No Exemptions
2010	No Exemptions
2009	No Exemptions
2008	No Exemptions
2007	No Exemptions
2006	No Exemptions
2005	No Exemptions
2004	No Exemptions
2003	No Exemptions
2002	No Exemptions
2001	No Exemptions
2000	No Exemptions
1999	No Exemptions

Exemption Details History

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Dallas Central Appraisal District

Business Personal Property Account #99200324700227300

Location Owner Value Exemptions Estimated Taxes History

Property Location (Current 2019)

Address: 1301 S SHILOH RD
Mapsco: 29-A (DALLAS)

DCAD Property Map

View Photo

2018 Appraisal Notice

Electronic Documents (ENS)

FILE YOUR BPP RENDITION ON-LINE

Owner (Current 2019)

COPIER EXPORTER INC
1301 S SHILOH RD
GARLAND, TEXAS 750428004

DBA: COPIER EXPORTER INC

Value

2018 Certified Values

Total: $17,550

Exemptions (2018 Certified Values)

No Exemptions

Estimated Taxes (2018 Certified Values)

	City	School	County and School Equalization	College	Hospital	Special District
Taxing Jurisdiction	GARLAND	GARLAND ISD	DALLAS COUNTY	DALLAS CO COMMUNITY COLLEGE	PARKLAND HOSPITAL	UNASSIGNED
Tax Rate per $100	$0.7046	$1.46	$0.2531	$0.124	$0.2794	N/A
Taxable Value	$17,550	$17,550	$17,550	$17,550	$17,550	$0
Estimated Taxes	$123.66	$256.23	$44.42	$21.76	$49.03	N/A
Tax Ceiling					N/A	N/A
					Total Estimated Taxes:	**$495.10**

DO NOT PAY TAXES BASED ON THESE ESTIMATED TAXES. You will receive an **official tax bill** from

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the appropriate agency when they are prepared. Please note that if there is an Over65 or Disabled Person **Tax Ceiling** displayed above, **it is NOT reflected** in the Total Estimated Taxes calculation provided. Taxes are collected by the agency sending you the **official** tax bill. To see a listing of agencies that collect taxes for your property. **Click Here**

The estimated taxes are provided as a courtesy and should not be relied upon in making financial or other decisions. The Dallas Central Appraisal District (DCAD) does not control the tax rate nor the amount of the taxes, as that is the responsibility of each Taxing Jurisdiction. Questions about your taxes should be directed to the appropriate taxing jurisdiction. We cannot assist you in these matters. These tax estimates are calculated by using the most current certified taxable value multiplied by the most current tax rate. **It does not take into account other special or unique tax scenarios, like a tax ceiling, etc.**. If you wish to calculate taxes yourself, you may use the Tax Calculator to assist you.

History

History

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Dallas Central Appraisal District

This website is for informational purposes only. Title research should be performed at the appropriate County Clerks office. This is not deemed a legal document.

Account History #99200324700227300

Owner Legal Desc Market Value Taxable Value Exemptions

Owner / Legal Description

Year	Legal Owner	Doing Business As (DBA)
2018	COPIER EXPORTER INC 1301 S SHILOH RD GARLAND, TEXAS 750428004	**1:** COPIER EXPORTER INC **2:** **3:** **4:** **5:** Deed Transfer Date:
2017	COPIER EXPORTER INC 1301 S SHILOH RD GARLAND, TEXAS 750428004	**1:** COPIER EXPORTER INC **2:** **3:** **4:** **5:** Deed Transfer Date:
2016	COPIER EXPORTER INC 1301 S SHILOH RD GARLAND, TEXAS 750428004	**1:** COPIER EXPORTER INC **2:** **3:** **4:** **5:** Deed Transfer Date:
2015	COPIER EXPORTER INC 1301 S SHILOH RD GARLAND, TEXAS 750428004	**1:** COPIER EXPORTER INC **2:** **3:** **4:** **5:** Deed Transfer Date:
2014	COPIER EXPORTER INC 1301 S SHILOH RD GARLAND, TEXAS 750428004	**1:** COPIER EXPORTER INC **2:** **3:** **4:** **5:** Deed Transfer Date:
2013	COPIER EXPORTER INC 11330 LUNA RD DALLAS, TEXAS 752293114	**1:** COPIER EXPORTER INC **2:** **3:** **4:** **5:** Deed Transfer Date:
2012	COPIER EXPORTER INC 11330 LUNA RD DALLAS, TEXAS 752293114	**1:** COPIER EXPORTER INC **2:** **3:** **4:** **5:**

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		Deed Transfer Date:
2011	COPIER EXPORTER INC 11330 LUNA RD DALLAS, TEXAS 752293114	**1:** COPIER EXPORTER INC **2:** **3:** **4:** **5:** Deed Transfer Date:
2010	COPIER EXPORTER INC 11330 LUNA RD DALLAS, TEXAS 752293114	**1:** COPIER EXPORTER INC **2:** **3:** **4:** **5:** Deed Transfer Date:
2009	COPIER EXPORTER INC 11330 LUNA RD DALLAS, TEXAS 752293114	**1:** COPIER EXPORTER INC **2:** **3:** **4:** **5:** Deed Transfer Date:
2008	COPIER EXPORTER INC 11330 LUNA RD DALLAS, TEXAS 752293114	**1:** COPIER EXPORTER INC **2:** **3:** **4:** **5:** Deed Transfer Date:
2007	COPIER EXPORTER INC 11330 LUNA RD DALLAS, TEXAS 752293114	**1:** COPIER EXPORTER INC **2:** **3:** **4:** **5:** Deed Transfer Date:
2006	COPIER EXPORTER INC 2614 ANDJON DR DALLAS, TEXAS 752201310	**1:** COPIER EXPORTER INC **2:** **3:** **4:** **5:** Deed Transfer Date:
2005	COPIER EXPORTER INC 2614 ANDJON DR DALLAS, TEXAS 752201310	**1:** COPIER EXPORTER INC **2:** **3:** **4:** **5:** Deed Transfer Date:
2004	COPIER EXPORTER INC 2614 ANDJON DR DALLAS, TEXAS 752201310	**1:** COPIER EXPORTER INC **2:** **3:** **4:** **5:** Deed Transfer Date:

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Market Value

Year	Improvement	Land	Total Market	Homestead Capped
2018	$17,550	$0	$17,550	N/A
2017	$17,410	$0	$17,410	N/A
2016	$17,410	$0	$17,410	N/A
2015	$17,410	$0	$17,410	N/A
2014	$16,870	$0	$16,870	N/A
2013	$16,870	$0	$16,870	N/A
2012	$16,850	$0	$16,850	N/A
2011	$16,850	$0	$16,850	N/A
2010	$15,350	$0	$15,350	N/A
2009	$15,350	$0	$15,350	N/A
2008	$15,350	$0	$15,350	N/A
2007	$15,350	$0	$15,350	N/A
2006	$15,350	$0	$15,350	N/A
2005	$15,350	$0	$15,350	N/A
2004	$15,350	$0	$15,350	N/A

Taxable Value

Year	City	ISD	County	College	Hospital	Special District
2018	$17,550	$17,550	$17,550	$17,550	$17,550	$0
2017	$17,410	$17,410	$17,410	$17,410	$17,410	$0
2016	$17,410	$17,410	$17,410	$17,410	$17,410	$0
2015	$17,410	$17,410	$17,410	$17,410	$17,410	$0
2014	$16,870	$16,870	$16,870	$16,870	$16,870	$0
2013	$16,870	$16,870	$16,870	$16,870	$16,870	$0
2012	$16,850	$16,850	$16,850	$16,850	$16,850	$0
2011	$16,850	$16,850	$16,850	$16,850	$16,850	$0
2010	$15,350	$15,350	$15,350	$15,350	$15,350	$0
2009	$15,350	$15,350	$15,350	$15,350	$15,350	$0
2008	$15,350	$15,350	$15,350	$15,350	$15,350	$0
2007	$15,350	$15,350	$15,350	$15,350	$15,350	$0
2006	$15,350	$15,350	$15,350	$15,350	$15,350	$0
2005	$15,350	$15,350	$15,350	$15,350	$15,350	$0
2004	$15,350	$15,350	$15,350	$15,350	$15,350	$0

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Exemptions

2018	No Exemptions
2017	No Exemptions
2016	No Exemptions
2015	No Exemptions
2014	No Exemptions
2013	No Exemptions
2012	No Exemptions
2011	No Exemptions
2010	No Exemptions
2009	No Exemptions
2008	No Exemptions
2007	No Exemptions
2006	No Exemptions
2005	No Exemptions
2004	No Exemptions

Exemption Details History

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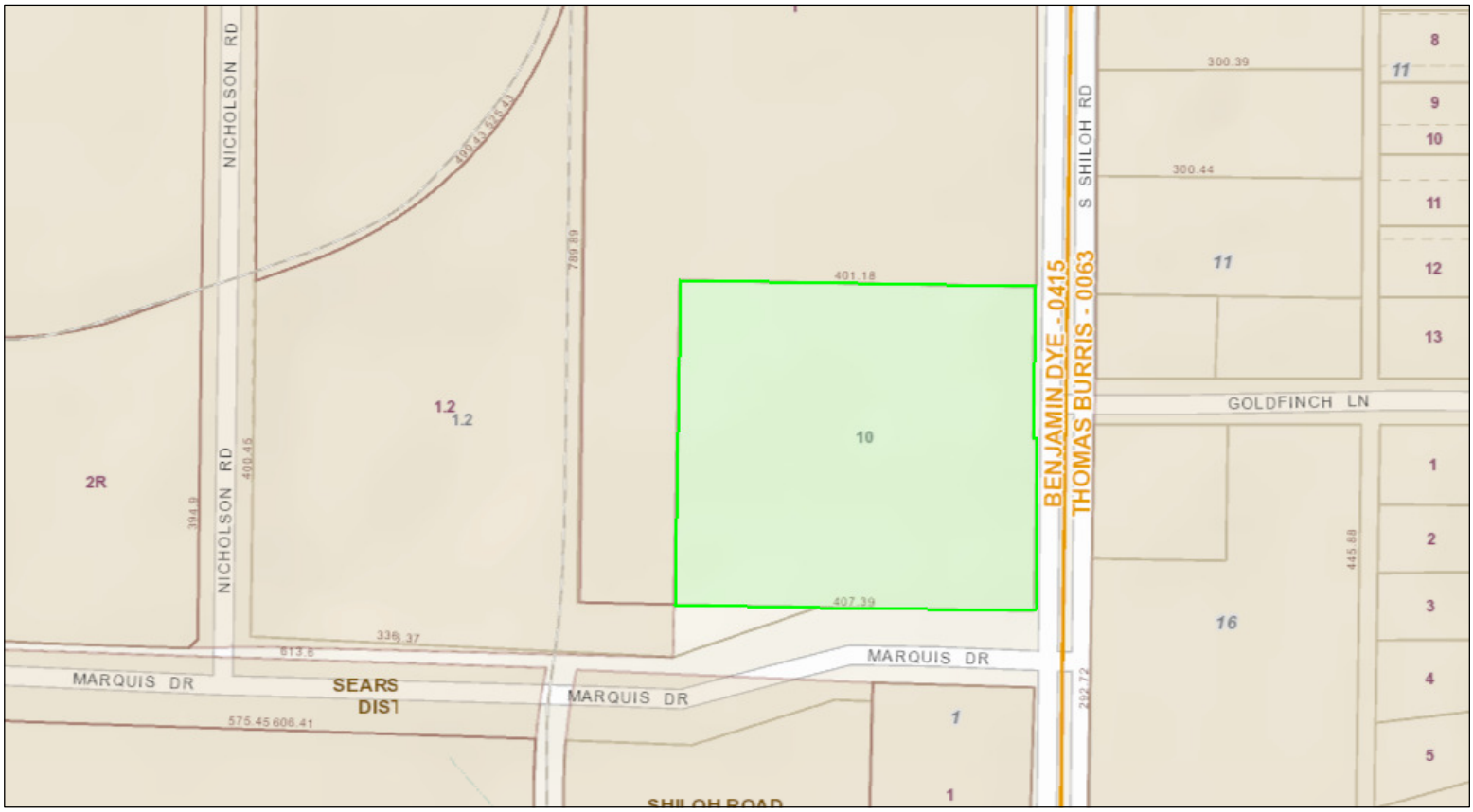
Former Globe Union

DCAD ID: 65041524510100000

Date of copy: 2/28/2019



This product is for informational purposes only and may not have been prepared for or be suitable for legal, engineering, or surveying purposes. It does not represent an on-the-ground survey and represents only the approximate relative location of property boundaries.

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S

Dallas Central Appraisal District
2949 N Stemmons Freeway
Dallas, TX 75247-6195
(214) 631-1342
www.dallascad.org

1 inch equals 188 feet

0 105 210 420 ft

0 30 60 120 m

DCAD, NCTCOG, USGS, Esri,Inc

Dallas Central Appraisal District

Residential Account #26345500080020000

Location Owner Legal Desc Value Main Improvement Additional Improvements Land Exemptions Estimated Taxes History

Property Location (Current 2019)

Address: 2406 CARDINAL LN
Neighborhood: 3GSJ38
Mapsco: 29-A (DALLAS)

DCAD Property Map

2019 Current Appraisal Notice

uFile Online Protest

Electronic Documents (ENS)

File Homestead Exemption Online

Print Homestead Exemption Form

Print/Mail Account Protest Form

Owner (Current 2019)

RAMOS JOSHUA RAY &
ELIZABETH ARVIZU
2406 CARDINAL LN
GARLAND, TEXAS 750428013

Multi-Owner (Current 2019)

Owner Name	Ownership %
RAMOS JOSHUA RAY &	100%

Legal Desc (Current 2019)

1: MEADOWLARK ESTATES 2
2: BLK H LOT 2
3:
4: INT201700325364 DD11162017 CO-DC
5: 3455000800200 1CG34550008
Deed Transfer Date: 11/17/2017

Value

2019 Proposed Values	
Improvement:	$172,420
Land:	+ $40,000
Market Value:	=$212,420
Capped Value: $198,880	
Revaluation Year:	2019
Previous Revaluation Year:	2018

Main Improvement (Current 2019)

Building Class	15	**Construction Type**	FRAME	**# Baths (Full/Half)**	2/ 0
Year Built	1959	**Foundation**	PIER AND BEAM	**# Kitchens**	1
Effective Year Built	1959	**Roof Type**	HIP	**# Bedrooms**	3
Actual Age	60 years	**Roof Material**	COMP SHINGLES	**# Wet Bars**	0

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Desirability	GOOD	**Fence Type**	WOOD	**# Fireplaces**	0
Living Area	1,638 sqft	**Ext. Wall Material**	BRICK VENEER	**Sprinkler (Y/N)**	N
Total Area	1,638 sqft	**Basement**	NONE	**Deck (Y/N)**	N
% Complete	100%	**Heating**	CENTRAL FULL	**Spa (Y/N)**	N
# Stories	ONE STORY	**Air Condition**	CENTRAL FULL	**Pool (Y/N)**	N
Depreciation	45%			**Sauna (Y/N)**	N

03 042

Additional Improvements (Current 2019)

#	Improvement Type	Construction	Floor	Exterior Wall	Area (sqft)
1	OUTBUILDING		UNASSIGNED	FRAME	400
2	ATTACHED GARAGE	BK-BRICK	CONCRETE	UNASSIGNED	520

Land (2019 Proposed Values)

#	State Code	Zoning	Frontage (ft)	Depth (ft)	Area	Pricing Method	Unit Price	Market Adjustment	Adjusted Price	Ag Land
1	SINGLE FAMILY RESIDENCES	SINGLE-FAMILY-7 DISTRICT	80	125	10,001.0000 UNASSIGNED	FLAT PRICE	$40,000.00	0%	$40,000	N

*** All Exemption information reflects 2019 Proposed Values. ***

Exemptions (2019 Proposed Values)

	City	School	County and School Equalization	College	Hospital	Special District
Taxing Jurisdiction	GARLAND	GARLAND ISD	DALLAS COUNTY	DALLAS CO COMMUNITY COLLEGE	PARKLAND HOSPITAL	UNASSIGNED
HOMESTEAD EXEMPTION	$15,910	$25,000	$39,776	$39,776	$39,776	$0
Taxable Value	$182,970	$173,880	$159,104	$159,104	$159,104	$0

Exemption Details

Estimated Taxes (2019 Proposed Values)

	City	School	County and School Equalization	College	Hospital	Special District
Taxing Jurisdiction	GARLAND	GARLAND ISD	DALLAS COUNTY	DALLAS CO COMMUNITY COLLEGE	PARKLAND HOSPITAL	UNASSIGNED
Tax Rate per $100	$0.7046	$1.46	$0.2531	$0.124	$0.2794	N/A
Taxable Value	$182,970	$173,880	$159,104	$159,104	$159,104	$0
Estimated Taxes	$1,289.21	$2,538.65	$402.69	$197.29	$444.54	N/A
Tax Ceiling	N/A	N/A	N/A	N/A	N/A	N/A
					Total Estimated Taxes:	**$4,872.37**

DO NOT PAY TAXES BASED ON THESE ESTIMATED TAXES. You will receive an **official tax bill** from the appropriate agency when they are prepared. Please note that if there is an Over65 or Disabled Person **Tax Ceiling** displayed above, **it is NOT reflected** in the Total Estimated Taxes calculation provided. Taxes are collected by the agency sending you the **official** tax bill. To see a listing of agencies that collect taxes for your property. **Click Here**

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Dallas Central Appraisal District

Residential Account #26345500180030000

Location Owner Legal Desc Value Main Improvement Additional Improvements Land Exemptions Estimated Taxes History

Property Location (Current 2019)

Address: 2342 MOCKINGBIRD LN
Neighborhood: 3GSJ38
Mapsco: 29-E (DALLAS)

DCAD Property Map

2019 Current Appraisal Notice

uFile Online Protest

Electronic Documents (ENS)

File Homestead Exemption Online

Print Homestead Exemption Form

Print/Mail Account Protest Form

Owner (Current 2019)

CALDERON AMY E &
NATHANIEL A
2342 MOCKINGBIRD LN
GARLAND, TEXAS 750428329

Multi-Owner (Current 2019)

Owner Name	Ownership %
CALDERON AMY E &	100%

Legal Desc (Current 2019)

1: MEADOWLARK ESTATES 2
2: BLK R LOT 3
3: & W 3.5 FT LT 4
4: INT20070428409 DD11202007 CO-DC
5: 3455001800300 1CG34550018
Deed Transfer Date: 11/30/2007

Value

2019 Proposed Values	
Improvement:	$146,420
Land:	+ $40,000
Market Value:	=$186,420
Capped Value: $150,629	
Revaluation Year:	2019
Previous Revaluation Year:	2018

Main Improvement (Current 2019)

Building Class	15	**Construction Type**	FRAME	**# Baths (Full/Half)**	2/ 0
Year Built	1957	**Foundation**	PIER AND BEAM	**# Kitchens**	1
Effective Year Built	1957	**Roof Type**	HIP	**# Bedrooms**	3
Actual Age	62 years	**Roof Material**	COMP SHINGLES	**# Wet Bars**	0

03 044

Desirability	AVERAGE	**Fence Type**	WOOD	**# Fireplaces**	0
Living Area	1,628 sqft	**Ext. Wall Material**	BRICK VENEER	**Sprinkler (Y/N)**	N
Total Area	1,628 sqft	**Basement**	NONE	**Deck (Y/N)**	N
% Complete	100%	**Heating**	CENTRAL FULL	**Spa (Y/N)**	N
# Stories	ONE STORY	**Air Condition**	CENTRAL FULL	**Pool (Y/N)**	N
Depreciation	50%			**Sauna (Y/N)**	N

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Additional Improvements (Current 2019)

#	Improvement Type	Construction	Floor	Exterior Wall	Area (sqft)
1	ATTACHED GARAGE	BK-BRICK	CONCRETE	UNASSIGNED	420

Land (2019 Proposed Values)

#	State Code	Zoning	Frontage (ft)	Depth (ft)	Area	Pricing Method	Unit Price	Market Adjustment	Adjusted Price	Ag Land
1	SINGLE FAMILY RESIDENCES	SINGLE-FAMILY-7 DISTRICT	81	130	9,986.0000 UNASSIGNED	FLAT PRICE	$40,000.00	0%	$40,000	N

*** All Exemption information reflects 2019 Proposed Values. ***

Exemptions (2019 Proposed Values)

	City	School	County and School Equalization	College	Hospital	Special District
Taxing Jurisdiction	GARLAND	GARLAND ISD	DALLAS COUNTY	DALLAS CO COMMUNITY COLLEGE	PARKLAND HOSPITAL	UNASSIGNED
HOMESTEAD EXEMPTION	$12,050	$25,000	$30,125	$30,125	$30,125	$0
Taxable Value	$138,579	$125,629	$120,504	$120,504	$120,504	$0

Exemption Details

Estimated Taxes (2019 Proposed Values)

	City	School	County and School Equalization	College	Hospital	Special District
Taxing Jurisdiction	GARLAND	GARLAND ISD	DALLAS COUNTY	DALLAS CO COMMUNITY COLLEGE	PARKLAND HOSPITAL	UNASSIGNED
Tax Rate per $100	$0.7046	$1.46	$0.2531	$0.124	$0.2794	N/A
Taxable Value	$138,579	$125,629	$120,504	$120,504	$120,504	$0
Estimated Taxes	$976.43	$1,834.18	$305.00	$149.42	$336.69	N/A
Tax Ceiling	N/A	N/A	N/A	N/A	N/A	N/A
					Total Estimated Taxes:	**$3,601.72**

DO NOT PAY TAXES BASED ON THESE ESTIMATED TAXES. You will receive an **official tax bill** from the appropriate agency when they are prepared. Please note that if there is an Over65 or Disabled Person **Tax Ceiling** displayed above, **it is NOT reflected** in the Total Estimated Taxes calculation provided. Taxes are collected by the agency sending you the **official** tax bill. To see a listing of agencies that collect taxes for your property. **Click Here**

The estimated taxes are provided as a courtesy and should not be relied upon in making financial or other decisions. The Dallas Central Appraisal District (DCAD) does not control the tax rate nor the amount of the taxes, as that is the responsibility of each Taxing Jurisdiction. Questions about your taxes should be directed to the appropriate taxing jurisdiction. We cannot assist you in these matters. These tax estimates are calculated by using the most current certified taxable value multiplied by the most current tax rate. **It does not take into account other special or unique tax scenarios, like a tax ceiling, etc.**. If you wish to calculate taxes yourself, you may use the Tax Calculator to assist you.

03 046

Dallas Central Appraisal District

Residential Account #26682500130090000

Location Owner Legal Desc Value Main Improvement Additional Improvements Land Exemptions Estimated Taxes History

Property Location (Current 2019)

Address: 1718 ROBIN LN
Neighborhood: 3GSJ26
Mapsco: 29-E (DALLAS)

DCAD Property Map

2019 Current Appraisal Notice

uFile Online Protest

Electronic Documents (ENS)

File Homestead Exemption Online

Print Homestead Exemption Form

Print/Mail Account Protest Form

Owner (Current 2019)

CHUM SANG & MANG KI
1718 ROBIN LN
GARLAND, TEXAS 750428230

Multi-Owner (Current 2019)

Owner Name	Ownership %
CHUM SANG & MANG KI	100%

Legal Desc (Current 2019)

1: WILLIAMS ESTATES 3 3RD INST
2: BLK 13 LT 9
3:
4: INT201600245872 DD08302016 CO-DC
5: 6825001300900 1CG68250013
Deed Transfer Date: 9/8/2016

Value

2019 Proposed Values	
Improvement:	$141,480
Land:	+ $32,000
Market Value:	=$173,480
Revaluation Year:	2018
Previous Revaluation Year:	2017

Main Improvement (Current 2019)

Building Class	15	**Construction Type**	FRAME	**# Baths (Full/Half)**	2/ 0
Year Built	1964	**Foundation**	PIER AND BEAM	**# Kitchens**	1
Effective Year Built	1964	**Roof Type**	HIP	**# Bedrooms**	2
Actual Age	55 years	**Roof Material**	COMP SHINGLES	**# Wet Bars**	0

03 047

Desirability	VERY GOOD	**Fence Type**	CHAIN	**# Fireplaces**	1
Living Area	1,502 sqft	**Ext. Wall Material**	BRICK VENEER	**Sprinkler (Y/N)**	N
Total Area	1,502 sqft	**Basement**	NONE	**Deck (Y/N)**	N
% Complete	100%	**Heating**	CENTRAL FULL	**Spa (Y/N)**	N
# Stories	ONE STORY	**Air Condition**	CENTRAL FULL	**Pool (Y/N)**	N
Depreciation	40%			**Sauna (Y/N)**	N

03 048

Additional Improvements (Current 2019)

#	Improvement Type	Construction	Floor	Exterior Wall	Area (sqft)
1	STORAGE BUILDING		UNASSIGNED	FRAME	120
2	ATTACHED GARAGE	BK-BRICK	CONCRETE	UNASSIGNED	560

Land (2019 Proposed Values)

#	State Code	Zoning	Frontage (ft)	Depth (ft)	Area	Pricing Method	Unit Price	Market Adjustment	Adjusted Price	Ag Land
1	SINGLE FAMILY RESIDENCES	SINGLE-FAMILY-10 DISTRICT	80	140	11,617.0000 UNASSIGNED	FLAT PRICE	$32,000.00	0%	$32,000	N

*** All Exemption information reflects 2019 Proposed Values. ***

Exemptions (2019 Proposed Values)

	City	School	County and School Equalization	College	Hospital	Special District
Taxing Jurisdiction	GARLAND	GARLAND ISD	DALLAS COUNTY	DALLAS CO COMMUNITY COLLEGE	PARKLAND HOSPITAL	UNASSIGNED
HOMESTEAD EXEMPTION	$13,878	$25,000	$34,696	$34,696	$34,696	$0
Taxable Value	$159,602	$148,480	$138,784	$138,784	$138,784	$0

Exemption Details

Estimated Taxes (2019 Proposed Values)

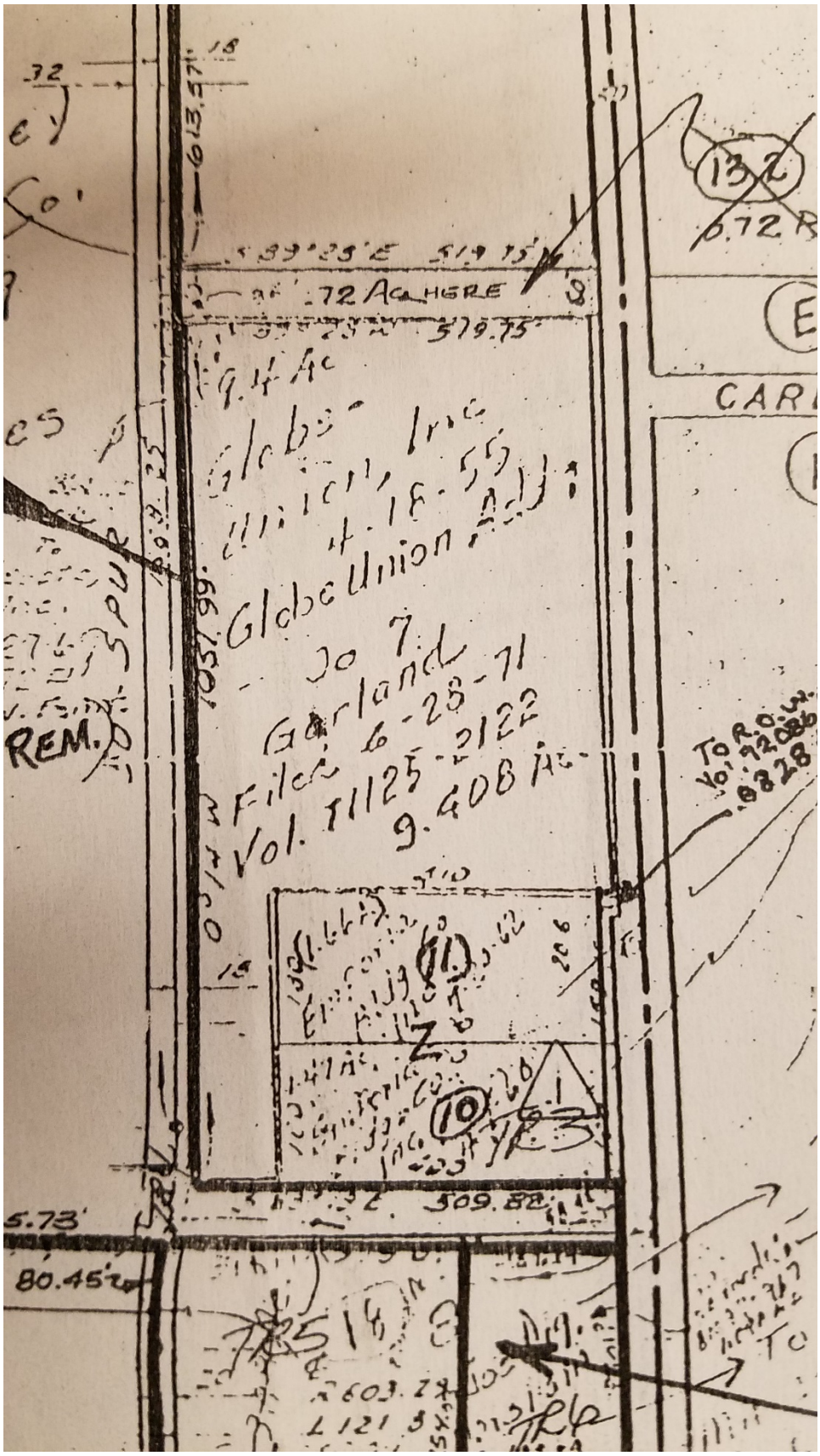
	City	School	County and School Equalization	College	Hospital	Special District
Taxing Jurisdiction	GARLAND	GARLAND ISD	DALLAS COUNTY	DALLAS CO COMMUNITY COLLEGE	PARKLAND HOSPITAL	UNASSIGNED
Tax Rate per $100	$0.7046	$1.46	$0.2531	$0.124	$0.2794	N/A
Taxable Value	$159,602	$148,480	$138,784	$138,784	$138,784	$0
Estimated Taxes	$1,124.56	$2,167.81	$351.26	$172.09	$387.76	N/A
Tax Ceiling	N/A	N/A	N/A	N/A	N/A	N/A
					Total Estimated Taxes:	**$4,203.48**

DO NOT PAY TAXES BASED ON THESE ESTIMATED TAXES. You will receive an **official tax bill** from the appropriate agency when they are prepared. Please note that if there is an Over65 or Disabled Person **Tax Ceiling** displayed above, **it is NOT reflected** in the Total Estimated Taxes calculation provided. Taxes are collected by the agency sending you the **official** tax bill. To see a listing of agencies that collect taxes for your property. **Click Here**

The estimated taxes are provided as a courtesy and should not be relied upon in making financial or other decisions. The Dallas Central Appraisal District (DCAD) does not control the tax rate nor the amount of the taxes, as that is the responsibility of each Taxing Jurisdiction. Questions about your taxes should be directed to the appropriate taxing jurisdiction. We cannot assist you in these matters. These tax estimates are calculated by using the most current certified taxable value multiplied by the most current tax rate. **It does not take into account other special or unique tax scenarios, like a tax ceiling, etc.**. If you wish to calculate taxes yourself, you may use the Tax Calculator to assist you.

03 049

Reference 4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Reference 5

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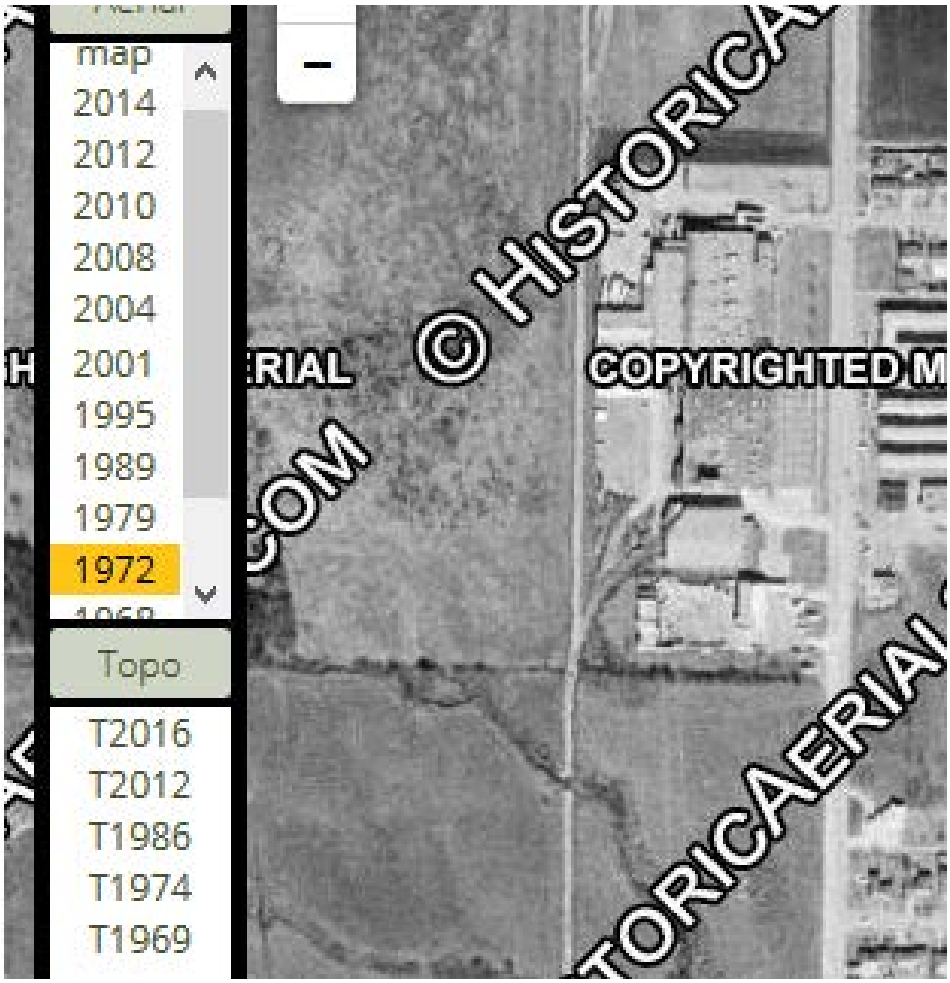
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© HISTORICAERIALS.COM
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Reference 6

October 10, 1973

Mr. R. F. Nicolai
Pollution Control Engineer
Globe Union Incorporated
5757 North Green Bay Ave.
Milwaukee, Wisconsin 53201

Re: Permit Application of 9-27-73, Garland, Dallas, County

Dear Mr. Nicolai:

The proposed application of rectifier room exhaust fans to your existing facilities will not result in the release of air contaminants. Consequently, a permit to construct will not be required for this work.

We appreciate your interest in air pollution control. Please call on us any time we may be of help.

Sincerely,

Steve Spaw, Director
Permits & Inventory Division
Texas Air Control Board

cc: Mr. Melvin Lewis, Regional Supervisor, Fort Worth
J. M. Pickard, M.D., Director, Dallas County Health Dept., Dallas

LEP/flp
bcc:Board,File

(72-6)

TEXAS AIR CONTROL BOARD
FORM PI-1, GENERAL APPLICATION
(Read Instructions Before Completing)

1580

I. PERMIT TO BE ISSUED TO GLOBE-UNION INC.
(Corporation, Company, Government Agency, Firm, etc.)

Mailing address: P. O. BOX 591 MILWAUKEE, WI 53201

Individual authorized to act for applicant: Name: G. E. Stoughton Title: Mgr., Corporate Facilities

Address: 5757 N. Green Bay Ave., Milwaukee, WI 53209 Telephone: (414) 228-2582

II. LOCATION OF PERMIT UNITS (Latitude and Longitude must be to the nearest 15 seconds)

Name of plant or site: Globe-Union Inc. Carland, Texas Plant Street address (if available): 1111 Shiloh Road

Nearest city: Garland County: Dallas Latitude: N32-54-15 Longitude: W-96-40-0

III. TYPE OF OPERATION OR PROCESS OF PERMIT UNIT: Lead-Acid Battery Mauufacture Plant

A. Name of operation or process of permit unit: Warm Air Exhaust System for Rectifier Room

B. Permit unit identification number: Globe-Union Dwg. 72847E, Sh. 2&4 and Pens litterature

C. Type (Check one): ☒ Permanent ☐ Portable

D. Operating schedule: Hours/day 24 Days/week 6 Weeks/year 52

IV. PERMIT UNIT CLASSIFICATION (Check applicable blocks):

A. ☒ New Permit Unit. Proposed start of construction 10/1/73 (Date) Start of operation 12/1/73 (Date)

B. ☐ Modification of Permit Unit

C. ☐ Change in Location

D. ☐ Change in Ownership

E. ☐ Permit Unit Now Operating Under Permit Number

SEP 28 1973

AIR POLLUTION CONTROL

V. If Items IV.A, B, or C were checked, submit the following information under either A or B:

A. Data requested in B1, B2 and B3 has been previously submitted under Permit No.

B.1 Submit three copies of an area map to appropriate scale showing the location of the property, the land use designations for adjacent ~~land owned~~ lands which may be affected by the emissions, geographical features such as highways, roads, streams and significant landmarks, distance to the center of nearest city or town if located outside an incorporated municipality. If the property is located within a town or city, a city map may be used to present this information, and if outside a town or city, a county highway map may be used. County highway maps may be ordered either through the Texas Highway Department, Austin, Texas, or through the State District Highway Engineer for the county.

Given previously 10/1/73

B.2 Give a legal description of the tract of land upon which the plant or facility is located. The term "legal description" means either a metes and bounds description, or the block and lot number of a platted subdivision which would be suitable to effectuate the transfer of title to real property.

B.3 Submit a plot plan of the property, to scale, showing the boundaries, the location of all sources of any air contaminants on the property, the distance from each source to the nearest boundary line, prevailing wind direction, true north direction, a scale and any other information deemed relevant by the applicant. Identify the sources by numbers; use the same numbers for those sources in this permit that will be assigned in the flow diagram.

VI. If Item IV.E is not checked, submit the following information:

A. Process Flow Diagram. Prepare and attach a flow diagram identifying significant individual processes and/or operations. Identify (by number) points where raw materials, chemicals, and fuels are introduced, where gaseous emissions and/or airborne particulates may be discharged including intermediate releases where finished products are obtained, and location of pollution control devices.

B. Description of Process. Prepare and attach a written description of each process and of the function of the equipment in the process. (Identify items of equipment by numbers corresponding to flow diagram numbers.) The description must be in sufficient detail to determine the general operation of the process. Particular attention must be given to explaining all stages in the process where there is or may be a discharge of any solid, liquid, or gaseous material(s) into the atmosphere. Estimate number and type of air pollution abatement devices to be used such as 1 electrostatic precipitator, 2 cyclones, 1 incinerator, 2 baghouses, etc.

VII. Has local Air Pollution Control Program been contacted? ☒ Yes ☐ No ☐ No active local program in the city or county.

on previous applications

VIII. I, Robert F. Nicolai (Name), Corporate Pollution Control Engineer (Title)

state that I have knowledge of the facts herein set forth and that the same are true and correct to the best of my knowledge and belief. I further state that to the best of my knowledge and belief, the project for which application is made will not in any way violate any provision of the Texas Clean Air Act, Article 4477-5, Vernon's Texas Civil Statutes, as amended, or any of the rules and regulations of the Texas Air Control Board or any local governmental ordinance or resolution enacted pursuant to the Texas Clean Air Act.

06 002

DATE September 26, 1973 SIGNATURE

R7E3

12 0873

TEXAS AIR CONTROL BOARD

Vicky:
Show to Pat.
Then file.
Nicolai

October 10, 1973

~~662~~
F/580

Mr. R. F. Nicolai
Pollution Control Engineer
Globe Union Incorporated
5757 North Green Bay Ave.
Milwaukee, Wisconsin 53201

Re: Permit Application of 9-27-73, Garland, Dallas, County

Dear Mr. Nicolai:

The proposed application of rectifier room exhaust fans to your existing facilities will not result in the release of air contaminants. Consequently, a permit to construct will not be required for this work.

We appreciate your interest in air pollution control. Please call on us any time we may be of help.

Sincerely,

Steve Spaw, Director
Permits & Inventory Division
Texas Air Control Board

cc: Mr. Melvin Lewis, Regional Supervisor, Fort Worth
J. M. Pickard, M.D., Director, Dallas County Health Dept., Dallas

TEXAS AIR CONTROL BOARD

12 Oct 73

Vicky: Show to Pat. Then file. Melvin

October 10, 1973

#662

Mr. R. F. Nicolai
Pollution Control Engineer
Globe Union Incorporated
5757 North Green Bay Ave.
Milwaukee, Wisconsin 53201

Re: Permit Application of 3-27-73, Garland, Dallas, County

Dear Mr. Nicolai:

The proposed application of rectifier room exhaust fans to your existing facilities will not result in the release of air contaminants. Consequently, a permit to construct will not be required for this work.

We appreciate your interest in air pollution control. Please call on us any time we may be of help.

Sincerely,

Steve Spaw, Director
Permits & Inventory Division
Texas Air Control Board

cc: Mr. Melvin Lewis, Regional Supervisor, Fort Worth
J. M. Pickard, M.D., Director, Dallas County Health Dept., Dallas

COPY

TEXAS AIR CONTROL BOARD
6330 HWY. 290 EAST, AUSTIN, TEXAS 78723, 512/451-5711

DICK WHITTINGTON, P.E.
CHAIRMAN

BOB G. BAILEY
VICE CHAIRMAN

STEVEN N. SPAW, P.E.
EXECUTIVE DIRECTOR

JOHN L. BLAIR
MARCUS M. KEY, M.D.
CALVIN B. PARNELL, JR., Ph.D., P.E.
WILLIAM H. QUORTRUP
C. H. RIVERS
WARREN H. ROBERTS
MARY ANNE WYATT

February 18, 1991

Mr. Jordan S. Harwood, P.E.
Manager, Environmental Control
JOHNSON CONTROLS BATTERY GROUP, INC.
P. O. Box 591
Milwaukee, WI 53201-0591

Re: Garland, Dallas County
Account ID No. DB-0411-W

Dear Mr. Harwood:

We appreciate being informed that Johnson Controls, Inc. has formed a wholly-owned subsidiary, Johnson Controls Battery Group, Inc. which is the new owner of the facilities identified below which were previously owned by Johnson Controls, Inc. Our files have been updated to indicate that the change has occurred.

Permit No.	Facility
R-662	Vacuum Cleaner
R-2402	Lead Oxide Plate Drying Oven
R-2617	Wirtz Grid Casting Machine
R-6710	Lead Panel Casters (2)
R-6898	Lead Oxide Panel Coating, Drying & Separating Facility
R-6899	Lead Remelt and Recovery System
R-6900	Cover & Container Heat Sealing Facility
R-6901	Cast on Strap Line No. 4
R-6902	Cast on Strap Line - Reed Stacker Line No. 3
R-6903	Lead Dioxide Storage Tanks - 191 & 192
R-6904	Battery Repairs & Cast on Strap Line

We understand that there will be no change in the type of pollutants emitted and no increase in the quantity of emissions. You are reminded that these facilities must be in compliance with all Rules and Regulations of the Texas Air Control Board and the requirements of these permits at all times.

Thank you for this information and for your commitment to comply. Your cooperation and interest in air pollution control are appreciated.

Sincerely,

Cecil Bradford

Cecil Bradford
CORE Division
Permits Program

cc: Mr. Melvin Lewis, Regional Director, Fort Worth

TEXAS AIR CONTROL BOARD

DATE: 01-31-94 PERMIT APPLICATION SUMMARY PAGE: 1
TIME: 18:38:20

***GENERAL PERMIT INFORMATION
PERMIT: 1580 ENGR: PERITT, LAWRENCE / GROUP: METL ID:DBC411W
ISSUED TO: JOHNSON CONTROLS BATTERY GROUP, INC.
UNIT NAME: RECTIFIER ROOM EXHAUST SYSTEM
OPERATING SCHEDULE: 24.0 HRS/DAY 6 DAYS/WK 52 WKS/YR
LAT: 32-54-15 LONG: 096-4-00 REGION: 4 COUNTY: DALLAS
NEAR CITY: GARLAND LOC: 1111 SHILOH ROAD

***PERMIT/SITE CONTACT INFORMATION:
PERSON: KERWIN SINGLETON ADDR1: P.O. BOX 591
TITLE: ENVIRONMENTAL ENGINEER ADDR2:
CITY: MILWAUKEE STATE: WI ZIP: 53201 PHONE: (214)494-2461

** CONSTRUCTION **		** OPERATING **		** CONTINUANCE **	
TYPE APPL(C,S,X):	(C)	OPERATION START :		NOTICE MAILED :	
APPL RECD :	07-20-93	OPER APPL RECD :		APPL RECD :	
DEFIC LTR SNT :		OPER APPL CMPLT :		DEFIC LTR SNT :	
SUPP INFO REQ :		DISP(I,D): ( )		SUPP INFO REQ :	
SUPP INFO RECD :		OPR TYPE(P,S) : ( )		SUPP INFO RECD :	
APPL CMPLT :		**********		APPL CMPLT :	
COMP LTR SNT :		* *		COMP LTR SNT :	
PUB NTC SNT :		* I= ISSUED D=DENIED *		PUB NTC SNT :	
PUB NTC PUB :		* E=EXPIRED *		PUB NTC PUB :	
PUB HEAR (R,H) :	( )	* C=CNST S=SPECIAL *		PUB HEAR(R,H) :	( )
CNST TYPE(C,X,S):	(X)	* X=EXEMPT R=OPER *		DISP(I,D,E):( ) :	
DISP (I) :	10-14-93	**********			
CNST START DATE :					

***EMISSIONS CHANGED :

***REMARKS:PERMIT EXEMPTED DUE TO INSIGNIFICANT EMISSIONS. OWN CHG FROM JOHNSON CONTROLS, INC. **PERMIT VOIDED AND CONSOLIDATED UNDER PERMIT 6898.**

***OTHER PERMIT DATES:
APP/PERMIT VOIDED: 12-14-93 REASON: RR
APP ON HOLD UNTIL: REASON:
CONST STOPPED UNTIL:

VOID/HOLD CODES:
CP-COMPANY REQUEST
DD-DATA DELAY
RE-REISSUED

PD-PLT DISMANTLED
TI-TIME EXPIRED
TD-TECH DIFFICULTY
NR-NO RESPONSE

***PERMIT TYPES/STANDARDS:
NEW MAJ SOURCE:> 100 TPY: SIC: 3691
MAJOR MODIFICATION: PORTABLE: RELATED PERMITS: SUFFIX REASON
NON-ATTAIN REVIEW: ISPS: TACB: CHG LOC:
INSIGNIFICANT EMISSIONS: X NESHAP: PSD-TX: CHG OWN: X
FUEL CONVERSION: TOXIC MATERIALS: STD EX NO.:

***AIR CONTAMINANT INFORMATION:

NAME	CODE	MAX ALLOWABLE RATE LBS/HR	MAX ALLOWABLE RATE TONS/YR	ACTUAL TONS/YR

***ABATEMENT EQUIPMENT:

TEXAS AIR CONTROL BOARD

DATE: 02-22-91 PERMIT APPLICATION SUMMARY PAGE: 1
TIME: 18:35:29

***GENERAL PERMIT INFORMATION
PERMIT: 1580 ENGR: PEWITT, LAWRENCE / GROUP: METL ID:DB0411W
ISSUED TO: JOHNSON CONTROLS BATTERY GROUP, INC.
UNIT NAME: RECTIFIER ROOM EXHAUST SYSTEM
OPERATING SCHEDULE: 24.0 HRS/DAY 6 DAYS/WK 52 WKS/YR
LAT: 32-54-15 LONG: 096-40-00 REGION: 8 COUNTY: DALLAS
NEAR CITY: GARLAND LOC: 1111 SHILOH ROAD

***PERMIT/SITE CONTACT INFORMATION:
PERSON: JORDAN S. HARWOOD ADDR1: P.O. BOX 591
TITLE: MGR ENVIRONMENTAL CONTROL ADDR2:
CITY: MILWAUKEE STATE: WI ZIP: 53201 PHONE: (414)228-2650

** CONSTRUCTION **		** OPERATING **		** CONTINUANCE **	
TYPE APPL(C,S,X):	(C)	OPERATION START :		NOTICE MAILED :	
APPL RECD :	09-28-73	OPER APPL RECD :		APPL RECD :	
DEFIC LTR SNT :		OPER APPL CMPLT :		DEFIC LTR SNT :	
SUPP INFO REQ :		DISP(I,D): ( )		SUPP INFO REQ :	
SUPP INFO RECD :		OPR TYPE(R,S) : ( )		SUPP INFO RECD :	
APPL CMPLT :		**********		APPL CMPLT :	
COMP LTR SNT :		* *		COMP LTR SNT :	
PUB NTC SNT :		* I= ISSUED D=DENIED *		PUB NTC SNT :	
PUB NTC PUB :		* E=EXPIRED *		PUB NTC PUB :	
PUB HEAR (R,H) :	( )	* C=CNST S=SPECIAL *		PUB HEAR(R,H) :	( )
CNST TYPE(C,X,S):	(X)	* X=EXEMPT R=OPER *		DISP(I,D,E):( ) :	
DISP (I) :	10-10-73	**********			
CNST START DATE :					

***EMISSIONS CHANGED :

***REMARKS:PERMIT EXEMPTED DUE TO INSIGNIFICANT EMISSIONS. OWN CHG FROM JOHNSON CONTROLS, INC.

***OTHER PERMIT DATES:
APP/PERMIT VOIDED: REASON:
APP ON HOLD UNTIL: REASON:
CONST STOPPED UNTIL:

VOID/HOLD CODES: PD-PLT DISMANTLED
CR-COMPANY REQUEST TI-TIME EXPIRED
DD-DATA DELAY TD-TECH DIFFICULTY
RE-REISSUED NR-NO RESPONSE

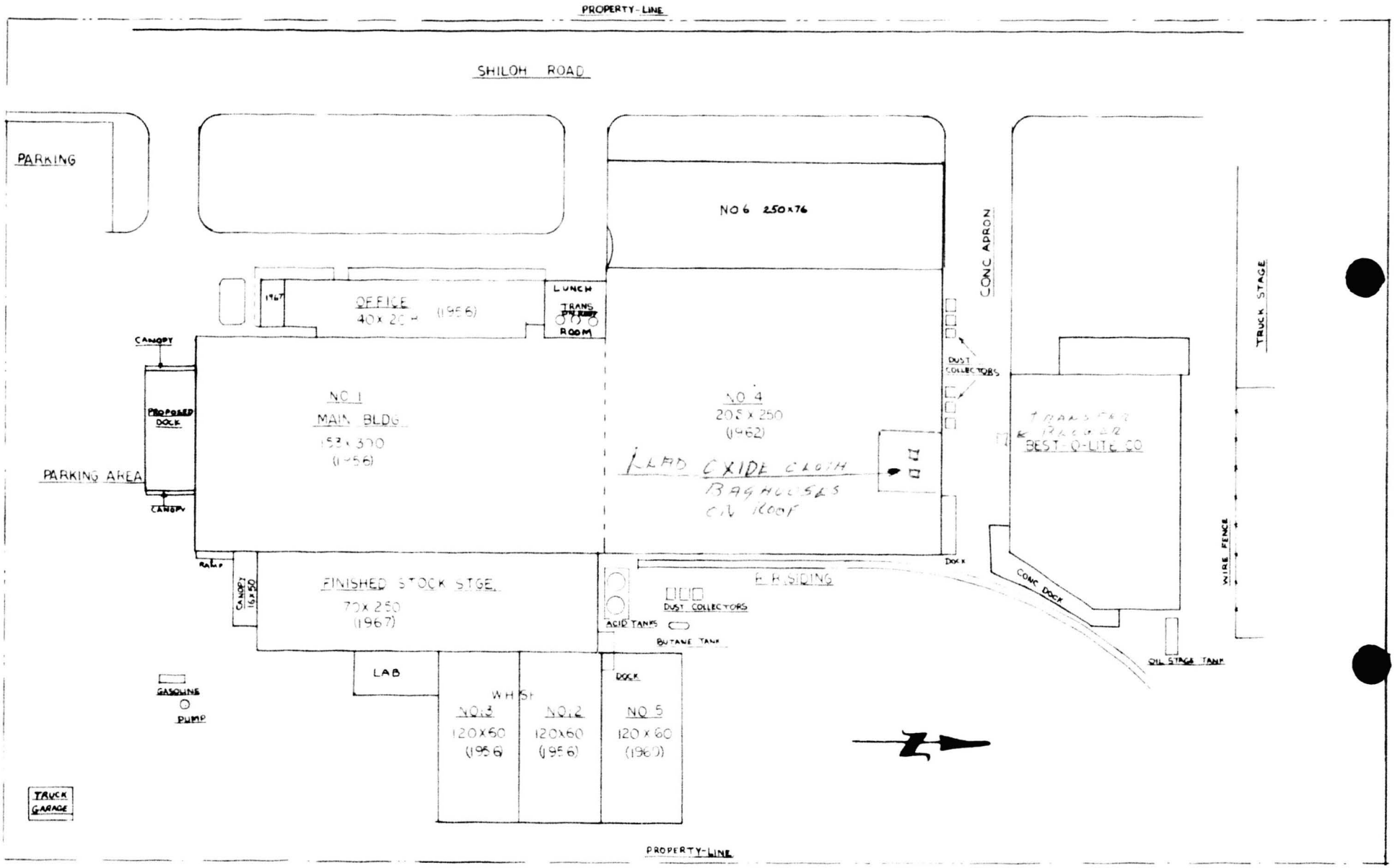
***PERMIT TYPES/STANDARDS:
NEW MAJ SOURCE:> 100 TPY: SIC: 3691
MAJOR MODIFICATION: PORTABLE: RELATED PERMITS: SUFFIX REASON
NON-ATTAIN REVIEW: NSPS: TACB: CHG LOC:
INSIGNIFICANT EMISSIONS: X NESHAP: PSD-TX: CHG OWN: X
FUEL CONVERSION: TOXIC MATERIALS: STD EX NO.:

***AIR CONTAMINANT INFORMATION:

NAME	CODE	MAX ALLOWABLE RATE LBS/HR	MAX ALLOWABLE RATE TONS/YR	ACTUAL TONS/YR

***ABATEMENT EQUIPMENT:

06 008



DALLAS, TEXAS

06 009

GLOBE-UNION INC.

RECEIVED
DEC 6 1973
PERMITS AND INVENTORY
AIR POLLUTION CONTROL

November 30, 1973

PI-2

Mr. Lawrence Pewitt
Texas Air Control Board
8520 Shoal Creek Boulevard
Austin, Texas 78758

Dear Mr. Pewitt:

SUBJECT: PERMIT APPLICATION FOR AN ADDITIONAL CLOTH BAGHOUSE AND EXHAUST FAN FOR BULK OXIDE SYSTEM, GLOBE-UNION, GARLAND

On October 26 and November 5, we submitted information for a permit covering the additional baghouse. Per your recent request, we are supplying additional information on the new forms. The previously submitted drawings and flow sheets detail our proposed installation.

The bulk (Barton and Ball Mill Type) lead oxide is received by truck and stored in hoppers within a building immediately to the south of the oxide tower. We use an airveyor system to transfer the oxide to two existing bulk oxide "day" storage hoppers. These hoppers are presently equipped with only one Ruemelin #205 baghouse gravity vent system. The new baghouse will be the same size and will be mounted adjacent to the present unit; thereby, splitting the venting load. The dust trapped by the filters drops back into the hoppers.

The air being vented is the air used for conveying the oxide, the oxide displacement air, along with any dust generated in the hopper filling operation. The second filter is being used to reduce the internal pressure by providing more cloth filtering surface, along with a push-pull fan operation.

If you have any questions, please feel free to call.

Very truly yours,

R. F. Nicolai
Pollution Control Engineer

RFN:dj

GLOBE-UNION INC. • 5757 NORTH GREEN BAY AVENUE • MILWAUKEE, WISCONSIN 53201 • 414 228 1200
CENTRALAB Electronics / CENTRALAB Semiconductors / GLOBE Batteries / INTERNATIONAL / U S CAPACITOR CORP

Texas Air Control Board

AUSTIN TEXAS

INTER-OFFICE

RECEIVED
TEXAS AIR CONTROL BOARD

FROM Melvin Lewis/David L. Thompson TO Lawrence E. Pewitt

SUBJECT Globe Union Inc. - Permit No. C-1716

LOCATION 1111 Shiloh Road, Garland, Dallas County

Investigator's Comments:

On January 30, 1974, an investigation of the Globe Union plant in Garland was conducted by this investigator. At the time of investigation this facility was in full operation and all processes were observed. The presently installed abatement equipment appeared to be in good condition and operating properly.

The proposed baghouse unit will be installed adjacent to the existing baghouse unit and will be utilized to increase the efficiency of the present system.

Recommendation:

That Permit No. C-1716 be granted.

SIGNED David L Thompson

DATE February 13, 1974

Texas Air Control Board

AUSTIN TEXAS

INTER-OFFICE

FROM Lawrence E. Pruitt, Project Engineer Permits and Inventory Division TO Melvin Lewis, Region 8

SUBJECT Request for Comments on Permit Application DATE: 12-7-73

Please give us your comments on the attached permit application within 15 days for a construction permit application, or within 10 days for an operating permit application.

Permit Application No. C-1716 R-

To Be Issued To: GLOBE UNION

Location: GARLAND (Nearest City) DALLAS (County)

Process Unit Identification Number: ID-GLO-0240

Engineer's Comments:

Melvin: This is to increase the capacity of the Lead Oxide Handling Facilities.

Lawrence

Region's Comments:

LEP/dmt,board,file

SIGNED 06 012

DATE

TEXAS AIR CONTROL BOARD

PHONE 512/451-5711
8520 SHOAL CREEK BOULEVARD

CHARLES R. BARDEN, P. E.
EXECUTIVE DIRECTOR

AUSTIN, TEXAS – 78758

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JOE C. BRIDGEFARMER, P.E.

June 26, 1974

Mr. G. E. Stoughton
Manager, Corporate Facilities
GLOBE-UNION INCORPORATED
P. O. Box 591
Milwaukee, Wisconsin 53201

Re: Permit No. R- 1716
Lead Oxide Transfer System
Garland, Dallas County

Dear Mr. Stoughton:

An operating permit for your new facility is enclosed. We appreciate your cooperation in sending us the necessary information to evaluate your proposed facility.

Thank you for your interest and cooperation in air pollution control.

Yours very truly,

Charles R. Barden

Charles R. Barden, P.E.
Executive Director
Texas Air Control Board

cc: Mr. Melvin Lewis, Regional Supervisor, Fort Worth
Dr. J. M. Pickard, Director, Dallas Co. Health Dept., Dallas

bcc: LEP/dt, board, file

File

***GENERAL PERMIT INFORMATION
PERMIT: 1716 ENGR: PEWITT, LAWRENCE / GROUP: METL ID:DB0411W
ISSUED TO: JOHNSON CONTROLS, INC. - GLOBE BATTERY DIVISION
UNIT NAME: LEAD OXIDE TRANSFER SYSTEM
OPERATING SCHEDULE: 6.0 HRS/DAY 5 DAYS/WK 50 WKS/YR
LAT: 32-54-15 LONG: 096-40-00 REGION: 8 COUNTY: DALLAS
NEAR CITY: GARLAND LOC: 1111 SHILOH RD

***PERMIT/SITE CONTACT INFORMATION:
PERSON: JON LAWRENCE ADDR1: P.O. BOX 461729
TITLE: PLT MGR ADDR2:
CITY: GARLAND STATE: TX ZIP: 75046 PHONE: (214)494-2461

***APPLICATION	CONSTRUCTION PERMIT:		OPERATING PERMIT:	
APPLI RECD: 11-06-73	SUPP INFO REQ:	11-06-73	OPERATION START:	
TYPE (C,S,X): (C)	SUPP INFO RECD:	12-10-73	APPLICATION RECD:	05-15-74
C=PERMIT	REGION COMM REQ:	12-10-73	PERMITS COMM REQ:	05-16-74
S=SPECIAL	REGION COMM RECD:	12-25-73	PERMITS COMM RECD:	06-02-74
X=EXEMPT	DISP (I,D,X,S):	(I)	DISP(I,D,S):	(I)
	AUTH: 01-17-74 DENIED:		AUTHORIZED DATE:	06-26-74
	CONST START:		DENIED DATE:	

***PERMIT AMENDED:

***REMARKS: BY LETTER 11/15/88 CO CLAIMS EQUIP. REMOVED IN 1978 & SYSTEM COVERED UNDER R6903.

***OTHER PERMIT DATES:		VOID/HOLD CODES:	PD-PLT DISMANTLED
APP/PERMIT VOIDED: 12-05-88	**REASON: RE**	CR-COMPANY REQUEST	TI-TIME EXPIRED
APP ON HOLD UNTIL:	REASON:	DD-DATA DELAY	TD-TECH DIFFICULTY
CONST STOPPED UNTIL:		RE-REISSUED	NR-NO RESPONSE

***PERMIT TYPES/STANDARDS:

NEW MAJ SOURCE:> 100 TPY:	SIC:		
MAJOR MODIFICATION:	PORTABLE:	RELATED PERMITS:	SUFFIX REASON
NON-ATTAIN REVIEW:	NSPS:	TACB:	CHG LOC:
INSIGNIFICANT EMISSIONS: X	NESHAP:	PSD-TX:	CHG OWN:
FUEL CONVERSION:	TOXIC MATERIALS:	STD EX NO.:	

***AIR CONTAMINANT INFORMATION: NAME	CODE	MAX ALLOWABLE RATE LBS/HR	TONS/YR	ACTUAL TONS/YR	INCREMENT TONS/YR

CCW 1-31-92

UB

Record of Telephone Call

Date March 16, 1989

Time 2:15 P.M.

Person making call Henry M. Curry Tel. 512 451-5711

Organization TACB Location Austin

Person receiving call Pat Fowler Tel. (214) 205-3460

Organization Garland Health Dept. Location Garland

Subject: Johnson Controls, Inc.

Summary: I talked to both Pat Fowler and with John Teel about the general reputation of Johnson regards environmental. Both gentlemen were very positive in their assessment of the company's attitude and actions toward health and environmental issues. They stated that there were very few complaints presently about the company, and most of the complaints were really just inquiries. Mr. Teel participated in a year-long study with Region 8 personnel in the early 1980's to sample for compliance with the NAAQS lead standard. The company was far below, to the best of his recollection, the property line limit. They believe that Johnson is a corporate good neighbor, spending time and money to comply with OSHA, the Garland Health Department permits, and control of air pollution.

NEW SOURCE TECHNICAL REVIEW

Permit No. R-2402 Company Johnson Controls, Inc. City Garland
___Permit ___Spl Permit ___Amend ___Revision County Dallas
___Exempt ___No change Exempt Status ___Correction
___Chg OWN ___Chg LOC ___NPR Other Continuance

*

REQUEST for COMMENTS: Remarks (N/R ,etc.):

REGION 8 :	x Approve by Spencer Savoie	___N/A:	
LOCAL-CITY :	x Approve by Pat Fowler	___N/A:	Health Dept.
-COUNTY:	___Approve by	x N/A:	
EFFECTS EVAL:	x Approve by Tom Dydek	___N/A:	
COMPLIANCE :	x N.C.A.P. by Jim Reed	___N/A:	
LEGAL ..... :	___N.L.A.P. by	x N/A:	

*

TECHNICAL REVIEW: Project description, etc.-

This process consists of using an oven to dry lead oxide battery plates made from a paste. The plates pass through the dryer at a controlled rate, where warm air is passed up through the plates and exhausted out a stack to the atmosphere. BACT is applied uncontrolled to these miniscule emissions. The 30 minute screening model showed lead impacts of 0.3308 micrograms/m3 whereas the quarterly standard for lead is 1.5 micrograms/m3. Although this plant is immediately adjacent to residential areas across a major thoroughfare there have been no complaints in the past 5 years. There have been no violations in the last 5 years. I recommend that this permit be continued.

MODELING:
A. Was modeling done? x YES, ___NO. Type: x Screen, ___Full
B. Will GLC of any air contaminant cause a violation of AAQS? ___YES, x NO
C. Remarks

*

APPLICABILITY: PSD? ___YES, x NO. NSPS? ___YES, x NO. Subpart:
NON-ATTAIN. review ___YES, x NO. NESHAPS? ___YES, x NO. Subpart:

MISCELLANEOUS
A. Applicant in agreement with special provisions? .... ___N/A, x YES, ___NO
x Phone, ___Letter. Co. Rep. Mark Ishahara 06/16/89
B. Applicant aware of 18 month expiration of permit? ... x N/A, ___YES, ___NO
C. NOV issued for construction without permit? ..... ___YES, x NO
NOV resolved by issuance of permit? ..... x N/A, ___YES, ___NO
D. Is this a sensitive location with respect to NUISANCE? .... ___YES, x NO
If YES, explain in technical review.
E. Is site within 3000 ft. of any SCHOOL?... ___YES (see tech review), x NO
F. Franchise TAX verified in good standing ..... x N/A, ___YES, ___NO

* Thomas M. Cheng 6/16/89 James Tucker 06-28-89

Permit Engineer (date) Backup Engr/Section Chief (date)

06 016

GLOBE Battery Division • GLOBE-UNION INC.

December 3, 1974

Mr. Lawrence A. Pewitt
Texas Air Control Board
8520 Shoal Creek Blvd.
Austin, Texas 78758

Re: Operating Permit Application # 2617

Dear Mr. Pewitt:

I am writing to confirm the telephone conversation between you and Mr. Fyffe, of our Dallas plant, on Wednesday Nov. 27th. This permit application is for a Wirtz grid casting machine that will replace an "8" mold style casting machine that is now operating in the Dallas plant. We have had a program underway for several years to replace all of the old style "8" mold casting machines as funds were available. The machine mentioned is the last one still operating at Dallas and I will assure you that it is to be removed completely from service and will not be kept on standby.

After the initial subject application was turned down we have had to review this project very closely. Since this is a direct replacement and does not add to our productivity, the economics are marginal to begin with, and an additional $10,000 to $12,000 to the installed cost for emission control puts the payback in doubt.

We had not anticipated that any emission control would be necessary and didnot include any in our cost projections since the emissions from the Wirtz caster is only a fraction of that from the existing "8" mold caster and the replacement will result in a net reduction in emissions. We feel that this is a valid consideration for this application and request that you review the application in light of it.

1111 SHILOH ROAD • GARLAND, TEXAS 75040

CENTRALAB Electronics / CENTRALAB Semiconductors / INTERNATIONAL / U S CAPACITOR CORP

I will be glad to furnish any information I can that might be helpful in your review. You may feel that a visit to the Dallas plant to view the operations first hand would be useful in your appraisal. If so, please be assured that we will assist in scheduling such a visit.

Sincerely,

GLOBE-UNION INC.

G.E. Stoughton
Mgr. Corporate Facilities

cc: C.O. Wanvig, III
W. Wall
R.F. Nicolai
J.M. Beaudoin
File

mf

TEXAS AIR CONTROL BOARD

DATE: 10-23-91 PERMIT APPLICATION SUMMARY PAGE: 1
TIME: 18:39:60

***GENERAL PERMIT INFORMATION
PERMIT: 2617 ENGR: BLACKSTOCK, RITA /CLARK, LEROY S. GROUP: METL ID:DB0411W
ISSUED TO: JOHNSON CONTROLS BATTERY GROUP, INC.
UNIT NAME: WIRTZ GRID CASTING MACHINE
OPERATING SCHEDULE: 24.0 HRS/DAY 5 DAYS/WK 52 WKS/YR
LAT: 32-54-15 LONG: 096-40-00 REGION: 8 COUNTY: DALLAS
NEAR CITY: GARLAND LOC: 1111 SHILOH RD.

***PERMIT/SITE CONTACT INFORMATION:
PERSON: JORDAN S. HARWOOD, P.E. ADDR1: P.O. BOX 591
TITLE: MANAGER-ENVIRONMENTAL CONTROL ADDR2:
CITY: MILWAUKEE STATE: WI ZIP: 53201 PHONE: (414)228-2650

** CONSTRUCTION **		** OPERATING **		** CONTINUANCE **	
TYPE APPL(C,S,X):	(C)	OPERATION START :		NOTICE MAILED	: 02-28-90
APPL RECD	: 07-29-74	OPER APPL RECD	: 09-05-75	APPL RECD	: 04-26-90
DEFIC LTR SNT	:	OPER APPL CMPLT	:	DEFIC LTR SNT	: 05-11-90
SUPP INFO REQ	:	DISP(I,D):	(I) 10-23-75	SUPP INFO REQ	: 06-22-90
SUPP INFO RECD	: 12-27-74	OPR TYPE(P,S)	: (P)	SUPP INFO RECD	: 06-25-90
APPL CMPLT	:	**********		APPL CMPLT	: 08-02-90
COMP LTR SNT	:	*	*	COMP LTR SNT	:
PUB NTC SNT	:	* I= ISSUED D=DENIED	*	PUB NTC SNT	: 06-29-90
PUB NTC PUB	:	* E=EXPIRED	*	PUB NTC PUB	: 07-15-90
PUB HEAR (R,H)	: ( )	* C=CNST S=SPECIAL	*	PUB HEAR(R,H)	: ( )
CNST TYPE(C,X,S):	(C)	* X=EXEMPT R=OPER	*	DISP(I,D,E):	(I) :09-13-90
DISP (I)	: 01-24-75	**********			
CNST START DATE :					

***EMISSIONS CHANGED :

***REMARKS:PROP.LINE SAMPLE MADE TO DETERMINE ACTUAL CONDITIONS FROM FAC. LEAD MEAS LESS THAN 0.5 MICROGRAMS PER CUBIC MTR ONE HR SAMPLE.OWN CHG FR JOHNSON CONTROLS, INC. PERM. **VOIDED 10/2/91-REISSUED UNDER R-6710.**

***OTHER PERMIT DATES:
APP/PERMIT VOIDED: 10-02-91 REASON: RE
APP ON HOLD UNTIL: REASON:
CONST STOPPED UNTIL:

VOID/HOLD CODES: PD-PLT DISMANTLED
CR-COMPANY REQUEST TI-TIME EXPIRED
DD-DATA DELAY TD-TECH DIFFICULTY
RE-REISSUED NR-NO RESPONSE

***PERMIT TYPES/STANDARDS:
NEW MAJ SOURCE:> 100 TPY: SIC: 3691
MAJOR MODIFICATION: PORTABLE: RELATED PERMITS: SUFFIX REASON
NON-ATTAIN REVIEW: NSPS: TACB: CHG LOC:
INSIGNIFICANT EMISSIONS: X NESHAP: PSD-TX: CHG OWN: X
FUEL CONVERSION: TOXIC MATERIALS: STD EX NO.:

***AIR CONTAMINANT INFORMATION:

NAME	CODE	MAX ALLOWABLE RATE LBS/HR	MAX ALLOWABLE RATE TONS/YR	ACTUAL TONS/YR

***ABATEMENT EQUIPMENT:

NEW SOURCE TECHNICAL REVIEW

Permit No: R-2617 Permit Type: RNEW
City: Garland County: Dallas

Company: JOHNSON CONTROLS

REQUEST FOR COMMENTS Remarks

REGION: 8 Approved by: Eddie Mack
COMP: X Approved by: Jim Reed

MODELING
A. Was modeling done? No Type?
B. Violation of NAAQS?
C. Remarks:

FEDERAL APPLICABILITY
PSD? No NSPS? No Subpart:
NON-ATTAIN? No NESHAPS? No Subpart:

MISCELLANEOUS
A. Applicant agrees with proposed sp. prov? yes Date: 8-16-90
Company representative? Mark Ishihara
Contacted by? phone
B. Applicant aware of 18 mo. permit expiration? N/A
C. NOV issued for unauthorized const./oper? No Date:
D. Sensitive location with respect to nuisance? No
E. Is site within 3000 feet of any school? No
F. Franchise tax verified in good standing? N/A Valid

TECHNICAL REVIEW:

Johnson Controls received its operating permit October 23, 1975 and has now applied for continuance of R-2617. This company manufactures Diehard and Interstate automobile batteries. This permit covers a Wirtz grid caster, in which the lead battery cell grids are cast. Lead is melted in a pot and flows down runners to the grid casting operation. The combustion gases are exhausted to the atmosphere. No control devices are employed in this process. The production rate for this machine is 0.5 tons/hour and 1,800 tons/year.

This permit has not been amended in the past fifteen years. Considering the age of this facility and the impact of emissions on the surrounding area, emission control technology is practicable. This facility will operate within the TACB rules and the Texas Clean Air Act.

NSPS Subpart A and KK are not applicable to this permit since it was constructed prior to January 14, 1980. NESHAPS is not applicable either.

Region and compliance personnel report no violations or complaints in the last five years. This facility is located in a residential

area. There are houses across the road to the east, northeast, and southeast beginning at less than 300 feet, and there is a daycare center less than 1000 feet to the south-southeast. The nearest public schools are located approximately 4000 feet to the northwest and 3800 feet to the southeast.

No comments or request for hearings were received during the fifteen days of public notice. All continuance requirements have been satisfied.

Rita Blackstock
Permit Engineer
'GSAVE'G

Date: 8-21-90

Section Chief/Backup

TEXAS AIR CONTROL BOARD

FROM Lawrence E. Pewitt Permits Section (Project Engineer) TO Executive Director

SUBJECT Permit to Operate No. R-662

1. NAME OF APPLICANT Globe Union Incorporated

2. TYPE OPERATION OR PROCESS Vacuum Cleaning System

3. NEW SOURCE [X] MODIFICATION [ ] PERMANENT [X] PORTABLE [ ]

4. IDENTIFICATION NUMBER 1

5. FACILITY LOCATION 1111 Shiloh Road, Garland, Dallas County, Texas
Latitude: 32°54'15" Longitude: 96°40'0"

COMMENTS

6. REGIONAL OFFICE: Favorable

7. LOCAL PROGRAM: No local program

8. AIR QUALITY: Favorable

9. COMPLIANCE: Favorable

10. LEGAL: No legal action pending

11. RESULTS OF EVALUATION OF APPLICATION

A. NAME AND RATE OF CONTAMINANTS TO BE EMITTED:

Air Contaminant	Emission Rate	Uncontrolled	Regulation Allowable
Particulate	0.03 lb/hr	Estimated 100 lb/hr	5.34 lb/hr

B. COMMENTS - TECHNICAL REVIEW:

Operation reported satisfactory by region inspection

C. SPECIAL PROVISIONS:

See attached sheet titled "Special Provisions R-662", 1-2

12. RECOMMENDATION - IT IS RECOMMENDED THAT THIS APPLICATION BE
X APPROVED (SUBJECT TO SPECIAL PROVISIONS NOTED ABOVE).
____ DENIED. WRITTEN OBJECTIONS ARE ATTACHED.

Date Received 9-4-73
Date Sent to Region 10-1-73

Signed Lawrence E. Pewitt

Date 3-6-74

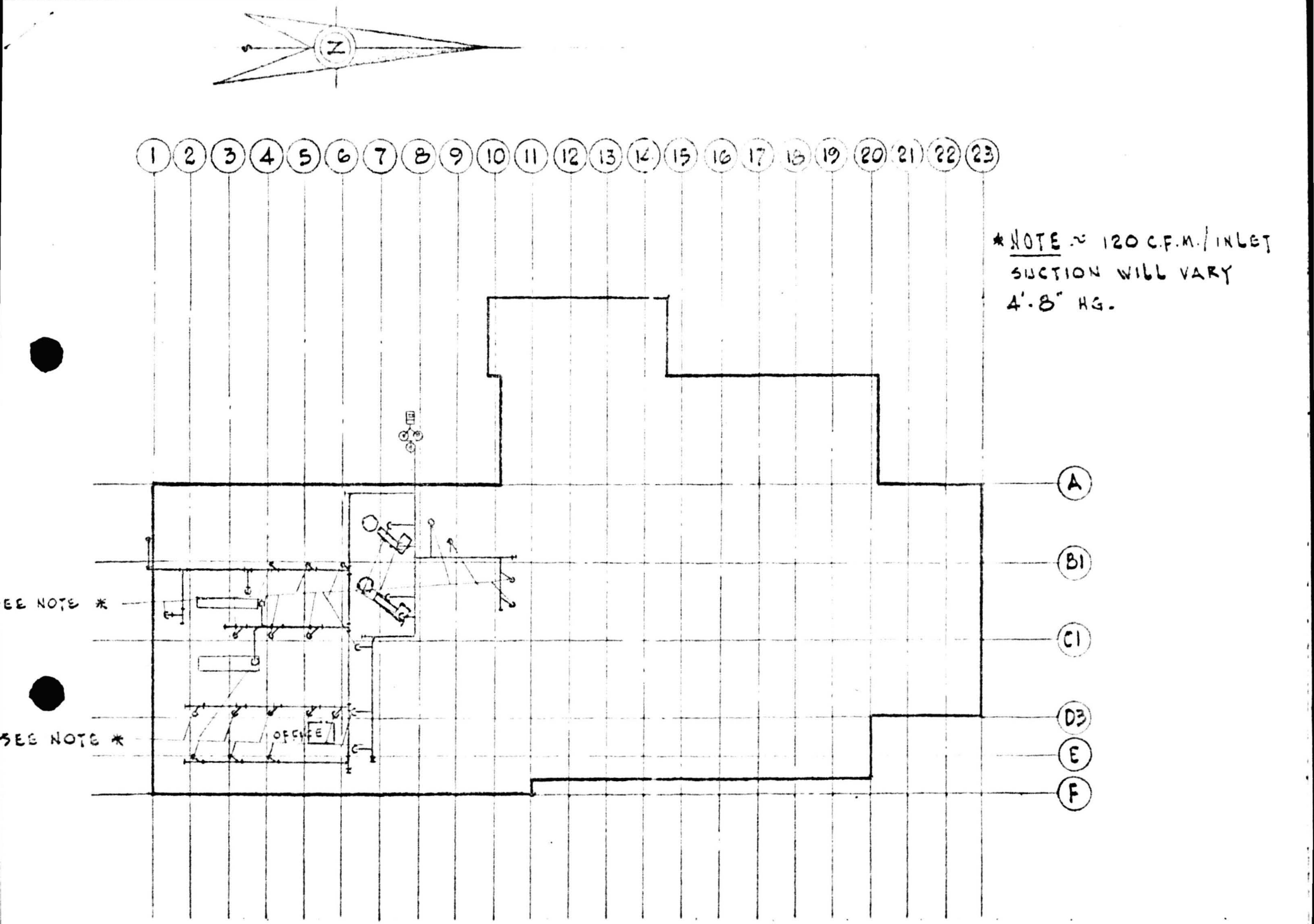
TEXAS AIR CONTROL BOARD

Re: General Application by Globe-Union Inc.
Garland, Texas Plant

Item VI

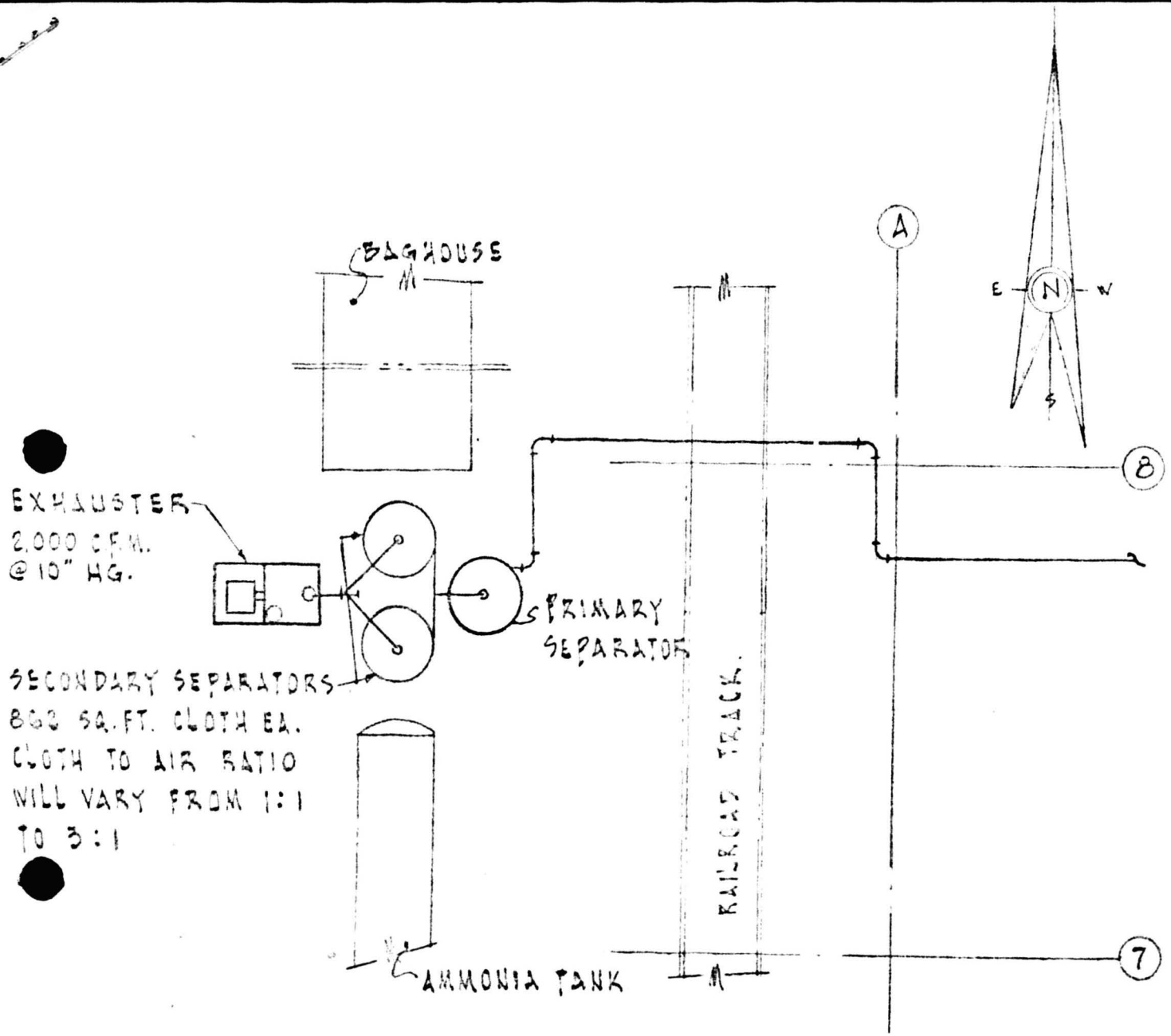
This system is being installed for general plant use in order to improve the "housekeeping". The dust that will be collected will be returned to the smelter. We have four (4) existing Ruemelin baghouses as reported in our other previous permit reports.

Texas - Company - I.D. GL00240

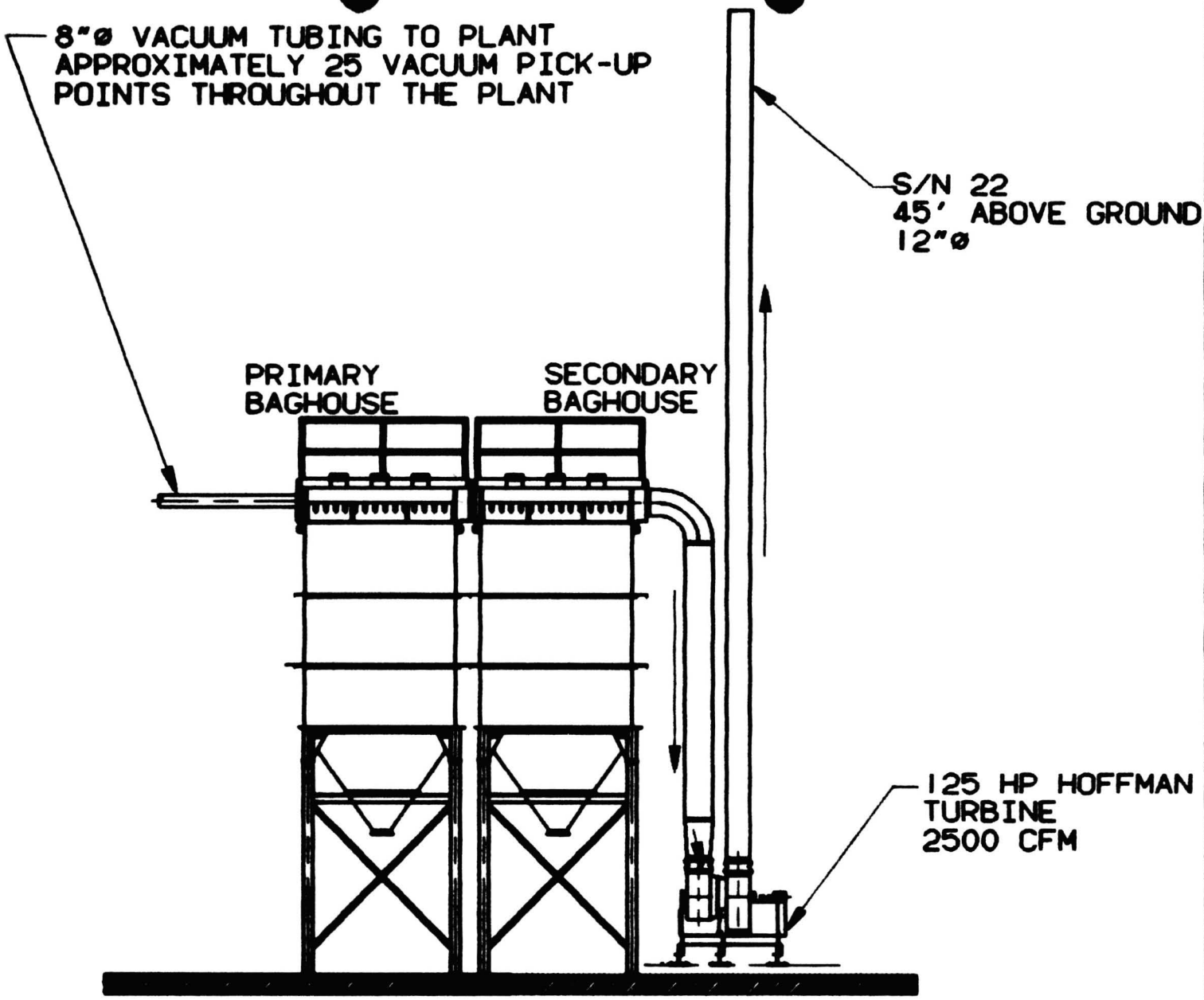


DALLAS VACUUM SYSTEM

06 024



DALLAS VACUUM SYSTEM.



SUNSPAN BAGHOUSES

PRIMARY—#SSBPT-76-HVR
SECONDARY—#SSBPT-52-HVR

RECEIVED
JUL 07 1992
PERMITS PROGRAM

NOTICE: THIS DRAWING IS FURNISHED FOR REFERENCE ONLY. THE FURNISHING OR POSSESSION OF THIS DRAWING OR ANY REPRODUCTIONS THEREOF, DOES NOT CONVEY ANY MANUFACTURING RIGHTS.

LTR	REVISION DESCRIPTION	DWR	APD

MACH TITLE

SUBJ TITLE DALLAS CENTRAL VACUUM SYSTEM

SCALE NTS	REF INFO			SH NO 1	A FILE DIV X-16
DWR DG PHILLIPS	DATE 6/23/92	APVD	DATE	JOHNSON CONTROLS SLI Battery Division	DWG NO 06 026
CHK JOHN GROSSE	DATE 6/23/92				
ENGR JOHN GROSSE	DATE 6/23/92				

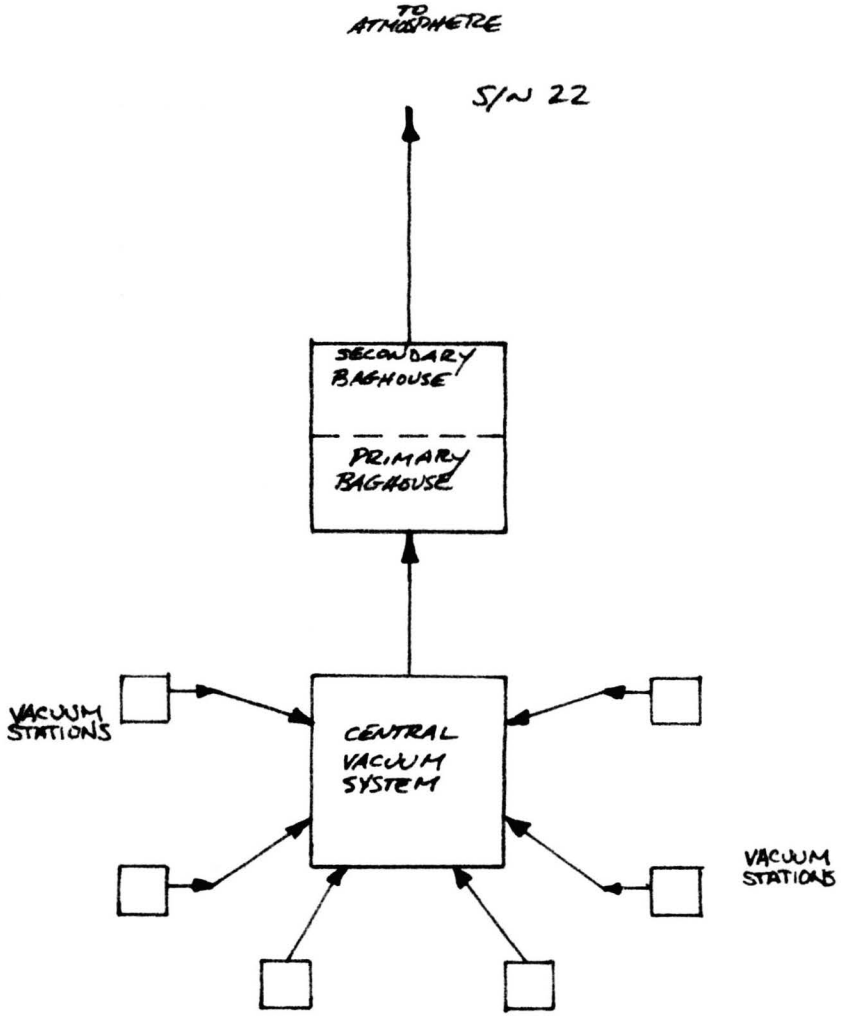
WORKSHEET

JOHNSON CONTROLS

Subject	Date	BY	PAGE
JCBGI - GARLAND FACILITY CVS	24 JUNE 92	KTS	

FIGURE 1

CENTRAL VACUUM SYSTEM FLOW DIAGRAM



TEXAS AIR CONTROL BOARD

12124 PARK 35 CIRCLE, AUSTIN, TEXAS 78753, 512/908-1000

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WARREN H. ROBERTS
MARY ANNE WYATT

January 14, 1993

Mr. Jordan S. Harwood, P.E.
Manager Environmental Control
JOHNSON CONTROLS BATTERY GROUP, INC.
P.O. Box 591
Milwaukee, Wisconsin 53201-0591

Re: Permit Amendment
Permit No. 662
Central Vacuum System
Garland, Dallas County
Account ID No. DB-0411-W

Dear Mr. Harwood:

This is in response to your letter dated June 26, 1992, permit application, Form PI-1, concerning the proposed amendment to Permit No. 662. We understand you propose to install a new central vacuum system controlled by baghouses to replace the existing central vacuum system.

Pursuant to Rule 116.5 of Regulation VI of the Texas Air Control Board, Permit No. 662 is hereby amended. This information will be incorporated into the existing permit file. Enclosed are general provisions, revised special provisions pages and maximum allowable emission rates table. Please return the previously-issued provisions pages and table to this office.

This amendment will be automatically void upon the occurrence of any of the following conditions:

1. Failure to begin construction of the changes authorized by this amendment within 18 months from the date of this authorization.

2. Discontinuance of construction of the changes authorized by this amendment for a period of 18 consecutive months or more.

3. Not completing the changes authorized by this amendment within a reasonable time.

Your cooperation in this matter is appreciated. If you have further questions, please contact Mr. Dan White of our Permits Program.

Sincerely,

William R. Campbell
Executive Director

Enclosures

cc: Mr. Melvin Lewis, Regional Director, Fort Worth

PERMIT AMENDMENT
TECHNICAL REVIEW

Permit No. : 662 Company: JOHNSON CONTROLS BATTERY GROUP, INC.
Project Type : RAMD City: GARLAND County: DALLAS
Facility Name: CENTRAL VACUUM SYSTEM Engineer: DAN WHITE

REQUEST FOR COMMENTS

REMARKS:

REGION: 8 Approved by: Mr. Ejaz Baig
LOCAL-CITY: N/A Approved by:
COUNTY: N/A Approved by:
EES: X Approved by: Mr. Jong-Song Lee
COMP: X N.C.A.P. by: Mr. Patrick Funair
LEGAL: N/A N.L.A.P. by:

REVIEW SUMMARY:

A. MISCELLANEOUS:
1). NOV issued for construction without a permit? ..... NO
2). NOV resolved by issuance of permit? ..... NO
3). Applicant in agreement with special provisions? ..... YES
Company representative? MR. KERWIN SINGLETON
Contacted by? PHONE Date? 01/11/93
4). Franchise Tax verified in good standing ..... N/A

B. PROJECT OVERVIEW: Johnson Controls wishes to replace a worn out dust collection system consisting of a dry cyclone and a .0015 grain/scf baghouse with a new primary baghouse coupled to a secondary baghouse with an outlet grain loading of .00044 grain/scf. This will reduce their emissions to less than one-third of their present permitted levels.

C. PROCESS DESCRIPTION: A central vacuum system is used to reclaim lead scrap and lead dust from various parts of the plant. The scrap and dust is loaded into sealed barrels and shipped off site to lead smelters. A secondary baghouse is used to control emissions.

D. SOURCES AND CONTROLS: This vacuum system is used as a general housekeeping system to glean dust and scrap which precipitate from other processes in the plant. The vacuum system passes through two baghouses equipped with Gore-Tex bags before being vented to the atmosphere. The baghouses are each eqipped with magnehelic pressure sensors. We require the company to install a continuous recorder for the secondary baghouse pressure sensor and to operate, as a condition of compliance, between 1 and 3 inches water column pressure drop.

E. BACT: In my opinion, baghouses represent BACT for particulates to include lead. These baghouses use GORE-TEX bags which, in my opinion, are superior to any other cloth filter bags for removing particulates. Stack sampling from other Gore-Tex equipped baghouses indicate performance is much better than .00044 gr/dscf; results are typically less than .00002 gr/dscf. The present level of .03 pounds/hour will be reduced to .01 pounds/hour and the presently permitted level of .1 tons per year will decrease to .03 tons per year.

F. IMPACTS EVALUATION:

1). Was modeling done? YES Type? SCREENING
2). Will GLC of any [redacted]r contaminant cause viola[redacted]n of NAAQS? .. NO
3). Is this a sensitive location with respect to nuisance? ..... NO
4). Is site within 3000 feet of any school? ..... NO
5). Toxics Evaluation: Health Effects had no adverse comments. Sampling data from a TACB monitor indicates this plant is below the NAAQS standard.

G. SAMPLING AND TESTING REQUIRED: NONE

H. FEDERAL PROGRAM APPLICABILITY:
PSD? NO NON-ATTAIN REVIEW? NO
NSPS? YES Subpart: A & KK
NESHAPS? NO
REMARKS: NONE

I. PUBLIC NOTICE RESULTS: Waived by Region 8.

J. COMMENTS: The TACB operates a HI-VOL ambient air sampler less than 200 feet from the maximum ground level concentration receptor indicated by the screening model. The data from that sampler was obtained from Mrs. Rose Irizarry from the Data Management and Analysis division of the TACB. The data she had available was for 4th quarter 1991 through 3rd quarter 1992. The monitor data for each of these quarters was 0.10, 0.05, 0.07, and 0.08 micrograms per cubic meter respectively. These data are order of magnitude less than the NAAQS standard of 1.5 micrograms per cubic meter per calendar quarter.

Dan White — Permit Engineer — 1/12/93 — Date:

Doug Dellen — Section Chief/Backup Engineer — 1/13/93 — Date:

Reference 7

2000/01/01 00:00

VER/H - verified/ historical E/NE - eligible/non-eligible EO/IR - emergency order/immediate removal
TRR/REF - to be referred/referred SSC - site screening complete NS/NFA - non-site/no further action
HR-I/C/R - HRS in progress/complete/revised ESC - enforcem. screening comm. SN/A - sampling needed/active facility
FO/RIFS/EPA/AG - Field Ops/Remedial Investigation Feasibility Study/Environmental Protection Agency/Attorney General

1/21 GR
date reviewed by 1/9/96 JT date updated by 2-21-96 KK date entered by 2-26-96

STATE SUPERFUND CANDIDATE SITE ELIGIBILITY / STATUS SHEET

SITE NAME (and aka's) Globe-Union, Inc. AKA: Johnson Controls Battery Group, Inc.

EPA # TXD 980626642 **TNRCC SWR #** 34361 **Other #**

LOCATION 1111 Shiloh Road

CITY Garland **COUNTY** Dallas

TYPE OF OPERATION inactive battery manufacturing facility **DATE OF OPERATION** 1976 to 7/95

TNRCC REGN# 04 **REFERRAL SOURCE/DATE:** (EPA) H ESC AG 8/17/92

SSDAT ACTION TAKEN/DATE: (VER) 1/09/96 EO HR-I REF
SS-C IR HR-C HR-R

CURRENT STATUS: EL (NE) NS NFA SN A (FO) RIFS EPA TBR other

CONTAMINANTS OF CONCERN (COC), ANALYTICAL RESULTS (if any) & WASTE QUANTITY AND PATHWAY: (See Narrative Below)

File reviewed by J. D. Thompson. Based upon Region File Review and Central File Record Review information, the site is currently a/an:

- o active facility - not eligible for Superfund refer to Field Operations. **A/FO**
- o active/inactive facility- currently under TNRCC enforcement. **NE/TBR FO; NE/TBR ESC**
- X inactive facility - no enforcement action/referral to Field Operations. **NE/FO**
- o eligible inactive facility - prioritize for immediate removal determination and HRS package preparation. **EL**
- o eligible inactive facility - prioritize for HRS Package preparation. **EL**
- o inactive facility with insufficient data for screening purposes - referred to field operations for sampling inspection. **FO/SN**
- o Non-site based on EPA/TNRCC investigation conducted on _____. **NS**
- o No further action under state superfund based on EPA/TNRCC investigation conducted on _____. **NFA**

COMMENTS: The Globe-Union, Inc., AKA: Johnson Controls Battery Group, Inc. facility located at 1111 Shiloh Road, Garland, Tx. operated as an automotive lead-acid battery manufacturing facility from 1976 to July, 1995, when the facility was closed and ceased production. All manufacturing/processing equipment were removed from the facility and distributed to other plants. The building is presently vacant according to the Corporate Environmental Manager (see attached telephone memo). Wastes included used lubricating and crankcase oils, lead contaminated wastes (i.e., clothing, PPE, storage batteries), waste cleaning and degreaseing thinners/distillates, and other non-halogenated solvents (i.e., xylene, acetone, ethyl acetate). These wastes were stored in drums in a container storage area for shipment off-site. The site was last inspected by the Region 4 I&HW Office on 6/2/86 and found non-compliant for incomplete notification requirements, manifest documentation, and HW accumulation documentation, and lacking a personnel training program and a contingency/emergency procedures notification plan, which were subsequently resolved. A copy of the current NOR, cover sheet from the last inspection, and a current status verification memo are attached.

RECOMMENDATION: ~~Recommend no further action since the site is an~~ Inactive registered RCRA facility undergoing closure; therefore, not currently eligible under the State Superfund Program criteria.

c:\everyone\sadet\forms\elig-stat.sht

James D. Thompson, Region 4

Approved

13E

Reference 8

From: Ron Evans
To: Stephen Ellis
Subject: Re: Globe-Union facility info
Date: Friday, April 12, 2019 3:00:58 PM

---

1. Who did you say was your source of information regarding Globe-Union operations? Is there a chance that you could put us in contact with that individual, or perhaps anyone who worked at the plant? **After we opened our business a lady dropped in asking if she could look around. In escorting her around she told me most of the info I gave you regarding Globe Union. Her father worked in the facility from the time it opened until it's closing.**
2. How long has CEI operated at the facility? Did it follow immediately after Texas American Express vacated the building? **CEI began operations in this facility in September of 2013. The building had been mostly vacant for appx 5 years.**
3. We discussed this, but I was never clear on Aadvanced Water Management's business there. We saw some of their materials in a front room, but I didn't see a business office. Is it merely a product storage location. **Bobby Williams, owner of Aadvanced WM was here when we bought from First State Bank. He was a caretaker and operated his business from here. We have allowed him to stay on in one of the offices and store his product.**
4. What other entities currently operate in the facility? The smaller buildings on the west side of the facility seem to be engaged in a different business, and there are other cars indicating employees beyond the number working for CEI. **The blue building on the south end we have leased to Tread, a truck tire service facility. Other that Bobby there are no other entities at this facility. The extra cars belong to truck drivers and some are from a company we started that failed and we are selling the fleet.**
5. There are a number of tractor-trailer rigs parked around the facility. Are they all associated with CEI? **The tractor trailers, for the most part, lease parking space from us. They have no affiliation with our facility.**

Ron Evans
Copier Exporter, Inc.
1301 S Shiloh RD
Garland, TX 75042
copierexporterinc.com
Ph 214 904 9000
fax 214 904 9004
cell 469 939 9238

On Fri, Apr 12, 2019 at 12:44 PM Stephen Ellis <stephen.ellis@tceq.texas.gov> wrote:

> Mr. Evans,
>
> I wanted to thank you again for giving your EPA/TCEQ visitors a tour of the former Globe-Union Battery facility last week. It proved very helpful in understanding how the site was used in the past. If I may take a little more of your time I had some follow-up questions that I hoped you could help with. For our purposes we need to document historical use of the facility. Your statement regarding 1700 workers on 3 shifts is a great example- a piece of information that really tells the scale of the operation. I thought of calling to further discuss

some items, but perhaps an email is more appropriate because you don't have to wait for me to feverishly take notes, and you can answer as time allows.

Questions:

1. Who did you say was your source of information regarding Globe-Union operations? Is there a chance that you could put us in contact with that individual, or perhaps anyone who worked at the plant?
2. How long has CEI operated at the facility? Did it follow immediately after Texas American Express vacated the building?
3. We discussed this, but I was never clear on Aadvanced Water Management's business there. We saw some of their materials in a front room, but I didn't see a business office. Is it merely a product storage location
4. What other entities currently operate in the facility? The smaller buildings on the west side of the facility seem to be engaged in a different business, and there are other cars indicating employees beyond the number working for CEI.
5. There are a number of tractor-trailer rigs parked around the facility. Are they all associated with CEI?

Thank you,

Stephen Ellis

TCEQ PASI Program Manager

Superfund Section, Remediation Division

(512) 239-5337

Stephen.Ellis@tceq.texas.gov

Reference 9

4/3/19

Globe-Union PA site visit 4/3/19

13:10 Arrive at Lowe's on NW Hwy near Garland and met up with Brad Kendrick, EPA SAM.
- held health & safety briefing

13:40 Arrive near site to view drainage by retention pond. Attempt to see drums allegedly placed by creek - no evidence.
photo 1 - east view over retention pond from Nicholson Street to site.
photo 2 - north view to mallard nests in retention pond from Marquis St.
photo 3 - north view to discarded tires at waters edge
photo 4 - south view to retention pond
photo 5 - animal holes at water edge

- there is no 'sheen' on the water, and all plant and animal life appears healthy

photo 6 - south view along creek south of Marquis St.
- natural flow of creek turned to a straight channel along property line.

photo 7 - northwest view to creek below pond
- the effective "beginning" of the creek which is fed by the retention pond
- site drainage is visible on double pipes at right

photo 8 - southeast view from RR. trestle to creek
- site drainage along west site boundary flows south, crosses under Marquis St, and enters creek from left.

Stephanie Ellis 4/3/19

photo 9 - north view along rr tracks which run behind site
- all site drainage from the west parking lot drains to depression on east side of r.r. tracks, then is channeled south

photo 10 - east view to sw corner of facility
- south parking lot drainage collects at fence line, is channeled west to drainage depression
- several tractor trailer rigs were parked around the facility

Site drainage:

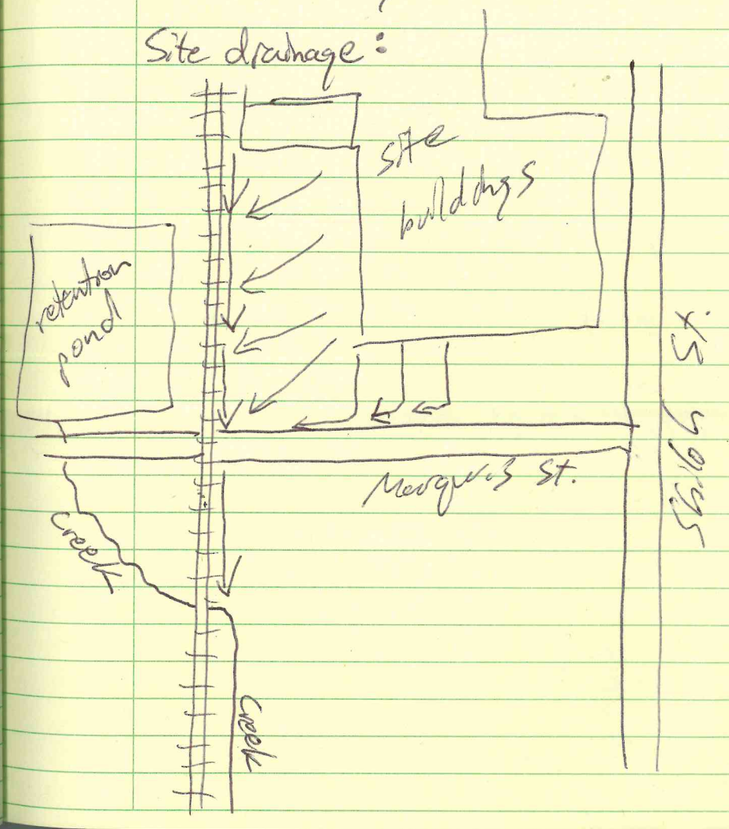


photo 11 - south view from photo 10 vantage point
- Maguire St. culvert is visible

photo 12 - south view along drainage depression
- drain pipe contains water, looks to be partially functional
- was this installed to direct runoff under r.r. spur to site?

photo 13 - north view along drainage depression

photo 14 - east view to northern facility building
- one man repairing tractor-trailer; otherwise, no evident activity

photo 15 - southeast view to northwest side parking lot
- vehicle and trailer storage

photo 16 - north view along drainage depression near nw site boundary
- Sherwin Williams paint factory on northern property border (behind fence)
- drain pipe may be draining from SW property

photo 17 - south view from nw corner of site along drainage depression

- over the length of the drainage depression there is no evidence of stressed vegetation

- there is a cut out portion of the fence (not pictured)

Stephen Ellis 4/3/19

SE 4/3/19

photo 18 - east view to facility building
- from 1982 PA photos this may have been the waste staging and smelting area

14:35 Entered site from Marquis St. to office
- met Ron Evans, who is effectively the on-site manager for Copier Exporter, Inc. (CEI)

Mr. Evans:
- CEI is the largest N. American exporter of used photocopiers.
- CEI buys, refurbishes, and resells
- They have five employees including one "absentee" owner

14:45 Mr. Evans guides us through facility
- he noted the drying tower just outside the CEI offices, stated that the upper floors are empty
- he stated that 1700 people worked over 3 shifts at the height of Globe-Union operations, as he understood from speaking with someone in 2011 who had first-hand knowledge.
- operations began in the 1940s

SE 4/3/19

photo 19 - north view into first room adjacent to CEI offices

photo 20 - northwest view into main factory floor
- less than half of total area was lit and filled with copiers in an apparently ordered fashion

photo 21 - east view to former main customer entrance at Globe-Union
- new fixtures in ceiling and paint on walls
- Mr. Evans stated they were re-doing the offices to move across the facility but scrapped the plan mid way through completion

- entered large room next to office containing large pallets of material which Mr. Evans said belonged to Aadvanced water management. Product is designed to be installed in yards to conserve water

photo 22 - south view from north portion of facility
- less organization, random debris in this section
- some wood pallets stacked at far north end, Mr. Evans stated that another entity engaged in the spray painting of pallets in this area in the recent past.

photo 23 - west view into middle of three pitched roof structures on west side of facility added after main facility was constructed.
contained plastic totes and trash

SE

SE 4/3/19

photo 24 - southwest view to holes above windows along west wall of facility
- piping access to former smelter pictured in '82 RA?

photo 25 - north view from southwest portion of facility.
- an employee is visible in the center repairing a copier

- re. the hole in the fence, Mr. Evans said fence-cutting is a frequent occurrence

15:10 Mr. Evans returned to his office while we taxed the west parking lot.

photo 26 - northeast view to former smelter and waste staging area
- building in center was constructed after the north smelter was removed (based on visual comparison with '82 RA photos)

photo 27 - southeast view to west wall of facility
- photo roughly taken from same location as '82 RA photo #9 which showed a single stack smelter and staged waste

photo 28 - northeast view to large holes visible in photo 24
- purpose unknown

SE 4/3/19

Stephen Ellis 4/3/19

photo 29 - south view across west parking lot of facility
- photo taken from same general location as photo #8 from '82 PA which showed waste staging area at left and double stack smelter in background (since removed).

photo 30 - east view to former rr spur dock
- photo taken from same general location as photo #14 from the '82 PA report

Note re. all parking lot photos: a hodgepodge of concrete exists due to the changing use of the site

photo 31 - northwest view to CEI entrance
- photo location from same vantage point as final (not numbered) photo in '82 PA report

15:50 BK and SE entered CEI office, thanked Mr. Evans for his assistance, and departed site.

15:55 Left Globe-Union facility to tour neighborhood
- mostly pier and beam homes with brick veneer, single story, well-kept yards

photo 32 - northwest view to creek looking upstream on Newcastle Drive
- heavy vegetation along creek edge borders back yards on both sides
- limestone creek bottom

17:25 BK & SE return to parking lot meeting location - end of day

SE 4/3/19

Reference 10

2017
Miller Park N
Globe-Union
S Shiloh Rd
Image U.S. Geological Survey
436 ft
1995

2/01

2017
Miller Park N
Globe-Union
S Shiloh Rd
Image U.S. Geological Survey
436 ft
1995

9/17

Reference 11

Globe-Union Battery Photographic Log

All photographs taken by Stephen Ellis on April 3, 2019

Photo 1: East view over retention pond from Nicholson St. to site.

Photo 2: North view from Marquis St. over retention pond with site to the right. Note built up duck nests.

Photo 3: North view to discarded tires in retention pond adjacent to site.

Photo 4: South view over retention pond adjacent to site. Note generally healthy and clean appearance.

Photo 5: Animal holes at edge of retention pond. These holes surrounded the pond.

Photo 6: Northwest view along railroad tracks south of Marquis St. The retention pond west of the site drains into this natural course of Stream 2C4.

Photo 7: Southeast view as Stream 2C4 flows under railroad trestle. Note that site drainage channeled to the east side of the railroad tracks and then south joins the stream from the left side of the photo.

Photo 8: South view along Stream 2C4 south of Marquis St. and the site. This portion of the stream has been altered to run along the property line before it crosses Shiloh St. and resumes its natural course.

Photo 9: North view along railroad tracks which run west of the site. All runoff from the west parking lot of the site flows to the east of the tracks then travels south through this culvert to join Stream 2C4 approximately 150 feet to the south.

Photo 10: East view to southwest corner of the facility property. Drainage from the south portion of the facility is channeled to the west where it travels under the fence and joins the drainage depression referred to in photo 9.

Photo 11: South view from vantage point of photo 10 showing path of all west and south parking lot site drainage to culvert under Marquis St.

Photo 12: South view to site drainage along railroad tracks. Note drain pipe in foreground (apparently still somewhat functional) which may have been installed under former railroad spur to site.

Photo 13: North view along drainage depression from same vantage point as photo 12.

Photo 14: East view to northern-most building of facility complex.

Photo 15: Southeast view from same vantage point as photo 14.

Photo 16: North view near northwest site corner showing drain pipe and site drainage depression. Note that runoff from the Sherwin Williams paint company factory to the north shares this drainage depression.

Photo 17: South view from northwest corner of the site to drainage depression.

Photo 18: East view across the west side parking lot of the site. Note that the smelters and waste staging area from the former Globe-Union facility were located along the back of this building.

Photo 19: North view into south portion of facility complex showing used copiers.

Photo 20: Northwest view to central part of the facility. Note that windows and bay doors to the left look to west parking lot and former smelters and waste staging area.

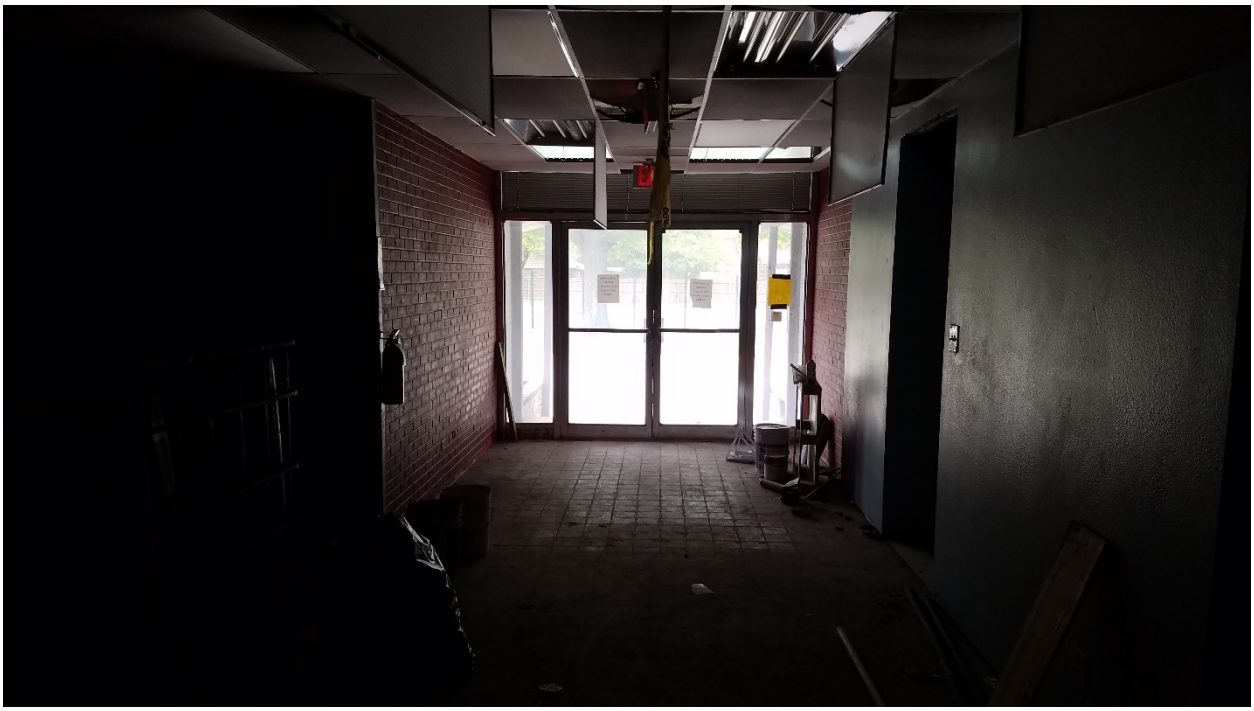


Photo 21: East view to original main customer entrance of facility.

Photo 22: South view from northern portion of the facility.

Photo 23: West view into central pitched roof warehouse on west side of property.

Photo 24: Southwest view to west wall of facility. Purpose of the large hole above the painted-over windows is unknown.

Photo 25: North view from southwest portion of the facility.

Photo 26: Northeast view to former smelter and waste staging area.

Photo 27: Southeast view to west wall of facility

Photo 28: Northeast view to holes in wall visible in photo 24.

Photo 29: South view across west parking lot of facility.

Photo 30: East view to southeast portion of the facility where the railroad spur tied in. Note the lighter colored concrete adjacent to the loading dock poured after spur removal.

Photo 31: Northwest view to entrance to Copier Exporter, Inc.

Photo 32: Northwest view to Stream 2C4 (looking upstream) at bridge on Newcastle Dr. in the neighborhood southeast of the site.

Reference 12

NFIP

NATIONAL FLOOD INSURANCE PROGRAM

PANEL 0220L

FIRM

FLOOD INSURANCE RATE MAP

DALLAS COUNTY, TEXAS AND INCORPORATED AREAS

PANEL 220 OF 725

(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

CONTAINS:

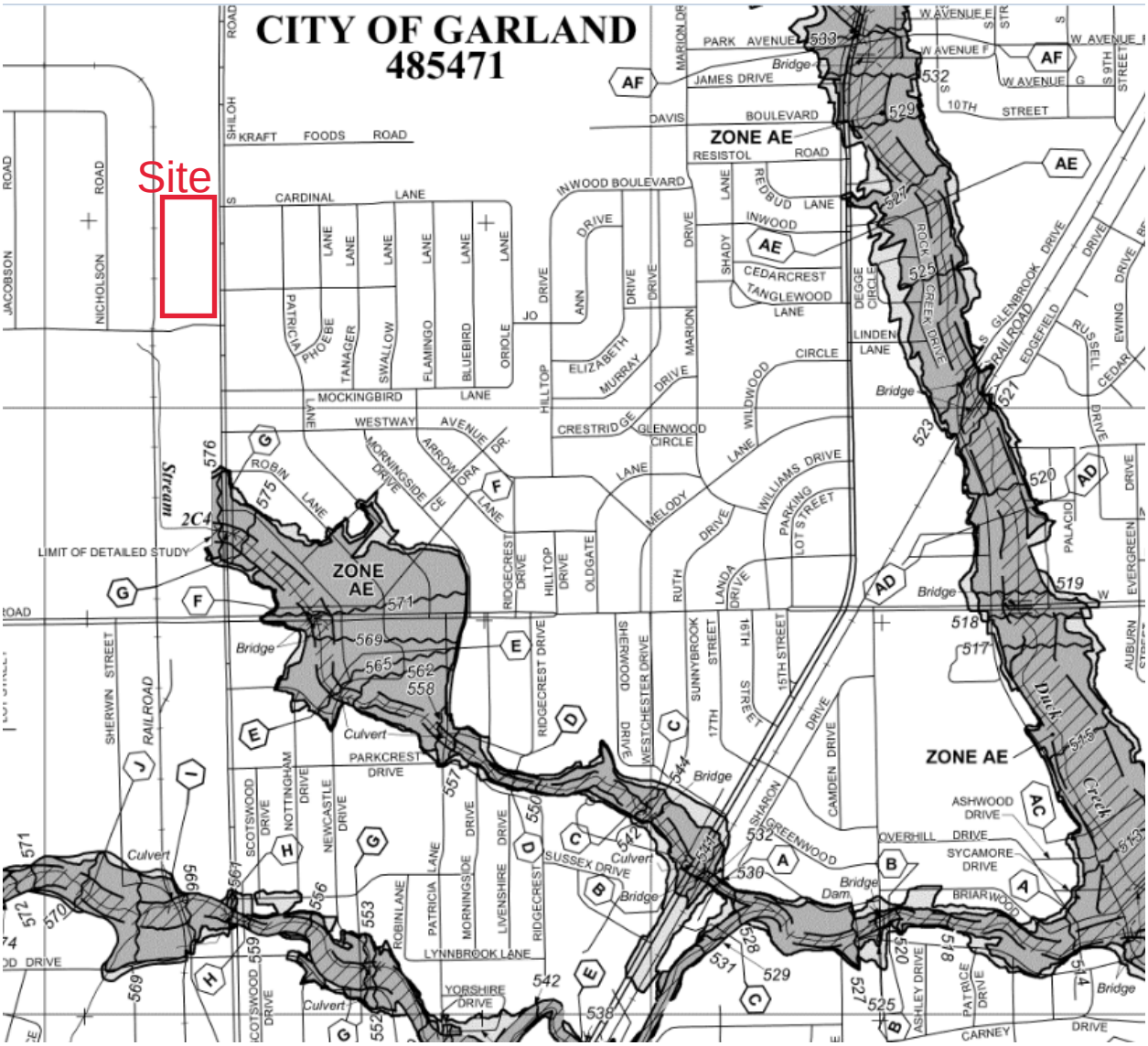
COMMUNITY	NUMBER	PANEL	SUFFIX
DALLAS, CITY OF	480171	0220	L
GARLAND, CITY OF	485471	0220	L
RICHARDSON, CITY OF	480184	0220	L

Notice to User: The **Map Number** shown below should be used when placing map orders; the **Community Number** shown above should be used on insurance applications for the subject community.

MAP NUMBER
48113C0220L

MAP REVISED
JULY 7, 2014

Federal Emergency Management Agency


CITY OF GARLAND
485471
Site
ZONE AE
LIMIT OF DETAILED STUDY
Stream
2C4
Bridge
Culvert
Dam
KRAFT FOODS ROAD
SHILOH ROAD
JACOBSON ROAD
NICHOLSON ROAD
CARDINAL LANE
MOCKINGBIRD LANE
WESTWAY AVENUE
ROBIN LANE
MORNINGSIDE DRIVE
ARROW DRIVE
PARKCREST DRIVE
RIDGECREST DRIVE
HILLTOP DRIVE
OLDGATE DRIVE
SHERWIN STREET
RAILROAD
SCOTSWOOD DRIVE
NOTTINGHAM DRIVE
NEWCASTLE DRIVE
ROBIN LANE
PATRICIA LANE
MORNINGSIDE DRIVE
LIVENSHIRE DRIVE
LYNNBROOK LANE
YORKSHIRE DRIVE
SUSSEX DRIVE
WESTCHESTER DRIVE
SHERWOOD DRIVE
SUNNYBROOK STREET
17TH STREET
16TH STREET
15TH STREET
SHARON DRIVE
CAMDEN DRIVE
GREENWOOD
OVERHILL DRIVE
ASHWOOD DRIVE
SYCAMORE DRIVE
BRIARWOOD
ASHLEY DRIVE
PATRICE DRIVE
CARNEY DRIVE
PARK AVENUE
JAMES DRIVE
DAVIS BOULEVARD
RESISTOL ROAD
INWOOD BOULEVARD
REDBUD LANE
INWOOD
SHADY LANE
CEDARCREST
TANGLEWOOD LANE
DEGGE CIRCLE
LINDEN LANE
ROCK CREEK DRIVE
GLENBROOK DRIVE
RAILROAD
EDGEFIELD
RUSSELL
EWING
CEDAR
CRESTRIDGE CIRCLE
GLENWOOD CIRCLE
WILDWOOD LANE
WILLIAMS DRIVE
PARKING LOT STREET
MELODY DRIVE
RUTH
LANDA DRIVE
PALACIO
EVERGREEN
AUBURN
W AVENUE E
W AVENUE F
W AVENUE G
10TH STREET
S 9TH STREET
Duck Creek
AE
AF
AD
AC
A
B
C
D
E
F
G
H
I
J

National Flood Hazard Layer FIRMette

FEMA

32°54'27.43"N

96°40'15.12"W

96°39'37.67"W

32°53'57.22"N

Feet

0 250 500 1,000 1,500 2,000

1:6,000

Legend

SEE FIS REPORT FOR DETAILED LEGEND AND INDEX MAP FOR FIRM PANEL LAYOUT

SPECIAL FLOOD HAZARD AREAS
- Without Base Flood Elevation (BFE) *Zone A, V, A99*
- With BFE or Depth *Zone AE, AO, AH, VE, AR*
- Regulatory Floodway

OTHER AREAS OF FLOOD HAZARD
- 0.2% Annual Chance Flood Hazard, Areas of 1% annual chance flood with average depth less than one foot or with drainage areas of less than one square mile *Zone X*
- Future Conditions 1% Annual Chance Flood Hazard *Zone X*
- Area with Reduced Flood Risk due to Levee. See Notes. *Zone X*
- Area with Flood Risk due to Levee *Zone D*

OTHER AREAS
- NO SCREEN — Area of Minimal Flood Hazard *Zone X*
- Effective LOMRs
- Area of Undetermined Flood Hazard *Zone D*

GENERAL STRUCTURES
- Channel, Culvert, or Storm Sewer
- Levee, Dike, or Floodwall

OTHER FEATURES
- 20.2 / 17.5 — Cross Sections with 1% Annual Chance / Water Surface Elevation
- Coastal Transect
- Base Flood Elevation Line (BFE)
- Limit of Study
- Jurisdiction Boundary
- Coastal Transect Baseline
- Profile Baseline
- Hydrographic Feature

MAP PANELS
- Digital Data Available
- No Digital Data Available
- Unmapped

N

The pin displayed on the map is an approximate point selected by the user and does not represent an authoritative property location.

This map complies with FEMA's standards for the use of digital flood maps if it is not void as described below. The basemap shown complies with FEMA's basemap accuracy standards

The flood hazard information is derived directly from the authoritative NFHL web services provided by FEMA. This map was exported on 4/23/2019 at 6:27:39 PM and does not reflect changes or amendments subsequent to this date and time. The NFHL and effective information may change or become superseded by new data over time.

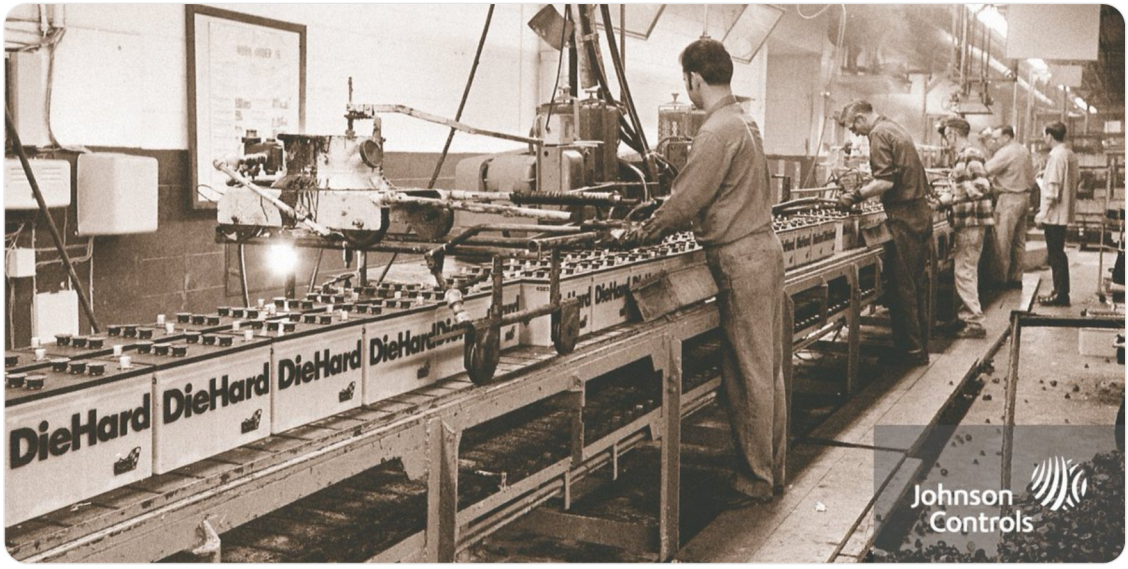
This map image is void if the one or more of the following map elements do not appear: basemap imagery, flood zone labels, legend, scale bar, map creation date, community identifiers, FIRM panel number, and FIRM effective date. Map images for unmapped and unmodernized areas cannot be used for regulatory purposes.

Reference 13

Johnson Controls
@johnsoncontrols

Follow

A look inside a Globe-Union battery plant in 1970. Globe-Union would become part of Johnson Controls in 1978. #TBT



11:31 AM - 26 May 2016

6 Retweets **9** Likes

2 6 9

Arthur M. Ambrosino @GSLDP · 27 May 2016

Replying to @johnsoncontrols

#EnergyMetalsNYS #REO #U #Th #Li #More #MineralRights4Sale gsldeepening.com ama2002@columbia.edu 562-537-1902 #AC/DC

Premitec UK Ltd @Premitec · 27 May 2016

Replying to @johnsoncontrols

How times have changed. You now use our scrap Shakers premitec.co.uk @Premitec

13 001

Reference 14

TEXAS SECRETARY of STATE
DAVID WHITLEY

BUSINESS ORGANIZATIONS INQUIRY - VIEW ENTITY

Filing Number:	802536847	**Entity Type:**	Domestic Limited Liability Company (LLC)
Original Date of Filing:	September 7, 2016	**Entity Status:**	In existence
Formation Date:	N/A		
Tax ID:	32061498872	**FEIN:**	
Duration:	Perpetual		

Name: REALM MANAGEMENT LLC

Address: 1301 SOUTH SHILOH RD
GARLAND, TX 75042 USA

REGISTERED AGENT | FILING HISTORY | NAMES | MANAGEMENT | ASSUMED NAMES | ASSOCIATED ENTITIES

View Image	Document Number	Filing Type	Filing Date	Effective Date	Eff. Cond	Page Count
	688579010002	Certificate of Formation	September 7, 2016	September 7, 2016	No	2
	694576970002	Certificate of Correction	October 14, 2016	October 14, 2016	No	3
	787335360001	Public Information Report (PIR)	December 31, 2017	January 9, 2018	No	1
	883067040001	Public Information Report (PIR)	December 31, 2018	April 18, 2019	No	2
	880450450001	Public Information Report (PIR)	December 31, 2018	April 8, 2019	No	2
	875886140001	Public Information Report (PIR)	December 31, 2018	March 20, 2019	No	1

Order | Return to Search

Instructions:

- To place an order for additional information about a filing press the 'Order' button.

14 001

TEXAS SECRETARY of STATE
DAVID WHITLEY

BUSINESS ORGANIZATIONS INQUIRY - VIEW ENTITY

Filing Number:	802536847	**Entity Type:**	Domestic Limited Liability Company (LLC)
Original Date of Filing:	September 7, 2016	**Entity Status:**	In existence
Formation Date:	N/A		
Tax ID:	32061498872	**FEIN:**	
Duration:	Perpetual		

Name: REALM MANAGEMENT LLC

Address: 1301 SOUTH SHILOH RD
GARLAND, TX 75042 USA

REGISTERED AGENT | FILING HISTORY | NAMES | MANAGEMENT | ASSUMED NAMES | ASSOCIATED ENTITIES

Name	Address	Inactive Date
DANNY RALHAN	1301 SOUTH SHILOH RD Garland, TX 75042 USA	

Order Return to Search

Instructions:

- To place an order for additional information about a filing press the 'Order' button.

14 002

TEXAS SECRETARY of STATE
DAVID WHITLEY

BUSINESS ORGANIZATIONS INQUIRY - VIEW ENTITY

Filing Number:	549006	**Entity Type:**	Foreign For-Profit Corporation
Original Date of Filing:	February 24, 1927	**Entity Status:**	Withdrawn
Formation Date:	N/A		
Tax ID:	00000000000	**FEIN:**	

Name:	GLOBE-UNION MFG CO
Address:	[ADDRESS NOT PROVIDED]
Fictitious Name:	N/A
Jurisdiction:	IL, USA
Foreign Formation Date:	N/A

REGISTERED AGENT | FILING HISTORY | NAMES | MANAGEMENT | ASSUMED NAMES | ASSOCIATED ENTITIES

Name	Name Status	Name Type	Name Inactive Date	Consent Filing #
GLOBE-UNION MFG CO	Inactive	Legal	October 8, 1936	
UNION BATTERY COMPANY	Prior	Legal	October 7, 1929	

Order | Return to Search

Instructions:

- To place an order for additional information about a filing press the 'Order' button.

14 003

TEXAS SECRETARY of STATE
DAVID WHITLEY

BUSINESS ORGANIZATIONS INQUIRY - VIEW ENTITY

Filing Number:	899306	**Entity Type:**	Foreign For-Profit Corporation
Original Date of Filing:	September 8, 1936	**Entity Status:**	Withdrawn
Formation Date:	N/A		
Tax ID:	00000000000	**FEIN:**	

Name:	GLOBE-UNION, INC.
Address:	[ADDRESS NOT PROVIDED]
Fictitious Name:	N/A
Jurisdiction:	DE, USA
Foreign Formation Date:	N/A

REGISTERED AGENT | FILING HISTORY | NAMES | MANAGEMENT | ASSUMED NAMES | ASSOCIATED ENTITIES

Name	Address	Inactive Date
Serve Secretary of State for mailing to	P O BOX 591 Milwaukee, WI 53201 USA	

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14 004

TEXAS SECRETARY of STATE
DAVID WHITLEY

BUSINESS ORGANIZATIONS INQUIRY - VIEW ENTITY

Filing Number:	899306	**Entity Type:**	Foreign For-Profit Corporation
Original Date of Filing:	September 8, 1936	**Entity Status:**	Withdrawn
Formation Date:	N/A		
Tax ID:	00000000000	**FEIN:**	

Name:	GLOBE-UNION, INC.
Address:	[ADDRESS NOT PROVIDED]
Fictitious Name:	N/A
Jurisdiction:	DE, USA
Foreign Formation Date:	N/A

REGISTERED AGENT | FILING HISTORY | NAMES | MANAGEMENT | ASSUMED NAMES | ASSOCIATED ENTITIES

View Image	Document Number	Filing Type	Filing Date	Effective Date	Eff. Cond	Page Count
N/A	2555558	Legacy Filing	September 8, 1936	September 8, 1936	No	N/A
N/A	2555559	MERGINTO	November 29, 1976	November 29, 1976	No	N/A
N/A	2555560	Application For Amended Certificate Of Authority	April 4, 1977	April 4, 1977	No	N/A
N/A	2555565	RSC	November 10, 1977	November 10, 1977	No	N/A
N/A	2555564	Application For Amended Certificate Of Authority	November 10, 1977	November 10, 1977	No	N/A
N/A	2555562	RSC	November 10, 1977	November 10, 1977	No	N/A
N/A	2555561	RST	November 10, 1977	November 10, 1977	No	N/A
N/A	2555563	Application For Amended Certificate Of Authority	November 10, 1977	November 10, 1977	No	N/A
N/A	2555566	DISS.	November 6, 1978	November 6, 1978	No	N/A

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14 005

TEXAS SECRETARY of STATE
DAVID WHITLEY

BUSINESS ORGANIZATIONS INQUIRY - VIEW ENTITY

Filing Number:	4361806	**Entity Type:**	Foreign For-Profit Corporation
Original Date of Filing:	September 22, 1978	**Entity Status:**	Withdrawn
Formation Date:	N/A		
Tax ID:	30003848501	**FEIN:**	

Name:	GLOBE-UNION INC.
Address:	[ADDRESS NOT PROVIDED]
Fictitious Name:	N/A
Jurisdiction:	DE, USA
Foreign Formation Date:	N/A

REGISTERED AGENT | FILING HISTORY | NAMES | MANAGEMENT | ASSUMED NAMES | ASSOCIATED ENTITIES

View Image	Document Number	Filing Type	Filing Date	Effective Date	Eff. Cond	Page Count
N/A	2845011	Legacy Filing	September 22, 1978	September 22, 1978	No	N/A
N/A	2845012	Application For Amended Certificate Of Authority	November 6, 1978	November 6, 1978	No	N/A
N/A	2845013	DISS	November 3, 1980	November 3, 1980	No	N/A

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TEXAS SECRETARY of STATE
DAVID WHITLEY

BUSINESS ORGANIZATIONS INQUIRY - VIEW ENTITY

Filing Number:	4361806	**Entity Type:**	Foreign For-Profit Corporation
Original Date of Filing:	September 22, 1978	**Entity Status:**	Withdrawn
Formation Date:	N/A		
Tax ID:	30003848501	**FEIN:**	

Name:	GLOBE-UNION INC.
Address:	[ADDRESS NOT PROVIDED]
Fictitious Name:	N/A
Jurisdiction:	DE, USA
Foreign Formation Date:	N/A

REGISTERED AGENT | FILING HISTORY | NAMES | MANAGEMENT | ASSUMED NAMES | ASSOCIATED ENTITIES

Name	Name Status	Name Type	Name Inactive Date	Consent Filing #
GLOBE-UNION INC.	Inactive	Legal	November 3, 1980	
JOHNSON-GLOBE, INC.	Prior	Legal	November 6, 1978	

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TEXAS SECRETARY of STATE
DAVID WHITLEY

BUSINESS ORGANIZATIONS INQUIRY - VIEW ENTITY

Filing Number:	1018506	**Entity Type:**	Foreign For-Profit Corporation
Original Date of Filing:	February 16, 1940	**Entity Status:**	In existence
Formation Date:	N/A		
Tax ID:	13903800103	**FEIN:**	

Name: JOHNSON CONTROLS, INC.
Address: PO BOX 591
Milwaukee, WI 53201 USA
Fictitious Name: N/A
Jurisdiction: WI, USA
Foreign Formation Date: N/A

REGISTERED AGENT | FILING HISTORY | NAMES | MANAGEMENT | ASSUMED NAMES | ASSOCIATED ENTITIES

View Image	Document Number	Filing Type	Filing Date	Effective Date	Eff. Cond	Page Count
	2563958	Application for Certificate of Authority	February 16, 1940	February 16, 1940	No	37
	256781860002	Application for Amended Certificate of Authority	February 6, 1950	February 6, 1950	No	10
	2563964	Application for Amended Certificate of Authority	January 14, 1957	January 14, 1957	No	1
	2563962	Application for Amended Certificate of Authority	March 3, 1960	March 3, 1960	No	5
	2563963	Application for Amended Certificate of Authority	February 27, 1970	February 27, 1970	No	6
	2563960	Change of Registered Agent/Office	February 3, 1972	February 3, 1972	No	1
	2563961	Application for Amended Certificate of Authority	December 2, 1974	December 2, 1974	No	5
	2563959	Change Of Registered Agent/Office	December 17, 1985	December 17, 1985	No	1
	2563965	Change Of Registered Agent/Office	July 13, 1990	July 13, 1990	No	2
	24994940001	Public Information Report (PIR)	December 31, 2002	January 27, 2003	No	1
	38873300001	Public Information Report (PIR)	December 31, 2003	July 30, 2003	No	1
	50505810001	Public Information Report (PIR)	December 31, 2003	December 31, 2003	No	1
	66846120001	Public Information Report (PIR)	December 31, 2004	August 5, 2004	No	1
	115741940001	Public Information Report (PIR)	December 31, 2005	January 29, 2006	No	2
	150115720001	Public Information Report (PIR)	December 31, 2006	November 4, 2006	No	1
	207448950001	Public Information Report (PIR)	December 31, 2007	March 7, 2008	No	2
	263553150001	Public Information Report (PIR)	December 31, 2008	June 25, 2009	No	1
	329358020001	Public Information Report (PIR)	December 31, 2009	September 22, 2010	No	2
	330162130001	Public Information Report (PIR)	December 31, 2009	September 24, 2010	No	3
	304538404171	Change of Name or Address by Registered Agent	April 19, 2010	April 19, 2010	No	1
	447940620001	Public Information Report (PIR)	December 31, 2012	October 16, 2012	No	3
	518678946055	Change of Name or Address by Registered Agent	December 2, 2013	December 2, 2013	No	1
	512944070001	Public Information Report (PIR)	December 31, 2013	November 5, 2013	No	2
	569155030001	Public Information Report (PIR)	December 31, 2014	September 22, 2014	No	2
	630481960001	Public Information Report (PIR)	December 31, 2015	September 14, 2015	No	2
	773268830001	Public Information Report (PIR)	December 31, 2017	November 12, 2017	No	2
	868344290001	Public Information Report (PIR)	December 31, 2018	February 15, 2019	No	2

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TEXAS SECRETARY of STATE
DAVID WHITLEY

BUSINESS ORGANIZATIONS INQUIRY - VIEW ENTITY

Filing Number:	8608206	**Entity Type:**	Foreign Limited Liability Company (LLC)
Original Date of Filing:	December 12, 1990	**Entity Status:**	In existence
Formation Date:	N/A		
Tax ID:	13916848719	**FEIN:**	391684871

Name: Johnson Controls Battery Group, LLC

Address: 5757 N. Green Bay Avenue
Glendale, WI 53209 USA

Fictitious Name: N/A

Jurisdiction: WI, USA

Foreign Formation Date: November 19, 1990

REGISTERED AGENT | FILING HISTORY | NAMES | MANAGEMENT | ASSUMED NAMES | ASSOCIATED ENTITIES

View Image	Document Number	Filing Type	Filing Date	Effective Date	Eff. Cond	Page Count
N/A	3198121	Application For Certificate Of Authority	December 12, 1990	December 12, 1990	No	N/A
	24994530001	Public Information Report (PIR)	December 31, 2002	January 27, 2003	No	1
	38873290001	Public Information Report (PIR)	December 31, 2003	July 30, 2003	No	1
	67195050001	Public Information Report (PIR)	December 31, 2004	August 10, 2004	No	1
	121463340001	Public Information Report (PIR)	December 31, 2005	March 20, 2006	No	1
	149677900001	Public Information Report (PIR)	December 31, 2006	October 31, 2006	No	1
	201246750001	Public Information Report (PIR)	December 31, 2007	January 26, 2008	No	1
	264407380001	Public Information Report (PIR)	December 31, 2008	June 30, 2009	No	1
	328957730001	Public Information Report (PIR)	December 31, 2009	September 21, 2010	No	3
	304538408210	Change of Name or Address by Registered Agent	April 19, 2010	April 19, 2010	No	1
	370809710001	Public Information Report (PIR)	December 31, 2010	June 3, 2011	No	3
	447940670001	Public Information Report (PIR)	December 31, 2012	October 16, 2012	No	3
	511928340002	Certificate of Assumed Business Name	October 30, 2013	October 30, 2013	No	2
	518678940491	Change of Name or Address by Registered Agent	December 2, 2013	December 2, 2013	No	1

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512944200001	Public Information Report (PIR)	December 31, 2013	November 5, 2013	No	2
569155090001	Public Information Report (PIR)	December 31, 2014	September 22, 2014	No	2
630481980001	Public Information Report (PIR)	December 31, 2015	September 14, 2015	No	2
725384380001	Public Information Report (PIR)	December 31, 2016	March 29, 2017	No	2
773268840001	Public Information Report (PIR)	December 31, 2017	November 12, 2017	No	2
842849630002	Certificate of Assumed Business Name	October 15, 2018	October 15, 2018	No	2
868344340001	Public Information Report (PIR)	December 31, 2018	February 15, 2019	No	2
877539430002	Amendment to Registration - Conversion or Merger	March 26, 2019	March 26, 2019	No	5
882779550002	Certificate of Assumed Business Name	April 17, 2019	April 17, 2019	No	2

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TEXAS SECRETARY of STATE
DAVID WHITLEY

BUSINESS ORGANIZATIONS INQUIRY - VIEW ENTITY

Filing Number:	800082932	**Entity Type:**	Domestic For-Profit Corporation
Original Date of Filing:	May 9, 2002	**Entity Status:**	In existence
Formation Date:	N/A		
Tax ID:	14708653762	**FEIN:**	
Duration:	Perpetual		

Name: COPIER EXPORTER INC.

Address: 11330 LUNA ROAD
DALLAS, TX 75229 USA

REGISTERED AGENT | FILING HISTORY | NAMES | MANAGEMENT | ASSUMED NAMES | ASSOCIATED ENTITIES

View Image	Document Number	Filing Type	Filing Date	Effective Date	Eff. Cond	Page Count
	11201510002	Articles of Incorporation	May 9, 2002	May 9, 2002	No	2
	46131680001	Public Information Report (PIR)	December 31, 2003	October 27, 2003	No	1
	74107190001	Public Information Report (PIR)	December 31, 2004	November 3, 2004	No	1
	126175580001	Public Information Report (PIR)	December 31, 2005	April 19, 2006	No	1
	145302650001	Public Information Report (PIR)	December 31, 2006	September 24, 2006	No	1
	268930018830	Tax Forfeiture	July 24, 2009	July 24, 2009	No	1
	319748650001	Public Information Report (PIR)	December 31, 2009	August 7, 2010	No	1
	303934560002	Reinstatement	April 16, 2010	April 16, 2010	No	N/A
	347280920001	Public Information Report (PIR)	December 31, 2010	December 23, 2010	No	1
	380877600001	Public Information Report (PIR)	December 31, 2011	August 4, 2011	No	1
	448017190001	Public Information Report (PIR)	December 31, 2012	October 16, 2012	No	1
	554053850001	Public Information Report (PIR)	December 31, 2013	July 17, 2014	No	1
	513947690001	Public Information Report (PIR)	December 31, 2013	November 8, 2013	No	1
	554023900001	Public Information Report (PIR)	December 31, 2013	July 17, 2014	No	1
	535288100001	Public Information Report (PIR)	December 31, 2013	March 24, 2014	No	1
	607232500001	Public Information Report (PIR)	December 31, 2014	May 19, 2015	No	1
	638567710001	Public Information Report (PIR)	December 31, 2015	October 30, 2015	No	1

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	741037470001	Public Information Report (PIR)	December 31, 2016	May 30, 2017	No	1
	725413650001	Public Information Report (PIR)	December 31, 2016	March 30, 2017	No	1
	818675210001	Public Information Report (PIR)	December 31, 2017	June 12, 2018	No	1
	775176270001	Public Information Report (PIR)	December 31, 2017	November 20, 2017	No	2
	866484620001	Public Information Report (PIR)	December 31, 2018	February 6, 2019	No	2
	845592680001	Public Information Report (PIR)	December 31, 2018	October 25, 2018	No	2

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TEXAS SECRETARY of STATE
DAVID WHITLEY

BUSINESS ORGANIZATIONS INQUIRY - VIEW ENTITY

Filing Number:	800082932	**Entity Type:**	Domestic For-Profit Corporation
Original Date of Filing:	May 9, 2002	**Entity Status:**	In existence
Formation Date:	N/A		
Tax ID:	14708653762	**FEIN:**	
Duration:	Perpetual		

Name: COPIER EXPORTER INC.

Address: 11330 LUNA ROAD
DALLAS, TX 75229 USA

REGISTERED AGENT | FILING HISTORY | NAMES | MANAGEMENT | ASSUMED NAMES | ASSOCIATED ENTITIES

Last Update	Name	Title	Address
February 6, 2019	DANNY RALHAN	PRESIDENT	1301 SOUTH SHILOH RD GARLAND, TX 75042 USA
February 6, 2019	DANNY RALHAN	DIRECTOR	1301 SOUTH SHILOH RD GARLAND, TX 75042 USA

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TEXAS SECRETARY of STATE
DAVID WHITLEY

BUSINESS ORGANIZATIONS INQUIRY - VIEW ENTITY

Filing Number:	153021000	**Entity Type:**	Domestic For-Profit Corporation
Original Date of Filing:	April 9, 1999	**Entity Status:**	In existence
Formation Date:	N/A		
Tax ID:	17528170883	**FEIN:**	
Duration:	Perpetual		

Name: AADVANCED WATER MANAGEMENT, INC.

Address: 1111 S SHILOH RD
GARLAND, TX 75042 USA

REGISTERED AGENT | FILING HISTORY | NAMES | MANAGEMENT | ASSUMED NAMES | ASSOCIATED ENTITIES

View Image	Document Number	Filing Type	Filing Date	Effective Date	Eff. Cond	Page Count
	6963695	Articles Of Incorporation	April 9, 1999	April 9, 1999	No	6
	18255490002	Articles of Amendment	October 14, 2002	October 14, 2002	No	2
	29395500001	Public Information Report (PIR)	December 31, 2002	March 14, 2003	No	1
	22832700001	Public Information Report (PIR)	December 31, 2002	January 14, 2003	No	1
	22996610001	Public Information Report (PIR)	December 31, 2002	January 14, 2003	No	1
	44419880001	Public Information Report (PIR)	December 31, 2003	October 10, 2003	No	1
	71280640001	Public Information Report (PIR)	December 31, 2004	October 4, 2004	No	1
	102394700001	Public Information Report (PIR)	December 31, 2005	September 3, 2005	No	1
	143606340001	Public Information Report (PIR)	December 31, 2006	September 10, 2006	No	1
	174573150001	Public Information Report (PIR)	December 31, 2007	June 16, 2007	No	1
	268740230001	Public Information Report (PIR)	December 31, 2008	July 25, 2009	No	1
	319635030001	Public Information Report (PIR)	December 31, 2009	August 6, 2010	No	1
	336329220001	Public Information Report (PIR)	December 31, 2010	October 24, 2010	No	1
	387543640001	Public Information Report (PIR)	December 31, 2011	September 6, 2011	No	1
	467361150001	Public Information Report (PIR)	December 31, 2012	February 24, 2013	No	1
	498295490001	Public Information Report (PIR)	December 31, 2013	August 27, 2013	No	1
	566402100001	Public Information Report (PIR)	December 31, 2014	September 4, 2014	No	1

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617904050001	Public Information Report (PIR)	December 31, 2015	July 26, 2015	No	1
741099640001	Public Information Report (PIR)	December 31, 2016	May 31, 2017	No	1
783456940001	Public Information Report (PIR)	December 31, 2017	December 21, 2017	No	2
839448590001	Public Information Report (PIR)	December 31, 2018	September 27, 2018	No	2

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TEXAS SECRETARY of STATE
DAVID WHITLEY

BUSINESS ORGANIZATIONS INQUIRY - VIEW ENTITY

Filing Number:	153021000	**Entity Type:**	Domestic For-Profit Corporation
Original Date of Filing:	April 9, 1999	**Entity Status:**	In existence
Formation Date:	N/A		
Tax ID:	17528170883	**FEIN:**	
Duration:	Perpetual		

Name: AADVANCED WATER MANAGEMENT, INC.

Address: 1111 S SHILOH RD
GARLAND, TX 75042 USA

REGISTERED AGENT | FILING HISTORY | NAMES | MANAGEMENT | ASSUMED NAMES | ASSOCIATED ENTITIES

Last Update	Name	Title	Address
September 27, 2018	W ROBERT WOMACK	PRESIDENT	2108 CARDINAL LANE GARLAND, TX 75042 USA
September 27, 2018	W ROBERT WOMACK	DIRECTOR	2108 CARDINAL LANE GARLAND, TX 75042 USA
September 27, 2018	EDWARD P PERRIN Jr	CHAIRMAN	4301 MCFARLIN BLVD DALLAS, TX 75205 USA
September 27, 2018	EDWARD P PERRIN Jr	DIRECTOR	4301 MCFARLIN BLVD DALLAS, TX 75205 USA

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TEXAS SECRETARY of STATE
DAVID WHITLEY

BUSINESS ORGANIZATIONS INQUIRY - VIEW ENTITY

Filing Number:	66568200	**Entity Type:**	Domestic For-Profit Corporation
Original Date of Filing:	July 29, 1983	**Entity Status:**	Voluntarily terminated
Formation Date:	N/A		
Tax ID:	17519028199	**FEIN:**	
Duration:	Perpetual		

Name: TEXAS AMERICAN EXPRESS, INC.

Address: 2179 SOUTH SHILOH ROAD 1
GARLAND, TX 75041 USA

REGISTERED AGENT | FILING HISTORY | NAMES | MANAGEMENT | ASSUMED NAMES | ASSOCIATED ENTITIES

View Image	Document Number	Filing Type	Filing Date	Effective Date	Eff. Cond	Page Count
	4963587	Articles of Incorporation	July 29, 1983	July 29, 1983	No	2
	4963584	Miscellaneous	September 10, 1985	September 10, 1985	No	1
	4963585	Change of Registered Agent/Office	October 27, 1989	October 27, 1989	No	1
	4963586	Change of Registered Agent/Office	December 22, 1995	December 22, 1995	No	1
	1723280002	Change of Registered Agent/Office	August 30, 2001	August 30, 2001	No	2
	19315450001	Resignation of Registered Agent	November 1, 2002	November 1, 2002	No	2
	19773280002	Change of Registered Agent/Office	November 12, 2002	November 12, 2002	No	1
	20166690001	Delivery Notice of Certified Mail	November 25, 2002	November 25, 2002	No	2
	23050060001	Public Information Report (PIR)	December 31, 2002	January 14, 2003	No	1
	30950790001	Public Information Report (PIR)	December 31, 2002	March 31, 2003	No	1
	52955820001	Public Information Report (PIR)	December 31, 2003	February 5, 2004	No	1
	86477710001	Public Information Report (PIR)	December 31, 2004	March 25, 2005	No	1
	124915110001	Public Information Report (PIR)	December 31, 2005	April 12, 2006	No	1
	149679420001	Public Information Report (PIR)	December 31, 2006	October 31, 2006	No	1
	176806140001	Public Information Report (PIR)	December 31, 2007	July 4, 2007	No	1
	326726800001	Public Information Report (PIR)	December 31, 2009	September 13, 2010	No	1
	335099630001	Public Information Report (PIR)	December 31, 2010	October 18, 2010	No	1

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	375628780001	Public Information Report (PIR)	December 31, 2011	July 7, 2011	No	1
	467267910001	Public Information Report (PIR)	December 31, 2012	February 24, 2013	No	1
	512214180002	Certificate of Termination	October 30, 2013	October 30, 2013	No	3
	514421440001	Public Information Report (PIR)	December 31, 2013	November 10, 2013	No	1

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TEXAS SECRETARY of STATE
DAVID WHITLEY

BUSINESS ORGANIZATIONS INQUIRY - VIEW ENTITY

Filing Number:	66568200	**Entity Type:**	Domestic For-Profit Corporation
Original Date of Filing:	July 29, 1983	**Entity Status:**	Voluntarily terminated
Formation Date:	N/A		
Tax ID:	17519028199	**FEIN:**	
Duration:	Perpetual		

Name: TEXAS AMERICAN EXPRESS, INC.

Address: 2179 SOUTH SHILOH ROAD 1
GARLAND, TX 75041 USA

REGISTERED AGENT | FILING HISTORY | NAMES | MANAGEMENT | ASSUMED NAMES | ASSOCIATED ENTITIES

Last Update	Name	Title	Address
November 10, 2013	RODERICK BELL	PRESIDENT	2179 SOUTH SHILOH ROAD GARLAND, TX 75041 USA
November 10, 2013	RODERICK BELL	SECRETARY	2179 SOUTH SHILOH ROAD GARLAND, TX 75041 USA

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Reference 15

Note: This is a reference cited in *AP 42, Compilation of Air Pollutant Emission Factors, Volume I Stationary Point and Area Sources.* AP42 is located on the EPA web site at www.epa.gov/ttn/chief/ap42/

The file name refers to the reference number, the AP42 chapter and section. The file name "ref02_c01s02.pdf" would mean the reference is from AP42 chapter 1 section 2. The reference may be from a previous version of the section and no longer cited. The primary source should always be checked.

AP-42 Section Number: 12.15

Reference Number: 3

Title: Lead Acid Battery Manufacture - Background Information for Proposed Standards

EPA 450/3-79-028a

US EPA

November 1979

1.0 SUMMARY

1.1 PROPOSED STANDARDS

The proposed standards would limit atmospheric lead emissions from new, modified, or reconstructed facilities at any lead-acid battery manufacturing plant which has a production capacity equal to or greater than 500 batteries per day (bpd). The facilities which would be affected by the standards, and the proposed emission limits for these facilities are listed below:

Facility	Lead Emission Limit
Lead-oxide production	5.0 mg/kg (0.010 lb/ton)
Grid casting	0.05 mg/m^3 (0.00002 gr/dscf)
Paste mixing	1.00 mg/m^3 (0.00044 gr/dscf)
Three-process Lead reclamation	1.00 mg/m^3 (0.00044 gr/dscf)
Other lead-emitting operations	2.00 mg/m^3 (0.00088 gr/dscf)
	1.00 mg/m^3 (0.00044 gr/dscf)

The emission limit for lead-oxide manufacture is expressed in terms of lead emissions per kilogram of lead processed, while those for other facilities are expressed in terms of lead concentrations in exhaust air.

In addition, 0 percent opacity standard is proposed for emissions from any of these affected facilities. The proposed standards would also require continuous monitoring of the pressure drop across the control system, to help insure proper operation of the system. Performance tests would be required to determine compliance with the proposed standards. A new reference method, Method

15 002

12, would be used to measure the amount of lead in exhaust gases, and Method 9 would be used to measure opacity. Process monitoring would be required during all tests.

The Administrator considered setting standards of performance for the lead-acid battery manufacturing industry which would limit sulfuric acid mist emissions, as well as atmospheric lead emissions. Thus, the emission control alternatives discussed in this Document include the use of mist eliminators to control acid mist emissions from dry formation operations. Sulfuric acid mist standards are not being proposed at this time, however.

1.2 SUMMARY OF ENVIRONMENTAL, ENERGY, AND ECONOMIC IMPACTS

New, modified and reconstructed facilities coming on-line over the next five years will emit about 95 Mg (104 tons) of lead to the atmosphere in the fifth year, if their emissions are controlled only to the extent required by State particulate regulations. At some existing plants, emissions are controlled to a greater extent than state particulate regulations require. This practice might be continued at new plants in the absence of the proposed standards of performance. The proposed standards would reduce potential lead emissions from facilities coming on-line during the next five years to about 2.8 Mg (3.1 tons) in the fifth year. This is approximately 97 percent lower than the emission level which would be allowed under state particulate regulations. The proposed standards would also result in decreased nonlead particulate emissions from new plants, since equipment installed for the purpose of controlling lead-bearing particulate emissions, would also control nonlead-bearing particulate emissions.

The results of dispersion modeling calculations indicate that the ambient atmospheric lead standard of 1.5 $\mu g/m^3$ (averaged over a calendar

15 003

quarter) will be met at plants compl-ing with the proposed standards. This is an important consideration, since most lead-acid battery plants are located in urban areas. Results of EPA dispersion modeling calculations indicate that the ambient lead standard will not be met in the neighborhoods of plants controlling emissions only to the extent required by existing state regulations.

The impact of the proposed standards on the wastewater and solid waste emissions of a lead-acid battery plant would depend on the technique used by that plant to comply with the proposed standards. The best demonstrated system for reduction of lead emissions is the use of fabric filters. High energy impingement scrubbers could also be used, but would have higher energy requirements and operating costs than fabric filters. At plants using impingement scrubbing to control emissions, lead-bearing wastewater would be generated. This would be treated along with other plant wastewater prior to being disposed from the plant. The fractional increase in the lead content of wastewater discharged from a plant using impingement scrubbing to control all atmospheric lead emissions except those from the three-process and lead oxide production facilities would be about 4.5 percent. At plants using fabric filtration to comply with the proposed standards, the captured pollutant would be reclaimed, and there would be no increase in wastewater or solid waste emissions due to the proposed standards.

The energy needed to operate control equipment required to meet the proposed standards at a new plant would be approximately 2 percent of the total energy needed to run the plant. The incremental energy demand resulting from the application of the proposed standards to the battery

manufacturing facilities expected to come on-line over the next five years would be about 2.8 Gigawatt hours of electricity in the fifth year. Approximately 4.8 thousand barrels of oil would be required to generate this electricity.

The capital cost of the installing emission control equipment necessary to meet the proposed standards on all new facilities coming on-line nationwide during the first five years of the standards would be approximately $8.6 million. The total annualized cost of operating this equipment in the fifth year of the proposed standards would be about $4 million.

These costs and energy and environmental impacts are considered reasonable, and are not expected to prevent or hinder expansion of the lead-acid battery manufacturing industry. Economic analysis indicates that, for plants with capacities larger than or equal to 500 bpd, the costs attributable to the proposed standards could be passed on with little effect on sales. The average incremental cost associated with the proposed standard would be about 30¢ per battery. This is about 1.6 percent of the wholesale price of a battery.

3.0 THE LEAD-ACID BATTERY INDUSTRY

3.1 GENERAL

The largest single use of lead in the United States is in the manufacture of lead-acid, or secondary, storage batteries. There are approximately 190 lead-acid battery plants in the United States, of which 91 have been estimated to be small plants.[1] The six largest companies, with branch plants distributed across the country, account for over 70 percent of the lead-acid battery market.

Lead-acid battery plants are scattered throughout the country, and are generally located in highly urbanized areas near markets for their batteries. Some of the larger plants have secondary smelting facilities, or lead oxide production facilities, or both; smaller firms tend to purchase the lead constituents from outside vendors.

3.1.1 Industry Profile

Two major types of lead-acid storage batteries are manufactured in the United States: 1) Starting-lighting-ignition (SLI) batteries, used in automobiles, golf carts, and aircraft, SIC (Standard Industrial Classification) 36911, and 2) industrial storage batteries for low-voltage power systems, industrial fork-lift trucks, and the like, SIC 36912. SLI units account for more than 80 percent of the market.[2]

3.1.1.1 Relationship of Battery Industry to Overall Economy--

Lead-acid battery shipments in 1974 were valued at $1.15 billion,[3] accounting for 0.08 percent of the 1974 gross national product (GNP) of

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$1397 billion.[4] Annual battery values and the GNP for the period 1960 to 1974 are presented in Figure 3-1, which also depicts the added value (shipment value minus raw material value).

The gross national product and lead-acid battery values have shown similar trends since 1960, both increasing approximately 280 percent. Total use of lead by battery manufacturers increased 235 percent during the 14-year period beginning in 1960.[5] The lead-acid battery industry employed 22,100 workers in 1972.[6] New battery plant and equipment expenditures for 1972 amounted to $30.8 million.[7] Of this amount, new machinery and equipment accounted for $21.1 million.[8]

3.1.1.2 Relationship of Battery Industry to Lead Industry--

The battery industry receives lead from two sources: mines and secondary lead smelters. The storage battery industry consumed 0.77 Tg (850,000 tons) of lead in 1974.[9] United States mine production of recoverable lead in 1975 was 0.56 Tg (620,000 tons).[10] Estimated secondary lead recovery in 1975 was 0.55 Tg (610,000 tons).[11] Scrapped lead-acid batteries account for the major portion of recovered lead, along with drosses and residues (lead-containing wastes and impurities that are processed to recover lead). Approximately 0.17 Tg (190,000 tons) of imported lead constitute the remainder of lead supplied to the industry in 1975.[12]

Lead consumption by individual products in the years 1971 through 1975 is summarized in Tables 3-1 and 3-1A. Lead storage batteries accounted for almost 0.64 Tg (700,000 tons), or more than half of the total lead consumed in 1975.[13] Metal grids and posts required 0.30 Tg (327,000 tons), while 0.34 Tg (373,000 tons) of lead was used in lead oxide for grid pasting.[14]

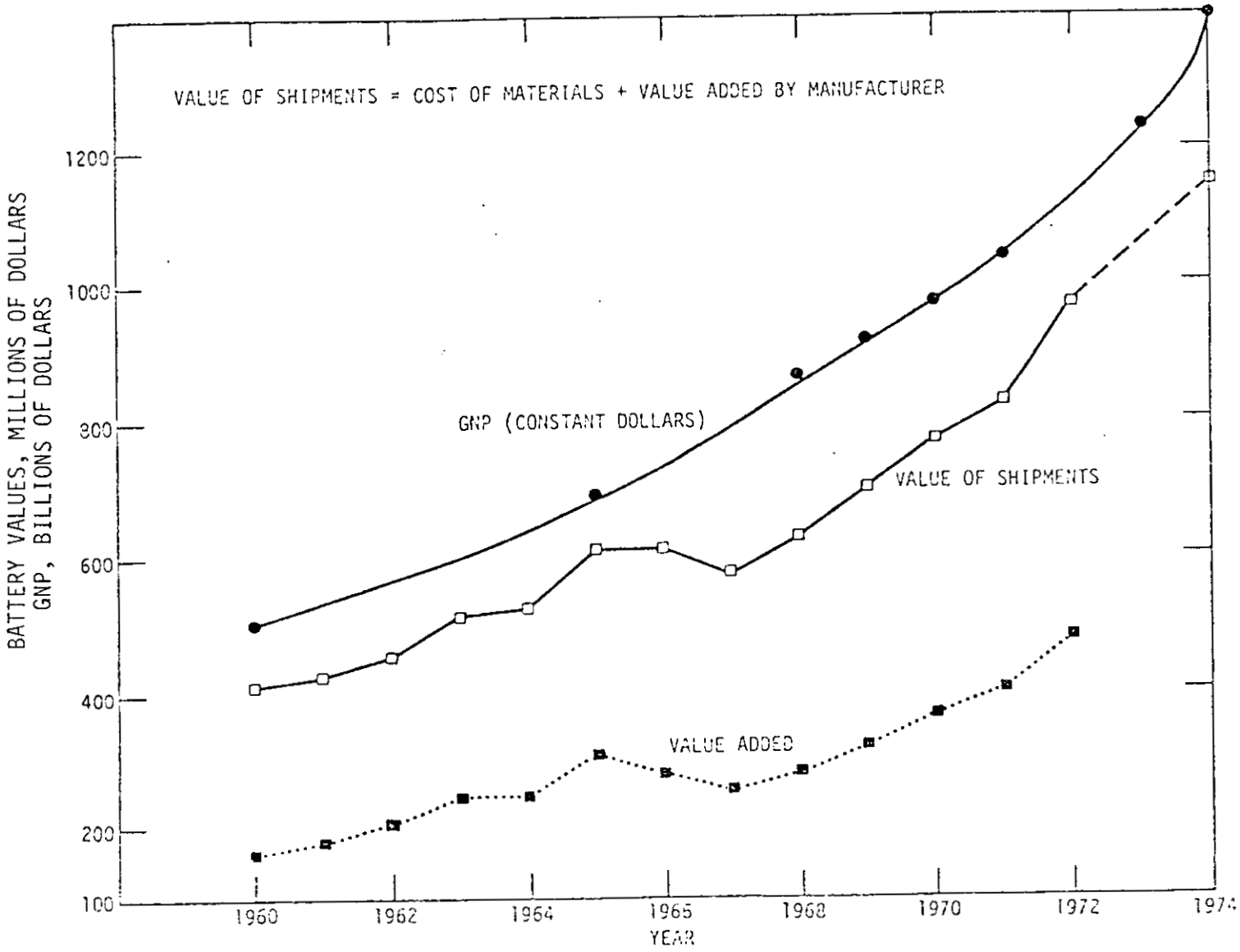

Figure 3-1. Trends in lead-acid battery shipments and in gross national product.

Table 3-1. UNITED STATES CONSUMPTION OF LEAD[18,19]

(in Gigagrams)

	1971	1972	1973	1974	1975
Ammunition	79.4	76.8	73.9	79.0	68.1
Bearing metals	14.8	14.4	14.2	13.3	11.1
Brass and bronze	18.2	18.0	20.6	20.1	12.2
Cable covering	48.0	41.7	39.0	39.4	20.0
Calking lead	27.2	20.4	18.2	17.9	13.0
Casting metals	6.6	8.5	6.5	6.8	7.0
Collapsible tubes	9.1	3.6	2.6	2.3	2.0
Foil	4.0	4.2	4.5	4.0	2.9
Pipe, traps and bends	16.5	16.1	19.3	14.9	12.9
Sheet lead	25.0	21.5	21.2	19.3	22.6
Solder	63.5	64.7	65.1	60.1	62.0
Storage batteries	616.7	659.2	698.0	772.8	634.5
Terne metal	1.3	0.5	2.4	2.1	1.4
Type metal	18.9	18.1	19.9	18.6	14.7
White lead	4.3	2.6	1.3	1.8	2.3
Red lead and litharge	56.1	63.3	81.2	87.2	59.3
Pigment colors	12.6	14.8	15.4	15.7	9.6
Other	0.7	0.3	0.4	0.7	0.2
Gasoline antiknock additives	239.7	252.5	248.9	227.3	189.2
Miscellaneous chemicals	0.4	0.8	0.9	0.6	0.2
Annealing	3.7	3.9	3.6	3.7	2.4
Galvanizing	1.3	1.3	1.2	1.5	1.1
Lead plating	0.5	0.6	0.7	0.5	0.3
Weights and ballast	15.8	19.3	18.9	19.4	18.2
Other uses unclassified	14.3	22.5	19.7	21.9	19.3
TOTAL	1,298.6	1,349.6	1,397.6	1,450.9	1,186.8

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Table 3-1A. UNITED STATES CONSUMPTION OF LEAD[18,19]

(in short tons)

	1971	1972	1973	1974	1975
Ammunition	87,567	84,699	81,479	87,090	75,081
Bearing metals	16,285	15,915	15,657	14,609	12,184
Brass and bronze	20,044	19,805	22,735	22,240	13,404
Cable covering	52,920	45,930	43,005	43,426	22,099
Calking lead	29,993	22,483	20,057	19,739	14,296
Casting metals	7,281	7,139	7,220	7,507	7,711
Collapsible tubes	10,041	4,020	2,860	2,488	2,216
Foil	4,417	4,592	4,985	4,404	3,205
Pipe, traps and bends	18,174	17,780	21,291	16,455	14,233
Sheet lead	27,607	23,667	23,394	21,294	24,859
Solder	70,013	71,289	71,770	66,280	57,344
Storage batteries	679,803	726,592	769,447	851,881	699,414
Terne metal	1,409	504	2,658	2,300	1,511
Type metal	20,812	19,944	21,922	20,516	16,211
White lead	4,731	2,814	1,479	1,996	2,498
Red lead and litharge	61,838	69,799	89,577	96,163	65,457
Pigment colors	13,916	16,264	16,963	17,336	10,618
Other	773	377	477	718	499
Gasoline antiknock additives	264,240	278,340	274,410	250,502	208,605
Miscellaneous chemicals	401	849	944	708	181
Annealing	4,068	4,329	3,974	4,097	2,629
Galvanizing	1,395	1,397	1,294	1,664	1,228
Lead plating	582	638	744	498	376
Weights and ballast	17,453	21,302	20,848	21,418	20,018
Other uses unclassified	15,751	24,826	21,749	24,098	21,221
TOTAL	1,431,514	1,485,254	1,541,209	1,599,427	1,297,098

3.1.1.3 Battery Usage and Sales Forecast--

Total battery shipments of 54.5 million SLI units in 1974 represented the first annual decline since 1967.[15,16] Figure 3-2 shows the shipments of SLI units (replacement, original equipment, and imported batteries) since 1947. Shipments of replacement units remained relatively constant. The decline in new car sales accounted for the total decrease.

Table 3-2 summarizes SLI battery use. SLI units account for 80 percent of the total lead-acid battery market in 1974.[17] Industrial batteries account for the remaining 20 percent. Approximately 80 percent of the SLI units are used in automobiles.[22]

TABLE 3-2. SUMMARY OF SLI BATTERY USE: 1974[23]

Classification	Portion of SLI market, %
Automobile	80
Heavy duty/commercial	14
Golf carts	2
Light utility	2
Marine	1
Miscellaneous	1

Several sources provide forecasts for the lead-acid battery industry. One of the trade organizations for this industry, the Battery Council International (BCI), predicts an annual growth rate of approximately 3 percent through 1979.[24] Another source estimates an average employment increase of 2.4 percent per year in the storage battery industry through 1985.[25]

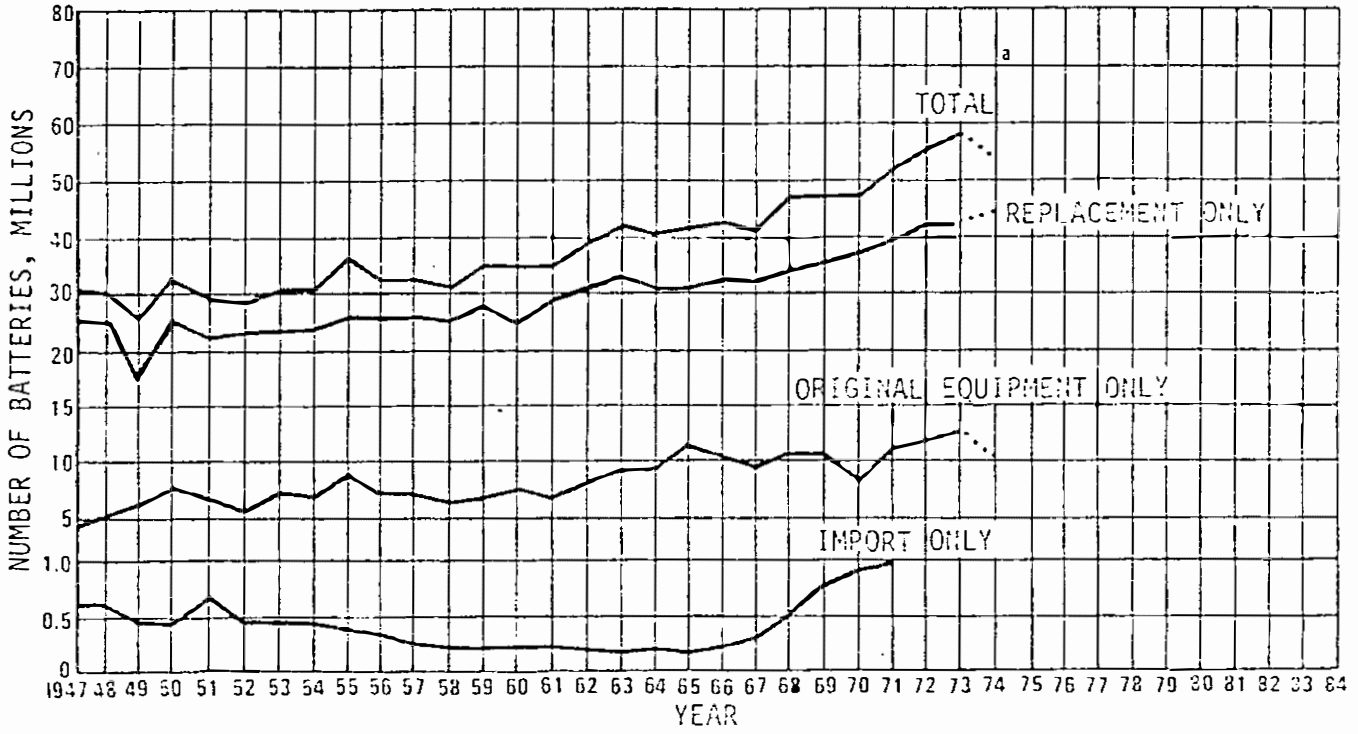


Figure 3-2. United States shipments of SLI lead-acid batteries from 1947 to 1974.[20,21]

3.1.1.4 Industry Expansion--

Quantitative information and estimates regarding industry expansion are not available in the literature at the present time. The decline in new car sales and the economic slump in the mid-1970's have caused uncertainty concerning industry growth, as have the increased activities of regulatory agencies such as OSHA and EPA. The result is a very nebulous picture concerning plant modification and new plant construction.

One source projects an annual growth rate of 5 percent.[26] Estimates of growth rate obtained from those plants responding to EPA inquiry (Section 114 Letters)* range from 40 to 120 percent through 1985, yielding a projected average annual rate of 3.5 to 8.2 percent. The BCI agrees with the lower estimate.[27]

The BCI report states that the sales increase for 1975 should be nil. The forecast for 1976 is a 4 percent gain, and for the remaining years, 1977 through 1979, a 3.7 percent gain. Thus, BCI projects a 3 percent annual growth rate over the next 5 years.[28]

Responses to EPA's Section 114 Letters indicated that nearly all growth would be realized through expansion of existing, larger plants, those with capacities of 2000 batteries per day (bpd) or more.

3.1.2 Process Description

A lead-acid battery consists of any number of cells, depending on the voltage rating of the battery. Stationary batteries contain up to 120 cells (240 volts), whereas automobile batteries generally contain 3

*These are etters sent to various manufacturers of lead acid batteries by which certain information is sought to assist EPA in developing standards of performance. Authority for requiring disclosure of information for this purpose is vested in the Administrator of EPA under Section 114 of the Clean Air Act. Hence these letters are referred to as "114 Letters."

or 6 cells (6 or 12 volts). Lead acid storage batteries range in size and weight. It is estimated that an average battery weighs 18.1 kg (40 lb), of which 11.8 kg (26 lb) is lead. The electrodes are made of lead, and the electrolyte consists of a solution of sulfuric acid and water. The cathode consists of lead peroxide and the anode consists of porous or spongy lead. Both the anode and the cathode are converted to lead sulfate when the battery is discharging. Many complicated chemical reactions take place inside a lead-oxide battery during discharge, resulting in neutralization of the two plates and weakening of the electrolytic solution by formation of water. Figure 3-3 shows the components of a battery.

The electrodes, or plates, consist of two parts: (1) an inactive lead grid, which provides mechanical support for the active portion (the plate) and a conductive path for the electric current, and (2) a lead oxide sulfate paste, which is applied and bonded to the grids. Other materials in the lead-acid battery include plastic, wood, or rubber separators and the outer case materials, which are usually vulcanized rubber, polypropylene, nylon, or acrylics. Figure 3-4 shows the arrangement of battery components in an element.

Consumer attention has recently been directed toward the waterless or "maintenance free" batteries. These batteries are typically supplied without vent plugs or provisions for adding water. Though they appear to be totally sealed, they are always vented in some way, usually by small holes in the top of the battery case. These batteries are practically identical to the conventional battery except in appearance; they all use lead-lead peroxide plates in a sulfuric acid electrolite. There are

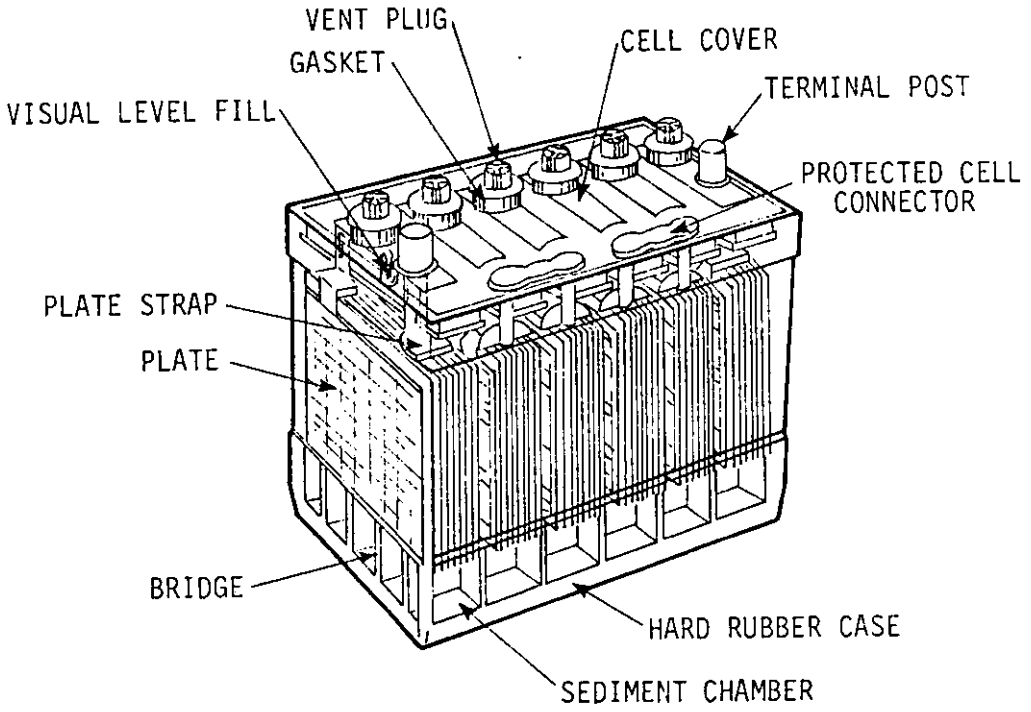


Figure 3-3. A lead-acid storage battery.

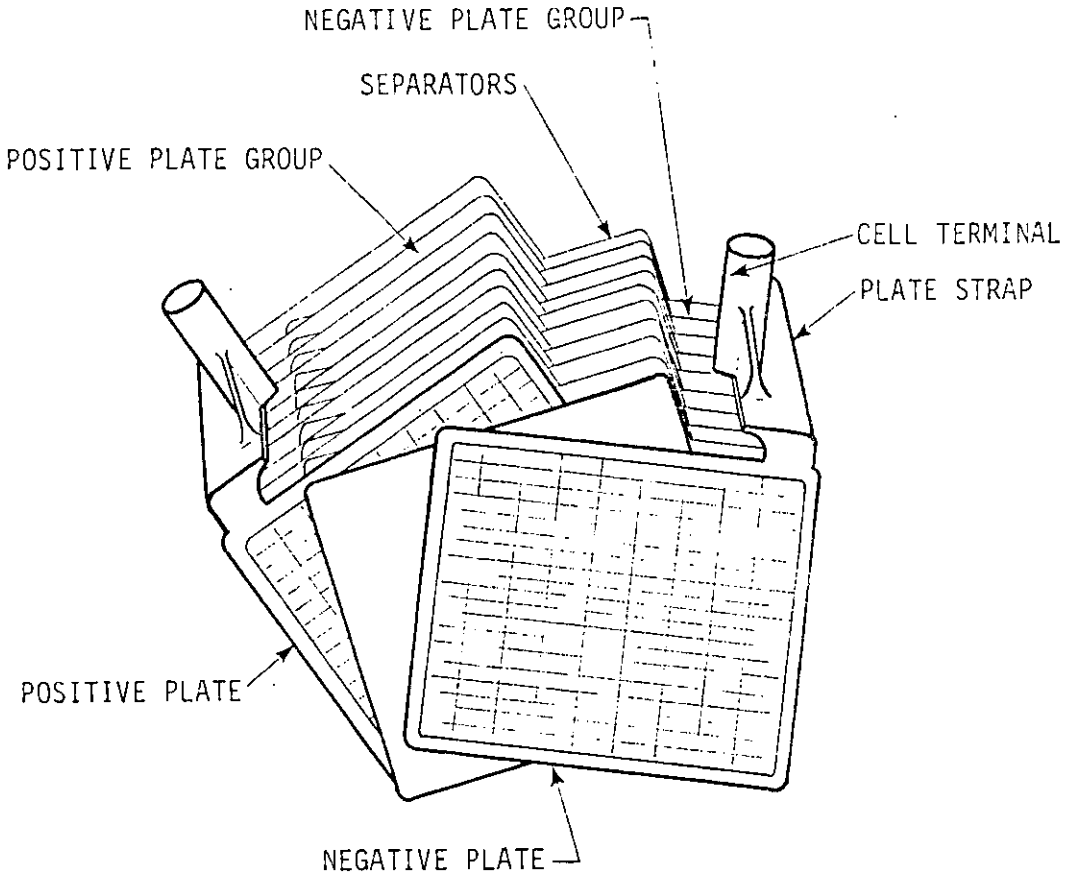


Figure 3-4. Components of a battery element (shown pulled apart).

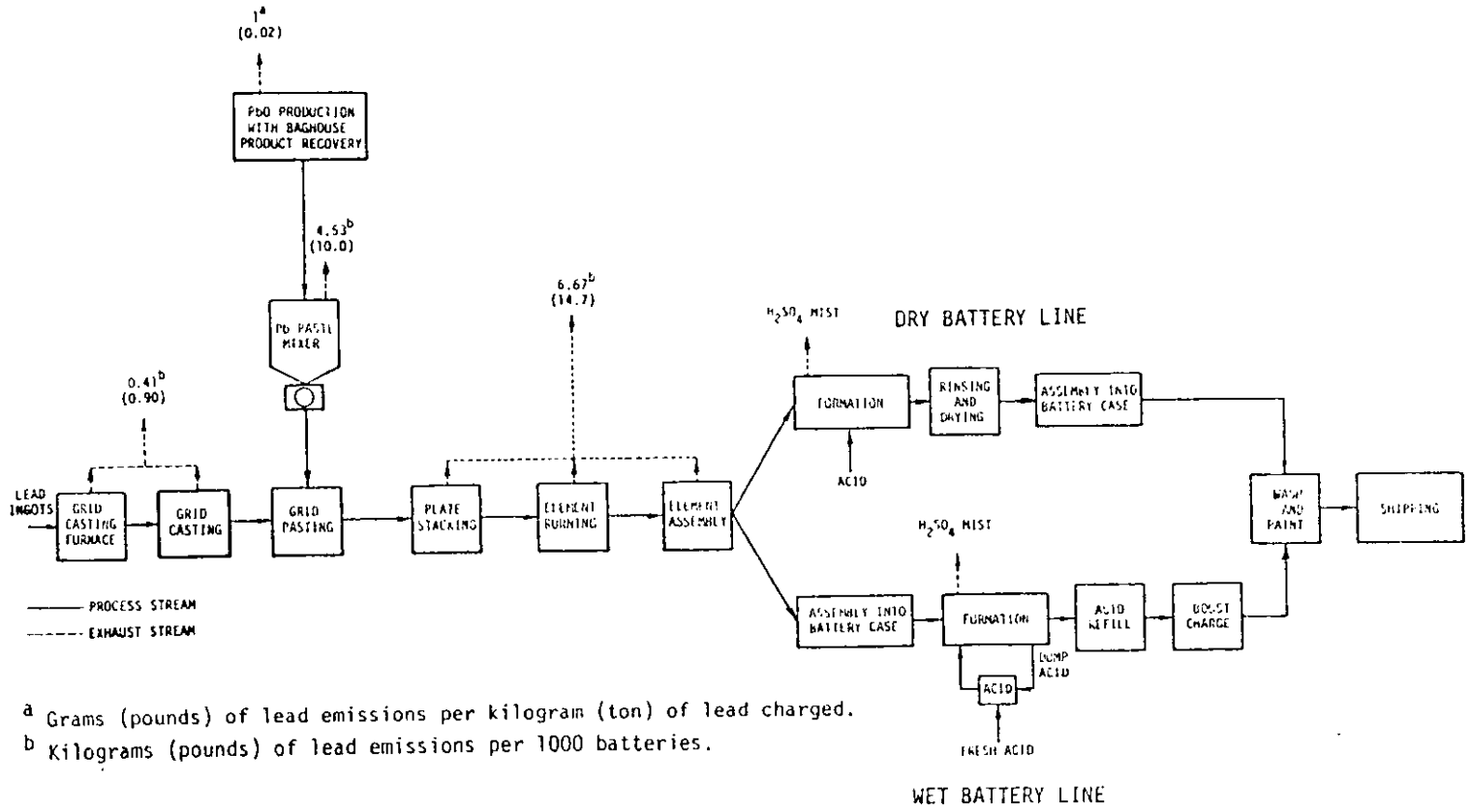
subtle differences in the lead alloy used in some of the plates (usually a substitution of calcium for some of the antimony) and generally they do consume so little water during normal operation that water addition is usually unnecessary during the life of the battery. However, manufacturing processes for these batteries, and the attendant emissions, are for all practical purposes identical to those for the conventional battery. Therefore, this document makes no distinction between this style of battery and conventional batteries.

Lead oxide (gray or black lead) is used in preparing the active materials. Many battery plants prepare the oxide in-house, and several processes are used.

A process flow diagram for the manufacture of lead-acid storage batteries is shown in Figure 3-5, with emission factors for uncontrolled process operations. As the figure indicates, this study encompasses only the battery manufacturing process and production of lead oxide (PbO); it does not include lead smelting operations.

Battery manufacturing begins with grid casting and paste mixing. The grids are generally cast in doublets (two grids per casting) from molten lead, to which 6 to 12 percent antimony has been added to provide hardness. These grids are coated with either positive or negative paste formed (a process discussed later), cut into two separate grids (a process called slitting) and then sent to be assembled into dry- or wet-type batteries.

Lead emission factors are shown in Figure 3-5, and estimated nationwide emissions are presented in Table 3-3. The lead emission factors for grid casting, paste mixing, and battery assembly are derived



[a] Grams (pounds) of lead emissions per kilogram (ton) of lead charged.
[b] Kilograms (pounds) of lead emissions per 1000 batteries.

Figure 3-5. Process flow diagram showing uncontrolled lead emission factors for lead-acid battery manufacture.

Table 3-3. NATIONWIDE EMISSIONS OF LEAD FROM THE MANUFACTURE OF LEAD-ACID STORAGE BATTERIES (1975)

Process	Throughput,[a] Gg (ton) Pb	Estimated average control efficiency,[b] %	Uncontrolled emission factor, g/kg (lb/ton) of lead throughput	Estimated actual emissions, Mg	Estimated actual emissions, (ton)
Lead oxide production	338 (373,000)	c	0.01 (0.02)	3.4	(3.7)
Grid casting	397 (327,000)	50	0.07 (0.139)[d]	10.3	(11.4)
Lead reclamation	6.2 (6,800)[e]	80	2.97 (5.9)	3.6	(4.0)
Paste mixing	338 (373,000)	90	0.86 (1.72)[d]	29.0	(32.0)
Three-process operation	635 (700,000)	90	0.56 (1.13)[d]	35.9	(39.6)
Total emissions for 1975				81.5	(90.0)

[a] Based on 1975 data.[29]

[b] Based on information obtained from battery manufacturers and control agencies throughout the study.

[c] Emission factor is based on controlled emissions; fabric filters are a part of the process.

[d] Based on test data in units of pounds of lead emissions per 1000 batteries and assumption of an average of 11.8 kg (26 lb) of lead per battery. Half is assumed to be in the castings and half in the paste.

[e] Estimated at 1 percent of total lead throughput.

11.8 Kg / 2 → 5.9 Kg

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from data obtained in tests performed as part of this study. Measurements of controlled and uncontrolled lead emissions were performed at selected plants manufacturing lead-acid batteries. (Reference to the individual plants in this report is by alphabetical code). Quantitative data on emissions of sulfuric acid mist from the formation process are not available.

Except for the lead oxide manufacturing facility, the particulate pollutant catch from the control systems, whether wet or dry, is reclaimed by a lead smelter. The particulate captured from the lead oxide manufacturing operation is used in the paste mixer.

3.2 GRID CASTING

Techniques for casting of grids vary with the alloy used, the type of molds, and mold preparation before casting. Molten lead alloy ingots are melted in a gas-fired lead pot at approximately 370°C (700°F). The furnace is often equipped with a hood to vent the fumes to a control device or to the atmosphere.

In some grid casting operations, melting pots are attached directly to the casting machines. The molten lead flows from the pots directly into the molds, where the grids are formed and then are ejected, trimmed, and stacked. Some facilities feed the molding machines from a central pot furnace, from which the molten lead is either pumped or fed by gravity. Pumping may cause air to be entrained in the molten lead, resulting in problems at the molding machines. Entrained air is not a problem with grid casting machines that are fed by gravity flow.

Emissions from the grid casting operations are generally low; even uncontrolled facilities can meet the most stringent state particulate

regulations. Some manufacturers control emissions from this operation and others do not. Exhausts from the grid casting furnace are usually vented to the atmosphere to protect workers from the lead emissions. The areas around the casting machines are generally unvented.

Testing of the grid casting facility at Plant D (see Chapter 4, Section 4.1) indicated uncontrolled lead concentrations ranging from 0.9 to 5.9 mg/m^3 (0.00039 gr/dscf to 0.0026 gr/dscf, 0.049 to 0.34 lb/hr). At Plant D, the grid casting facility is operated for 24 hours each day and the production capacity is 4000 bpd. The measured lead emissions are equivalent to 408 g (0.9 lb) per 1000 batteries, or approximately 51.1 g/hr (0.113 lb/hr) for a typical 2000 bpd plant.

3.3 PASTE MIXING

The paste mixing operation, a batch-type process, is done with a muller, Day, or dough-type mixer. From 272 to 1361 kg (600 to 3000 lb) of lead oxide is added to the mixer; water and sulfuric acid are then added, and the mixture is blended to form a stiff paste. Because reactions of the process are exothermic, mixers are usually water-jacketed and air-cooled to prevent excessive temperature buildup which causes the paste to become stiff and difficult to apply to the grids. Approximately 1 weight percent of expander (generally a mixture of barium sulfate, carbon black, and organics) is added to batches of paste for negative plates.[30] Carbon black also provides color identification for the negative paste. A duct system vents the moisture-laden exhaust gases from the mixer. The duration of the mixing cycle depends on the type of mixer, ranging from 15 minutes to an hour. Typical formulas for positive and negative pastes are shown in Table 3-4.

TABLE 3-4. TYPICAL FORMULAS FOR POSITIVE AND NEGATIVE BATTERY PASTES[31]

Ingredient	Positive	Negative
Lead oxide, kg (lb)	272 (600)	272 (600)
Dynel fiber, kg (lb)	0.068 (0.15)	0.068 (0.15)
Expander, kg (lb)	None	1.90 (4.2)
Water, liter (quart)	23 (25)	26 (28)
H_2SO_4 (1.375-1.400 s.g.), liter (quart)	25 (26)	21 (22)

The major emissions from paste mixing occur during charging of the dry ingredients to the mixer. The high-emissions phase is about the first 10 minutes of a 60-minute mixing cycle. The emissions are in the form of lead oxide, with small amounts of other paste constituents such as Dynel, organics, and carbon black.

Source tests were performed at Plant D where the mixer was vented to a baghouse during materials charging and to a Roto-Clone during mixing. The baghouse also controlled the plate slitting operation, and the Roto-Clone also controlled the grid casting operation. Two tests run at the baghouse inlet during charging showed uncontrolled lead emissions of 115 and 34 mg/m^3 (0.050 and 0.015 gr/dscf, 10.4 lb Pb/hr and 2.99 lb Pb/hr). A single test to determine emissions from the slitting process indicated lead emissions of 43 mg/m^3 (3.88 lb/hr, 0.0188 gr/dscf). On the basis of these data, an emission factor for the total mixing operation (both charging and mixing) is estimated to be approximately 5.1 kg (11.2 lb) of lead per 1000 batteries, or 0.636 kg/hr (1.40 lb/hr) for a typical 2000 bpd plant.

3.4 THREE-PROCESS OPERATION - STACKING/BURNING/ASSEMBLY

After the plates are cured, they are normally sent to the three-process operation, which includes plate stacking, burning, and assembly of elements into the battery case. Some plants are equipped with an associated plate slitter, which cuts the double plates apart. At most plants the plates are parted by hand, after which they are stacked in an alternating positive and negative block formation with separators sandwiched between each plate to insulate the oppositely charged plates while permitting free ionic flow. These separators are made from materials such as wood, treated paper, plastic, or rubber. Although machines have been designed to stack the plates and separators automatically, hand stacking is common.

Leads (pronounced leeds) are welded to the tabs of each positive plate and each negative plate, fastening the assembly (element) together. This is the burning operation. An alternative to the welding or burning process is the cast-on-strap process, in which molten lead is poured around and between the plate tabs to form the connection. Then a positive and a negative terminal are welded to the element. The completed elements are then assembled into battery cases either before formation (wet batteries) or after formation (dry batteries). The difference between wet and dry batteries is explained in Section 3.5.

Most lead emissions are generated during plate stacking and burning or casting operations. Handling of plates between process steps also generates considerable lead emissions. Typically, operators straighten stacks by striking them against a grated surface. Upon impact, particles of paste become airborne. Work areas are generally vented to collect these particles and to protect the health of the workers.

Source tests at Plants B and D, with capacities of 4500 and 4000 bpd respectively, indicate that uncontrolled lead emissions from the three-process operation range from 20 to 54 mg/m^3 (0.0087 to 0.023 gr/dscf, 1.37 to 6.31 lb/hr) during full operation.* These tests indicate total three-process emissions, since testing of each process step in the facility is not feasible. On the basis of these data (presented completely in Chapter 4), an estimated emission factor for the three-process operation is 6.67 kg (14.7 lb) of lead per day for each 1000 bpd capacity, or 0.835 kg/hr (1.84 lb/hr) for a typical 2000 bpd plant.

3.5 FORMATION

During formation the inactive lead oxide-sulfate paste is chemically converted into an active electrode. Formation is essentially an oxidation-reduction reaction, in which the lead oxide in the positive plates is oxidized to lead peroxide and in the negative plates are reduced to metallic lead. This is accomplished by placing the unformed plates in a dilute (10-25 percent)[32] sulfuric acid solution and connecting the positive plates to the positive pole of a direct current (dc) source and the negative plates to the negative pole of the dc source.

During the formation process, hydrogen is released in the form of small bubbles, which carry sulfuric acid with them as they break through the surface of the solution and enter the atmosphere above the container. The process, therefore, is a source of sulfuric acid mist emissions.

*Emissions data for the plate slitting operation at Plant D are included in the mixer emissions data since they are also vented to the baghouse that controls mixer exhaust.

Charging rate and temperature affecn the emissions of sulfuric acid mist, which generally increase with increasing temperature and rate of charge. Also, as the process nears the end of the formation cycle, the release of hydrogen bubbles increases. Emissions therefore increase with time.

3.5.1 Wet Formation Process

In manufacture of wet lead-acid batteries, the elements are assembled into the case before forming. It is common practice to place the cells in the battery case, place the lid on the battery, and add sulfuric acid. The plates are then formed within the battery case. After formation, the spent acid is dumped from the battery and new acid is added. With addition of a boost charge the unit is ready for use, requiring only decoration and manufacturer's markings.

Wet formation generally takes 1 to 4 days. Most plants use a 36- to 48-hour forming cycle. The charging rate is high during the first 24 to 36 hours and lower during the remaining 12 hours. The ampere rates depend on the battery size.

Emissions from wet formation processes are usually not controlled or ducted to a stack. Therefore, no data are available on quantitative emissions from the wet formation process. However, because of the slow charging rate, the fact that there is a lid or cap on the battery during formation, and the absence of a strong acid odor at wet formation processes, emissions from the process are believed to be small.

3.5.2 Dry Formation Process

The plates used in dry batteries are formed in several ways. Some plates are individually formed in tanks of sulfuric acid and then assembled.

Most, however, are assembled into elements before formation. The completed elements are then formed by placing the elements in large tanks of sulfuric acid and by then making an electrical connection to form the elements. Some manufacturers place the assembled elements directly in the battery case for formation. Thereafter, they remove the formed elements, dump the acid, rinse and dry the cases and elements, reassemble them, and ship the batteries dry. Dry formation typically last 16 hours, with the plates or elements loaded into tanks during the day shift, and formed during the evening and night shifts.

When forming batteries by the dry formation process, the acid mist can be controlled by the use of mist eliminators or scrubbers, but is commonly controlled by application of some sort of cover over the acid bath or receptable. The cover is usually of a surface foaming agent such as Alkonol or Dupanol.

Two dry formation processes have been sampled by EPA. The first test did not yield any valid results because the process was not operating properly (one of the three formation circuits was inoperative). Also, emissions from the control device were not detectable when EPA Reference Method 8 was used to collect emissions over a two hour sampling period. The second EPA test (Plant L) showed uncontrolled emissions toward the end of the cycle to average 66 mg/m^3 (0.029 gr/dscf, 0.70 lb/hr). This formation room formed 20,000 battery plates over a 16 hour period.

3.6 LEAD OXIDE PRODUCTION

The lead monoxide used in battery paste production is called lead oxide, black oxide, or battery oxide. The typical lead oxide contains approximately 70 percent PbO. The balance is free metallic lead. Lead

oxide is produced either by the ball mill process or Barton process.

Each of the lead oxide manufacturing processes incorporates a baghouse for product recovery, since the value of the product is relatively high. Air-to-cloth ratios of these fabric filters generally are about 3/1, whether the filters are designed for product recovery or for emissions control. As a result, emissions from the lead oxide production facility are low.

3.6.1 Ball Mill Process

In the ball mill process oxidation is initiated by heat generated by tumbling pure lead pigs (ingots) in a mill. During the tumbling action the lead oxide that forms on the surface of the lead pigs and fine particles of unoxidized lead is broken off, forming a fine dust that is removed from the mill by a circulating air stream. The larger fraction is ground further in a hammermill. Air flow through the mill, the temperature of the charge, and the weight of the charge are controlled to product a specified ratio of lead oxide to finely divided metallic lead. The product is conveyed by totally enclosed screw conveyors to storage bins. Enough product is entrained in the mill exhaust gases to justify gas cleaning for product recovery. Fabric filtration is always a part of the process.

Tests performed at Plant B (shown in Appendix C) yielded average lead emissions of 0.475 g/kg (0.0095 lb/ton) of lead input. This plant operates two ball mill production lines equipped with fabric filters, one with an air-to-cloth ratio of 2/1 and the other with a ratio of 4/1. The filters are vented to a common stack.

3.6.2 Barton Process

In the Barton process, molten lead is fed to a circular pot and stirred rapidly. A series of baffles within the pot atomize the lead into extremely small droplets, which are then oxidized by an air stream directed over the surface of the molten lead. The resulting lead oxide is conveyed by the air stream to a fabric filter where the product is removed. The particle-size distribution, apparent density, and reactivity of the oxide are controlled by the temperature maintained in the pot and by the volume and speed of the air stream that carries away the reacted products. The larger particles are captured in a cyclone prior to the fabric filter and pulverized in a hammermill. They are then conveyed and collected by another fabric filter.

3.7 LEAD RECLAMATION

Lead reclamation is the process whereby relatively clean lead scrap is remelted and cast into pigs for use in the process. The melting is generally done in a pot-type furnace. Scrap, in the form of small parts or defective grids and plates, is charged to the furnace. This is often done sporadically, only when enough material is available for charging. Emissions from pot-type furnaces tend to be minimal. The lead is melted at relatively low temperatures and emissions usually are visible only when oily scrap or floor sweepings are charged. Source tests on Plant G's lead recovery process show uncontrolled lead emissions averaging 298 g/kg (5.9 lb/ton) of scrap input.

Many of the smaller plants have no lead reclamation facilities and send out the scrap for reclamation. No figures exist which indicate the amount of scrap which is reclaimed at battery plants nationwide. However,

based on observations made during plant visits under this study, it would appear that approximately 5 percent of the lead that enters the industry's process stream winds up as scrap and that one-fifth of the battery manufacturing capacity, nationwide, recycles its lead in nonsmelting processes, i.e., a pot-type furnace. The net result is an estimated nonsmelting recycle rate of 1 percent of all lead charged to the battery manufacturing processes nationwide.

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4.0 EMISSION CONTROL TECHNIQUES

The lead-acid battery industry currently applies various particulate controls with efficiencies ranging from 50 to 99.8 percent.[1] An estimated 60 percent of these control devices used are baghouses with efficiencies ranging from 96 to 99.8 percent; the remaining 40 percent consists of venturi scrubbers, packed bed scrubbers, impingement and entrainment scrubbers, and cyclones with reported efficiencies ranging from 50 to 98 percent.[2]

Manufacturers often vent a number of processes to the same control device via a collection system of ducts and hoods. The control systems used at individual plants depend upon plant layout and economics of product recovery. Sections 4.1 through 4.5 describe emission control techniques applicable to facilities in the lead-acid battery industry. These sections also present the results of source tests performed for this study and other applicable data.

For this background study, emisions tests were conducted at four lead-acid battery plants (plants B, D, G, and L). Measurements of lead emissions from controlled sources were conducted according to the proposed EPA Reference Method 12---Determination of Inorganic Lead Emissions from Stationary Sources. EPA Reference Method 8, was used to measure emissions of sulfuric acid mist from formation processes.

In a prior study, lead emissions were tested at three plants (plants B, J, and K). The method used to measure lead emissions in these tests was similar to Method 12.

The results of emissions tests are presented in Appendix C and summarized in this chapter. The ranges of emission concentrations are depicted as data bars in several figures. These figures allow comparison of lead emission concentrations detected in the emission tests.

4.1 GRID CASTING MACHINES AND FURNACES

Emissions from grid casting furnaces are often uncontrolled, and many plants vent this facility to the surrounding work space rather than directly to the outside air. Some plants have used low-energy wet scrubbers to control these exhausts. There are no known applications of fabric filters on this facility.

Particle size data for particulates emitted from grid casters are presented in Figure 4-1.

4.1.1 Scrubbers

An impingement and entrainment scrubber, such as the type N Roto-Clone, is a common device for controlling grid casting emissions. These units are relatively small, with moderate power requirements (1245 Pa or 5 in. W.G. pressure drop) and low water requirements (makeup water typically less than 0.134 l/m^3 or 1 gal./1000 acf). Liquid-to-gas ratios generally range about 2.6 l/m^3 (20 gal./1000 acf) of exhaust. Collection efficiency is generally about 90 percent as indicated by EPA tests at Plant D.

Multiwash centrifugal or cascade scrubbers are also used. These units typically accomodate up to 1415 m^3/min (50,000 acfm) with water injection requirements as low as 0.4 l/m^3 (3 gal./1000 acf).

Frequently, grid casting machines and furnaces are vented along with other operations, such as small parts casting and lead reclamation, to a single low-energy scrubber.

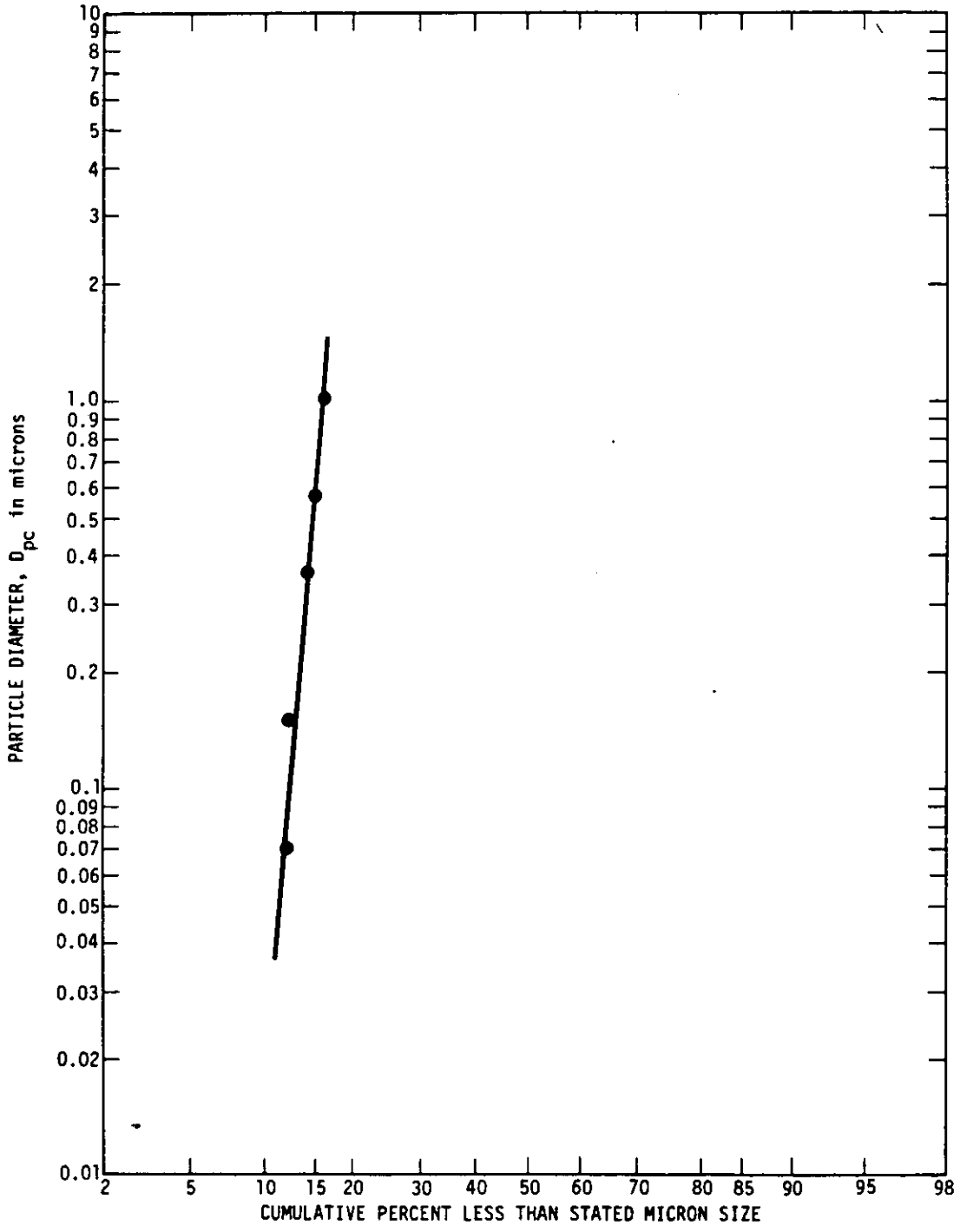


Figure 4-1. Particle size of particulate emissions from a grid casting operation.

4.1.1.1 Test Data--

Figures 4-2 and 4-3 indicate uncontrolled and controlled lead emissions, respectively, from a grid casting facility. All tests of grid casting emissions for this NSPS study were conducted at plant D. The grid casting facility and the paste mixing facility (during the mixing portion of its operating cycle only) were vented to an impingement and entrainment scrubber, having a pressure drop of 1245 Pa (5 in. W.G.), in a cycle shown graphically in Figure 4-4. Plant D has a production capacity of 4000 bpd but normally produces only 3200 bpd. Eight sets of concurrent source tests were run to determine uncontrolled and controlled emissions. Each set consisted of a test at the Roto-Clone inlet and one at the Roto-Clone outlet. Of these tests, four were run to determine uncontrolled grid casting emissions and one to determine controlled grid casting emissions. Other tests were run continuously through the entire mixing cycle (see Figure 4-4), and others were run only during those periods when both mixer emissions and grid casting emissions were vented to the Roto-Clone.

Uncontrolled lead emissions from grid casting ranged from 0.89 to 5.9 mg/m^3 (3.9×10^{-4} to 25.6×10^{-4} gr/dscf, 0.048 to 0.34 lb/hr), with an average of 2.65 mg/m^3 (11.6×10^{-4} gr/dscf, 0.15 lb/hr). The controlled emissions from grid casting were tested simultaneously with the test that yielded the highest uncontrolled lead concentration of grid casting lead emissions. In these concurrent tests, the Roto-Clone demonstrated a lead removal efficiency of 94 percent.

The process was operating normally during all tests. Although the small parts production facility is also ducted to the same Roto-Clone, no small parts were produced during the test periods. The small parts melting pot was fired at all times, however, and an unknown amount of

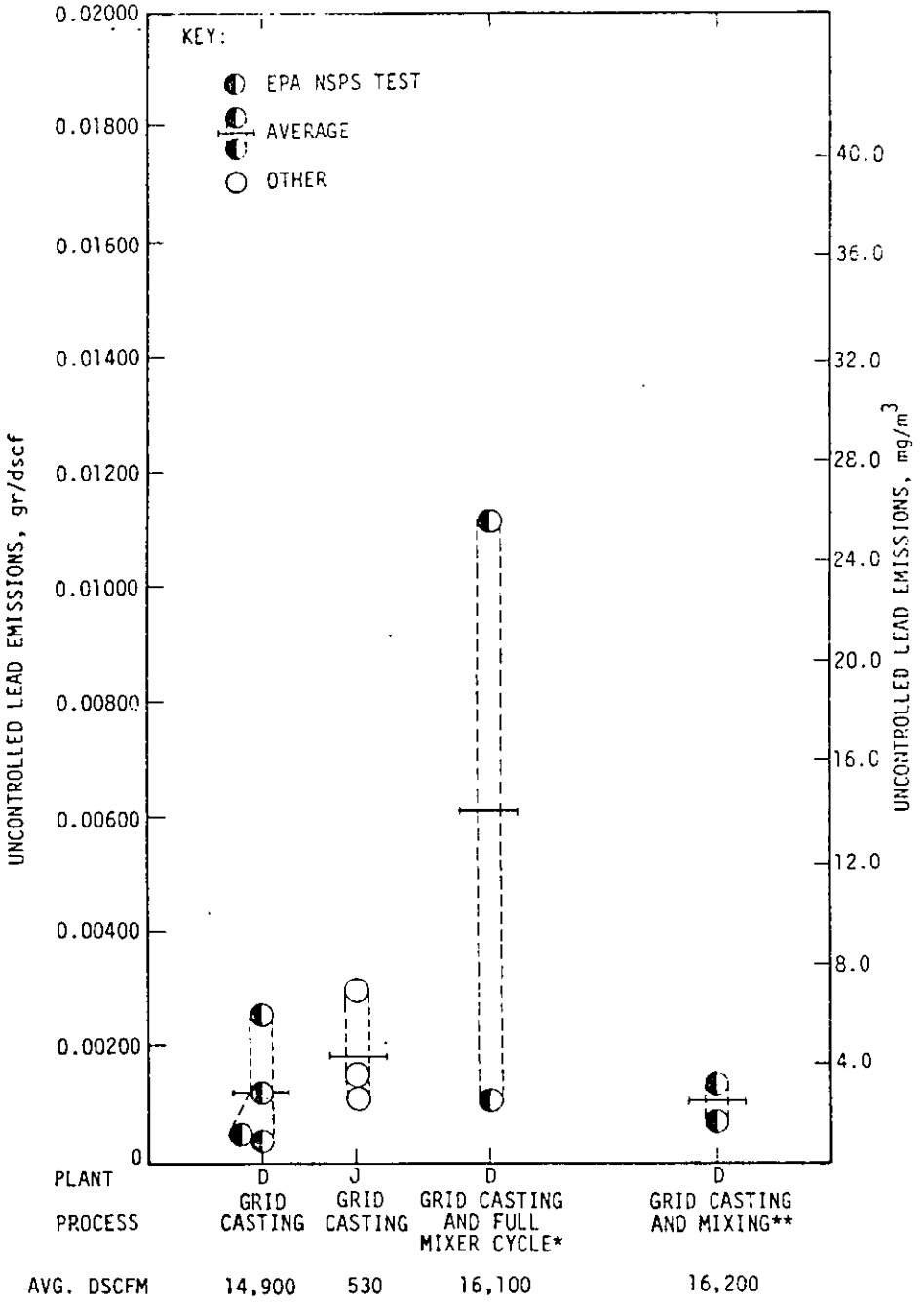


Figure 4-2. Uncontrolled emissions from grid casting and combined grid casting and mixing.[a]

[a] At Plant D both grid casting and paste mixing exhausts were vented in common duct. See Figure 4-4.

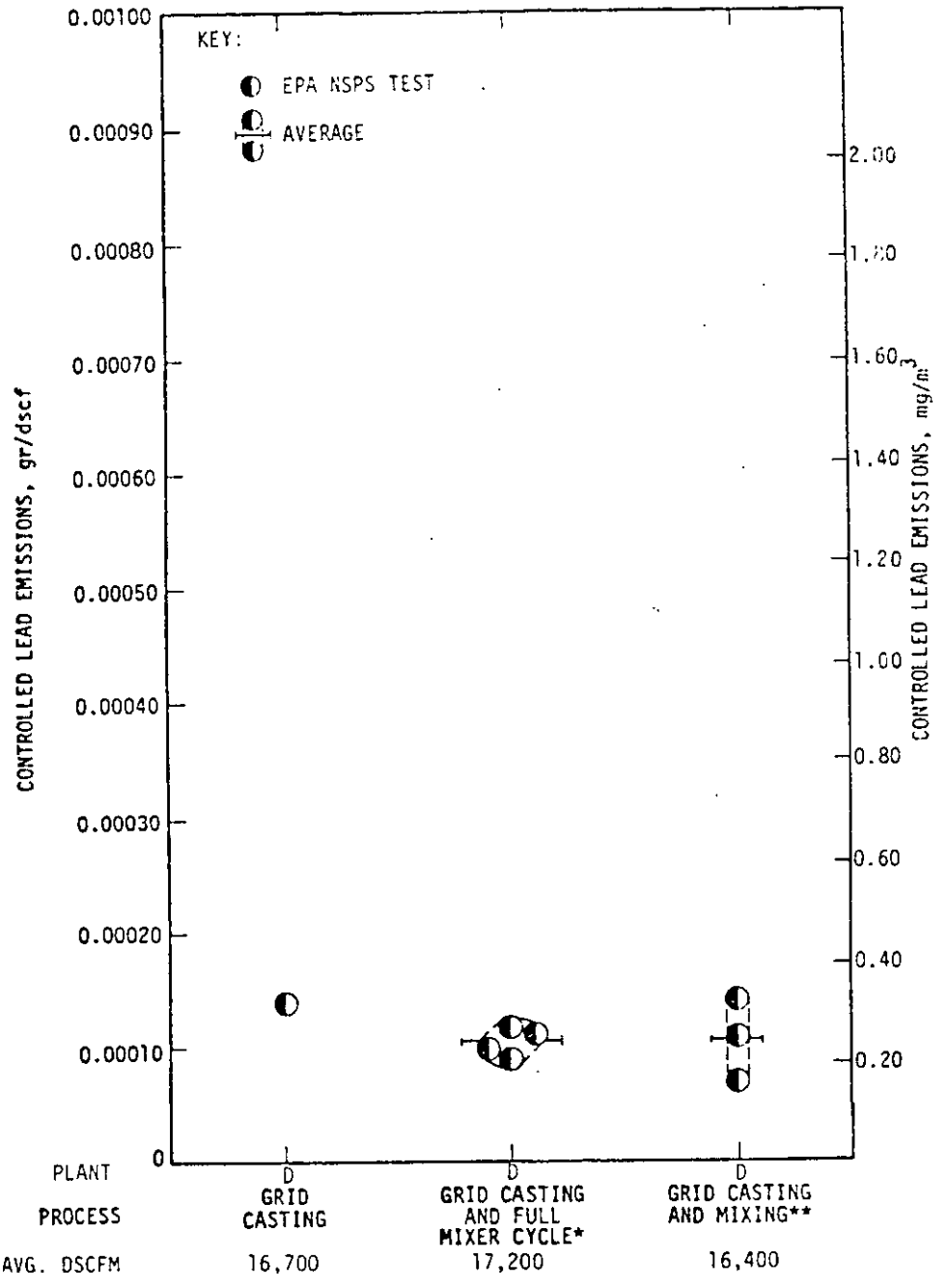
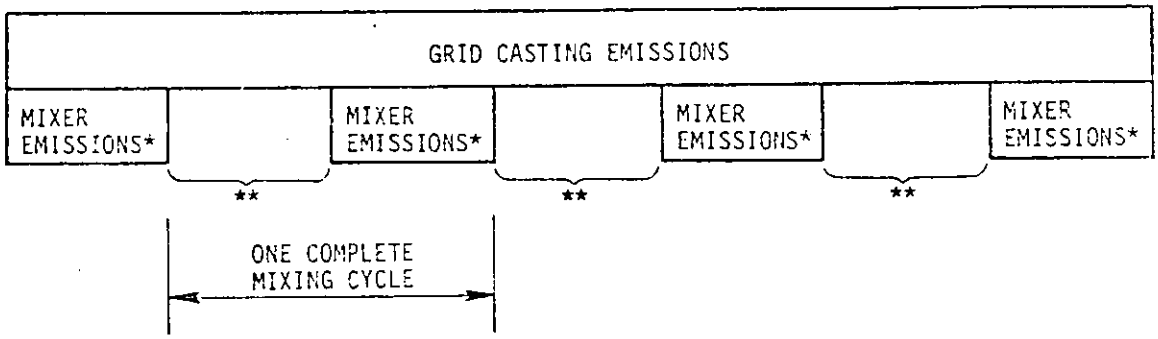


Figure 4-3. Controlled emissions from grid casting and from combined grid casting and mixing.[a]

[a] At Plant D both grid casting and paste mixing exhausts were vented in a common duct. See Figure 4-4.



* Gases vented from mixer to Roto-Clone only during that portion of the cycle in which the ingredients are actually mixed.

** During that portion of the mixing cycle in which the ingredients are charged to the mixer, the mixer is vented to a baghouse---not to the Roto-Clone.

Figure 4-4. Graphic representation of emissions vented to Plant D Roto-Clone over a period of time.

lead emissions may be attributed to this melting pot. However when there are no parts being cast there is virtually no activity at this facility. Also the pot temperature is kept just below the melting point of lead thereby avoiding the formation of lead fumes. Therefore it is estimated that these emissions are negligible in relation to the grid casting emissions. Test results relative to mixer emissions (which occurred concurrent with the grid casting emissions) are discussed in Section 4.2.

In another study, grid casting emissions were tested at plant J. Uncontrolled lead emissions from this plant ranged from 2.70 to 7.05 mg/m^3 (11.8 to 30.8 gr/dscf) with an average value of 4.39 mg/m^3 (19.2 gr/dscf). The grid casting facility at this plant was not equipped with any emission control equipment.

4.1.2 Fabric Filters

As previously stated, there are no known applications of fabric filters on this facility. This is because of the potential blinding from mold release agents and the spark hazard from oil and powdered cork. The spark hazard has been minimized by using spark arresters in the control network in other metallurgical processes, and can be eliminated by simply recycling only clean scrap to the grid casting pots.

Another reason industry is reluctant to use fabric filters to control emissions from grid casting furnaces is the fear that mold release agents, most notably sodium silicate and acelylene soot, will cause fabric blinding and render the filter ineffective. Sodium silicate is commonly used in the industry to prevent the lead from sticking to the grid molds. It is applied by spraying an aqueous suspension of the material directly onto the molds.

The reason operators surmise that this will blind the fabric is its physical characteristics. It is a slimy substance which does not appear to dry readily. However, in practice, fabric blinding apparently does not occur. A major manufacturer which supplies sodium silicate to battery manufacturers successfully uses fabric filters to control emissions from his sodium silicate spray dryers, and reports no major operational or maintenance difficulties.[3]

Another technique used by some manufacturers to prevent lead from sticking to the molds is called acetylene burning. This is simply the use of an acetylene torch, without oxygen, to produce soot. This soot is blown onto the molds with the torch and produces an oily, carbonaceous film which acts as the mold release agent. This method is somewhat archaic and not used, or used very infrequently, by many major manufacturers. One major manufacturer uses this method only when manufacturing batteries for submarines.[4] Another manufacturer states that only one of his ten plants uses acetylene burning. When asked why only one of the ten plants uses the technique, the company's representative stated that this is simply the method they had gotten used to and they saw no reason to force a change.[5] EPA could not locate an installation which uses fabric filters to control acetylene soot. However, there are apparently several viable alternatives to acetylene burning at battery plants and this need not be a deterrent to the use of fabric filters. Based on the performance of fabric filters on the three-process operation (discussed in Section 4.3) an air-to-cloth ratio of about 6/1 should be adequate to control this process to 99 percent lead removal. No data are available for this specific application, however.

4.2 PASTE MIXER

Both baghouses and scrubbers are used to control paste mixing emissions. Some plants vent the mixer to a baghouse during the material charging phase and then to a wet collector during the final "wet" mixing phase. Most plants use only a scrubber.

Typically when two control devices are used, other operations are controlled by the same devices. For example, at Plant D, a baghouse controls the mixer during the charging period of the mixing cycle and it also controls the plate slitting machine at all times. The wet collector at Plant D is a Type N Roto-Clone that controls the paste mixer during the mixing period of the cycle and also controls the grid and small parts casting machines and furnaces at all times. Use of the Roto-Clone during the mixing cycle prevents possible plugging of the bags by the moist exhaust. The exhaust stream is transferred from one control device to the other via an automatically operated damper located at the mixer hood.

Particle size for particulate emissions from the paste mixer at Plant D are presented in Figure 4-5.

4.2.1 Scrubbers

An impingement entrainment scrubber such as the Type N Roto-Clone is frequently used to control mixing operations. These units are relatively small, (in the range of 30 to 300 m^3/min [1,000 to 10,000 acfm]) with a pressure drop of approximately 1245 Pa (5 in. W.G.). Makeup water is generally less than 0.134 l/m^3 (1 gal./1000 acf) and liquid-to-gas ratios generally are about 2.6 l/m^3 (20 gal./1000 acf) of exhaust. Most of the water loss is due to evaporation; about 20 percent results from recirculation tank blowdown. Collection efficiency is approximately 90 percent, as indicated below.

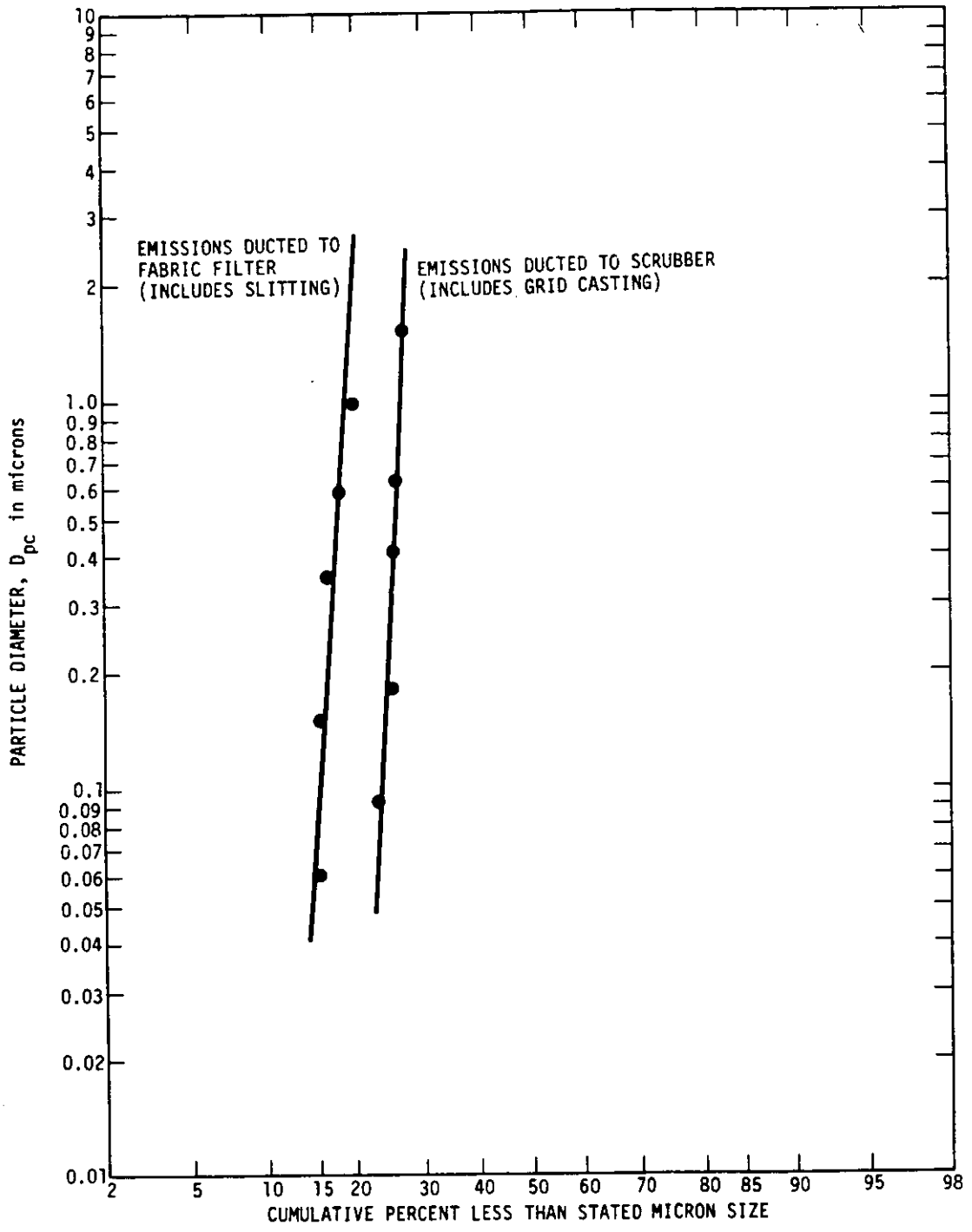


Figure 4-5. Particle size of particulate emissions from a paste mixer.

4.2.1.1 Test Data--

All paste mixing source tests under this program were run at Plant D. Source tests were run at the inlet and outlet of the Roto-Clone, having a pressure drop of 1245 Pa (5 in. W.G.), both continuously (including the time when the mixer exhausts were ducted to the baghouse) and during the mixing portion of the cycle only. Two inlet samples and four outlet samples were taken during full mixing cycles; two inlet samples and three outlet samples were taken during mixing only. Figures 4-2 and 4-3 show the results of these tests. During full mixing cycles (the continuous tests), uncontrolled lead emissions at the inlet were 2.4 and 25.4 mg/m^3 (10.6×10^{-4} and 111×10^{-4} gr/dscf, 0.153 and 1.47 lb/hr); the controlled lead emissions ranged from 0.21 to 0.27 mg/m^3 (0.9 to 1.2×10^{-4} gr/dscf, 0.013 to 0.017 lb/hr). The two sets of tests run concurrently indicated Roto-Clone removal efficiencies for lead of 98.8 and 89.5 percent. Uncontrolled lead emissions measured during the mixing portion of the cycle only (keep in mind that all Roto-Clone data include emissions from the grid casting operation) were 1.6 and 3.2 mg/m^3 (7.0×10^{-4} and 13.9×10^{-4} gr/dscf, 0.09 and 0.20 lb/hr). Controlled emissions ranged from 0.16 to 0.32 mg/m^3 (0.7×10^{-4} to 1.4 to 10^{-4} gr/dscf, 0.0096 to 0.021 lb/hr). Roto-Clone efficiencies during the two sets of tests run concurrently were 89.6 and 89.7 percent.

As the figures indicate, results of the tests at the Roto-Clone show no clear difference in lead emissions in relation to the operating mode of the processes vented to the control device. Results of the source tests for controlled lead emissions indicate that the Roto-Clone can reduce lead concentrations to less than 0.34 mg/m^3 (1.5×10^{-4} gr/dscf) (approximately 0.02 lb/hr at this plant). Furthermore, efficiency calculations indicate that a properly maintained wet collector can control approximately 90 percent of the lead emissions from grid casting and paste mixing.

In a previous study, paste mixing emissions were tested at plant J. At this plant, the entire mixing cycle is controlled by a Schneible multistage impingement scrubber with a pressure drop of 500 Pa (2 in. W.G.). The lead removal efficiency of this scrubber was 86 percent.[6] The inlet and outlet grain loadings of lead averaged 77.3 and 10.8 mg/m^3 (338 x 10^{-4} and 47.0 x 10^{-4} gr/dscf), respectively. The measured exhaust rate was approximately 5.4 m^3/min (190 dscfm).

While the efficiencies of the Cascade scrubber and Roto-Clone (86 and 90 percent respectively) at Plants J and D are about the same, comparisons are difficult regarding the relative efficiencies of the two devices. The lead particulate concentration of the inlet stream at Plant J is an order of magnitude higher than the concentration at Plant D and it is generally accepted that the more concentrated the exhaust stream, the more efficient the control device.

4.2.2 Fabric Filters

Fabric filters with air-to-cloth ratios ranging from 4/1 to 8/1 are used to control particulate and lead emissions from the charging phase of paste mixing. The bags are typically made from orlon felt, polyester, cotton sateen, dacron, or wool. Pressure drops across the bags are 249 to 1494 Pa (1 to 6 inches W.G.).

There appear to be no technological reasons why fabric filters cannot be used to control emissions from the entire mixing cycle. This is currently being done at at least one facility.[7] However, the fabric filter at this facility does not have provisions for preventing the paste mixer gas from falling below its dew point in the baghouse. Consequently, this installation occasionally experiences a high pressure drop across the fabric filter, apparently because of the moisture which combines with the particulate to form a mud cake which blinds the bags.

Condensation of moisture in fabric filters is a potential problem which has been overcome by other industries.[8] The solution usually involves insulation of the baghouse and all ductwork leading to it, and often requires the installation of a small auxilliary heater to keep the gas temperature above its dew point. This auxilliary heat is sometimes needed only during startup or shutdown of the facility. To provide a margin of safety, it is recommended that the gas temperature be maintained 50-75° F above its dew point.[9]

4.2.2.1 Test Data--

The mixer at Plant D is vented to a baghouse during the dry materials charging portion of the mixing cycle and while the mixer is idle. This baghouse has no provisions for preventing condensation of moisture. Therefore, as explained in Section 4.2, the gases are diverted to a scrubber during the portion of the cycle when moisture is evolved. The same baghouse continuously controls the slitting operation. The slitter divides the pasted grids into two plates. Slitting is not common to all lead-acid battery manufacturers and is considered an affected facility under "other lead-emitting operations." Many plants break the pasted grids into two plates after curing.

Source tests were run at the inlet and outlet of the Plant D baghouse. One test was run during slitting only, one was run during the full mixing cycle (including the times when the mixer was vented to the scrubber), and two were run during mixer charging only. Figures 4-6 and 4-7 show the results of these tests.

Prior to the tests, lead emissions from the slitting operations were expected to be negligible when compared with the emissions from

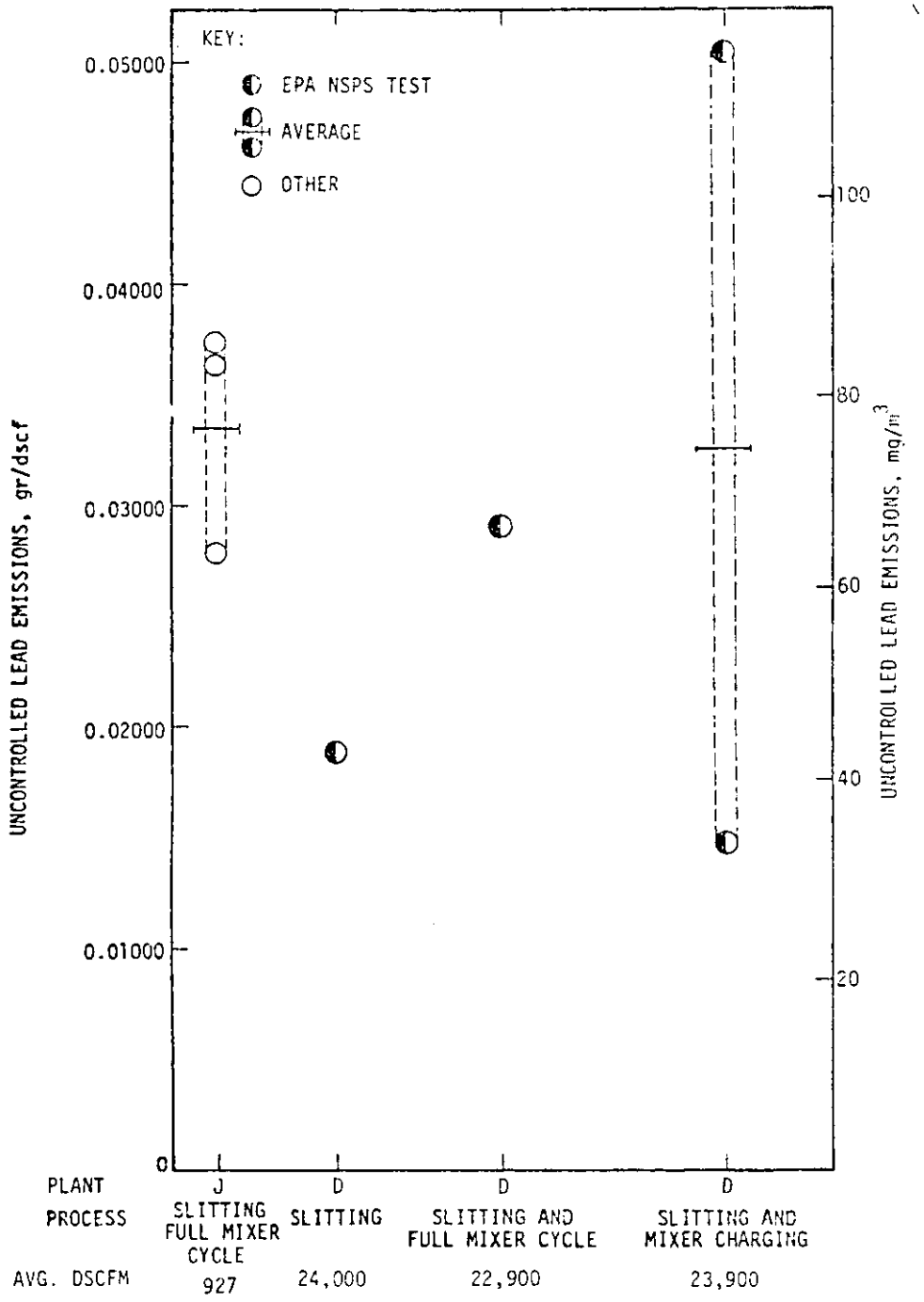


Figure 4-6. Uncontrolled paste mixing and slitting emissions.[a]

[a] At Plant D both grid casting and paste mixing exhausts were vented in a common duct. See Figure 4-4. The slitting station exhausts were also vented to the same common duct.

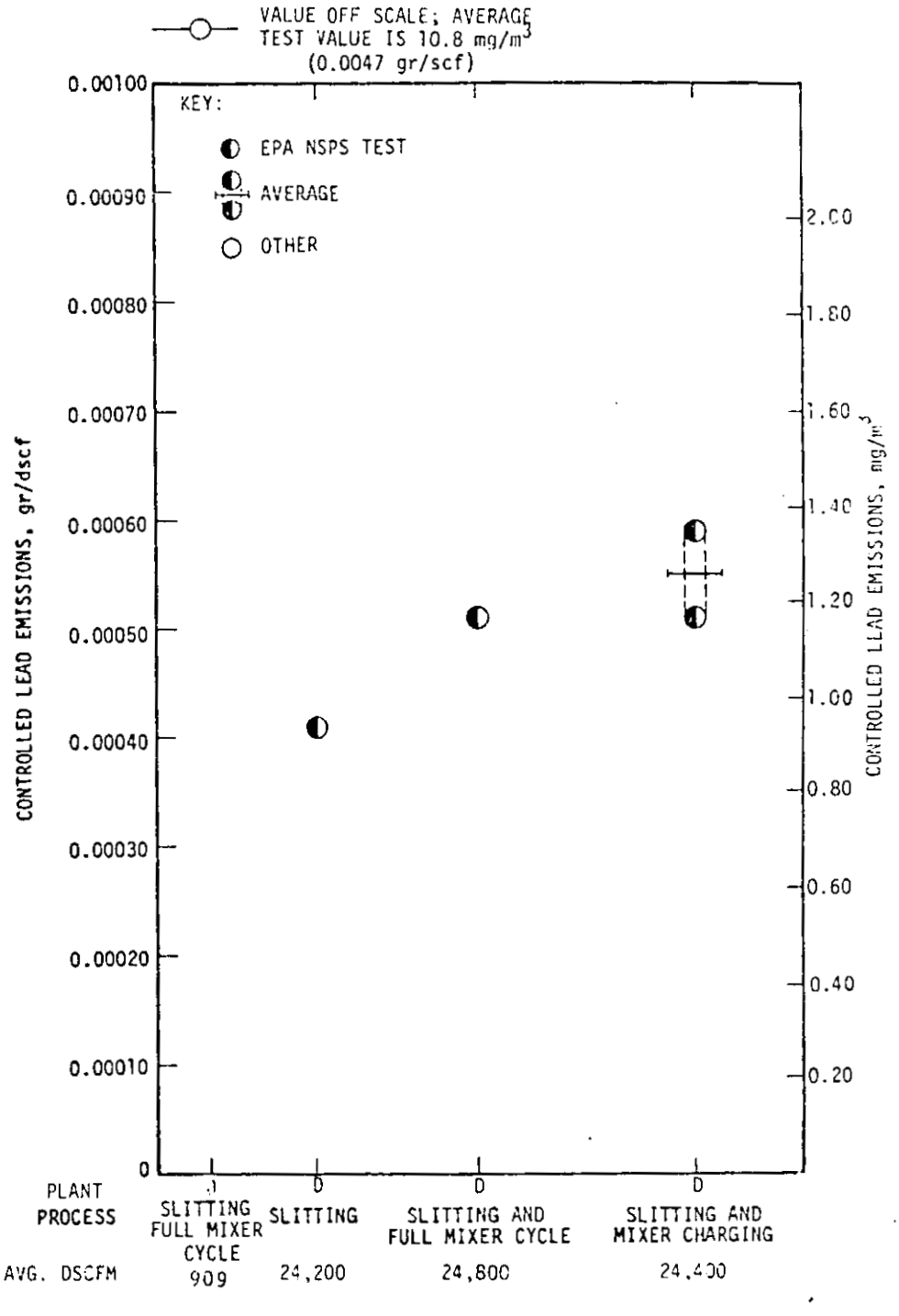


Figure 4-7. Controlled paste mixing and slitting emissions.[a]

[a] At Plant D both grid casting and paste mixing exhausts were vented in a common duct. See Figure 4-4. The slitting station exhausts were also vented to the same common duct.

materials charging.[10] However, the source test conducted during slitting indicated inlet and outlet concentrations of 43.0 and 0.94 mg/m^3 (188 x 10^{-4} and 4.1 x 10^{-4} gr/dscf, 3.88 and 0.060 lb/hr), respectively. Concentrations during the full mix cycle were 66.6 and 1.2 mg/m^3 (291 x 10^{-4} and 5.1 x 10^{-4} gr/dscf, 5.72 and 0.108 lb/hr) at inlet and outlet, respectively. Two tests were run at the baghouse during materials charging and slitting only. One indicated concentrations of 116 and 1.2 mg/m^3 (505 x 10^{-4} and 5.1 x 10^{-4} gr/dscf, 10.4 and 0.106 lb/hr) at the inlet and outlet, respectively; the other test indicated inlet and outlet concentrations of 33.6 and 1.4 mg/m^3 (147 x 10^{-4} and 5.9 x 10^{-4} gr/dscf, 2.99 and 0.124 lb/hr), respectively.

Because of the small number of tests for each operating mode and the variability of the data, it is impractical to estimate mixer emissions by difference; that is, by subtracting the emissions attributable to slitting. However, the source tests do indicate that a baghouse controlling emissions from the materials charging and slitting operations can reduce lead concentrations to less than 1.37 mg/m^3 (6.0 x 10^{-4} gr/dscf) (approximately 0.125 lb/hr at Plant D). Calculations of removal efficiency also show that a properly maintained baghouse controlling these processes can reduce lead emissions by at least 98 percent.

4.3 THREE-PROCESS OPERATION (STACKING, BURNING AND ASSEMBLY)

Well-controlled lead-acid battery plants use fabric filters or scrubbers to control the three-process operation. Most plants vent the stacking, burning, and assembly operations into a common duct prior to cleaning the gases. Other plants clean exhausts from paste mixing and the three-process operation with a common system.

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Particle size data for particulate emissions from the three-process operations at Plants B and D are presented in Figures 4-8 and 4-9.

4.3.1 Fabric Filters

Based on plants surveyed by EPA, the industry typically uses shaker-type fabric filters having air-to-cloth ratios of 6/1 to 7/1 to control three-process emissions. Hood design is very important because of the large number of emission points (stacking, burning, and assembly usually are performed at several stations).

4.3.1.1 Test Data--

The three-process operation facilities at Plants B and D were tested, with results as shown in Figures 4-10 and 4-11. Plant capacities are 4500 and 4000 bpd at B and D, respectively. During the tests, Plant B averaged 1660 batteries during 7 hours of production and Plant D averaged 1600 batteries during approximately 7 hours of production. Air-to-cloth ratios of the baghouses are 6.5/1 and 3.3/1 at Plants B and D, respectively. Three-process production is essentially the same at both plants.

Three pairs of tests at the baghouse inlet and outlet were performed at Plant B, which processes both wet and dry batteries in the three-process operation. The plates and separators at this plant are stacked at four manual stacking stations and two automated stations. The stacks are processed on two automatic element assembly units (cast-on-strap [or COS] machines) and on a proprietary system. Lead concentrations at the baghouse inlet were 30.0, 33.6, and 19.9 mg/m^3 (131×10^{-4}, 147×10^{-4}, and 87×10^{-4} gr/dscf, 1.99, 2.30, and 1.37 lb/hr) in the three tests. Outlet concentrations were 0.44, 0.07, and 0.04 mg/m^3 (1.94×10^{-4},

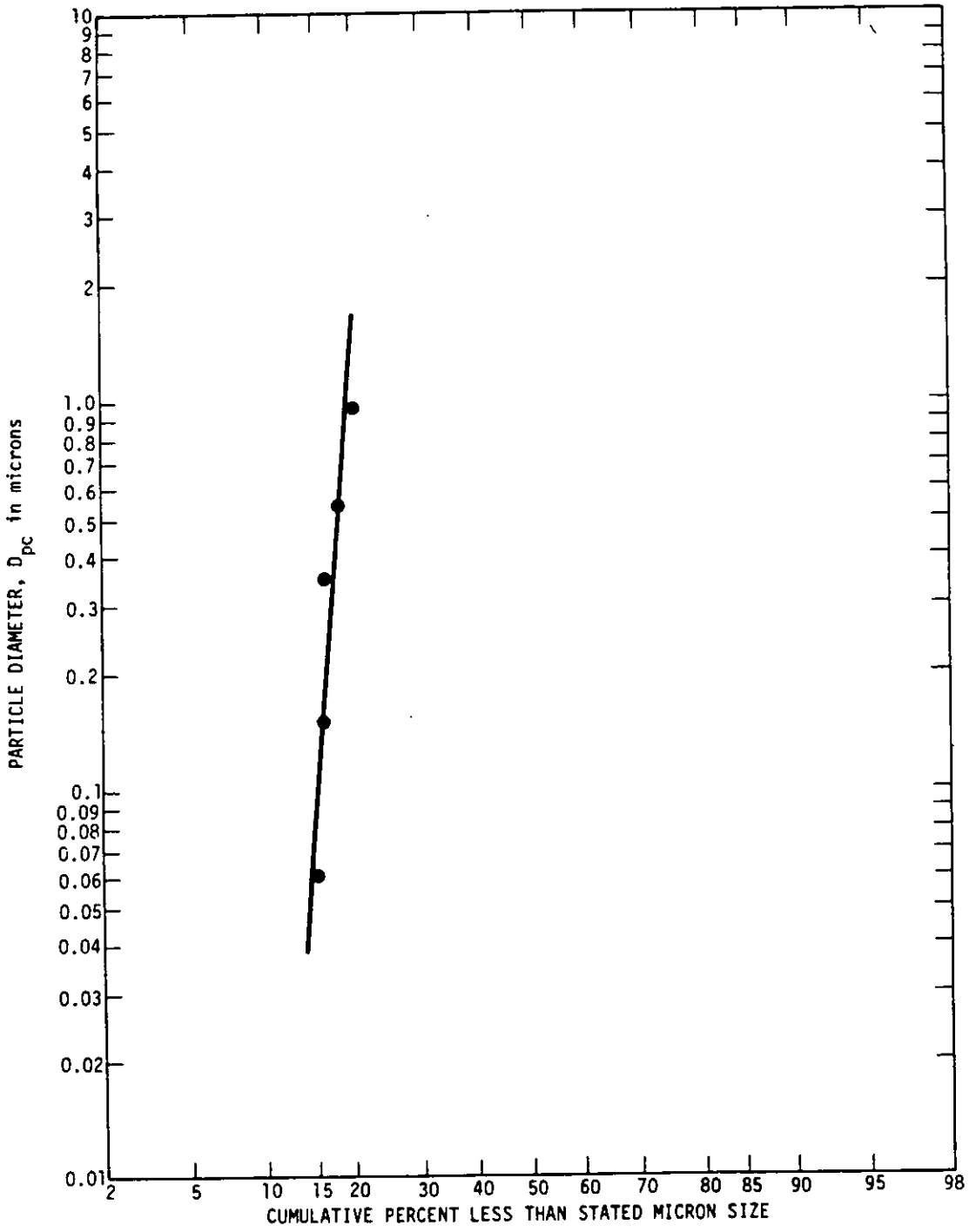


Figure 4-8. Particle size of particulate emissions from a three-process operation.

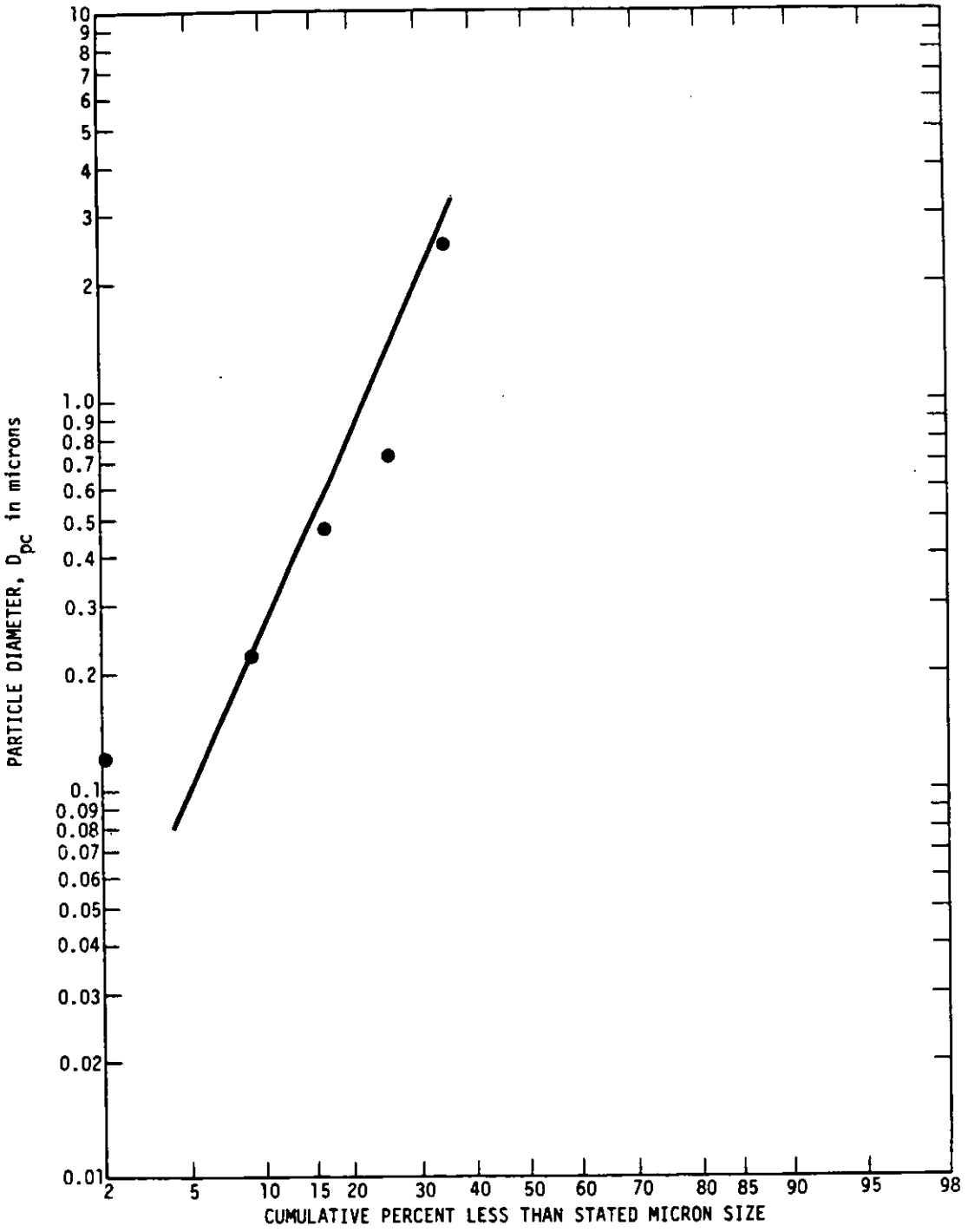
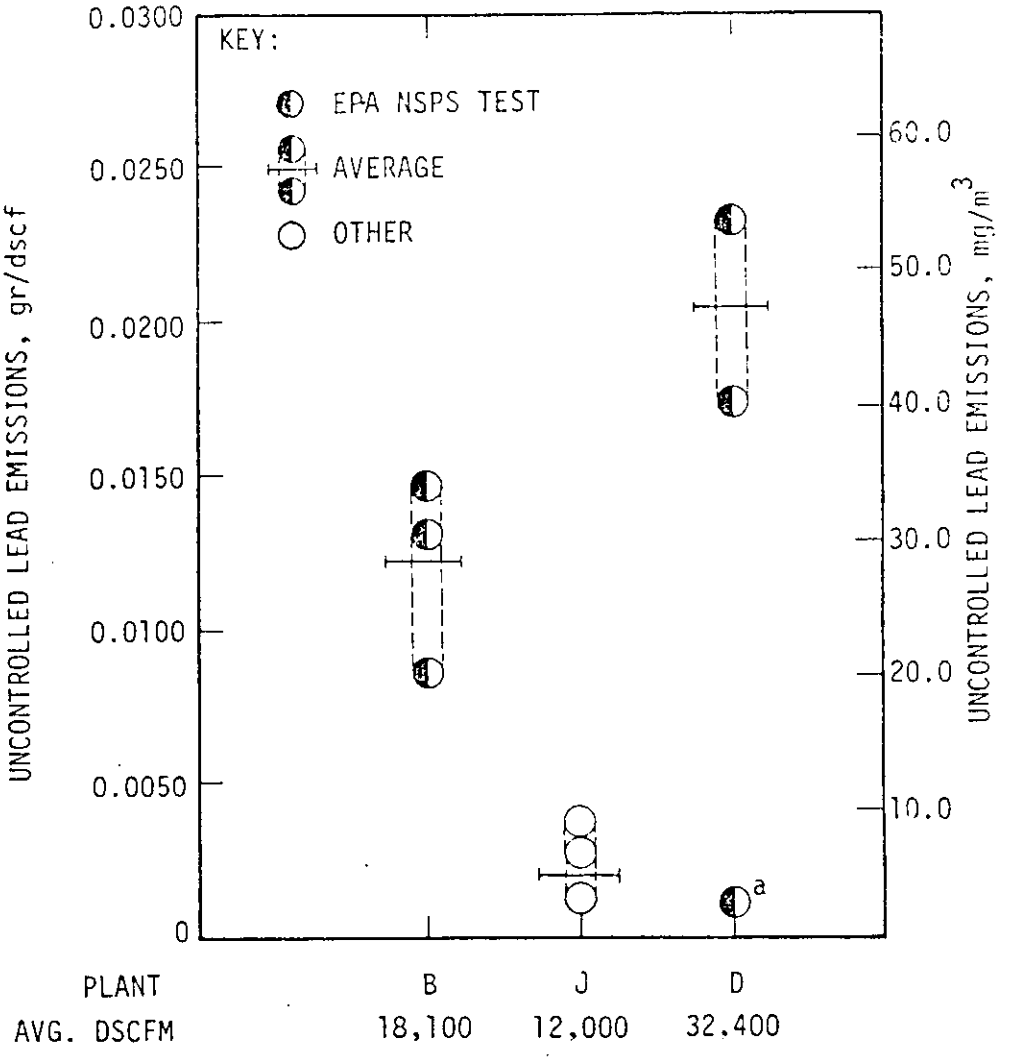
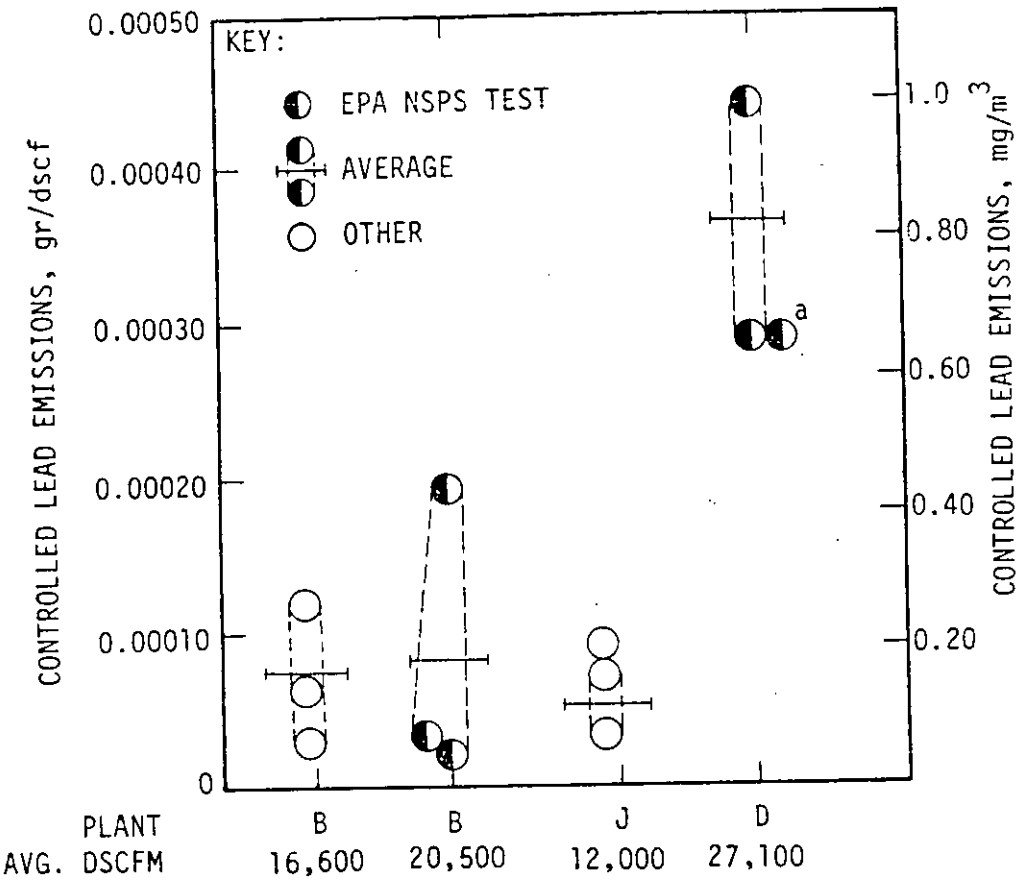


Figure 4-9. Particle size of particulate emissions from a three-process operation.



[a] Sample point not included in average because of process equipment downtime during test.

Figure 4-10. Uncontrolled three-process-operation lead emissions.



[a] Sample point not included in average because of process equipment downtime during test.

Figure 4-11. Controlled three-process-operation lead emissions.

0.32×10^{-4}, and 0.19×10^{-4} gr/dscf, 0.0347, 0.0056, and 0.0033 lb/hr). The average lead concentrations at the baghouse inlet and outlet, respectively, were 27.9 and 0.19 mg/m^3 (122×10^{-4} and 0.82×10^{-4} gr/dscf, 1.87 and 0.015 lb/hr), giving an average control efficiency of 99.2 percent.

Three pairs of tests were also performed at the inlet and outlet of baghouses controlling three-process operations at Plant D. The three-process facility at Plant D consists of three production lines. Two of the lines are equipped with mechanical stackers and COS machines. The other line has a mechanical stacker, and the elements are joined by manually burning the leads, (pronounced leeds). Baghouse inlet concentrations were 40.0, 53.3, and 2.4 mg/m^3 (175×10^{-4}, 233×10^{-4}, and 10.6×10^{-6} gr/dscf; 5.09, 6.31, and 0.29 lb/hr). The outlet concentrations were 0.55, 1.0, and 0.66 mg/m^3 (2.4×10^{-4}, 4.4×10^{-4}, and 2.9×10^{-4} gr/dscf; 0.071, 0.093, and 0.071 lb/hr). The markedly lower concentrations at the inlet in the third test apparently are attributable to process down-time during the test. The outlet lead emissions were not significantly affected. The average inlet and outlet concentrations, respectively, over the two sets of tests were 46.7 and 0.82 mg/m^3 (204×10^{-4} and 3.6×10^{-4} gr/dscf; 5.7 and 0.082 lb/hr), giving an average control efficiency of 98.6 percent.

In tests performed earlier at Plants B and J the controlled lead emissions averaged 0.15 and 0.13 mg/m^3 (0.67×10^{-4} and 0.56×10^{-4} gr/dscf), respectively. Uncontrolled lead emissions at Plant J averaged 4.3 mg/m^3 (18.7×10^{-4} gr/dscf), indicating a baghouse efficiency of 97 percent.

The results show that a baghouse can control the three-process facility to levels less than 1.15 mg/m^3 (5.0×10^{-4} gr/dscf) with lead removal efficiencies greater than 97 percent.

4.3.2 Scrubbers

Impingement type scrubbers are sometimes used to control three-process emissions. These scrubbers typically operate with a pressure drop of approximately 1245 Pa (5 inches W.G.) with lead collection efficiencies ranging about 90 percent as indicated by tests at Plant D (grid casting and paste mixing). Makeup water requirement for this type of scrubber is usually less than 0.134 l/m^3 (1 gal./1000 acf) at a liquid-to-gas ratio of 2.6 l/m^3 (20 gal./1000 acf) of exhaust.

4.4 LEAD OXIDE PRODUCTION

Lead oxide in the form of fine particulate matter is manufactured in a ball mill or a Barton pot. Most lead oxide facilities of both types use mechanical collectors followed by a baghouse to capture the lead oxide production after it leaves the ball mill or Barton pot. Most of the product is separated in a settling chamber or cyclone, and the baghouse serves to increase the product collection efficiency. The baghouse is considered as both process equipment and air pollution control equipment. Therefore, for economic reasons, wet collection devices such as high-energy scrubbers or Roto-Clones are not used.

4.4.1 Fabric Filters

Based upon EPA survey data air-to-cloth ratios of baghouses for collection of lead oxide range from 2/1 to 4/1. A low ratio is needed to prevent blow-through of the collected material from one side of the bag to the other.

4.4.1.1 Test Data--

The lead oxide production facility at Plant B was tested, with results as shown in Figure 4-12. Lead oxide is produced by two ball mills, each followed by two baghouses which provide particulate control and also collect the product. One ball mill is controlled by two baghouses in parallel having air-to-cloth ratios of 2/1 and pressure drops of 249 to 498 Pa (1 to 2 inches W.G.); the other ball mill is controlled by two baghouses in parallel having air-to-cloth ratios of 4/1 and pressure drops of about 1494 Pa (6 inches W.G.). Exhausts from all four baghouses are combined and released to the atmosphere through a single stack. The normal feed rate to each ball mill is 189 grams of lead per second (1500 pounds per hour), input for the two mills totaling 378 g/sec (3000 lb/hr); the feed rate can be increased as required to 314 grams per second (2500 pounds per hour) to give a total rate of 624 g/sec (5000 lb/hr). Throughout the tests, the lead feed rate was 189 g/sec (1500 lb/hr) through each ball mill, totaling 378 g/sec (3000 lb/hr).

Three tests were run at the common outlet of the four baghouses associated with lead oxide production. No tests were performed at the baghouse inlets. The lead concentrations in the three tests were 1.1, 2.3, and 1.1 mg/m^3 (4.9×10^{-4}, 9.9×10^{-4}, and 4.9×10^{-4} gr/dscf; 0.010, 0.022, and 0.011 lb/hr), giving an average lead concentration of 1.5 mg/m^3 (6.6×10^{-4} gr/dscf, 0.014 lb/hr). These values are equivalent to emissions of 3.17, 6.35, and 3.17 grams (0.007, 0.014, and 0.007 pounds) of lead per ton of lead input to the process. Tests at Plant B in 1974 indicated average lead emissions of 0.39 mg/m^3 (1.7×10^{-4} gr/dscf, 0.0026 lb per ton of lead input).[11]

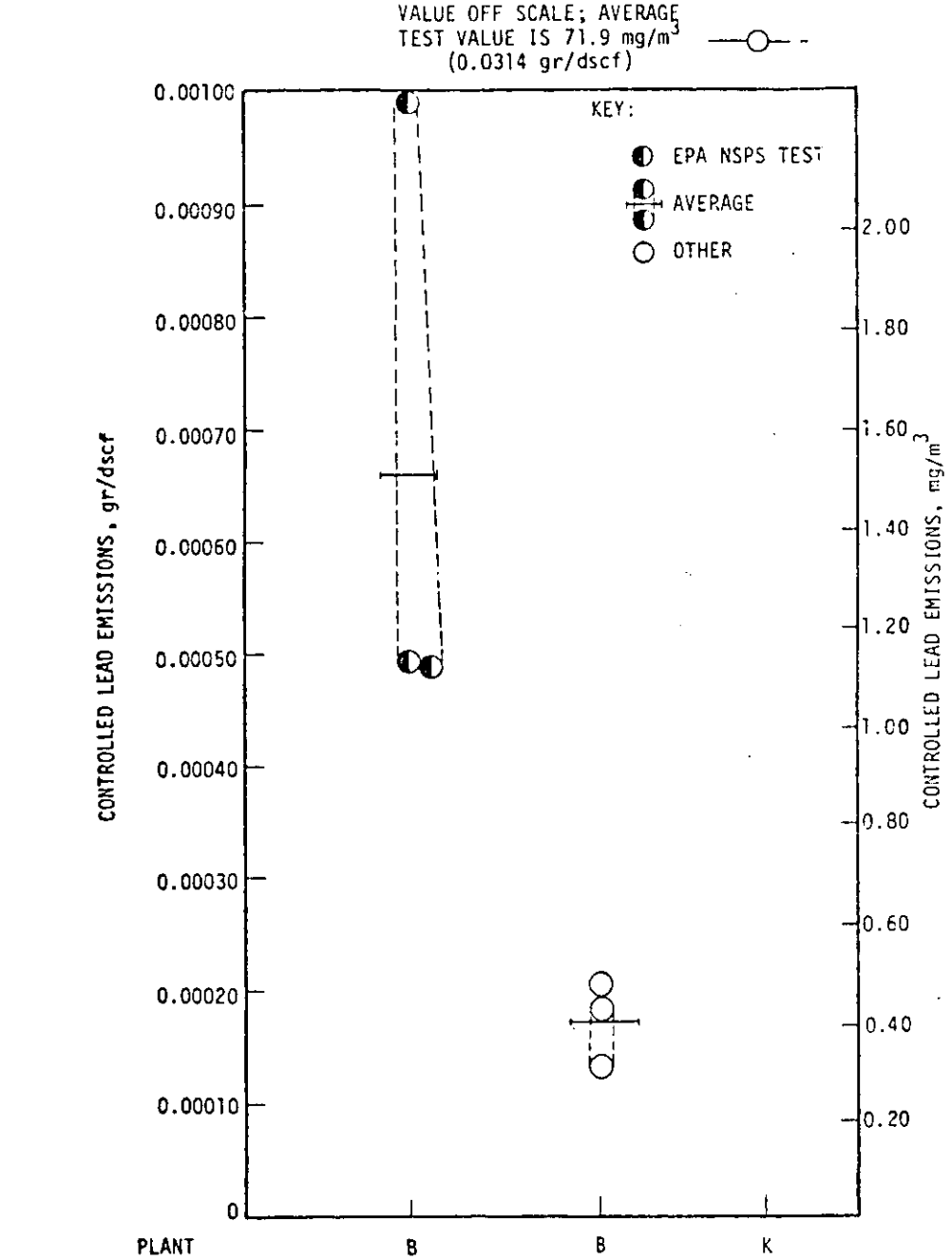


Figure 4-12. Emissions from lead oxide production using a baghouse for product recovery.

The test results show that operation of baghouses in a control recovery system can reduce lead emissions from a ball mill lead oxide production facility to less than 1.1 mg/m^3 (5.0 x 10^{-4} gr/dscf).

The only data available on lead emissions from a baghouse-controlled Barton Process are from tests performed in 1973 at a lead oxide manufacturing plant.[12] These data show emissions at the baghouse outlet averaging 71.9 mg/m^3 (314 x 10^{-4} gr/dscf or 0.45 lb/ton of lead input). This level is significantly higher than those obtained in tests of ball mill emissions. However, the test report did not specify air-to-cloth ratio, or fabric type so no conclusions can be drawn regarding Barton Process versus ball mill lead oxide production emissions. No other test data on Barton pot emissions are available.

4.5 LEAD RECLAMATION

The exhaust gas stream from the lead reclamation process is similar to the grid casting and small parts casting exhaust gases in that both are characterized by high temperatures and lead fumes. Since these gas streams are similar in character it is not uncommon to vent these processes to a common control device.

Particle size data for particulates emitted from a lead reclamation furnace are presented in Figure 4-13.

4.5.1 Scrubbers

Lead reclamation furnaces are generally controlled with low-energy wet scrubbers. Low-energy multistage or Roto-Clone-type wet collectors are used most frequently, with pressure drops less than 2 kPa (8 inches W.G.) and liquid-to-gas ratios of 0.4 to 0.7 l/m^3 (3 to 5 gal./1000 acf).

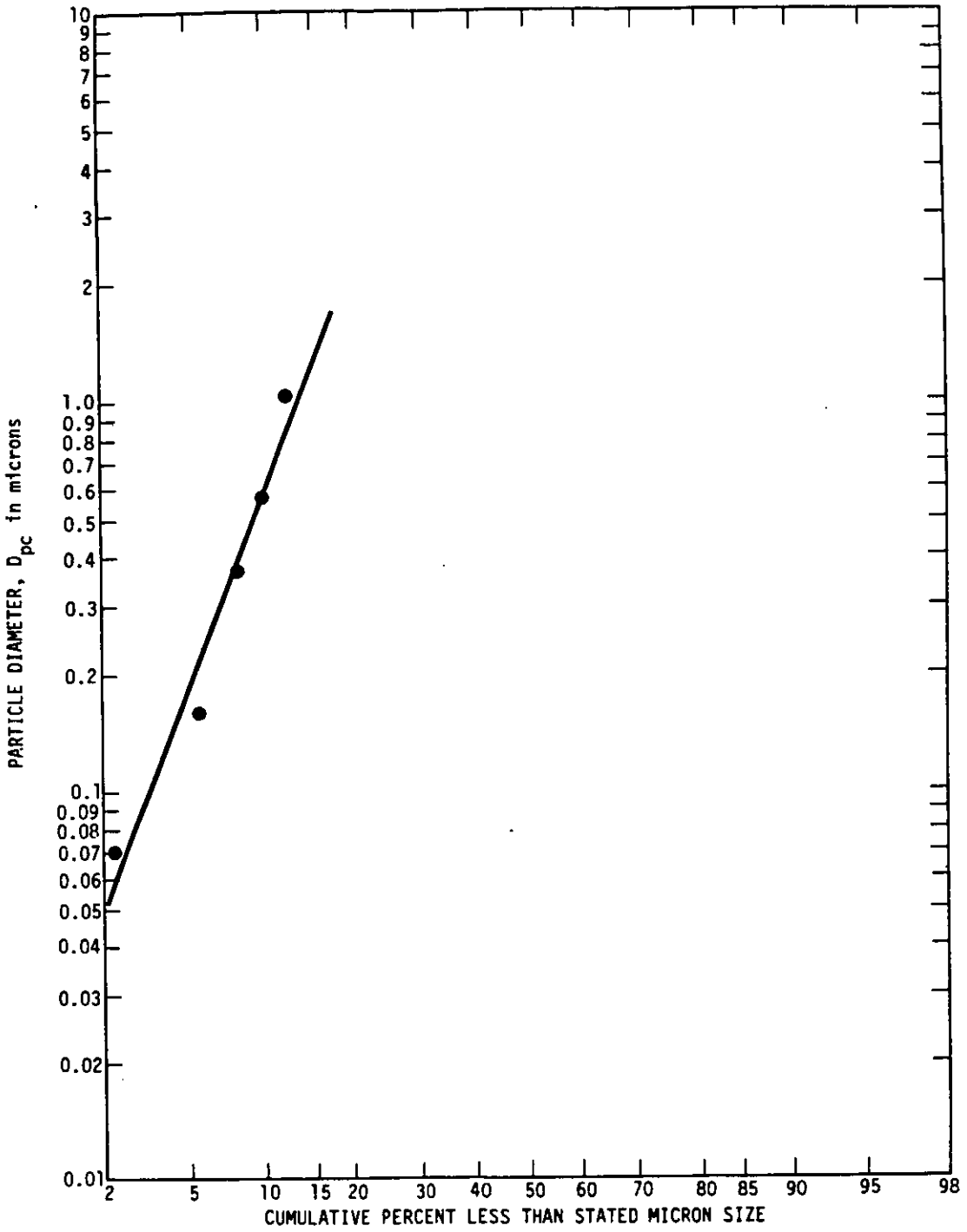


Figure 4-13. Particle size of particulate emissions from a lead reclaim furnace.

The lead reclamation facility at Plant G is controlled with a cascade scrubber. Tests of uncontrolled and controlled lead emissions gave the results shown in Figures 4-14 and 4-15, respectively. Charges of scrap lead during three tests were 431, 404, and 508 kg (950, 890, and 1120 lb). The liquid-to-gas ratio ranges from 0.53 to 0.70 l/m^3 (4 to 5 gal./1000 acf) of exhaust at a pressure drop of 498 to 747 Pa (2 to 3 in. W.G.). This scrubber also controls the small parts casting facility, which was not operating during the tests.

Three tests for lead were run at both the inlet and outlet of the cascade scrubber. Lead concentrations at the inlets were 175, 214, and 293 mg/m^3 (765 x 10^{-4}, 937 x 10^{-4}, and 1280 x 10^{-4} gr/dscf; 2.10, 2.69, and 3.72 lb/hr). Concentrations at the outlet were 2.2, 4.3, and 3.9 mg/m^3 (9.4 x 10^{-4}, 19 x 10^{-4}, and 17 x 10^{-4} gr/dscf; 0.028, 0.059, 0.050 lb/hr). Average inlet and outlet concentrations were 229 and 3.4 mg/m^3 (1000 x 10^{-4} and 15 x 10^{-4} gr/dscf, 2.8 and 0.046 lb/hr), respectively. These values indicate an average control efficiency of 98.3 percent.

The test results demonstrate that a low-energy scrubber can reduce emissions from lead reduction to average less than 3.7 mg/m^3 (16 x 10^{-4} gr/dscf, 0.05 lb/hr) at a plant with a facility of this size.

4.5.2 Fabric Filters

A survey of plants performed by EPA indicates that fabric filters are not used on lead reclamation facilities at lead-acid battery plants. They are, however, applied to hot exhaust streams in other industries. Examples are baghouse applications for control of emissions from electric arc furnaces and sinter plant windboxes in the iron and steel industry. Tests of baghouses at Plants B and D indicate that a lead collection

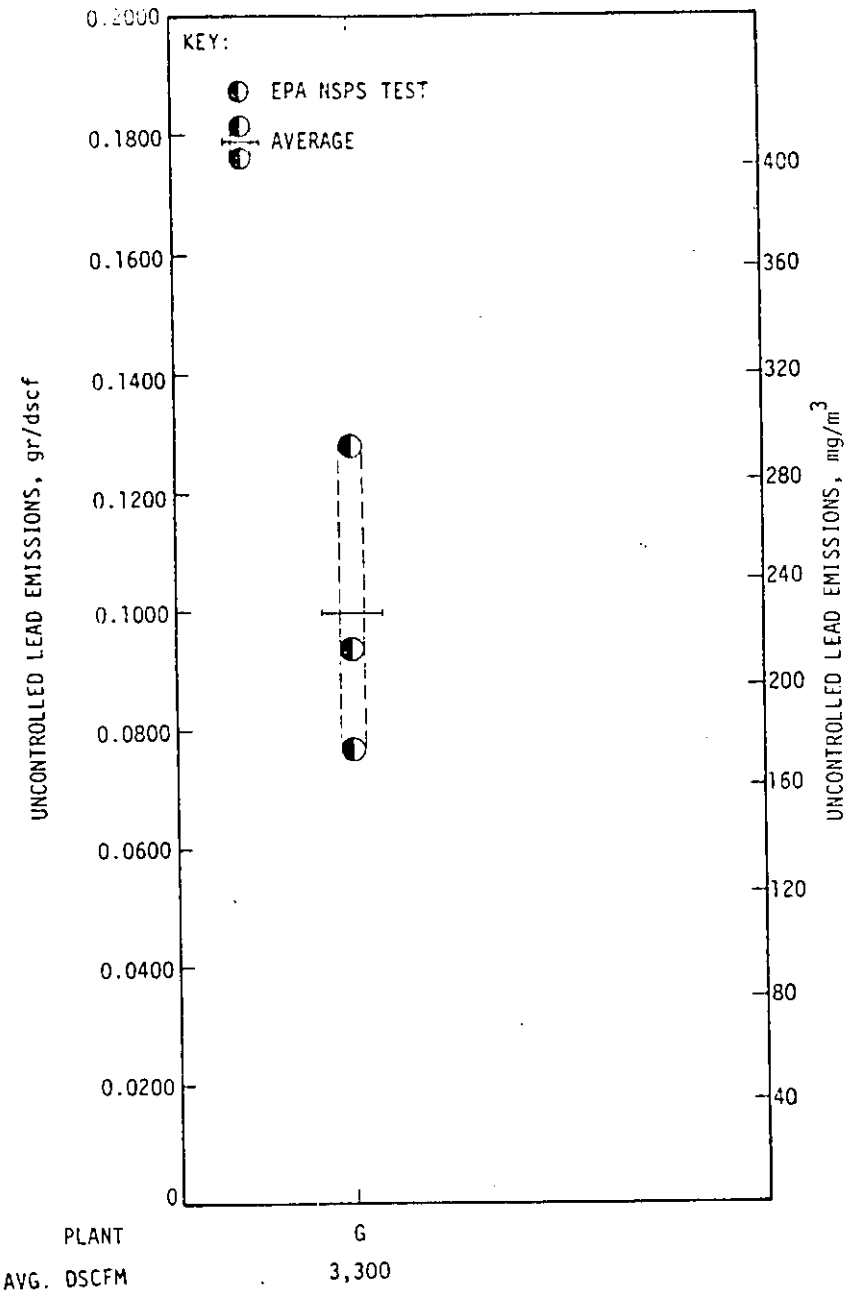


Figure 4-14. Uncontrolled lead emissions exhaust to a cascade scrubber controlling lead reclaim emissions.

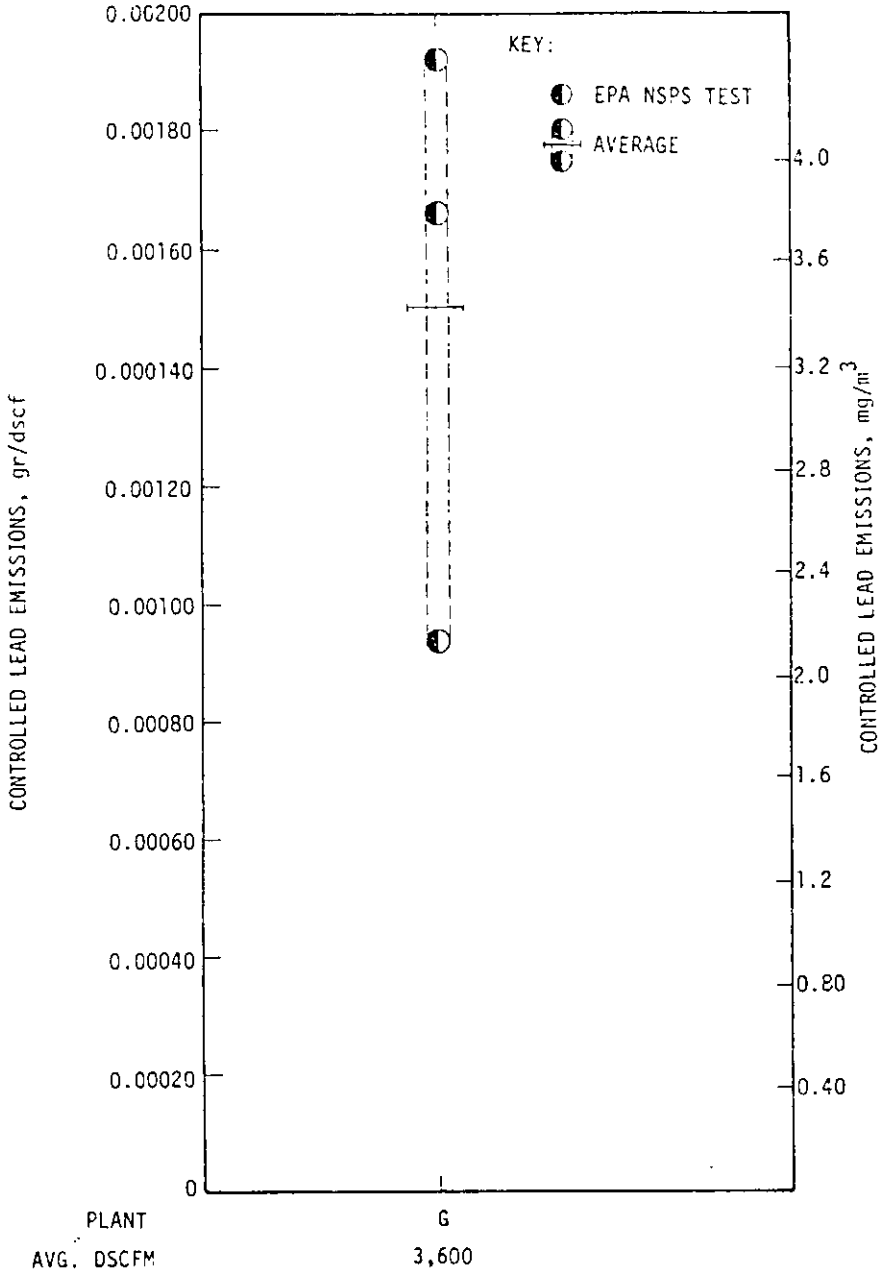


Figure 4-15. Controlled lead emissions from a cascade scrubber controlling lead reclaim emissions.

efficiency in excess of 98 percent can be achieved. These devices controlled exhaust gases from the three-process operation stations and had air-to-cloth ratios of 6/1 and 3/1 respectively.

4.6 FORMATION

As explained in Chapter 3, formation processes are divided into two categories, those which form in the battery case and those which form in open tanks. Formation processes do not emit lead, but are a source of sulfuric acid mist. Battery plates formed inside the battery case are formed slowly (1 to 4 days) and are usually destined for wet-charged batteries. Battery plates formed in open tanks are formed more rapidly (usually 16 hours) and are used to make dry-charged batteries. The type of emissions control for these processes depends on whether or not the formation area is enclosed.

Very little data on emissions from formation processes are available from any source. However, based on observations during plant inspections, the processes which appear to generate much higher emissions are those which form the plates in open vats. This is also evidenced by the fact that most companies which form the battery plates inside the assembled battery have no ductwork to remove emissions from the work area, and there appears to be no concern about industrial hygiene from either plant or government personnel. Plants which do duct the emissions from the work area (those which form in an open vat) have a more acute emission problem. These plants typically use either foam, scrubbers, mist eliminators, or combinations of these control techniques to minimize emissions to the production area and the outside air. Following are emission control practices used for formation processes.

4.6.1 Control Techniques

4.6.1.1 Good Work Practice--

When the formation area is not vented to a control device, such as when the battery is formed after complete assembly, the operator should form the batteries slowly and keep every battery filler cap on the battery at all times during the formation period. This minimizes emissions to the work area, and hence to the atmosphere. One large battery manufacturing company leaves the top of the battery case off during the assembly process and does not install the top until after formation is complete. During formation, a dummy, reuseable cover is placed on top of the batteries being formed. This helps to reduce emissions since much of the sulfuric acid mist impinges on the slave cover and condenses back into the battery.[13]

4.6.1.2 Water Sprays--

Many plants which form in the battery case (wet formation) spray the batteries with water during the formation process. The spray may absorb some sulfuric acid mist but is primarily used to keep the temperature of the batteries lower than it would normally be since, as experienced in Chapter 3, sulfuric acid mist emissions increase proportionally with acid temperature during formation.[14]

4.6.1.3 Ceramic-Disk Caps--

One manufacturer who forms the batteries while they are completely assembled in the case has a patented battery filler cap which has a ceramic disk on the inside of the cap. The only escape for the gas is through the cap, and this manufacturer claims that the disk absorbs hydrogen (which is a carrier for the sulfuric acid mist), thus virtually

eliminating sulfuric acid mist emissions generated during formation. The acid is dumped from the battery after formation and the batteries are centrifuged to remove any remaining acid. After centrifuging, the "wet" batteries are filled with fresh acid and the "dry" batteries are shipped as is.[15]

4.6.1.4 Foam Covers--

Some companies which form the batteries in open tanks (dry formation) cover the tanks with a layer of foam. Two foaming agents typically used are Alkonol and Dupanol. These foaming agents control sulfuric acid mist by collecting the mist particles from the surface of the sulfuric acid solution before they can escape into the formation room. Three formation processes using foam were surveyed by EPA. Subjective measurements of the mist cloud above forming tanks and the characteristic acid odor in the forming room suggested a decrease in acid mist emissions when foam is used. Emission measurements at one plant (Plant L) did not confirm a reduction in emissions (see Section 4.6.2 and Appendix C).

4.6.1.5 Scrubbers--

The only companies which use scrubbers are those which form the batteries in open vats (dry formation). The scrubbers used by these companies are typically low energy type scrubbers, such as the Heil fume washer (a scrubber and mist eliminator), and several non-commercial designs. Plants which use scrubbers either enclose the formation tanks and duct the emissions to the scrubber, or they form the battery in a room which can be closed off. The emissions in the room are then ducted to the scrubber.

4.6.1.6 Mist Eliminators--

Some companies which form their batteries in open vats use mist eliminators rather than scrubbers. A popular brand used by this industry is the Tri-Mer scrubber. This mist eliminator catches the mist particles as they go through a fan separator followed by a packed tower. The packing is then periodically washed (called flushing) on a schedule ranging from once per day to two or three times per shift.

4.6.2 Test Data

Two open vat-type (dry) formation processes have been sampled by EPA. The first test did not yield any valid results because the process was not operating properly (one of three formation circuits was inoperative). Also, emissions from the control device were not detectable when EPA Reference Method 8 was used to collect emissions over a two-hour sampling period. Uncontrolled emissions were not sampled at this plant.

The second formation process (Plant L) was sampled during four separate sixteen-hour cycles. The emission control on formation at this plant consisted of the use of foam in combination with a scrubber/mist eliminator. Samples were taken at the inlet and outlet of the scrubber/mist eliminator during three formation cycles when foam was in use and one cycle when foam was not applied. Because emissions from the formation process increase towards the end of the sixteen-hour cycle, only samples taken during the last five hours of each cycle were analyzed for average emissions. These results are shown in Figures 4-16 and 4-17. Acid mist emissions without the use of foam were 65 mg/m^3 (0.028 gr/dscf, .66 lb/hr) before the scrubber and 1.6 mg/m^3 (0.0007 gr/dscf, 0.02 lb/hr) after the scrubber/mist eliminator. With the use of foam, emissions averaged 66 mg/m^3 (0.029 gr/dscf, 0.70 lb/hr) before the scrubber and

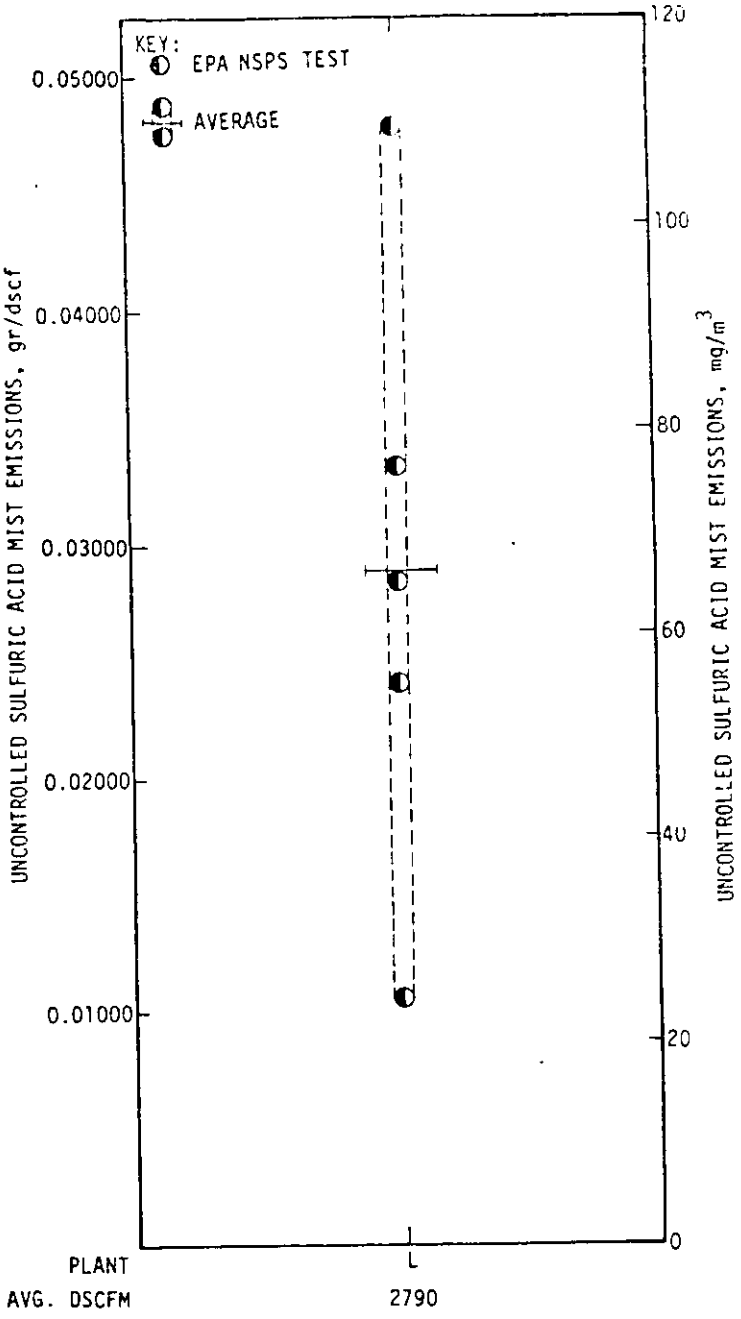


Figure 4-16. Uncontrolled formation emissions.

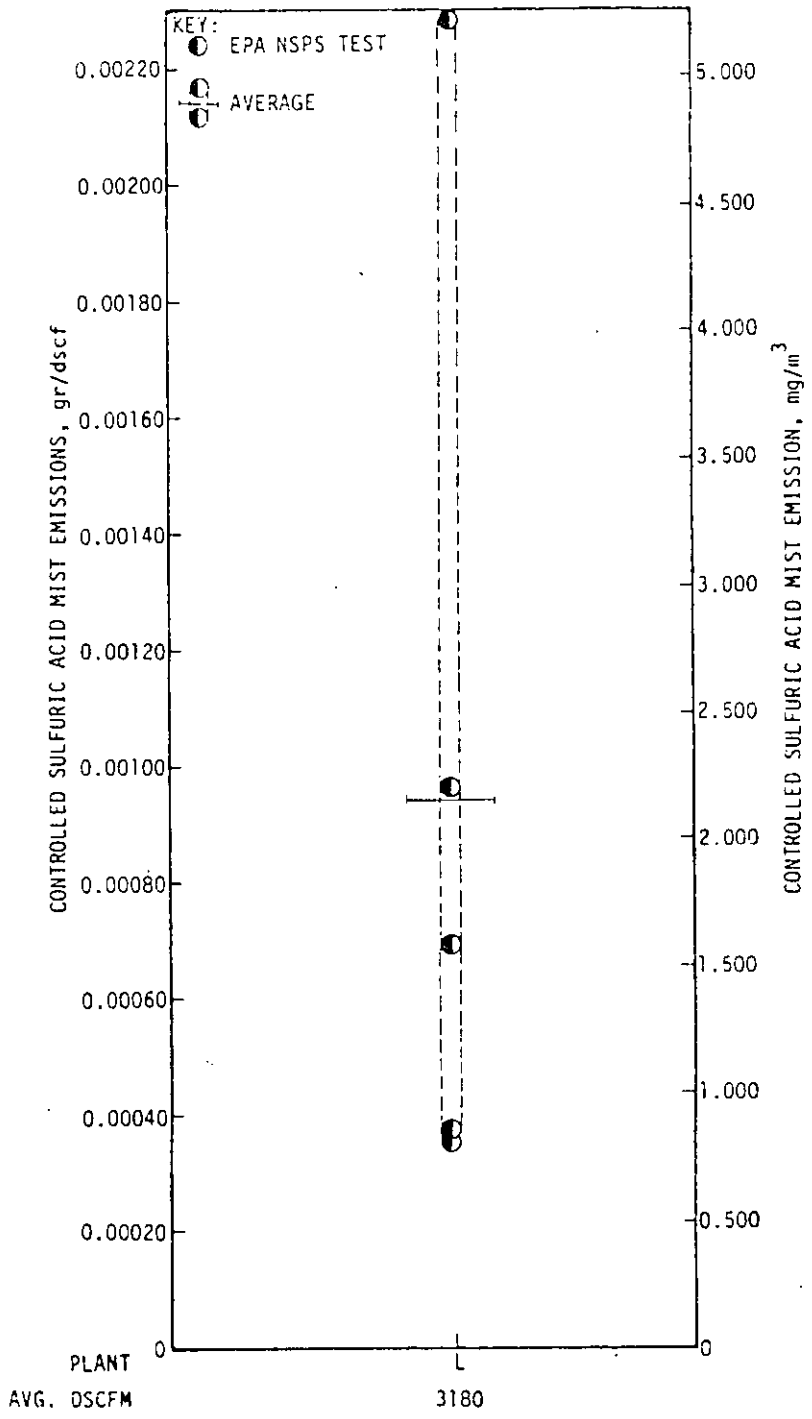


Figure 4-17. Controlled formation emissions.

2.3 mg/m^3 (0.001 gr/dscf, 0.03 lb/hr) after control. Additional detail on these tests is presented in Appendix C.

4.7 CONTROL PERFORMANCE SUMMARY

Figures 4-18 and 4-19 respectively, show average uncontrolled and controlled lead emissions from all processes tested during the EPA test program. Table 4-1 summarizes control equipment parameters during these tests. Details of the tests are presented in Appendix C.

The lead-acid storage battery industry generally uses low energy scrubbers to control production processes which evolve gases containing moisture or possible spark hazards. EPA has concluded that fabric filters can be used to control all lead emitting processes, provided that necessary precautions are taken to prevent moisture condensation and sparks. This conclusion is partially based on the similarity of emission characteristics (especially particle size) of all battery manufacturing processes for which we have emission data. Also, fabric filters are commonly used to control emissions from other industries having similar moisture and spark hazards.

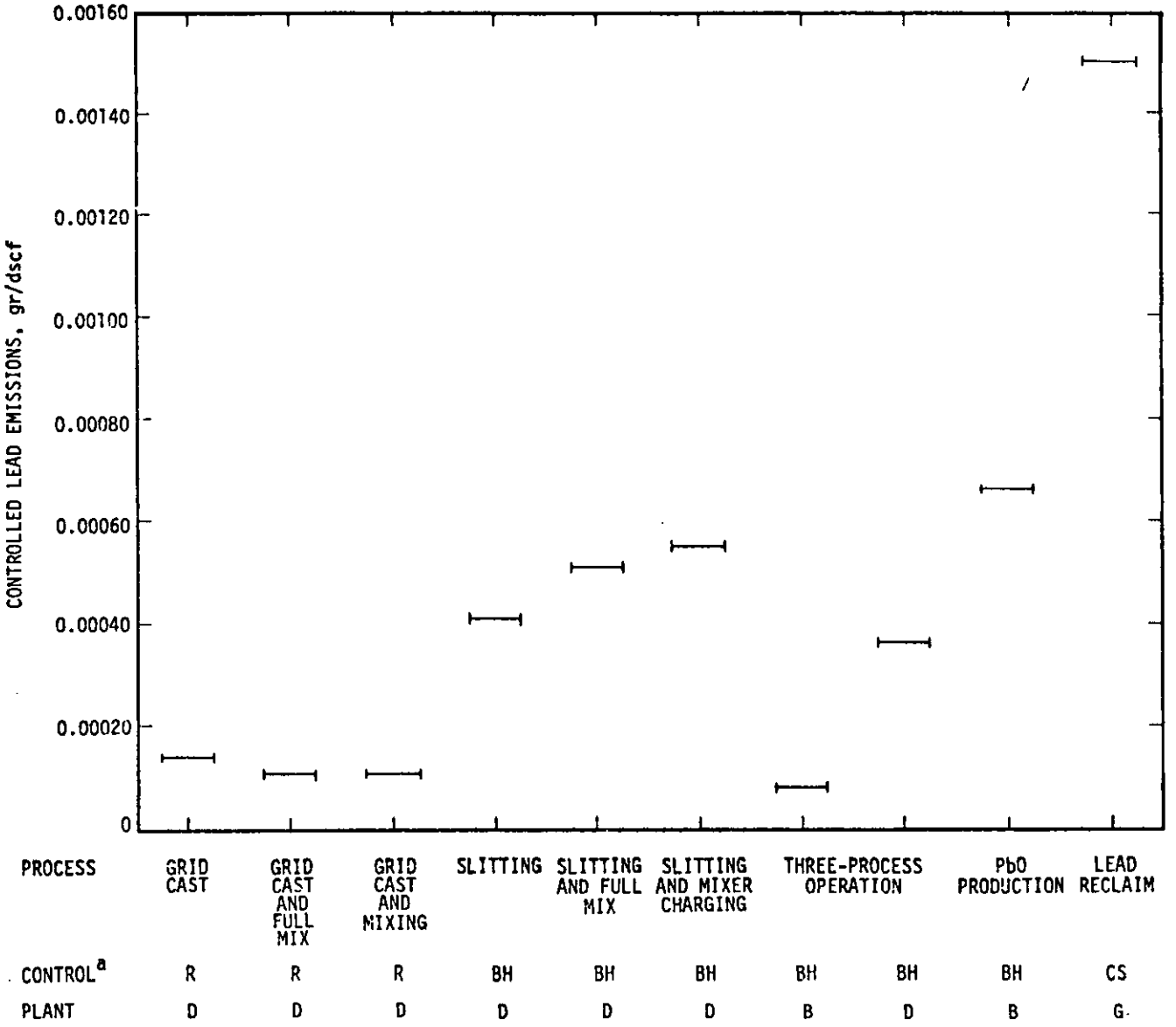


Figure 4-18. Average controlled lead emissions from tested facilities (gr/dscf).

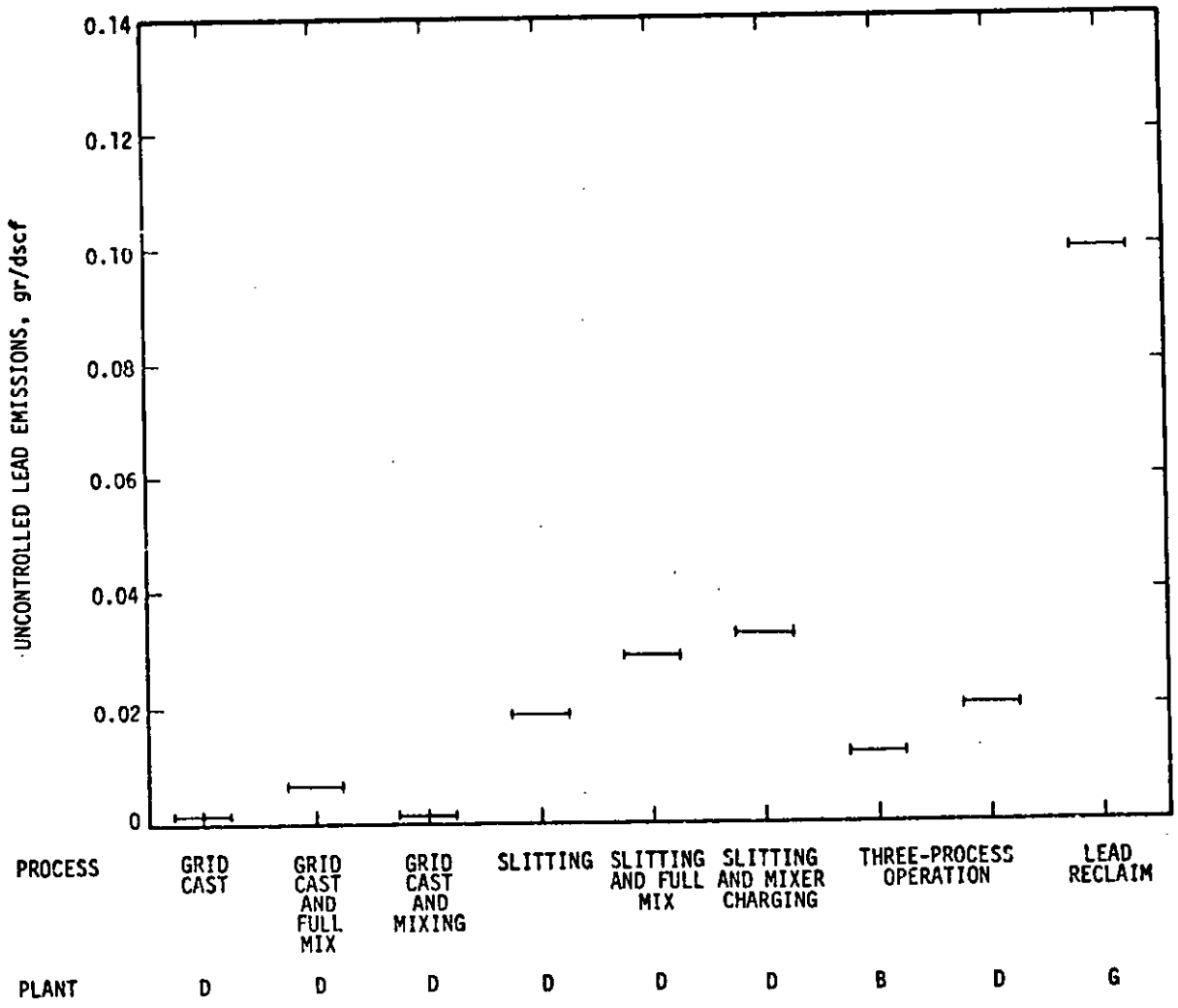


Figure 4-19. Average uncontrolled lead emissions from tested facilities (gr/dscf).

Table 4-1. CHARACTERISTICS OF CONTROL DEVICES TESTED

	Generic type of control device	Source (plant) code	Test Program Information				
			Specific type of device	Lead removal efficiency, percent	Air-to-cloth ratio	Water-to-gas ratio, l/m^3 (gal/1000 acf)	Pressure drop, Pa (in. W.G.)
Grid casting	Impingement and entrainment scrubber	D	Type N Roto-Clone	90	N/A	2.6 (20) (in motion)	1245 (5)
Paste mixing Materials charging	Baghouse	D	Shaker type	98	3/1	N/A	249 (1)
Mixing	Impingement and entrainment scrubber	D	Type N Roto-Clone	90	N/A	2.6 (20) (in motion)	1245 (5)
Three-process operation	Baghouse	B	Pulse jet type	99.3	6/1	N/A	1245 (5)
		D	Shaker type	98.6	3/1	N/A	498 (2)
Lead oxide manufacturing	Baghouse	B[a]	Shaker type (2)	b	4/1	N/A	249-498 (1-2)
			Pulse jet type (2)		2/1	N/A	1494 (6)
Lead reclamation	Centrifugal and impingement scrubber	G	Cascade scrubber	98.3[c]	N/A	0.53 to 0.70 (4-5)	498-747 (2-3)

[a] Four baghouses ducted to common stack.

[b] No inlet tests taken. Baghouses are considered process equipment (for product recovery) as well as control devices.

[c] Source tests show 98 percent efficiency for this low-energy scrubber.

[d] Manufacturers' trade names have been used herein for purposes of clarity only. The use thereof shall not be deemed as an endorsement of any particular brand of equipment or substance by EPA.

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15. Ibid.

5.0 MODIFICATIONS AND RECONSTRUCTION

5.1 GENERAL

New Source Performance Standards apply to new, modified, and reconstructed facilities. Therefore, existing facilities are not affected until a modification or reconstruction is determined to have taken place. The definitions of modification and reconstruction are presented in the general provisions applicable to all New Source Performance Standards in 40 CFR 60.14 and 60.15 and are discussed in this chapter.

A step-by-step approach to determining whether a physical or operational change constitutes a modification or reconstruction under the regulations is shown in Figure 5-1. Following are simplified definitions of some of the terms used in the regulations:

- Source - Generally an entire plant or process consisting of more than one facility.
- Facility - A particular operation within a source. For example, in a lead-acid battery plant, the grid casting operation, the paste mixing operation, the three-process operation, etc., would be considered as separate facilities.
- Affected Facility - One that is subject to the emission limitations of an NSPS. An affected facility is one that is newly built or one that has been modified or reconstructed.

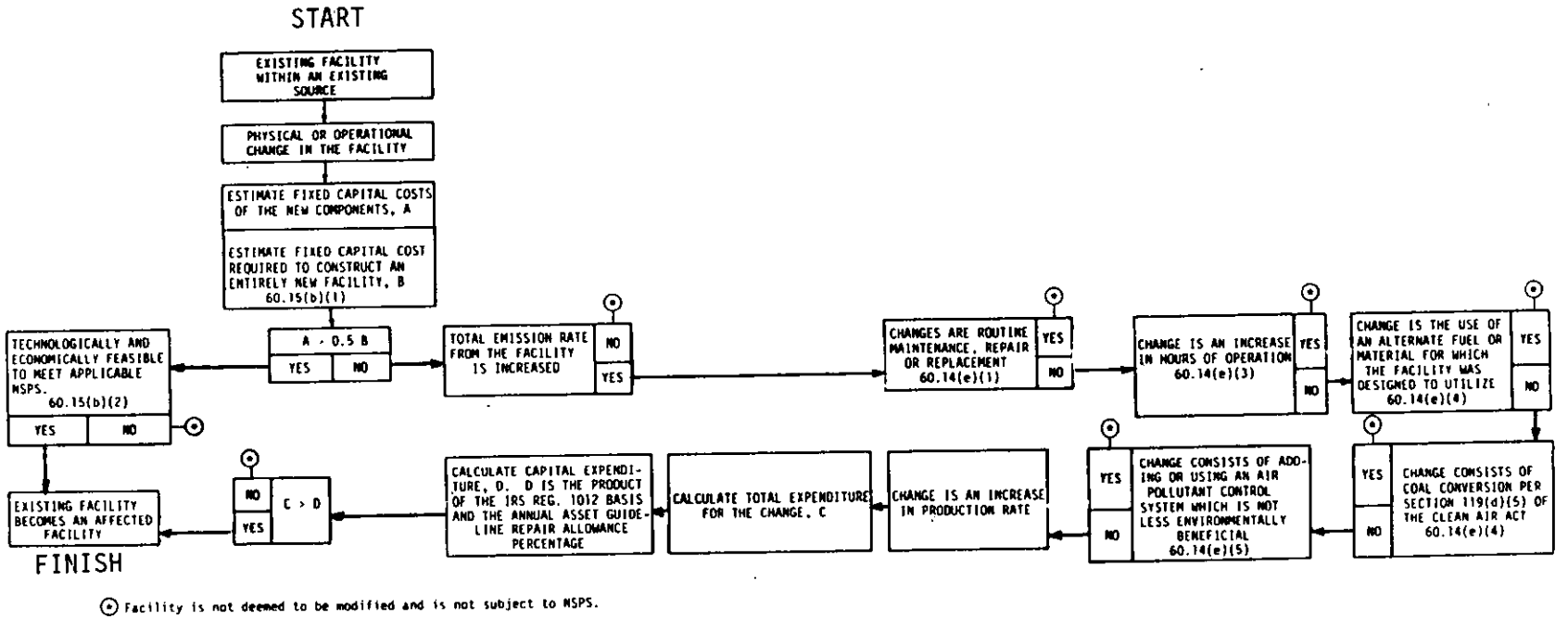

Figure 5-1. Method of determining whether changes to existing facility constitute a modification or reconstruction under 40 CFR 60.14 and 60.15.

5.1.1 Reconstruction

Irrespective of any change in pollutant emission rates, a replacement of components of an existing facility may be deemed a reconstruction of that facility if (1) the fixed capital cost of the new components exceeds 50 percent of the fixed capital cost that would be required to construct a comparable entirely new facility, and (2) it is technologically and economically feasible to meet the applicable standards.

5.1.2 Modification

If a physical or operational change results in an increase in the rate of emission to the atmosphere of any pollutant to which an NSPS applies, the facility is deemed to be modified. Certain exceptions apply, as shown in Figure 5-1.

When the purpose of the change in a facility or operation is to increase production rates and such change causes an increase in emission rates, the facility is deemed modified only if the total expenditures (both capital and expense dollars) attributable to the change exceed the product of the facility's "1012 Basis" and the "Annual Asset Guideline Repair Allowance Percentage (AAGRAP)." The first figure is determined in accordance with Internal Revenue Code Section 1012. Very simply stated, it may be thought of as the initial cost, or basis, of the facility. The latter figure is given in Internal Revenue Service Publication 534 (latest edition). Table 5-1 lists the AAGRAP values applicable to various facilities for which NSPS regulations have been promulgated.

TABLE 5-1. ANNUAL ASSET GUIDELINE REPAIR ALLOWANCE PERCENTAGES FOR SPECIFIED FACILITIES PER IRS PUBLICATION 534 (1975 EDITION)

Facility	AAGRAP
Nitric acid production unit	5.5
Sulfuric acid production unit	5.5
Lead smelter cupola	4.5
Catalytic cracking unit at a petroleum refinery	7.0
Electric arc furnace	8.0

5.2 APPLICABILITY OF 40 CFR 60.14 AND 60.15 TO THE LEAD-ACID BATTERY MANUFACTURING INDUSTRY

5.2.1 Capital Costs of Facilities

In general, the cost of any piece of equipment represents approximately 25 to 33 percent of the total installed capital costs. Cost breakdowns for a typical installation are given in Tables 8-10 and 8-11. Estimated capital costs associated with the purchase of various components are shown in Table 5-2. As mentioned earlier, the replacement of components may be considered a reconstruction if the fixed capital cost of the new components exceeds 50 percent of the fixed capital cost that would be required to construct a comparable entirely new facility. Thus the replacement of a rotary mill in a lead oxide manufacturing facility would not be considered a reconstruction where the fixed capital cost of the mill is $45,000 and the total fixed capital costs of an entirely new facility would approximate $125,000.

5.2.2 Routine Maintenance, Repair, and Replacement[4]

Routine maintenance, repair, or replacement of components are specifically exempted under section 60.14(e)(1). Therefore it is important

Table 5-2. F.O.B. PRICE OF VARIOUS COMPONENTS FOR LEAD-ACID BATTERY MANUFACTURING FACILITIES

Facility	Component	Capacity	Other specs	Cost, $[a]
Grid casting	Furnace	1814 kg (4000 lb)		$ 2,350
		2492 kg (5500 lb)		5,210
	Grid casting machine	18 grids/min		13,600
	Small parts casting machine			8,360
Paste mixing	Mixer	252 kg/sec (2000 lb/hr)	Includes motor	13,300
	Mixer	630 kg/sec (5000 lb/hr)	Includes motor	24,000
	Mixer	1134 kg/sec (9000 lb/hr)	Includes motor	33,100
Three-process operation	Automatic stackers	170 plates/min		21,900
	Automatic burning	4 btry/min		6,480
	Automatic assembly	100 btry/shift		3,440
		800 btry/shift		14,600
Formation	Rectifiers	3500 bpd		10,400
PbO manufacturer	Rotary mill	1 tph	With motor	15,700
	Conveyors and storage			8,350
	Baghouse	111 m^3/min (4000 cfm)		11,500
Lead reclamation	Pot furnace			5,220

[a] These estimates are based on mid-1976 dollars and are quotations obtained from vendors by telephone and from various cost estimating and equipment pricing guides. Costs for specific installations will vary. These figures can be used for "order of magnitude" estimates only.

to consider the physical changes that constitute routine maintenance, repair, or replacement.

Grid casting furnaces require periodic inspection and annual repairs such as relining. These furnaces are normally relined only five or six times and then are replaced. Grid casting machines are highly mechanized and therefore require periodic inspection and replacement of small parts and an annual complete overhaul. With a good maintenance program, a grid casting machine can operate for many years.

Paste mixers usually require considerable maintenance because operators tend to overload the equipment. Gears, shafts, drives, and other movable parts cannot sustain the mechanical attrition and must be replaced. The paste mixer shell and other stationary hardware can last for many years, however, requiring very little maintenance. Like the grid casting machine, the paste machine is highly mechanized and requires periodic inspections and annual overhauls. Replacement of chains, bearings, and drives is common.

Automatic stacking machines, burning machines, and group assembly machines require continual maintenance. Conveyor chains, bearings, and small parts are periodically replaced. These machines are also cleaned periodically and overhauled annually. At plants where the stacking, burning, and assembly are done manually, little if any routine maintenance is required.

Equipment for forming dry batteries may corrode during the years and eventually need replacement. Where batteries are formed in their cases, corrosion is not a problem. Although rectifiers can burn out if they are not adequately cooled, this is unlikely; they typically require

no maintenance and last for many years. At one plant visited during this study the rectifiers were over 20 years old.

Lead oxide ball mills require routine repairs. The classifying screens of the rotary ball mill must be replaced about monthly. Bearings and other small parts are replaced periodically. The shell of the mills will last up to 20 years before total replacement is necessary. The inner cast iron liner of the impact mill must be replaced annually. Fabric filter bags are normally replaced annually. Screw conveyors from the baghouse are likely to jam frequently and require regular maintenance.

Barton pots also require periodic relining and other minor repairs. Eventually these pots must be replaced.

5.2.3 Use of Alternative Materials

In general, the same materials have been used in lead-acid batteries ever since self-starters were put on automobiles. Almost by definition, they cannot be replaced with alternative materials. Alloy metals are sometimes added to the lead, usually at the smelter. In brief, the exemption cited in section 60.14 (e)(4) relative to the use of alternative materials has little application to the manufacture of lead-acid batteries.

The only foreseeable application of this section would relate to paste mixing. The mixing facility is designed to mix oxides derived from both ball mills and Barton pots. Because some regard the latter as finer and more difficult to contain and capture,[5] it is possible that use of Barton pot oxides could cause relatively greater emissions from the mixer. (None of the industry spokesmen contacted had information in this regard; one pointed out that because both oxides are often ground in a hammermill as a final step, the particle characteristics may be

similar). Use of various alternate materials as binders and expanders also may increase emissions from the mixer. Even old paste is sometimes ground for use in the negative paste mix. Under section 60.14(e)(4), such a change in the use of materials would not be deemed a modification if the mixer was designed to accommodate the alternative material.

5.2.4 Use of Different Control Device

Section 60.14(e)(5) provides an exemption where an increase in pollutant emission rate is due to the addition or use of any system or device whose primary function is the reduction of air pollutants and it is determined by the Administrator of EPA that such system is not less environmentally beneficial than the original system. An example of this is replacement of a 99.9 percent efficient scrubber (from which lead-contaminated water emanates) with a 99.7-percent-efficient dry collector such as a fabric filter. Replacement of the same scrubber with a 70-percent-efficient cyclone would be considered less environmentally beneficial and thus a modification.

5.2.5 Increase in Production Rate Accomplished Without a Capital Expenditure

If the purpose of a physical or operational change is to increase the production rate and if such change results in an increase in emission rate, the facility will be considered a modified facility only if the total costs associated with the change constitute a capital expenditure. If the total costs are lower than those constituting a capital expenditure, such change is not considered a modification (section 60.14[e][2]). Capital expenditure is the product of the IRS Regulation 1012 Basis and the Annual Asset Guideline Repair Allowance Percentage (AAGRAP). The 1977 Edition of IRS publication 534 sets the AAGRAP at 5.5 percent for

the lead-acid battery industry. Simply stated, therefore, if the total cost of the change exceeds 5.5 percent of the original cost of the facility, the change could constitute a modification.

5.3 ILLUSTRATIVE EXAMPLES

The enforcement division of the appropriate EPA regional office should be contacted whenever a source has questions regarding modifications and reconstruction. Their judgment will supercede any general examples that can be given in a document such as this. However, some examples are offered below, showing how the regulation might apply to the lead-acid storage battery industry.

As one example, consider a grid casting facility with a 1012 basis of $515,000. If the furnace is changed to increase production and the change results in an increase in the emission rate to the atmosphere of any pollutant to which a standard applies, the change will be considered a modification if the cost exceeds $28,325 (5.5 percent of $515,000).

As another example, if a plant operator replaces the motor, paddle wheel and shell of his paste mixer, the repaired mixer will be subject to the new source performance standards, even if emissions to the atmosphere are not increased. This is assuming that the cost of the new components of the repaired mixer "exceeds 50 percent of the fixed capital cost that would be required to construct a comparable entirely new facility [mixer]" and that "it is technically and economically feasible to meet the applicable standards" (Section 60.15).

REFERENCES FOR SECTION 5

1. Federal Register, Vol. 40, No. 242. Tuesday, December 16, 1975. p. 58416.

2. Private Communication between David Augenstein of PEDCo Environmental, Inc., Cincinnati, Ohio, and Sam Hurley of Winkel Machine Co., Inc. Kalamazoo, Michigan. January 1976.

3. Private Communication between David Augenstein of PEDCo Environmental, Inc., Cincinnati, Ohio, and George Tiegel of the Tiegel Manufacturing Co. Belmont, California. January 1976.

4. Private Communication between David Augenstein of PEDCo Environmental, Inc., Cincinnati, Ohio, and John Collinson of ESB Canada Limited, Toronto, Ontario. February 1976.

5. Private Communication between Donald Henz of PEDCo Environmental, Inc., Cincinnati, Ohio, Lee Beck of U.S. Environmental Protection Agency, and Robert Stuart of Globe Union, Canby, Oregon. June 14, 1976.

6.0 EMISSION CONTROL SYSTEMS

This chapter describes emission control systems that are considered likely candidates to represent the best system of emission reduction. An emission control system is a combination of a production process or type of process equipment (Chapter 3) and an emission control technique (Chapter 4). In the lead-acid battery industry there are no significant differences in types of process equipment that would limit the use of one control technique and dictate use of another. For most of the process operations, however, there is the choice of providing a wet collector or a fabric filter. None of the operations requires the use of a series of control devices, such as cyclone, baghouse, and afterburner. (When a baghouse is preceded by a cyclone at a lead oxide production facility, the cyclone is considered part of the process equipment. The baghouse is also part of the process to the extent of economic removal of valuable lead-oxide from the stack gas. The capacity of the baghouse to remove lead oxide beyond the point where it is economical is considered capacity added for emission control).

Given the definition of a control system as consisting of a production process together with a specific control technique, the next step is to develop a set of control "alternatives"; these are strategies for combining the various processes with the available control techniques to achieve optimum reduction of lead emissions throughout an entire plant. The selected alternatives, or strategies, discussed in this chapter are

later considered in terms of their environmental impacts (Chapter 7) and economic impacts (Chapter 8).

6.1 APPLICATION OF CONTROL TECHNIQUES

The applicability and performance of a control technique with respect to a specific facility or group of facilities depend on the characteristics of the exhaust gas and particles, and on the operational characteristics of the control device and the facility. Other lead-emitting operations, such as slitting or lug breaking, can be ducted to any device controlling lead emissions from another facility. Table 6-1 summarizes the control systems that are, or could be, applied to well-controlled facilities in lead-acid battery manufacturing plants.

6.2 SELECTED CONTROL ALTERNATIVES

As discussed earlier, some facilities may be vented to common control systems. The possible combinations are many. Eight control alternatives for lead emissions are presented in Table 6-2. Control alternatives I through V are applicable to plants of production capacity greater than 500 batteries per day. Small plants (production capacity less than 500 bpd) typically do not have lead oxide manufacture and lead reclamation facilities. Also, it is expected that the economic impact of requiring emission controls on small plants will be more severe than on larger plants. Therefore, control alternatives VI, VII, and VIII are presented to give consideration to small producers of lead-acid batteries.

Selection of these eight alternatives is based on current applications, engineering judgement, and in the cases of systems I, VI, and VII, technology transfer. It is emphasized that these alternatives are not equally effective in abating lead emissions. All eight alternatives include a fiber mist eliminator for acid mist control.

Table 6-1. SUMMARY OF CONTROL SYSTEMS APPLICABLE TO LEAD-ACID BATTERY MANUFACTURING FACILITIES

Facility	Control technique				
	Impingement and entrainment scrubber 1245 PA (in W.G.) 2.6 l/m^3 (20 gal/1000 acfm)	Cascade scrubber 498 - 747 Pa (2-3 in W.G.) 0.14-0.67 l/m^3 (4-5 gal/1000 acf)	Fabric filter 6/1 A/C pulse jet	Fabric filter 2/1 A/C shaker	Mist eliminator
Grid casting furnace	X		X[a]		
Grid casting machine	X		X		
Paste mixer	X		X		
Three-process operation	X		X		
Lead reclamation furnace	X	X	X[a]		
Formation					X
Lead oxide mill				X	

[a] Based on technology transfer.

Table 6-2. SELECTED CONTROL ALTERNATIVES FOR LEAD-ACID BATTERY MANUFACTURING INDUSTRY

Plant size, BPD	Control alternative	Facilities[a]	Control system[b]
500, 2000, & 6500	I	A, B, F	Fabric filter, 6/1 A/C
		C, E	Fabric filter, 6/1 A/C
		G	Mist eliminator
		D	Fabric filter, 2/1 A/C
	II	B, C, E	Fabric filter, 6/1 A/C
		F	Impingement and entrainment scrubber
		A	Impingement and entrainment scrubber
		G	Mist eliminator
		D	Fabric filter, 2/1 A/C[c]
	III	C, E	Fabric filter, 6/1 A/C
		A, B, F	Impingement and entrainment scrubber
		G	Mist eliminator
		D	Fabric filter, 2/1 A/C
	IV	A, B, C	Impingement and entrainment scrubber
		E	Fabric filter, 6/1 A/C
		F	Impingement and entrainment scrubber
		G	Mist eliminator
		D	Fabric filter, 2/1 A/C[c]
	V	A, B, C, F	Impingement and entrainment scrubber
		E	Fabric filter, 6/1 A/C
		G	Mist eliminator
		D	Fabric filter, 2/1 A/C[c]
100 & 250[d]	VI	A, B, C	Fabric filter, 6/1 A/C
		E	Fabric filter, 6/1 A/C
		G	Mist eliminator
	VII	A, B, C, E	Fabric filter, 6/1 A/C
		G	Mist eliminator
	VIII	A, B, C	Impingement and entrainment scrubber
		E	Fabric filter, 6/1 A/C
		G	Mist eliminator

[a] Facilities key: A - grid casting furnace; B - grid casting machines; C - paste mixer; D - lead oxide manufacturing; E - three-process operation; F - lead reclamation furnace; G - formation.

[b] Facilities are vented to common control systems as shown.

[c] Small plants (500 bpd or less) are assumed to have no lead oxide manufacturing facilities.

[d] Plants smaller than 500 BPD are assumed to have no lead reclamation facilities.

Electrostatic precipitators and higb energy scrubbers are commonly used to control particulate emissions from other industries. They are not considered in any of the control alternatives in this study because they are not used in the lead-acid storage battery industry, and have no economic or environmental advantage over fabric filters.

6.3 EFFECTIVENESS OF SELECTED LEAD EMISSIONS CONTROL SYSTEMS

Approximate uncontrolled lead emission rates of the facilities used in lead-acid battery plants are presented in Table 6-3. These have been calculated using emission testing data presented and discussed in Chapter 4. The emission reduction which would result from the use of any one of the selected control alternatives can be calculated using the collection efficiencies of the control system components (see Table 6-4). Tables 6-5 and 6-5A compare the expected lead emission rates of 500, 2000, and 6500 bpd plants using control alternatives I through V and 100 and 250 bpd plants using alternatives VI through VIII with the approximate emission rates of plants using no emission controls. Tables 6-6 and 6-6A compare the expected lead emission rates of plants using the selected control alternatives with the expected emission rates of plants controlling emissions only to the extent required by typical State regulations. State Implementation Plan (SIP) regulations generally limit particulate emissions from a process to a percentage of the throughput of the process. In order for a lead-acid battery plant to comply with typical SIP regulations, emissions from the paste mixing and lead reclamation facilities generally must be controlled (uncontrolled emissions from lead oxide production facilities, grid casting facilities and three-process facilities generally do not exceed SIP limits). SIP emission rates presented in Tables 6-6 and 6-6A were

Table 6-3. UNCONTROLLED EMISSIONS OF LEAD FROM LEAD-ACID BATTERY MANUFACTURING FACILITIES[a]

Facility code	Facility description	Lead emissions		
		$\mu g/m^3$ (gr/scf)	g/1000 btry (lb/1000 btry)	g/kg Pb throughput (lb/ton Pb throughput)
A	Grid casting furnace	0.094[b] (0.00116)	408[b] (0.90)[b]	
B	Grid casting machine			
C	Paste mixing	1.07 (0.0132)	5079 (11.2)	
D	PbO manufacturing	0.107 (0.00132)[c]	53 (0.116)[c]	0.01 (0.02)[c]
E	Three-process operation	1.33 (0.0163)	6666 (14.7)	
F	Lead reclamation	8.14 (0.10)	349 (0.77)	2.95 (5.9)

[a] Based on source test data from Plants B, D, and G.

[b] Facilities A and B were vented to a single control device. It is estimated that 50 percent emanates from each facility. Figures represent emissions from both facilities.

[c] This number is twice the value measured in tests at the outlet of a well-controlled facility.

15 090

TABLE 6-4. ESTIMATED LEAD COLLECTION EFFICIENCIES OF SELECTED CONTROL SYSTEMS

Control device	Lead collection efficiency, %
Fabric filter, 2/1 A/C	50[a]
Fabric filter, 6/1 A/C	99
Impingement and entrainment scrubber	90

[a] It is estimated that well-controlled lead oxide manufacturing facilities emit only half as much lead as one designed only for economical recovery of lead oxide. Hence only a 50 percent efficiency is stated.

Table 6-5. EFFECT OF CONTROL ALTERNATIVES ON LEAD EMISSIONS FROM VARIOUS SIZED BATTERY MANUFACTURING PLANTS

Control alternative[a]	Plant size, bpd	Lead emissions, kg/day		percent removal
		Uncontrolled	Controlled	
I	500	6.25	0.063	99.0
	2000	25.1	0.291	98.8
	6500	81.6	0.988	98.8
II	500	6.25	0.088	98.6
	2000	25.1	0.388	98.4
	6500	81.6	1.311	98.4
III	500	6.25	0.098	98.4
	2000	25.1	0.424	98.3
	6500	81.6	1.43	98.3
IV	500	6.25	0.326	94.8
	2000	25.1	1.31	94.8
	6500	81.6	4.38	94.6
V	500	6.25	0.326	94.8
	2000	25.1	1.31	94.8
	6500	81.6	4.41	94.6
VI	100	1.22	0.0122	99.0
	250	3.04	0.0304	99.0
VII	100	1.22	0.0122	99.0
	250	3.04	0.0304	99.0
VIII	100	1.22	0.0615	94.9
	250	3.04	0.1540	94.9

[a] Table 6-2 describes the selected control alternatives.

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Table 6-5A. EFFECT OF CONTROL ALTERNATIVES ON LEAD EMISSIONS FROM VARIOUS SIZED BATTERY MANUFACTURING PLANTS

(English Units)

Control alternative[a]	Plant size, bpd	Lead emissions, lb/day		percent removal
		Uncontrolled	Controlled	
I	500	13.8	0.138	99.0
	2000	55.3	0.665	98.8
	6500	180	2.18	98.8
II	500	13.8	0.193	98.6
	2000	55.3	0.885	98.4
	6500	180	2.89	98.4
III	500	13.8	0.214	98.4
	2000	55.3	0.940	98.3
	6500	180	3.15	98.3
IV	500	13.8	0.718	94.8
	2000	55.3	2.88	94.8
	6500	180	9.67	94.6
V	500	14.8	0.718	94.8
	2000	55.3	2.88	94.8
	6500	180	9.73	94.6
VI	100	2.68	0.0268	99.0
	250	6.70	0.0670	99.0
VII	100	2.68	0.0268	99.0
	250	6.70	0.0670	99.0
VIII	100	2.68	0.136	94.9
	250	6.70	0.339	94.9

[a] Table 6-2 describes the selected control alternatives.

Table 6-6. EFFECT OF CONTROL ALTERNATIVES ON LEAD EMISSIONS COMPARED WITH SIP CONTROLS

Control alternative[a]	Plant size, bpd	Lead emissions, kg/day		Percent Improvement
		SIP Controls	NSPS Controls	
I	500	3.81	0.063	98.3
	2000	15.3	0.291	98.0
	6500	49.8	0.988	98.0
II	500	3.81	0.088	97.7
	2000	15.3	0.388	97.4
	6500	49.8	1.311	97.4
III	500	3.81	0.098	97.4
	2000	15.3	0.424	97.2
	6500	49.8	1.43	97.2
IV	500	3.81	0.326	91.4
	2000	15.3	1.31	91.4
	6500	49.8	4.38	91.1
V	500	3.81	0.326	91.4
	2000	15.3	0.31	91.4
	6500	49.8	4.41	91.1
VI	100	0.76	0.0122	98.4
	250	1.90	0.0304	98.4
VII	100	0.76	0.0122	98.4
	250	1.90	0.0304	98.4
VIII	100	0.76	0.0615	91.9
	250	1.90	0.154	91.9

[a]Table 6-2 describes the selected control alternatives.

Table 6-6A. EFFECT OF CONTROL ALTERNATIVES ON LEAD EMISSIONS COMPARED WITH SIP CONTROLS

(English Units)

Control alternative[a]	Plant size, bpd	Lead emissions, lb/day		Percent Improvement
I	500	8.38	0.138	98.3
	2000	33.7	0.665	98.0
	6500	109	2.18	98.0
II	500	8.38	0.193	97.7
	2000	33.7	0.885	97.4
	6500	109	2.89	97.4
III	500	8.38	0.214	97.4
	2000	33.7	0.94	97.2
	6500	109	3.15	97.2
IV	500	8.38	0.718	91.4
	2000	33.7	2.88	91.4
	6500	109	9.67	91.1
V	500	8.38	0.718	91.4
	2000	33.7	2.88	91.4
	6500	109	9.73	91.1
VI	100	1.67	0.0268	98.4
	250	4.18	0.067	98.4
VII	100	1.67	0.0268	98.4
	250	4.18	0.067	98.4
VIII	100	1.67	0.136	91.9
	250	4.18	0.339	91.9

[a]Table 6-2 describes the selected control alternatives.

obtained by assuming 90 percent control of paste mixing and lead reclamation emissions. All of the emission rates predicted in Tables 6-5, 6-5A, 6-6, and 6-6A were calculated with the assumption that 500 bpd plants do not have lead oxide production facilities and plants smaller than 500 bpd do not have lead oxide production or lead reclamation facilities.

7.0 ENVIRONMENTAL IMPACT

The projected impacts of each alternative control system on ambient air, water quality, solid waste, energy demand, and other concerns are discussed in this chapter. These are presented in terms of incremental impacts and are compared with the impacts of uncontrolled sources and sources controlled to meet existing State regulations.

7.1 AIR POLLUTION IMPACT

7.1.1 Lead Emissions

Lead acid rates from lead-acid battery plants of various sizes are discussed in Chapter 6. The ambient impacts of these emissions, and their health impacts and national impacts, are discussed below. Existing standards which apply to lead acid battery plants are also discussed.

7.1.1.1 Ambient Impact--

A point source atmospheric dispersion model, CRSTER, was used to approximate ambient concentrations of lead around typical 500 and 6500 bpd lead acid battery plants.

The single-source CRSTER model is a steady-state, Gaussian-plume-dispersion model designed for point-source applications. It calculates pollutant concentrations for each hour of a year at 180 selected receptor sites. The hourly concentrations are averaged to obtain concentration estimates for time increments of specified length, such as one hour, 24 hours, and 1 year.

Input to the model consists of the pollutant source characteristics and a file of hour-by-hour dispersion conditions. The source characteristics

include the emission rate, stack height, stack diameter (inner), and stack-gas temperature and exit velocity. The file of hour-by-hour dispersion conditions is developed by a pre-processor program from weather observations recorded over a 1-year period. Currently, the weather data are from 1964 records.

The lead emission rates used as input to the model were based on data from the EPA test program. The 500 bpd model plant does not include a lead oxide mill or lead reclamation facility, and emissions estimated from the test data for a 6500 bpd model plant include emissions from lead reclamation, slitting, and the lead oxide mill.

Figures 7-1, 7-2, and 7-3 and Table 7-1 present the maximum impacts on ambient air of emissions from battery plants with and without NSPS controls. Emission rates used for the uncontrolled cases are those for plants controlling emissions only to the extent required by SIP particulate regulations (see Table 6-6). The emission rates used for the controlled cases are those for plants using control alternative 1 (fabric filter control of all lead emissions).

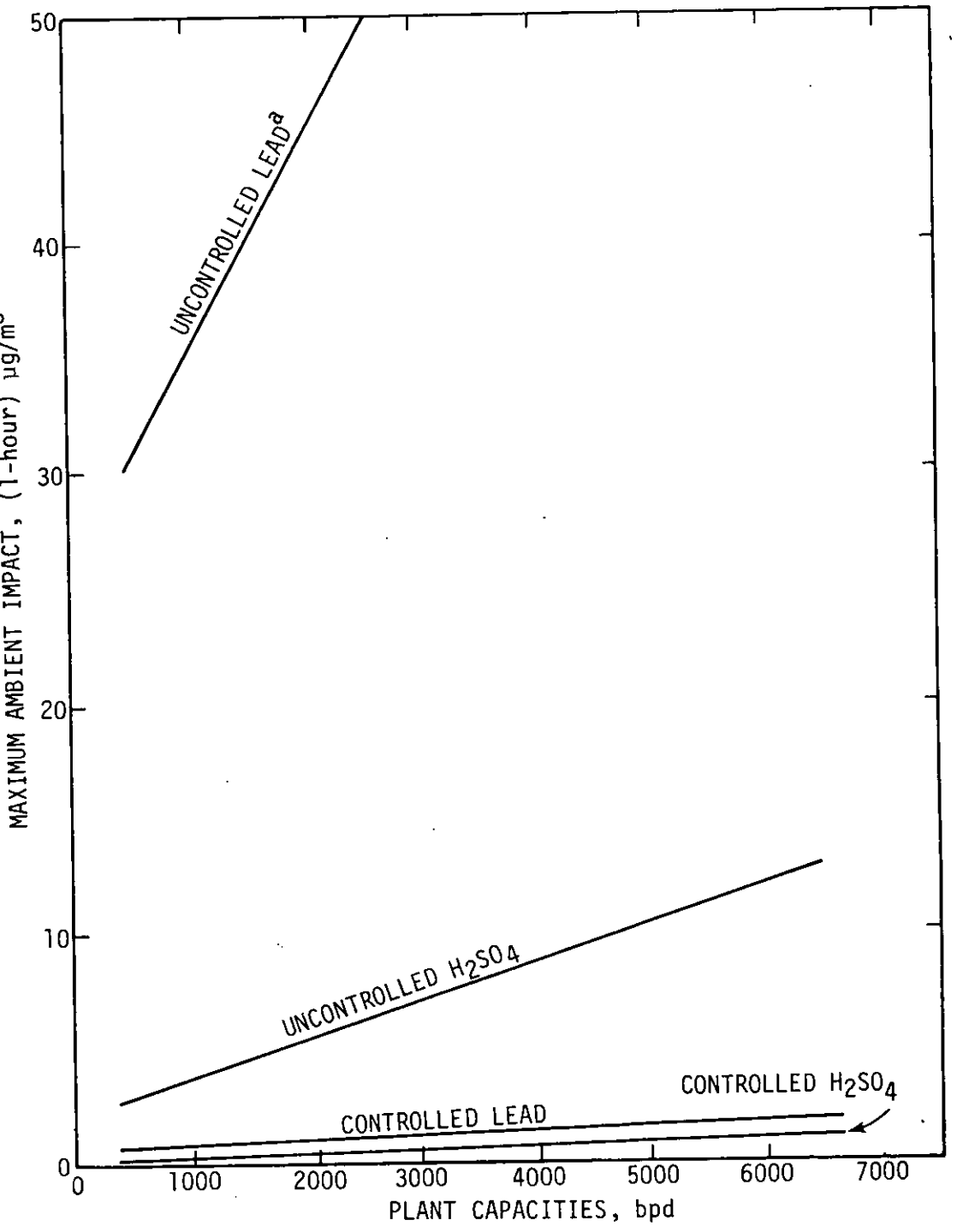
7.1.1.2 Health Effects of Lead Emissions--

Airborne lead is believed to contribute to increased lead levels in man.[2] However, it is outside the scope of this study to detail health effects. The reader is directed to the EPA document titled "Air Quality Criteria for Lead"[3] for a comprehensive discussion of the health effects of lead emissions.

7.1.1.3 Nationwide Emissions of Lead--

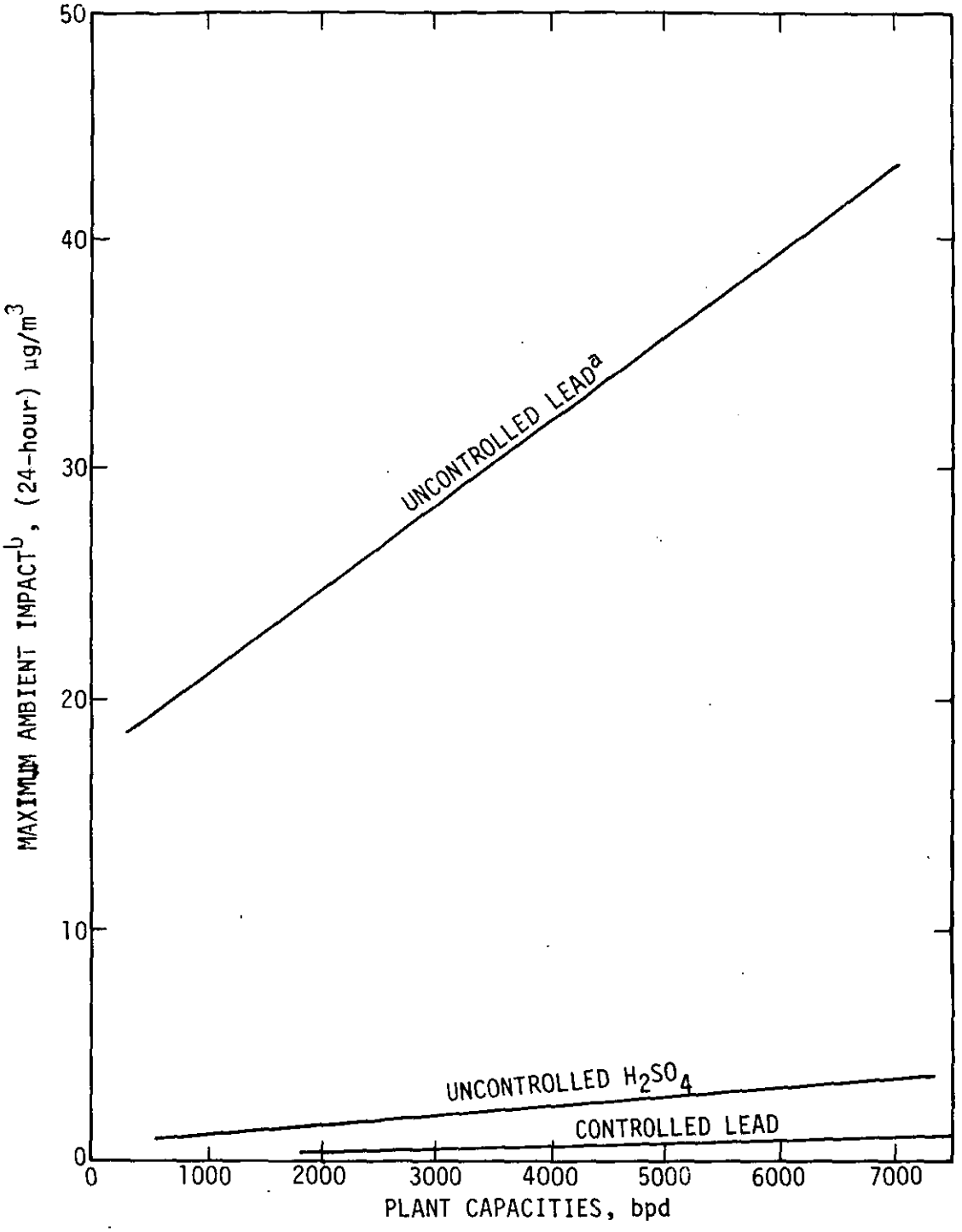
U.S. total lead consumption in 1975 was 1200 Gg (1,270,000 tons) of which 617 Gg (680,000 tons) was used in storage batteries.[4] Total

15 098



[a]Controlled only to the extent required by typical SIP regulations.

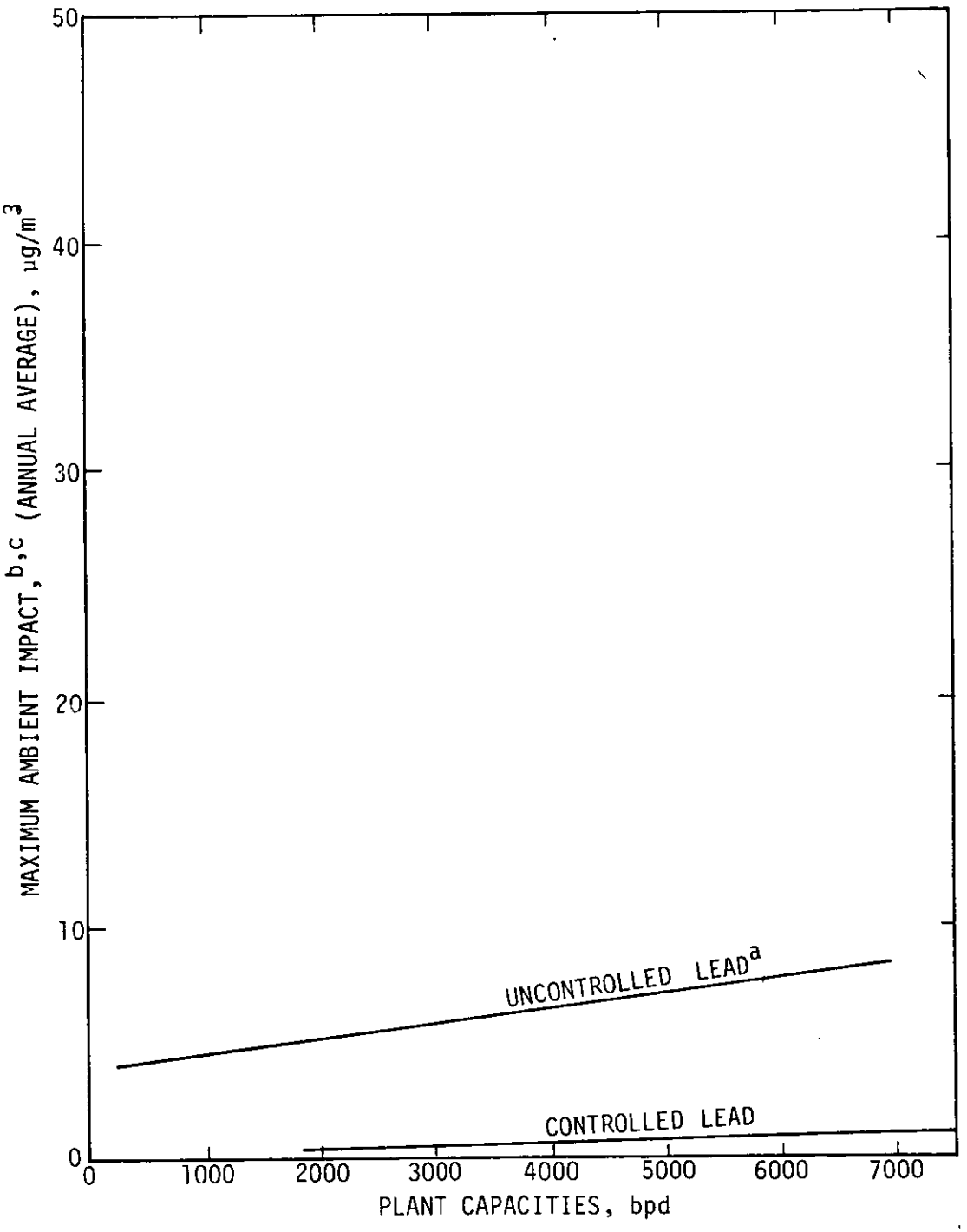
Figure 7-1. Maximum ambient impact of lead-acid battery manufacturing plants for various plant production rates - 1-hour maximum.



[a]Controlled only to the extent required by typical SIP regulations.

[b]The ambient impact of controlled acid mist emissions is less than 1 $\mu g/m^3$ and is not shown.

Figure 7-2. Maximum ambient impact of lead-acid battery manufacturing plants for various plant production rates - 24-hour maximum.



[a]Controlled only to the extent required by typical SIP regulations.

[b]The ambient impacts of both controlled and uncontrolled acid mist emissions are less than 1 $\mu g/m^3$ and are not shown.

[c]The maximum ambient impact is at 50 m from the source.

Figure 7-3. Maximum ambient impact of lead-acid battery manufacturing plants[a] for various plant production rates - Annual mean.

Table 7-1. APPROXIMATE EMISSION RATES[a] AND MAXIMUM RESULTANT GROUND-LEVEL LEAD AND SULFURIC-ACID MIST CONCENTRATIONS FOR TWO PLANT SIZES

Control status	Plant size, bpd	Lead emissions, g/sec	Sulfuric-acid mist emissions, g/sec	Averaging time	Maximum lead ambient concentrations, $\mu g/m^3$	Maximum H_2SO_4 ambient concentrations, $\mu g/m^3$
Uncontrolled[b]	500	0.13	.007	one-hour	31	3
				24-hour	19	1
				annual	4	<1
	6500	0.58	0.096	one-hour	88	13
				24-hour	41	3
				annual	8	<1
Controlled[c]	500	0.0022	0.0004	one-hour	1	<1
				24-hour	<1	<1
				annual	<1	<1
	6500	0.0114	0.005	one-hour	2	1
				24-hour	1	<1
				annual	<1	<1

[a] Data basis: EPA source test program.

[b] Subject to SIP particulate regulations on paste mixing and lead reclaim.

[c] Per control alternative 1 (see Table 6-2).

annual atmospheric emissions of lead are estimated at 194 Gg (214,000 tons),* of which approximately 82 Mg (90 tons) originate from battery manufacturing processes (See Chapter 3.0).

7.1.1.4 Current Standards for Lead--

The ambient criteria standard for lead is 1.5 mg/m^3 averaged over a calendar quarter. In Ontario, Canada, lead emissions may not impart a calculated downwind concentration of more than 10 $\mu mg/m^3$ (30 minutes) using the Pasquill-Gifford equations. Measured downwind concentrations may not exceed 5 $\mu g/m^3$ (24-hour) and 2 $\mu g/m^3$ (30-day). Montana and Pennsylvania have set ambient air standards for lead at 5 $\mu g/m^3$ (30-day). Reportedly the most stringent standard is that of the USSR, 0.7 $\mu g/m^3$, 24-hour average.

7.1.2 Sulfuric-Acid Mist Emissions

Both the wet and dry formation processes generate sulfuric acid mist. Emission data are sparse. One report indicates an emission rate of 14 kg (30 lb) of sulfuric acid (H_2SO_4) mist per 1000 batteries.[7] Another report[8] estimates an emission factor of 19 kg (42 lb) acid mist per 1000 batteries.

In wet formation, battery plates are formed in individual, preassembled battery cases. Based on plant observations, the slow rate of charging (one to four days), and the fact that there is usually a lid or cap on the assembled battery, sulfuric acid mist emissions to the atmosphere from wet formation are believed to be small.

*Estimated from Reference 5 and 6 by the following method:

$$\frac{\text{1975 lead consumption}}{\text{1970 lead consumption}} \times \text{1970 emissions} = \text{1975 lead emissions}$$

During dry formation, battery plates are formed prior to battery assembly in open vats over a shorter formation cycle (16 hours) and therefore emissions are more of a problem. Because the release of hydrogen bubbles in the formation process increases with time, emissions are greater towards the end of the cycle.

EPA tests on the dry formation process at a 6000 battery per day plant showed average uncontrolled sulfuric acid mist emissions of 66 mg/m^3 during the last 5 hours of the formation cycle (about 1.1 kg [2.4 lb] of sulfuric acid mist per 1000 batteries). Emissions of sulfuric acid mist can generally be controlled 95 to 99 percent by use of fiber mist eliminators.

7.1.2.1 Ambient Impact--

As with lead, the CRSTER model was used to approximate the ambient concentrations of sulfuric-acid mist. The emission rates used as input to the model were based on EPA test data from a dry formation process at Plant L. Figures 7-1, 7-2, and 7-3, and Table 7-1 indicate the maximum impacts on ambient air of emissions from uncontrolled and well controlled sources. It was assumed that a well controlled formation facility would be equipped with a mist eliminator that was 95 percent efficient for sulfuric acid mist collection.

7.1.2.2 Health Effects of Sulfuric-Acid Mist Emissions--

Short-term human exposure to sulfuric-acid mist can cause temporary and permanent damage to the lungs and bronchial tubes. Long-term exposure can cause skin damage, inflamation of the eyes, mouth, and stomach, and permanent tooth damage.[9,10]

7.1.2.3 Current Standards for Sulfuric Acid Mist--

Emissions of sulfuric acid mist from formation processes are generally unregulated. One State limits these emissions to 357 mg/m^3 (0.156 gr/dscf).[11] However, the concentrations of acid mist in exhausts from wet formation rooms are generally below this level.[12] Table 7-2 lists the allowable ambient air concentrations of sulfuric acid mist in several jurisdictions.

TABLE 7-2. ALLOWABLE AMBIENT AIR CONCENTRATIONS OF SULFURIC ACID MIST

Jurisdiction	Allowable concentration for various average times, $\mu g/m^3$		
	Maximum	1-hr	24-hr
Montana		30	
Missouri			10
New York	100		

7.1.3 Secondary Air Pollution Impact

All of the control alternatives described in Section 6 (see Table 6-2) would require the use of fans to drive exhaust gases through particle collection devices. These fans would require electrical energy, and, because relatively low concentrations of lead are emitted at lead-acid battery plants, the amount of energy required to collect 1 pound of pollutant would be high.

The generation of electricity results in a certain amount of air pollution, therefore, standards of performance for the lead-acid battery manufacturing industry would have a negative secondary air pollution impact. This impact can be estimated using the power requirements of

*These figures do not include energy used by of lead removed by SIP control equipment (see section 7.1.1).

emission controls and the proposed standards of performance for new, modified, and reconstructed electric utility steam generating units.[13] For each kilogram of lead collected as a result of NSPS controls (Alternate I), approximately 23 grams of NO_x, 40 grams of SO_2, and 3 grams of particulate matter would be emitted at a power plant. For each kilogram of mist collected, approximately 83 grams of NO_x, 144 grams of SO_2, and 12 grams of particulate matter would be emitted at a power plant. Thus, although there would be a negative secondary air pollution impact associated with the proposed standards, this impact would be small compared with the beneficial primary impact.

7.2 WATER POLLUTION IMPACT

Assessing the impacts of the control alternatives on water pollution requires data on uncontrolled effluent characteristics, excluding wastewater streams from air pollution control devices. The increase in pollutant loadings and discharge flow attributed to the application of wet collectors can then be determined and compared with the uncontrolled levels.

7.2.1 Effluent Characteristics

A typical lead-acid battery manufacturing plant generates approximately 250 liters (66.5 gal) of wastewater per battery manufactured.[14] This wastewater contains approximately 2 to 4 percent sulfuric acid, by weight, and less than 0.0025 percent lead by weight.[15] This water can be completely neutralized, and more than 90 percent of the lead can be removed in wastewater treatment facilities.[16]

7.2.2 Incremental Pollutant Loadings Due to Air Pollution Control Systems

The acid scrubbed from exhausts from the formation process adds to the overall burden of wastewater treatment. Essentially all of this,

however, can be neutralized to the point that, for all practical purposes, no increase in pollution results from the formation facility controls.

Incremental lead loadings to the in-plant raw wastewater from wet collection devices can be estimated by assuming 90 percent collection efficiency of the wet collectors and 90 percent removal of lead in the scrubber liquor recirculation facility. At a recirculation rate of 0.5 l/m^3 (4.0 gal/1000 acf) and 5 percent recirculation tank overflow, a total increase in hydraulic flow and the concentration can be determined and compared with the manufacturing effluent data. Tables 7-3 and 7-3A show these parameters for four of the control alternatives described in Table 6-2 as applied to a 6500 bpd plant.*

7.2.3 Summary of Water Pollution Impact

Where wet collection techniques are used to control atmospheric lead emissions, the increase in lead discharged to municipal sewage systems or surface waters is predicted to range from 0.43 to 4.6 percent, depending on the control alternative selected. The increase in flow rates into a waste treatment system is anticipated to range from 1.1 to 2.4 percent. Where fabric filtration is used to control lead emissions, there will be no impact on water emissions. Therefore, it is concluded that control of the airborne pollutants will have no significant impact on water pollution.

7.3 SOLID WASTE IMPACT

7.3.1 Sources of Waste Materials

Tables 7-4 and 7-4A show the sources, quantities, and disposition of waste materials based on production of 1000 batteries.[17] All solid

*Control alternative I does not incorporate wet control devices and therefore does not contribute to water pollution.

Table 7-3. LEAD CONTENT OF SCRUBBER BLOWDOWN AND EFFECT ON WASTEWATER SYSTEM OF A 6500-BPD PLANT (METRIC UNITS)

Control Alternative[a]	Scrubber controlled exhaust m^3/min.	effluent lead content,[b] kg/day	Scrubber blowdown			Increase in total plant effluent,%	
			Quantity,[c] lpm	Lead concentration,[d] mg/liter	Lead content,[e] kg/yr.	Flow[f]	Lead[g]
II	453	3.24	12	18.5	80	1.1	0.43
III	708	4.43	19	16.3	110	1.7	0.60
IV	977	34.2	26	90.9	854	2.4	4.6
V	977	34.2	26	90.9	854	2.4	4.6

[a] See Table 6-2.

[b] Assuming 90% collection efficiency.

[c] Assuming 540 l/m^3 recirculation rate and 5% overflow or blowdown.

[d] Directly from recirculation tank prior to final treatment.

[e] Assuming 90% efficient wet collector and 90% lead removal in recirculation tank.

[f] Based on 240 m^3 wastewater/1000 batteries (63,500 gal wastewater/1000 batteries).

[g] Based on 11.3 kg lead/1000 batteries (25 lb lead/1000 batteries).

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Table 7-3A. LEAD CONTENT OF SCRUBBER BLOWDOWN AND EFFECTS ON WASTEWATER SYSTEM OF A 6500-BPD PLANT (ENGLISH UNITS)

Control Alternative[a]	Scrubber controlled exhaust, acfm	Scrubber effluent lead content,[b] lb/day	Scrubber Blowdown			Increase in total plant effluent, %	
			Quantity,[c] gpm	Lead concentration,[d] mg/l	Lead content,[e] TPY	Flow[f]	Lead[g]
II	16,000	7.14	3.2	18.5	0.089	1.1	0.43
III	25,000	9.77	5.0	16.3	0.122	1.7	0.60
IV	34,500	75.3	6.9	90.9	0.941	2.4	4.6
V	34,500	75.3	6.9	90.9	0.941	2.4	4.6

[a] See Table 6-2 for a description of each Control Alternative; Control Alternative I is not shown since it utilizes only dry control devices and does not add to the plant's hydraulic flow.

[b] Assuming 90% collection efficiency.

[c] Assuming 4.0 gal./acf recirculation rate and 5% overflow or blowdown.

[d] Directly from recirculation tank prior to final treatment.

[e] Assuming 90% efficient wet collector and 90% lead removal in recirculation tank.

[f] Based on 63,500 gal. wastewater/1000 batteries.

[g] Based on 25 lb lead/1000 batteries.

Table 7-4. SOURCES, QUANTITIES, AND DISPOSITION OF WASTE MATERIALS (METRIC UNITS)[16]

Type of waste	Source	Quantity kg/1000 batteries	Disposition
Dusts, dross, and rejected materials	Grid manufacturing	544 kg Pb	Reclaim
Lead and lead oxide paste	Paste preparation	36 kg Pb/PbO	Reclaim
Lead and lead oxide in rise waters	Pasting area	90 kg Pb/PbO in 1% solution	Wastewater treatment
Rejected plates	Plate curing	180 kg PbO 362 kg Pb	Reclaim
Rejected assembled elements	Three-process	180 kg PbO 362 kg Pb	Reclaim
Raw wastewater solutions	Pasting area formation battery rinsing	190 m^3 2-4% H_2SO_4 6-11 kg Pb	Wastewater treatment
Sludges	Wastewater treatment	Caustic neutralization - 10 kg Lime neutralization - 13.4 Mg	Landfill
Air Contaminants	Total plant	0.4-2 kg Pb/PbO	Reclaim

Table 7-4A. SOURCES, QUANTITIES, AND DISPOSITION OF WASTE MATERIALS (ENGLISH UNITS)[16]

Type of waste	Source	Quantity lb/1000 batteries	Disposition
Dusts, dross, and rejected materials	Grid manufacturing	1200 lb Pb	Reclaim
Lead and lead oxide paste	Paste preparation	80 lb Pb/PbO in	Reclaim
Lead and lead oxide in rinse waters	Pasting area	200 lb Pb/PbO in 1% solution	Wastewater treatment
Rejected plates	Plate curing	400 lb PbO 800 lb Pb	Reclaim
Rejected assembled elements	Three-process	400 lb PbO 800 lb Pb	Reclaim
Raw wastewater solutions	Pasting area formation battery rinsing	50,000 gallons 2-4% H_2SO_4 13-25 lb Pb	Wastewater treatment
Sludges	Wastewater treatment	Caustic neutralization - 22 lb Lime neutralization 29,400 lb	Landfill
Air contaminants	Total plant	1-5 lb Pb/PbO	Reclaim

wastes excluding wastewater treatment sludges are recycled directly to the manufacturing facilities, reclaimed in the plant, or shipped to a smelter.

Wastewater streams containing lead and sulfuric acid are treated by caustic or lime neutralization facilities. Lime treatment produces very large quantities of sludge, whereas caustic neutralization generates little solid waste. Caustic treatment is more costly than lime neutralization.

7.3.2 Waste Characterization

This discussion concerns only the waste generated by manufacturing processes and does not consider nonprocess waste generated in the form of rubbish.

7.3.2.1 Lead Items--

Defective lead parts such as grids, posts, and connectors are returned to the grid-casting lead pots or the small-parts lead pot. Plates are either sent to a smelter or separated by a tumbler into paste and grids. In the latter case, the paste is frequently used as an ingredient in the paste mixer and the grids are remelted in the reclamation furnace.

7.3.2.2 Separators--

Rejected separators may be used as spacers or shims in blocking the element in the container. Generally, separators that have become saturated with sulfuric acid must be discarded. This disposal accounts for very little solid waste, however.

7.3.2.3 Containers and Covers--

The current trend is toward polypropylene containers and covers, although some manufacturers still use rubber. Defective containers must be discarded. Polypropylene containers can be used as fuel in lead

blast furnaces and therefore are often sent to a smelter. Some plants send cases to the manufacturer for recycling. In short, defective polypropylene cases do not enter the solid waste stream.

Rubber containers can break rather easily if dropped. Broken containers must be discarded, since they are not useful as fuel nor can they be recycled. Defective covers usually contain lead bushings, which are separated from the covers and sent to a smelter. Scrapped rubber containers and covers are treated as rubbish and are generally landfilled.

7.3.2.4 Finished Batteries--

Batteries that are found to be defective when they are partially or fully assembled are sent to a smelter for recycling. They do not enter the solid waste stream at the battery manufacturing facility.

7.3.2.5 Paste--

Positive paste that becomes contaminated must be discarded or used as an ingredient for negative paste. If the paste becomes hard or lumpy, it cannot be softened and must be discarded. This paste is sent to a smelter for refining.

7.3.2.6 Sulfuric Acid--

If sulfuric acid is discharged from a plant and is neutralized with lime, solid waste is generated at the effluent treatment facility. Well-managed operations seldom discard sulfuric acid. The acid dumped from wet charged batteries after the formation process is used in place of water to make acid of higher specific gravity, which is used for the final fill of the batteries. Thus the "used" acid is actually shipped out in the wet batteries.

7.3.2.7 Sludge--

Virtually all the process-related solid waste results from the treatment of battery plant effluent, which results from acid leakage and

spillage, washing and rinsing of dry battery elements, and housekeeping (hosing the floors). A typical plant generates approximately 250 liters (66.4 gallons) of wastewater per battery produced.[18] This effluent is neutralized by treatment with lime or caustic soda. The former produces large amounts of sludge, approximately 13 Mg (15 tons) per 1000 batteries manufactured.[19] Caustic soda treatment produces less than 11.3 kg (25 lb) of sludge per 1000 batteries manufactured. Regardless of the neutralization method, the sludge contains approximately 2.5 kg (5.6 lb) $Pb(OH)_2$ and 5.3 kg (11.7 lb) $PBSO_4$ per 1000 batteries manufactured. Table 7-5 summarizes the process solid wastes generated at various-sized lead-acid battery manufacturing facilities.

TABLE 7-5. ESTIMATED DAILY PROCESS SOLID WASTES GENERATED AT LEAD-ACID BATTERY MANUFACTURING FACILITIES

	Plant size, bpd		
Type of waste	500	2000	6500
Sludge (lime treatment), Mg (tons)	6.5 (7.5)	26 (30)	84.5 (97.5)
Sludge (caustic soda treatment), kg (lb)	5.5 (12)	22 (48)	73 (160)
$Pb(OH)_2$, kg (lb)	1.3 (2.8)	5.0 (11.2)	16.5 (36.4)
$PbSO_4$, kg (lb)	2.6 (5.8)	10.6 (23.4)	34.5 (76.1)

7.3.3 Incremental Solid Waste Impact

The increase in solid waste production due to increase emissions control will be slight. The largest increase is in sludge generated by lime treatment of the blowdown from the formation facility control system. Smaller increases are due to collection of air pollutants at

the power plant that generates electricity to power the battery plant's control devices.

The amount of sludge produced at the lime wastewater treatment facility is proportional to the amount of sulfuric acid neutralized. Most plants can reuse the acid collected by mist eliminators used to control emissions from the formation process. If the acid mist is diluted or contaminated, however, it must be discharged through the waste treatment system. An addition of 94 kg/day (208 lb/day) of acid mist from a wet collector controlling the formation operation at a 6500 bpd plant will produce an additional 14.5 kg (32 lb) of sludge per day. Therefore, the increase in solid waste expected from waste treatment sludge is only 0.15 percent.

Wastewater streams from other air pollution control devices will not increase the volume or change the composition of the sludge. Also, sludge production will be insignificant at a 6500 bpd plant that uses caustic to treat effluents from the formation process.

The solid wastes from dry collection of lead air pollutants are sent to in-plant or outside reclamation furnaces or smelters for lead recovery. These wastes are collected at the rate of 13.4 to 25 kg (29.6 to 54.8 lb) of lead per 1000 batteries produced, depending upon the control alternative applied.

Additional solid wastes resulting from generation of electricity for the control systems can be as much as 9.1 Mg (10 tons) per year for a coal-burning plant with sulfur oxides controls.

Table 7-6 summarizes the maximum solid waste impacts due to the NSPS. These figures are based on a battery plant using control alternative

I (see Table 6-2) and served by a coal-fired utility. The data indicate that solid waste production will not increase by more than 0.5 percent.

TABLE 7-6. POTENTIAL SOLID WASTE IMPACTS OF A BATTERY PLANT USING CONTROL ALTERNATIVE I

Source	Quantity Mg/yr per 1000 bpd (TPY/1000 bpd) capacity Uncontrolled	Increase with controls	Disposition
Waste treatment (lime)	3360 (3700)	5.0 (5.5)	landfill
Air pollution control (fabric filter)	0	6.3 (6.9)	recovery
Power plant	0	4.5 (5.0)	landfill
Total	3360 (3700)	15.8 (17.4)	

7.4 ENERGY IMPACTS

Any of the alternative control systems installed to comply with a new source performance standard will require electricity. The major portion of the electrical energy is needed to operate the fans installed to overcome the pressure drop across the control systems. Lesser amounts of electrical energy are needed for motors that operate the pumps in scrubber control devices and the shaking mechanisms in fabric filters. The additional fan energy requirements for the control systems described in Chapter 6.0 are reitterated (from section 7.1.3) below:

Plant Size (bpd)	Power Requirements (MWhr/yr) Lead Controls	Acid Mist Controls
100	17	7.5
250	17	7.5
500	28	9.6
2000	80	40
6500	252	129

These requirements are based on pressure drops of 1245 kPa (5 in. W.G.) for lead emission control equipment, and 620 kPa (2.5 in. W.G.) for reclaimation emission controls are not included since existing state regulations (SIP's) require control of these emissions. Also, energy requirements to overcome duct pressure drops are not included, since ducting to ventialte process exhausts is required to meet OSHA standards. Finally, the above figures do not include energy requirements of lead oxide manufacture emission controls, because such controls are required for product recovery.

Tables 7-7 and 7-7A compare the eneagy requirements (in terms of cal's and Btu's respectively) for 100, 250, 500, 2000, 6500 bpd plants for the four following entities: process; exhaust; SIP control; NSPS lead control; and NSPS acid mist control. Process energy demands are based on reported total plant energy requirements of various sized battery plants less estimated energy requirements for exhaust, SIP control, and NSPS control. Exhaust energy demands were estimated using typical exhaust rates and assuming an average 620 kPa (2.5 in. W.G.) ductwork pressure drop for all process exhaust streams. Energy demands for SIP control are based on a 1245 kPa (5 in. W.G.) pressure drop. Energy requirements for product recovery equipment for lead oxide manufacturing processes are considered process energy. Finally, all demands for electrical energy (fan requirements) are expressed in terms of the amount of thermal energy required to generate the needed electricity (assuming a power plant efficiency of 34 percent).

Projections for 1985 lead-acid battery industry-wide energy usage were made by assuming that energy demands will increase at the same rate as

TABLE 7-7. ENERGY REQUIREMENTS FOR LEAD ACID BATTERY MANUFACTURING PLANTS AND EMISSION CONTROL EQUIPMENT (METRIC UNITS)

Plant size, bpd	Manufacturing processes		Process and plant exhaust		SIP controls		NSPS Lead controls[a]		NSPS Acid Mist controls	
	Gcal/yr	Equivalent oil, kl/yr	Gcal/yr	Equivalent oil, kl/yr	Gcal/yr	Equivalent oil, kl/yr	Gcal/yr	Equivalent oil, kl/yr	Gcal/yr	Equivalent oil, kl/yr
100	1,680	167	45.2	4.55	4.1	0.41	43	4.73	19.0	2.09
250	4,200	416	45.2	4.55	4.1	0.41	43	4.73	19.0	2.09
500	8,400	833	63.4	6.36	33.0	3.29	69.9	7.10	24.0	2.44
2000	13.200	1,310	193	19.1	81.2	7.95	203	20.1	101	10.1
6500	27,900	2,780	584	58.3	198	19.6	638	32.3	326	32.3

[a]Excludes energy required for SIP controls.

TABLE 7-7A. ENERGY REQUIREMENTS FOR LEAD ACID BATTERY MANUFACTURING PLANTS AND EMISSION CONTROL EQUIPMENT (ENGLISH UNITS)

Plant size, bpd	Manufacturing processes		Process and plant exhaust		SIP controls		NSPS Lead controls[a]		NSPS Acid Mist controls	
	10^9 Btu/yr	Equivalent oil, 1000 ga/yr	10^9 Btu/yr	Equivalent oil, 1000 gal/yr	10^9 Btu/yr	Equivalent oil, 1000 gal/yr	10^9 Btu/yr	Equivalent oil, 1000 gal/yr	10^9 Btu/yr	Equivalent oil, 1000 gal/yr
100	6.6	180	0.18	1.20	0.02	0.11	0.18	1.25	0.08	0.55
250	16.5	190	0.18	1.20	0.02	0.11	0.18	1.25	0.08	0.55
500	33	220	0.25	1.68	0.13	0.87	0.24	1.66	0.13	0.86
2000	52	347	0.76	5.04	0.32	2.10	0.80	5.32	0.40	2.66
6500	110	734	2.30	15.4	0.78	5.18	2.5	16.7	1.3	8.53

[a]Excludes energy required for SIP controls.

industry manufacturing capacity (i.e., 40 percent from 1975 to 1985). This would mean that the 1975 estimated industry energy requirements 1.2 Pcal/yr (4.8 trillion Btu/yr) or 0.21 Tg or coal or 0.12 Gl of residual oil (0.23 million tons of coal or 0.76 million barrels of residual oil) will increase to 1.7 Pcal/yr (6.7 trillion Btu/yr) by 1985. Energy which would be required to meet New Source Performance Standards represents about 3.2 percent of this figure, or 52 Tcal/yr (210 million Btu/yr). Approximately 35 Tcal/yr (140 million Btu/yr would be needed to control lead emissions while 17 Tcal/yr (70 million Btu/yr) would be needed to control acid mist emissions. Note that each control alternative has the same energy demand and the various control alternatives do not effect makeup air. The NSPS energy requirements are in addition to energy demands for the process exhaust and SIP control.

7.5 OTHER ENVIRONMENTAL IMPACTS

Application of a control system could cause no significant increase in noise, heat, or static electrical energy. None of the eight plants visited in this study reported problems regarding these environmental hazards.

7.6 OTHER ENVIRONMENTAL CONCERNS

7.6.1 Irreversible and Irretrievable Commitment of Resources

Increased emission control of the battery industry would result in a trade off of environmental gains at the expense of energy losses. All the control devices required to bring battery manufacturing facilities into compliance with increased emissions control requirements must be powered by electrical energy. These power requirements result in an irretrievable commitment of coal, oil, natural gas, or nuclear fuel as

an energy source for power plants. Section 7.4 discusses the energy penalties associated with lead-acid battery plant control strategies.

7.6.2 Environmental Impact of Delayed Standards

Delay in setting of standards will allow the construction of new battery facilities without controls. Manufacturers may, however, in anticipation of SIP regulations for lead, install control equipment on both new and existing facilities.

At present, most state regulations do not specifically regulate lead-acid battery facilities. A few states have standards regulating lead-bearing particulates from secondary nonferrous operations. Other states have ambient air standards for sulfuric acid, and one state specifically limits emissions of sulfuric acid from the stack.[20] Concentrations of sulfuric acid in formation exhausts are too low to require controls under the regulations of that state.

A delay of one year in the adoption of the NSPS will result in the nationwide emission of approximately 4 Mg (4.4 tons) of lead over and above that permitted by anticipated SIP regulations.

A delay in promulgation of a New Source Performance Standard for sulfuric acid mist may cause only a slight increase in uncontrolled acid mist emissions, since many new installations tend to control exhausts from dry formation processes.

7.6.3 Environmental Impact of No Standard

As mentioned earlier, most states do not now regulate emissions of lead or sulfuric acid from lead-acid battery manufacturing facilities. In the absence of SIP regulations, "no standard" would cause lead and sulfuric acid mist emissions from these plants to increase as lead-acid

battery production increases. Also, the increased process venting requirements, due to the recently established OSHA lead-in-air standard of 50 $\mu g/m^3$, may increase lead emissions to the atmosphere. However, with the promulgation of a lead ambient air quality standard, the increase in lead emissions would be less severe.

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8.0 ECONOMIC IMPACTS

8.1 INDUSTRY ECONOMIC PROFILE

8.1.1 Introduction

The lead-acid storage battery industry is the largest single consumer of lead in the United States. In 1977, the industry accounted for approximately 945,000 short tons of lead, which is 59.7 percent of the total 1,582,000 short tons of lead consumed domestically.[1] Total U.S. lead supplies in 1977 originated from imports (14.4%), secondary production (44.7%), refinery production (32.8%) and inventory (8.0%).[2]

Traditionally, lead-acid batteries account for 90 percent of total storage battery sales. Because of the flourishing activity in the U.S., some foreign concerns are attempting to penetrate the market. Britain's Chloride group and France's SAFT have purchased a few small U.S. battery makers, and Germany's leading battery producer, Varta AG, is moving into Canada and looking toward entrance into the U.S. market.

8.1.2 Number, Size of Plants and Regional Distribution

The industry in this country is dominated by six companies. Table 8.2 indicates that these six manufacturers hold over 70 percent of the market, the top four accounting for 60 percent of industry sales.[3,4]

There are approximately 190 lead-acid battery plants in

Table 8.1

CONSUMPTION OF LEAD IN THE UNITED STATES

BY PRODUCT[1]

(in thousand short tons)

1977

	Amount	Percentage
Metal Products		
Ammunition	68.3	4.3%
Brass and Bronze	16.7	1.1
Cable Covering	15.1	1.0
Sheet Lead	16.7	1.1
Solder	64.3	4.1
Storage Battery Grids, etc.	459.3	29.0
Storage Battery Oxide	486.5	30.8
Other	59.1	3.7
Pigments		
White Lead	6.6	.4
Red Lead and Litharge	78.0	4.9
Pigment Colors	14.7	.9
Other	.6	.04
Chemicals		
Gasoline Antiknock Additives	232.9	14.7
Miscellaneous Chemicals	.1	-
Miscellaneous Uses		
Annealing	2.7	.2
Galvanizing	1.4	.09
Lead-plating	.5	.03
Weights and Ballast	19.1	1.2
Other Uses Unclassified	39.5	2.5
Total	1,582.1	100.0*

*Does not add to 100 because of rounding.

Table 8.2

LEADING DOMESTIC STORAGE BATTERY MANUFACTURERS[3]

Parent Co./Address	Branch Plant Location	Estimated 1974 sales million, $	Share of U.S. Market %
ESB, Inc. Philadelphia, Pa.	Los Angeles, Calif. Milipitas, Calif. Woodland, Calif. Denver, Colo. Fairfield, Conn. Atlanta, Ga. Warsaw, Ill. Logansport, Ind. Burlington, Iowa Minneapolis, Minn. Kansas City, Mo. Omaha, Neb. Buffalo, N.Y. Cheektowaga, N.Y. Raleigh, N.C. (2 plants) Allentown, Pa. Philadelphia, Pa. Sumter, S.C. Memphis, Tenn. Dallas, Tex. Racine, Wisc.	241.3	21.0
General Motors Corp. Delco-Remy Div. Detroit, Mich.	Anaheim, Calif. Muncie, Ind. Olathe, Kan. New Brunswick, N.J. Fitzgerald, Ga.	204.6	17.8
Gould, Inc. Chicago, Ill.	City of Industry, Cal. Orlando, Fla. Kankakee, Ill. Leavenworth, Kan. Howell, Mo. St. Paul, Minn. (3 locations) Trenton, N.J. Zanesville, Ohio Salem, Ore. Memphis, Tenn. Dallas, Tex. Lynchburg, Va.	151.1	13.1

Table 8.2 Continued

Parent Co./Address	Branch Plant Location	Estimated 1974 sales million, $	Share of U.S. Market %
Globe-Union, Inc. Milwaukee, Wisc.	Fullerton, Calif. Middletown, Del. Tampa, Fla. St. Joe, Mo. Atlanta, Ga. Geneva, Ill. Louisville, Ky. Owosso, Mo. Oregon City, Ore. Candy, Ore. Garland, Tex. N. Bennington, Vt.	82.0	7.4
Northwest Industries, Inc. General Battery Div. Chicago, Ill.	Selma, Ala. Stratford, Conn. Salina, Kansas Frankfort, Ind. Portland, Ore. Reading, Pa. Toledo, Ohio Greer, S.C. Dallas, Tex. Hamburg, Pa. Laureldale, Pa.	78.5	6.8
Eltra Corp. New York, N.Y.	Attica, Ind. Brookston, Ind. Vincennes, Ind. Oklahoma City, Okla. Reading, Pa. Laureldale, Pa. Temple, Pa. East Point, Ga. Manchester, Iowa	62.1	5.4

the U.S., of which about 91 have been estimated to be small plants* (less than 500 bpd).[5] These 190 plants are scattered throughout the country and are generally located in highly urbanized areas near the market for their batteries. Figure 8-1 shows the regional distribution of these 190 plants.

Of the approximately 91 small plants, 31 are classified as assemblers. As will be considered in section 8.4.4, assemblers purchase all of the materials and parts that are required for a battery and assemble these parts into a finished battery. They generally perform all of the functions of the small manufacturer except grid casting and pasting. The impact of the sulfuric acid mist control and lead NSPS control cost on these small manufacturers and assemblers will be shown in section 8.4.4.

Small manufacturers and assemblers are generally one-plant operations, though some manufacturers and assemblers may have warehouse space in locations other than their plant. Therefore, for the 91 small plants there are approximately 91 firms. Direct delivery to client accounts is generally the rule as this is a most profitable distribution pattern for the plants.

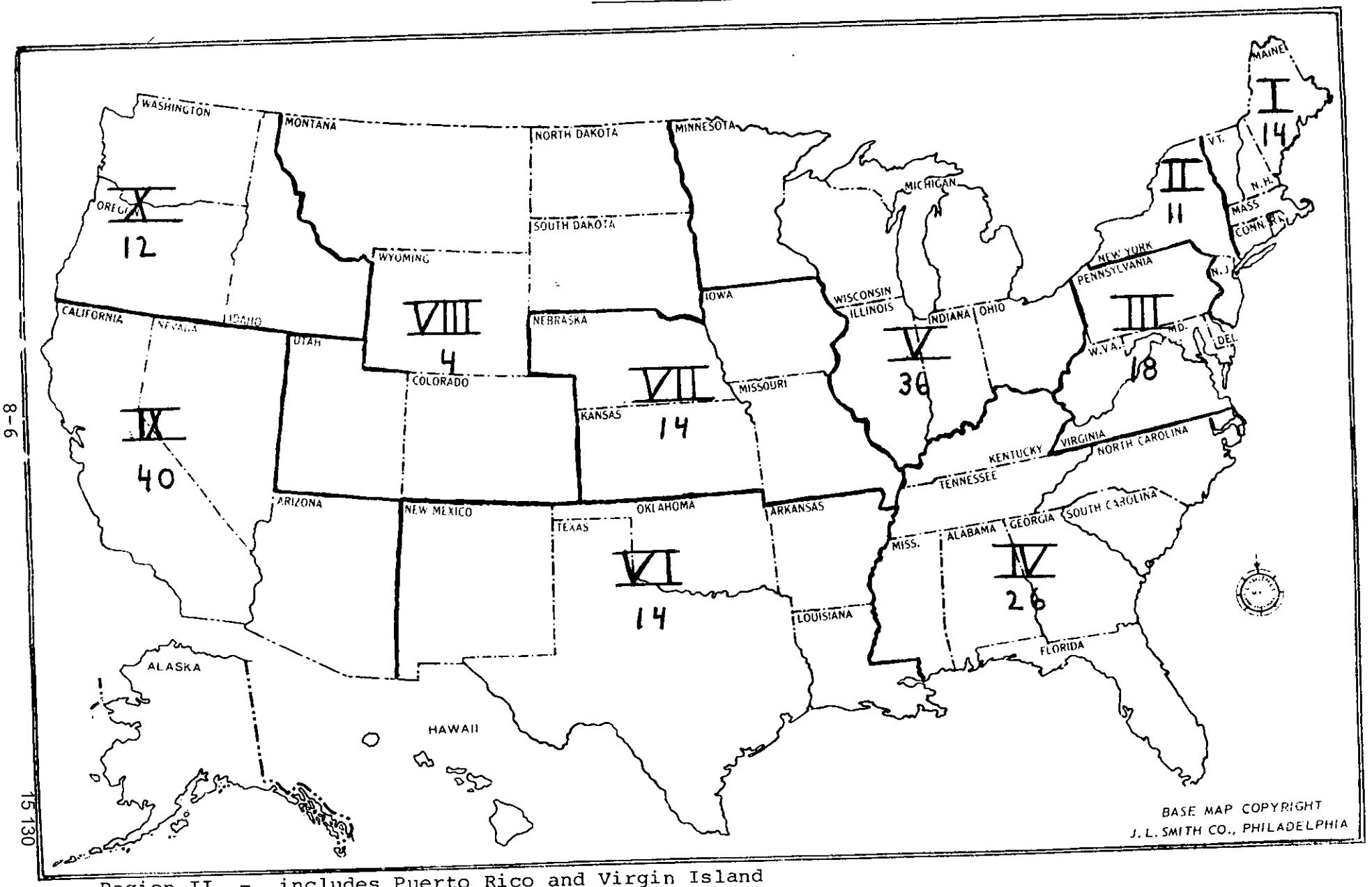
As was seen in section 3.5, battery manufacturing can be distinguished by the formation process - wet or dry formation. No information is available on the number of plants forming wet versus dry or a combination of wet/dry. The

*Excluding small plants of the larger multiplant companies.

Figure 8-1

REGIONAL DISTRIBUTION OF LEAD-ACID BATTERY PLANTS

EPA REGIONS



Region II - includes Puerto Rico and Virgin Island
Region IX - includes Hawaii
Region X - includes Alaska

15 130

large plants probably have dry formation capability if they are selling to retail markets, since dry forming increases the shelf life of a battery. Small plants generally specialize in wet formation; if any dry formation is performed, it is usually a small portion of their total battery production.

Employment in the industry is approximately 19,000 people.[6] Since a 500 BPD plant would generally employ 20-25 people and a 100 BPD plant about 5 or 6 people, small plant employment accounts for about 1300 of the total, based on an average of 15 people per small plant.

8.1.3 Markets

The market for lead-acid storage batteries is composed of two segments. The first and largest segment consists of replacement batteries for automobiles, trucks and buses, heavy equipment, recreational vehicles, farm machinery, and other vehicles. The replacement market accounted for 78.8 percent of industry sales in 1977. The second largest market, holding 21.2 percent of sales, is the original equipment market, consisting of batteries sold to producers of new cars, new trucks, and other new products. Table 8-3 summarizes shipments to these markets for the past 10 years.

The industry as a whole has enjoyed an average growth rate of 4.9 percent per year between 1968 and 1977. In 1974 and 1975 the economic recession caused a slowdown in sales and production of new vehicles and therefore in battery sales.

Except for a decline in 1975, replacement battery shipments

Table 8.3

BATTERY SHIPMENTS BY DOMESTIC PRODUCERS[7]

Year	Replacement Batteries		Original Equipment		Exports		Total Units, (thousands)
	Units, (thousands)	Share of Market, %	Units, (thousands)	Share of Market, %	Units, (thousands)	Share of Market, %	
1968	33793	75.2	10718	23.8	456	1.0	44967
1969	35510	76.5	10147	21.9	760	1.6	46417
1970	37863	80.7	8239	17.6	819	1.7	46921
1971	39143	77.2	10673	21.0	928	1.8	50708
1972	43220	77.9	11270	20.3	983	1.8	55473
1973	43453	76.1	12637	22.1	1017	1.8	57107
1974	44408	81.5	10058	18.5	a	a	54466[b]
1975	42582	82.5	8985	17.5	a	a	51567[b]
1976	49203	78.6	13365	21.4	a	a	62568[b]
1977	54601	78.7	14718	21.3	a	a	69319[b]

[a]Export figures not available.
[b]Does not include exports.

have increased each year of this 10-year span at an average rate of 5.5 percent a year. Original equipment battery shipments have been volatile but have increased at an average rate of 3.6 percent per year.

According to Globe-Union, the replacement market will continue to be strong. With more than 50 million vehicles entering the automobile aftermarket by 1990, the number of battery units should reach more than 285 million. Replacement battery shipments should reach 62.5 to 63.5 million units in 1982, an increase of approximately 25 percent over the 1977 level. Table 8-4 shows a forecast for replacement battery shipments for the years 1978 to 1982. Growth areas for the industry lie in trucks and commercial vehicles, both for original equipment and replacement batteries. Another source with potential for further market penetration lies in recreational vehicles, such as motorcycles, snowmobiles, golf carts, and motor boats. Globe-Union reports that this market accounted for $50 million in sales in 1970, and estimates that by 1985 the recreational market may account for over $200 million.[8]

Table 8.4

REPLACEMENT BATTERY SHIPMENTS[9]

(In Millions)

Year	Number of Units	Percent Change From Previous Year
1978	57.3	-
1979	58.3	1.7%
1980	57.7	-1.1
1981	59.2	2.6
1982	63.0	6.4

8.1.4 Distribution

Distribution of batteries by any plant usually takes place in a limited geographical area. Because the weight of lead-acid storage batteries is high relative to shipment value, transportation cost is high and significant cost savings accrue from geographical location adjacent to markets. It is generally economically inefficient to ship beyond a 250 to 300 mile radius. If a company wants national distribution of its product, plants have to be located in regional markets. Proximity to markets appears to be a key to the economic viability of many small producers, whose unit manufacturing costs and F.O.B. plant prices are significantly higher than those of larger companies.

The large producers are distributing primarily to the large original equipment markets (OEM) such as the automobile companies, and large retail accounts such as Sears, Roebuck, and Co. and J.C. Penney. Warehouse distribution of their batteries to smaller accounts is also made. Smaller firms sell primarily to fleet accounts such as local cab companies, government and business firms, local gas stations, discount stores, and the like.

The marketing chain for batteries is primarily from battery producer to warehouse to jobber to retailer, although individual links in the chain are often bypassed. This is particularly true of the smaller producer who is selling to fleet accounts. Deliveries to these accounts are made in company-owned trucks because it is more profitable to deliver directly.

In this way the small firm can accrue the markup which would have been applied by the intermediaries to the final buyer. These markups vary by 20 to 65% from the warehouse price depending on the client account.[10]

Competition between the large and small producer for some client accounts exists through local warehouse distribution of the larger company's battery to clients in the smaller producer's market. The smaller producer, however, offers additional services such as faster delivery time, personalized service, better credit arrangements, and pick-up of small quantities of junk batteries from customers.

No alternative source can provide energy for a cost comparable to that provided by the lead-acid storage battery in its automobile application. This cost efficiency tends to be true for other uses of SLI batteries such as golf carts and snowmobiles. Potential substitutes, such as the nickel-cadmium, nickel-zinc, nickel-iron, silver-zinc and silver-cadmium batteries, cost from three to five times as much as lead-acid batteries.

8.1.5 Imports

Imports and exports of storage batteries are, in general, associated with the imports and exports of automobiles. The high transport costs associated with storage batteries make competitive pressure from foreign manufacturers a neglibile factor in response to battery price movements.

8.2 COST ANALYSIS OF ALTERNATIVE CONTROL SYSTEMS

The approach to determining the costs associated with the alternative control systems involved three steps: 1) selecting five representative model plants; 2) applying the selected five control alternatives for lead and the sulfuric acid mist control system as discussed in Chapter 6; and 3) determining the total control costs based upon each strategy and typical exhaust volumes. This three-step procedure is applied to both new and modified plants. The results of this analysis are used in determining economic impacts of the alternative systems in Section 8.4. (The listing of eight control alternatives, as shown in Table 6-2, is repeated for convenient reference as Table 8-6).

Of the approximately 200 battery manufacturing plants in the United States, nearly 50 percent manufacture less than 500 units per day and 30 percent manufacture between 500 and 6500 units per day.* Based on these statistics, the following model plant sizes were selected: small - 100, 250, and 500 bpd; medium - 2000 bpd; and large - 6500 bpd. Typical parameters for uncontrolled exhaust from the facilities within these model plants are given in Tables 8-7 and 8-7A. These parameters were estimated from data obtained from plant representatives, design calculations, and various reports of source tests.

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* Based on employment data obtained from Reference 25 and assuming output at 25 batteries per man-day.

Table 8-6. SELECTED CONTROL ALTERNATIVES FOR LEAD-ACID BATTERY MANUFACTURING INDUSTRY

Control alternative	Facilities[a]	Control system[b]
I	A, B, F	Fabric filter, 6/1 A/C
	C, E	Fabric filter, 6/1 A/C
	G	Mist eliminator
	D	Fabric filter, 2/1 A/C
II	B, C, E	Fabric filter, 6/1 A/C
	F	Impingement and entrainment scrubber
	A	Impingement and entrainment scrubber
	G	Mist eliminator
	D	Fabric filter, 2/1 A/C[c]
III	C, E	Fabric filter, 6/1 A/C
	A, B, F	Impingement and entrainment scrubber
	G	Mist eliminator
	D	Fabric filter, 2/1 A/C
IV	A, B, C	Impingement and entrainment scrubber
	E	Fabric filter 6/1 A/C
	F	Impingement and entrainment scrubber
	G	Mist eliminator
	D	Fabric filter, 2/1 A/C[c]
V	A, B, C, F	Impingement and entrainment scrubber
	E	Fabric filter, 6/1 A/C
	G	Mist eliminator
	D	Fabric filter, 2/1 A/C[c]
VI	A, B, C	Fabric filter, 6/1 A/C
	E	Fabric filter, 6/1 A/C
	G	Mist eliminator
VII	A, B, C, E	Fabric filter, 6/1 A/C
	G	Mist eliminator
VIII	A, B, C	Impingement and entrainment scrubber
	E	Fabric filter, 6/1 A/C
	G	Mist eliminator

[a] Facilities key: A - Grid casting furnace; B - Grid casting machines; C - Paste mixer; D - Lead oxide manufacturing; E - Three process operation and assembly; F - Lead reclaim furnace; G - Formation.

[b] All facilities are vented to common control systems as shown.

[c] Small (≦ 500 bpd) plants are assumed to have no PbO manufacturing facilities.

Table 8-7. TYPICAL UNCONTROLLED EXHAUST PARAMETERS FOR BATTERY MANUFACTURING FACILITIES[a] (METRIC UNITS)

Facility code letter	Facility	Temperature, °C	Moisture, %	Total particulate loading, mg/m^3	Volume by plant size, m^3/min				
					100 bpd	250 bpd	500 bpd	2000 bpd	6500 bpd
A	Grid casting furnace[b]	115	2-3	<23	27.5	27.5	33.7	57.0	127
B	Grid casting machine[b]	38	2-3	<23	27.5	27.5	33.7	57.0	127
C	Paste mixer	38	2-4	137	62.0	62.0	67.9	89.5	154
D	Lead oxide manufacturing	115	2-3	21[d]	c	c	c	87.2	216
E	Three-process operation	27	1-2	46	403	403	472	733	1517
F	Lead reclaim furnace	115	2-3	>229	f	f	198	198	198
G	Formation	27	N.A.	4000[e]	75.3	177	347	1366	4020

[a] Based on exhaust data obtained from industry responses to EPA's inquiries (Section 114 Letters), design calculations and source test reports.

[b] The grid casting facility consists of a furnace and a machine. Sometimes these elements are separate, as where one furnace feeds many casting machines.

[c] For purposes of this study, it is assumed that plants making only 500 bpd or less have no PbO manufacturing facilities.

[d] Measured at outlet of baghouse, which is part of the process.

[e] Test data from outlet of fan separator tested at Plant G indicated <10 ppm H_2SO_4 (<38.9 mg/m^3); assuming control device was 99 percent efficient, uncontrolled emission approximates 4000 mg/m^3.

[f] It is assumed for the purposes of this study that plants making <500 bpd have no lead reclaim furnace.

Table 8-7A. TYPICAL UNCONTROLLED EXHAUST PARAMETERS FOR BATTERY MANUFACTURING FACILITIES[a] (ENGLISH UNITS)

Facility code letter	Facility	Temperature, °F	Moisture, %	Total particulate loading, gr/dscf	Volume by plant size, acfm				
					100 bpd	250 bpd	500 bpd	2000 bpd	6500 bpd
A	Grid casting furnace[b]	240	2-3	<0.01	970	1050	1190	2015	4470
B	Grid casting machine[b]	100	2-3	<0.01	970	1050	1190	2015	4470
C	Paste mixer	100	2-4	0.06	2190	2270	2400	3160	5460
D	Lead oxide manufacturing	240	2-3	0.009[d]	c	c	c	3080	7630
E	Three-process operation	80	1-2	0.02	14220	15140	16680	25900	53600
F	Lead reclaim furnace	240	2-3	>0.10	f	f	7,000	7,000	7,000
G	Formation	80	N.A.	1.6[e]	2660	6260	12260	48300	142000

[a] Based on exhaust data obtained from industry responses to EPA's inquiries (Section 114 Letters), design calculations and source test reports.

[b] The grid casting facility consists of a furnace and a machine. Sometimes these elements are separate, as where one furnace feeds many casting machines.

[c] For purposes of this study, it is assumed that plants making only 500 bpd or less have no PbO manufacturing facilities.

[d] Measured at outlet of baghouse, which is part of the process.

[e] Test data from outlet of fan separator tested at Plant G indicated <10 ppm H_2SO_4 (<0.017 gr/dscf); assuming control device was 99 percent efficient, uncontrolled emission approximates 1.6 gr/dscf.

[f] For purposes of this study, it is assumed that plants making less than 500 batteries per day have no lead reclaim furnace.

Uncontrolled lead emissions based on data obtained from tests performed in this study are shown in Table 8-8. Typical uncontrolled emissions of lead from the grid-casting, three-process operation, and lead oxide manufacturing facilities are less than 0.5 kg/metric ton (1 lb/ton) of process weight. At a production rate of 200 batteries per hour (approximately 3.6 Mg/hr [8,000 lb/hr] process weight rate) uncontrolled lead emissions from the three-process operation would approximate 1.3 kg/hr (2.9 lb/hr). If it is assumed that lead represents only 50 percent of the total particulate emissions,** this facility would still comply with a typical process weight rate regulation (for particulate matter) as set forth in a State Implementation Plan (SIP) because of its high process weight rate. Similarly, the grid casting and lead oxide manufacturing facilities would comply with this regulation.

** Tests made during this study measured only lead. Other contaminants such as bits of material from separators, cork from the mold release agent, and the like must be considered. It is estimated that the lead constitutes at least 50 percent of the total particulate matter.

Table 8-8. UNCONTROLLED LEAD EMISSIONS FROM VARIOUS LEAD-ACID BATTERY MANUFACTURING FACILITIES[a]

Facility	Emissions
Grid casting	0.4 kg/1000 (0.9 lb/1000) batteries[b]
Paste mixing	5.1 kg/1000 (11.2 lb/1000) batteries[b]
Three-process operation	6.6 kg/1000 (14.7 lb/1000) batteries[b]
PbO manufacturing	0.01 kg/Mg (0.02 lb/ton) of lead throughput
Reclamation	3.0 kg/Mg (5.9 lb/ton) of lead charged

[a] Based on data obtained from source tests performed in this study.

[b] For estimating purposes, each battery weighs 18 kg (40 lb) and contains 12 kg (26 lb) of lead, of which approximately half is in the paste and half is in the cast parts.

The paste mixing and lead reclamation facilities apparently would not comply with such a regulation, and therefore controls would be required for these facilities even without the promulgation of a New Source Performance Standard.*

* The possible effects of future SIP regulations for lead are not considered in this chapter.

Very few SIP's regulate sulfuric acid mist emissions from the formation facility. New Jersey has set a limit of 10 mg/scf. A spokesman for the New Jersey Air Pollution Control Agency states that the plant in his jurisdiction complies with both this regulation and New Jersey's particulate matter regulation without use of a control device.[11]

8.2.1 New Facilities

8.2.1.1 Capital Cost of Control Systems - Control equipment costs are shown in Tables 8-9 and 8-9A. All costs in this section are based on 4th-quarter 1977 dollars. This equipment represents the most efficient from a pollutant control viewpoint and is currently used only on the best-controlled facilities. Costs were obtained directly from vendors and updated to 4th-quarter 1977 using the Marshall and Swift Index.[12,13]

Two major categories of costs have been developed: installed capital costs and total annualized costs. The installed capital cost for each control device system includes the purchased cost of the major and auxiliary equipment, cost of site preparation and equipment installation, and design engineering cost. Because of the short installation times required for construction of these control systems, no construction interest charges are included. No attempt is made to include costs of research and develop-

Table 8-9 AIR POLLUTION CONTROL EQUIPMENT COSTS FOR LEAD-ACID BATTERY MANUFACTURING FACILITIES (METRIC UNITS)

Equipment type	Sized, m^3/min	Exhaust gas parameters			Cost,[a] F.O.B. site
		Temperature, °C	Moisture, %	Particulate loadings, mg/m^3	
Impingement and entrainment scrubber	28	27-115	1-4	46-137	$ 7,200
	425	27-115	1-4	46-137	20,000
Fabric filter, (pulse-jet with 6/1 A/C ratio)	142	27	1-4	46-137	10,500
	1982	27	1-4	46-137	100,600
Fabric filter, (shaker-type with 2/1 A/C ratio)	40	115	2-3	114-229	6,900
	125	115	2-3	114-229	12,100
Fabric filter, (shaker-type with 3/1 A/C ratio)	40	115	2-3	114-229	5,600
	125	115	2-3	114-229	10,400
Mist eliminator	57	27	N.A.	3663	4,370[b]
	87	27	N.A.	3663	5,000
	142	27	N.A.	3663	5,600
	1982	27	N.A.	3663	53,300

[a] 4th-quarter. 1977 dollars; includes cost of fans, motors, drives, pumps, pump motors, sludge injector, walkways, and ladders as is appropriate. All costs obtained from Reference 29 except as otherwise noted and updated to 4th-quarter 1977.

[b] Reference 15. Costs were updated to 4th-quarter 1977.

Table 8-9A. AIR POLLUTION CONTROL EQUIPMENT COSTS FOR LEAD-ACID BATTERY MANUFACTURING FACILITIES (ENGLISH UNITS)

Equipment Type	Size, scfm	Exhaust gas parameters			Cost,[a] F.O.B. site
		Temperature, °F	Moisture, %	Particulate loading, gr/dscf	
Impingement and entrainment scrubber	1,000	80-240	1-4	0.02-0.06	$ 7,200
	15,000	80-240	1-4	0.02-0.06	20,000
Fabric filter, (pulse-jet with 6/1 A/C ratio)	5,000	80	1-4	0.02-0.06	10,500
	70,000	80	1-4	0.02-0.06	100,600
Fabric filter, (shaker-type with 2/1 A/C ratio)	1,400	240	2-3	0.05-0.10	6,900
	4,400	240	2-3	0.05-0.10	12,100
Fabric filter, (shaker-type with 3/1 A/C ratio)	1,400	240	2-3	0.05-0.10	5,600
	4,400	240	2-3	0.05-0.10	10,400
Mist eliminator	2,000	80	N.A.	1.6	4,370[b]
	3,000	80	N.A.	1.6	5,000
	5,000	80	N.A.	1.6	5,600
	70,000	80	N.A.	1.6	53,300

[a] 4th-quarter. 1977 dollars; includes cost of fans, motors, drives, pumps, pump motors, sludge injector, walkways, and ladders as is appropriate. All costs obtained from Reference 29 except as otherwise noted and updated to 4th-quarter 1977.

[b] Reference 15. Costs were updated to 4th-quarter 1977.

ment, possible loss of production during equipment installation, or losses during start-up. All capital costs reflect 4th-quarter 1977 prices for equipment, installation materials, and installation labor. Tables 8-10 and 8-11 present the various capital cost factors for installation of fabric filters and wet collectors, respectively. These factors are based on published information[16] and engineering judgment. Application of these factors to the equipment costs produces the cost curves shown in Figures 8-2 and 8-3. These Figures also show control system costs as reported by Plants B, C, D, E, G, and H updated to 4th-quarter 1977 by use of the Marshall and Swift (M & S) equipment cost index.

8.2.1.2 Annualized Cost of Control Systems - The total annualized cost consists of three categories: direct operating cost, capital charges, and (where applicable) credit for dust recovery. The first category accounts for operating and maintenance costs, which include these items:

- Utilities, including electric power and process water
- Operating labor
- Maintenance and supplies
- Solid waste disposal

Since the material collected in the pollutant control system is toxic, it is sent to a smelter for lead recovery. The value of the recovered lead tends to offset the refining

Table 8-10. COMPONENT CAPITAL COST FACTORS FOR A FABRIC FILTER AS A FUNCTION OF EQUIPMENT COST, Q

Component	Direct costs	
	Material	Labor
Equipment	1.00Q	0.25Q
Ductwork	0.04Q	0.21Q
Instrumentation	0.04Q	0.006Q
Electrical	0.11Q	0.16Q
Foundations	0.03Q	0.05Q
Structural	0.03Q	0.05Q
Sitework	0.02Q	0.02Q
Painting	0.004Q	0.02Q
Total direct costs	1.27Q	0.77Q

Component	Indirect costs	
	Measure of costs	Factor
Engineering	10% material and labor	0.204Q
Contractor's fee	15% material and labor	0.306Q
Shakedown	5% material and labor	0.102Q
Spares	1% material	0.013Q
Freight	3% material	0.038Q
Taxes	3% material	0.038Q
Total indirect costs		0.696Q
Contingencies - 20%	of direct and indirect costs	0.547Q
Total capital costs		3.28Q

Table 8-11. COMPONENT CAPITAL COST FACTORS FOR A WET COLLECTOR (SCRUBBER OR MIST ELIMINATOR) AS A FUNCTION OF EQUIPMENT COST, Q

Component	Direct costs	
	Material	Labor
Equipment	1.00Q	0.25Q
Ductwork	0.03Q	0.13Q
Instrumentation	0.04Q	0.006Q
Electrical	0.11Q	0.16Q
Foundations	0.03Q	0.05Q
Structural	0.03Q	0.05Q
Sitework	0.02Q	0.02Q
Painting	0.004Q	0.02Q
Piping	0.15Q	0.16Q
Total direct costs	1.41Q	0.85Q

Component	Indirect costs	
	Measure of costs	Factor
Engineering	10% material and labor	0.226Q
Contractor's fee	15% material and labor	0.339Q
Shakedown	5% material and labor	0.113Q
Spares	1% material	0.014Q
Freight	3% material	0.042Q
Taxes	3% material	0.042Q
Total indirect costs		0.776Q
Contingencies - 20%	of direct and indirect costs,	0.607Q
Total capital costs		3.64Q

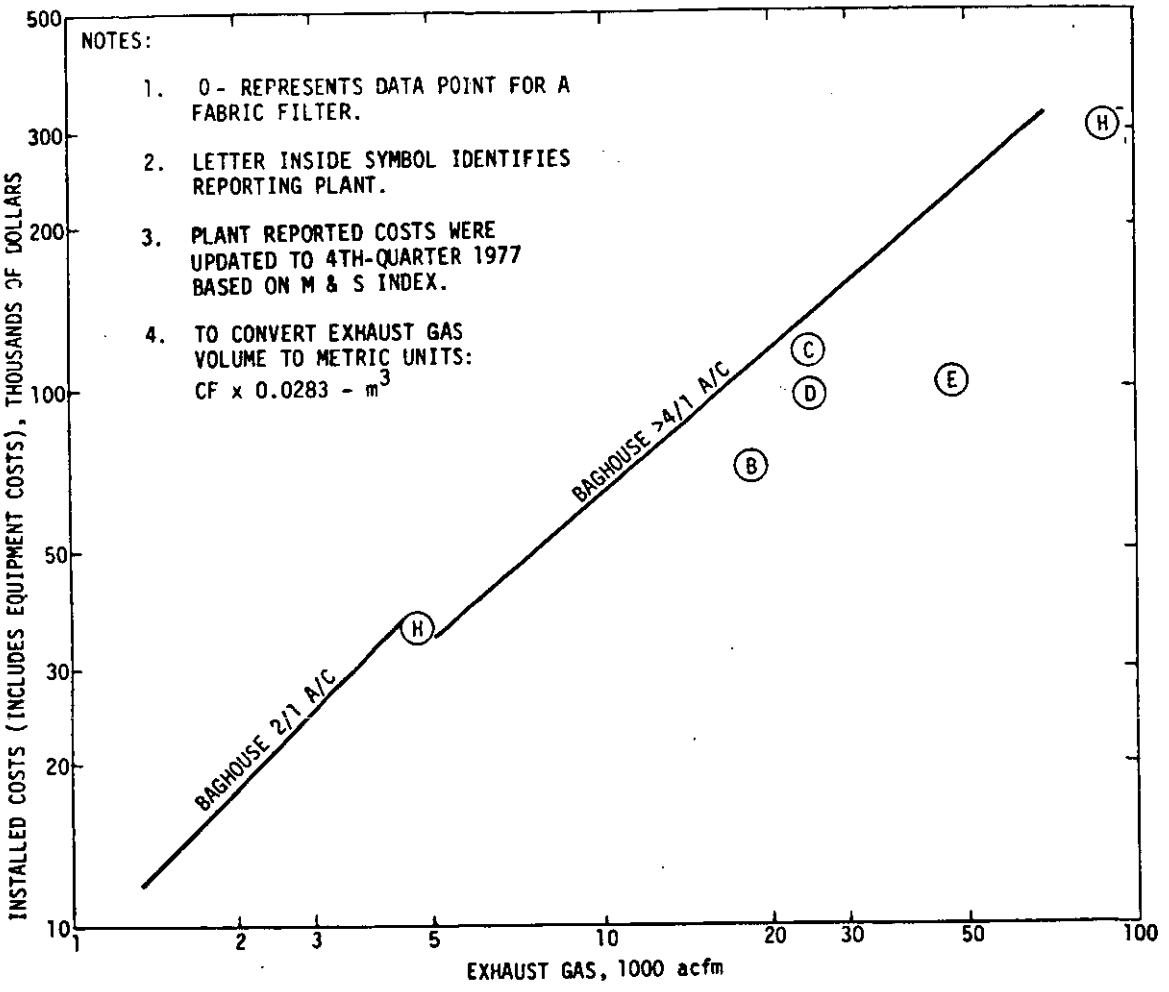

Figure 8-2. Reported installed costs of fabric filter control systems compared with estimated cost curves used in this study (4th-quarter 1977 dollars).

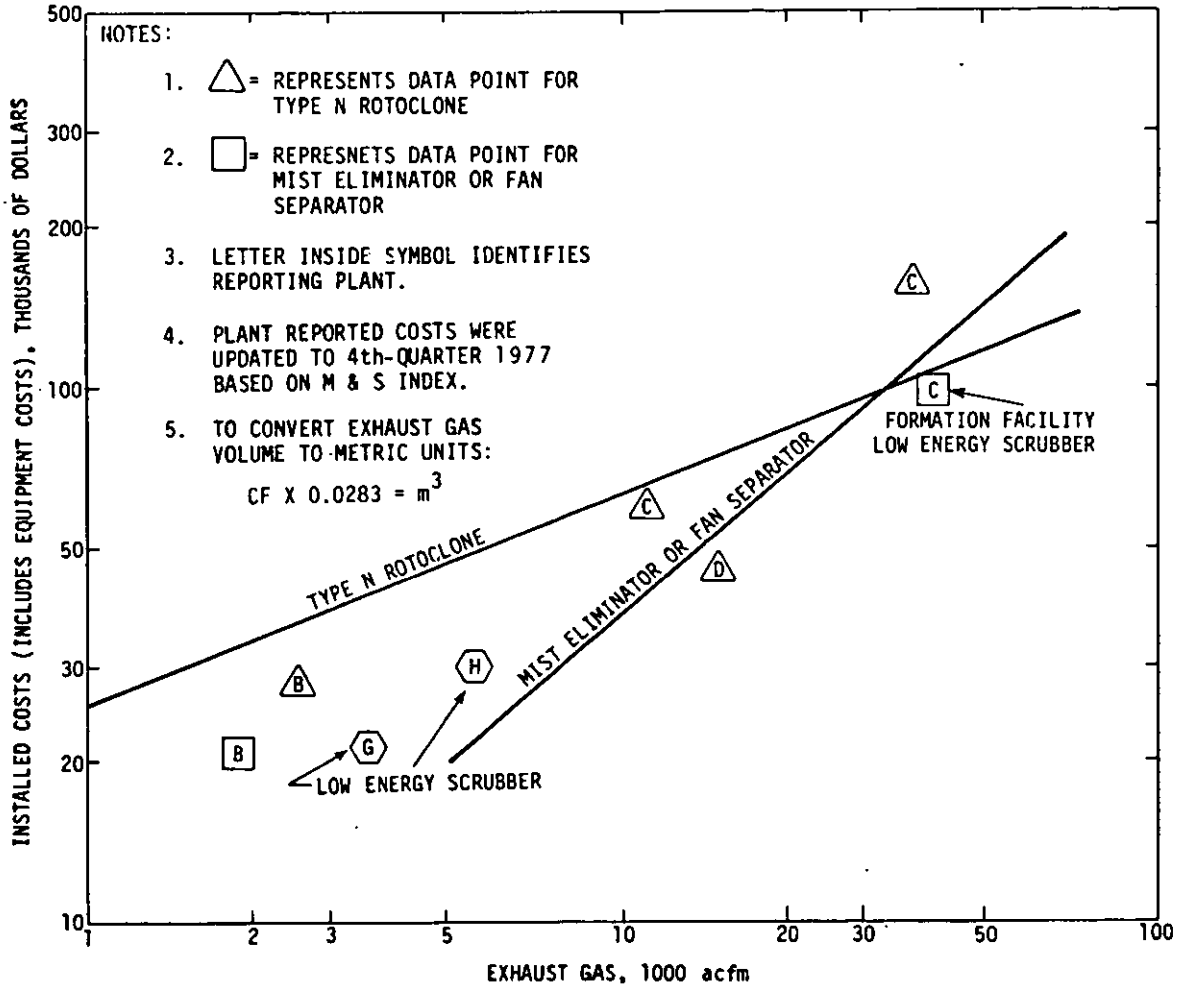

Figure 8-3. Reported installed costs of wet scrubber systems compared with estimated cost curves used in this study (4th-quarter 1977 dollars).

costs. Generally, no solid waste disposal costs due to air pollution control are incurred in the lead-acid battery industry. The industry therefore receives no dust recovery credit.[17,18]

Capital charges account for depreciation, interest, administrative overhead, property taxes, and insurance. Depreciation and interest are computed by use of a capital recovery factor (CRF), the value of which depends on the operating life of the device and on the interest rate. (An operating life of 15 years and an annual interest rate of 10 percent are assumed). Insurance cost is fixed at an additional 0.3 percent of the installed capital cost per year. Because most states have liberalized their tax laws regarding air pollution control equipment, the cost of taxes is considered to be negligible. The values used for overhead are shown in Table 8-12 and the various items and unit values used in computing total annualized costs are listed in Table 8-13.

Annualized costs of operation of control devices on all facilities except formation and lead oxide manufacturing are a function of the number of operating shifts per day. For purposes of this study, the following are designated: three shifts for a large plant, two shifts for a medium plant, and one shift for the small plants. The formation facility nor-

Table 8-12. ITEMS USED IN COMPUTING TOTAL ANNUALIZED COSTS

Item	Unit value
Operating factor	2000 hours/year/operating shift
Operating labor	$5/man-hour
Utilities	
Electric power	$0.03/kWh
Process water	$0.0625/$m^3$ ($0.25/thous. gal)
Solid waste disposal	0
Dust recovery credit	0
Capital recovery factor[a]	13.2% of installed capital cost

[a] For all air pollution control equipment; 15 year life, 10 percent interest assumed.

Table 8-13. CALCULATION OF ANNUALIZED COSTS OF AIR POLLUTION CONTROL SYSTEMS

Cost component	Method of calculation
Direct operating costs	
Utilities	
Water	Amount used per year x $0.0625/m^3 ($0.25/1000 gal)
Electricity	Amount used per year x $0.03/kWh
Operating labor	
Direct	Number of manhours per year x $5.00
Supervision	15% of direct labor
Maintenance and supplies	
Labor and material	6% of total capital costs
Supplies	15% of labor and material
Capital charges	
Overhead	
Plant	50% of operating labor plus 50% of maintenance and supplies
Payroll	20% of operating labor
Fixed costs	
Capital Recovery	13.2% of total capital costs
Insurance	0.3% of total capital costs

mally operates 16 to 24 hours per day, regardless of plant size. For estimating purposes, it is assumed that this facility operates three shifts per day. Table 8-12 illustrates how annualized costs are computed for air pollution control systems used in the lead-acid battery manufacturing industry. Since all the dust or sludge collected in the control systems is sold to a lead smelter for a low price, the solid waste disposal cost and dust recovery credit are a tradeoff. The utilities and labor factors used in calculating the annualized costs are shown in Tables 8-14 and 8-14A. Smelters generally take waste only from customers and would refuse lead waste from noncustomers even if it were delivered to the smelter at no cost.[19]

8.2.1.3 Cost of Alternative Control Measures - Each of the ten model plants (five new, five retrofit) consists of from five to seven separate facilities (see Tables 3-7 and 8-7A). These facilities can each be controlled separately. In practice, these facilities are often controlled by common systems. Of the five selected alternative control systems for control of lead emissions from the larger plants, system I corresponds to best control technology for emission reduction considered; the other systems are presented for analysis of the cost aspects of various other levels of control. Control alternatives VI and VII represent the best control

Table 8-14. UTILITIES AND LABOR REQUIRED FOR OPERATION OF VARIOUS CONTROL DEVICES FOR LEAD-ACID BATTERY MANUFACTURING FACILITIES (Metric Units)

Control	Pressure drop across device, Pa	Electric power requirements, kWh/hr/1000 m^3	Water usage m^3/1000 m^3	Operating factor, hr/yr	Direct labor, hr/yr
Fabric filter, 6/1 A/C	1245	20	0	2000-6000[a]	200-600[a]
Fabric filter, 2/1 A/C	0[b]	0[b]	0	0[b]	0[b]
Mist eliminator	249	4.2	67	6000	600
Impingement and entrainment scrubber	1245	20	134	2000-6000[a]	200-600[a]

[a] Depends on number of shifts/day device is operating; it is assumed that a small plant operates one shift; a medium plant, two shifts; a large plant, three shifts.

[b] This device is only used on the PbO manufacturing facility, which requires a fabric filter as part of the process. For estimating purposes, it is assumed that there is no significant difference between the utilities and labor required for the two systems.

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Table 3-14A. . UTILITIES AND LABOR REQUIRED FOR OPERATION OF VARIOUS CONTROL DEVICES FOR LEAD-ACID BATTERY MANUFACTURING FACILITIES (English Units)

Control device	Pressure drop across device, in. W.G.	Electric power requirements, kWh/hr/1000 scfm	Water usage gal/1000 scfm	Operating factor, hr/yr	Direct labor, hr/yr
Fabric filter, 6/1 A/C	5	0.59	0	2000-6000[a]	200-600[a]
Fabric filter, 2/1 A/C	0[b]	0[b]	0	0[b]	0[b]
Mist eliminator	1	0.118	0.5	6000	600
Impingement and entrainment scrubber	5	0.59	1.0	2000-6000[a]	200-600[a]

[a] Depends on number of shifts/day device is operating; it is assumed that a small plant operates one shift; a medium plant, two shifts; a large plant, three shifts.

[b] This device is only used on the PbO manufacturing facility, which requires a fabric filter as part of the process. For estimating purposes, it is assumed that there is no significant difference between the utilities and labor required for the two systems.

technology for smaller plants. They differ only in configuration. The three alternatives, (VI, VII, and VIII) are considered for the cost aspects.

The control systems for which costs have been estimated are fabric filters, impingement and entrainment scrubbers, and mist eliminators, all of which are technically capable of achieving the various emission reductions. Each system includes all auxiliary equipment such as fans, motors, drives, pumps, sludge ejectors, walkways, and ladders, as is appropriate. It is necessary to provide insulation and auxiliary heating for fabric filters to which mixer gases are exhausted. However, this requirement depends on the geographic location of the baghouse, the exhaust gas' dew point, and the concentration of acid mist and water vapor. Those control alternatives in which the mixer gases are vented to a baghouse also vent the three process operation to the same device. This dilutes the mixer exhaust from a 6500 BPD plant by a 6 to 1 factor. In warm climates condensation may be controlled by installing the baghouse inside the building. The annualized cost of this precaution would be $700, $1100, and $2400 for a 500 BPD, 2000 BPD, and 6500 BPD plants respectively, based on an annual space cost of $3.50 per square foot. For purposes of this report, the cost of insulation and auxiliary heat sufficient to maintain

a 55-65°C (130-150°F) exhaust gas temperature for condensation control was added. No allowance is made for handling and conveying systems for the collected sludge and dust. This material is normally manually dumped directly from the control device into reusable 0.2 cubic meter (55-gallon) drums or plastic bags and is shipped to a smelter. The estimated total particulate catch of an entire 6500 bpd plant is estimated at 158 kg (350 lb) per day. Shipment in plastic bags would require 10 bags per day, which can be purchased for approximately $4.00. This cost is insignificant relative to the estimated total annualized costs of more than $100,000.

For purposes of estimating the cost of the best demonstrated technology with regard to lead oxide manufacturing controls, it is assumed that the average facility incorporates a baghouse having an air-to-cloth ratio of 3 to 1 (3/1 A/C). This is part of the process equipment. To reach the collection efficiency of the control system tested at Plant G, it may be necessary to use fabric filters with an A/C of 2/1. Therefore the incremental cost of a 2/1 A/C baghouse is added to the overall control costs shown herein. None of the selected lead emissions control systems discharges water. Impingement and entrainment scrubbers generally use water at a rate of only 134 m^3/1000 m^3 (1

gpm/1000 acfm), only 20 percent of which is due to recirculation tank blowdown. The balance is lost through evaporation. This use results in a maximum increase of only 1 to 2 percent in total hydraulic flow for the plant (see Table 7-11). This increase would probably not require expansion of the water treatment system nor would it significantly increase the operating costs.

The mist eliminator used to control acid mist requires 67 m^3 water per 1000 m^3 (1/2 gpm per 1000 scfm). A typical battery plant requires 42 to 290 liters (11 to 74 gal) water per battery depending on whether batteries are wet- or dry-charged,[20] the dry-charge battery requiring the higher amount. A typical plant requirement is given as an average of 250 liters/battery (66.5 gal/battery).[21] Thus the daily water flow to the plant's wastewater system is as follows:

Plant size, bpd	Manufacturing wastewater, m^3 (gal)/day		Water added for H_2SO_4 mist control, m^3 (gal)/day*	
100	25	(6,600)	5	(1,200)
250	62	(16,500)	11	(2,900)
500	124	(33,000)	22	(5,800)
2000	503	(133,000)	87	(23,000)
6500	1627	(430,000)	260	(68,000)

The cost to build and operate the additional water treatment capacity must be added to the cost of the acid mist control. Based on the data reported in Reference [22] it is estimated

* Based on 16 hrs. per day.

that the additional capital costs and annualized costs for treatment of the mist eliminator water are as follows:

Plant size, bpd	Capital costs	Annualized costs
100, 250*	$ 300	$ 300
500	$ 1,000	$ 1,000
2000	$10,000	$ 6,000
6500	$15,000	$10,000

The estimated total costs of each control system for each control alternative are shown in Tables 8-15 through 8-22. Not all these costs are attributable to the promulgation of a New Source Performance Standard, since two facilities (lead reclamation and paste mixing) require controls just to meet typical SIP regulations for particulate matter. The applicable costs of these SIP controls must be deducted from the overall costs shown in Tables 8-15 through 8-22 SIP control costs are shown in Table 8-23. For estimating the SIP control costs, it is assumed that each facility is vented to a separate impingement and entrainment scrubber having a 90 percent total particulate collection efficiency.

Tables 8-24 through 8-28 show the net capital cost of lead control resulting from a New Source Performance Standard for lead. Table 8-29 lists the overall net capital

* Capital costs and annualized costs are assumed to level off at the 250 BPD plant capacity level.

Table 8-15. COST OF EMISSION CONTROL SYSTEMS

FOR CONTROL ALTERNATIVE I FOR NEW PLANTS

Plant size, bpd	Affected facilities[a]	Control device to which facilities are vented	Exhaust rate		Installed cost, $1000
			m^3/min	acfm x 1000	
500	C,E	Fabric filter, 6/1 A/C	541	19.1	150[d]
	A,B,F	Fabric filter, 6/1 A/C	266	9.4	66[d]
	G	Mist eliminator	348	12.3	44
	D[b]				0
					260
2000	C,E	Fabric filter, 6/1 A/C	825	29.1	225[d]
	A,B,F	Fabric filter, 6/1 A/C	311	11.0	77[d]
	G	Mist eliminator	1367	48.3	145[c]
	D	Fabric filter, 2/1 A/C	88	3.1	4[c]
					451
6500	C,E	Fabric filter, 6/1 A/C	1670	59.0	440[d]
	A,B,F	Fabric filter, 6/1 A/C	453	16.0	105[d]
	G	Mist eliminator	4020	142.0	370[c]
	D	Fabric filter, 2/1 A/C	215	7.6	13[c]
					928

[a] Facility codes are as follows: A, grid casting furnace; B, grid casting machine; C, paste mixing; D, PbO manufacturing; E, Three-process operation; F, lead reclaim furnace; G, formation.

[b] For purposes of this study it is assumed that a 500-bpd plant does not manufacture PbO.

[c] Incremental cost between 2/1 A/C and 3/1 A/C baghouse.

[d] Includes additional 10 percent for modification of basic system of prevention of spark carryover.

Table 8-16. COST OF EMISSION CONTROL SYSTEMS

FCR CONTROL ALTERNATIVE II FOR NEW PLANTS

Plant size, bpd	Affected facilities[a]	Control device to which facilities are vented	Exhaust rate		Installed cost, $1000
			m^3/min	acfm x 1000	
500	B,C,E	Fabric filter, 6/1 A/C	575	20.3	160
	F	Impingement and entrainment scrubber	198	.7	55
	A	Impingement and entrainment scrubber	34	1.2	27
	G	Mist eliminator	348	12.3	44
	D[b]				0
					286
2000	B,C,E	Fabric filter, 6/1 A/C	880	31.1	230
	F	Impingement and entrainment scrubber	198	7.0	55
	A	Impingement and entrainment scrubber	57	2.0	34
	G	Mist eliminator	1367	48.3	145
	D	Fabric filter, 2/1 A/C	88	3.1	4[c]
					468
6500	B,C,E	Fabric filter, 6/1 A/C	1798	63.5	465
	F	Impingement and entrainment scrubber	198	7.0	55
	A	Impingement and entrainment scrubber	127	4.5	46
	G	Mist eliminator	4020	142	370
	D	Fabric filter, 2/1 A/C	215	7.6	13[c]
					949

[a] Facility codes are as follows: A, grid casting furnace; B, grid casting machine; C, paste mixing; D, PbO manufacturing; E, Three-Process operation; F, lead reclaim furnace; G, formation.

[b] For purposes of this study it is assumed that a 500-bpd plant does not manufacture PbO.

[c] Incremental cost between 2/1 A/C and 3/1 A/C baghouse.

Table 8-17. COST OF EMISSION CONTROL SYSTEMS

FOR CONTROL ALTERNATIVE III FOR NEW PLANTS

Plant size, bpd	Affected facilities[a]	Control device to which facilities are vented	Exhaust rate		Installed cost, $1000
			m^3/min	acfm x 1000	
500	C,E	Fabric filter, 6/1 A/C	541	19.1	150
	A,B,F	Impingement and entrainment scrubber	266	9.4	61
	G	Mist eliminator	348	12.3	44
	D[b]				0
					255
2000	C,E	Fabric filter, 6/1 A/C	825	29.1	225
	A,B,F	Impingement and entrainment scrubber	311	11.0	66
	G	Mist eliminator	1367	48.3	145
	D	Fabric filter, 2/1 A/C	88	3.1	4[c]
					440
6500	C,E	Fabric filter, 6/1 A/C	1670	59	440
	A,B,F	Impingement and entrainment scrubber	453	16	75
	G	Mist eliminator	4020	142	370
	D	Fabric filter, 2/1 A/C	215	7.6	13[c]
					898

[a] Facility codes are as follows: A, grid casting furnace; B, grid casting machine; C, paste mixing; D, PbO manufacturing; E, Three-Process operation; F, lead reclaim furnace; G, formation.

[b] For purposes of this study it is assumed that a 500-bpd plant does not manufacture PbO.

[c] Incremental cost between 2/1 A/C and 3/1 A/C baghouse.

Table 8-18. COST OF EMISSION CONTROL SYSTEMS

FOR CONTROL ALTERNATIVE IV FOR NEW PLANTS

Plant size, bpd	Affected facilities[a]	Control device to which facilities are vented	Exhaust rate		Installed cost, $1000
			m^3/min	acfm x 1000	
500	A,B,C	Impingement and entrainment scrubber	136	4.8	48
	E	Fabric filter, 6/1 A/C	472	16.7	98
	F	Impingement and entrainment scrubber	198	7.0	55
	G	Mist eliminator	349	12.3	44
	D[b]				0
					245
2000	A,B,C	Impingement and entrainment scrubber	204	7.2	50
	E	Fabric filter, 6/1 A/C	733	25.9	140
	F	Impingement and entrainment scrubber	198	7.0	55
	G	Mist eliminator	1367	48.3	145[c]
	D	Fabric filter, 2/1 A/C	88	3.1	4
					394
6500	A,B,C	Impingement and entrainment scrubber	408	14.4	72
	E	Fabric filter, 6/1 A/C	1517	53.6	260
	F	Impingement and entrainment scrubber	198	7.0	55
	G	Mist eliminator	4020	142	370[c]
	D	Fabric filter, 2/1 A/C	215	7.6	13
					770

[a] Facility codes are as follows: A, grid casting furnace; B, grid casting machine; C, paste mixing; D, PbO manufacturing; E, Three-Process operation; F, lead reclaim furnace; G, formation.

[b] For purposes of this study it is assumed that a 500-bpd plant does not manufacture PbO.

[c] Incremental cost between 2/1 A/C and 3/1 A/C baghouse.

Table 8-19. COST OF EMISSION CONTROL SYSTEMS

FOR CONTROL ALTERNATIVE V FOR NEW PLANTS

Plant size, bpd	Affected facilities[a]	Control device to which facilities are vented	Exhaust rate		Installed cost, $1000
			m^3/min	acfm x 1000	
500	A,B,C,F	Impingement and entrainment scrubber	334	11.8	67
	E	Fabric filter, 6/1 A/C	472	16.7	98
	G	Mist eliminator	349	12.3	44
	D[b]				0
					204
2000	A,B,C,F	Impingement and entrainment scrubber	402	14.2	70
	E	Fabric filter, 6/1 A/C	733	25.9	140
	G	Mist eliminator	1367	48.3	145
	D	Fabric filter, 2/1 A/C	88	3.1	4[c]
					359
6500	A,B,C,F	Impingement and entrainment scrubber	606	21.4	84
	E	Fabric filter, 6/1 A/C	1517	53.6	260
	G	Mist eliminator	4020	142	370
	D	Fabric filter, 2/1 A/C	215	7.6	13[c]
					727

[a] Facility codes are as follows: A, grid casting furnace; B, grid casting machine; C, paste mixing; D, PbO manufacturing; E, Three-Process operation; F, lead reclaim furnace; G, formation.

[b] For purposes of this study it is assumed that a 500-bpd plant does not manufacture PbO.

[c] Incremental cost between 2/1 A/C and 3/1 A/C baghouse.

Table 8-20. COST OF EMISSION CONTROL SYSTEMS

FOR CONTROL ALTERNATIVE VI FOR NEW PLANTS

Plant size, bpd	Affected facilities[a]	Control device to which facilities are vented	Exhaust rate		Installed cost
			m^3/min	acfm	
100	A,B,C	Fabric filter, 6/1 A/C	117	4130	$ 39,100[c]
	E	Fabric filter, 6/1 A/C	402	14,200	85,000
	G	Mist eliminator	75	2660	11,500
	D[b]				0
	F[d]				0
					$ 135,000
250	A,B,C	Fabric filter, 6/1 A/C	124	4370	$ 40,700[c]
	E	Fabric filter, 6/1 A/C	428	15,100	90,000
	G	Mist eliminator	177	6260	24,500
	D[b]				0
	F[d]				0
					$ 155,000

[a] Facility codes are as follows: A, grid casting furnace; B, grid casting machine; C, paste mixing; D, PbO manufacturing; E, Three-process operation; F, lead reclaim furnace; G, formation.

[b] For purposes of this study it is assumed that a 500-bpd or less plant does not manufacture PbO.

[c] Includes additional 10 percent for modification of basic system of prevention of spark carryover.

[d] For the purposes of this study, it is assumed that a plant making less than 500 bpd does not have a lead reclaim furnace.

Table 8-21. COST OF EMISSION CONTROL SYSTEMS

FOR CONTROL ALTERNATIVE VII FOR NEW PLANTS

Plant size, bpd	Affected facilities[a]	Control device to which facilities are vented	Exhaust rate		Installed cost
			m^3/min	acfm	
100	A,B,C,E	Fabric filter, 6/1 A/C	518	18,300	$ 159,000[c]
	G	Mist eliminator	75	2,660	11,500
	D[b]				0
	F[d]				0
					$ 171,000
250	A,B,C,E	Fabric filter, 6/1 A/C	552	19,500	$ 171,000[c]
	G	Mist eliminator	177	6,260	24,500
	D[b]				0
	F[d]				0
					$ 196,000

[a] Facility codes are as follows: A, grid casting furnace; B, grid casting machine; C, paste mixing; D, PbO manufacturing; E, Three-process operation; F, lead reclaim furnace; G, formation.

[b] For purposes of this study it is assumed that a 500-bpd or less plant does not manufacture PbO.

[c] Includes additional 10 percent for modification of basic system of prevention of spark carryover.

[d] For the purposes of this study, it is assumed that a plant making less than 500 bpd does not have a lead reclaim furnace.

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Table 8-22. COST OF EMISSION CONTROL SYSTEMS

FOR CONTROL ALTERNATIVE VIII FOR NEW PLANTS

Plant size, bpd	Affected facilities[a]	Control device to which facilities are vented	Exhaust rate		Installed cost
			m^3/min	acfm	
100	A,B,C	Impingement and entrainment scrubber	117	4130	$ 44,500
	E	Fabric filter, 6/1 A/C	402	14,200	85,000
	G	Mist eliminator	75	2660	11,500
	D[b]				
	F[c]				0
					$ 141,000
250	A,B,C	Impingement and entrainment scrubber	124	4370	$ 45,500
	E	Fabric filter, 6/1 A/C	428	15,100	90,000
	G	Mist eliminator	177	6260	24,500
	D[b]				0
	F[c]				
					$ 160,000

[a] Facility codes are as follows: A, grid casting furnace; B, grid casting machine; C, paste mixing; D, PbO manufacturing; E, Three-process operation; F, lead reclaim furnace; G, formation.

[b] For purposes of this study it is assumed that a 500-bpd or less plant does not manufacture PbO.

[c] For the purposes of this study, it is assumed that a plant making less than 500 bpd does not have a lead reclaim furnace.

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Table 8-23. COSTS OF CONTROL SYSTEMS REQUIRED TO MEET TYPICAL SIP REGULATIONS[a]

Plant size, bpd	Facility	Exhaust rate		Installed cost, $1000[b]	Direct operating cost, $1000[b]	Annualized capital, $1000[b]	Total Annualized cost, $1000[b]
		m^3/min	acfm x 1000				
100	Paste mixing	51	2.2	35	3.8	6.7	10.5
250	Paste mixing	51	2.3	35	3.9	6.8	10.7
500	Paste mixing	67	2.4	36	3.9	6.9	10.8
	Lead reclamation	198	7.0	55	5.6	10.0	15.6
				91	9.5	16.9	26.4
2000	Paste mixing	91	3.2	40	5.7	8.6	14.3
	Lead reclamation	198	7.0	55	5.6	10.0	15.6
				95	11.3	18.6	29.9
6500	Paste mixing	156	5.5	50	8.9	11.3	20.2
	Lead reclamation	198	7.0	55	5.6	10.0	15.6
				105	14.5	21.3	35.8

[a] The control device consists of an impingement and entrainment scrubber.

[b] 4th-quarter 1977 dollars.

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Table 8-24 . CAPITAL COSTS OF LEAD EMISSIONS CONTROL FROM NEW LEAD-ACID BATTERY MANUFACTURING FACILITIES - 100 BPD PLANT

Control alternative	Lead emissions, kg/day		Lead emissions, lb/day		Effectiveness of lead control, percent		Installed cost, 4th-qtr. 1977 dollars x 1000		Installed cost of control allocable to NSPS, 4th-qtr. 1977 dollars x 1000
	SIP	NSPS	SIP	NSPS	SIP	NSPS	SIP	NSPS	
VI	0.759	0.0122	1.67	0.0268	38	99.0	35	124	89
VII	0.759	0.0127	1.67	0.0268	38	99.0	35	159	124
VIII	0.759	0.0615	1.67	0.136	38	94.9	35	129	94

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Table 8-25. CAPITAL COSTS OF LEAD EMISSIONS CONTROL FROM NEW LEAD-ACID BATTERY MANUFACTURING FACILITIES - 250 BPD PLANT

Control alternative	Lead emissions, kg/day		Lead emissions, lb/day		Effectiveness of lead control, percent		Installed cost, 4th-qtr. 1977 dollars x 1000		Installed cost of control allocable to NSPS, 4th-qtr. 1977 dollars x 1000
	SIP	NSPS	SIP	NSPS	SIP	NSPS	SIP	NSPS	
VI	1.90	0.0304	4.18	0.067	38	99.0	35	130	95
VII	1.90	0.0304	4.18	0.067	38	99.0	35	171	136
VIII	1.90	0.154	4.18	0.339	38	94.9	35	135	100

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Table 8-26. CAPITAL COSTS OF LEAD EMISSIONS CONTROL FROM NEW LEAD-ACID BATTERY MANUFACTURING FACILITIES, 500-BPD PLANT

Control alternative	Lead emissions, kg/day		Lead emissions, lb/day		Effectiveness of lead control, percent		Installed cost, 4th-qtr. 1977 dollars x 1000		Installed cost of control allocable to NSPS, 4th-qtr. 1977 dollars x 1000
	SIP	NSPS	SIP	NSPS	SIP	NSPS	SIP	NSPS	
I	3.82	0.063	8.42	0.138	39	99.0	91	216	125
II	3.82	0.086	8.42	0.193	39	98.6	91	242	151
III	3.82	0.097	8.42	0.214	39	98.4	91	211	120
IV	3.82	0.326	8.42	0.718	39	94.8	91	201	110
V	3.82	0.326	8.42	0.718	39	94.8	91	160	69

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Table 8-27. CAPITAL COSTS OF LEAD EMISSIONS CONTROL FROM NEW LEAD-ACID BATTERY MANUFACTURING FACILITIES, 2000-BPD PLANT

Control alternative	Lead emissions, kg/day		Lead emissions, lb/day		Effectiveness of lead control, percent		Installed cost, 4th-qtr. 1977 dollars x 1000		Installed cost of control allocable to NSPS, 4th-qtr. 1977 dollars x 1000
	SIP	NSPS	SIP	NSPS	SIP	NSPS	SIP	NSPS	
I	16.2	0.030	33.7	0.665	38	98.8	95	306	211
II	16.2	0.400	33.7	0.885	38	98.4	95	323	228
III	16.2	0.439	33.7	0.940	38	98.3	95	295	200
IV	16.2	1.350	33.7	2.880	38	94.8	95	249	154
V	16.2	1.360	33.7	2.880	38	94.8	95	214	119

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Table 8-28.. CAPITAL COSTS OF LEAD EMISSIONS CONTROL FROM NEW LEAD-ACID BATTERY MANUFACTURING FACILITIES, 6500-BPD PLANT

Control alternative	Lead emissions, kg/day		Lead emissions, lb/day		Effectiveness of lead control, percent		Installed cost, 4th-qtr. 1977 dollars x 1000		Installed cost of control allocable to NSPS, 4th-qtr. 1977 dollars x 1000
	SIP	NSPS	SIP	NSPS	SIP	NSPS	SIP	NSPS	
I	50.1	0.988	110.5	2.18	39	98.8	105	558	453
II	50.1	1.310	110.5	2.89	39	98.4	105	579	474
III	50.1	1.430	110.5	3.15	39	98.3	105	528	423
IV	50.1	4.390	110.5	9.67	39	94.6	105	400	295
V	50.1	4.410	110.5	9.73	39	94.6	105	357	252

Table 8-29. NET CAPITAL COSTS OF CONTROL ALTERNATIVES FOR LEAD-ACID BATTERY MANUFACTURING PLANTS[a,b]

Control alternative	Installed cost of control systems allocable to NSPS, 4th-qtr. 1977 dollars x 1000				
	100 bpd plant	250 bpd plant	500 bpd plant[c]	2000 bpd plant[d]	6500 bpd plant[e]
I			170	366	838
II			196	383	859
III			165	355	808
IV			155	309	680
V			114	274	637
VI	101	120			
VII	136	161			
VIII	106	125			

[a] Includes controls for both lead emissions and sulfuric acid mist emissions and includes additional wastewater treatment capacity for the acid mist control system.

[b] Cost of controls necessary to meet SIP requirements are not included; these costs are estimated to be $91,000, $95,000, and $105,000 for 500-bpd, 2000-bpd, and 6500-bpd plants, respectively; and $35,000 for the 100 and 250 bpd plants.

[c] $1000 added for additional wastewater treatment capacity.

[d] $10,000 added for additional wastewater treatment capacity.

[e] $15,000 added for additional wastewater treatment capacity.

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cost of each control alternative for both lead and acid mist emissions. Annualized control costs for new plants are shown in Tables 8-30 through 8-34. These costs are exclusive of those costs incurred to meet SIP regulations. The annualized costs of sulfuric acid mist control are shown in Table 8-35.

8.2.2 Modified/Reconstructed Facilities

8.2.2.1 Capital Cost of Control Systems - The cost for installing a control system in an existing plant that has been modified, reconstructed, or expanded (given the same exhaust gas parameters) is greater as a result of special design considerations, more complex piping requirements, etc. Estimating this additional installation cost or retrofit penalty is difficult because of many factors peculiar to the individual plant. In preparation of this section, such factors as lack of space, additional ducting, and additional engineering were considered.

Configuration of equipment in the existing plant governs the location of the control system. Depending on process or stack location, long ducting runs from ground level to the control device and to the stack may be required. A sizable increase in costs may be incurred if the control equipment must be placed on the roof, which may require steel structural support. Other cost components that may be increased

Table 8-30. ANNUALIZED COSTS OF LEAD CONTROLS ALLOCABLE TO A NEW SOURCE PERFORMANCE STANDARD FOR A NEW 100 BPD PLANT

Control alternative	Effectiveness of lead removal compared with SIP regulations, units Pb removed/yr[a]		Direct costs, $1000/yr[b]	Annualized capital, $1000/yr[b]	Total annualized costs, $1000/yr[b]	Dollars per unit of lead removed,	
	kg	lb				kg	lb
VI	186	410	12.5	16.1	28.6	154	70
VII	186	410	26.1	18.2	44.3	238	108
VIII	174	383	9.0	17.1	26.1	150	68

[a] (SIP emissions - NSPS emissions) x 250 days/yr.

[b] Excludes costs associated with mixer which is controlled under SIP regulations. Does not include formation control costs and water treatment costs.

Table 8-31. ANNUALIZED COSTS OF LEAD CONTROLS ALLOCABLE TO A NEW SOURCE PERFORMANCE STANDARD FOR A NEW 250 BPD PLANT

Control alternative	Effectiveness of lead removal compared with SIP regulations, units Pb removed/yr[a]		Direct costs, $1000/yr[b]	Annualized capital, $1000/yr[b]	Total annualized costs, $1000/yr[b]	Dollars per unit of lead removed,	
	kg	lb				kg	lb
VI	467	1030	13.2	17.2	30.4	65	30
VII	467	1030	27.9	19.1	47.0	101	45
VIII	438	965	9.4	18.2	27.6	63	29

[a] (SIP emissions - NSPS emissions) x 250 days/yr.

[b] Excludes costs associated with mixer which is controlled under SIP regulations. Does not include formation control costs and water treatment costs.

Table 8-32. ANNUALIZED COSTS OF LEAD CONTROLS ALLOCABLE TO A NEW SOURCE PERFORMANCE STANDARD FOR A NEW 500 BPD PLANT

Control alternative	Effectiveness of lead removal compared with SIP regulations, units Pb removed/yr[a]		Direct costs,[b] $1000/yr	Annualized capital[b] $1000/yr	Total annualized costs,[b] $1000/yr	Dollars per unit of lead removed	
	kg	lb				kg	lb
I	936	2070	27.6	19.9	47.5	51	23
II	934	2060	32.2	24.7	56.9	61	28
III	930	2050	27.7	19.9	47.6	51	23
IV	875	1930	10.5	19.7	30.2	35	16
V	875	1930	6.5	12.9	19.4	22	10

[a] (SIP emissions - NSPS emissions) x 250 days/yr.

[b] Excludes costs associated with mixer and reclamation facilities, both of which are controlled under SIP regulations. Does not include formation control costs and water treatment costs.

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Table 8-33. ANNUALIZED COSTS OF LEAD CONTROLS ALLOCABLE TO A NEW SOURCE PERFORMANCE STANDARD FOR A NEW 2000-BPD PLANT

Control alternative	Effectiveness of lead removal compared with SIP regulations, units Pb removed/yr[a]		Direct costs,[b] $1000/yr	Annualized capital[b] $1000/yr	Total annualized costs,[b] $1000/yr	Dollars per unit of lead removed	
	kg	lb				kg	lb
I	3740	8240	71.7	36.2	108	29	13
II	3720	8190	71.7	42.2	122	33	15
III	3710	8180	71.7	35.2	107	29	13
IV	3490	7690	17.5	30.6	48.1	14	6.3
V	3490	7690	13.5	23.4	36.9	11	4.8

[a] (SIP emissions - NSPS emissions) x 250 days/yr.

[b] Excludes costs associated with mixer and reclamation facilities, both of which are controlled under SIP regulations. Does not include formation control costs and water treatment costs.

Table 8-34. ANNUALIZED COSTS OF LEAD CONTROLS ALLOCABLE TO A NEW SOURCE PERFORMANCE STANDARD FOR A NEW 6500-BPD PLANT

Control alternative	Effectiveness of lead removal compared with SIP regulations, units Pb removed/yr[a]		Direct costs, $1000/yr[b]	Annualized capital[b] $1000/yr	Total annualized costs, $1000/yr[b]	Dollars per unit of lead removed	
	kg	lb				kg	lb
I	12,292	27100	200	83.5	284	23	11
II	12,202	26900	217	86.0	303	25	11
III	12,156	26800	198	78.5	277	23	10
IV	11,430	25200	33.5	57.5	91	8.0	3.6
V	11,430	25200	28.5	49.5	78	6.8	3.1

[a] (SIP emissions - NSPS emissions) x 250 days/yr.

[b] Excludes costs associated with mixer and reclamation facilities, both of which are controlled under SIP regulations. Does not include formation control costs and water treatment costs.

Table 8-35. ANNUALIZED COSTS OF SULFURIC ACID MIST CONTROLS FOR NEW FACILITIES[a,b]

Plant size, bpd	Direct operating costs of control system, $1000/yr	Annualized capital charges of control system, $1000/yr	Annualized cost of additional wastewater treatment, $1000/yr	Total annualized costs, $1000/yr
100	3.8	4.0	0.2	8.0
250	6.1	6.9	0.3	13.3
500	8.5	10.5	1.0	20.0
2000	17	27	6.0	50.0
6500	30	55	10.0	95.0

[a] Based on installation of a mist eliminator.

[b] No SIP regulations are applicable; 100 percent of costs allocable to NSPS regulations.

because of space restrictions and plant configuration are contractor's fees and engineering fees. These fees, estimated at 15 percent and 10 percent respectively under normal conditions, can be expected to increase to 20 percent and 15 percent respectively for a retrofit. These fees vary from place to place and job to job depending on the difficulty of the job, the risks involved, and current economic conditions. The fees cited are PEDCo's estimates.

The requirement for additional ducting can vary considerably, depending on plant configuration. For purposes of this study, it is estimated that approximately 50 percent more ducting may be required to install a control system in an existing plant.

If the space is tight within the plant, it may be necessary to install the control equipment on the roof. It is estimated that a roof-top installation could double the structural costs. The additional labor costs were determined by assuming that 10 percent of the labor will be required to tie the system into the process. This work would most likely have to be done at premium-time wage rates in accordance with governmental regulations and/or union agreements. These rates are assumed to be double the straight-time pay.

Applying these additional cost factors to those in Tables 8-10 and 8-11 shows that the cost of retrofit installations runs approximately 20 percent higher than the cost of new installations. Breakdowns of retrofit cost factors are shown in Tables 8-36 and 8-37 for fabric filters and wet collectors.

8.2.2.2 Annualized Cost of Control Systems - The annualized costs of control systems for modified/reconstructed facilities are calculated similarly to those for new facilities. The cost components that are proportional to capital costs, (see Table 8-12) are approximately 20 percent higher than those for new facilities.

8.2.2.3 Cost of Alternative Control Measures - The costs of the eight control alternatives listed in Table 8-6 were calculated on the same basis as those costs applicable to new facilities, (see Section 8.2.1.3). Tables 8-38 through 8-42 show the net capital and annualized costs for the eight control alternatives applicable to existing facilities that have been reconstructed or modified; Table 8-43 shows the costs of sulfuric acid mist control. The additional wastewater costs resulting from use of a fan separator have been added. For estimating purposes, it was assumed that these costs are double those incurred for a new plant. It is important to note that these costs are estimates. Retrofit situations vary over a broad range, since, for example, some

Table 8-36. COMPONENT CAPITAL COST FACTORS FOR A RETROFIT INSTALLATION OF A FABRIC FILTER AS A FUNCTION OF EQUIPMENT COST, Q

Component	Direct costs	
	Material	Labor
Equipment	1.00Q	0.25Q
Ductwork	0.06Q	0.30Q
Instrumentation	0.04Q	0.006Q
Electrical	0.11Q	0.16Q
Foundations	0.03Q	0.05Q
Structural	0.04Q	0.08Q
Sitework	0.02Q	0.02Q
Painting	0.004Q	0.02Q
Premium time labor		0.09Q
Total direct costs	1.30Q	0.98Q

Component	Indirect costs	
	Measure of costs	Factor
Engineering	15% material and labor	0.342Q
Contractor's fee	20% material and labor	0.456Q
Shakedown	5% material and labor	0.114Q
Spares	1% material	0.013Q
Freight	3% material	0.039Q
Taxes	3% material	0.039Q
Total indirect costs		1.003Q
Contingencies - 20% of direct and indirect costs		0.656Q
Total capital costs		3.94Q

Table 8-37. COMPONENT CAPITAL COST FACTORS FOR A RETROFIT INSTALLATION OF A WET COLLECTOR (SCRUBBER OR MIST ELIMINATOR) AS A FUNCTION OF EQUIPMENT COST, Q

Component	Direct costs	
	Material	Labor
Equipment	1.00Q	0.25Q
Ductwork	0.04Q	0.20Q
Instrumentation	0.04Q	0.006Q
Electrical	0.11Q	0.16Q
Foundations	0.03Q	0.05Q
Structural	0.04Q	0.08Q
Sitework	0.02Q	0.02Q
Painting	0.004Q	0.02Q
Piping	0.15Q	0.16Q
Premium Time Labor	-	0.09Q
Total direct costs	1.43Q	1.03Q

Component	Indirect costs	
	Measure of costs	Factor
Engineering	15% material and labor	0.369Q
Contractor's fee	20% material and labor	0.492Q
Shakedown	5% material and labor	0.123Q
Spares	1% material	0.014Q
Freight	3% material	0.042Q
Taxes	3% material	0.042Q
Total indirect costs		1.082Q
Contingencies - 20% of direct and indirect cost		0.708Q
Total capital costs		4.25Q

Table 8-38.. COSTS OF LEAD EMISSIONS CONTROL ALTERNATIVES FOR AN EXISTING 100-BPD PLANT

Control alternative[a]	Effectiveness of lead removal compared with SIP regulations, units Pb removed/yr[b]		Installed cost, $1000[c]	Direct operating cost, $1000/yr[c]	Annualized capital charges, $1000/yr[c]	Total annualized cost, $1000/yr[c]	Dollar per unit of lead removed	
	kg	lb					kg	lb
VI	186	410	107	13.7	19.1	32.8	176	80
VII	186	410	149	27.8	22.4	50.2	270	123
VIII	174	383	113	10.3	20.3	30.6	176	80

[a] See Table 8-5 for a description of each Control Alternative.

[b] (SIP emissions - NSPS emissions) x 250 days/yr.

[c] Does not include costs associated with mixing and reclaim facilities, both of which are controlled under SIP regulations.

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Table 8-39. COSTS OF LEAD EMISSIONS CONTROL ALTERNATIVES FOR AN EXISTING 250-BPD PLANT

Control alternative[a]	Effectiveness of lead removal compared with SIP regulations, units Pb removed/yr[b]		Installed cost, $1000[c]	Direct operating cost, $1000/yr[c]	Annualized capital charges, $1000/yr[c]	Total annualized cost, $1000/yr[c]	Dollar per unit of lead removed	
	kg	lb					kg	lb
VI	467	1030	114	14.5	20.4	34.9	74	34
VII	467	1030	163	29.8	23.7	53.5	115	52
VIII	438	965	120	10.8	21.6	32.4	74	34

[a] See Table 8-5 for a description of each Control Alternative.

[b] (SIP emissions - NSPS emissions) x 250 days/yr.

[c] Does not include costs associated with mixing and reclaim facilities, both of which are controlled under SIP regulations.

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Table 8-40. COSTS OF LEAD EMISSIONS CONTROL ALTERNATIVES FOR AN EXISTING 500-BPD PLANT

Control alternative[a]	Effectiveness of lead removal compared with SIP regulations, units Pb removed/yr[b]		Installed cost $1000[c]	Direct operating cost, $1000/yr[c]	Annualized capital charges, $1000/yr[c]	Total annualized cost $1000/yr[c]	Dollar per unit of lead removed	
	kg	lb					kg	lb
I	936	2070	150	29.4	24.2	53.6	57	26
II	934	2060	181	34.3	29.8	64.1	69	31
III	930	2050	144	29.4	24.0	53.4	57	26
IV	875	1930	132	12.0	23.4	35.4	40	18
V	875	1930	83	7.5	15.2	22.7	26	12

[a] See Table 8-5 for a description or each Control Alternative.

[b] (SIP emissions - NSPS emissions) x 250 days/yr.

[c] Does not include costs associated with mixing and reclaim facilities, both of which are controlled under SIP regulations.

Table 8-41. COSTS OF LEAD EMISSIONS CONTROL ALTERNATIVES FOR AN EXISTING 2000-BPD PLANT

Control alternative[a]	Effectiveness of lead removal compared with SIP regulations, units Pb removed/yr[b]		Installed cost $1000[c]	Direct operating cost, $1000/yr[c]	Annualized capital charges, $1000/yr[c]	Total annualized cost $1000/yr[c]	Dollar per unit of lead removed	
	kg	lb					kg	lb
I	3740	8240	253	74.7	43.4	118	32	14
II	3710	8190	274	82.9	50.0	133	36	16
III	3710	8180	240	74.5	42.0	117	32	14
IV	3490	7690	185	19.7	36.1	55.8	16	7.3
V	3490	7690	143	15.2	27.4	42.6	12	5.5

[a] See Table 8-5 for a description of each Control Alternative.

[b] (SIP emissions - NSPS emissions) x 250 days/yr.

[c] Does not include costs associated with mixing and reclaim facilities, both of which are controlled under SIP regulations.

Table 8-42. COSTS OF LEAD EMISSIONS CONTROL ALTERNATIVES FOR AN EXISTING 6500-BPD PLANT

Control alternative[a]	Effectiveness of lead removal compared with SIP regulations, units Pb removed/yr[b]		Installed cost $1000[c]	Direct operating cost, $1000/yr[c]	Annualized capital charges, $1000/yr[c]	Total annualized cost $1000/yr[c]	Dollar per unit of lead removed	
	kg	lb					kg	lb
I	12,292	27100	544	206	98.9	305	25	11
II	12,202	26900	569	224	102	326	27	12
III	12,156	26800	508	204	92.9	297	24	11
IV	11,430	25200	354	37.6	67.5	105	9.1	4.2
V	11,430	25200	302	42.0	58.1	100	8.7	4.0

[a] See Table 8-5 for a description of each Control Alternative.

[b] (SIP emissions - NSPS emissions) x 250 days/yr.

[c] Does not include costs associated with mixing and reclaim facilities, both of which are controlled under SIP regulations.

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Table 8-43. SULFURIC ACID MIST CONTROL COSTS FOR EXISTING RECONSTRUCTED/ MODIFIED BATTERY FORMATION FACILITIES[a]

Plant size, BPD	Installed costs, $1000		Direct operating costs of mist eliminator $1000/yr	Annualized capital charges of mist eliminator $1000	Annualized costs of additional water treatment $1000	Total annualized costs, $1000
	Mist eliminator	additional wastewater treatment capacity				
100	13.8	0.6	4.0	4.4	0.6	9.0
250	29.4	0.6	6.4	7.7	0.6	14.7
500	52.8	2.0	9.1	12.0	2.0	23.1
2000	174	20.0	13.0	43.9	12.0	74.9
6500	444	30.0	35.2	67.6	20.0	123

[a] 4th-quarter 1977 dollars

are reconstructions and others are expansions. Thus it is unlikely that the new plant exhaust parameters would fit all the retrofit applications. For estimating purposes, it must be assumed that exhaust parameters remain constant. Additionally, plants that reconstruct or modify their facilities are not likely to undertake changing all their facilities at the same time. Consequently, the overall capital and annualized costs shown in Tables 8-38 through 8-43 are not likely to be incurred at the same time. All the costs must be incurred at some point in time, as each of the facilities becomes an affected facility.

8.2.3 Cost-effectiveness of Alternative Control Measures

It is informative to compare the annualized costs of the various alternative lead control measures to the quantities of lead removed by them. This comparison, or cost-effectiveness analysis, is done in this section for the five sizes of the new model battery plants. (Since an NSPS impacts most heavily on new, rather than existing plants, the cost-effectiveness analysis will be limited to them.)

There are several ways this comparison can be made. First, the various incremental annualized costs (that is, those costs solely due to NSPS control) may be divided by the incremental quantities of lead removed. Tables 8-30 through 8-34 list these cost-effectiveness quotients. It is

clear from the tables that the quotients vary both with the plant capacity and the control alternative. The quotients vary from nearly $7.00 to $25.00 per Kg in the 6500 battery per day (bpd) plant, but are much higher in the smallest plant (100 bpd) where they range from $150.00 to $238.00 per Kg. This clearly indicates that control costs benefit from a positive economy of scale.

The quotients for control alternatives I through VIII are plotted in Figure 8-4 against the model battery plant capacity. Note, first of all, that the cost-effectiveness quotients decrease significantly as the plant size increases. This demonstrates the economy of scale characteristic mentioned above. Moreover, as the size increases to the largest capacity, 6500 bpd, the quotients continue to decrease, although more gradually. If extrapolated beyond 6500 bpd, the curves would tend to approach certain limiting values. Beyond these values, cost-effectiveness would be effectively independent of plant size.

Also notice that the cost-effectiveness curves are not ordered according to their respective control efficiencies. For instance, the curve for Alternative I, the most stringent with 99 percent lead emissions control, lies below the curve for Alternative II, which represents a lower control efficiency (98 percent) for the larger plants. Likewise the curve for Alternative VI lies below an equally efficient

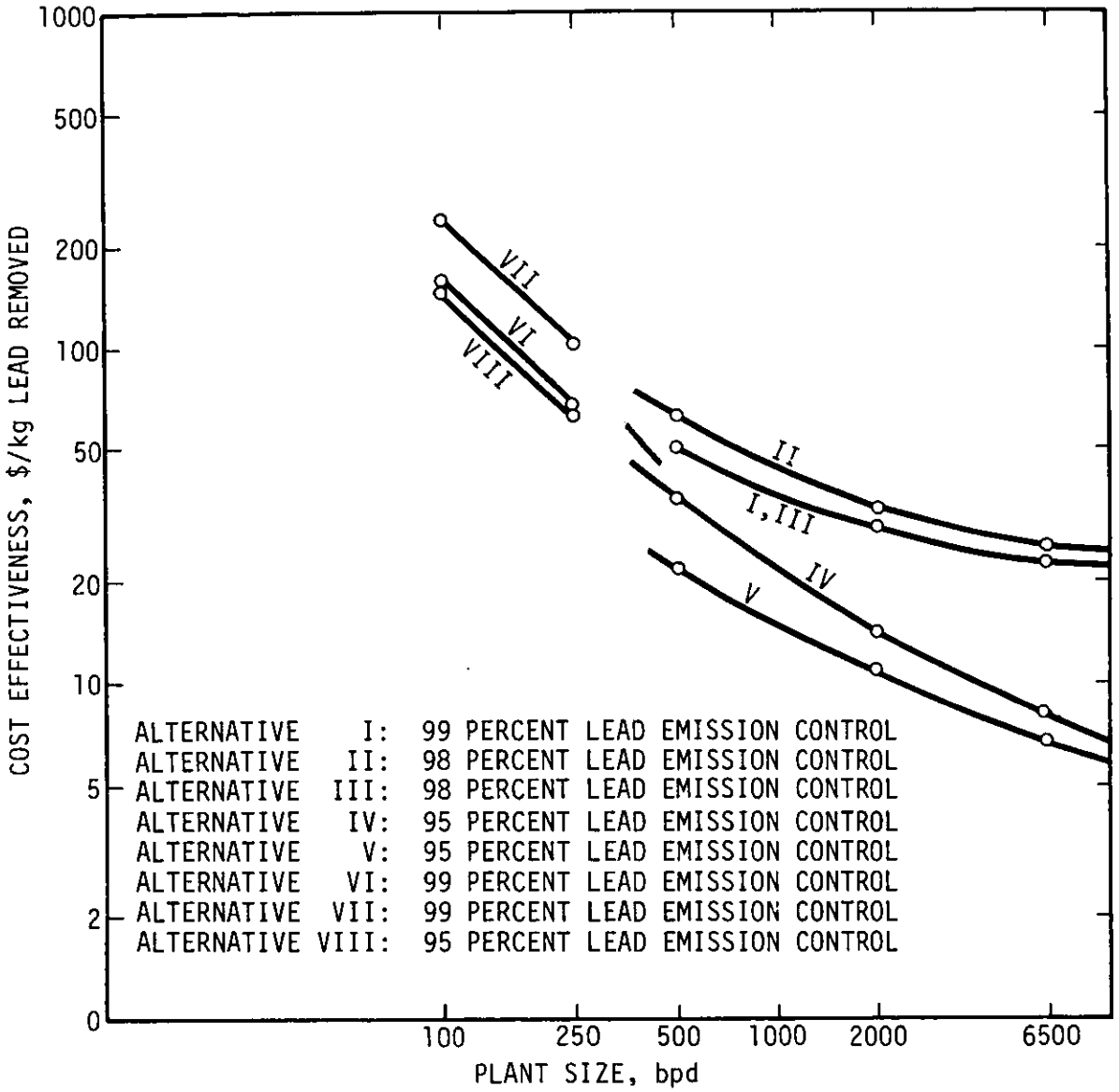

Figure 8-4 Cost-effectiveness of Model Plant Control Alternatives.

Alternative VII and barely above Alternative VIII which represents a much lower efficiency (95 percent). In other words, one would expect Alternatives I, VI, and VII to be less cost-effective (i.e., more costly) than all the others, simply because they require the greatest degree of control. This, however, is not the case in Alternatives I and VI. This situation can be understood if it is remembered that each alternative represents a different group of control systems and for each of these systems there is a different relationship between cost and gas flowrate. For example, the Alternative I costs for the 2000 and 6500 bpd plants include three fabric filters, while the corresponding Alternative II costs include two fabric filters and two impingement and entrainment scrubbers---a total of four lead control systems. Alternative VI is less costly than Alternative VII because the moist mixer gases and the three-process operation exhausts are vented to separate fabric filters. Thus Alternative VI does not require heating as large a fabric filter as does Alternative VII.

Finally, as Figure 8-4 shows, Alternative VIII (at 95 percent) is the most cost-effective for the smallest plants, while Alternative V (95 percent) is the most cost-effective for the 2000 and 6500 bpd plant sizes.

8.3 OTHER COST CONSIDERATIONS

8.3.1 Costs Imposed by Water Pollution Regulations

Effluent limitations, new source standards, and pretreatment standards regulating water emissions from lead-acid battery plants are expected to be proposed in 1980. Upon promulgation of these regulations, existing plants discharging to surface waters will be subject to effluent limitations which will reflect best practicable technology (BPT) currently available. After 1983, these effluent limitations will reflect best available technology (BAT) economically achievable. New battery plants discharging to surface waters will be subject to new source standards which will reflect BAT.

Existing plants discharging to municipal treatment systems will be subject to Federal pretreatment standards which will reflect BPT. New plants discharging to municipal treatment systems will be required to meet Federal pretreatment standards which will be more stringent than those for existing plants.

One study reports that of the 200 lead-acid battery plants in the United States in 1972, approximately 150 were neutralizing their wastewater effluents. Of these 150 plants, about 46 use lime treatment and 14 use caustic treatment.[23] The number of plants applying such treatments will increase rapidly as Federal effluent limitations become effective. The costs associated with water pollution control

are presented in Table 8-44. Wastewater generated by impingement and entrainment scrubbers used to control atmospheric lead emissions would make up only a small percentage of the wastewater generated at a lead-acid battery plant. The additional wastewater would not significantly affect the costs of water treatment. Use of a mist eliminator to control acid mist requires increased water treatment capacity. This extra cost is included with the mist eliminator control costs in Table 8-43.

8.3.2 Costs Imposed by Solid Waste Disposal Regulations

As mentioned earlier, 60 plants were producing wastewater treatment sludges in 1972. These sludges require some type of landfill disposal. Estimated annualized costs for providing solid waste disposal for lime and caustic treatment facilities are presented in Table 8-45 and Table 8-46, respectively. These costs are based on costs applicable to an 1800-BPD plant[24] and scaled to 100, 250, 500, 2000, and 6500 bpd plants by use of the $t^{0.6}$ law.

8.3.3 Costs Associated with OSHA Compliance

The costs of compliance with regulations of the Occupational Safety and Health Administration have been estimated for five factors, as shown in Table 8-47, which also lists the assumptions upon which the compliance cost estimate is based. The 25 batteries/man-day figure is an average based on information obtained from several plant representatives.

Table 8-44. ANNUALIZED COSTS ASSOCIATED WITH WATER POLLUTION CONTROL (4th-Quarter 1977 Dollars)[a]

Degree of control	Annualized costs by plant size, $1000				
	100 bpd[b]	250 bpd[b]	500 bpd[c]	2000 bpd[c]	6500 bpd[c]
Pre-NPDES[d]	2.2	4.5	19.9	60.5	162
Best Practicable Technology, (BPT)[e,f]	18.6	30.6	81.5	169	314
Best Available Technology, (BAT)[e,f]	24.0	40.5	116	262	510

[a] Costs obtained from references were updated per the Chemical Engineering (CE) Index for Plant Costs.

[b] Based on 0.075 m^3 (20.0 gal) water per battery. This represents the mix of wet and dry units typical for small (less than 500 BPD) plants reported to U.S. EPA.

[c] Based on 0.25 m^3 (66.5 gal) water per battery.[25]

[d] Reference 26.

[e] Reference 27.

[f] Since effluent limitations and new source standards for battery manufacturing. have not been proposed, the costs set forth for BPT and BAT are estimates, rather than firm costs.

Table 8-45. ANNUALIZED COSTS ASSOCIATED WITH SOLID WASTE DISPOSAL FOR PLANTS USING LIME NEUTRALIZATION (4th Quarter-1977 Dollars)[a]

Type of disposal	Annualized costs by plant size, $1000				
	100 bpd	250 bpd	500 bpd	2000 bpd	6500 bpd
On-site land storage	4.4	8.7	14.7	41.2	106
On-site land storage with leachate collection and treatment system	6.5	13.6	23.5	67.6	176
Chemical fixation and landfill	15.0	30.5	51.4	150	382

[a] Costs for 1800 bpd were obtained from Reference 28 and scaled to various plant sizes using the $t^{0.6}$ law and updated to 4th quarter-1977 costs per the Chemical Engineering (CE) Index for Plant Costs.

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Table 8-46. ANNUALIZED COSTS ASSOCIATED WITH SOLID WASTE DISPOSAL FOR PLANTS USING CAUSTIC SODA NEUTRALIZATION (4th Quarter-1977 Dollars)[a]

Type of disposal	Annualized costs by plant size, $1000		
	100-500 bpd	2000 bpd	6500 bpd
On-site landfill	<0.5	2.2	5.3
Off-site landfill (contractor)	<0.5	0.9	2.0
Off-site landfill	<0.5	0.9	2.0
Secured landfill	<0.5	1.6	4.0

a Costs for 1800 bpd were obtained from Reference 29 and scaled to various plant sizes using the $t^{0.6}$ law and updated to 4th quarter-1977 costs per the Chemical Engineering (CE) Index for Plant Costs.

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Table 8-47. COST FACTORS AND ASSUMPTIONS FOR OSHA COMPLIANCE (METRIC UNITS)

OSHA Factor	Assumptions upon which estimate is made
Employee care	° 25 batteries/man-day ° $35/employee/mo.
Heat for makeup air	° 4600 degree-days/year ° $3.00/GJ ° Air volumes as follows: 100-bpd plant 600 m^3/min, 8 hr/day 250-bpd plant 730 m^3/min, 8 hr/day 500-bpd plant 1160 m^3/min, 8 hr/day 2500-bpd plant 2580 m^3/min, 16 hr/day 6500-bpd plant 6360 m^3/min, 24 hr/day
Exhaust hoods and ducts	° 457 meters/min velocity ° 122 m ductwork/plant ° annualized costs = 20% of capital costs
Electricity	° $0.03/kWh ° Pressure loss: 1.6 Pa/m duct ° Each plant has four separate systems with overall ΔP of 100 Pa. (including fittings & dampers, etc.)
Fans & motors	° Four equal sized units per plant ° Annualized costs = 30% of capital costs

Table 8-47A. COST FACTORS AND ASSUMPTIONS FOR OSHA COMPLIANCE (ENGLISH UNITS)

OSHA factor	Assumptions upon which estimate is made
Employee care	° 25 batteries/man-day ° $35/employee/mo.
Heat for makeup air	° 4600 degree-days/year ° $3.00/MM Btu ° Air volumes as follows: 100-bpd plant 21,000 cfm, 8 hr/day 250-bpd plant 25,600 cfm, 8 hr/day 500-bpd plant 40,800 cfm, 8 hr/day 2000-bpd plant 91,000 cfm, 16 hr/day 6500-bpd plant 224,000 cfm, 24 hr/day
Exhaust hoods and ducts	° 1500 fpm velocity ° 400 ft ductwork/plant ° annualized costs = 20% of capital costs
Electricity	° $0.03/kWh ° Pressure loss: 0.2 in. W.G./100 lf duct ° Each plant has four separate systems with overall ΔP of 0.4 in. W.G. (including fittings and dampers, etc.)
Fans and motors	° Four equal sized units per plant ° Annualized costs = 30% of capital costs

Simply put, it represents plant capacity divided by plant employees. It is estimated that $35 per employee per month is required for blood tests, laundry, and shower facilities.[30] All the plant air that is exhausted must be made up. In cold climates, this requires the addition of heat. The heating costs are based on 4600 degree days per year (average for St. Louis, Missouri), a fuel cost of $3.00 per MM Btu, and a heat exchange efficiency of 60 percent. If the plant uses propane, the costs will be somewhat higher. The volume of air to be heated corresponds to the exhaust rates shown in Table 8-15. The capital costs of ductwork, hoods, fans, and motors are based on engineering judgment and published data.[31] Likewise, the ventilation system pressure drop, velocity, and length and number of runs are based on engineering judgment. Calculated annualized costs for the control alternatives are approximately 30 percent of the capital costs, (See Tables 8-29 through 8-35) . That percentage value is used for the costs associated with the fans and motors. Since the ductwork and hoods require less maintenance and no operating labor, the associated annualized costs are estimated at 20 percent of the capital costs.

Overall OSHA compliance costs are shown in Table 8-48. These costs do not include the impact of any new regulations

or amendments that OSHA may be considering. Should OSHA adopt more stringent standards, the compliance costs could easily double.

The battery industry has no operations that require the expenditure of funds for noise control.

Table 8-48. ESTIMATED OSHA COMPLIANCE COSTS FOR LEAD-ACID BATTERY MANUFACTURING PLANTS

	Annualized costs, $1000				
OSHA factor	100 bpd	250 bpd	500 bpd	2000 bpd	6500 bpd
Employee care	1.7	4.2	8.4	33.6	109.0
Heat for makeup air	4.1	5.2	8.2	39.4	132.0
Exhaust hoods and ducts	1.6	2.0	2.4	3.6	5.5
Electricity	0.1	0.1	0.2	1.1	4.1
Fans and motors	4.6	4.8	5.6	8.8	18.7
Totals	12.1	16.3	24.8	86.5	269.3

8.3.4 Costs Associated with Compliance Testing

Each source subject to a New Source Performance Standard must undergo a compliance testing program. In the case of lead-acid battery manufacturing plants, the following facilities and pollutants may be affected:

Facility	Pollutant
Grid Casting	Lead
Paste Mixer	Lead
Lead Oxide Manufacturing	Lead
Three-Process Operation	Lead
Lead Reclamation	Lead
Formation	Sulfuric Acid Mist

Concentrations of lead and sulfuric acid mist in well-controlled gas streams from these facilities are very small and extended sampling time is required to gather a measurable sample. For example, it was necessary to sample for 16 straight hours to gather a measurable sulfuric acid mist sample for a test performed under this study. It is estimated that a standard three-run compliance test program will cost approximately $6,000-$7,500 for lead and $10,000-$11,500 for sulfuric acid mist.* These costs include the expenses of a presurvey travel, lodging and report preparation for the test crews. The total impact of these costs are shown in Table 8-49. Except for the fact that smaller plants, for purposes of this study, have fewer Affected Facilities, the test costs are insensitive to plant size. As can be seen, the compliance test program is a large proportion of, and in addition to, the capital costs of the Control Alternatives.

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* The higher cost applied to a single stack test program. The smaller figure applies to any stacks sampled beyond the first stack in a multi-stack test program.

Table 8-49. COMPLIANCE TESTING COSTS APPLICABLE TO NEW SOURCE PERFORMANCE STANDARDS FOR LEAD-ACID BATTERY MANUFACTURING FACILITIES

Control Alternative	Plant Size Range, BPD	No. of Stacks		Total Cost, $1,000
		Pb	H_2SO_4	
I	$\geq$ 500	3	1	29.5
II	$\geq$ 500	4	1	35.5
III	$\geq$ 500	3	1	29.5
IV	$\geq$ 500	4	1	35.5
V	$\geq$ 500	3	1	29.5
VI	< 500	2	1	23.5
VII	< 500	1	1	17.5
VIII	< 500	2	1	23.5

8.3.5 Composite Costs of Environmental Regulatory Requirements

This subsection summarizes the cost impacts of the various environmental regulations discussed earlier and compares these costs with those related to air pollution control. These latter costs consist of costs for SIP compliance and costs related to compliance with an NSPS. Table 8-50 lists the various annualized costs of compliance with environmental regulatory requirements for typical new plants. The costs of compliance source tests, shown in Table 8-49, are not annualized.

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Table 8-50. . ANNUALIZED COSTS OF COMPLIANCE WITH ENVIRONMENTAL REGULATORY REQUIREMENTS FOR TYPICAL NEW LEAD-ACID BATTERY MANUFACTURING PLANTS

Environmental regulatory requirements	Annualized costs by plant size, $1000 4th quarter-1977 dollars				
	100 bpd	250 bpd	500 bpd	2000 bpd	6500 bpd
Water pollution control[a]	24.0	40.5	116	262	510
Solid waste disposal[b]	6.5	13.6	23.5	67.6	176
OSHA	12.1	16.3	24.8	86.5	269
Air pollution control					
SIP[c]	12.9	12.9	36.0	41.0	47.5
NSPS[d]	36.6	43.7	67.5	158	379
Totals	92	127	268	615	1,380

[a] Based on BAT controls.

[b] Assumes lime neutralization of waste and on-site land storage with leachate collection and treatment system.

[c] [SIP-related capital costs ÷ NSPS-related capital costs] x [NSPS-related annualized costs].

[d] Control alternatives I and VI.

8.3.6 Regulatory Agency Manpower Requirements

States are required to adopt regulations for non-criteria pollutants addressed in the Federal standards and to obtain EPA approval of a plan to implement enforcement of these regulations. State and local agencies will be responsible for issuance of construction permits and for compliance verification of new sources. These agencies will be responsible for permits, compliance schedules, enforcement, and compliance verification on existing sources. In addition, agencies will provide periodically updated reports on compliance status and legal matters relative to new and existing sources.

In summary, regulation of sulfuric acid mist emissions under an NSPS adds another pollutant to the list of those to be regulated by state agencies. As a practical matter, it is estimated that particulate matter and sulfur oxides probably require 80 percent of an agency's resources currently. It is further estimated that the remaining 20 percent of their workload will be increased by less than 1/20, giving an estimated net increase of 1 percent in the cost of agency operations. Typical annual budgets for state air programs range from $250,000 to $2 million. Therefore a proposed NSPS for the formation facility in lead battery plants may require an additional cost of $2500 to $20,000 for local agencies.

8.4 ECONOMIC IMPACT OF CONTROL ALTERNATIVES

This section presents an assessment of economic impacts of alternative NSPS lead control systems and sulfuric acid mist control. Integral to this assessment are the NSPS compliance cost data developed in the technical analysis (described in Section 8.2) and the industry economic conditions discussed in Section 8.1 and in this section. The assessment focuses only on incremental cost effects of the regulations which include both sulfuric acid mist control and NSPS lead particulate control. Th scope of the impact analysis if limited to establishments engaged in manufacturing lead-acid storage batteries.

The economic assessment includes an evaluation of the impact of the proposed regularoty alternatives on industry growth and prices. It considers potential impacts on the operations of existing plants, categorized by size, product mix, processes performed, age, and financial status.

As will be shown in the following pages, the incremental cost impact of NSPS regulations on the lead-acid battery industry as a whole will not cause significant economic disruption. The more significant impacts are summarized as follows:

- Increased long-run prices on the order of 1 to 1.5 percent of the average value of battery shipments are predicted.

- Industry volume is projected to grow throughout the period of NSPS introduction at an average annual growth rate of 3.5 percent or more per year. This growth rate will not be significantly affected by a pass-through of NSPS costs.

- Impacts on the lead-acid storage battery manufacturing industry are limited because of the general lack of economically feasible alternative sources (such as imports) or substitutes (alternative energy sources) for the major battery use applications.

- No significant regional, community, or balance of trade impacts are expected as a result of the NSPS regulation.

- The impact of NSPS lead and sulfuric acid mist control on small plants (producing in the range of 100 batteries per day) will be substantial. Return on investment will fall from 11 to 19 percentage points and obtaining financing of control equipment will be difficult. This impact is further aggravated when compliance testing costs are also considered.

Although it is believed that the NSPS regulation in itself will not have a significant effect on the projected baseline conditions of the industry, the complete "package" of governmental regulations, as discussed in Section 8.3, probably will have significant impact. The cumulative cost impact is estimated to be over 5 percent of the value of shipments. The total cost increase may be higher, since a number of these regulatory programs are not yet finalized.

8.4.1 Regulatory Alternatives

In response to the regulations analyzed here, the plant manager will generally have more than one control alternative

available to meet them. Of these, some alternatives will involve higher capital expenditure costs and thus higher total unit costs than others.

Only impacts under Alternative I are reviewed in the analysis of large plants. This alternative was selected because control Alternative I has been determined in section 8.2 to be the best control technology for emission reduction.

For small plants control Alternatives VI and VII represent the best control technology for emission reduction. Alternative VI was selected for analysis because it has lower capital and annualized costs than alternative VII.

The basic economic analysis assumes that NSPS regulations will impact in the following manner:

1. New sources will be subject to the regulations on all facilities. Facilities will be considered reconstructed and will be covered if "(1) the fixed capital cost of the new components exceeds 50 percent of the fixed capital cost that would be required to construct a comparable entirely new facility and (2) it is technologically and economically feasible to meet the applicable standards set forth...". With certain exceptions, "any physical or operational change to an existing facility which results in an increase in the emission rate to the atmosphere of any pollutant to which a standard applies shall be considered a modification..." and the facility will come under NSPS.

2. Based on 1 above, it is assumed that expansion of

any facility at an existing source will be subject to the regulations, no matter how small the resulting increase in capacity. This will result from the reconstruction and modification provisions of the NSPS.

3. Technological improvements at existing sources, whether or not they involve expansion of output capacity, are subject to the NSPS reconstruction and/or modification provisions, under conditions similar to those stated in 2 above.

4. Because of the NSPS definition of "facilities", it is reasonable to assume that all replacement of major capital items at existing plants will fall under NSPS, including cases that involve neither expansion of capacity nor technical upgrading. This is true because replacement would generally be covered under reconstruction. Thus, all facilities at existing plants that continue operations on a long-term basis will eventually fall under NSPS, except insofar as some equipment might effectively be reconstructed through piecemeal expenditures on maintenance and repair.

These assumptions governing interpretation of the regulations have been formulated with the objective of portraying cases having the greatest potential impacts.

The analysis of modified/reconstructed plants assumes a "worst case" analysis, i.e., the replacement/reconstruction of all affected facilities immediately after the promulgation of the regulations. "Worst case" analysis is standard practice

in NSPS economic impact assessments.

8.4.1.1 Limitations of the Analysis

The socio-economic impact analysis in Section 8.4 is subject to the following general limitations:

1. The analysis is based on publicly available information, interviews with selected industry representatives and information obtained in earlier EPA studies. No formal economic survey of lead-acid battery plants was possible, therefore many of the observations about industry conditions and trends are based on qualitative information.

2. Although the analysis is designed to measure incremental cost impacts, no attempt was made to survey existing plants concerning specific SIP, water pollution control or current OSHA requirements, or the current status of compliance with these requirements. All SIP and current OSHA required equipment is assumed to be in place.

8.4.2 Market Impact of NSPS

8.4.2.1 Baseline Industry Expansion

As described earlier, shipments of lead-acid storage battery units increased at an average annual rate of about 5 percent between 1968 and 1977. Although the industry should experience steady growth, the future rate of growth is subject to much speculation. Over-all growth estimates obtained from plants responding to EPA inquiry (Section 114 Letters) range from 40 to 120 percent through 1985. This is a projected average annual rate of 3.5 to 8.2 percent. BCI agrees with

the lower estimate. Responses to EPA's Section 114 Letters indicate that nearly all growth would be realized through expansion of existing larger plants (more than 2000 BPD capacity).

The lead-acid battery industry is intimately tied to the automobile industry, through both the original equipment and replacement battery markets. As such, the industry is strongly dependent on auto production for its economic viability. Expanding auto sales not only stimulate current production of lead-acid batteries, but also production 3 to 4 years in the future when previously purchased automobiles are in need of a replacement battery. Current demand for batteries is dependent on current and previously purchased automobiles, i.e., current automobile sales, sales 3 to 4 years ago, and sales 6 to 8 years ago.

Most of the output expansion in the lead-acid storage battery industry occurs through modifications and additions to existing plants. The major mode of output expansion in the lead-acid storage battery industry since the mid-1950's has been expansion of existing plants in the 1200-4000 BPD range. In late 1974, plants less than 10 years of age comprised only 22 percent of all establishments and accounted for less than 20 percent of lead-acid battery capacity. Larger new plants (with capacities of 1600 BPD or higher) accounted for only 15 percent of estimated industry capacity. By contrast, plants between 10 and 24 years old producing 1200

available to meet them. Of these, some alternatives will involve higher capital expenditure costs and thus higher total unit costs than others.

Only impacts under Alternative I are reviewed in the analysis of large plants. This alternative was selected because control Alternative I has been determined in section 8.2 to be the best control technology for emission reduction.

For small plants control Alternatives VI and VII represent the best control technology for emission reduction. Alternative VI was selected for analysis because it has lower capital and annualized costs than alternative VII.

The basic economic analysis assumes that NSPS regulations will impact in the following manner:

1. New sources will be subject to the regulations on all facilities. Facilities will be considered reconstructed and will be covered if "(1) the fixed capital cost of the new components exceeds 50 percent of the fixed capital cost that would be required to construct a comparable entirely new facility and (2) it is technologically and economically feasible to meet the applicable standards set forth...". With certain exceptions, "any physical or operational change to an existing facility which results in an increase in the emission rate to the atmosphere of any pollutant to which a standard applies shall be considered a modification..." and the facility will come under NSPS.

2. Based on 1 above, it is assumed that expansion of

any facility at an existing source will be subject to the regulations, no matter how small the resulting increase in capacity. This will result from the reconstruction and modification provisions of the NSPS.

3. Technological improvements at existing sources, whether or not they involve expansion of output capacity, are subject to the NSPS reconstruction and/or modification provisions, under conditions similar to those stated in 2 above.

4. Because of the NSPS definition of "facilities", it is reasonable to assume that all replacement of major capital items at existing plants will fall under NSPS, including cases that involve neither expansion of capacity nor technical upgrading. This is true because replacement would generally be covered under reconstruction. Thus, all facilities at existing plants that continue operations on a long-term basis will eventually fall under NSPS, except insofar as some equipment might effectively be reconstructed through piecemeal expenditures on maintenance and repair.

These assumptions governing interpretation of the regulations have been formulated with the objective of portraying cases having the greatest potential impacts.

The analysis of modified/reconstructed plants assumes a "worst case" analysis, i.e., the replacement/reconstruction of all affected facilities immediately after the promulgation of the regulations. "Worst case" analysis is standard practice

to 4000 BPD accounted for about 37 percent of estimated capacity[32].

8.4.2.2 Control Costs

The regulatory alternatives under consideration for the lead-acid battery manufacturing industry include acid mist controls on the dry formation process. If a standard is promulgated for acid mist emissions under Section 111(b) of the Clean Air Act, States would be required to develop standards for acid mist emissions from existing formation processes. In addition, existing plants would be required to meet the NSPS for any facilities which are newly constructed, modified, or reconstructed.

Table 8.51 presents the annual sulfuric acid mist control cost for large existing plants and the cost per battery at capacity and at an 80% operating rate. Capacity is battery production per day multiplied by the number of annual working days (250 working days/year is used). The operating rate is defined as actual production divided by capacity production.

Table 8.51

SULFURIC ACID CONTROL COSTS - EXISTING PLANT

WET/DRY OR DRY FORMING

(In Thousand of Dollars)

	500 BPD	2000 BPD	6500 BPD
Annual Cost	$23.1	$74.9	$123.0
Cost Per Battery at Capacity	$.184	$ .15	$ .077
Cost Per Battery at 80% Capacity	$ .23	$.187	$ .096

Table 8.52 shows the annual sulfuric acid mist control and lead NSPS control costs for plants at capacity and at 80% of capacity, if all plants were to replace their affected facilities or to fall under the reconstructed/modified clause immediately after promulgation of the standard.

Table 8.52

INCREMENTAL ANNUAL SULFURIC ACID MIST AND LEAD NSPS CONTROL COSTS

RECONSTRUCTED/MODIFIED PLANT - CONTROL ALTERNATIVE I

(In Thousand of Dollars)

	500 BPD	2000 BPD	6500 BPD
Annual Cost	$76.7	$192.9	$428.0
Cost Per Battery at Capacity	$ .61	$ .385	$ .261
Cost Per Battery at 80% Capacity	$.767	$ .482	$ .329

Table 8.53 presents the annual control costs for new plants.

Table 8.53

INCREMENTAL ANNUAL SULFURIC ACID MIST AND LEAD NSPS CONTROL COSTS

NEW PLANT - CONTROL ALTERNATIVE I

(In Thousand of Dollars)

	500 BPD	2000 BPD	6500 BPD
Annual Cost	$70.6	$182.9	$407.0
Cost Per Battery at Capacity	$ .56	$ .365	$ .25
Cost Per Battery at 80% Capacity	$.706	$ .456	$ .31

8.4.2.3 Demand Conditions

No quantitative studies of the price elasticity of demand for batteries have been identified during this analysis. Price elasticity of demand is defined as the percent change in sales divided by the corresponding percent price change, and determines the quantitative effect on sales from a change in the price charged for a battery.

Batteries are purchased for replacement of existing batteries and for inclusion in original equipment. In the replacement market the price elasticity of demand for a commodity is determined by the availability of good substitutes for the product, the number of uses to which the product can be put, and the price of the commodity relative to consumer incomes. In the original equipment market, a battery is not purchased per se, but is purchased as part of a larger product (such as an automobile, golf cart or industrial equipment). The elasticity of price demand in this case is determined by the availability of good substitutes for the battery in its use in the final product, the price elasticity of demand for the final product and the ratio of the cost of the battery to the total cost of the product of which it is a part. The smaller the number of good substitutes, the smaller the number of uses to which the product can be put, and the smaller the price of the product relative to consumer's income, the lower is the elasticity of demand for the product.

By the same reasoning the smaller the ratio of the battery's cost to the total cost of the final product of which it is part and the lower the price elasticity of the final product, the more inelastic is the demand for the product. Of these factors the availability of adequate substitutes is the most important to price elasticity. In the automobile industry, the major market for lead-acid batteries, there is currently no adequate substitute for the battery, either in its original, new car application or in its battery replacement application. While there are some potential substitutes, these have not as yet proved generally feasible for use. In fact research is being conducted on the development of lead-acid battery powered electric vehicles.

The cost of a battery relative to the total cost of the final product of which it is part is small; e.g. at $40 per battery, the battery price is only .8% of the price of a $5,000 car. If the battery price should double, the price of a car would only increase 0.8%. For these reasons the price elasticity of demand for lead-acid batteries is likely to be inelastic, i.e. a change in price brings about a less-than-proportionate change in sales.

On the whole, when the original equipment and replacement markets are considered together, the price elasticity of demand for lead-acid batteries is likely to be inelastic. The effect of this is that the industry as a whole can pass through the control cost with little effect on sales volume.

However, some smaller plants will not be able to capture all of the cost because they will be competing in the same market as larger plants whose control costs are lower on a per battery basis. For example, while the 6500 BPD plant may be able to recapture all of its control costs, the 2000 BPD plant will be able to capture only a portion of its control costs (the same amount as the larger producer is passing through) in some markets, e.g., the large retail accounts. In those markets where it is shipping to distributors and his competition is similar or smaller size plants, the 2000 BPD plant will be able to pass through the entire cost per battery. The 500 BPD plant will be constrained in the same manner as the smaller plants considered in Section 8.4.4.

8.4.2.4 Price Effects

Long-Run Market Price Response to NSPS

The long-run increase in battery prices resulting from NSPS will be determined by the total incremental unit costs applicable to newly built, economically efficient, production units entering the industry. Over the long-run, industry output can be maintained only through the construction of entirely new plants. The entry and retirement of lead-acid battery plants historically has proceeded at a very slow pace; this long-run adjustment of facilities and operations could take 20 years or more. Over an horizon of 5 to 10 years,

adjustment of output will be accomplished primarily by modifications and expansions of existing plants that are, or can become, economically efficient. Since battery production is dominated by the 2000 BPD and larger plants, and since the cost pass-through of smaller plants will be constrained, the medium long-term market price increase will probably be in the $.30 to $.40 price per battery range. This represents from 1.6% to 2.2% of the estimated 1976 manufacturer's price of approximately $18 per auto battery and about 1 to 1.5% of auto battery prices at retail.*

Short-Run Response of Market Price to NSPS

In the short-run, existing battery plants will have to meet only the sulfuric acid mist control standard. The relatively minor long-term battery price increase resulting from NSPS should be mitigated by the gradual pace at which the regulations will become effective. Since the regulations affect existing plants only insofar as they expand, modernize, or replace major equipment items, operating costs will not increase at these plants (as a result of NSPS) until they undertake such investments. Over time, the number and output of plants that have not expanded and replaced equipment will steadily decline. Many of the plants that make replacements will do so on a facility-by-facility basis and thus will incur the incremental NSPS costs gradually. The full price increase attributable to NSPS should become effective only when the

*Estimate obtained from those plants responding to EPA inquiry (Section 114 letters).

total potential output from (a) plants that have not made replacements or expansions in all of their facilities, and (b) new fully reconstructed plants is insufficient to meet the expanding demand for batteries.

8.4.2.5 Growth Effects

The impact on industry growth should not be significant. The 1 to 1.5% increase in price at retail will be effected over a number of years. In the original equipment market the demand for batteries should show little or no decrease and will continue to be primarily dependent on the cyclical nature of the auto industry. In the replacement market demand may be more sensitive to price. Any decrease in smaller company production will be accomodated by expanded production from larger companies. In this way the control costs can be spread over an even larger production. An increase of 1 to 1.5% in the price of a battery will not stimulate faster research into alternative products to the lead-acid battery and it should remain the only feasible product in its many applications for the foreseeable future.

8.4.3 Other Costs

Although the NSPS regulations alone should have a relatively minor impact on battery industry prices and output, their implications are more serious when considered as part of a package of government regulations. The industry either recently has, or shortly will, incur significant additional capital and operating expenditures due to water pollution

control, solid waste disposal, new OSHA regulations and lead ambient air regulations. As these expenditures (which generally neither increase output nor reduce manufacturing costs) will all be required of the industry within a few years, the major adverse impacts arising from their cumulative force will be difficult to assess in terms of the individual regulatory components.

The overall impact of these regulations on the industry is likely to be significant. Cumulative annual costs of BAT water pollution costs and solid wastes costs, as shown in Table 8.50 for the 2000 BPD plant, represent 3.1 percent of the estimated 1976 manufacturer's price of $18. Cumulative costs will be significantly higher at plants where current OSHA and SIP regulations are not now being met.

8.4.4 Impact on Small Plants

8.4.4.1 Introduction

As noted earlier in section 8.1, approximately 50 percent of the plants in the lead-acid battery industry produce fewer than 500 BPD. Because small plants are such a large portion of the industry and because small plants are generally affected more severely than large firms, two small plant sizes have been selected, 100 BPD and 250 BPD, for a detailed analysis of the economic impact of both the sulfuric acid mist control costs and the incremental NSPS lead control costs.

Small lead acid battery plants have a number of production and marketing characteristics which distinguish them

from larger battery producers. Most of these smaller plants have all of the production capabilities of the larger firms with the exception of lead oxide production and lead reclamation; i.e., these firms have parts casters, grid casters, paste mixers, three process (3-P) operation and formation capability. These firms will be referred to here as "manufacturers". A smaller segment (approximately 31 plants) produces lead acid batteries without the capability of producing and pasting grids. These firms, referred to here as "assemblers", generally have only the 3-P and formation capability. In effect the assemblers purchase all of the parts required for a battery and assemble them into a finished battery.

Another distinguishing characteristic of the small battery producers is the manner in which they form (charge) batteries. There are two processes available for forming the battery: wet formation and dry formation. Few, if any, small plants are dry forming all of their batteries. Most plants which have dry formation also have wet formation capability. The majority of plants have only wet formation capability.

Most independent small firms are one-plant operations and specialize in producing either Starting, Lighting and Ignition (SLI) batteries or industrial batteries, though some plants either allot a small amount of production or purchase for resale the type in whose production they are

not specializing. Both SLI and industrial batteries are available in numerous sizes, and industrial batteries are generally larger than SLI batteries. The production processes required to produce SLI and industrial batteries are the same. There are only slight differences in the major pieces of necessary equipment. The distinguishing characteristic is the size of the plates. Industrial batteries require larger plates which are produced by using larger grid casting molds on the casting machine. The amount of paste on the plate may also be greater on some industrial batteries. In some cases industrial batteries are custom-made to meet the client demand and, in such cases, the small firm will also typically service the batteries after sale. The majority of small plants, however, specialize in the production of SLI batteries.

Although the small plants serve several markets, their major market segments are large and small fleet accounts such as bus and truck companies and local government. Sales are also made to warehouse distributors and to off-the-street customers. Different markups are applied to each market segment.

As was seen in Section 8.4.2.4, the average battery price of large producers taken from Section 114 letters was $18 per battery. For small producers the average price used in the calculations which follow is $27. This difference in price is probably explained in the lower production costs of large manufacturers and the fact that smaller plants can receive

larger markups because of the markets they serve. Battery distribution is generally performed only regionally and transportation costs prohibit a plant from distributing to larger geographical markets. Small plants deliver to accounts higher up in the marketing chain and deliver directly to their clients so that they receive the entire markup applied to these market segments.

Most industry representatives do not forecast construction of new small plants. Demand will be accommodated from existing plants which replace their facilities. For this reason the economic impact discussion which follows is based on those plants which will reconstruct/modify their existing facilities. Replacement of existing facilities will constitute a reconstruction.

8.4.4.2 Methodology

This section will describe the general methodology used to measure the economic impact on small plants.

The economic impact is evaluated by developing model plants based on representative characteristics of small lead acid battery producers. As will be seen, these characteristics include production capabilities, asset size and other financial characteristics. The models do not represent any particular firm as any individual firm will differ in one or more of these characteristics. The models are meant to provide an indication of the degree of impact on all firms by incorporating in the model the major charcteristics prevailing in this segment of the industry.

Eight model plants are considered here as follows: each of the two model size plants, 100 BPD and 250 BPD, are distinguished by two production capabilities, manufacturing and assembling. A further distinction is made on the basis of the formation capability, i.e., whether the batteries are formed wet or both wet and dry. Dry formation alone is not included because no small plant using dry formation only was identified in field investigations and during interviews with industry representatives.

These distinctions, in addition to plant size, are included in the analysis for two reasons:

- Costs associated with NSPS lead control* will differ between manufacturers and assemblers.
- Costs associated with sulfuric acid mist control will differ between wet and dry forming plants.

Since assemblers do not have casting and pasting capability, no incremental lead control costs are imposed on them for these processes and the economic impact differs between assemblers and manufacturers. Since control costs for sulfuric acid mist will be imposed primarily on dry forming plants,** control costs are higher for these plants

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*Lead control costs are incremental control costs, i.e., costs over and above that required for meeting SIP.

**The recommended standards for formation operations are written for "any formation process which forms before the battery is completely assembled (including installation of battery filler cups) or which forms over a period of less than 24 hours". Most wet formation processes will occur in a period over 24 hours.

and, therefore, the economic impact will differ between plants on this account.

The regulatory alternatives under consideration for the lead-acid battery industry include acid mist controls on the dry formation process. Should a standard be promulgated for acid mist emissions under section 111(b) of the Clean Air Act, States would be required to develop standards for acid mist emissions from existing formation processes. For this reason sulfuric acid mist control costs are analyzed individually on existing plants. They are also analyzed with lead NSPS control costs on reconstructed/modified plants because reconstructed/modified plants will also have to meet sulfuric acid mist control in the absence of a specific NSPS for sulfuric acid.

The first step in the analysis requires establishing the total assets of each size plant before the imposition of sulfuric acid mist or lead controls. This result provides "baseline" conditions upon which the return on investment (ROI)* is calculated. Total assets will consist of fixed assets after depreciation and current assets.

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*Defined as (Earnings Before Tax)/(Total Assets); the ROI indicates the investment efficiency of the plant.

The second step estimates the current earnings and profit rate for both manufacturers and assemblers in each of the selected size plants before imposition of the incremental control costs. This procedure is necessary in order to be able to measure the effect of the incremental control costs on earning and, therefore, ROI and the ability of the firm to finance these costs.

The next step uses the total assets from step 1, earnings level from step 2 and the control costs developed in Section 8.2 to determine the ROI before and after incremental control costs are required. This ROI analysis has been conducted for three different scenarios:

- For existing wet/dry forming plants from sulfuric acid mist control alone.
- Lead and sulfuric acid mist control for wet/dry forming reconstructed/modified plants who would be replacing all of their facilities immediately.
- Lead control for wet forming reconstructed/modified plants who would be replacing all of their facilities immediately.

In order to complete this analysis, attention has been given to the fraction of the increase in cost of production due to controls that could be recouped through increased prices (cost pass-through) and the amount that would have to be absorbed. The manner in which the cost pass-through was derived is explained in section 8.4.4.5.

The final step involves the evaluation of the capability of firms to finance the control equipment which is needed to meet the standard. This capability is estimated for two scenarios, a "worst case" situation where no control cost could be passed through, and where a portion of the cost as established in the preceding step could be passed through. This financing capability is based on determining the debt coverage* for each firm after incremental control costs are imposed, i.e., the ability of their annual cash flow** to support repayment of control equipment debt in addition to existing debt repayment.

8.4.4.3 Baseline Economics

Table 8.54 shows the total assets of existing lead-acid battery manufacturing and assembling plants forming by both the wet and dry process. Fixed investment consists of the equipment, land and building required for production in each size and type of plant in addition to OSHA and SIP control equipment. Current values for equipment and building were deflated to 1967 values by use of the Chemical Engineering equipment and machinery index and the Engineering News-Record building index, respectively, to develop historical equipment and building costs.

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*Defined as (Annual Cash Flow)/(Annual Debt Repayment).

**The term cash flow is used as an abbreviation for "net funds inflow from operations". Since we are using earnings before interest and taxes it is not comparable to the traditional use of the term cash flow which is computed by adding depreciation to net earnings without adding back interest expense.

Table 8.54

BASELINE ECONOMICS

CAPITAL INVESTMENT FOR EXISTING LEAD-ACID BATTERY PLANTS

WET AND DRY FORMATION

(In Thousand of Dollars)

	Manufacturing		Assembling	
	100 BPD	250 BPD	100 BPD	250 BPD
Fixed Investment				
Casting	$ 15.0	$ 24.5	$ -	$ -
Pasting	6.7	10.0	-	-
3-P Process	10.0	11.6	10.0	11.6
Formation	12.5	17.5	12.5	17.5
Land	15.0	20.0	15.0	10.0
Building	68.6	101.8	60.0	98.3
Other Fixed Investment				
OSHA	23.3	26.0	15.8	15.4
SIP - particulates	35.0	35.0	-	-
Total Fixed Investment	$186.1	246.4	113.3	152.8
Accumulated Depreciation[1]	54.1	77.1	32.0	46.0
Fixed Investment After Depreciation	132.0	169.3	81.3	106.8
Current Assets[2]	132.0	169.3	81.3	106.8
Total Assets Before Control	$264.0	$338.6	$162.6	$213.6

[1]Building at .25 ; process equipment at .66; OSHA, SIP at .133.

[2]At 100% of fixed investment after depreciation.

Deflation of equipment and building values was necessary because existing plants whose facilities had been purchased in the past were analyzed and current depreciation is dependent on this historical purchase price. Accumulated depreciation was subtracted to derive fixed investment after depreciation. Accumulated depreciation is based on process equipment being depreciated by 66%, building by 25% and OSHA and SIP equipment by 13.3%. Only the major pieces of equipment were included in the asset base. The process equipment in this industry has a long useful life span, 25 to 30 years or more.

Many plants visited had fully depreciated their equipment while others had newer equipment, i.e., less than 10 years old. The average age of equipment was taken to be 10 years old and depreciated at 6.6% per year to yield accumulated depreciation of 66%. The age of the building tends to vary greatly from plant to plant and the 25% rate, used as representative of the industry, is based on a 10 year old building being depreciated at 2.5% per year. OSHA and SIP control equipment is assumed to have been put in place two years ago so that with a useful life of 15 years 13.3% of the cost is depreciated.

In the ROI analysis that follows, ROI before control appears high relative to other industries. This stems from two factors: the first is characteristic of the industry, the second is dependent on the manner in which models are constructed. Small plant production is labor intensive relative to the amount of capital required for production. This

labor intensity can be shown by the labor cost per battery relative to depreciation cost per battery. Figures which were developed during this analysis show a relationship of labor cost to capital cost per battery of approximately 10 to 1. Even if capital costs were doubled so that a 5 to 1 ratio prevailed this would still indicate labor intensity. Because of the high value added by labor, ROI will tend to be high relative to industries where larger capital requirements are necessary for production. The second reason for these seemingly high ROI figures arises from the small total asset base (ROI = net earnings/total assets) which was used. Our model asset parameters include only the major pieces of equipment and plant required for production. Ancillary equipment such as fork lift trucks, delivery trucks, office furniture, and minor pieces of equipment such as a number of different sized casting molds were excluded. Also excluded were additional warehouse space which a number of larger small plants have in different locations. For these reasons the asset base is low and the ROI developed is high relative to what would be shown if a complete inventory of fixed assets were included. This qualification does not negate the impact which will be shown in the following analysis.

In order to derive total assets, current assets had to be added to fixed assets after depreciation. Current assets are based on 100% of fixed assets after depreciation. While

this rate cannot be as fully substantiated as the other rates, one firm visited has current assets of 135% of fixed assets after depreciation but the building was carried as a personal asset of the owner.

Table 8.55 shows the baseline economics for plants with only wet formation capability and is constructed in the same manner as Table 8.54. The principal difference in Table 8.55 from Table 8.54 is fixed investment in formation equipment. Wet forming requires less investment in equipment than wet and dry forming together. Accumulated depreciation is therefore changed as are current assets. The total assets before control for wet forming plants is shown in the last row of Table 8.55. Both current OSHA and SIP investment costs are assumed fully in place and are included in the total asset base.

8.4.4.4 Estimated Earnings Before Control

Tables 8.56 and 8.57 indicate, for manufacturing and assembling plants, respectively, the estimated earnings before imposition of sulfuric acid mist and lead incremental control costs. In these tables, revenue is based on an operating rate of 80% and a battery price of $27. The operating rate is based on information supplied through interviews with plant owners, and varies from 50 to 100%. The battery price is calculated from a price list of 23 types of SLI batteries supplied by a firm to different market segments such as warehouses, fleets and off-the-street sales. Since prices vary by market segment

Table 8.55

BASELINE ECONOMICS

CAPITAL INVESTMENT FOR EXISTING LEAD-ACID BATTERY PLANTS

WET FORMATION ONLY

(In Thousand of Dollars)

	Manufacturing		Assembling	
	100 BPD	250 BPD	100 BPD	250 BPD
Fixed Investment				
Casting	$ 15.0	$ 24.5	$ -	$ -
Pasting	6.7	10.0	-	-
3-P Process	10.0	11.6	10.0	11.6
Formation	5.0	7.5	5.0	7.5
Land	15.0	20.0	15.0	20.0
Building	68.5	106.8	60.0	98.3
Other Fixed Investment				
OSHA	23.3	26.0	15.8	15.4
SIP - particulates	35.0	35.0	-	-
Total Fixed Investment	$178.5	241.4	105.8	152.8
Accumulated Depreciation[1]	49.3	60.1	26.0	39.2
Fixed Investment After Depreciation	129.2	181.3	79.8	113.6
Current Assets[2]	129.2	181.3	79.8	113.6
Total Assets Before Control	$258.4	$362.6	$159.6	$227.2

[1]Building at .25; process equipment at .66 ; OSHA, SIP at .133.

[2]At 100% of fixed investment after depreciation.

Table 8.56

ESTIMATED FINANCIAL DATA

for

SMALL LEAD-ACID BATTERY MANUFACTURING PLANTS[1]

BEFORE NSPS LEAD AND SULFURIC ACID MIST CONTROLS

	Model Plant Size	
	100 BPD	250 BPD
Revenue[2]	$540,000	$1,350,000
Operating Expenses	$470,400	$1,168,500
Earnings Before Taxes	$ 69,600	$ 181,500
Earnings Rate Before Taxes	12.9%	13.4%
Taxes[3]	$ 20,400	$ 74,100
Earnings After Taxes	$ 49,200	$ 107,400
Earnings Rate After Taxes	9.1%	8.0%

[1]For Wet and Wet/Dry Formation.

[2]Based on operating rate of 80% and battery price of $27.00 per battery.

[3]Calculated at 22% of first $50,000 and 48% on remainder of earnings before taxes rather than at official rate of 20% of first $25,000, 22% of next $25,000 and 48% of remainder over $50,000.

Table 8.57

ESTIMATED FINANCIAL DATA

for

SMALL LEAD-ACID BATTERY ASSEMBLING PLANTS[1]

BEFORE NSPS LEAD AND SULFURIC ACID MIST CONTROLS

	Model Plant Size	
	100 BPD	250 BPD
Revenue[2]	$540,000	$1,350,000
Operating Expenses	$487,400	$1,215,500
Earnings Before Taxes	$ 52,600	$ 134,500
Earnings Rate Before Taxes	9.7%	10.0%
Taxes[3]	$ 12,200	$ 51,600
Earnings After Taxes	$ 40,400	$ 82,900
Earnings Rate After Taxes	7.5%	6.1%

[1]For Wet and Wet/Dry Formation.

[2]Based on operating rate of 80% and battery price of $27.00 per battery.

[3]Calculated at 22% of first $50,000 and 48% on remainder of earnings before taxes rather than at official rate of 20% of first $25,000, 22% of next $25,000 and 48% of remainder over $50,000.

due to the discount/markup structure, an average price for different types of batteries sold to each market segment was developed. This price was then weighted by the corresponding share of the market segment to derive a weighted average price of SLI batteries for small plants.

Operating expenses have been calculated from information supplied at various interviews. Cost of production is derived from data such as the amount of lead necesary for each part, miscellaneous supplies such as battery cases, labor manhours per battery and wage rates provided during interviews. Delivery and utility costs are included and plant and equipment depreciation determined from the baseline economics. Plant was depreciated at the rate of 2.5% per year and equipment at 6.6% per year. An overhead charge of 40% of labor cost is also included. Earnings before taxes is the difference between revenue and operating expenses. Applicable Federal tax rates are used to derive earnings after taxes. The percent earnings before tax are in the range of 8 to 15% which are supported by data obtained during field interviews.

8.4.4.5 Return on Investment (ROI) Impact

As discussed in Section 8.4.4.1 sulfuric acid mist control will affect all plants doing any dry forming of batteries. Table 8.58 shows the decline in ROI from sulfuric acid mist control on those small plants doing a combination of wet and dry forming. Data included in Table 8.58 are derived as follows: Earnings before tax is taken from Tables 8.56 and 8.57

Table 8.58

RETURN ON INVESTMENT IMPACT

SMALL LEAD-ACID BATTERY PLANTS

COST PASS-THROUGH

(In Thousand of Dollars)

Type of Plant	Existing
Type of Formation	Wet and Dry
Type of Control	Sulfuric Acid Mist

	Manufacturing		Assembling	
	100 BPD	250 BPD	100 BPD	250 BPD
Earnings Before Tax	$ 69.6	$181.5	$ 52.6	$134.5
Total Assets	$264.0	$338.6	$162.6	$213.6
ROI Before Control	26.4%	53.5%	32.3%	62.9%
Total Annualized Control Cost	$ 9.0	$ 14.7	$ 9.0	$ 14.7
Control Cost Per Battery[1]	$ .45	$ .29	$ .45	$ .29
Cost Pass Through	$ .26	$ .26	$ .26	$ .26
Earnings Before Tax and After Control[2]	$ 65.8	$180.0	$ 48.8	$133.0
Total Assets After Control	$278.4	$368.6	$177.0	$243.6
ROI After Control	23.6%	48.8%	27.6%	54.6%

[1]At 80% operating rate.

[2]After total annualized control cost absorbed subtracted.

and total assets from Table 8.54. The annual sulfuric acid mist control cost is taken from Table 8.43 and is divided by the number of batteries produced at an 80% operating rate (250 working days per year is used in calculating annual production) to yield control cost per battery. The cost pass-through per battery, which will be developed further below, is determined in Table 8.59.

Earnings before tax and after control is determined by subtracting total annualized control cost absorbed from earnings before control. In the case of the 100 BPD manufacturer, $0.19 per battery is absorbed ($0.45-$0.26) or $3,800 so that earnings before control is reduced by $3,800 ($65,800 = $69,600 - $3,800).

Table 8.59 presents the derivation of the cost pass-through of $0.26 per battery after sulfuric acid mist controls. Because there are few adequate substitutes for lead-acid batteries in the SLI category, the industry as a whole should be able to pass on part or all of the control cost which it has to incur without a significant impact to its earnings potential. However, the smaller operations must compete with larger companies in various markets. Because control cost is lower for larger producers the small operators cannot pass on the entire amount of their cost increase without incurring losses in their market segments.

Table 8.51 in Section 8.4.2.2 showed the sulfuric acid mist control cost per battery at capacity and at an 80% operating rate for the 500, 2000 and 6500 BPD manufacturer. The

Table 8.59

COST PASS-THROUGH PER BATTERY

SULFURIC ACID MIST CONTROL ONLY

EXISTING PLANTS

Description of Market	Large Plant Price Increase	Markup With Respect to Warehouse, Charged by Small Plant	Distribution of Small Plant Sales By Market	Partial Pass Through By Market
• Warehouse	$.20	--	.1	$.02
• Large Fleets	.20	1.25	.4	.10
• Small Fleets	.20	1.33	.4	.11
• Off-the-Street Retail	.20	1.45	.1	.03
Total Average Cost Pass Through per Battery				$.26

main cost pass-through restraint to the small producer is taken to be the manufacturer in the 2000 BPD area. The 6500 BPD operator is generally selling to the large OEM markets and to large retail accounts. A $.20 per battery cost pass-through is assumed which is slightly larger than the 2000 BPD operator's at an 80% operating rate.

The major market for the smaller battery companies, including the 500 BPD operator, are fleet accounts. In this market, the small plants are faced with competition from the larger producers, i.e., through warehouse distributors who handle the larger companies' batteries and market them to fleet accounts. Therefore the control cost which the larger producers incur is inflated in the battery price to fleet accounts by the distributors' markup. Although price competition prevails, there are significant non-price reasons, (such as faster delivery time, better credit arrangements and ability to service the batteries) for the fleet account's preference for the small plant.

The small firms can then pass through $.20 per battery to their lowest price client, which is the warehouse. But since the market share to this market is only 10% of production, the control cost captured is only $.02 per battery taken over all production. The market shares are meant to represent the model plant's distribution of sales to various market segments. As can be seen the bulk of sales is to the fleet accounts. From the warehouse price the small plant will

generally markup his price 25% to large fleet accounts or $0.25. Therefore, with 40% of sales going to this account $0.10 per battery of the control cost is captured taken over all production.

With these various market shares and markups, the small operator can recapture an estimated $0.26 of the $0.45 per battery control cost.

The 100 BPD manufacturer and assembler must therefore absorb $0.19 per battery of the sulfuric acid mist control cost and the 250 BPD manufacturer and assembler $0.03 per battery. Table 8.58 shows that ROI declines after control. For both manufacturer and asembler this decline is not substantial with sulfuric acid mist control alone.

Table 8.60 shows the ROI impact of both sulfuric acid mist control and NSPS lead control if the operators replace all of the affected facilities immediately after the standards are promulgated. The total assets with new investment are determined from Table 8.54 by adding total assets before control to new investment in process equipment. New investment cost is based on the current market price of the process equipment for the affected facilities: casting, pasting, three process (3-P) operation, and formation. The annual control cost is taken from Table 8-38, Alternative VI for lead and Table 8-43 for sulfuric acid mist control.

The combination of NSPS lead and sulfuric acid mist control costs increase the control cost per battery substantially from sulfuric acid mist control alone. The cost pass-

Table 8.60

RETURN ON INVESTMENT IMPACT

SMALL LEAD-ACID BATTERY PLANTS

COST PASS-THROUGH

(In Thousand of Dollars)

Type of Plant	Reconstructed/Modified
Type of Formation	Wet and Dry
Type of Control	Sulfuric Acid Mist and NSPS Lead

	Manufacturing		Assembling	
	100 BPD	250 BPD	100 BPD	250 BPD
Earnings Before Tax	$ 69.6	$181.5	$ 52.6	$134.5
Total Assets	$352.6	$465.9	$207.7	$271.9
ROI Before Control	19.7%	39.0%	25.3%	49.5%
Total Annualized Control Cost	$ 41.8	$ 49.6	$ 40.2	$ 47.7
Control Cost Per Battery[1]	$ 2.09	$ .99	$ 2.01	$ .95
Cost Pass Through	$ .574	$ .574	$ .574	$ .574
Earnings Before Tax and After Control[2]	$ 33.4	$152.2	$ 20.9	$111.8
Total Assets After Control	$474.0	$609.9	$324.1	$409.9
ROI After Control	7.0%	25.0%	6.4%	27.2%

[1]At 80% operating rate.

[2]After control cost absorbed and equipment depreciation subtracted.

through per battery under this condition, calculated in Table 8.61, is taken from Table 8.52 and is slightly above the cost per battery for the 2000 BPD plant at an 80% operating rate. The manner in which effective cost pass-through is determined in Table 8.61 is the same as that used above in Table 8.59, i.e., by market-segment analysis. The cost pass-through for Table 8.61 is used in Table 8.60 to calculate earnings impact after controls due to absorbed costs. The ROI declines for all situations analyzed in Table 8.60 for NSPS lead and sulfuric acid mist controls taken together show a range of from 12 to 22 percent.

Table 8.62 indicates the ROI impact on small plants forming batteries by the wet process only. These plants would incur only NSPS lead control. Annual control cost in Table 8.62 is taken from Table 8.38. Other entries are derived in a manner similar to that described above for Tables 8.58 and 8.60. Immediate replacement of all of their affected facilities after the initiation of the standard would decrease the ROI by 10 to 11 percentage points for manufacturers and by 16 to 17 percentage points for assemblers.

As Table 8.58 indicates, all existing wet/dry forming plants should be able to meet the sulfuric acid mist control standard without incurring severe economic impacts. Declines in ROI range from 3 to 8 percentage points and the resulting ROI after control is sufficiently high relative to alternative investment opportunities to permit continued operation in the industry.

Table 8.61

COST PASS-THROUGH PER BATTERY

SULFURIC ACID MIST AND NSPS LEAD CONTROLS

EXISTING PLANTS

Description of Market	Large Plant Price Increase	Markup With Respect to Warehouse, Charged by Small Plant	Distribution of Small Plant Sales By Market	Partial Pass Through By Market
• Warehouse	$.45	--	.1	$.045
• Large Fleets	.45	1.25	.4	.225
• Small Fleets	.45	1.33	.4	.239
• Off-the-Street Retail	.45	1.45	.1	.065
Total Average Cost Pass Through per Battery				$.574

Table 8.62

RETURN ON INVESTMENT IMPACT

SMALL LEAD-ACID BATTERY PLANTS

COST PASS-THROUGH

(In Thousand of Dollars)

Type of Plant	Reconstructed/Modified
Type of Formation	Wet
Type of Control	NSPS Lead

	Manufacturing		Assembling	
	100 BPD	250 BPD	100 BPD	250 BPD
Earnings Before Tax	$ 69.6	$181.5	$ 52.6	$134.5
Total Assets	$332.0	$469.9	$189.7	$265.5
ROI Before Control	21.0%	38.6%	27.7%	50.7%
Total Annualized Control Cost	$ 32.8	$ 34.9	$ 31.2	$ 33.0
Control Cost Per Battery[1]	$ 1.64	$ .70	$ 1.56	$ .66
Cost Pass Through	$ .574	$ .574	$ .574	$ .574
Earnings Before Tax and After Control[2]	$ 43.4	$168.0	$ 30.9	$127.6
Total Assets After Control	$439.0	$583.9	$291.7	$373.5
ROI After Control	9.9%	28.7%	10.5%	34.1%

[1]At 80% operating rate.

[2]After control cost absorbed and equipment depreciation subtracted.

Although most small plants are using only the wet forming process, there will be certain cases where a wet forming small plant is competing in the same area as a wet/dry forming small plant. In this case the wet forming plant will have a competitive advantage over the wet/dry forming plant.

The wet/dry forming plant operator may have to decide whether to completely absorb the contol cost or to discontinue dry forming. To completely absorb the control cost will decrease ROI another 2.0%, from 23.6% to 21.7% for the 100 BPD manufacturer. Since dry forming is likely to be a minor portion of battery production,* the more likely alternative may be to discontinue dry forming production.

8.4.4.6 Control Equipment Financing Capability

This section presents an analysis of the potential ability of plants to obtain financing for the required control equipment necessary to meet the standards. The analysis is based on the debt coverage ratio which shows the ability of annual cash flows to repay existing and new debt incurred. Debt coverage is an objective means of determining a firm's ability to repay a loan, but financial institutions also look at management capability, long-term relationship between the company and the financial institution, etc. These evaluations can only be made on a case-by-case basis and cannot be analyzed here.

*In the few plants where this combination was observed, dry forming ranged from 10% to 30% of production.

In Table 8.63 Earnings Before Interest and Taxes (EBIT) after control is derived by taking the earnings before tax figure from Tables 8.56 and 8.57 and adding back interest on existing debt and new process equipment debt, where applicable. Annual control cost exclusive of interest is then subtracted. Since existing debt is composed of both long term liabilities of a year or longer (in most cases 5 to 20 year duration) and short term debt of a term less than a year, interest on existing debt was calculated by using a 10% interest rate on debt of an average 10 year duration, a capital recovery factor [CRF] of .16275. Interest on control equipment was based on a CRF of .132, 10% interest over 15 years. The annual interest used was the annual average over the term of the loan. Depreciation is the sum of annual depreciation of the building and process equipment, added to annual depreciation of the control equipment. Annual cash flow is the summation of EBIT and depreciation.

Annual debt repayment consists of debt items which must be paid from company funds - principal and interest for existing control equipment and new process equipment debt, where applicable. The annual interest and principal are taken as the annual average over the term of the debt. The principal for each category was converted to the pretax amount which is needed to yield an after-tax outlay equal to the fixed charge for each category of debt.* This was required in

*The tax rate used was the effective tax rate as calculated from Tables 8.56 and 8.57.

Table 8.63

FINANCIAL CAPABILITY ANALYSIS

OF SMALL LEAD-ACID BATTERY PLANTS

ASSUMING NO COST PASS-THROUGH

(In Thousand of Dollars)

Type of Plant	Existing
Type of Formation	Wet and Dry
Type of Control	Sulfuric Acid Mist

	Manufacturing		Assembling	
	100 BPD	250 BPD	100 BPD	250 BPD
EBIT After Control	$ 71.3	$179.4	$ 50.7	$128.4
Depreciation After Control[1]	$ 8.1	13.5	5.5	9.9
Annual Cash Flow	79.4	192.9	56.2	138.3
Total Assets	$264.0	$338.6	$162.6	213.6
Debt Obligations Before Control[2]	132.0	169.3	81.3	103.6
Annual Debt Repayment[3]				
Existing Debt	26.4	39.7	23.5	23.3
Control Equipment Debt	2.2	5.2	2.2	5.1
Total Annual Debt Repayment	28.6	44.9	25.7	28.4
Debt Coverage[4]	2.8	4.3	2.2	4.9

[1]Building at .025; equipment at .066; OSHA, SIP and new control equipment at .066.
[2]At 50% of total assets before controls.
[3]CRF = 0.16275 for existing debt; = 0.132 for control equipment debt.
[4]Annual cash flow/total annual debt repayment.

order to bring it to a basis comparable to that of the tax deductible fixed charges. Annual interest for each category is then added to the converted principal amount, summed for each category and compared to cash flow to determine the adequacy of cash flow to cover the debt repayment.

As Table 8.63 shows annual cash flow for all size plants for sulfuric acid mist control in the "worst case"* situation is adequate to support both existing debt and control equipment debt repayment.

Table 8.64 presents the financial capability of reconstructed/modified plants to support both sulfuric acid mist and NSPS lead control costs in the worst case situation. In this scenario plants must not only be able to support existing and control equipment debt repayment but also new process equipment debt repayment which engenders the lead control costs. New equipment debt is based on 100% financing of the affected process facilities. New equipment debt is based on a CRF of .132, 10% interest over 15 years. For this scenario the annual cash flow is barely sufficient to cover debt repayment for both the 100 BPD manufacturer and assembler. Financial institutions would not be very likely to grant financing of the control equipment under these conditions, and the plant would have to look elsewhere such as the Small Business Administration for financing.

*Described here as without any cost pass-through.

Table 8.64

FINANCIAL CAPABILITY ANALYSIS

OF SMALL LEAD-ACID BATTERY PLANTS

ASSUMING NO COST PASS-THROUGH

(In Thousand of Dollars)

Type of Plant	Reconstructed/Modified
Type of Formation	Wet and Dry
Type of Control	Sulfuric Acid Mist and NSPS Lead

	Manufacturing		Assembling	
	100 BPD	250 BPD	100 BPD	250 BPD
EBIT After Control	$ 53.8	$160.1	$ 30.9	$108.1
Depreciation After Control[1]	$ 19.3	24.6	13.2	16.2
Annual Cash Flow	73.1	184.7	44.1	124.3
Total Assets with New Investment	$352.6	$465.9	$207.7	$271.9
Debt Obligations Before Control	221.0	296.6	126.4	158.6
Existing Debt[2]	132.4	169.3	81.3	103.6
New Equipment Debt[3]	88.6	127.3	45.1	55.0
Annual Debt Repayment[4]				
Existing Debt	26.6	39.7	15.6	23.3
New Equipment Debt	13.7	17.7	6.7	9.2
Control Equipment Debt	18.3	23.4	17.6	22.7
Total Annual Debt Repayment	58.6	80.8	39.9	55.2
Debt Coverage[5]	1.2	2.3	1.1	2.3

[1]Building at .025; equipment at .066; OSHA, SIP and new control equipment at .066.
[2]At 50% of total assets before new investment, same as Table 8.54.
[3]At 100% financing.
[4]CRF = 0.16275 for existing debt; = 0.132 for new equipment and control equipment debt.
[5]Annual cash flow/total annual debt repayment.

Debt coverage for reconstructed/modified wet formation plants is improved when NSPS lead controls are considered alone (Table 8.65). Nevertheless, both the 100 BPD manufacturer and assembler will still be unlikely to finance the new process and control equipment.

No financial capability analysis was performed for sulfuric acid mist controls alone with partial cost pass-through because in the worst case situation (as depicted in Table 8.63) the cash flow was sufficient to support debt repayment. The analysis performed for sulfuric acid mist and NSPS lead controls together (Table 8.66) and NSPS lead controls alone (Table 8.67) with partial cost pass-through shows that both the 100 BPD manufacturer and assembler would still have a difficult time in obtaining financing based on consideration of debt coverage ratios alone.

In the "worst case" situation, sulfuric acid mist control equipment financing should be possible for all existing plants, even if all the control cost must be absorbed. The 250 BPD plants should be able even in the worst case situation to obtain financing from financial institutions. Their debt coverage is sufficient to allow institutions to grant financing.

The 100 BPD plants are not likely to be able to obtain financing in the worst case situations. With partial cost pass-through of $.574 per battery financing should still prove difficult, particularly so for the plants incurring

Table 8.65

FINANCIAL CAPABILITY ANALYSIS

OF SMALL LEAD-ACID BATTERY PLANTS

ASSUMING NO COST PASS-THROUGH

(In Thousand of Dollars)

Type of Plant	Reconstructed/Modified
Type of Formation	Wet
Type of Control	NSPS Lead

	Manufacturing		Assembling	
	100 BPD	250 BPD	100 BPD	250 BPD
EBIT After Control	$ 59.9	$175.4	$ 37.2	$120.8
Depreciation After Control[1]	$ 17.4	21.3	11.2	13.1
Annual Cash Flow	77.3	196.7	48.4	133.9
Total Assets with New Investment	$332.0	$469.9	$189.7	$265.5
Debt Obligations Before Control	213.2	288.6	109.9	151.9
Existing Debt[2]	139.6	181.3	79.8	113.6
New Equipment Debt[3]	73.6	107.3	30.1	38.3
Annual Debt Repayment[4]				
Existing Debt	28.3	41.4	16.9	25.0
New Equipment Debt	11.5	18.5	4.6	6.3
Control Equipment Debt	16.3	19.4	15.2	18.0
Total Annual Debt Repayment	56.1	79.3	36.7	49.3
Debt Coverage[5]	1.4	2.5	1.3	2.7

[1]Building at .025; equipment at .066; OSHA, SIP and new control equipment at .066.
[2]At 50% of total assets before control, same as Table 8.55.
[3]At 100% financing.
[4]CRF = 0.16275 for existing debt; = 0.132 for new equipment and control equipment debt.
[5]Annual cash flow/total annual debt repayment.

Table 8.66

FINANCIAL CAPABILITY ANALYSIS

OF SMALL LEAD-ACID BATTERY PLANTS

WITH PARTIAL COST PASS-THROUGH[1]

(In Thousand of Dollars)

Type of Plant	Reconstructed/Modified
Type of Formation	Wet and Dry
Type of Control	Sulfuric Acid and NSPS Lead

	Manufacturing		Assembling	
	100 BPD	250 BPD	100 BPD	250 BPD
EBIT After Control	$ 65.3	$189.8	$ 41.9	$136.8
Depreciation After Control[2]	$ 19.3	24.6	13.2	16.2
Annual Cash Flow	85.6	214.4	55.1	153.0
Total Assets with New Investment	$352.6	$465.9	$207.7	$271.9
Debt Obligations Before Control	220.4	296.6	126.5	159.3
Existing Debt[3]	131.8	169.3	81.3	103.6
New Equipment Debt[4]	88.6	127.3	45.1	55.7
Annual Debt Repayment[5]				
Existing Debt	26.6	39.7	15.6	23.3
New Equipment Debt	13.7	17.7	6.7	9.2
Control Equipment Debt	18.3	23.4	17.6	22.7
Total Annual Debt Repayment	58.6	80.8	39.9	55.2
Debt Coverage[6]	1.5	2.7	1.4	2.8

[1]Cost pass through of $.574 per battery.
[2]Building at .025; equipment at .066; OSHA, SIP and new control equipment at .066.
[3]At 50% of total assets before control, same as Table 8.54.
[4]At 100% financing.
[5]CRF = 0.16275 for existing debt; = 0.132 for new equipment and control equipment debt.
[6]Annual cash flow/total annual debt repayment.

Table 8.67

FINANCIAL CAPABILITY ANALYSIS

OF SMALL LEAD-ACID BATTERY PLANTS

WITH PARTIAL COST PASS-THROUGH[1]

(In Thousand of Dollars)

Type of Plant	Reconstructed/Modified
Type of Formation	Wet
Type of Control	NSPS Lead

	Manufacturing		Assembling	
	100 BPD	250 BPD	100 BPD	250 BPD
EBIT After Control	$ 71.4	$204.1	$ 48.7	$149.5
Depreciation After Control[2]	$ 17.4	21.3	11.2	13.1
Annual Cash Flow	88.8	223.4	59.9	162.6
Total Assets with New Investment	$332.0	$469.9	$189.7	$265.5
Debt Obligations Before Control	213.2	288.6	109.9	151.9
Existing Debt[3]	139.6	181.3	79.8	113.6
New Equipment Debt[4]	73.6	107.3	30.1	38.3
Annual Debt Repayment[5]				
Existing Debt	28.3	41.4	16.9	25.0
New Equipment Debt	11.5	18.5	4.6	6.3
Control Equipment Debt	16.3	19.4	15.2	18.0
Total Annual Debt Repayment	56.1	79.3	36.7	49.3
Debt Coverage[6]	1.6	2.8	1.6	3.3

[1]Cost pass through of $.574 per battery.
[2]Building at .025; equipment at .066; OSHA, SIP and new control equipment at .066.
[3]At 50% of total assets before control, same as Table 8.55.
[4]At 100% financing.
[5]CRF = 0.16275 for existing debt; = 0.132 for new equipment and control equipment debt.
[6]Annual cash flow/total annual debt repayment.

both sulfuric acid mist and lead NSPS control costs. In the latter case it is likely that the wet/dry forming plant may consider discontinuing dry formation as this would enhance debt coverage and possible ability to finance the lead control equipment.

The preceding analysis was based on an operating rate of 80 percent. If conditions for individual 100 BPD plants should allow them to operate closer to capacity, their debt coverage would be improved, though not substantially.

For both sulfuric acid mist and lead control together or lead control alone, obtaining financing is still problematic for the 100 BPD plant.

8.4.4.7 Compliance Testing Costs

Sulfuric acid mist and lead particulate compliance testing costs for manufacturers and assemblers are shown in Table 8.68. Tables 8.69 to 8.76 show the ROI impact and financing capability for existing and reconstructed/ modified plants when compliance testing cost is considered in addition to the equipment control cost.

The testing costs were assumed to be 100 percent financed at 10 percent interest over 7 years. The CRF of .20541 was then applied to determine the annualized cost for testing. This cost was applied to the ROI and financial capability tables exclusive of testing costs.

As can be seen in the Summary table in section 8.4.4.9, testing costs aggravate the impacts facing all size plants.

The 100 BPD manufacturers and assemblers facing both sulfuric acid mist and NSPS lead control or NSPS lead control alone experience an even lower ROI. Their ability to finance control equipment and testing costs together is further deteriorated.

Table 8.68

COMPLIANCE TESTING ANNUALIZED COSTS

SMALL PLANTS

Plant Description	Testing Costs[1]
Sulfuric Acid Mist	
(Wet/Dry Existing)	
Manufacturing	$11,500
Assembling	$11,500
Sulfuric Acid Mist and NSPS Lead	
(Wet/Dry Reconstructed)	
Manufacturing	$23,500
Assembling	$17,500
NSPS Lead	
(Wet Reconstructed)	
Manufacturing	$13,500
Assembling	$ 7,500

[1]Costs are independent of plant size but depend on emission being tested and number of stacks tested.

Table 8.69

RETURN ON INVESTMENT IMPACT

SMALL LEAD-ACID BATTERY PLANTS

COST PASS-THROUGH

TESTING COST INCLUDED

(In Thousand of Dollars)

Type of Plant	Existing
Type of Formation	Wet and Dry
Type of Control	Sulfuric Acid Mist

	Manufacturing		Assembling	
	100 BPD	250 BPD	100 BPD	250 BPD
Earnings Before Tax	$ 69.6	$181.5	$ 52.6	$134.5
Total Assets	$264.0	$338.6	$162.6	$213.6
ROI Before Control	26.4%	53.6%	32.3%	63.0%
Total Annualized Control Cost	$ 11.4	$ 17.1	$ 11.4	$ 17.1
Control Cost Per Battery[1]	$ .57	$ .34	$ .57	$ .34
Cost Pass Through	$ .26	$ .26	$ .26	$ .26
Earnings Before Tax and After Control[2]	$ 63.4	$177.5	$ 46.4	$130.5
Total Assets After Control	$278.4	$368.6	$177.0	$243.6
ROI After Control	22.7%	48.1%	26.2%	53.6%

[1]At 80% operating rate.

[2]After control cost and testing cost absorbed and equipment depreciation subtracted.

Table 8.70

RETURN ON INVESTMENT IMPACT

SMALL LEAD-ACID BATTERY PLANTS

COST PASS-THROUGH

TESTING COST INCLUDED

(In Thousand of Dollars)

Type of Plant	Reconstructed/Modified
Type of Formation	Wet and Dry
Type of Control	Sulfuric Acid Mist and NSPS Lead

	Manufacturing		Assembling	
	100 BPD	250 BPD	100 BPD	250 BPD
Earnings Before Tax	$ 69.6	$181.5	$ 52.6	$134.5
Total Assets	$352.6	$465.9	$207.7	$271.9
ROI Before Control	19.8%	39.0%	25.3%	49.5%
Total Annualized Control Cost	$ 46.6	$ 54.6	$ 43.8	$ 51.7
Control Cost Per Battery[1]	$ 2.33	$ 1.09	$ 2.19	$ 1.03
Cost Pass Through	$ .574	$ .574	$ .574	$ .574
Earnings Before Tax and After Control[2]	$ 28.6	$147.2	$ 17.3	$107.8
Total Assets After Control	$474.0	$609.9	$324.1	$409.9
ROI After Control	6.0%	24.1%	5.3%	26.3%

[1]At 80% operating rate.

[2]After control cost and testing cost absorbed and equipment depreciation subtracted.

Table 8.71

RETURN ON INVESTMENT IMPACT

SMALL LEAD-ACID BATTERY PLANTS

COST PASS-THROUGH

TESTING COST INCLUDED

(In Thousand of Dollars)

Type of Plant	Reconstructed/Modified
Type of Formation	Wet
Type of Control	NSPS Lead

	Manufacturing		Assembling	
	100 BPD	250 BPD	100 BPD	250 BPD
Earnings Before Tax	$ 69.6	$181.5	$ 52.6	$134.5
Total Assets with New Investments	$332.0	$469.9	$189.7	$265.5
ROI Before Control	21.0%	38.6%	27.7%	50.7%
Total Annualized Control Cost	$ 35.6	$ 37.4	$ 32.7	$ 34.5
Control Cost Per Battery[1]	$ 1.78	$ .75	$ 1.64	$ .69
Cost Pass Through	$ .574	$ .574	$ .574	$ .574
Earnings Before Tax and After Control[2]	$ 40.6	$165.5	$ 29.3	$126.1
Total Assets After Control	$439.0	$583.9	$291.7	$373.5
ROI After Control	9.2%	28.3%	10.0%	33.7%

[1]At 80% operating rate.

[2]After control cost and testing cost absorbed and equipment depreciation subtracted.

Table 8.72

FINANCIAL CAPABILITY ANALYSIS

OF SMALL LEAD-ACID BATTERY PLANTS

WORST CASE SITUATION[1]

TESTING COST INCLUDED

(In Thousand of Dollars)

Type of Plant	Existing
Type of Formation	Wet and Dry
Type of Control	Sulfuric Acid Mist

	Manufacturing		Assembling	
	100 BPD	250 BPD	100 BPD	250 BPD
EBIT After Control	$ 69.7	$177.8	$ 49.1	$126.8
Depreciation After Control[2]	$ 8.1	13.5	5.5	9.9
Annual Cash Flow	77.8	191.3	54.6	136.7
Total Assets	$264.0	$338.6	$162.6	$213.6
Debt Obligations Before Control[3]	132.4	169.3	81.3	103.6
Annual Debt Repayment[4]				
Existing Debt	26.4	39.7	23.5	23.3
Control Equipment Debt	5.3	8.7	5.1	8.5
Total Annual Debt Repayment	31.7	48.4	28.6	31.8
Debt Coverage[5]	2.5	4.0	1.9	4.3

[1]Assuming no cost pass-through.
[2]Building at .025; equipment at .066; OSHA, SIP and new control equipment at .066.
[3]At 50% of total assets before control, same as Table 8.55.
[4]CRF = 0.16275 for existing debt; = 0.132 for control equipment debt.
[5]Annual cash flow/total annual debt repayment.

Table 8.73

FINANCIAL CAPABILITY ANALYSIS

OF SMALL LEAD-ACID BATTERY PLANTS

WORST CASE SITUATION[1]

TESTING COST INCLUDED

(In Thousand of Dollars)

Type of Plant	Reconstructed/Modified
Type of Formation	Wet and Dry
Type of Control	Sulfuric Acid Mist and NSPS Lead

	Manufacturing		Assembling	
	100 BPD	250 BPD	100 BPD	250 BPD
EBIT After Control	$ 50.5	$156.8	$ 28.5	$105.7
Depreciation After Control[2]	$ 19.3	24.6	13.2	16.2
Annual Cash Flow	69.8	181.4	41.7	121.9
Total Assets with New Investment	$352.6	$465.9	$207.7	$271.9
Debt Obligations Before Control	220.4	296.6	126.4	158.6
Existing Debt[3]	131.8	169.3	81.3	103.6
New Equipment Debt[4]	88.6	127.3	45.1	55.0
Annual Debt Repayment[5]				
Existing Debt	26.6	39.7	15.6	23.3
New Equipment Debt	13.7	17.7	6.7	9.2
Control Equipment Debt	24.4	30.5	22.0	27.8
Total Annual Debt Repayment	64.7	87.9	44.3	60.3
Debt Coverage[6]	1.1	2.1	0.9	2.0

[1]Assuming no cost pass-through.
[2]Building at .025; equipment at .066; OSHA, SIP and new control equipment at .066.
[3]At 50% of total assets before control, same as Table 8.55.
[4]At 100% financing.
[5]CRF = 0.16275 for existing debt; = 0.132 for new equipment and control equipment debt.
[6]Annual cash flow/total annual debt repayment.

Table 8.74

FINANCIAL CAPABILITY ANALYSIS

OF SMALL LEAD-ACID BATTERY PLANTS

WORST CASE SITUATION[1]

TESTING COST INCLUDED

(In Thousand of Dollars)

Type of Plant	Reconstructed/Modified
Type of Formation	Wet
Type of Control	NSPS Lead

	Manufacturing		Assembling	
	100 BPD	250 BPD	100 BPD	250 BPD
EBIT After Control	$ 58.0	$173.5	$ 36.2	$119.8
Depreciation After Control[2]	$ 17.4	21.3	11.2	13.1
Annual Cash Flow	75.4	194.8	47.4	132.9
Total Assets with New Investment	$332.0	$469.9	$189.7	$265.5
Debt Obligations Before Control	213.2	288.6	109.9	151.9
Existing Debt[3]	139.6	181.3	79.8	113.6
New Equipment Debt[4]	73.6	107.3	30.1	38.3
Annual Debt Repayment[5]				
Existing Debt	28.3	41.4	16.9	25.0
New Equipment Debt	11.5	18.5	4.6	6.3
Control Equipment Debt	24.4	30.5	22.0	27.8
Total Annual Debt Repayment	64.2	90.4	43.5	59.1
Debt Coverage[6]	1.2	2.2	1.1	2.2

[1]Assuming no cost pass-through.
[2]Building at .025; equipment at .066; OSHA, SIP and new control equipment at .066.
[3]At 50% of total assets before control, same as Table 8.55.
[4]At 100% financing.
[5]CRF = 0.16275 for existing debt; = 0.132 for new equipment and control equipment debt.
[6]Annual cash flow/total annual debt repayment.

Table 8.75

FINANCIAL CAPABILITY ANALYSIS

OF SMALL LEAD-ACID BATTERY PLANTS

WITH PARTIAL COST PASS-THROUGH[1]

TESTING COST INCLUDED

(In Thousand of Dollars)

Type of Plant	Reconstructed/Modified
Type of Formation	Wet and Dry
Type of Control	Sulfuric Acid Mist and NSPS Lead

	Manufacturing		Assembling	
	100 BPD	250 BPD	100 BPD	250 BPD
EBIT After Control	$ 62.0	$186.5	$ 39.5	$134.4
Depreciation After Control[2]	$ 19.3	24.6	13.2	16.2
Annual Cash Flow	81.3	211.1	52.7	150.6
Total Assets with New Investment	$352.6	$465.9	$207.7	$271.9
Debt Obligations Before Control	220.4	296.6	126.4	159.3
Existing Debt[3]	131.8	169.3	81.3	103.6
New Equipment Debt[4]	88.6	127.3	45.1	55.7
Annual Debt Repayment[5]				
Existing Debt	26.6	39.6	15.6	23.3
New Equipment Debt	13.7	17.7	6.7	9.2
Control Equipment Debt	24.4	30.5	22.0	27.8
Total Annual Debt Repayment	64.7	87.8	44.3	60.3
Debt Coverage[6]	1.3	2.4	1.2	2.5

[1]Cost pass through of $.574 per battery.
[2]Building at .025; equipment at .066; OSHA, SIP and new control equipment at .066.
[3]At 50% of total assets before control, same as Table 8.55.
[4]At 100% financing.
[5]CRF = 0.16275 for existing debt; = 0.132 for new equipment and control equipment debt.
[6]Annual cash flow/total annual debt repayment.

Table 8.76

FINANCIAL CAPABILITY ANALYSIS

OF SMALL LEAD-ACID BATTERY PLANTS

WITH PARTIAL COST PASS-THROUGH[1]

TESTING COST INCLUDED

(In Thousand of Dollars)

Type of Plant	Reconstructed/Modified
Type of Formation	Wet
Type of Control	NSPS Lead

	Manufacturing		Assembling	
	100 BPD	250 BPD	100 BPD	250 BPD
EBIT After Control	$ 69.5	$202.2	$ 47.7	$148.5
Depreciation After Control[2]	$ 17.4	21.3	11.2	13.1
Annual Cash Flow	86.9	223.5	58.9	161.6
Total Assets with New Investment	$332.0	$469.9	$189.7	$265.5
Debt Obligations Before Control	213.2	288.6	109.9	151.9
Existing Debt[3]	139.6	181.3	79.8	113.6
New Equipment Debt[4]	73.6	107.3	30.1	38.3
Annual Debt Repayment[5]				
Existing Debt	28.3	41.4	16.9	25.0
New Equipment Debt	11.5	18.5	4.6	6.3
Control Equipment Debt	19.6	23.2	17.0	20.1
Total Annual Debt Repayment	59.4	83.1	38.5	51.4
Debt Coverage[6]	1.5	2.7	1.5	3.1

[1]Cost pass through of $.574 per battery.
[2]Building at .025; equipment at .066; OSHA, SIP and new control equipment at .066.
[3]At 50% of total assets before control, same as Table 8.55.
[4]At 100% financing.
[5]CRF = 0.16275 for existing debt; = 0.132 for new equipment and control equipment debt.
[6]Annual cash flow/total annual debt repayment.

8.4.4.8 Other Cost Considerations

Not considered in the previous analysis were solid waste costs, water pollution costs and costs associated with meeting the recently established Occupational Safety and Health Administration's (OSHA) 50 $\mu g/m^3$ lead-inair standard. All of these costs will have to be met in the future.

Annual solid waste costs are given in Tables 8.45 and 8.46. Plants discharging wastewater to navigable waters will be subject to effluent limitations when these are promulgated. However, most plants are located in urban areas, and are probably discharging to municipal sewers. The majority of plants will, therefore, be subject to pretreatment standards.

The pretreatment standard is expected to be the same as the BPT standard. Table 8.77 compares the control cost estimated to meet the BPT standards* (which should be similar to pretreatment costs) and the control cost required to meet the NSPS lead control standard. The pretreatment cost for assemblers would be the same as shown for manufacturers. As can be seen these costs approach and, in the case of the 250 BPD wet/dry plant, exceed the lead control costs. No cost estimate is available for meeting the 50 $\mu g/m^3$ OSHA standard in the lead acid battery industry.

When these anticipated costs are imposed on small plants the effects shown for the 100 BPD operator will be aggravated.

*Costs for wet forming plants from Table 8.44. For wet/dry forming calculated from Table 8.44.

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Plants larger than 100 BPD will begin to show the same decline of ROI to low levels and a similar decline in debt coverage ratios.

Table 8.77

COMPARISON OF CONTROL COSTS FOR PRETREATMENT AND NSPS LEAD

ANNUALIZED CONTROL COSTS

(In Thousands of Dollars)

	Wet Forming Manufacturing		Wet/Dry Forming[1] Manufacturing	
	100 BPD	250 BPD	100 BPD	250 BPD
Pretreatment	$18.6	$30.6	$29.7	$48.8
NSPS Lead (Reconstructed/ Modified plants)	32.8	34.9	32.8	34.9

[1] Based on 80% of production wet, 20% dry.

8.4.4.9 Conclusion

Table 8.78 shows a summary of the economic impacts which were discussed in previous sections. As can be seen, existing wet/dry plants which have to meet sulfuric acid mist control should be able to meet the standard without incurring significant impacts. ROI* does not decrease drastically and their debt coverage remains adequate to obtain financing after control costs are incurred.

*It should be reiterated here that these ROI figures in Table 8.78 are high for reasons cited in section 8.4.4.3.

Table 8.78

SUMMARY OF ECONOMIC IMPACTS

Plant Description	ROI Before Control	ROI After Control	ROI After Control and Testing	Debt Coverage (After Control)[1]	Debt Coverage After Control and Testing[1]
Sulfuric Acid Mist (Wet/Dry Existing)					
Manufacturing					
100 BPD	26.4%	23.6%	22.7%	2.8	2.5
250 BPD	53.5	48.8	48.1	4.3	4.0
Assembling					
100 BPD	32.3	27.6	26.2	2.2	1.9
250 BPD	62.9	54.6	53.6	4.9	4.3
Sulfuric Acid Mist and NSPS Lead (Wet/Dry Reconstructed)					
Manufacturing					
100 BPD	19.7	7.0	6.0	1.5	1.3
250 BPD	39.0	25.0	24.1	2.7	2.4
Assembling					
100 BPD	25.3	6.4	5.3	1.4	1.2
250 BPD	49.5	27.2	26.3	2.8	2.5
NSPS Lead (Wet Reconstructed)					
Manufacturing					
100 BPD	21.0	9.9	9.2	1.6	1.5
250 BPD	38.6	28.7	28.3	2.8	2.7
Assembling					
100 BPD	27.7	10.5	10.0	1.6	1.5
250 BPD	50.7	34.1	33.7	3.3	3.1

[1]With partial cost pass through except for sulfuric acid mist control alone where no cost pass through is assumed.

Though ROI declines by 15 percentage points for the 250 BPD wet/dry reconstructed manufacturing plants and 23 percentage points for the assembling plants meeting both sulfuric acid mist control and NSPS lead control, their ROI is still sufficiently high (even if the calculated asset base were doubled) relative to alternative investments for them to remain in the industry. Obtaining financing for control equipment and testing costs should also prove possible based on their debt coverage ratio. The 100 BPD plant is unlikely to be able to finance the required control equipment and may be unwilling to remain in the industry with the depressed ROI which develops after control, even with some cost pass through.

The 250 BPD wet reconstructed plants who have to meet only the NSPS lead control standard are less severely impacted than the wet/dry plants in all respects. In only having to meet NSPS lead standard, their ROI and debt coverage are both adequate and higher than the wet/dry plant. The 100 BPD wet plant would be in a situation after control where he may also consider leaving the industry. With his debt coverage of 1.5 it should not prove possible to obtain conventional financing.

Another financing possibility for the 100 BPD operator is to seek financing through the SBA. Long-term, low interest loans for control equipment, which may include process changes as control methods, will enable him to spread his annual capital cost burden over a longer time span.

In the preceding analysis it was assumed that all affected facilities, namely, casting, pasting and the 3-P operation, would be replaced simultaneously shortly after the promulgation of the standards, and, therefore, would all require NSPS controls at the same time. It is felt that this is very unlikely to happen in reality.

A number of realistic alternatives exist for the small operator even after the promulgation of lead and sulfuric acid mist regulations. The small operator could continue and is likely to utilize his existing process equipment without substantial reconstruction or replacement up to a point in the future when the equipment maintenance costs become prohibitive. At that time his market position is likely to dictate his strategy. Should his business sales be expanding the small plant management could then decide to replace each affected facility over a period of time. This strategy would insure that the incurring of control costs would take place over a period of time and at his own convenience and would mitigate the ROI and cash flow problems shown in previous sections. Should his sales be constant or decreasing he could decide to discontinue battery production entirely and expand the service part of the business, or to become a distributor of larger companies batteries. In certain cases where the plant is in a stronger financial position and where the market is somewhat protected by transportation costs or product specialization, the company may attempt to expand to spread the control costs over a larger sales base.

With each of the alternatives listed above, the economic impact of the NSPS lead standard will be felt gradually over a long period of time instead of immediately after the promulgation of the standard, and all at once, as depicted in the analysis above.

As mentioned in Section 8.4.4.5, the wet/dry plant has the option of discontinuing dry formation to avoid the sulfuric acid mist control. This cost cannot be postponed, however, because it applies to existing plants as well as to new and reconstructed/modified plants. When pretreatment water pollution control costs are also considered, the incentive to discontinue dry production becomes even more pronounced for the small plant.

Thus, the impact of NSPS lead and sulfuric acid mist regulations is to generally favor a status-quo in terms of exisitng plant equipment. New plants are not expected to be built with capacities of 500 BPD or less, and any replacement, reconstruction or modification of an existing plant can be so structured as to minimize a one-time, immediate, significant economic impact projected in the preceding analysis, and to spread it out at the discretion of the plant management.

There is no data on the size distribution of the approximately 91 small plants. Most assemblers, though, would probably be in the 100 BPD area so that minimum estimate of the number of small plants which would be severely impacted is approximately 30.

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9.0 RATIONALE FOR THE PROPOSED STANDARDS

9.1 SELECTION OF SOURCE FOR CONTROL

The largest single use of lead in the United States is in the manufacture of lead-acid, or secondary, storage batteries. There are approximately 190 lead-acid storage battery manufacturing plants in the United States.[1] Projections of growth rate in the lead-acid battery industry range from 3 to 5 percent annually over the next 5 years.

Facilities at lead-acid battery plants emit lead-bearing and non-lead-bearing particulates, and sulfuric-acid mist. Both lead and sulfuric acid mist have been determined to be health related pollutants. Total lead emissions from the industry in 1975 were estimated to be about 82 Mg (90 tons), or about 0.4 percent of the total atmospheric lead emissions from stationary sources in the United States. Most lead-acid battery plants are located near residential areas. Therefore, under the provisions of Section 111(b)(1)(A) of the Clean Air Act, as amended, the Administrator has included the lead-acid battery industry as an air pollution source category which may reasonably be anticipated to endanger public health or welfare.

9.2 SELECTION OF POLLUTANTS AND AFFECTED FACILITIES

9.2.1 Selection of Pollutants

Lead-acid battery plants emit both lead-bearing and nonlead-bearing particulate matter from lead oxide production, grid casting, paste mixing, lead reclamation and assembling facilities. As mentioned earlier, it has

been determined that lead is a health related pollutant. Atmospheric dispersion modeling was used to estimate maximum ambient concentrations of lead in the vicinity of lead-acid battery plants. The results of this study are discussed in detail in Section 7.1.1.1. The estimated annual ambient impacts of 500 and 6500 bpd plants controlled only to the extent required by existing State regulations are 4 $\mu g/m^3$ and 8 $\mu g/m^3$, respectively. The National Ambient Air Quality Standard for lead is 1.5 $\mu g/m^3$ on a quarterly basis. For this reason, and because most lead-acid battery plants are located near residential areas, standards are proposed for the lead fraction of the particulate emissions. The reduction of lead emissions to the levels of the proposed standards at affected 500 and 6500 bpd plants would result in the reduction of the average annual ambient impacts of lead emissions from these plants to less than 1 $\mu g/m^3$.

Standards are not proposed for the nonlead fraction of particulate emissions for two reasons. First, such emissions are slight. Second, limitation of the lead emissions will also reduce emissions of other particulates.

In addition to lead-bearing particulate matter, plants using dry formation techniques emit sulfuric acid mist. This mist results from the entrainment of sulfuric acid in hydrogen bubbles which are generated during the formation process. Wet formation takes place in covered battery cases. Therefore, acid mist emissions from wet formation are small. Two literature sources indicate acid mist emission rates from dry formation of 14 Kg (30 lb) and 19 Kg (42 lb) per 1000 batteries.[2,3]

Because sulfuric acid mist has been determined to be a health related pollutant, the Administrator considered proposing standards for the lead-acid battery manufacturing industry which would limit acid mist emissions

as well as lead emissions. If the emission rate measured by EPA for dry formation had been as high as the rates presented in the literature, there may have been cause to propose acid mist standards. However, EPA tests or dry formation at one plant indicate that the sulfuric acid mist emission rate from this facility is only about 1.1 Kg per 1000 batteries (see Section 7.1.2). Dispersion modeling studies based the results of EPA emission tests indicate that the maximum ambient impact of sulfuric acid mist emissions from the dry formation process at a plant as large as 6500 batteries per day would be less than 1 $\mu g/m^3$. Therefore, standards for acid mist are not being proposed at this time.

EPA is required to review new source performance standards at least every four years, and, if appropriate, revise them. Thus, new source performance standards for lead-acid battery manufacture may be revised in the future to include standards limiting sulfuric acid mist emissions.

9.2.2 Applicability

The proposed standards of performance would apply to facilities at any lead-acid battery plant that has a production capacity greater than or equal to 500 bpd. Plants with capacities smaller than 500 bpd are exempted from the proposed standards for several reasons. First, projections of the economic impact of standards on existing small plants (100 and 250 bpd) undergoing reconstruction or modification indicated that standards would have a severe negative impact on such plants. Also, although almost 50 percent of the lead-acid battery plants in the United States produce fewer than 500 bpd, these plants account for only about 2 percent of total lead-acid battery production. Finally, industry representatives do not forecast construction or expansion of small plants. In fact there has been a trend

in recent years of small plants closing due to unprofitability. Increased demand for batteries in the future is expected to be accommodated by expansion of existing plants producing over 2000 bpd.

9.2.3 Selection of Affected Facilities

Processes selected as affected facilities are grid casting, lead oxide production, paste mixing, three-process operation, lead reclamation, and other lead-emitting operations. These processes often consist of several machines or production lines which perform the same function and which are located in the same area and ducted to the same control device. Therefore, for each of the processes mentioned above, the affected facility is the entire operation.

9.2.2.1 Grid Casting--

The grid casting operation includes grid casting furnaces, which melt the lead, and grid casting machine which cast the liquid metal into grids. Although emissions from the grid casting operations are generally low, most grid casting work areas must be ventilated to comply with the in-plant OSHA lead concentration standard of 50 $\mu g/m^3$. Source tests for the present study detected uncontrolled lead emissions of approximately 0.4 kg (0.9 lb) per 1000 batteries. This is about 3.2 percent of the overall plant uncontrolled lead emissions of 12.6 kg (27.7 lb) per 1000 batteries (including lead reclamation and lead oxide production). Therefore, grid casting is designated an affected facility.

9.2.2.2 Lead Oxide Manufacturing--

The lead monoxide used in battery paste production is called lead oxide, black oxide, or battery oxide. It is produced either by the ball mill or the Barton process. Fabric filters are always used as part of the process for product recovery. Source tests for this study indicate lead emissions of 0.05 kg (0.116 lb) per 1000 batteries from a typical lead oxide facility. Although the lead emissions from a typical lead

oxide manufacturing process are low, it is estimated that well-controlled lead oxide manufacturing facilities emit only half as much lead as one designed only for economical recovery of lead oxide. Thus, the lead oxide production process is designated an affected facility.

9.2.2.3 Paste Mixing--

The paste making operation is a batch process that consists of materials charging followed by blending in either a muller, Day, or dough-type mixer. Emissions are in the form of lead oxide with small amounts of other paste constituents such as Dynel, organics, and carbon black. Paste mixing is selected as an affected facility because uncontrolled lead emissions from the process are approximately 5.1 kg (11.2 lb) per 1000 batteries. This is 40 percent of the total estimated lead emissions from a lead-acid battery plant.

9.2.2.4 Three-process Operation--

The three-process operation includes plate stacking, burning, and assembly of elements into the battery case. Emissions consist of lead, lead oxide, and nonlead bearing particulate from the separators. These emissions are generated during plate handling, plate stacking, and burning or casting operations. Source tests indicate that lead emissions from the three-process operation are 6.7 kg (14.7 lb) per 1000 batteries. This is over 50 percent of the estimated emissions of lead from a lead-acid battery plant. Therefore, the three-process operation is designated as an affected facility.

9.2.2.5 Lead Reclamation--

Lead reclamation is an operation wherein relatively clean scrap is remelted and cast into ingots for use in the process. This is often a

sporadic operation, on stream only wben large quantities of defective small parts, grids, and plates are available. The lead is melted at relatively low temperatures 370° C (700° F), but lead emissions can be high during scrap charging or dross removal. Lead emissions are estimated at 0.35 kg (0.77 lb) per 1000 batteries or 3.0 kg/Mg (5.9 lb/ton) of lead charged. A 4000-bpd plant that operates its lead reclamation facility for an 8-hour shift every 2 weeks would emit approximately 1.7 kg/h (3.8 lb/h) during operation. This amount is comparable to lead emissions from the three-process operation at the same plant. Thus, the lead reclamation operation has been designated as an affected facility. Reverberatory furnaces which are used for lead reclamation but which are affected by standards of performance for secondary lead smelters (40 CFR 60.120) would not be affected under the proposed standards.

9.2.2.6 Other Lead-Emitting Operations--

Any lead-acid battery plant facility from which lead emissions are collected and ducted and not considered part of the grid casting, paste mixing, three-process operation, lead oxide production, or lead reclamation facilities, and which is not a reverberatory furnace affected by standards of performance for secondary lead smelters is considered an "other lead emitting operation". An example is slitting, a process whereby lead grids, cast in doublets, are slit (with an enclosed saw) into separate plates. These types of facilities could be controlled by a separate control device, but are usually ducted to a control device serving other facilities. EPA has selected other lead emitting operations as affected facilities to ensure that these processes are controlled.

9.3 SELECTION OF THE BEST SYSTEM OF EMISSION REDUCTION CONSIDERING COSTS

Emission control alternatives for a lead-acid battery plant are

Table 9-1. SELECTED CONTROL ALTERNATIVES FOR LEAD-ACID BATTERY MANUFACTURING INDUSTRY

Plant size, BPD	Control alternative	Facilities[a]	Control system[b]
500, 2000, & 6500	I	A, B, F	Fabric filter, 6/1 A/C
		C, E	Fabric filter, 6/1 A/C
		D	Fabric filter, 2/1 A/C
	II	B, C, E	Fabric filter, 6/1 A/C
		F	Impingement and entrainment scrubber
		A	Impingement and entrainment scrubber
		D	Fabric filter, 2/1 A/C[c]
	III	C, E	Fabric filter, 6/1 A/C
		A, B, F	Impingement and entrainment scrubber
		D	Fabric filter, 2/1 A/C
	IV	A, B, C	Impingement and entrainment scrubber
		E	Fabric filter, 6/1 A/C
		F	Impingement and entrainment scrubber
		D	Fabric filter, 2/1 A/C[c]
	V	A, B, C, F	Impingement and entrainment scrubber
		E	Fabric filter, 6/1 A/C
		D	Fabric filter, 2/1 A/C[c]
100 & 250[d]	VI	A, B, C	Fabric filter, 6/1 A/C
		E	Fabric filter, 6/1 A/C
	VII	A, B, C, E	Fabric filter, 6/1 A/C
	VIII	A, B, C	Impingement and entrainment scrubber
		E	Fabric filter, 6/1 A/C

[a]Facilities key: A - grid casting furnace; B - grid casting machines; C - paste mixer; D - lead oxide manufacturing; E - three-process operation; F - lead reclamation furnace.

[b]Facilities are vented to common control systems as shown.

[c]Small plants (500 bpd or less) are assumed to have no lead oxide manufacturing facilities.

[d]Plants smaller than 500 BPD are assumed to have no lead reclamation facilities.

Table 9-2. SUMMARY OF ALTERNATIVE CONTROL SYSTEMS COSTS AND CONTROL EFFECTIVENESS FOR LEAD-ACID BATTERY PLANTS (METRIC UNITS)

Control alternative[a]	Plant capacity, bpd	Lead emissions, kg/day		Lead removal, %	New plant control systems cost, $1000[b]		Existing plant control systems cost, $1000	
		Uncontrolled	Controlled		Installed[c]	Annualized[d]	Installed[c]	Annualized[d]
I	500	6.2	0.06	99.0	125	47.4	105	53.6
	2000	25.0	0.30	98.8	211	108	253	118
	6500	81.6	0.99	98.8	453	284	544	305
II	500	6.2	0.09	98.6	151	56.9	181	64.1
	2000	25.0	0.40	98.4	228	122	274	133
	6500	81.6	1.31	98.4	474	303	569	326
III	500	6.2	0.10	98.4	120	47.6	144	53.4
	2000	25.0	0.42	98.3	200	107	240	117
	6500	81.6	1.43	98.3	423	277	508	297
IV	500	6.2	0.33	94.8	110	30.2	132	35.4
	2000	25.0	1.30	98.4	154	48.1	185	55.8
	6500	81.6	4.38	94.6	295	91	354	105
V	500	6.2	0.33	94.8	69	19.4	83	22.7
	2000	25.0	1.30	98.4	119	36.9	143	42.6
	6500	81.6	4.41	94.6	252	78	302	100
VI	100	1.22	0.0122	99.0	89	28.6	107	32.8
	250	3.04	0.0304	99.0	95	30.4	114	34.9
VII	100	1.22	0.0122	99.0	124	44.3	149	50.2
	250	3.04	0.0304	99.0	136	47.0	163	53.5
VIII	100	1.22	0.0615	94.9	94	26.1	113	30.6
	250	3.04	0.154	94.9	100	27.6	120	32.4

[a] A description of each control alternative is presented in Chapter 6. None of there alternatives include acid mist control.

[b] Mid-1976 dollars.

[c] Excludes SIP compliance costs estimated at $35,000, $35,000, $91,000, $95,000, and $105,000 for plants with capacities of 100, 250, 500, 2000, and 6500 bpd, respectively.

[d] Excludes costs of controlling facilities that require controls to meet SIP regulations.

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Table 9-2A. SUMMARY OF ALTERNATIVE CONTROL SYSTEMS COSTS AND CONTROL EFFECTIVENESS FOR LEAD-ACID BATTERY PLANTS (ENGLISH UNITS)

Control alternative[a]	Plant capacity, bpd	Lead emissions, lb/day		Lead removal, %	New plant control systems cost, $1000[b]		Existing plant control systems cost, $1000	
		Uncontrolled	Controlled		Installed[c]	Annualized[d]	Installed[c]	Annualized[d]
I	500	13.8	0.138	99.0	125	47.4	105	53.6
	2000	55.3	0.665	98.8	211	108	253	118
	6500	180	2.18	98.8	453	284	544	305
II	500	13.8	0.193	98.6	151	56.9	181	64.1
	2000	55.3	0.885	98.4	228	122	274	133
	6500	180	2.89	98.4	474	303	569	326
III	500	13.8	0.214	98.4	120	47.6	144	53.4
	2000	55.3	0.940	98.3	200	107	240	117
	6500	180	3.15	98.3	423	277	508	297
IV	500	13.8	0.718	94.8	110	30.2	132	35.4
	2000	55.3	2.88	94.8	154	48.1	185	55.8
	6500	180	9.67	94.6	295	91	354	105
V	500	13.8	0.718	94.8	69	19.4	83	22.7
	2000	55.3	2.88	94.8	119	36.9	143	42.6
	6500	180	9.73	94.6	252	78	302	100
VI	100	2.68	0.0268	99.0	89	28.6	107	32.8
	250	6.70	0.0670	99.0	95	30.4	114	34.9
VII	100	2.68	0.0268	99.0	124	44.3	149	50.2
	250	6.70	0.0670	99.0	136	47.0	163	53.5
VIII	100	2.68	0.136	94.9	94	26.1	113	30.6
	250	6.70	0.339	94.9	100	27.6	120	32.4

[a]A description of each control alternative is presented in Chapter 6. None of there alternatives include acid mist control.

[b]Mid-1976 dollars.

[c]Excludes SIP compliance costs estimated at $35,000, $35,000, $91,000, $95,000, and $105,000 for plants with capacities of 100, 250, 500, 2000, and 6500 bpd, respectively.

[d]Excludes costs of controlling facilities that require controls to meet SIP regulations.

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discussed in Chapter 6, and the economic impacts of the alternatives are discussed in Chapter 8. Table 9-1 summarizes control alternatives for lead emissions, while Tables 9-2 and 9-2A summarize the costs of the alternatives and their overall lead removal efficiencies. The control alternatives and their economic impacts are discussed in further detail in Chapters 6 and 8.

The impacts of alternatives I through V were analyzed for 500, 2000, and 6500 bpd plants. Alternatives VI through VIII are control alternatives for smaller plants, and take into account the differences between these plants and larger plants. The impacts of these alternatives were analyzed for 100 and 250 bpd plants. For reasons discussed earlier, standards are not being proposed for plants smaller than 500 bpd.

As discussed in Chapter 8, for plants with capacities greater than 500 bpd, the costs of any control alternative are not viewed as being a detriment to industry expansion, nor are they of the magnitude that would impose a negative impact on the debt structure of an individual company. Plants of this size can pass on control costs to the consumer with little effect on sales. The replacement demand for lead batteries will remain high since substitutes have not yet been proven feasible for general use. The original equipment market for lead batteries will not be affected since the battery cost compared to the final product (e.g., automobiles, etc.) is small.

The proposed standards are based on the control of all lead emissions from lead-acid battery plants by fabric filtration (Alternative I). This basis was chosen because fabric filters achieve a better degree of emission reduction than low energy scrubbers at a reasonable cost, and because, the use of fabric filtration to control all lead emissions from lead-acid battery plants is possible if spark arresters are used when necessary and exhaust gases are kept above the dew point.

The use of control techniques other than fabric filtration would not be precluded by the proposed standards. High energy impingement scrubbers could be used to meet the emission limits. However, these would have higher operating costs and energy requirements than fabric filters. Scrubbers would also generate lead contaminated water, which would probably require treatment prior to disposal.

9.4 SELECTION OF THE FORMAT OF THE PROPOSED STANDARD

In general, lead-acid battery manufacturing facilities may be considered independent of one another in that there is no continuous flow of materials. Grid casting operations, lead oxide production operations, paste mixing operations, lead reclamation operations, and three-process operations are independent. Also, not all plants have lead reclamation and lead oxide production operations, and some plants sell lead oxide.

Because of the independent nature of the facilities, two different forms were chosen for the proposed standards. The format of the proposed standards applicable to grid casting, paste mixing, three-process operation, lead reclamation, and other lead-emitting operations, is a concentration standard. The format of the standard for lead oxide manufacturing is mass per unit of lead input.

These forms were chosen for the proposed standards from a group of several possible formats. The standards could, for example, have been expressed in terms of grams of lead emissions per 1000 batteries, or in

terms of the lead removal efficiency of the emission control system. The rationale for the choice of the forms of the proposed standards over other possible forms is discussed in detail below.

9.4.1 Multiple Forms

Each affected facility or each process within an affected facility could be subjected to standards having different forms. For example, the standard for paste mixing could be expressed in terms of grams of lead emissions per kilograms of lead oxide charged to the mixer, whereas the standard for the three-process operation could be expressed as grams of lead emissions per 1000 batteries produced. Although this may seem to be the best approach on an individual process basis, the practice of exhausting more than one facility to a common cntrol device complicates the application of different standards to combined gas streams. The difficulties lie in designating the emissions in an acceptable common form and determining an allowable limit for the combined processes or facilities.

A standard that also requires that each affected facility be exhausted to an individual control system would allow various forms to be applied easily to different processes. However, such a standard, by requiring several control systems where one may have sufficed, would increase both the cost of compliance and the cost of compliance testing.

9.4.2 Process Throughput

A standard based on an allowable mass of emissions per mass of process throughput was considered for lead reclamation, three-process operation, grid casting, and paste mixing. However, though lead throughput can usually

be determined for each of these processes, emissions depend more on other factors such as the type of scrap processed by a lead reclamation furnace, the number (rather than the weight) of plates processed by a grid casting operation, the method of battery assembly, and the length of the formation cycle. Also, some of these processes typically share control devices with other processes. Therefore, a format of process throughput is not proposed for lead reclamation, the three-process operation, grid casting, paste mixing, and other miscellaneous facilities.

The device controlling emissions from a lead oxide production facility is never shared by other processes. Therefore, a standard based on production throughput could be applied to this process. Also, the amount of lead used by the facility can be readily determined. Concentration units could be applied to the process, but would provide no incentive for the operator to minimize the amount of air which bleeds into the process, which operates under negative pressure. For these reasons, the recommended format of the lead oxide production standard is allowable mass per unit of lead feed (g/kg).

9.4.3 Common Control System

Consideration was given to a standard that would require all facilities to be vented to one control system. This would facilitate compliance testing and would allow placement of all plants on the same unit basis. A standard with this format might also encourage the reduction of handling steps and more efficient production techniques to reduce emissions. If all processes were vented to one system, a single lead standard could apply to each plant regardless of the production techniques.

There are also disadvantages to implementing a standard that requires a single control system. It would limit acceptable plant layout designs to

those that minimize ductwork to the control device. Also, plants covered by the modification and reconstruction provisions could not use existing controls. In addition, these plants might find it impractical to install the long ducts needed to vent all facilities to a common device. During compliance tests, a shutdown of one facility would invalidate the test, and more than one process engineer would be required to monitor normal operation at all processes during compliance tests.

It is not recommended that a common control system condition be added to the standard because of possible plant design problems, potential higher cost of a common control system, and the difficulties associated with compliance testing.

9.4.4 Removal Efficiency Standard

An efficiency format would encourage optimum performance of all controls. This type of format, however, would double the sampling effort since both inlet and outlet samples would be required. Also, an increase in lead control efficiency does not necessarily indicate a decrease in atmospheric lead emissions.

9.4.5 Concentration Standard

Concentration units [milligrams per cubic meter (grains per dry standard cubic foot)] are recommended for the standard for grid casting, paste mixing, three-process operation, lead reclamation, and other lead-emitting operations.

Concentration units have the disadvantage of being dependent on the air volume flow rate. In the lead-acid battery industry, the minimim air flow requirement is dictated by the OSHA in-plant regulation of 50 µg lead/m^3 of

air based on an 8-hour time-weighted average. Each process must be ventilated sufficiently to meet these standards. No data regarding the optimum ventilation requirements for lead-acid battery manufacturing processes has been uncovered in this study. A maximum air flow rate would be limited by the economics of the greater energy requirements to heat and cool makeup air and the required fan systems. Since the industry is already acutely aware of the high cost of makeup air, it is unlikely that dilution will be used to circumvent a standard that requires the presence of a control device.

On the other hand, gas flow rates are routinely measured as part of the source test procedures; with these flow rate values, emissions in concentration units can be calculated easily. Concentration units will place the standards for the above facilities on a common basis, and thus will eliminate the problems involved in interpretation of the standards for processes vented to a common control device.

With the recommended form of the standard, the major processes common to all battery plants can be assigned a quantitative concentration limit. Lead reclamation and other lead-emitting operations can be vented to a common control device and are also assigned a concentration limit. Standards for the lead oxide production facility, which is not common to all battery plants, and always has its own control system can be based on process throughput.

9.5 SELECTION OF EMISSION LIMITS

Table 9-3 summarizes the recommended emission limits that reflect the degree of emission reduction achievable through the application of the best system of emission reduction based on the Administrator's judgment. The cost of achieving the emission reduction, the nonair-quality health

Table 9-3. RECOMMENDED EMISSION LIMITS FOR LEAD-ACID BATTERY PLANTS

Facility	Pollutant	Recommended Standards*
Grid casting	lead	0.05 mg/m^3 (0.00002 gr/dscf)
Paste mixing	lead	1.00 mg/m^3 (0.00044 gr/dscf)
Three process	lead	1.00 mg/m^3 (0.00044 gr/dscf)
PbO mfg	lead	5.0 mg/Kg (0.010 lb/ton)
Lead reclamation	lead	2.00 mg/m^3 (0.00088 gr/dscf)
Other lead-emitting operations	lead	1.00 mg/m^3 (0.00044 gr/dscf)

*Recommended standards for lead oxide manufacture are in terms of allowed emissions per Kg of lead processed, while those for other facilities are in terms of allowed concentrations in exhaust air.

and environmental impacts, and the energy requirements have been taken into consideration in determining these standards.

The proposed limits for lead emission from grid casting, paste mixing, three-process operation, lead oxide production, lead reclamation, and other lead emitting facilities are based on emissions levels attainable using fabric filtration. In the development of background data for the proposed standards, atmospheric lead emissions from facilities at four lead-acid battery plants were measured using the proposed Method 12. In a previous study, lead emissions from facilities at two lead-acid battery manufacturing plants and one lead oxide manufacturing plant were measured using a similar test method.

The emission limit for three-process operation facilities, lead-oxide production facilities, and other lead emitting facilities are based on lead levels measured in exhausts from fabric filters controlling emissions from such facilities. Fabric filters are not currently used in the lead-acid battery industry to control emissions from grid casting or lead reclamation; and are not generally used to control emissions from the mixing phase of paste mixing. The emission limits for grid casting, paste mixing, and lead reclamation are, therefore, based on lead levels found in uncontrolled emissions from such facilities, and on the demonstrated emission reduction capabilities of fabric filters.

Three-process facilities controlled by fabric filters indicated fabric filter lead collection efficiencies of about 99 percent. Because particulate emissions from all lead emitting facilities at battery plants are simliar in composition and particle size, the Administrator has determined that comparable collection efficiencies can be achieved for emissions from grid casting, paste mixing, and lead reclamation. It should also be noted that control efficiencies

of 99 percent and greater are achieved by well maintained fabric filters in other applications.[4,5]

9.5.1 Grid Casting

Impingement scrubbing, rather than fabric filtration, is currently used in the lead-acid battery manufacturing industry to control emissions from grid casting. Emissions from grid casting facilities were measured at two plants. At one of these plants, grid casting emissions were controlled by an impingement scrubber. At the other, grid casting emissions were not controlled. The average lead concentration in exhaust from the uncontrolled facility was 4.37 mg/m^3 (19.1×10^{-4} gr/dscf). Average uncontrolled and controlled lead emissions from the scrubber controlled facility were 2.65 mg/m^3 (11.6×10^{-4} gr/dscf) and 0.32 mg/m^3 (1.4×10^{-4} gr/dscf), respectively. Thus the lead collection efficiency of the scrubber was about 90 percent.

Fabric filtration can be used to control these emissions if spark arresters are used and the exhaust gas is kept above the dew point. Also, because of the low concentration of lead in the exhaust, proper maintenance of the fabric filter would be important. The lead standard for grid casting, 0.05 mg/m^3 (0.2×10^{-4} gr/dscf), is based on the exhaust concentration achievable using a fabric filter with about 99 percent collection efficiency to control emissions.

9.5.2 Paste Mixing

Lead emissions from a paste mixing facility equipped with an impingement scrubber were measured. Average uncontrolled and controlled lead concentrations from this facility were 77.4 mg/m^3 (338×10^{-4} gr/dscf) and 10.8 mg/m^3 (47.0×10^{-4} gr/dscf), respectively.

Fabric filtration is not generally used to control emissions from the entire paste mixing cycle because of the high moisture content of paste mixer exhaust during the mixing cycle. However, fabric filtration can be used to control emissions from the entire cycle if the exhaust gas is kept above the dew point. The proposed lead emission standard for paste mixing, 1 mg/m^3 (4.4×10^{-4} gr/dscf), is based on the level achievable using a fabric filter with about 99 percent collection efficiency for the entire cycle.

In developing data for the proposed standards, EPA conducted tests at a plant where paste mixing emissions were controlled by two separate systems. At this plant, paste mixing required a total of 21 to 24 minutes per batch. During the first 14 to 16 minutes of a cycle (the charging phase), exhaust from the paste mixer was ducted to a fabric filter which also controlled emissions from a grid slitting (separating) operation. During the remainder of the cycle (mixing), paste mixer exhaust was ducted to an impingement scrubber which also controlled emissions from the grid casting operation. Uncontrolled or controlled emissions for the paste alone were not tested. The average concentration of lead in emissions from the fabric filtration system used to control charging emissions was 1.3 mg/m^3 (5.5×10^{-4} gr/dscf). The average lead content of exhaust from the scrubber used to control mixing emissions was 0.25 mg/m^3 (1.1×10^{-4} gr/dscf). The average lead concentration in controlled emissions from this facility was about 0.95 mg/m^3 (4.2×10^{-4} gr/dscf) which is slightly below the proposed emission limit of 1 mg/m^3 (4.4×10^{-4} gr/dscf). A lower average emission concentration should be achieved by using fabric filtration to control emissions from all phases of paste mixing.

9.5.3 Three-Process Operation

The proposed lead concentration limit for three-process operation emissions is 1 mg/m^3 (4.4×10^{-4} gr/dscf). This limit is based on the results of EPA tests conducted at four plants where fabric filtration was used to control three-process operation emissions. All of these tests showed lead concentration below the proposed limit in controlled emissions from the three-process operation facilities.

9.5.4 Lead Reclamation

Lead emissions from a lead reclamation facility where emissions controlled by an impingement scrubber were measured. The average lead concentrations in the inlet and outlet streams of the scrubber were 227 mg/m^3 (990×10^{-4} gr/dscf) and 3.7 mg/m^3 (16×10^{-4} gr/dscf), respectively. The collection efficiency of the scrubber was, therefore, about 98 percent.

Fabric filtration is not currently used to control emissions from lead reclamation facilities because of the high temperature of lead reclamation exhaust. However, fabric filters have been applied to hot exhaust streams at secondary lead smelters and in other industries. Therefore, the proposed standard for lead reclamation facilities of 2 mg/m^3 (8.8×10^{-4} gr/dscf), is based on the emission level attainable using a fabric filter with a collection efficiency of about 99 percent.

9.5.5 Lead Oxide Manufacturing

The proposed standard for lead oxide production is 5 milligrams of lead per kilogram of lead processed (10 lb/ton). This limit is based on the results of tests of emissions from a ball mill lead oxide production facility with a fabric filter emission control system. The tests showed an average controlled lead emission rate of 4.2 mg/Kg (8.4 lb/ton) for this facility. EPA has not conducted tests of emissions from a well controlled Barton process. However, in both the ball mill process and

the Barton process, lead oxide product must be removed from an air stream. Also, EPA tests of a Barton process indicated that Barton and ball mill processes have similar air flow rates per unit production rate (see Appendix C). Therefore, it has been determined that a similar level of control could be achieved for a Barton process as has been demonstrated for the ball mill process.

9.5.6 Other Lead Emitting Operations

Emissions from other lead emitting operations are generally collected and ducted to minimize worker exposure. Emissions from these operations are similar in composition and concentration to emissions from non-automated three-process operations. The proposed standard for other lead emitting operations is 1 mg/m^3 (4.4×10^{-4} gr/dscf) because emissions from these operations can be controlled to the same extent as emissions from three-process operation facilities.

Emissions were measured from a slitting facility which would be classified as an "other lead emitting operation", controlled by a fabric filter. Controlled emissions from the fabric filter had an average lead content of 0.938 mg/m^3 (4.1×10^{-4} gr/dscf), which is below the proposed emission limit for other lead emitting operations.

9.6 OPACITY STANDARDS

A standard of 0 percent opacity is proposed for emissions from all affected facilities in order to ensure proper operation of emission control equipment. Grid casting, paste mixing, three-process operation, and lead oxide manufacturing facilities were observed by EPA to have emissions with 0 percent opacity during periods of 7 hours and 16 minutes; 1 hour and 30 minutes; 3 hours and 51 minutes; and 3 hours and 19 minutes, respectively. Emissions ranging from 5 to 20 percent opacity were observed for a total of 11 minutes and 15 seconds during 3 hours and 22 minutes of observation at the lead reclamation operation source tested

by EPA, which was controlled by a low-energy scrubber. However, the proposed standard is based on control of this process by a fabric filter, similar to three-process operations and paste mixers for which emissions with 0 percent opacity have been observed. A standard of 0 percent opacity is, therefore, also proposed for emissions from lead reclamation furnaces.

Under the proposed standards, opacity would be determined by taking the average opacity over a 6-minute period using EPA Test Method 9, and rounding the average to the nearest whole percentage. The rounding procedure is specified in the proposed standards in order to allow occasional brief emissions with opacities greater than 0 percent. When a fabric filter is used to control emissions, the outlet concentration from the filter may increase immediately after a component filter bag is cleaned. In the case of a lead-acid battery plant, filter cleaning may result in occasional emissions with opacities greater than 0 percent. Under Method 9, individual opacity readings are rounded to the nearest 5 percent. However, the average accuracy of any particular opacity reading is $\pm$ 7.5 percent opacity. Therefore, the opacity of low level visible emissions during filter cleaning would be interpreted to be 5 percent or greater. If the rounding off procedure were not specified, one opacity reading of 5 percent during a 6-minute period could be considered as indicative of a violation of the proposed 0 percent opacity standard. However, the Administrator does not intend for occasional emissions greater than 0 percent opacity occurring during filter cleaning to be considered violations of the proposed standards. Therefore, the standards would specify that the average opacity be rounded to the nearest whole percentage. With this specification, 6-minute average opacities less than 0.5 percent would not be considered violations of the proposed standards. Emissions which result in 6-minute average opacities of 0.5 percent or greater are expected to be indicative of fabric filter malfunctions rather than filter cleaning emissions.

9.7 MODIFICATIONS/RECONSTRUCTION CONSIDERATIONS

Emission limitations promulgated under Section 111(b) of the Clean Air Act (New Source Performance Standards or NSPS) apply to modified and reconstructed facilities as well as to new facilities. The definitions of modification and reconstruction and the applicability of these provisions to the lead-acid battery industry are discussed in detail in Section 5.1. Basically, with certain exceptions, a modification occurs when a physical or operational change to an existing facility results in an increase in the emission rate to the atmosphere of any pollutant to which an NSPS applies.

Irrespective of any change in pollutant emission rates, a replacement of components of an existing facility may be deemed a reconstruction of that facility if (1) the fixed capital cost of the new components exceeds 50 percent of the fixed capital cost that would be required to construct a new facility, and (2) it is technologically and economically feasible to meet the applicable standards. One such case could be the replacement of the motor, paddle wheel, and shell of a paste mixer. These repairs would likely exceed 50 percent of the cost of a new paste mixing facility.

The enforcement division of the appropriate EPA regional office should be contacted whenever a source has questions regarding modification or reconstruction. Their judgement will supercede any general examples that can be given in a document such as this.

9.8 SELECTION OF MONITORING REQUIREMENTS

To provide a convenient means for enforcement personnel to ensure that an emission control system installed to comply with standards of performance is properly maintained and operated, monitoring requirements are generally included in standards of performance.

Continuous opacity monitoring is not recommended for lead battery plants because EPA has not determined performance specifications for opacity monitoring for this application. Because even uncontrolled emissions are generally invisible, it is unlikely that available instruments could detect control device malfunction by an opacity change for affected facilities. Also, continuous monitors that directly measure lead concentrations are not commercially available. An indication of proper operation of a scrubber or a fabric filter that can easily be monitored is the pressure drop across the device. This indicator can be continuously monitored with a pressure gauge and strip chart. The installed cost would be less than $2000 with about $400 per year required for operation and maintenance expenses.

Records of the pressure drops for each control device should be kept up to 2 years before discarding. A decrease in pressure drop of about 50 percent could indicate a decrease in lead removal efficiency because of either a fabric filter bag failure or a decrease in scrubber liquid-to-gas ratio. During plant visits, enforcement personnel can examine the pressure charts to determine possible control device malfunctions.

9.9 SELECTION OF PERFORMANCE TEST METHODS

Proposed EPA Reference Method 12, "Determination of Lead Emissions from Stationary Sources;" and EPA Method 9, "Visual Determination of the Opacity of Emissions From Stationary Sources" were selected as the performance test methods to determine compliance with standards of performance limiting lead, and opacity, respectively, from lead battery plants. Methods 1, 2, and 4 are also used for sample and velocity ttraverses, velocity and volumetric flow rate, and stack gas moisture.

Proposed EPA Method 12 is essentialy the same method as was used in gathering the NSPS data, except that it has been revised to include the revisions to Method 5 (Federal Register, August 18, 1977). These revisions were made to make the methods easier to use and to assure that good testing practices were followed. The test results that were obtained before the revisions followed good test practices and will not be affected. Reputable testing firms were used for the lead-battery manufacturing test program; the results obtained are accurate and reliable. Method 12 was developed by the EPA because of the low levels of lead anticipated at the outlet of lead source control devices. This method has greater sensitivity to lead concentrations than atomic absorption analysis of a sample of particulate collected by Method 5.

Method 9 was selected for monitoring opacity. This method was used in the test program and was judged to be applicable to lead battery plants. The method is complete as to methodology, and provides consistent procedures to be applied to all plants tested for compliance with the NSPS.

During all tests, a process engineer should be stationed inside the plant to assure normal operation. When the paste mixer is vented to two control devices, a process engineer must coordinate the process operation with compliance tests. Process downtimes are normally of short duration and should not invalidate the compliance test.

If different processes within a three-process operation facility are controlled by different control devices, source tests must be run on all applicable stacks and an equivalent concentration determined. Total lead emissions from all the stacks can be determined and divided by the total exhaust flow rate. This equivalent concentration can then be compared with the standard.

To determine compliance when two or more facilities at the same plant are ducted to a common control device, the exhaust rate from each source and the controlled lead concentrations must be measured. An equivalent standard for the applicable facilities can be calculated by multiplying each applicable standard by the fractional exhaust flow rate of that facility and adding the numbers. This equivalent standard can then be compared with the measured concentration to determine compliance.

During performance tests on the lead oxide manufacturing the process feed rate must be recorded. This is needed so that lead emission rates for the lead oxide manufacturing process can be expressed in terms of process throughput and compared with the NSPS.

REFERENCES FOR CHAPTER 9

1. Data developed by JACA Consulting, Inc., Philadelphia, Pennsylvania, under EPA Contract No. 68-02-2804 in Support of Lead Ambient Air Standard.

2. Thakker, B. Screening Study to Develop Background Information and Determine the Significance of Emissions from Lead Battery Manufacture. Vulcan-Cincinnati, Inc. Prepared for the U. S. Environmental Protection Agency under Contract No. 68-02-0299, Task No. 3. December 1972. p. 16.

3. Boyle, T. F., and R. B. Reznik. Lead-Acid Batteries, Source Assessment Document No. 17. Prepared by Monsanto Research Corporation, Dayton, Ohio, for the U. S. Environmental Protection Agency. Cincinnati, Ohio. Contract No. 68-02-1874. June 1976 (Draft). p. 42.

4. Compilation of Air Pollutant Emission Factors, Third Edition. U. S. Environmental Protection Agency. AP-42. August 1977.

5. Air Pollution Engineering Manual. U. S. Environmental Protection Agency. AP-40. 1967.

APPENDIX A

EVOLUTION OF THE SELECTION OF THE BEST SYSTEMS OF EMISSION REDUCTION

In development of Standards of Performance for lead-acid battery plants, emissions from selected plants were sampled to help determine the best demonstrated control technology available for new plants. The following steps were involved:

1) Selection of candidate best-controlled plants.
2) Selection of plants to be source tested.
3) Selection of test procedures.
4) Sampling of emissions.
5) Analysis of samples, resolution of data, and development of recommendations.

A chronology of these events is presented in Table A-1.

A.1 SELECTION OF CANDIDATE BEST-CONTROLLED PLANTS

The best controlled lead-acid battery plants were selected by identifying the major emission sources of concern in the industry and then identifying plants that control emissions from these sources effectively. Information was obtained from source test emission data, industry manuals and publications, earlier surveys, and literature on air pollution control and process

Table A-1.

CHRONOLOGY OF EVENTS LEADING TO THE BACKGROUND DOCUMENT FOR NEW SOURCE PERFORMANCE STANDARDS FOR LEAD-ACID BATTERY PLANTS

Date	Event
July 29, 1975	Initial meeting for study regarding Lead Industry New Source Performance Standards at EPA offices in Durham, North Carolina.
August 5, 1975	Meeting with Mr. John Bitler, Chairman of the Air and Water Standards Committee, Battery Council International (BCI) in Reading, Pennsylvania.
August 5, 1975	Visit to General Battery Corporation, Reading, Pennsylvania.
August 28, 1975	Written requests for information regarding lead-acid battery facilities mailed to state air agencies.
August-September, 1975	Written requests for information regarding lead-acid battery facilities mailed to industry representatives.
September 8, 1975	Interim Report No. 1 completed.
September 9, 1975	(Contractor) Project Manager attended Chicago meeting of BCI Air and Water Standards Committee.
October 20, 1975	Visit to Plant G.
October 21, 1975	Visit to Plant B.
October 22, 1975	Visit to Plant D.
October 23, 1975	Visit to Plant F.
November 11, 1975	Visit to Plant E.
November 18, 1975	Visit to Plant C.

Table A-1 (continued).

Date	Event
December 5, 1975	Visit to Plant A.
December 31, 1975	Interim Report No. 2 completed.
February 16, 1976	Meeting for review of Interim Report No. 2 at EPA offices in Durham. Best-controlled plants selected for source testing.
June 14-24, 1976	Source tests conducted at Plant D. Grid casting, paste mixing, and three-process-operations were tested.
August 16-20, 1976	Source tests conducted at Plant B. Three-process-operations and lead oxide production were tested.
August 23-26, 1976	Source tests conducted at Plant G. Formation and lead reclamation processes were tested.
February 8-10, 1977	Visits to formation facilities at ESB, Inc., Allentown, Pennsylvania; and General Battery Co. in City of Industry, California.
April 18-22, 1977	Source tests conducted at the formation process of Plant L.
September 27-28, 1977	National Air Pollution Control Techniques Advisory Committee Meeting (NAPCTAC), Alexandria, Kentucky.
September 27, 1978	EPA Working Group Meeting, Durham, North Carolina.
May 1979	Steering Committee Review

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equipment. More than 60 representatives of battery manufacturing companies, trade associations, and air pollution control agencies were contacted through verbal and written communications.

A.1.1 Pollutant Selection

Emissions from lead-acid battery operations are primarily particulate matter containing lead and lead oxide, and sulfuric acid fumes. The available data indicate that emissions from uncontrolled processes could cause ambient levels of lead to exceed 5 μg/m3 (24-hr average) in the vicinity of the larger plants. These levels may cause symptoms of lead poisoning to appear in certain individuals. Emissions of sulfuric acid mist are sensibly detectable at some formation facilities. Plant discharges are generally invisible even when uncontrolled, and particulate emission rates are well below state standards.

Lead was selected as a pollutant for control because of the potential impact of uncontrolled emissions. Because the acid mist emission rate from battery plants was found to be very low, acid mist was not selected for control.

A.1.2 Plant Selection

After selection of the pollutants of concern, the plants that best control these pollutants were identified. Eight plants were selected by consultation with representatives of all the major battery manufacturers, the two battery trade associations, the lead trade association, and state air regulatory agencies. The investigating team visited these plants to determine the facilities to be recommended for source testing. Table A-2 lists the plants and their locations.

TABLE A-2. LEAD-ACID BATTERY PLANTS SELECTED FOR INVESTIGATION

Plant	Location
General Battery Corporation	Reading, Pennsylvania
General Battery Corporation	Los Angeles, California
ESB Incorporated	Buffalo, New York
ESB Incorporated	Allentown, Pennsylvania
ESB Canada Limited	Mississauga, Ontario, Canada
Globe Union	Canby, Oregon
Estee Battery Company	Los Angeles, California
Douglas Battery Manufacturing	Winston-Salem, North Carolina
Delco Battery Manufacturing	Anaheim, California
Standard Electric Company	San Antonio, Texas

A.2 SELECTION OF PLANTS TO BE TESTED

Process and emissions information was obtained during tours of the candidate plants. On the basis of this information, processes from four lead-acid battery plants were recommended for source testing. The recommendations were based on the degree of emissions or process control exercised at the plants and on locations of the source test sites. Relative control efficiencies were evaluated through conversations with plant operators, review of available test data, and visual observations. Table A-3 lists the processes, test locations, and control systems selected for source testing.

TABLE A-3. PROCESSES, TEST LOCATIONS, AND CONTROL SYSTEMS RECOMMENDED FOR SOURCE TESTING

Process	Plant code	Control device	Test locations[a]
Grid casting	D	Roto-Clone	Inlet Outlet
PbO manufacture	B	Baghouse	Outlet
Paste mixing	D	Roto-Clone (mixing cycle) Baghouse (materials charging)	Inlet Outlet Inlet Outlet
Three-process operations	D	Baghouse	Inlet Outlet
	B	Baghouse	Inlet Outlet
Lead reclamation	G	Cascade scrubber	Inlet Outlet
Formation	G	Packed bed mist eliminator	Outlet
	L	Foam + scrubber mist eliminator	Inlet Outlet

[a] Locations relative to control device.

A.3 SELECTION OF TEST PROCEDURES

Standard EPA test methods were available for the pollutants of concern. The EPA Methods provide detailed sampling methodology. Selection of the sampling site and the number of sampling points were well defined. This level of detail was considered necessary for compliance testing to minimize subjectivity and to ensure accuracy, reproducibility, and representativeness.

Unlike in-stack filter methods such as the ASME PTC27 Method and WP-50 Method, EPA specifies all-glass construction except for the probe. A glass probe is required only if the probe length is less than about 8 feet and stack temperatures do not exceed 1320°C (608°F). This will usually be the case in battery plants. Glass equipment is believed superior because it is less reactive.

Therefore, it was decided that the EPA methods would be used for determination of lead and sulfuric acid emissions and of opacities. EPA Methods 5 and 8 were recommended for collection of particulate and sulfuric acid mist emissions, respectively. The lead content of the particulate sample collected by Method 5 was then determined by atomic absorption analysis.

A proposed EPA Method 12 was developed for testing lead emissions at the outlet of the control device because of the low concentrations anticipated at that point. The method was developed to provide greater sensitivity. To confirm the accuracy of the proposed Method 12 for lead-acid battery plant lead emissions, EPA personnel decided to run two sample trains concurrently to determine lead emissions from control device outlets, one train extracting the sample in accordance with EPA Method 5 and the other incorporating a nitric acid impinger train followed by a filter.

The recommended test methods were complete as to both sample extraction and analysis. In addition to the analyses specified in the EPA test methods, particle size classifications

were performed by use of impactors, and samples of trace elements were collected. Process data were collected from plant production records and by direct observation.

A.4 DEVELOPMENT OF THE DATA BASE FOR THE STANDARD

Source tests were conducted at the three selected plants during June and August 1976, and April 1977. Results of these tests are summarized in Appendix C. These data, along with values delineating the cost and environmental impacts of several levels of emission control, were presented to the National Air Pollution Control Techniques Advisory Committee (NAPCTAC) in 1977.

APPENDIX B

INDEX TO ENVIRONMENTAL IMPACT CONSIDERATIONS

Agency guidelines for preparing regulatory action Environmental Impact Statements (39 Fr 37419; October 21, 1974)	Location within the standards support and Environmental Impact Statement
Background and description of proposed action; Summary of proposed standards.	The proposed standards are summarized in Chapter 1, section 1.1.
Statutory basis for proposed standards.	The statutory basis for the proposed standards is summarized in Chapter 2.
Relationship to other regulatory agency actions.	The various relationships between the proposed standards and other regulatory agency actions are summarized in Chapter 2.
Industry affected by the proposed standards.	A discussion of the industry affected by the standards is presented in Chapter 3, section 3.1. Further details covering the "business/economic" nature of the industry is presented in Chapter 8.
Specific processes affected by the standard.	The specific processes and facilities affected by the proposed standards are summarized in Chapter 1, Section 1.1. A discussion of the rationale for selecting these particular processes or facilities is presented in Chapter 9, Section 9.2.2. A detailed technical discussion of the sources and processes affected by the proposed standards is presented in Chapter 3, Section 3.2 through 3.7.
Alternatives to proposed standard.	A discussion of the alternative emission control systems and their effectiveness is presented in Chapter 6. The costs associated with these systems are presented in Chapter 8, Section 8.2.
Environmental impact.	Estimates of primary and secondary impact of the proposed standards are discussed in Chapter 7.

APPENDIX C

SUMMARY OF TEST DATA

Four lead-acid storage battery plants were tested by EPA to evaluate the best control techniques for controlling lead emissions from grid casting, paste mixing, three-process operation, lead oxide manufacturing, and lead reclamation. Also, a vat-type formation process (dry formation) was tested for emissions of sulfuric acid mist. A brief description of each plant and a summary of the test results are presented in Sections C.1 through C.4.

C.1 PLANT B

Plant B has a normal operating output of 3500 bpd, with a maximum of 4500 bpd.

The major operations are lead oxide production, grid casting, paste mixing, battery assembly (the three-process operation), and formation. Figure C-1 illustrates the general flow of material through Plant B.

The plant manufactures lead oxide by the ball mill process, operating two production lines 5 days per week, 24 hours per day. The normal feed rate for each production line is fifteen 100-pound lead pigs per hour (3000 lb/hr total). The pigs are fed into a Harding rotary mill, which tumbles the pigs to form lead

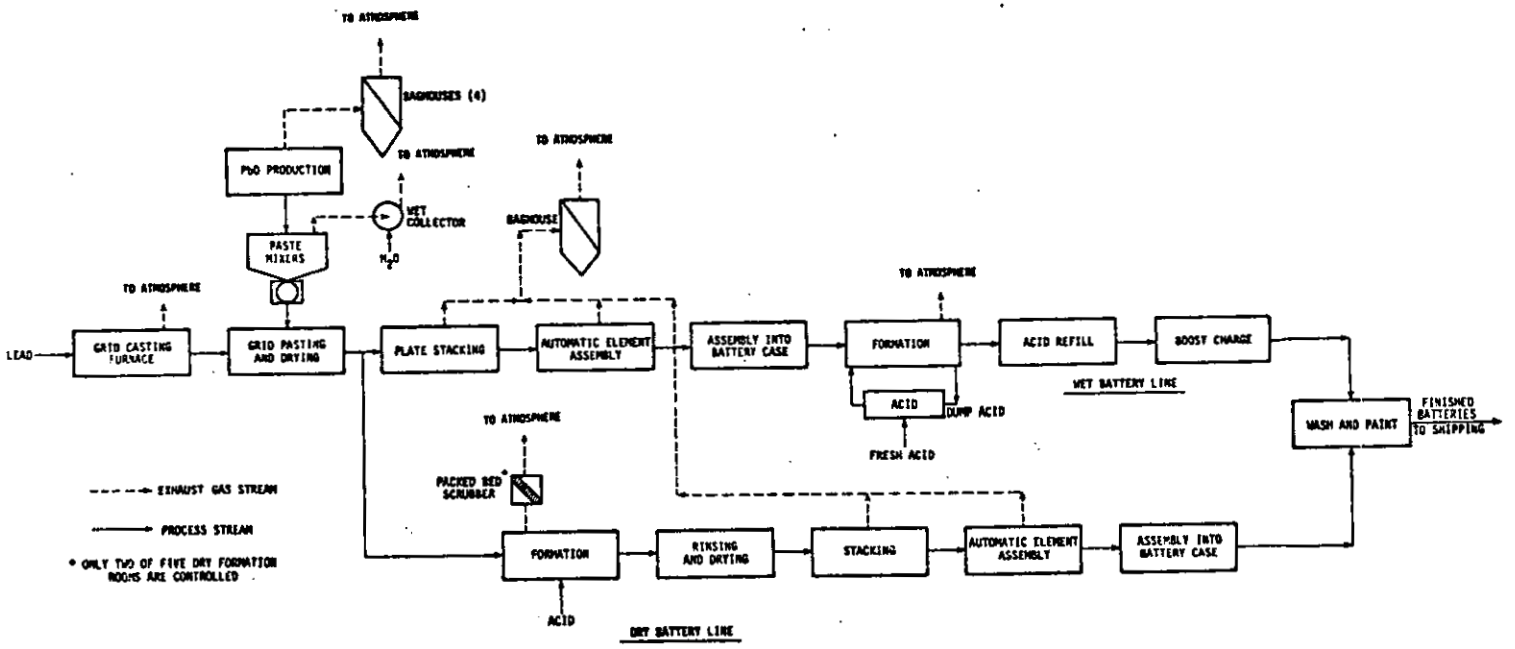

Figure C-1. Production flow diagram, Plant B.

oxide. The material is then screened with a vibrating rotary screen and milled with a Raymond impact mill; the product, collected with a cyclone, consists of approximately 70 percent lead oxide and 30 percent lead. Each lead oxide production line is equipped with two baghouses to provide particulate control and also to collect the product that is not retained by the cyclone separator. Water sprays maintain rotary mill temperatures at about 210°C (410°F).

Production line 1 is controlled by two Mikropul two-compartment baghouses, each having air-to-cloth ratios of 2/1 with both compartments on line. One baghouse controls the screens that follow the rotary mill, and the other controls the product recovery cylone separator and the barrel filling station. The felted dacron bags are cleaned in each compartment every 15 minutes by shaking. During shaking the air-to-cloth ratio is 4/1. These units were rebagged in April 1976.

Lead oxide production line 2 is controlled by two Mikropulsaire baghouses (model no. 64S-6-POTR), each having air-to-cloth ratios of 4/1. One baghouse controls the screens following the rotary mill and the other controls the product recovery cylone separator, a vibrating screen following the cyclone, and the barrel filling station. The felted dacron bags are continuously cleaned by pulse jet.

Exhausts from all four baghouses are combined and released to the atmosphere through a 15-m (50-ft) stack.

The grid casting facility consists of four machines. Each grid cast makes two battery plates after pasting and slitting. The cast grids are taken to the grid pasting machine, where both positive and negative pastes are applied to the grids. After pasting, these double plates are dried, slit in half to make two plates, stacked, and formed.

The paste is produced by mixing dry lead oxide powder, water, and sulfuric acid in two 907-kg/hr (2000-lb/hr) paste mixers. Each mixer is controlled by a separate low-energy impingement-type wet collector designed for a pressure drop of 1992 to 2490 Pa (8-10 in. W.G.) at 56.6 m^3/min (2000 acfm).

The plates used in the dry battery production line are formed in vats of sulfuric acid. After charging, or forming, the plates are rinsed, slit, and stored.

Plates for both wet and dry batteries are processed similarly in the three-process operation. The plates and separators are automatically or manually stacked in the proper sequence. Plant B has four hand stacking stations and two automated stations, (a Reed stacker and a Winkel stacker). Leads (pronounced leeds) and posts are cast on some of these stacks of plates to form elements. Two automatic element assembly units (cast-on-strap machines) are used. The balance of the stacks of plates are processed on a proprietary system, in which the stacks are inserted into specially constructed battery cases and the leads and posts are connected to the plate stacks at a burning station.

The three-process operation is controlled by a Mikro-pulsaire (Model No. 11F 26410) baghouse. Ducts from each process are joined into a 0.76 m (30-inch) duct, and the baghouse exhausts through a 15-m (48-foot) stack that is 0.76 m (30 in.) in diameter. The baghouse is bagged with felted bags and is rated at 566 m^3/min (20,000 acfm) with an air-to-cloth ratio of 6.5/1. The felted bags are continuously cleaned by pulse jet.

Following the three-process operation, batteries from the dry battery line are washed, painted, and sent to shipping; batteries from the wet production line are sent to be formed. These batteries are filled with dilute sulfuric acid and formation is initiated. After the batteries are formed, the acid is replaced with fresh acid. The wet formed batteries are then given a boost charge, washed, painted, and sent to shipping.

At Plant B, source tests were performed on the three-process operation and the lead oxide production facility. The test results are summarized in Tables C-1 and C-1A. Qualified observers were present during the tests and saw no visible emissions from the stacks being tested.

C.2 PLANT D

Plant D has a normal operating output of 2400 bpd with a maximum of 4000 bpd. The plant is a conventional wet-battery operation, except that the finished units are sent to another plant for formation. Figure C-2 is a schematic diagram of Plant D production flows.

Table C-1. TEST RESULTS SUMMARY FOR PLANT B (METRIC UNITS)

Process	Test No.	Exhaust flow, m^3/min		Exhaust flow, am^3/min		Pb concentration, mg/m^3		Pb emissions, kg/hr		Process throughput	Emission factor g/throughput		Control efficiency %
		Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet		Inlet	Outlet	
Three-process	1	504	580	530	580	29.9	0.444	0.903	0.016	0.28[a]	3225	56.25	98.3
	2	516	565	547	599	33.6	0.0732	1.043	0.003	0.28[a]	3724	9.07	99.76
	3	516	567	548	604	19.9	0.0435	0.621	0.001	0.28[a]	2218	5.44	99.75
	AVG.	512	571	542	594	27.9	0.188	0.856	0.007	0.28[a]	3056	23.59	99.3
Lead oxide mill	4	N/M	65	N/M	76	N/M	1.13	N/M	0.005	1361[b]	N/M	3.18	N/M
	5	N/M	67	N/M	78	N/M	2.27	N/M	0.010	1361[b]	N/M	6.35	N/M
	6	N/M	67	N/M	78	N/M	1.12	N/M	0.005	1361[b]	N/M	3.18	N/M
	AVG.	N/M	66	N/M	77	N/M	1.51	N/M	0.007	1361[b]	N/M	4.24	N/M

[a] 1000 batteries/hour

[b] kg of lead input/hour

N/M - Not Measured

Table C-1A. TEST RESULTS SUMMARY FOR PLANT B (ENGLISH UNITS)

Process	Test No.	Exhaust flow, dscfm		Exhaust flow, acfm		Pb concentration, gr/dscf		Pb emissions, lb/hr		Process through-put	Emission factor lb/throughput		Control efficiency %
		Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet		Inlet	Outlet	
Three-process	1	17,800	20,490	18,710	21,340	0.0131	0.000194	1.99	0.0347	0.28[a]	7.11	0.124	98.3
	2	18,210	19,950	19,320	21,150	0.0147	0.000032	2.30	0.0056	0.28[a]	8.21	0.020	99.76
	3	18,210	20,010	19,360	21,340	0.0087	0.000019	1.37	0.0033	0.28[a]	4.89	0.012	99.75
	AVG.	18,070	20,150	19,130	21,280	0.0122	0.000082	1.89	0.0145	0.28[a]	6.74	0.052	99.3
Lead oxide mill	4	N/M	2,310	N/M	2,680	N/M	0.000494	N/M	0.0105	1.5[b]	N/M	0.007	N/M
	5	N/M	2,370	N/M	2,760	N/M	0.000994	N/M	0.0217	1.5[b]	N/M	0.014	N/M
	6	N/M	2,370	N/M	2,750	N/M	0.000489	N/M	0.0106	1.5[b]	N/M	0.007	N/M
	AVG.	N/M	2,350	N/M	2,730	N/M	0.000659	N/M	0.0143	1.5[b]	N/M	0.009	N/M

[a] 1000 batteries/hour

[b] Tons of lead input/hour

N/M - Not Measured

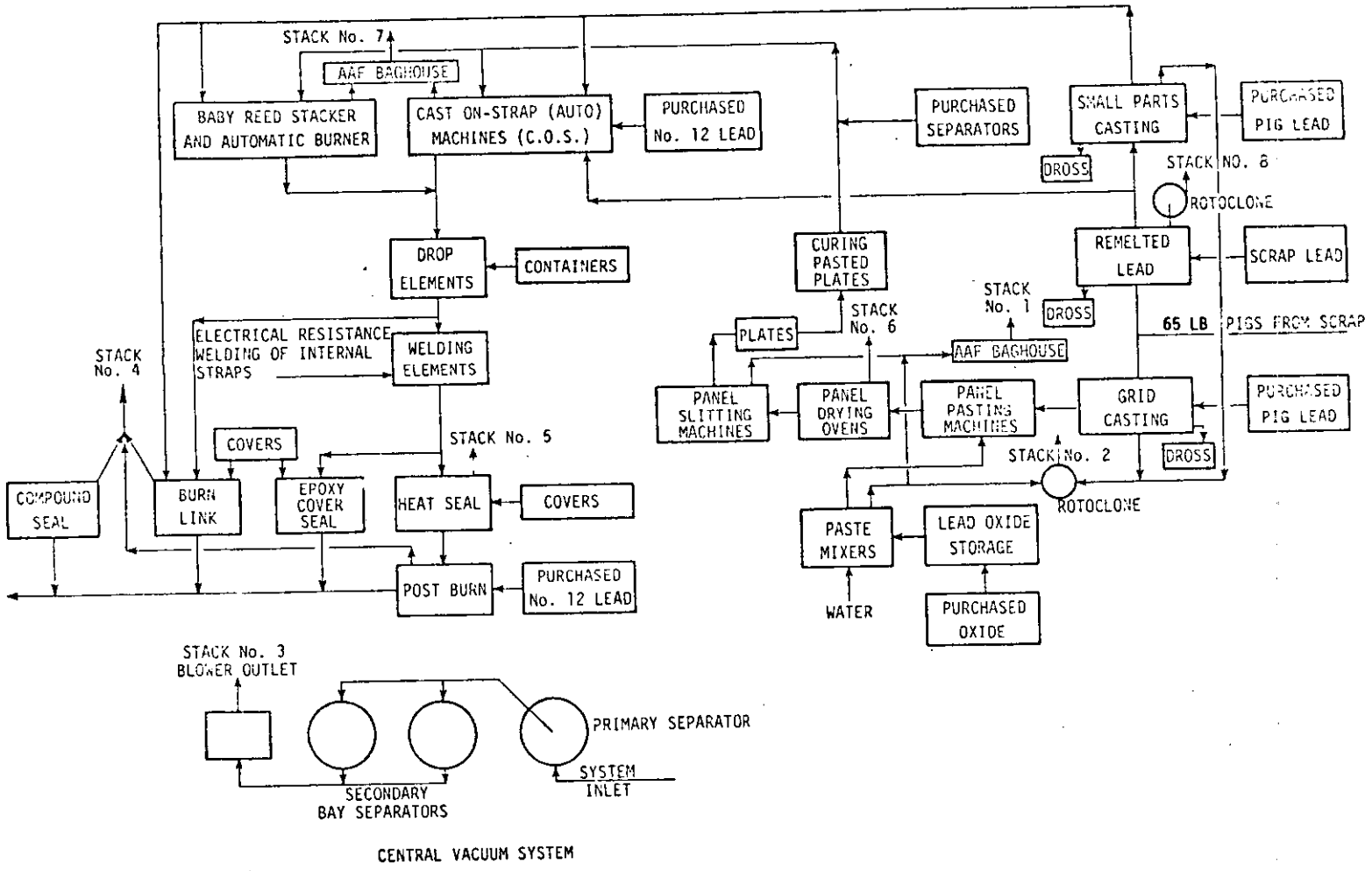

Figure C-2. Production flow diagram, Plant D.

The plant operates three Wirtz grid-casting furnaces, each with three grid casters (a total of nine casters) vented to a common stack. The exhaust ducting is designed for a fourth furnace. A small-parts casting furnace connects to the main casting exhaust system, which is cleaned by an American Air Filter Type N Roto-Clone system (size 24, Arrangement D). The small parts produced are battery element straps used at the Tiegel burning machine.

Plant D is operating one Beardsley and Piper paste mixer, although two identical mixers were originally installed. The second mixer, transfer conveyor, dryer, and curing station have been removed. The common components, such as the baghouse and lead oxide hopper, were designed as part of the mixer system. Positive batches require 1088 kg (2400 lb) of lead oxide; negative batches require 816 kg (1800 lb) of lead oxide.

The paste mixer exhaust vents to two separate control systems. As the lead oxide is dumped, the gases are vented through an American Air Filter Type 3-96 baghouse, equipped with a 56 kW (75-hp) fan. This baghouse has three compartments, with a total of 636 bags. Total cloth area is 813 m^2 (8755 ft^2), yielding an air-to-cloth ratio of 3.3/1. One compartment is closed for approximately 1 minute each 30 minutes for shaking. The air-to-cloth ratio during shaking increases to 4.9/1. The exhaust gases are rerouted during mixing via an automatic damper to the AAF Type N Roto-Clone, which also cleans the casting operation exhaust gas.

The paste is continuously applied to the grids as they are automatically fed to the pasting machine. The pasted grid is then dried, slit (each grid becomes two plates after pasting and slitting), and stacked. The pasting operation is not vented, but the drying operation is. Slitting and stacking operations are vented to the same baghouse that controls the mixer during the portion of the mixing cycle when dry ingredients are added to the mix. The slitting machine can handle 23,500 plates per hour. A spare slitting machine that is used periodically is also vented to the baghouse. This machine was idle during the tests, and its exhaust system was dampered from the baghouse.

The plates are stacked in the proper sequence and joined on three production lines. Two of these lines are equipped with mechanical stackers and a COS machine that casts the straps onto the elements. The other line uses a mechanical stacker, but the elements are joined by burning on leads with a Tiegel machine, which operates much more slowly than the COS machines. The COS machines produce six-celled batteries exclusively; the Tiegel machine produces industrial batteries with three, four, and six cells. Vents from the assembly area enter a common 0.914-m (36-in.)- diameter manifold, which connects to an AAF Type 3-106 baghouse equipped with a 75 kW (100-hp) fan. Total cloth area is 9757 square feet, yielding an air-to-cloth ratio of 3.3/1. One compartment is closed for approximately 1 minute each 30 minutes for shaking. The air-to-cloth ratio during shaking increases to 4.9/1. The assembly area hoods and ducts were designed to capture particulate emissions.

Tests were performed on the grid casting, paste mixing, and the three-process operation at Plant D. The results are summarized in Tables C-2 and C-2A. Qualified observers were present during the tests and saw no visible emissions from the stacks being tested.

C.3 PLANT G

Plant G has a capacity of 1800 bpd and a normal operating output of 1500 bpd. The major facilities include grid casting, paste mixing, the three-process operation, and formation. There is also a small parts casting unit and a lead reclaim pot. Both wet and dry batteries are produced. Figure C-3 is a schematic diagram of Plant G production flow.

Grids are cast on six grid casting machines, which receive lead from two melting pots. This process is not controlled.

One paste mixer is used for both positive and negative pastes. The mixer emissions are controlled by a Schneible, type F61BL, low-energy cascade type, 116-m^3/min (4100-acfm) wet scrubber with a pressure drop of about 1743 to 1992 Pa (7 to 8 in. W.G.).

Finished grids are pasted, dried, and stored. The plate drying ovens are vented to the atmosphere by natural draft. The dried plates can be sent to formation if they are to be used in making dry batteries or to the three-process operation for use in wet batteries.

Table C-2. TEST RESULTS SUMMARY FOR PLANT D (METRIC UNITS)

Process	Test No.	Exhaust flow, m^3/min		Exhaust flow, am^3/min		Pb concentration, mg/m^3		Pb emissions, kg/hr		Emission factor, g Pb/1000 batteries		Control efficiency %
		Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	
Three-process Operation	1	964	803	981	809	40.0	0.664	2.309	0.032	9661	134.5	98.6
	2	893	698	918	700	53.5	1.01	2.862	0.042	11935	176.1	98.5
	3[a]	897	805	920	808	2.44	0.664	0.132	0.032	549	134.5	75.5
	AVG.	918	769	940	772	31.9	0.778	1.768	0.035	4481	148.4	90.9
Grid casting (Roto-Clone controlled)	6[b]	414	N/M	502	N/M	0.89	N/M	0.022	N/M	92	N/M	N/M
	7[b]	399	N/M	480	N/M	1.01	N/M	0.024	N/M	100	N/M	N/M
	12[c]	437	473	515	496	5.86	0.320	0.154	0.009	644	37.9	94.1
	13[b]	438	N/M	499	N/M	2.81	N/M	0.077	N/M	308	N/M	N/M
	AVG.	422	473	499	496	2.65	0.320	0.069	0.009	286	37.9	94.1
Grid casting and full mixing cycle (Roto-Clone controlled)	4	435	469	499	498	25.5	0.275	0.696	0.008	2784	32.2	98.8
	7[b]	N/M	462	N/M	512	N/M	0.252	N/M	0.007	N/M	28.4	N/M
	13[b]	N/M	487	N/M	525	N/M	0.206	N/M	0.006	N/M	24.6	N/M
	15	477	526	548	562	2.43	0.229	0.072	0.008	289	30.3	89.5
	AVG.	456	506	524	524	14.0	0.229	0.384	0.007	1536	28.9	94.2
Grid casting and mixing (Roto-Clone controlled)	5	435	452	498	490	1.60	0.160	0.044	0.005	174	18.0	89.6
	6[b]	N/M	459	N/M	504	N/M	0.252	N/M	0.007	N/M	28.4	N/M
	14	482	485	548	505	3.18	0.320	0.096	0.010	384	25.6	89.7
	AVG.	458	465	523	500	2.38	0.252	0.070	0.007	279	24.0	89.6
Slitting (Baghouse controlled)	10	681	685	733	693	43.1	0.938	1.838	0.028	7340	113.7	98.5
Slitting and full mixing cycle (Baghouse controlled)	9	649	702	699	712	66.6	1.17	2.709	0.051	10845	204.6	98.1
Slitting and mixer charging (Baghouse controlled)	8	681	685	726	689	115	1.17	4.925	0.050	19700	200.8	99.0
	11	671	697	708	691	33.7	1.35	1.416	0.059	5680	234.9	96.0
	AVG.	676	691	717	690	74.6	1.26	3.170	0.054	12690	217.8	97.5

[a] Several equipment downtimes during test.

[b] Inlet tested prior to merger of grid casting and mixing exhaust.

[c] Filter broke. Catch was still collected.

N/M - Not Measured

Table C-2A. TEST RESULTS SUMMARY FOR PLANT D (ENGLISH UNITS)

Process	Test No.	Exhaust flow, dscfm		Exhaust flow, acfm		Pb concentration, gr/dscf		Pb emissions, lb/hr		Emission factor lb Pb/1000 batteries		Control efficiency %
		Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	
Three-process Operation	1	34,026	28,366	34,660	28,572	0.01746	0.00029	5.09	0.071	20.4	0.284	98.6
	2	31,525	24,641	32,423	24,712	0.02334	0.00044	6.31	0.093	25.2	0.372	98.5
	3[a]	31,674	28,413	32,500	28,523	0.00106	0.00029	0.29	0.071	1.16	0.284	75.5
	AVG.	32,408	27,140	33,194	27,269	0.01395	0.00034	3.90	0.078	15.6	0.313	90.9
Grid Casting (Roto-Clone controlled)	6[b]	14,609	N/M	17,724	N/M	0.00039	N/M	0.0488	N/M	0.195	N/M	N/M
	7[b]	14,095	N/M	16,934	N/M	0.00044	N/M	0.0532	N/M	0.213	N/M	N/M
	12[c]	15,432	16,718	18,199	17,521	0.00256	0.00014	0.339	0.020	1.36	0.08	94.1
	13[b]	15,484	N/M	17,627	N/M	0.00123	N/M	0.163	N/M	0.652	N/M	N/M
	AVG.	14,905	16,718	17,621	17,521	0.00116	0.00014	0.151	0.020	0.605	0.08	94.1
Grid Casting and full mixing cycle (Roto-Clone controlled)	4	15,359	16,569	17,651	17,594	0.01114	0.00012	1.47	0.017	5.88	0.068	98.8
	7[b]	N/M	16,313	N/M	18,073	N/M	0.00011	N/M	0.015	N/M	0.060	N/M
	13[b]	N/M	17,208	N/M	18,548	N/M	0.00009	N/M	0.013	N/M	0.052	N/M
	15	16,852	18,559	19,358	19,849	0.00106	0.00010	0.153	0.016	0.612	0.064	89.5
	AVG.	16,105	17,162	18,494	18,516	0.00610	0.00010	0.811	0.015	3.24	0.061	94.2
Grid Casting and mixing (Roto-Clone controlled)	5	15,347	15,949	17,599	17,312	0.00070	0.00007	0.0921	0.0096	0.368	0.038	89.6
	6[b]	N/M	16,219	N/M	17,787	N/M	0.00011	N/M	0.015	N/M	0.060	N/M
	14	17,032	17,130	19,353	17,842	0.00139	0.00014	0.203	0.021	0.812	0.084	89.7
	AVG.	16,190	16,433	18,476	17,647	0.00104	0.00011	0.1476	0.015	0.590	0.061	89.7
Slitting (Baghouse controlled)	10	24,038	24,179	25,882	24,485	0.01884	0.00041	3.88	0.060	15.5	0.24	98.5
Slitting and full mixing cycle (Baghouse controlled)	9	22,935	24,806	24,679	25,142	0.02909	0.00051	5.72	0.108	22.9	0.432	98.1
Slitting and mixer charging (Baghouse controlled)	8	24,064	24,180	25,636	24,346	0.05046	0.00051	10.4	0.106	41.6	0.424	99.0
	11	23,701	24,614	24,996	24,391	0.01471	0.00059	2.99	0.124	12.0	0.496	96.0
	AVG.	23,882	24,397	25,316	24,368	0.03258	0.00055	6.70	0.115	26.8	0.459	97.5

[a] Several equipment downtimes during test.

[b] Inlet tested prior to merger of grid casting and mixing exhaust.

[c] Filter broke. Catch was still collected.

N/M - Not Measured.

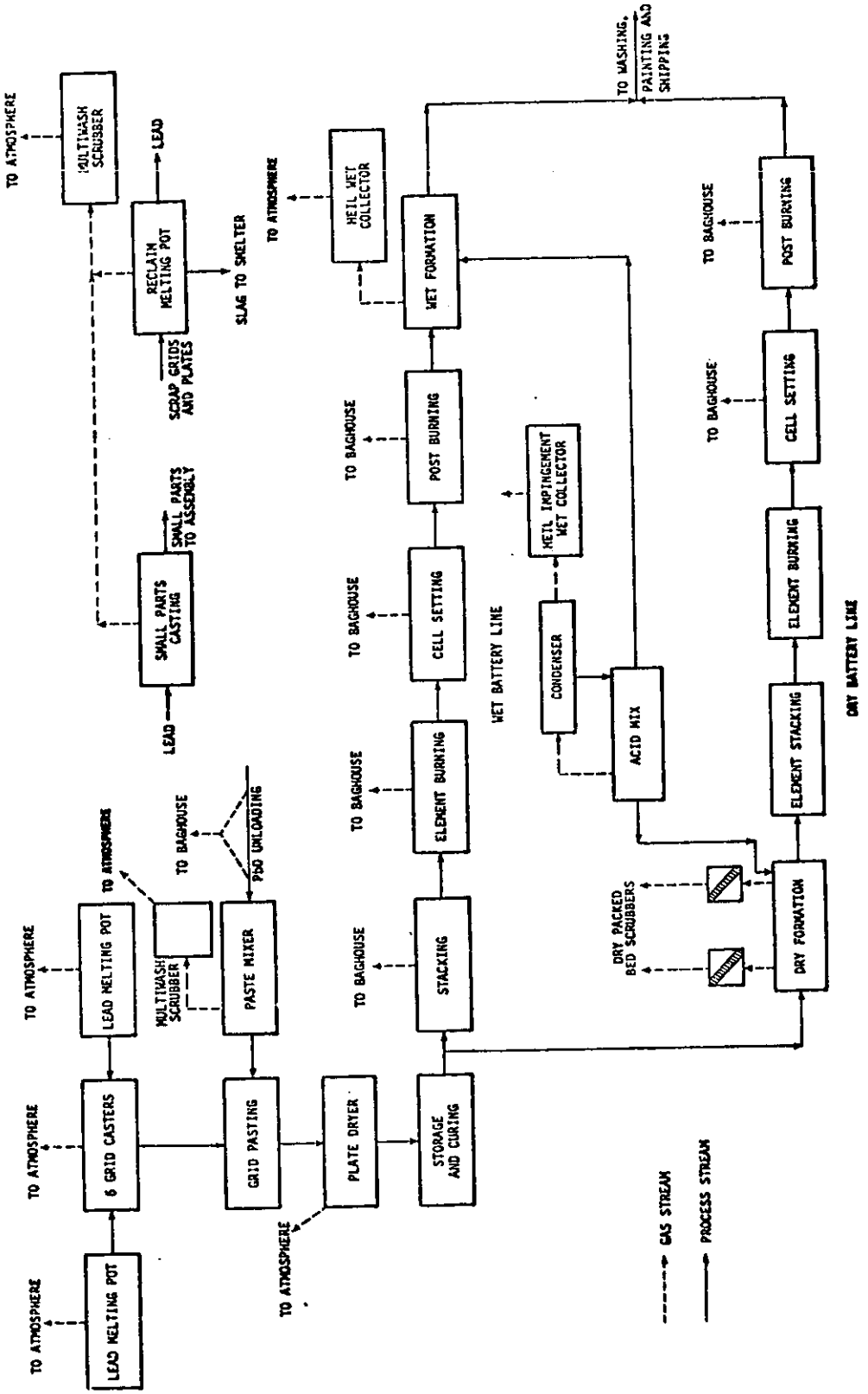

Figure C-3. Production flow diagram, Plant G.

The dry formation process is totally enclosed and is vented through two Tri-Mer mist eliminators installed in parallel. These units, designed to operate with a water spray, are operated in a dry mode. The packed beds are manually flushed after each cycle with a water and detergent solution. Sulfuric acid mist is collected and recycled. Part of the cleaned air from each scrubber is returned to the formation room for ventilation and the remainder is exhausted to the atmosphere through two stacks. After formation, the elements are dried, rinsed, and sent to the three-process operation.

The three-process operation for both dry and wet battery manufacture consists of stacking the plates, element burning to connect the plates, cell setting (inserting the assemblies into a battery case) and post burning. Emissions from the stacking operation and lead oxide production are vented in a common duct to a 212-m^3/min (7500-acfm) Mikro-Pulsaire, type 8FTV fabric filter. Cell setting and plate welding emissions are vented in a common duct to an identical fabric filter. Exhausts from both baghouses are ducted in turn to a common stack. A 30 kW (40-hp) fan provides suction for both baghouses.

After the three-process operation, the dry batteries are washed, painted, and shipped; the wet batteries are sent to formation. Acid mist from the wet forming room is vented through a Heil water spray scrubber. Wet batteries are washed, painted, and shipped following the formation process.

Deformed grids, posts, connectors, and some scrap plates are remelted in a reclamation furnace and formed into lead pigs to be reused. Most scrap plates and elements along with reclamation furnace slag are sent to a lead smelter for recovery. The reclamation furnace and the small-parts casting facility are vented in a common duct to a Schneible Model No. F-41 multiwash scrubber operating with a water-to-gas ratio of 15.2 to 19.0 liters per 28.3 m^3 (4 to 5 gallons per 1000 acf). The pressure drop is typically 498 to 747 Pa (2 to 3 in. W.G.) with a rated exhaust rate of 99 to 119 m^3/min (3500 to 4200 acfm).

Source tests were performed on the lead reclamation and formation processes at Plant G. Results of the reclamation facility tests are summarized in Tables C-3 and C-3A. Qualified observers were present during the tests and saw no visible emissions from the stacks that were tested.

C.4 PLANT L

Plant L produces about 6000 lead-acid storage batteries per day, using four vat-type formation rooms for manufacturing dry-charged batteries. The plant also manufactures wet-charged batteries. The formation room tested houses two formation circuits, and forms about 20,000 battery plates per day.

The formation process begins with the insertion of pasted battery plates into individual slots in formation tanks, which are about 18 inches wide and 3 feet long. After the plates are loaded into the tanks, the positive plates are connected in a

Table C-3. TEST RESULTS SUMMARY FOR PLANT G (METRIC UNITS)

Process	Test No.	Exhaust flow, m^3/min		Exhaust flow, am^3/min		Pb concentration, mg/m^3		Pb emissions, kg/hr		Scrap input, kg/hr	Emission factor g/kg feed		Control efficiency, %
		Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet		Inlet	Outlet	
Lead reclamation (Cascade scrubber controlled)	1	92	100	101	107	293	2.14	0.95	0.013	430.9	2.12	0.032	98.6
	2	94	102	107	111	175	4.39	1.21	0.027	403.7	2.92	0.071	97.8
	3	96	100	108	109	214	3.80	1.57	0.023	508.0	3.20	0.048	98.6
	AVG.	94	101	105	109	229	3.44	1.26	0.021	447.5	2.75	0.050	98.3

Table C-3A. TEST RESULTS SUMMARY FOR PLANT G (ENGLISH UNITS)

Process	Test No.	Exhaust flow, dscfm		Exhaust flow, acfm		Pb concentration, gr/dscf		Pb emissions, lb/hr		Scrap input, tons/hr	Emission factor lb/ton feed		Control efficiency %
		Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet		Inlet	Outlet	
Lead reclamation (Cascade scrubber controlled)	1	3255	3464	3540	3775	0.0765	0.000936	2.10	0.0283	0.475	4.72	0.064	98.6
	2	3341	3594	3756	3915	0.0937	0.00192	2.69	0.0591	0.445	6.45	0.142	97.8
	3	3407	3520	3804	3800	0.128	0.00166	3.72	0.0503	0.560	7.09	0.096	98.6
	AVG.	3334	3526	3700	3830	0.0994	0.00150	2.84	0.0459	0.493	6.09	0.101	98.3

positive source of direct current (DC) and the negative plates are connected to a negative DC source. The tanks are then filled with sulfuric acid which has a specific gravity of about 1.04. After the acid has been added, a foaming agent called Alkanol is added to each tank, and the current is switched on. During the formation process, the lead oxide paste on the positive plates is oxidized to lead peroxide and the lead oxide paste on the negative plates is reduced to metallic lead.

The current is applied to the plates for about 18 hours, which encompasses the entire second and third (evening and night) shifts. The formed plates are removed and unformed plates loaded during the first (day) shift.

Sulfuric acid mist emissions from the process are controlled in two ways. First, emissions from the acid bath contact the foam layer at the surface of the bath and are partially absorbed by the foam layer. The second control mechanism is collection of the unabsorbed mist particles in a Heil Model 704 scrubber which has a water-to-gas ratio of 0.035 to 0.07 liters per cubic meter (1-2 gal./1000 acf) and a pressure drop of 498 to 747 pascal (23 inches of water-gage).

Emissions from parts of four formation cycles were sampled. Only one cycle (Cycle No. 3) was sampled throughout the entire cycle. All emission tests except those on Cycle No. 3 were performed when emissions from the process were controlled using a

combination of foam and scrubbing. Emission results from tests on Cycle No. 3 show emissions when the process is controlled by scrubbing only. Additional information on these tests is presented in Tables C4 and C4A.

C.5 OTHER TEST DATA

Other test data used in this study are summarized in Tables C5 and C5A. The data were obtained from tests performed at Plants B, J, and K prior to this study. Both Plants B and J manufacture lead acid batteries while Plant K produces lead oxide.

Table C-4. TEST RESULTS SUMMARY FOR PLANT L (METRIC UNITS)

Plant	Process	Formation Cycle No.	Test No.	Approximate Number of Hours into the Formation Cycle[a] Start	End	Exhaust Flow m^3/min Inlet	Outlet	Actual Exhaust Flow am^3/min Inlet	Outlet	H_2SO_4 Mist Concentration mg/m^3 Inlet	Outlet	H_2SO_4 Mist Emissions, kg/hr Inlet	Outlet	Control Efficiency, %[b]
L	Formation	1	1[c]	6.5	10.5	81.59	107.37	87.56	113.6	6.56	0.57	0.032	0.0046	89
L	Formation	1	2	11.0	16.0	78.53	92.51	84.79	96.73	55.21	0.87	0.259	0.0050	98
L	Formation	2	3	8.0	10.0	83.15	87.14	91.98	93.11	53.34	0.30	0.263	0.0014	99
L	Formation	2	4	12.0	14.0	78.79	91.72	87.11	96.47	76.17	2.20	0.358	0.0122	97
L	Formation	2	5	15.0	16.0	84.02	94.47	93.19	99.64	109.49	5.23	0.549	0.0295	95
L	Formation	3	6	0.0	3.0	85.04	95.94	92.63	101.46	21.82	0.63	0.109	0.0036	97
L	Formation	3	7	3.0	8.5	77.78	101.74	84.90	107.54	33.55	0.60	0.159	0.0036	98
L	Formation	3	8	8.0	9.5	78.53	N/M	85.81	N/M	54.64	N/M	0.254	N/M	N/M
L	Formation	3	9	9.5	13.0	80.29	92.99	87.87	98.14	86.96	1.37	0.417	0.0077	98
L	Formation	3	10	13.0	16.0	76.33	89.37	83.68	94.58	65.21	1.60	0.299	0.0086	97
L	Formation	4	11	12.5	16.0	77.66	82.21	86.80	88.13	24.42	0.90	0.113	0.0045	96

[a]This was a 16 hour formation cycle. The numbers in these columns represent the approximate length of time the process was sampled, and the phase of the formation cycle that was sampled (e.g., Test No. 2 was performed during the last five hours of the first cycle sampled).

[b]Since inlet and outlet samples were not collected simultaneously, these efficiencies are estimates.

[c]Results invalidated by sample equipment failure.

N/M - Not Measured

Table C-4A. TEST RESULTS SUMMARY FOR PLANT L (ENGLISH UNITS)

Plant	Process	Formation Cycle No.	Test No.	Approximate Number of Hours into the Formation Cycle[a]		Exhaust Flow Rate, dscfm		Actual Flow Rate, scfm		H_2SO_4 Mist Emissions, 10^{-4} gr/dscf		H_2SO_4 Mist Emissions, lb/hr		Control Efficiency, %[b]
				Start	End	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	
L	Formation	1	1[c]	6.5	10.5	2883	3794	3094	4014	28.67	2.49	0.07	0.008	89
L	Formation	1	2	11.0	16.0	2775	3269	2996	3418	241.29	3.80	0.57	0.011	98
L	Formation	2	3	8.0	10.0	2938	3079	3250	3290	233.99	1.31	0.58	0.003	99
L	Formation	2	4	12.0	14.0	2784	3241	3078	3409	333.07	9.67	0.79	0.027	97
L	Formation	2	5	15.0	16.0	2969	3338	3293	3521	478.52	22.86	1.21	0.065	95
L	Formation	3	6	0.0	3.0	3005	3390	3273	3585	95.36	2.75	0.24	0.008	97
L	Formation	3	7	3.0	8.5	2748	3595	3003	3800	146.64	2.62	0.35	0.008	98
L	Formation	3	8	8.0	9.5	2775	N/M	3032	N/M	238.80	N/M	0.56	N/M	N/M
L	Formation	3	9	9.5	13.0	2837	3286	3105	3468	380.05	5.99	0.92	0.017	98
L	Formation	3	10	13.0	16.0	2697	3158	2957	3342	285.00	6.99	0.66	0.019	97
L	Formation	4	11	12.5	16.0	2744	2905	3067	3114	106.73	3.93	0.25	0.010	96

[a] This was a 16 hour formation cycle. The numbers in these columns represent the approximate length of time the process was sampled, and the phase of the formation cycle that was sampled (e.g., Test No. 2 was performed during the last five hours of the first cycle sampled).

[b] Since inlet and outlet samples were not collected simultaneously, these efficiencies are estimates.

[c] Results invalidated by sample equipment failure.

N/M - Not Measured

Table C-5. TEST RESULTS SUMMARY FOR PLANTS B, J, AND K (METRIC UNITS)

Plant	Process	Control Device	Test No.	Process throughput, Mg/hr	Exhaust Flow Rate, m^3/min		Actual Exhaust Flow Rate, am^3/min		Pb Concentration, mg/m^3		Pb Emissions, kg/hr		Control efficiency %
					Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	
B	PbO Mill (Ball Mill)	Product recovery fabric filter	1	1.4	N/M	72.32	N/M	87.16	N/M	0.45	N/M	0.0020	N/M
			2	1.4	N/M	80.50	N/M	93.98	N/M	0.30	N/M	0.0015	N/M
			3	1.4	N/M	77.11	N/M	92.68	N/M	0.43	N/M	0.0020	N/M
			AVG.	1.4	N/M	76.63	N/M	91.27	N/M	0.40	N/M	0.0018	N/M
B	Three-process	Fabric Filter	1	N/M	N/M	526.95	N/M	555.18	N/M	0.05	N/M	0.0015	N/M
			2	N/M	N/M	445.71	N/M	470.71	N/M	0.27	N/M	0.0073	N/M
			3	N/M	N/M	438.97	N/M	473.09	N/M	0.14	N/M	0.0037	N/M
			AVG.	N/M	N/M	470.54	N/M	499.65	N/M	0.15	N/M	0.0042	N/M
J	Grid Casting	Uncon-trolled	1	N/M	N/M	11.9	N/M	15.7	N/M	3.41	N/M	0.0025	N/M
			2	N/M	N/M	11.6	N/M	15.5	N/M	7.05	N/M	0.0049	N/M
			3	N/M	N/M	10.5	N/M	14.1	N/M	2.70	N/M	0.0017	N/M
			AVG.	N/M	N/M	11.3	N/M	15.1	N/M	4.39	N/M	0.0030	N/M
J	Paste mixer	Schneible Scrubber	1	N/M	26.5	27.6	28.71	29.59	63.2	10.5	0.100	0.0187	81.4
			2	N/M	26.8	23.7	29.82	25.85	84.0	10.0	0.135	0.0155	88.5
			3	N/M	25.5	25.9	28.74	28.32	84.9	11.7	0.130	0.0199	85.2
			AVG.	N/M	26.3	25.7	29.08	27.92	77.4	10.8	0.122	0.0181	85.0
J	Three-process	Fabric Filter	1	N/M	321.34	355.23	325.05	374.63	5.95	0.17	0.115	0.0035	96.9
			2	N/M	331.42	352.66	347.19	368.86	2.63	0.07	0.053	0.0015	97.2
			3	N/M	321.85	360.16	334.39	375.00	4.28	0.15	0.083	0.0033	96.0
			AVG.	N/M	324.88	356.02	335.55	372.82	4.28	0.13	0.083	0.0028	96.7
K	PbO Mill (Barton Pot)	Product recovery fabric filter	1	0.70	N/M	35.4	N/M	47.0	N/M	54.2	N/M	0.115	N/M
			2	0.68	N/M	32.8	N/M	44.4	N/M	57.2	N/M	0.113	N/M
			3	0.60	N/M	35.4	N/M	48.4	N/M	104.4	N/M	0.223	N/M
			AVG.	0.66	N/M	34.5	N/M	46.6	N/M	71.9	N/M	0.150	N/M

N/M - Not Measured

Table C-5A. TEST RESULTS SUMMARY FOR PLANTS B, J, AND K (ENGLISH UNITS)

Plant	Process	Control Device	Test No.	Process throughput, ton/hr	Exhaust Flow Rate, dscfm		Actual Exhaust Flow Rate, acfm		Pb Concentration, 10^{-4}gr/dscf		Pb Emissions, lb/hr		Control efficiency %
					Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	
B	PbO Mill (Ball Mill)	Product recovery fabric filter	1	1.5	N/M	2554	N/M	3078	N/M	1.97	N/M	0.0043	N/M
			2	1.5	N/M	2843	N/M	3319	N/M	1.33	N/M	0.0032	N/M
			3	1.5	N/M	2723	N/M	3273	N/M	1.88	N/M	0.0044	N/M
			AVG.	1.5	N/M	2706	N/M	3223	N/M	1.73	N/M	0.0040	N/M
B	Three-process	Fabric Filter	1	N/M	N/M	18609	N/M	19606	N/M	0.215	N/M	0.0034	N/M
			2	N/M	N/M	15740	N/M	16623	N/M	1.19	N/M	0.0161	N/M
			3	N/M	N/M	15502	N/M	16707	N/M	0.609	N/M	0.0081	N/M
			AVG.	N/M	N/M	16617	N/M	17645	N/M	0.671	N/M	0.0092	N/M
J	Grid casting	Uncontrolled	1	N/M	N/M	420	N/M	555	N/M	14.9	N/M	0.0054	N/M
			2	N/M	N/M	410	N/M	548	N/M	30.8	N/M	0.0108	N/M
			3	N/M	N/M	370	N/M	497	N/M	11.8	N/M	0.0037	N/M
			AVG.	N/M	N/M	400	N/M	533	N/M	19.2	N/M	0.0066	N/M
J	Paste mixer	Schneible Scrubber	1	N/M	936	974	1014	1045	276	46.0	0.221	0.0412	81.4
			2	N/M	945	837	1053	913	367	43.7	0.297	0.0342	88.5
			3	N/M	901	916	1015	1000	371	51.3	0.286	0.0439	85.2
			AVG.	N/M	927	909	1027	986	338	47.0	0.268	0.0398	85.0
J	Three-process	Fabric Filter	1	N/M	11348	12545	11479	13230	26.0	0.73	0.253	0.0078	96.9
			2	N/M	11704	12454	12261	13026	11.5	0.30	0.116	0.0032	97.2
			3	N/M	11366	12719	11809	13243	18.7	0.66	0.182	0.0072	96.0
			AVG.	N/M	11473	12573	11850	13166	18.7	0.56	0.184	0.0061	96.7
K	PbO Mill (Barton Pot)	Product recovery fabric filter	1	0.77	N/M	1250	N/M	1660	N/M	237	N/M	0.253	N/M
			2	0.75	N/M	1160	N/M	1570	N/M	250	N/M	0.249	N/M
			3	0.66	N/M	1250	N/M	1710	N/M	456	N/M	0.491	N/M
			AVG.	0.73	N/M	1220	N/M	1650	N/M	314	N/M	0.331	N/M

N/M - Not Measured

APPENDIX D

EMISSION MEASUREMENT AND CONTINUOUS MONITORING

D.1 EMISSION MEASUREMENT METHODS

As part of the work done under EPA Contract No. 68021219, Arthur D. Little, Inc. performed a review of the recent literature pertaining to lead sampling and analysis. Their recommendation was to employ a Modified EPA Method 5 sampling train for sample collection, with lead analysis to be performed by atomic absorption spectrometry (AAS). Based on this advice, EPA combined these techniques in a working draft, "Determination of Lead Emissions from the Manufacturing of Lead Batteries".

The new source performance standards were based on the results of lead sampling conducted with this method by EPA on grid casting furnaces, paste mixing operations, three process operation, lead oxide production, and lead reclamation.

In this adaptation of the Method 5 sampling train, 100 ml of 0.1N HNO_3 was placed in each of the first two impingers to facilitate collection of gaseous lead. Since no separation of gaseous and particulate lead was attempted, a filter, which was of high purity glass fiber, was located between the third and fourth impingers as a backup collector. After sampling was completed, the filter portion was extracted for lead in a nitric acid reflux procedure.

A rigourous pretreatment with HNO_3 of all sample-exposed surfaces and containers, blank analyses of filters and 0.1N HNO_3, and the most recent revisions of the Method 5 sample recovery procedure were all employed to insure that high quality samples were obtained.

Since emissions from the manufacture of lead batteries are relatively free of other pollutants, possible sample matrix effects associated with AAS were insignificant insofar as the impinger portion of the sample from this source was concerned. However, as a precaution against this problem with the filter portion due to the presence of the filter, the analytical technique known as the Method of Standard Additions was used for that fraction of the sample. In addition to lead determination, data were obtained by EPA at one plant on the formation process for sulfuric acid mist.

D.2 CONTINUOUS MONITORING

EPA has not determined performance specifications for opacity monitoring at lead battery plants. Opacity monitoring is, however, considered feasible, except when a wet scrubber is used to control lead emissions.

The equipment and installation costs for a single opacity monitor are estimated to be approximately $18,000 to $20,000. Annual operating costs, including data recording and reduction, are estimated to be between $8,000 and $9,000.

D.3 PERFORMANCE TEST METHODS

EPA Method 12 is recommended as the performance test method for lead emission from lead acid storage battery plants. EPA Method 9 is recommended for the determination of opacity. EPA Method 8 is recommended for the determination of sulfuric acid mist emissions.

EPA Method 12 is essentially the same method as was used in gathering the NSPS data, except that it has been revised to include all of the recent revisions to Method 5.

The cost of a test consisting of three lead runs with analysis and the determination of visible emissions is estimated to be about 6 to 8 thousand dollars. This cost estimate is based on the assumption that the testing is performed by independent contractors; the use of in-house or plant personnel will slightly reduce the cost.

APPENDIX E

ENFORCEMENT ASPECTS

E.1 GENERAL

The recommended standards of performance will limit emissions of lead from grid casting, lead oxide production, paste mixing, the three-process operation, and "other lead-emitting operations" and emissions of sulfuric acid mist from the formation process. The control systems that can be installed to comply with the lead standards are combinations of scrubbers and fabric filters. Scrubbers and mist eliminators can control formation emissions. The control system may serve one or several affected facilities simultaneously. Aspects of enforcing these standards are discussed below for each affected facility.

E.2 GRID CASTING

The design and operation of the grid casting units affect the level of uncontrolled emissions from the operation. Machine design is fixed and cannot be altered during tests. The casting operation is automatic, but each operator may control the temperature of his melting pot if there is not a central pot. During compliance testing, each pot should be at its normal operating temperature and all grid casting machines should be operating.

The rate of grid production is fixed by a constant machine speed. Thus, the operation of all machines indicates a maximum production rate.

Because of the units of the standard (gr/dscf), lead throughput data is not required. The process engineer should observe the process and record any operating problems that can affect compliance test results, such as breakdown of a machine or shutdown by the operator. A process monitor is necessary because production records alone may not be adequate to determine normal operation. The quantity of deformed plates produced generally is not recorded, but emissions are generated by the casting of both perfect and malformed plates. Thus, although production records may show a low production figure for the test day, the lead throughput during the test may be at a maximum.

Short downtimes during the test should not invalidate the results. It is often necessary to spray the molds with a special cork solution to prevent the grids from sticking. The process engineer will determine whether process downtime during the compliance test is excessive.

E.3 PASTE MIXING

Paste mixing is a batch operation done in a muller, day, or dough-type mixer. The process design for a given facility is fixed and cannot be changed during a compliance test. The paste mixing process involves two phases, materials charging and blending. Often each phase is controlled by a different device. At plants using two devices for the mixing cycle, the compliance

test will require two different test locations. The tests should be performed only while the mixer is ducted to the control device tested. A process engineer can coordinate process operation with compliance tests.

Compliance tests should be performed while the mixer is operating at maximum load. Process operating records should be consulted to verify that the paste recipe during compliance tests is the one normally used at that facility. If the same mixer is used for both positive and negative batches, tests should be run during mixing of positive batches when possible. Typically more dry lead oxide is used in positive batches, since a wet lead oxide sludge (recovered from deformed plates) is often used in negative batches. The positive batches, therefore, may generate more lead emissions. The source tests performed in this study showed no significant differences in controlled lead emissions from mixing of positive and negative batches.

E.4 THREE-PROCESS OPERATION

The three-process operation consists of slitting and stacking, burning, and assembly. These functions are done in many different ways, as described in Chapter 3. Lead emissions depend on the process design, the materials-handling techniques, and the number of process steps. Compliance tests should be performed during full operation. It is not practical to require that all processes operate at all times throughout the tests, since a minor breakdown or a changeover in the type of battery being produced may require short downtimes that should not signifi-

cantly affect overall process emissions. The process engineer must determine whether the downtimes of various three-process operations are significant enough to invalidate the compliance test.

In many three-process operations, one process may operate only if another process is shutdown. For example, a hand stacking station may operate only when an automatic unit is down or vice versa depending on the needs of the plant. If there is any indication that lead emissions from the two processes are significantly different, the process judged to generate the greatest amount of emissions should be operating during the compliance test.

Some plants may control different processes within a three-process operation facility with different control devices. In such instances, source tests must be run on all applicable stacks. Since it is likely that lead concentrations will be different in each exhaust stream, an equivalent concentration must be determined. This is done by determining total lead emissions in grains per minute and dividing by the total exhaust flow rate in dry standard cubic feet per minute. This equivalent concentration can then be compared with the standard.

E.5 LEAD OXIDE PRODUCTION

Lead oxide is produced by the ball mill and the Barton processes. Each must comply with the standard. The process is continuous, and equipment failures are few. If the equipment is just starting up after a shutdown, at least 4 hours of operation

should be allowed before compliance testing to ensure that steady-state conditions have been achieved.

The lead oxide process may be controlled by more than one baghouse. The baghouses may or may not exhaust through a common stack. Only one test location is required if there is a common exhaust. Otherwise each stack must be tested. Proper baghouse operation can be checked by observing the pressure drop of the control device.

Lead emissions are proportional to the lead feed rate to the system. During compliance tests, the feed rate should be normal. If the feed rate varies significantly, tests should be performed during the maximum feed rate. The process engineer can monitor feed rate by counting the number of lead ingots fed to the system. The ingots typically weigh about the same.

E.6 LEAD RECLAMATION

The lead reclamation systems consist of a melting pot in which relatively clean lead is remelted and cast into ingots for use in the plant. This category does not include operations similar to those in the secondary lead smelters on the premises of a few lead-acid battery plants. Lead emissions depend on scrap feed rate, type of scrap, and operating techniques. Compliance tests should be performed at the maximum feed rate, while the "dirtiest" scrap is fed to the recovery process, and while operating techniques are normal. Since the lead reclamation system is on-stream only periodically, the plant must be

notified well in advance so that enough scrap can be stored for all applicable tests.

Unlike most other lead-acid battery facilities, the operation of a lead reclamation facility is controlled mainly by the operator. The lead pot is usually heated continuously, but the temperature is raised from about 316°C to about 427°C (600°F to about 800°F) when scrap is being dumped into the pot. After dumping, the contents of the pot furnace is agitated with a metal rod so that the lead will sink. This can be done manually or automatically. Slag is removed from the surface periodically, and when there is room in the pot, more scrap is dumped in. The molten lead can be removed at any time and poured into molds. The process engineer can judge by observation whether the process is operating normally.

E.7 OTHER LEAD EMITTING OPERATIONS

Many lead-acid battery plants operate processes that are not common to all plants. A process such as lug breaking may be required at some plants because of the equipment used or the type of battery produced. Under the standard, such processes are required to be limited to lead emissions of not greater than 1.00 mg/m^3 (0.00044 gr/dscf). Compliance with OSHA regulations (50 $\mu g/m^3$) requires that all processes emitting significant lead emissions will be vented. These processes can normally be vented to controls serving other processes.

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16. ABSTRACT

Standards of performance for the control of emissions from lead-acid battery manufacturing plants are being proposed under the authority of section 111 of the Clean Air Act. These standards would apply to new, modified, or reconstructed facilities at any lead-acid battery manufacturing plant with a production capacity equal to or greater than 500 batteries per day. This document contains background information, environmental and economic impact assessments, and the rationale for the standards, as proposed under 40 CFR Part 60, Subpart KK.

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Emission Standards and Engineering Division

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air, Noise, and Radiation
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

November 1980

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ENVIRONMENTAL PROTECTION AGENCY

Background Information
and Final
Environmental Impact Statement
for Lead-Acid Battery Manufacture

Prepared by:

Don R. Goodwin 11/28/80

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Director, Emission Standards and Engineering Division
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1. The promulgated standards of performance limit emissions of lead from new, modified, and reconstructed lead-acid battery manufacturing facilities. Section 111 of the Clean Air Act (42 U.S.C. 7411), as amended, directs the Administrator to establish standards of performance for any category of new stationary source of air pollution that ". . . causes or contributes significantly to air pollution which may reasonably be anticipated to endanger public health or welfare."

2. Copies of this document have been sent to the following Federal Departments: Labor, Health and Human Services, Defense, Transportation, Agriculture, Commerce, Interior, and Energy; the National Science Foundation; the Council on Environmental Quality; members of the State and Territorial Air Pollution Program Administrators; the Association of Local Air Pollution Control Officials; EPA Regional Administrators; and other interested parties.

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1. SUMMARY

On January 14, 1980, the Administrator proposed standards of performance for lead-acid battery manufacture (45 FR 2790) under Section 111 of the Clean Air Act. Public comments were requested on the proposal in the Federal Register. There were 21 commenters composed mainly of lead-acid battery industry and State Agency representatives. Also commenting were representatives of the U.S. Department of Commerce and industries not associated with lead-acid battery manufacturing. The comments that were submitted, along with responses to these comments, are summarized in this document. The summary of comments and responses serves as the basis for the revisions made to the standards between proposal and promulgation.

1.1 SUMMARY OF CHANGES SINCE PROPOSAL

A number of changes have been made to the standards since their proposal. The most significant of these are changes in the emission limitations for the grid casting and lead reclamation facilities. The promulgated emission limits for these facilities are based on levels achievable using impingement scrubbers, while the proposed emission limits were based on levels achievable using fabric filtration. Also, the opacity standard for lead reclamation has been changed from 0 to 5 percent, because of the change in the emission limit for this facility. The changes in the standards of performance for grid casting and lead reclamation are illustrated in Table 1-1, which presents the proposed and promulgated emissions limitations for all facilities affected by the standards.

Another change is the redefinition of the paste mixing facility to include several operations ancillary to paste mixing. These ancillary operations are lead oxide storage, conveying, weighing, and metering operations; paste handling and cooling operations; and plate pasting, takeoff, cooling, and drying operations.

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TABLE 1-1. SUMMARY OF CHANGES MADE TO LEAD EMISSION LIMITATIONS BETWEEN PROPOSAL AND PROMULGATION

Affected facility	Proposed lead emission limit[a]	Promulgated lead emission limit[a]
Lead oxide production	5.0 mg/kg (0.010 lb/ton)	No change from proposed limit
Grid casting	0.05 mg/dscm (0.00002 gr/dscf)	0.40 mg/dscm (0.00024 gr/dscf)
Paste mixing	1.0 mg/dscm (0.00044 gr/dscf)	No change from proposed limit
Three-process operation	1.0 mg/dscm (0.00044 gr/dscf)	No change from proposed limit
Lead reclamation	2.0 mg/dscm (0.00088 gr/dscf)	4.5 mg/dscm (0.0022 gr/dscf)
Other lead-emitting operations	1.0 mg/dscm (0.00044 gr/dscf)	No change from proposed limit

[a]For lead oxide production, the emission limit is expressed in terms of lead emissions per kilogram of lead processed.
For grid casting, paste mixing, three-process operation, lead reclamation, and other lead-emitting facilities, emission limits are expressed in terms of lead emissions per dry standard cubic meter of exhaust air.

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In addition, the units of the small size cutoff for the standards for lead-acid battery manufacture have been changed from batteries per day (bpd) to lead throughput. The promulgated standards will affect new, modified, or reconstructed facilities at any plant with the capacity to produce in one day batteries which would contain, in total, an amount of lead greater than or equal to 5.9 Mg (6.5 tons). This cutoff corresponds to the 500 bpd cutoff in the proposed standards, and is based on an average battery lead content of 11.8 kg (26 lb) of lead per battery.

The promulgated standards will not require pressure drop monitoring and recording for fabric filters. The pressure drop monitoring and recording requirement has been retained for scrubbers. However, the continuous recording requirement has been changed to a requirement that pressure drop be recorded every 15 minutes. Finally, because of the change in the standard for grid casting, the minimum sampling time for this facility has been reduced from 180 minutes to 60 minutes.

1.2 SUMMARY OF IMPACTS OF THE PROMULGATED ACTION

1.2.1 Alternatives to the Promulgated Action

The control alternatives considered for the lead-acid battery manufacture source category are discussed in Chapter 6 of the Background Information Document (BID) for the proposed standards (Volume I). Five regulatory alternatives were considered for plants larger than the small size cutoff. The control techniques on which the alternatives were based are summarized in Table 1-2.

The promulgated standards correspond to Alternative III, which is based on the use of fabric filtration to control emissions from lead oxide production, paste mixing, three process operation, and other lead-emitting facilities, and scrubbers typically used in the lead-acid battery manufacturing industry to control emissions from grid casting and lead reclamation facilities. This alternative is considered to reflect the degree of emission control achievable through the use of the best demonstrated technology considering costs, nonair quality health and environmental impacts, and energy requirements for lead-acid battery manufacture. The rationale for the selection of Alternative III as a basis for the promulgated standards is discussed in Chapter 2, Section 2.2.

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TABLE 1-2. CONTROL ALTERNATIVES CONSIDERED FOR PROPOSED ACTION

	Control techniques on which regulatory alternatives were based				
	Alternative I	Alternative II	Alternative III	Alternative IV	Alternative V
Lead oxide production	A	A	A	A	A
Grid casting -- furnaces	F[a]	S	S	S	S
-- machines	F[a]	F[a]	S	S	S
Paste mixing	F	F	F	S	S
Three-process operation	F	F	F	F	F
Lead reclamation	F	S	S	S	S

A -- Fabric filter, 2:1 air to cloth ratio
F -- Fabric filter, 6:1 air to cloth ratio
S -- Impingement scrubber, ΔP = 1.25 kPa (5 in. W.G.)

[a]As noted in the text, it has been determined that standards for grid casting and lead reclamation cannot be based on fabric filtration.

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The proposed standards corresponded to Alternative I. The emission limits and the impact analyses for this alternative had been based on the application of fabric filters to all affected facilities; however, as noted in the preamble to the proposed standards, the emissions limits for Alternative I could also have been achieved using high energy venturi scrubbers. In light of arguments presented by a number of commenters (Chapter 2, Section 2.2), it has been determined that standards for grid casting and lead reclamation facilities cannot be based on the use of fabric filters. Therefore, the costs, and energy and water requirements of venturi scrubbers, which would have met the proposed standards for grid casting and lead reclamation, have been estimated.[1] These estimates have been used to revise the energy, economic, and water pollution impacts projected for Alternative I.

As noted in Volume I of the BID, growth projections for the lead-acid battery manufacturing industry over the next five years range from 3 to 5 percent per year. The environmental, economic, and energy impacts estimated for the promulgated standards in this chapter and in Volume I are based on a growth rate of 3.5 percent per year.

1.2.2 Environmental Impacts of Promulgated Action

The environmental impacts of the regulatory alternatives for lead-acid battery manufacture are discussed in Chapters 6 and 7 of the BID for the proposed standards. The impacts of the promulgated action are summarized and compared to the impacts of the proposed regulation in this subsection. The differences between the impacts of the promulgated standards and the proposed standards are due to the changes in emissions limits for grid casting and lead reclamation. The change in the paste mixing facility definition and other changes are not expected to have significant impacts on lead emissions. The following discussion in conjuction with the environmental impact analysis in Volume I of the BID, represents the final Environmental Impact Statement for the promulgated standards.

1.2.2.1 Air pollution impacts

The lead emission impact of the promulgated standards is compared with the impact of the proposed standards in Table 1-3 for the 500, 2000 and 6500 bpd (5.9, 23.6 and 76.7 Mg/day or 6.5, 26.0, and 84.5 tons/day of lead)

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TABLE 1-3a. ESTIMATED IMPACTS OF PROPOSED AND PROMULGATED STANDARDS ON ATMOSPHERIC EMISSIONS (metric units)

	Uncontrolled lead emissions (kg/yr)	Baseline emissions[a] (kg/yr)	Allowable lead emissions (kg/yr) Proposed standards	Allowable lead emissions (kg/yr) Promulgated standards
500 BPD Plant	1562.8	952.2	66.1	70.0
Lead oxide production facility	--[b]	--[b]	--[b]	--[b]
Grid casting facility	51.0	51.0	0.4	3.2
Paste mixing facility	634.9	63.5	8.1	8.1
Three-process operation facility	833.3	833.3	56.6	56.6
Lead reclamation facility	43.6	4.4	1.0	2.1
2000 BPD Plant	6277.5	3835.0	215.9	230.2
Lead oxide production facility	26.5	26.5	13.3	13.3
Grid casting facility	204.0	204.0	1.4	10.9
Paste mixing facility	2539.5	254.0	21.5	21.5
Three-process operation facility	3333.0	3333.0	175.9	175.9
Lead reclamation facility	174.5	17.5	3.8	8.6
6500 BPD Plant	20401.9	12463.4	661.6	709.1
Lead oxide production facility	86.1	86.1	43.1	43.1
Grid casting facility	663.0	663.0	4.6	36.6
Paste mixing facility	8253.4	825.3	55.4	55.4
Three-process operation facility	10832.3	10832.3	546.1	546.1
Lead reclamation facility	567.1	56.7	12.4	27.9

[a] No additional regulatory action.

[b] It is assumed that plants in the 500 bpd size range have no lead oxide manufacturing facilities.

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TABLE 1-3b. ESTIMATED IMPACTS OF PROPOSED AND PROMULGATED STANDARDS ON ATMOSPHERIC EMISSIONS (English units)

	Uncontrolled lead emissions (lb/yr)	Baseline emissions[a] (lb/yr)	Allowable lead emissions (lb/yr)	
			Proposed standards	Promulgated standards
500 BPD Plant	3445.3	2099.1	145.8	154.4
Lead oxide production facility	--[b]	--[b]	--[b]	--[b]
Grid casting facility	112.4	112.4	0.9	7.1
Paste mixing facility	1399.7	140.0	17.9	17.9
Three-process operation facility	1837.1	1837.1	124.8	124.8
Lead reclamation facility	96.1	9.6	2.2	4.6
2000 BPD Plant	13839.2	8454.4	476.0	507.5
Lead oxide production facility	58.4	58.4	29.3	29.3
Grid casting facility	449.7	449.7	3.1	24.0
Paste mixing facility	5598.5	559.9	47.4	47.4
Three-process operation facility	7347.9	7347.9	187.8	187.8
Lead reclamation facility	384.7	38.5	8.4	19.0
6500 BPD Plant	44977.6	20476.6	1458.4	1563.2
Lead oxide production facility	189.8	189.8	95.0	95.0
Grid casting facility	1461.6	1461.6	10.1	80.7
Paste mixing facility	18195.3	1819.5	122.1	122.1
Three-process operation facility	23880.7	23880.7	1203.9	1203.9
Lead reclamation facility	1250.2	125.0	27.3	61.5

[a]No additional regulatory action.

[b]It is assumed that plants in the 500 bpd size range have no lead oxide manufacturing facilities.

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model plant sizes. As shown in this table, the changes in the standards for grid casting and lead reclamation will have only a slight impact on the emission reduction attributable to the NSPS. The promulgated standards are expected to reduce total lead air emissions from facilities coming on-line during the next five years to about 3.1 Mg (3.4 tons) in the fifth year, while the proposed standards were expected to reduce emissions from these facilities to 2.8 Mg/yr (3.1 tons/yr). Both of these figures represent a decrease in lead emissions of about 97 percent from the lead emissions which would be allowed under current State Implementation Plan (SIP) limits for particulate matter.

Table 1-4 compares the estimated ambient air lead concentration impact of the promulgated action with that of the proposed standards. As shown in the table, the changes in the standards for grid casting and lead reclamation are not expected to have a significant impact on ambient lead concentrations in the vicinities of battery plants. The results of dispersion modelling calculations indicate that the maximum annual ambient impact of lead emissions from a 6500 bpd plant complying with the promulgated regulation would be less than the national ambient air quality standard of 1.5 $\mu g/m^3$ (averaged over a calender quarter).

1.2.2.2 Water pollution impact

The estimated wastewater impact of the promulgated action is compared with that of the proposed standards in Table 1-5. As noted in Section 1.2.1 of this chapter, the water pollution impact analysis for the proposed standards has been revised based on the estimated effluents for venturi scrubbers which would meet the proposed standards for grid casting and lead reclamation.

The promulgated action is expected to result in an increase in the lead content of wastewater of about 0.6 percent, for a typical lead-acid battery plant. It is anticipated that, in early 1981, EPA's Office of Water and Waste Management will propose a regulation which would require zero lead wastewater discharge from grid casting and lead reclamation. Zero discharge from scrubbers controlling these facilities could be accomplished by clarifying and recycling the scrubber effluent. The cost of this treatment is estimated

TABLE 1-4. COMPARISON OF AMBIENT LEAD CONCENTRATION IMPACTS OF PROPOSED AND PROMULGATED REGULATIONS

	Lead emissions (g/sec)	Maximum ambient lead concentration impacts ($\mu g/m^3$)		
		Hour average	24-hour average	Annual average
500 BPD Plant				
Baseline[a]	0.13	34	19	4
Proposed standards	0.0022	1	<1	<1
Promulgated standards	0.0024	1	<1	<1
6500 BPD Plant				
Baseline[a]	0.58	88	41	8
Proposed standards	0.011	2	1	<1
Promulgated standards	0.013	2	1	<1

[a]No additional regulatory action.

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TABLE 1-5a. COMPARISON OF WATER POLLUTION IMPACTS OF PROMULGATED AND PROPOSED STANDARDS

(Metric units)

	Total scrubber blowdown		Increase above baseline		Increase in total plant effluent[a]	
	Volume (kl/day)	Lead content (kg/yr)	Volume (kl/day)	Lead content (kg/yr)	Volume (percent)	Lead content (percent)
Baseline[b]						
500 bpd plant	0.5	3.9				
2000 bpd plant	2.0	15.7				
6500 bpd plant	7.0	51.4				
Proposed standards -- (original estimate)[c]						
500 bpd plant	0	0	0	0	0	0
2000 bpd plant	0	0	0	0	0	0
6500 bpd plant	0	0	0	0	0	0
Proposed standards -- (revised estimate)[d]						
500 bpd plant	14.6	9.4	14.1	5.5	11.2	0.7
2000 bpd plant	50.8	37.5	48.8	21.8	9.7	0.7
6500 bpd plant	170.0	121.8	163.0	70.4	10.0	0.7
Promulgated standards						
500 bpd plant	2.0	8.9	1.5	5.0	1.3	0.6
2000 bpd plant	7.8	35.5	5.8	19.8	1.3	0.6
6500 bpd plant	27.4	115.2	20.4	63.8	1.3	0.6

[a]Based on a total process effluent of about 250 liters per battery, containing about 25 ppm lead by weight.

[b]Emission control technology required to meet typical SIP particulate emissions

[c]Based on fabric filter control of all affected facilities.

[d]Based on venturi scrubber control of grid casting and lead reclamation facilities.

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TABLE 1-5b. COMPARISON OF WATER POLLUTION IMPACTS OF PROMULGATED AND PROPOSED STANDARDS

(English units)

	Total scrubber blowdown		Increase above baseline		Increase in total plant effluent[a]	
	Volume (10^3 gal/day)	Lead content (lb/yr)	Volume (10^3 gal/day)	Lead content (lb/yr)	Volume (percent)	Lead content (percent)
Baseline[b]						
500 bpd plant	0.07	9				
2000 bpd plant	0.27	35				
6500 bpd plant	0.93	112				
Proposed standards (original estimate)[c]						
500 bpd plant	0	0	0	0	0	0
2000 bpd plant	0	0	0	0	0	0
6500 bpd plant	0	0	0	0	0	0
Proposed standards (revised estimate)[d]						
500 bpd plant	1.93	21	1.86	12	11.2	0.7
2000 bpd plant	6.73	82	6.46	47	9.7	0.7
6500 bpd plant	22.53	269	21.40	157	10.0	0.7
Promulgated standards						
500 bpd plant	0.26	19	6.19	10	1.3	0.6
2000 bpd plant	1.04	75	0.77	40	1.3	0.6
6500 bpd plant	3.63	243	2.70	131	1.3	0.6

[a]Based on a total process effluent of about 250 liters per battery, containing about 25 ppm lead by weight.

[b]Emission control technology required to meet typical SIP particulate emissions.

[c]Based on fabric filter control of all affected facilities.

[d]Based on venturi scrubber control of grid casting and lead reclamation facilities.

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to be less than one percent of the costs which would be allocable to the recommended NSPS for a completely modified or reconstructed 2000 battery per day plant.[1]

1.2.3 Energy and Economic Impacts of Promulgated Action

1.2.3.1 Energy impacts

The energy impacts of the proposed regulation and the regulatory alternatives considered for lead-acid battery manufacture are estimated in Chapter 7 of Volume I of the BID. The estimated impacts of the proposed standards were based on the application of fabric filters to all affected facilities. As noted in Section 1.2.1 of this Chapter, the energy impacts for the proposed regulation have been recalculated based on application of high energy venturi scrubbers rather than fabric filters to grid casting and lead reclamation exhausts. The major portion of the energy required to operate an air emission control system for a lead-acid battery manufacturing facility is electrical energy required to operate the fan which overcomes the pressure drop through the system. Based on particle size data and scrubber efficiency data, it is estimated that high energy venturi scrubbers with pressure drops of about 7.5 kPa (30 in. W.G.) would be needed to meet the emissions limitations for grid casting and lead reclamation in the proposed regulation (Chapter 2, Section 2.2).

In contrast, the promulgated emission standards for grid casting and lead reclamation are based on levels demonstrated to be achievable by impingement scrubbing with a scrubber pressure drop of about 1.25 kPa (5 in. W.G.). Also, the emissions limitations for paste mixing, three-process operation, and other lead emitting facilities in both the proposed and promulgated standards are based on the application of fabric filters with pressure drops of about 1.25 kPa (5 in. W.G.).

The incremental electricity requirements attributable to the promulgated regulation (Alternative III) and the proposed regulation (Alternative I) are compared in Table 1-6. For the proposed regulation, both the original and revised estimates of the electrical energy requirement are presented.

TABLE 1-6. ELECTRICITY REQUIREMENTS FOR PROPOSED AND PROMULGATED STANDARDS

Plant size	Electricity requirements attributable to NSPS (MWh/yr)		
	Proposed regulation		Promulgated regulation
	Original estimate[a]	Revised estimate[b]	
500 BPD	28	51	28
2000 BPD	80	154	80
6500 BPD	252	500	252

[a]Based on fabric filter control of all affected facilities.

[b]Based on venturi scrubber control of grid casting and lead reclamation facilities.

In addition to these electricity requirements, heat energy is expected to be required to raise exhaust gases from paste mixing above their dewpoint and thus prevent baghouse blinding due to excess moisture (Chapter 2, Section 2.2). This requirement would be the same for the promulgated and proposed actions. Total energy requirements for the proposed and promulgated regulations are compared with plant energy requirements in Table 1-7. For the proposed action, the original and revised estimates of total energy requirements are presented. Process energy demands are based on reported total process energy requirements for various plant sizes (Volume I, Chapter 7). Exhaust energy requirements represent requirements for venting facilities to prevent employee exposure. Baseline control energy requirements represent energy needs for controlling emissions to the degree required under a typical SIP particulate regulation. All electrical energy requirements in Table 1-7 are expressed in terms of the amount of heat which would be required to generate the needed electricity (assuming an average power plant efficiency of 34 percent).

The energy required at a new plant to operate emission control devices installed to meet the promulgated regulation will be about 2.7 percent of the total plant energy requirement. The total nationwide increase in electrical energy demand attributable to the promulgated action will be about 2.8 GWh of electricity in the fifth year after promulgation. The fifth year nationwide energy demand increase resulting from action will be approximately 50 PJ/hr (48 x 10^9 BTU/yr), or the equivalent of about 8.1 thousand barrels of oil per year.

1.2.3.2 Economic impact

The economic impacts of the proposed regulation and the regulatory alternatives are discussed in Chapter 8 of Volume I of the BID. As noted above, the proposed regulation corresponded to Alternative I. The estimated economic impact for the proposed action was based on the application of fabric filters to all affected facilities. However, it has been determined that the proposed emission limits for grid casting and lead reclamation cannot be based on fabric filtration and that high energy (7.5 kPa or 30 in. W.G. pressure drop) venturi scrubbers would be required to achieve

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TABLE 1-7. TOTAL ENERGY REQUIREMENTS FOR PROPOSED AND PROMULGATED STANDARDS

(Metric units)

Plant size	Manufacturing process requirements (TJ/yr)	Process and plant exhaust requirements (TJ/yr)	Baseline[a] control requirements (TJ/yr)	NSPS control requirements[b] (TJ/yr)		
				Proposal--original estimate[c]	Proposal--revised estimate[d,e]	Promulgated regulation[e]
500 BPD	35	0.26	0.14	0.25	0.80	0.56
2000 BPD	55	0.80	0.34	0.84	2.34	1.54
6500 BPD	116	2.43	0.82	2.64	7.09	4.46

(English units)

Plant size	Manufacturing process requirements (10^9 BTU/yr)	Process and plant exhaust requirements (10^9 BTU/yr)	Baseline[a] control requirements (10^9 BTU/yr)	NSPS control requirements[b] (10^9 BTU/yr)		
				Proposal--original estimate[c]	Proposal--revised estimate[d,e]	Promulgated regulation[e]
500 BPD	33	0.25	0.13	0.24	0.76	0.53
2000 BPD	52	0.76	0.32	0.80	2.22	1.46
6500 BPD	110	2.30	0.78	2.50	6.72	4.23

[a]Control techniques required to meet typical SIP particulate regulations.

[b]In excess of energy requirements for baseline controls.

[c]Based on fabric filter control of all affected facilities.

[d]Based on venturi scrubber control of grid casting and lead reclamation facilities.

[e]Includes heat energy requirements for paste mixing exhausts.

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these limits. Therefore, the economic impacts for the proposed action have been recalculated based on the costs of venturi scrubbers for the grid casting and lead reclamation facilities.

The costs of compliance with the promulgated regulation for new and existing plants are compared with the revised costs for the proposed standards in Table 1-8. For the proposed regulation, the original and revised estimates of economic impacts are presented. The predicted annualized costs of the promulgated action range from 8 percent lower, for existing 6500 bpd plants, to 28 percent lower, for new 500 bpd plants, than the annualized costs which would have resulted for the proposed standards. Also, the projected capital costs for plants complying with the promulgated standards are much lower (18 to 40 percent) than those which would have resulted from the proposed standards.

The cost per battery at a plant where all facilities are affected by the promulgation is expected to range from 23 cents per battery, for a new 6500 bpd plant, to 54 cents per battery, for a completely reconstructed or modified 500 bpd plant. The average incremental cost associated with the promulgated regulation will be about 29 cents per battery, which amounts to about 1.6 percent of the wholesale price of a battery. The total nationwide capital cost of the installed emission control equipment necessary to meet the promulgated regulation for all new, modified, or reconstructed facilities coming on-line over the next five years will be about $8.2 million. The total annualized cost of operating this equipment in the fifth year after promulgation will be about $3.9 million.

1.2.4 Other Environmental Concerns

1.2.4.1 Irreversible and irretrievable commitment of resources

The extent to which the proposed standards for lead-acid battery manufacture would have involved a tradeoff between lead air pollution reduction and energy losses is discussed in Section 7.6.1 of Chapter 7 of the BID for the proposed standards. There are no significant changes to the impacts discussed in this section.

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TABLE 1-8. ECONOMIC IMPACTS OF PROPOSED AND PROMULGATED STANDARDS[a]

	Costs allocable to NSPS for proposed action--original estimate[b]			Costs allocable to NSPS for proposed action--revised estimate[c]			Costs allocable to NSPS for promulgated action		
	Capital cost ($1000)	Annualized cost ($1000/yr)	Cost per battery ($)[d]	Capital cost ($1000)	Annualized cost ($1000/yr)	Cost per battery ($)[d]	Capital cost ($1000)	Annualized cost ($1000/yr)	Cost per battery ($)[d]
New Plants									
500 bpd	125	47.5	0.48	200	66.8	0.67	120	47.6	0.48
2000 bpd	211	108	0.27	278	129	0.32	200	107	0.26
6500 bpd	453	284	0.22	517	323	0.25	423	277	0.21
Existing Plants									
500 bpd	150	53.6	0.54	235	69.7	0.69	144	53.4	0.54
2000 bpd	253	118	0.30	329	133	0.33	240	117	0.29
6500 bpd	544	305	0.23	615	327	0.25	508	297	0.23

[a]1977 dollars.

[b]Based on fabric filter control of all affected facilities.

[c]Based on venturi scrubber control of grid casting and lead reclamation facilities.

[d]Based on production at 80 percent of capacity.

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1.2.4.2 Environmental impact of delayed standards

The impacts of a delay in setting new source performance standards for lead-acid battery manufacture are discussed in Section 7.6.2 of Chapter 7 of Volume I. There has been no significant change to this impact.

1.2.4.3 Environmental impact of no standard

The environmental impacts of not setting new source performance standards for lead-acid battery manufacture are discussed in Chapter 7, Section 7.6.3 of Volume I of the BID. These impacts have not changed significantly since proposal.

1.3 REFERENCES FOR CHAPTER 1

1. Memo from Battye, W., GCA/Technology Division to Vatavuk, W., EPA Economic Analysis Branch. October 13, 1980. Revised control costs for grid casting and lead reclamation facilities. (Docket No. IV-B-11)

2. SUMMARY OF PUBLIC COMMENTS

A list of commenters, their affiliations, and the EPA docket number assigned to each comment is shown in Table 2-1. Twenty-one letters commenting on the proposed standards and the Background Information Document for the proposed standards were received. The comments have been combined into the following nine categories:

1. General
2. Emission Control Technology
3. Modification and Reconstruction
4. Economic Impact
5. Environmental Impact
6. Legal Considerations
7. Test Methods and Monitoring
8. Reporting and Recordkeeping
9. Miscellaneous

The comments and issues are discussed, and responses are presented in the following sections of this chapter. A summary of the changes to the regulation is presented in Section 1.2 of Chapter 1.

2.1 GENERAL

Comment: The proposed standards exempted facilities at any plant with a production capacity of less than 500 bpd. Some commenters felt that the number of batteries which can be produced at a plant was not the appropriate criterion on which to base the size cutoff. It was pointed out that lead-acid batteries are produced in a variety of sizes, and that emissions from battery production are probably related more to the amount of lead used to produce batteries than to the number of batteries produced.

Response: These are considered to be reasonable comments. Economic impacts of standards as well as emissions are expected to be related to the amount of lead used in a particular battery production operation rather than

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TABLE 2-1. LIST OF COMMENTERS ON THE PROPOSED STANDARDS OF PERFORMANCE FOR LEAD-ACID BATTERY MANUFACTURE

Docket number[a]	Commenter and affiliation
IV-D-1	Mr. James H. Hazelwood Georgia Marble Company 2575 Cumberland Parkway, Northwest Atlanta, Georgia 30339
IV-D-2	Mr. James K. Hambright, Director Department of Environmental Resources Bureau of Air Quality P.O. Box 2063 Harrisburg, Pennsylvania 17120
IV-D-3	Mr. Thomas Hatterscheide Gould, Incorporated P.O. Box 43140 St. Paul, Minnesota 55164
IV-D-4	Mr. Richard A. Leiby Assistant Safety Director East Penn Manufacturing Company, Inc. Main Office Lyon Station, Pennsylvania 19536
IV-D-5	Mr. John A. Bitler Vice President, Environmental Resources General Battery Corporation Box 1262 Reading, Pennsylvania 19603
IV-D-6	Mr. William V. Skidmore Acting Deputy General Counsel U.S. Department of Commerce Washington, D.C. 20230
IV-D-7	Mr. Edwin H. Seeger Prather, Seeger, Doolittle and Farmer 1101 Sixteenth Street, Northwest Washington, D.C. 20036
IV-D-8	Mr. W. R. Johnson Environmental Activities Staff General Motors Corporation General Motors Technical Center Warren, Michigan 48090

[a]The identification code for the lead-acid battery manufacture docket is OAQPS-79-1.

Table 2-1. (continued)

Docket number[a]	Commenter and affiliation
IV-D-9	Mr. Robert L. Grunwell, President The Hydrate Battery Corporation 3220 Odd Fellows Road Lynchburg, Virginia 24506
IV-D-10	Mr. Richard A. Valentinetti Chief, Air and Solid Waste Programs Agency of Environmental Conservation State Office Building Montpelier, Vermont 05602
IV-D-11	Mr. Sudhir Jagirdar, P.E. Senior Sanitary Engineer State of New York Department of Environmental Conservation 202 Mamaroneck Avenue White Plains, New York 10601
IV-D-12	Mr. Harry H. Hovey, Jr. Director, Division of Air State of New York Department of Environmental Conservation 50 Wolf Road Albany, New York 12233
IV-D-13	Mr. Jack Boys Prestolite Battery Division 511 Hamilton Street Toledo, Ohio 43694
IV-D-14	Mr. James F. McAvoy, Director Environmental Protection Agency State of Ohio Box 1049 Columbus, Ohio 43216
IV-D-15	Mr. Charles C. Miller Director, Air and Land Quality Division Iowa Department of Environmental Quality 900 East Grand Avenue Des Moines, Iowa 50310
IV-D-16	Mr. W. M. Pallies Manager, Health and Safety Exide Corporation P.O. Box 336 Yardley, Pennslyvania 19067

Table 2-1. (continued)

Docket number[a]	Commenter and affiliation
IV-D-17	Mr. J. M. Beaudoin, Manager Health, Safety, and Environmental Control Globe-Union Incorporated 5757 North Green Bay Avenue Milwaukee, Wisconsin 53201
IV-D-18	Mr. John M. Daniel State Air Pollution Control Board Room 1106 Ninth Street Office Building Richmond, Virginia 23219
IV-D-19	Mr. Roger Winslow, President Voltmaster Company, Incorporated P.O. Box 388 Corydon, Iowa 50060
IV-D-20	Mr. Ray Donnelly, Director Office of Legislation and Interagency Programs U.S. Department of Labor Occupation Safety and Health Administration Washington, D.C. 20210
IV-D-25	Mr. Carl C. Mattia Manager, Environmental Activities The PQ Corporation P.O. Box 840 Valley Forge, Pennsylvania 19482

[a]The identification code for the lead-acid battery manufacuture docket is OAQPS-79-1.

to the number of batteries produced. At the time of proposal, it was estimated that odd-size lead-acid batteries represent a very small share of the lead-acid battery market; however the comments received on the proposed standards indicate that a significant number of odd-sized batteries are produced. Industrial batteries, which can be as much as 50 times larger than automobile batteries, are estimated to represent about 7 percent of total U.S. lead-acid battery production.[1]

The small size cutoff for the promulgated regulation is expressed in terms of lead throughput. The promulgated standards will affect new, modified, and reconstructed facilities at any plant with the capacity to produce in one day batteries which would contain, in total, an amount of lead greater than or equal to 5.9 Mg (6.5 tons). This cutoff is equivalent to the 500 bpd cutoff for plants producing typical automobile batteries. The level is based on an average battery lead content of 11.8 kg (26 lb) of lead per battery.

Comment: One commenter questioned whether plant capacity is to be determined based on the maximum demonstrated production rate or the estimated maximum production rate, for the purposes of the small size cutoff.

Response: For the purposes of the small size cutoff, the parameter to be used to determine the production capacity of a plant is the design capacity. The design capacity is the maximum production capability of the plant and can be determined using the design specifications of the plant's component facilities, taking into account process bottlenecks. The design capacity of a plant can be confirmed by checking production records. The figure cited as a plant's production capacity should not be less than the maximum production rate in the plant's records.

Comment: Several commenters felt that the 500 bpd cutoff should be raised to 2000 bpd. This contention was based on the fact that Federal regulations which set minimum standards for State implementation plans (SIPs) for the lead NAAQS do not require ambient air quality monitoring or atmospheric dispersion analyses for plants smaller than 2000 bpd (40 CFR 51.80(a)(1) and 51.84(a)). The commenters considered these cutoffs to be indicative of decision by EPA that battery plants smaller than 2000 bpd are not material contributors to lead air pollution.

Response: It should be noted that the Federal regulations to which the commenters referred only set minimum standards for a lead SIP. Also, as discussed in Section 2.6 of this chapter, the regulatory approach for NAAQS regulations promulgated under Section 109 of the Clean Air Act differs from that for standards of performance promulgated under Section 111 of the Act. The small size cutoff for the standards of performance for lead-acid battery manufacture is based on a thorough analysis of the economic impacts of these standards. The analysis indicated that the economic impact of standards on plants smaller than about 250 bpd could be severe, but showed that the economic impact would be reasonable for plants with capacities greater than or equal to 500 bpd. None of the commenters submitted information indicating that the economic impact of standards might be severe for plants in the 500 to 2000 bpd size range. Therefore, although the small size cutoff is now expressed in terms of lead throughput rather than battery production, the level of the cutoff remains at the lead throughput capacity which corresponds to a production capacity of 500 bpd.

Comment: One commenter stated that the choice of a size cutoff of 500 bpd appears to be arbitrary.

Response: As noted above, the size cutoff of 500 bpd (5.9 Mg/day or 6.5 tons/day of lead) is based on a thorough economic impact analysis of the new source performance standards.

Comment: One commenter stated that, as the regulation is written, the standards of performance would not apply to facilities at plants producing only lead-acid battery components, such as grids.

Response: Standards of performance for lead-acid battery manufacture have been developed as a result of determination made by the Administrator that lead-acid battery manufacturing plants contribute significantly to air pollution, which may reasonably be anticipated to endanger public health or welfare. No such determination has been made for plants producing only certain battery components. In fact, it is not expected that such plants will be constructed, because of the high cost of transporting lead components from plant to plant. EPA will review this regulation four years

after the date of promulgation. If battery component plants become prevalent, consideration will be given at that time to applying this regulation to such plants.

Comment: Another commenter felt that the stack gas concentration standards for grid casting, paste mixing, three-process operation, lead reclamation, and other lead-emitting facilities do not allow for differences in the quantity of emissions between small plants and large plants. This commenter recommended that the emissions limits for these facilities be expressed in terms of allowable lead emissions per lead throughput, rather than in terms of exhaust gas lead concentration.

Response: The airflow rate from a particular type of facility increases with the production capacity of the facility. Because the standards for grid casting, paste mixing, three-process operation, lead reclamation, and other lead-emitting facilities limit lead concentration in airstreams, the allowable lead emissions from these facilities increase as the airflow rates increase. Thus, the exhaust gas concentration standards mentioned by the commenter allow for emissions differences between large and small plants.

Comment: Several commenters contended that the 0 percent opacity standard is impractical. These commenters were concerned that emissions from facilities which emit fine particles would exceed 0 percent opacity. Also, some were concerned that emissions from facilities controlled by fabric filters would exceed 0 percent opacity during fabric filter cleaning. However, one commenter stated that the 0 percent opacity standard appears to be achievable for all affected facilities.

Response: The 0 percent opacity standard for lead oxide manufacturing, grid casting, paste mixing, three-process operation and "other lead emitting" facilities is considered reasonable. Lead oxide manufacturing, grid casting, paste mixing, and three-process operation facilities were observed by EPA to have emissions with 0 percent opacity for periods of 3 hours and 19 minutes, 7 hours and 16 minutes, 1 hour and 30 minutes, and 3 hours and 51 minutes, respectively. For grid casting, the observations were made at a facility controlled by an impingement scrubber. For lead oxide production and three-process operation facilities, the observation periods included fabric

filter cleaning phases. Also, under the promulgated standards, compliance with the opacity standard is to be determined by taking the average opacity over a 6-minute period, according to EPA Test Method 9, and rounding the average to the nearest whole percentage. The rounding procedure is specified in order to allow occasional brief emissions with opacities greater than 0 percent, which may occur during fabric filter cleaning.

A standard of 0 percent opacity was also proposed for lead reclamation facilities. Emissions with opacities greater than 0 percent were observed from the lead reclamation facility tested by EPA, which was controlled by an impingement scrubber. However, because the proposed emission limit for lead reclamation was based on transfer of fabric filtration technology, the 0 percent opacity standard was considered reasonable. As noted in Section 2.2 of this chapter, the final emission limit for lead reclamation is based on the demonstrated emission reduction capabilities of the impingement scrubber system tested by EPA. Therefore, the opacity standard for lead reclamation has also been changed. The final opacity standard is 5 percent, based on observations at the facility tested by EPA. Emissions from this facility were observed for 3 hours and 22 minutes, and, during this period, emissions ranging from 5 to 20 percent opacity were observed for a total of about 11 minutes. The highest 6-minute average opacity during the 3 hour and 22 minute observation period was 4.8 percent. Therefore, the 5 percent opacity standard for lead reclamation is considered reasonable.

Under the general provisions applicable to all new source performance standards (40 CFR 60.11), an operator of an affected facility may request the Administrator to determine the opacity of emissions from the affected facility during the initial performance test. If the Administrator finds that an affected facility is in compliance with the applicable standards for which performance tests are conducted, but fails to meet an applicable opacity standard, the operator of the facility may petition the Administrator to make an appropriate adjustment to the opacity standard for the facility.

Comment: Some commenters stated that EPA should established a relationship between opacity and emissions before setting opacity standards.

Response: Opacity limits are being promulgated in addition to mass emission limits because the Administrator believes that opacity limits provide the only effective and practical method for determining whether emission control equipment, necessary for a source to meet the mass emission limits, is continuously maintained and operated properly. It has not been the Administrator's position that a single, constantly invariant and precise correlation between opacity and mass emissions must be identified for each source under all conditions of operation. Such a correlation is unnecessary to the opacity standard, because the opacity standard is set at a level such that if the opacity standard is exceeded for a particular facility, one would expect that the applicable emission limitation will also be exceeded. Furthermore, as noted above, a mechanism is provided in the general provisions whereby the operator of a facility can request that a separate opacity standard be set for that facility if, during the initial performance test, the Administrator finds that the facility is in compliance with all applicable performance standards but fails to meet an applicable opacity standard.

Comment: Some commenters felt that additional testing should be conducted before standards are promulgated. Several felt that the Administrator should conduct tests of emissions from Barton lead oxide manufacturing process, rather than base a standard for this process on tests of a ball mill lead oxide process. This comment is discussed in Section 2.2 of this chapter. One commenter contended that the EPA data base is narrow, and that tests should be conducted to determine the variability of the efficiency of emission control systems.

Response: The Administrator has determined that the data base developed by EPA provides adequate support for the promulgated new source performance standards. Standards promulgated under Section 111(b) of the Clean Air Act are intended to require the best demonstrated control technology, considering cost, nonair quality health and environmental impact, and energy impacts. Thus, the promulgated standards are based on tests of facilities which have been determined by EPA to be well controlled and typical of facilities used in the industry. As noted by some commenters, EPA has not tested emissions from facilities producing maintenance-free or low-maintenance batteries or Barton lead oxide production facilities. Differences between such facilities

and the facilities tested by EPA are discussed in detail below and in Section 2.1 of this chapter. These differences are not expected to have a significant effect on the controlled lead concentrations achievable using the emission control techniques tested by EPA. Commenters did not refer to nor is EPA aware of any other specific process variations which might influence emissions. In order to allow for variations which may occur between emission concentrations from a particular type of facility, the promulgated lead emissions limits are set above the levels shown to be achievable in EPA tests.

Comment: Some commenters stated that changes have occurred in the lead-acid battery manufacturing industry, which may influence emissions, since the EPA tests were conducted. The changes cited by the commenters were the production of maintenance-free and low-maintenance batteries, and the increasing of volumes of air ventilated from facilities in order to meet more stringent OSHA standards regulating in-plant lead levels.

The commenters briefly described the difference between maintenance-free or low-maintenance batteries and normal-maintenance batteries. The only substantial difference is that a calcium-lead alloy is used to make low-maintenance and maintenance-free batteries, while standard batteries are made using an antimonial lead alloy. This difference influences the grid casting and lead reclamation facilities, where molten lead is processed. The major change is in the makeup of the dross which must be removed from molten lead in these facilities. For grid casting, the calcium alloy also requires the use of soot as a mold release agent. For the antimonial lead alloy used in standard batteries, either soot or sodium silicate can be used.

The commenters stated that exhaust volumes for lead-acid battery facilities have been increased a a result of the revised OSHA standards. One commenter contended that this change will increase the concentration of uncontrolled emissions.

Response: The different makeup of dross in grid casting and lead reclamation facilities producing maintenance-free and low maintenance batteries is not expected by EPA to cause noticeable differences in lead emissions between these facilities and facilities producing standard lead-acid batteries.

The commenters did not give reasons why this difference might be expected to affect emissions. Dross consists of contaminants in the molten lead alloy which float to the surface and must periodically be removed. The presence of a dross layer has an impact on emissions, in that the dross layer serves to reduce fuming from the molten lead. However, this will occur regardless of the composition of the dross layer. Also, because the dross layer is made up chiefly of contaminants from the lead, the entrainment of dross particles in air exhausted from grid casting or lead reclamation facilities will not significantly affect lead emissions. Thus, the effect of the dross layer composition on emissions is expected to be much less than the effects of process operation parameters, such as the frequency of dross removal and the temperature of the molten lead alloy.

The use of soot rather than sodium silicate as a mold release agent in grid casting will not affect uncontrolled lead emissions from this facility. However, the presence of entrained soot in uncontrolled grid casting emissions may require the use of scrubbers rather than fabric filters to control these emissions. This problem is discussed in detail in Section 2.2 of this chapter.

It is acknowledged that the exhaust volumes at the facilities tested by EPA may not have been sufficient for the attainment of the 50 $\mu g/m^3$ OHSA in-plant lead concentration standard. At the time of the tests conducted by EPA the OSHA standard was 200 $\mu g/m^3$. However, higher exhaust volumes would cause a decrease in the concentration of uncontrolled emissions rather than an increase. Also, the additional lead particles captured as a result of the higher exhaust volumes will consist mainly of large particles which are readily captured by control systems.

Comment: One commenter stated that there is a trend in the lead-acid battery manufacturing industry to the use of finer lead oxide in battery pastes in order to increase battery efficiency. The commenter also contended that this particle size change will influence the collection efficiency attainable with fabric filters.

Response: Lead emissions from lead-acid battery manufacture are generated by two mechanisms. Lead oxide fumes are produced in welding, casting, and reclaiming operations, and to a certain extent in lead oxide production. Agglomerates of lead and lead oxide particles are emitted from operations involving the handling of lead oxide, lead oxide paste, and lead grids. The particles which are most difficult to capture are the fume particles. The emission rate and characteristics of these fume particles are not dependent on the size of the lead oxide particles used in battery pastes, but on the temperature of the lead during the operations from which they are emitted. For these reasons, trends in the industry to the use of smaller lead oxide particles are not expected to change the particle size distributions of emissions in such a way that collector performance will be affected.

2.2 EMISSION CONTROL TECHNOLOGY

Comment: Several commenters thought that the proposed standards would have required the use of fabric filtration to control emissions.

Response: The proposed standards would not have required that specific control technology be used for any affected facility, nor will the promulgated standards require specific control techniques. Rather, the standards set emission limits which have been demonstrated to be achievable by the use of the best control systems considering costs, energy impacts and nonair quality environmental impact. The standards do not preclude the use of alternative control techniques, as long as the emission limits are achieved.

Comment: The selection of fabric filtration as the best system of emission reduction for grid casting and lead reclamation facilities was criticized by a number of commenters. These facilities are normally uncontrolled or controlled by impingement scrubbers. The commenters pointed out that only one grid casting facility in the United States is controlled by a fabric filtration system and that this system has been plagued by fires. They explained that the surfaces of exhaust ducts for grid casting and lead reclamation operations become coated with hydrocarbons and other flammable materials. For grid casting, these include bits of cork from the molds, oils used for lubrication, and soot, which is often used as a mold release agent. For lead reclamation, hydrocarbons from plastic and other contaminants

charged with lead scrap become entrained in exhaust gases and deposit on the walls of exhaust ducts. These materials are readily ignited by sparks which, the commenters contended, are unavoidable. The commenters stated that fires started in the exhaust ducts will generally propagate to the control system. One commenter indicated that problems caused by such fires are not generally severe for scrubbers, but fires would cause serious damage and emissions excursions if fabric filters were used. The commenters stated that spark arresters would not solve the fire problem, because they too would become coated with flammable materials which would be ignited by sparks.

Apart from the problem of fires, commenters contended that contaminants present in the exhaust gases from grid casting and lead reclamation would cause frequent bag blinding if fabric filters were applied to these facilities. In addition to the materials listed above, sodium silicate, which is often used as a mold release agent for grid casting, was cited by the commenters as an extremely hygroscopic compound which would cause bag blinding.

Commenters also felt that the EPA particle size and emissions test data did not support the contention made by EPA that a fabric filter could achieve 99 percent emission reduction for emissions from grid casting and lead reclamation.

Response: Based on the information available when standards for lead-acid battery manufacture were proposed, EPA had concluded that fabric filtration could be used to control emissions from grid casting and lead reclamation, and that 99 percent collection efficiency could be attained. The problem of bag blinding could be avoided by keeping the exhaust gases from these facilities at temperatures above their dewpoints. Also, it was thought that exhaust duct fires could be prevented by the use of spark arresters. Therefore, the proposed standards for grid casting and lead reclamation were based on tests of uncontrolled emissions from these facilities, and on fabric filter efficiencies demonstrated for the three-process operations for facility and for industries with emissions of similar character to those from lead-acid battery manufacture. In light of the point made by commenters that spark arresters would not prevent fires, EPA has concluded that the standards for grid casting and lead reclamation facilities should not be based on fabric filters.

The proposed emission limitations for grid casting and lead reclamation could probably be achieved using a high energy scrubber such as a venturi; however, because of the particle size of emissions from these facilities, a scrubber pressure drop of about 7.5 kPa (30 in. W.G.) would be required.[2-5] The energy requirement to overcome this pressure drop is not considered reasonable for these facilities. The emission limits for paste mixing, three-process operation, and other lead-emitting facilities are based on the application of fabric filters with average pressure drops of about 1.25 kPa (5 in. W.G.). Thus, the electricity requirement per unit volume of exhaust gas to operate venturi scrubbers for the grid casting and lead reclamation facilities would be roughly six times the electricity requirement per unit volume to control other plant exhausts.

The Administrator has determined that, for the lead-acid battery manufacturing industry, impingement scrubbers operating at a pressure drop of about 1.25 kPa (5 in. W.G.) represent the best system of emission reduction considering costs, nonair quality health and environmental impact and energy requirements for grid casting and lead reclamation. Therefore, in the promulgated standards, the emission limitations for grid casting and lead reclamation have been raised to levels which have been shown to be achievable in tests of scrubbers controlling these facilities. This change represents a change from the regulatory alternative chosen from the proposed standards. The environmental, economic, and energy impacts of the alternative which has been chosen for the promulgated standards are discussed in Chapter 8 of Volumes I. It is estimated that standards based on the application of impingement scrubbers to grid casting and lead reclamation facilities will result in a 50 percent decrease in NSPS electricity requirements from standards requiring venturi scrubbers for these facilities, while having only a slight impact on the emission reduction attributable to the NSPS. (Chapter 1, Tables 1-3, 1-4, and 1-6).

EPA measured lead emissions from two grid casting facilities (Volume I, Chapter 4 and Appendix C). One of these facilities was uncontrolled, and the other was controlled by an impingement scrubber. The average lead concentration in the exhaust from the uncontrolled facility was 4.37 mg/dscm

(19.1 x 10^{-4} gr/dscf). Average uncontrolled and controlled lead emissions from the scrubber controlled facility were 2.65 mg/dscm (11.6 x 10^{-4} gr/dscf) and 0.32 mg/dscm (1.4 x 10^{-4} gr/dscf), respectively. The promulgated standard for grid casting, 0.4 mg/dscm (1.76 x 10^{-4} gr/dscf), is based on the controlled lead emission rate for this facility. The facility is considered typical of grid casting facilities used in the lead-acid battery manufacturing industry. EPA is not aware of any process variations which would result in a significant increase in the emission concentration achievable using a scrubber control system. However, in order to allow for variations in grid casting emissions, the promulgated lead emission limit has been set above the level shown to be achievable in the EPA test.

Grid casting test results were also submitted by two commenters. Data submitted by one commenter for a grid casting facility show average uncontrolled lead emissions of about 2 mg/dscm (9 x 10^{-4} gr/dscf).[6] The test method used to collect these data is similar to Method 12. Data submitted by the other commenter showed average uncontrolled lead emissions of about 1.1 mg/dscm (4.7 x 10^{-4} gr/dscf); however, the test method used to gather these data is not known.[7]

Lead reclamation emissions were measured by EPA for a facility controlled by an impingement scrubber (Volume I, Chapter 4 and Appendix C). Average lead concentrations in the inlet and outlet streams from the scrubber were 227 mg/dscm (990 x 10^{-4} gr/dscf) and 3.7 mg/dscm (16 x 10^{-4} gr/dscf). The standard for lead reclamation, 4.5 mg/dscm (19.8 x 10^{-4} gr/dscf), is based on the controlled emission rate measured for this facility. This facility is considered typical of lead reclamation facilities used in the lead-acid battery manufacturing industry. EPA is not aware of any process variations which would result in a significant increase in the emission concentration achievable using a scrubber control system. In order to allow for variation in lead reclamation emissions, the promulgated lead emission standard has been set above the emission level shown to be achievable in the EPA test.

Comment: Several commenters criticized the choice of fabric filtration as the best system of emission reduction for the entire paste mixing cycle. The paste mixing operation is a batch operation consisting of two phases:

charging and mixing. The paste mixing facility is generally controlled by impingement scrubbing, although fabric filtration is often used to control exhaust from the charging phase. The commenters felt that if fabric filtration were to be used for the entire cycle, the moisture present in the exhaust during the mixing phase would cause bag blinding. Therefore, they requested that the emission limit for paste mixing be raised to a level achievable using impingement scrubbers.

Response: If fabric filters are used to meet the emission limit, bag blinding can be prevented by keeping paste mixer exhausts at temperatures above their dew points. The energy which would be required to heat the exhaust gases and the costs for providing insulation for ducts and fabric filters applied to paste mixing facilities were taken into consideration in the energy and economic analyses for the new source performance standards. These costs and energy requirements are considered reasonable. In addition, data submitted by one commenter show that the standard for paste mixing is achievable using scrubbers. Tests were conducted of emissions from two scrubber controlled paste mixing facilities, using methods similar to Method 12. These tests indicated average controlled lead emissions of 0.04 mg/dscm (0.19×10^{-4} gr/dscf) and 0.07 mg/dscm (0.30×10^{-4} gr/dscf) for the two facilities.[8,9] Both of these average concentrations are well below the 1 mg/dscm (4.4×10^{-4} gr/dscf) standard for paste mixing.

Comment: Some commenters contended that EPA test data did not adequately support the statement that 99 percent collection efficiency could be achieved for paste mixing emissions. The commenters felt that the standard for paste mixing should be relaxed.

Response: The standard for paste mixing is considered achievable. Emissions from a paste mixing facility controlled by an impingement scrubber were tested by EPA. The average uncontrolled lead concentration from this facility was 77.4 mg/dscm (338×10^{-4} gr/dscf). Thus, the promulgated regulation is expected to require about 98.7 percent control of lead emissions from paste mixing. EPA tests of a fabric filtration system controlling a three-process operation showed an average lead collection

efficiency of 99.3 percent. This fabric filtration system underwent bag cleaning during testing. Also, EPA tests and statements made by several commenters indicate that the particle size distribution for paste mixing emissions is similar to that for three-process operation emissions. Emissions from paste mixing are made up of lead oxide agglomerates, while emissions from three-process operation facilities are made up mainly of agglomerates with some fumes and some other large particles. The above data clearly show that efficiencies greater than 98.7 percent can be achieved for paste mixing emissions.

In addition, EPA tests of a controlled paste mixing facility indicate that the 1 mg/dscm standard for paste mixing is achievable. EPA conducted tests at a plant where paste mixing emissions were controlled by two separate systems. At this plant, paste mixing required a total of 21 to 24 minutes per batch. During the first 14 to 16 minutes of a cycle (the charging phase), exhaust from the paste mixer was ducted to a fabric filter which also controlled emissions from the grid slitting (separating) operation. During the remainder of the cycle (mixing), paste mixer exhaust was ducted to an impingement scrubber which also controlled emissions from the grid casting operation. Uncontrolled or controlled emissions for the paste mixer alone were not tested. The average concentration of lead in emissions from the fabric filtration system used to control charging emissions was 1.3 mg/dscm (5.5×10^{-4} gr/dscf). The average lead content of exhaust from the scrubber used to control mixing emissions was 0.25 mg/dscm (1.1×10^{-4} gr/dscf). The average lead concentration in controlled emissions from this facility was about 0.95 mg/dscm (4.2×10^{-4} gr/dscf) which is slightly below the emission limit of 1 mg/dscm (4.4×10^{-4} gr/dscf). A lower average emission concentration could be achieved by using fabric filtration to control emissions from all phases of paste mixing.

Also, as noted above, one commenter submitted data showing that the standard for paste mixing is achievable using impingement scrubbing to control emissions from the entire cycle.

Comment: Several commenters criticized the fact that the standard for lead oxide production is based on tests conducted at a ball mill lead oxide production facility, but will apply to Barton lead oxide production facilities as well as ball mill facilities. Some commenters stated that the particle size of lead oxide to be collected depends on the type of oxide produced. One commenter stated that Barton facilities are more commonly used to produce lead oxide than ball mill facilities.

Response: However, in both the ball mill process and the Barton process, all of the lead oxide product must be removed from an air stream. In the ball mill process, lead pigs or balls are tumbled in a mill, and the frictional heat generated by the tumbling action causes the formation of lead oxide. The lead oxide is removed from the mill by an air stream. In the Barton process, molten lead is atomized to form small droplets in an air stream. These droplets are then oxidized by the air round them.

EPA tests on a Barton process indicated that Barton and ball mill processes have similar air flow rates per unit production rate (Appendix C of the BID, Volume I). Because these air streams carry all of the lead oxide produced, the concentrations of lead oxide in the two streams must also be similar.

Data submitted by one commenter indicate that the percentage of fine particles in lead oxide produced by the Barton process is similar to the percentage of fine particles in lead oxide produced by the ball mill. [10] These data were obtained by placing samples of captured ball mill and Barton oxides in a Coulter particle counter. The size distributions measured by this technique are representative of the size of the product oxide, rather than the airborne oxide entering the collector. However, the similarity of the percentages of small particles for ball mill and Barton oxides suggest a similarity in the percentages of small particles in the feed streams to the collectors for these two processes.

The similarities between the concentrations and particle size distributions of the oxide bearing air streams in the Barton and ball mill processes support EPA's contention that a similar level of emission control could be achieved for a Barton process as has been demonstrated for the ball mill process. Also, no test data were submitted by the commenters to show that the standard for lead oxide production cannot be achieved by a well controlled Barton process. It should be noted that, to allow for variations in lead oxide manufacturing emissions, the promulgated standard has been set above the emission rate shown to be achievable in the EPA ball mill facility test.

Comment: Several commenters felt that the standard for lead oxide production was too stringent. These commenters stated that engineering calculations using typical fabric filter and cyclone efficiencies indicate that the standard for lead oxide production would not be met by a facility controlled by a cyclone and a fabric filter in series.

Response: The emission limit for lead oxide production of 5 milligrams of lead per kilogram of lead processed is considered reasonable. The limit is based on results of tests of emissions from a ball mill lead oxide production facility with a fabric filter control system. The test showed an average controlled emission rate of 4.2 mg/Kg (8.4 lb/ton) for this facility. The emission limit for lead oxide production of 5 milligrams of lead per kilogram of lead processed is considered reasonable. The limit is based on results of tests of emissions from a ball mill lead oxide production facility with a fabric filter control system. The test showed an average controlled emission rate of 4.2 mg/kg (8.4 lb/ton) for this facility. In estimating the emission reduction which could be achieved for a lead oxide production facility, the commenters used typical fabric filter and cyclone efficiencies. It should be noted that uncontrolled dust streams from lead oxide production are extremely concentrated. At such concentrations, fabric filter and cyclone reduction capabilities are higher than under typical conditions.

Comment: Several commenters stated that the emission limit for the three-process operation was not supported by the BID for the proposed standards. However, one commenter stated that the emission limit appears achievable.

Response: The limit for the three-process operation is based on the results of EPA tests conducted at four plants where fabric filtration was used to control three-process operation emissions. Each of the sets of tests conducted by EPA showed average controlled lead concentrations below the proposed limit. The standard for the three-process operation has been set well above the average emission concentration detected in all of the EPA tests. Therefore, the lead emission limit for the three-process operation facility is considered reasonable.

2.3 MODIFICATION AND RECONSTRUCTION

Comment: One commenter questioned whether the standards would apply to modified or recontructed facilities at a plant where production capacity is increased from below the small size cutoff to above the cutoff as a result of the modification or reconstruction.

Response: Circumstances under which an "existing facility" may become an affected facility (a facility which must be in compliance with applicable standards) are described in the modification and reconstruction provisions for new source performance standards (40 CFR 60.14, 60.15). For the purposes of these provisions, an existing facility is defined as "any apparatus of a type for which a standard is promulgated (§60.2(aa))." A lead-emitting operation at a lead-acid battery plant which is smaller than the size cutoff (5.9 Mg/day or 6.5 tons/day of lead throughput) is of a type for which a standard is promulgated and is, therefore, an existing facility. Upon undergoing "modification" or "reconstruction" (defined in §60.14 and §60.15), such a facility would be considered as an affected facility if, during its modification or reconstruction, the production capacity of the plant containing the facility is increased above the small size cutoff.

2.4 ECONOMIC IMPACT

Comment: One commenter contended that new source performance standards would impose a substantial and burdensome cost of the lead-acid battery manufacturing industry. Another stated that battery sales have fallen by 25 percent in recent years.

Response: The economic impacts of new source performance standards on the lead-acid battery manufacturing industry are analyzed and described in detail in Volumes I and II of the BID. These impacts are summarized in Chapter 1. The projected economic impacts are considered reasonable. The expected annualized cost of compliance with the promulgated standards at a typical affected plant is expected to be only about 1.6 percent of the wholesale price of a battery; and the economic impact analysis indicates that this cost could be passed on with little effect on sales.

The market for lead-acid batteries is tied to the automobile market for both original equipment and replacement batteries. The 25 percent drop in sales cited by the second commenter results from the recent decline in the demand for domestic automobiles. This decline is not expected to continue and the sales of the domestic automobile industry are expected to increase in the near future.

Comment: Several commenters contended that the cost of compliance with OSHA standards was not adequately addressed in Volume I of the BID. The commenters also felt that the OSHA standards would require higher ventilation rates than are currently needed, and would thus cause the costs of compliance with new source performance standards to be higher than the estimates made by EPA.

Response: The OSHA compliance costs presented in Volume I are based on the capital and operating control costs which were expected to be required to meet the employee exposure standards of 200 $\mu g/m^3$ originally proposed by OSHA in 1975. The controls include employee care, general plant maintenance, and local ventilation of in-plant lead emission sources. On November 14, 1978, OSHA promulgated an employee exposure standard of 50 $\mu g/m^3$. However, the controls necessary to comply with this standard are expected to be similar to those which would have been necessary for the originally proposed 200 $\mu g/m^3$ standard.[11,12] In addition, the economic impact projected for the OSHA standards in Volume I may be higher than the actual economic impact, because, in a number of cases, work practices can be used to achieve the OSHA standard in place of technological controls.

In Volume I of the BID, the statement is made that a change in the OSHA standards could cause the control costs for the new source performance

standards to increase substantially. However, the facility exhaust rates used to estimate the costs of achieving the NSPS were set at levels which would provide good ventilation for the facilities under consideration. The exhaust rates were chosen to achieve a face velocity of 250-300 ft/min for hoods, and 300-350 ft/min for slot-type vents.[13,14] One industry representative stated that face velocities have been increased from 150-200 ft/min to 350-500 ft/min in order to reduce lead levels in the working zone to below $50\mu g/m^3$.[15] Thus, although the ventilation rates used in the industry to comply with the current OSHA standards may be much higher than those which have been used in the past, they are not much higher than the ventilation rates used to calculate the economic impacts of the promulgated new source performance standards. Thus, it is not expected that the change in the OSHA standards would have a significant impact on the results of the economic impact analysis for the NSPS.

Comment: One commenter stated that the new source performance standards would indirectly require the installation of stacks which would meet the criteria specified by EPA Reference Method 1 for sampling and gas velocity measurements. The commenter stated that the impacts of this requirement were not addressed.

Response: The costs of stacks which meet EPA Method 1 criteria are not considered attributable to new source performance standards. Under SIP regulations, most States require an initial performance test for any new source. Therefore, in the absence of the promulgated standards, most new facilities would nonetheless be required to have stacks.

2.5 ENVIRONMENTAL IMPACT

Comment: A number of commenters stated that lead-acid battery manufacture accounts for a small percentage of total nationwide lead emissions and contended, for this reason, that new source performance standards for lead-acid battery manufacture should not be set. One commenter cited data which indicate that lead emissions from lead-acid battery manufacture accounted for only about 0.32 percent of industrial lead emissions or about 0.014 percent of total nationwide lead emissions in 1975.

Response: It is acknowledged that lead-acid battery plants account for a relatively small share of total nationwide atmospheric lead emissions. In 1975, about 95 percent of U.S. lead emissions resulted from the production of alkyl lead gasoline additive, the burning of leaded gasoline, and the disposal of crankcase oil from vehicles which burn leaded gasoline. These emissions will be reduced substantially as the use of alkyl lead gasoline additives is curtailed. Another 1 percent of nationwide lead emissions is from mining and smelting operations, which are generally located in remote areas. Because lead-acid battery plants are generally located in urban areas -- near the markets for their batteries -- lead emissions from lead-acid battery manufacture may reasonably be anticipated to endanger public health or welfare. Therefore, the Administrator considers the development of new source performance standards for lead-acid battery manufacture to be justified.

Comment: Several commenters recommended that the grid casting facility be removed from the list of affected facilities. According to EPA estimates, grid casting accounts for about 3.2 percent of overall uncontrolled battery plant lead emissions. The commenters stated that it is unreasonable to require sources to control facilities generating such a small percentage of total plant emissions.

Response: Although grid casting is small source of emissions relative to other facilities, it is not an insignificant source. Lead emissions from this facility are controlled at a number of existing plants. Also, if other facilities at a plant were controlled to the extent required under the new source performance standards, but grid casting facilities were left uncontrolled, emissions from grid casting would amount to about 50 percent of the total plant lead emissions. Therefore, the standard for grid casting is considered environmentally beneficial. Also, the costs and energy requirements of controls for this facility have been included in the energy and economic impact analyses of the new source performance standards and are considered reasonable.

2.6 LEGAL CONSIDERATIONS

Comment: One comment which involved legal considerations was that, if fabric filtration is considered the best available control technology for a facility, then an equipment standard requiring fabric filtration should be set for

that facility rather than a performance standard. The commenter pointed out that, under Section 111(h) of the Clean Air Act, the Administrator is empowered to promulgate a design, equipment, work practice, or operational standards, or combination thereof.

Response: Section 111(h) states that an equipment standard may be promulgated only if the Administrator determines that it is not feasible to prescribe or enforce a standard of performance. Thus, because performance standards are feasible for the lead-acid battery manufacture source category, the Administrator has no reason to promulgate equipment standards for this source category.

Comment: Another comment which involved legal considerations was that, because a National Ambient Air Quality Standard for lead has been established, new source performance standards regulating lead emissions would be redundant and unnecssary.

Response: It should be noted that the purposes of standards of performance for new sources promulgated under Section 111 of the Clean Air Act differ from the purposes of national ambient air quality standards, which are promulgated under Section 109 of the Act. National ambient air quality standards are established to protect the public health or welfare. Under Section 109 of the Clean Air Act, national ambient air quality standards are to be set at levels such that the attainment and maintenance of the standards are requisite to protect the public health or welfare.

New source performance standards promulgated under Section 111 of the Clean Air Act are not designed to achieve any specific air quality levels, but are instead established to enhance air quality. Under Section 111, such standards are to reflect the degree of emission limitation achievable through application of the best demonstrated technological system of emission reduction considering cost, any nonair quality health and environmental impact, and energy requirements.

Congress expressed several reasons for requiring the setting of new source performance standards reflecting the degree of emission reduction achievable through application of the best demonstrated control technology.[13] First, national standards are needed to avoid situations where some States

may attract industries by relaxing standards relative to other States. Second, because the national ambient air quality standards create air quality ceilings which are not to be exceeded, stringent standards for new sources enhance the potential for long term growth. Third, stringent standards may help achieve long-term cost savings by avoiding the need for expensive retrofitting when pollution ceilings may be reduced in the future. Fourth, the standard-setting process should create incentives for improved technology.

2.7 TEST METHODS AND MONITORING

2.7.1. Reference Method 12

Comment: A number of commenters felt that Reference Method 12 was cumbersome and recommended the development of a simpler screening method. The commenters stated that a battery plant may have as many as two dozen stacks and that, at an average cost of $6000 per stack test, the cost of testing an entire plant could be extremely high.

Response: Because controlled emission levels are expected to be near the emission limits for facilities affected by the regulation, a screening method less accurate than Method 12 would not be suitable for determining compliance with the lead-acid battery manufacture regulation. Also, the per plant costs of conducting performance tests using Method 12 are not expected to be as high as the commenters expected. Although existing plants often have a large number of stacks, it is expected that, for newly constructed, modified, or reconstructed plants or facilities, emissions will be ducted to a small number of stacks. In addition, the estimate of $6000 per stack for a compliance test applies only for plants where one or two stacks are to be tested. For plants with a large number of stacks, the cost per stack should decrease considerably.

Comment: One commenter recommended that the minimum sampling time for Method 12 be extended. Others stated that the minimum sampling time for grid casting in the proposed regulation was too long.

Response: For tests with Method 12, the minimum amount of lead needed for good sample recovery and analysis is 100 μg. The minimum sampling rates and times ensure that enough lead will be collected. For grid casting, the

minimum sampling time has been changed from 180 minutes, in the proposed regulation, to 60 minutes, in the promulgated action. The change reflects the alteration in the standard for grid casting.

2.7.2 Reference Method 9

Comment: Two commenters expressed concern that Method 9 is not accurate enough to be used to enforce a standard of 0 percent opacity. One commenter stated that it is difficult to discern the difference between 0 percent opacity and 1 percent opacity for a given reading.

Response: No single reading is made to the nearest percent, rather, readings are to be recorded in increments of 5 percent opacity and averaged over a period of 6 minutes (24 readings). For the regulation for lead-acid battery manufacture, the 6 minute average opacity figure is to be rounded to the nearest whole number. The opacity standard for lead-acid battery manufacture is based on opacity data taken for operating facilities, and these data have shown that this standard can be met (Section 2.1 of this chapter).

2.8 REPORTING AND RECORDKEEPING

Comment: A number of commenters contended that the proposed pressure drop monitoring and recording requirement for control systems would not serve to insure proper operation and maintenance of fabric filters. The commenters pointed out that a leak in a fabric filter would not result in a measurable difference in the pressure drop across the filter. One commenter suggested that the pressure drop monitoring requirement be replaced by an opacity monitoring requirement. Another commenter suggested that the pressure drop requirement be replaced by a requirement of visible inspection of bags for leaks.

Response: Based on the arguments presented by these commenters, it is agreed that proposed pressure monitoring requirement for fabric filters would not serve its intended purpose. Therefore, this requirement has been eliminated. However, pressure drop is considered to be a good indicator of proper operation and maintenance for scrubbers. Therefore, the pressure drop monitoring and recording requirement for scrubbers has been retained.

The pressure drop monitoring requirement for fabric filters has not been replaced by another monitoring requirement. The cost of opacity monitoring equipment may in some cases be comparable to the cost of emission control systems for lead-acid battery manufacturing facilities.[17] This cost is considered unreasonable. Although periodic visual inspection of bags would provide an indication of bag integrity, visual records would not be useful to EPA in the enforcement of the promulgated standards.

Comment: A number of commenters stated that while pressure drop monitoring is useful for scrubbers, continuous recording of pressure drop would be unnecessary and expensive. Some commenters questioned whether a device which cyclically monitors the pressure drop across several emission control systems would be considered a continuous recorder for the systems. These commenters also asked how often such a recorder would have to monitor the pressure drop across a particular control device to be considered a continuous recorder for that device. One commenter suggested the substitution of periodic manual recording of pressure drop for the continuous pressure drop recording requirement. Another commenter questioned the purpose of requiring pressure drop monitoring and recording without a requirement that action be taken at certain pressure drop levels.

Response: The purpose of pressure drop recording requirements is to allow the verification by EPA regional enforcement personnel that emission control systems are properly operated and maintained. The costs of pressure drop recording devices were analyzed and are considered reasonable.[17] The point of what sort of device would satisfy the recording requirement has been clarified in the promulgated standards. It has been determined that for the purposes of this regulation a device which records pressure drop at least every 15 minutes would accomplish the same purposes as a continuous pressure drop recorder. Manual pressure drop recording would not ensure proper operation and maintenance of a control system.

2.9 MISCELLANEOUS

Comment: A number of commenters recommended that the definition of the paste mixing facility be expanded to include operations ancillary to paste mixing, such as lead oxide storage, conveying, weighing, and metering operations;

paste handling and cooling operations; and plate pasting, takeoff, cooling, and drying operations. The commenters stated that paste mixing and operations ancillary to the paste mixing operation are generally interdependent, in that one operation is not run without the others. Also, emissions from paste mixing and ancillary operations are often ducted to the same control device. The commenters were concerned that a minor change made to a paste mixing machine could cause the machine to be affected by the promulgated standards under the reconstruction provisions applicable to all new source performance standards. They stated that the recommended change would avoid this possibility.

Response: These comments are considered reasonable. The operations ancillary to paste mixing were not intended to be considered separate facilities, and the definition recommended by the commenters for the paste mixing facility is considered an appropriate definition. Therefore, this recommendation has been adopted in the promulgated regulation. Because the standard which was proposed for paste mixing is identical to that which was proposed for operations ancillary to paste mixing (other lead-emitting operations), this change will not affect the environmental impacts of the standards.

Comment: One commenter recommended that the operations comprising the three-process operation facility be treated separately. The commenter stated that emissions concentrations may differ for the three operations.

Response: In the development of the new source performance standards, it was found that the operations which make up the "three-process operation" are generally ducted to a common control device.

Comment: One commenter stated that the standards for lead-acid battery manufacture should also cover battery reclaiming operations.

Response: New, modified, and reconstructed lead battery reclaiming operations are covered by new source performance standards for secondary lead smelters, which were promulgated March 8, 1974, and regulate particulate emissions. Because most lead emissions from secondary lead smelters are in the form of particulate matter, the particulate standards serve to regulate lead emissions as well. The possibility of revising the standards to regulate sulfur oxide emissions is currently being studied by EPA.

Comment: Another commenter recommended that precautions be taken to prevent fugitive emissions resulting from the handling of material collected by fabric filters. The commenter cited as an example a plant at which the fabric filter catch is conveyed to storage containers using flexible canvas ducts. These allow the reentrainment into the atmosphere of dust collected by the fabric filter.

Response: Lead emissions from the handling of captured particulate matter are not expected to be significant in comparison with process emissions. Also, the means of handling captured particulate matter would vary from plant to plant. Thus, the Administrator did not consider the development of national standards for such emissions to be justified.

Comment: A revised version of the CRSTER dispersion model was used to assess the ambient air impact of standards of performance for lead-acid battery manufacture. One commenter stated that the CRSTER model, as documented by its users manual (EPA-480/2-77-013), does not address a number of important factors, including aerodynamic building and stack tip downwash, transitional plume rise, spatial separation of emission points, and the fact that most battery plant exhaust gases are discharged at ambient or near ambient temperatures. The commenter also stated that EPA new source review guidelines provide for the use of meteorological data for five years; while for the model lead-acid battery plants, the model was run using data for only one year.

Response: The revised CRSTER model used in the development of the new source performance standards was not fully described in Volume I of the BID. In fact, all of the factors mentioned by the commenter are addressed in the revised model which is described in the docket for the proposed standards (see docket item no. II-B-24). Since the modeling was performed for a hypothetical plant, there was no requirement to use multiple years of meteorological data. As was pointed out, direct extrapolation of the results to an actual plant should not be attempted. If an actual plant were to be modeled, multiple years of meteorological data would be required.

Comment: In the preamble to the proposed standards, the public was specifically invited to submit comments with supporting data on acid mist control. Only one comment was received regarding the acid mist issue. The commenter did not refer specifically to acid mist emissions from lead-acid battery manufacturing, but made the general statement that EPA should devote more attention to all sulfuric acid emissions and effluents.

Response: Since no evidence was submitted which indicated that sulfuric acid mist emissions from lead-acid battery manufacture may reasonably be anticipated to contribute significantly to air pollution, there is no basis for regulation of sulfuric acid mist emissions from this industry at this time.

2.10 REFERENCES FOR CHAPTER 2

1. Economic Impact Statement--Inorganic Lead. Prepared by D.B. Associates for the Occupational Safety and Health Administration. Washington, D.C. February 1977. p. 5-42.

2. Letter and attachments from Hatterscheide, T.E., Gould, Inc. to Central Docket Section, EPA. March 6, 1980. p. 15. Public comment. (Docket No. IV-D-3)

3. Letter and attachments from Beaudoin, J.M., Globe-Union, Inc. to Central Docket Section, EPA. March 13, 1980. Figure 2. Public comment. (Docket No. IV-D-17)

4. Lead-Acid Battery Manufacture -- Background Information for Proposed Standards. U.S. Environmental Protection Agency. EPA-450/3-79-028a. November 1979.

5. Memo from Battye, W., GCA/Technology Division to Fitzsimons, J.G., EPA. April 18, 1980. 7p. Pressure drop requirements to achieve 99 percent control of grid casting and lead reclamation emissions. (Docket No. IV-B-6)

6. Letter and attachments from St. Louis, R., Pennsylvania Department of Environmental Resources. June 9, 1976. 27p. Report of Emissions Testing. (Docket No. IV-D-27)

7. Reference 2. pp. 7,8.

8. Letter and attachments from Hambright, J.K. Pennsylvania Department of Environmental Resources to central Docket Section, EPA. March 6, 1980. Enclosure 5. Public comment. (Docket No. IV-D-2)

9. Report of Emission Testing Performed December 10, 1975 on Entoleter Scrubber, Prestolite Battery Division, Eltra Corp. Temple, Pennsylvania. Spotts, Stevens, and McCoy, Inc. January 15, 1976. 24p. (Docket No. IV-D-27)

10. Reference 2. pp. 13, 14.

11. Occupational Safety and Health Administration, Department of Labor. Occupational Exposure to Lead -- Attachments to the Preamble for the Final Standard. Federal Register. Washington, D.C. 43(225):45585-54488, 54503-54506. November 1978.

12. National Institute for Occupational Safety and Health. The Industrial Environment -- its Evaluation and Control. Washington, D.C. U.S. Government Printing Office, 1973. p. 597-608.

13. Ferris, W. Battery Plant Ventilation Study. Prepared by AB Machine and Equipment Co., inc., Memphis, Tennessee for PEDCo Environmental, Cincinnati, Ohio. October 27, 1980. (Docket No. II-A-1)

References (continued)

14. Telephone conversation between Battye, W., GCA/Technology Division and Ferris, W., Battery Equipment Service Co., Bradenton, Florida. July 3, 1980. (Docket No. IV-E-8)

15. Telephone conversation between Battye, W., GCA/Technology Division and Hatterscheide, T.E., Gould, Inc. April 7, 1980. (Docket No. IV-E-5)

16. Committee on Interstate and Foreign Commerce, House of Representatives. Clean Air Act Amendments of 1977, Report No. 95-294. Washington, D.C. U.S. Government Printing Office, 1977. pp. 184-186.

17. Memo from Battye, W., GCA/Technology Division to Fitzsimons, J.G., EPA. August 15, 1980. Cost of opacity monitors for lead-acid battery manufacturing facilities. (Docket No. IV-D-8)

TECHNICAL REPORT DATA *(Please read Instructions on the reverse before completing)*		
1. REPORT NO. EPA-450/3-79-028b	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Lead-Acid Battery Manufacture - Background Information for Promulgated Standards		5. REPORT DATE November 1980 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Office of Air Quality Planning and Standards Environmental Protection Agency Research Triangle Park, NC 27711		10. PROGRAM ELEMENT NO. 11. CONTRACT/GRANT NO. 68-02-3057
12. SPONSORING AGENCY NAME AND ADDRESS DAA for Air Quality Planning and Standards Office of Air, Noise and Radiation U.S. Environmental Protection Agency Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED Draft 14. SPONSORING AGENCY CODE EPA/200/04

15. SUPPLEMENTARY NOTES Volume I discussed the proposed standards and the resulting environmental and economic effects. Volume II contains a summary of public comments, EPA responses and discussion of the differences between the proposed and promulgated standards.

16. ABSTRACT

Standards of performance for the control of emissions from lead-acid battery manufacturing plants are being promulgated under the authority of Section 111 of the Clean Air Act. These standards would apply to new, modified, or reconstructed facilities at any lead-acid battery manufacturing plant with the capacity to produce in one day batteries which would contain in total an amount of lead greater than or equal to 5.9 Mg (6.5 tons). This document contains information on the public comments made after proposal, EPA responses and differences between the proposed and promulgated standards.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air pollution Pollution control Standards of performance Lead-acid battery manufacturing plants Lead	Air Pollution Control	13B

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
Unlimited	Unclassified	56
	20. SECURITY CLASS *(This page)*	22. PRICE
	Unclassified	

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

United States
Environmental Protection
Agency

Office of Air, Noise, and Radiation
Office of Air Quality Planning and Standards
Research Triangle Park NC 27711

15 406

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Publication No. EPA-450/3-79-028b

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EPA 335

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Reference 16

About Us

History

OUR HISTORY

In 1885, long before anyone talks about carbon footprints or climate change, Warren Johnson launches a company to explore new ways to harness and conserve precious energy resources. In doing so, he also launches a tradition of customer-focused innovation—a tradition that has inspired thousands of employees for more than 130 years and that continues to drive the success of Johnson Controls. Even before he founds the firm now known as Johnson Controls, Warren Johnson is the quintessential inventor. His pneumatic tower clocks, electric storage batteries, wireless telegraph business and steam-powered luxury cars and postal service trucks anticipate—and shape—the future.

16 001

History Timeline

1978

Johnson Controls becomes the leader in U.S. automotive battery production when it acquires Globe-Union. Founded in 1911 as Globe Electric, the company had invented the thin-wall, high-strength polypropylene battery case, a universally recognized breakthrough in battery design.

36 / 61

0

16 002

Reference 17

POTENTIAL HAZARDOUS WASTE SITE
IDENTIFICATION AND PRELIMINARY ASSESSMENT

EPA

REGION: 6 | SITE NUMBER (To be assigned by HQ): TX8389

NOTE: This form is completed for each potential hazardous waste site to help set priorities for site inspection. The information submitted on this form is based on available records and may be updated on subsequent forms as a result of additional inquiries and on-site inspections.

GENERAL INSTRUCTIONS: Complete Sections I and III through X as completely as possible before Section II (Preliminary Assessment). File this form in the Regional Hazardous Waste Log File and submit a copy to: U.S. Environmental Protection Agency; Site Tracking System; Hazardous Waste Enforcement Task Force (EN-335); 401 M St., SW; Washington, DC 20460.

I. SITE IDENTIFICATION

A. SITE NAME: GLOBE UNION, INC.

B. STREET (for other identifier): 1111 Shiloh Rd., P.O. Box 401729

C. CITY: Garland TXR990606642

D. STATE: TX

E. ZIP CODE: 75040

F. COUNTY NAME: Dallas

G. OWNER/OPERATOR (If known)

1. NAME: Mr. Ken K. Fisher, Engineering Manager

2. TELEPHONE NUMBER: (214)494-2461

H. TYPE OF OWNERSHIP

☐ 1. FEDERAL ☐ 2. STATE ☐ 3. COUNTY ☐ 4. MUNICIPAL ☒ 5. PRIVATE ☐ 6. UNKNOWN

I. SITE DESCRIPTION: Manufacturer of storage batteries for automotive, commercial and marine use.

J. HOW IDENTIFIED (i.e., citizen's complaints, OSHA citations, etc.): US Notifier (TX, S 1151)

K. DATE IDENTIFIED (mo., day, & yr.): 6/8/81

L. PRINCIPAL STATE CONTACT

1. NAME: Mrs. Debbie Jones, TDWR, Duncanville, TX

2. TELEPHONE NUMBER: (214)298-6171

185181

II. PRELIMINARY ASSESSMENT (complete this section last)

A. APPARENT SERIOUSNESS OF PROBLEM

☐ 1. HIGH ☐ 2. MEDIUM ☐ 3. LOW ☒ 4. NONE ☐ 5. UNKNOWN

B. RECOMMENDATION

☒ 1. NO ACTION NEEDED (no hazard)

☐ 2. IMMEDIATE SITE INSPECTION NEEDED
a. TENTATIVELY SCHEDULED FOR:
b. WILL BE PERFORMED BY:

☐ 3. SITE INSPECTION NEEDED
a. TENTATIVELY SCHEDULED FOR:
b. WILL BE PERFORMED BY:

☐ 4. SITE INSPECTION NEEDED (low priority)

C. PREPARER INFORMATION

1. NAME: Hillol K. Ray, FIT Hillol K Ray

2. TELEPHONE NUMBER: (214)742-4521

3. DATE (mo., day, & yr.): 7/19/82

III. SITE INFORMATION

A. SITE STATUS

☒ 1. ACTIVE (Those industrial or municipal sites which are being used for waste treatment, storage, or disposal on a continuing basis, even if intermittently.)

☐ 2. INACTIVE (Those sites which no longer receive wastes.)

☐ 3. OTHER (specify): (Those sites that include such incidents like "midnight dumping" where no regular or continuing use of the site for waste disposal has occurred.)

B. 1. GENERATOR ON SITE?

☐ 1. NO ☒ 2. YES (specify generator's four-digit SIC Code): 3691

C. AREA OF SITE (in acres): 3 to 4 (approx.)

D. IF APPARENT SERIOUSNESS OF SITE IS HIGH, SPECIFY COORDINATES

1. LATITUDE (deg.-min.-sec.): 32°38'40"N

2. LONGITUDE (deg.-min.-sec.): 96°35'32"W

E. ARE THERE BUILDINGS ON THE SITE?

☐ 1. NO ☒ 2. YES (specify): Office, maintenance shops etc.

Hillol K Ray 8-26-82

Continue On Reverse

Continued From Front

IV. CHARACTERIZATION OF SITE ACTIVITY

Indicate the major site activity(ies) and details relating to each activity by marking 'X' in the appropriate boxes.

A. TRANSPORTER	B. STORER	C. TREATER	D. DISPOSER
X 1. RAIL	1. PILE	1. FILTRATION	1. LANDFILL
2. SHIP	2. SURFACE IMPOUNDMENT	2. INCINERATION	2. LANDFARM
3. BARGE	3. DRUMS	3. VOLUME REDUCTION	3. OPEN DUMP
4. TRUCK	4. TANK, ABOVE GROUND	4. RECYCLING/RECOVERY	4. SURFACE IMPOUNDMENT
5. PIPELINE	5. TANK, BELOW GROUND	5. CHEM./PHYS. TREATMENT	5. MIDNIGHT DUMPING
6. OTHER (specify): Lead oxide from Mexico	6. OTHER (specify):	6. BIOLOGICAL TREATMENT	6. INCINERATION
		7. WASTE OIL REPROCESSING	7. UNDERGROUND INJECTION
		8. SOLVENT RECOVERY	8. OTHER (specify):
		X 9. OTHER (specify): pH control of wastewater in (See Attach A)	

E. SPECIFY DETAILS OF SITE ACTIVITIES AS NEEDED

During the FIT inspection, it was noted that Globe Union, Inc. runs a very clean operation. The City of Garland monitors the plant effluent by collecting and analyzing samples every month and is satisified with the Globe Union, Inc. operation.

V. WASTE RELATED INFORMATION

A. WASTE TYPE

☐ 1. UNKNOWN ☒ 2. LIQUID ☒ 3. SOLID ☐ 4. SLUDGE ☐ 5. GAS

B. WASTE CHARACTERISTICS

☐ 1. UNKNOWN ☐ 2. CORROSIVE ☐ 3. IGNITABLE ☐ 4. RADIOACTIVE ☐ 5. HIGHLY VOLATILE
☒ 6. TOXIC ☐ 7. REACTIVE ☐ 8. INERT ☐ 9. FLAMMABLE

☐ 10. OTHER (specify):

C. WASTE CATEGORIES

1. Are records of wastes available? Specify items such as manifests, inventories, etc. below.

Yes, at Globe Union, Inc. office

2. Estimate the amount (specify unit of measure) of waste by category; mark 'X' to indicate which wastes are present.

a. SLUDGE	b. OIL	c. SOLVENTS	d. CHEMICALS	e. SOLIDS	f. OTHER
AMOUNT: None	AMOUNT: None	AMOUNT: None	AMOUNT: None	AMOUNT: 12.5	AMOUNT: 80,000
UNIT OF MEASURE	UNIT OF MEASURE	UNIT OF MEASURE	UNIT OF MEASURE	UNIT OF MEASURE: tons/month	UNIT OF MEASURE: gallons/day
X (1) PAINT, PIGMENTS	X (1) OILY WASTES	X (1) HALOGENATED SOLVENTS	X (1) ACIDS	X (1) FLYASH	X (1) LABORATORY CHEMICALS
(2) METALS SLUDGES	(2) OTHER (specify):	(2) NON-HALOGENTD. SOLVENTS	(2) PICKLING LIQUORS	(2) ASBESTOS	(2) HOSPITAL
(3) POTW		(3) OTHER (specify):	(3) CAUSTICS	(3) MILLING/MINE TAILINGS	(3) RADIOACTIVE
(4) ALUMINUM SLUDGE			(4) PESTICIDES	(4) FERROUS SMLTG. WASTES	(4) MUNICIPAL
(5) OTHER (specify):			(5) DYES/INKS	(5) NON-FERROUS SMLTG. WASTES	X (5) OTHER (specify): Wastewater from casting basins, floor sweeping etc., after processing is recycled into the system
			(6) CYANIDE	X (6) OTHER (specify): Used gloves, shoes & aprons, scrap materials, unusable plates for storage batteries	
			(7) PHENOLS		
			(8) HALOGENS		
			(9) PCB		
			(10) METALS		
			(11) OTHER (specify)		

17,002

Continue On Page 3

Continued From Page 2

V. WASTE RELATED INFORMATION (continued)

3. LIST SUBSTANCES OF GREATEST CONCERN WHICH MAY BE ON THE SITE (place in descending order of hazard).

Lead

4. ADDITIONAL COMMENTS OR NARRATIVE DESCRIPTION OF SITUATION KNOWN OR REPORTED TO EXIST AT THE SITE.

VI. HAZARD DESCRIPTION

A. TYPE OF HAZARD	B. POTENTIAL HAZARD (mark 'X')	C. ALLEGED INCIDENT (mark 'X')	D. DATE OF INCIDENT (mo.,day,yr.)	E. REMARKS
1. NO HAZARD	X			
2. HUMAN HEALTH				
3. NON-WORKER INJURY/EXPOSURE				
4. WORKER INJURY				
5. CONTAMINATION OF WATER SUPPLY				
6. CONTAMINATION OF FOOD CHAIN				
7. CONTAMINATION OF GROUND WATER				
8. CONTAMINATION OF SURFACE WATER				
9. DAMAGE TO FLORA/FAUNA				
10. FISH KILL				
11. CONTAMINATION OF AIR				
12. NOTICEABLE ODORS				
13. CONTAMINATION OF SOIL				
14. PROPERTY DAMAGE				
15. FIRE OR EXPLOSION				
16. SPILLS/LEAKING CONTAINERS/ RUNOFF/STANDING LIQUIDS				
17. SEWER, STORM DRAIN PROBLEMS				
18. EROSION PROBLEMS				
19. INADEQUATE SECURITY				
20. INCOMPATIBLE WASTES				
21. MIDNIGHT DUMPING				
22. OTHER (specify):				

Continued From Front

VII. PERMIT INFORMATION

A. INDICATE ALL APPLICABLE PERMITS HELD BY THE SITE.

☐ 1. NPDES PERMIT ☐ 2. SPCC PLAN ☐ 3. STATE PERMIT (specify): _____

☒ 4. AIR PERMITS See Attach. A ☐ 5. LOCAL PERMIT ☐ 6. RCRA TRANSPORTER

☐ 7. RCRA STORER ☐ 8. RCRA TREATER ☐ 9. RCRA DISPOSER

☐ 10. OTHER (specify): _____

B. IN COMPLIANCE?

☒ 1. YES ☐ 2. NO ☐ 3. UNKNOWN

4. WITH RESPECT TO (list regulation name & number): Air Permits as mentioned above

VIII. PAST REGULATORY ACTIONS

☒ A. NONE ☐ B. YES (summarize below)

IX. INSPECTION ACTIVITY (past or on-going)

☐ A. NONE ☒ B. YES (complete items 1, 2, 3, & 4 below)

1. TYPE OF ACTIVITY	2. DATE OF PAST ACTION (mo., day, & yr.)	3. PERFORMED BY: (EPA/State)	4. DESCRIPTION
Sampling Inspection	7/12/82 thru 7/14/82	City of Garland	Effluent samples (see photo # 6, pg. 2 of 5)
Sampling Inspection	6/7/82 thru 6/9/82	"	" "
Visual Inspection	1/82	"	Walking along the facility and process areas, effluent discharge points etc.

X. REMEDIAL ACTIVITY (past or on-going)

☒ A. NONE ☐ B. YES (complete items 1, 2, 3, & 4 below)

1. TYPE OF ACTIVITY	2. DATE OF PAST ACTION (mo., day, & yr.)	3. PERFORMED BY: (EPA/State)	4. DESCRIPTION

NOTE: Based on the information in Sections III through X, fill out the Preliminary Assessment (Section II) information on the first page of this form.

ATTACHMENT A

POTENTIAL HAZARDOUS WASTE SITE
IDENTIFICATION AND PRELIMINARY ASSESSMENT SUPPLEMENT SHEET

Instruction - This sheet is provided to give additional information in explanation of a question on the Form 2070-2.

Corresponding number on Form	Additional Remark and/or Explanation
IV.C.9.	neutralization basin, inside the process building.
VII.A.4.	Air Quality Control Board, State of Texas

Permit #	Issued On	Exp. Date
R6710	1/15/80	None (unless revoked for violation)
R6898	1/15/80	"
R6900	1/31/80	"
R6903	1/31/80	"
R6901	1/14/81	"
R6902	1/14/81	"
R6899	1/16/81	"

1. MANIFEST NUMBER
Generator I.D. No. G-9356
Sequence No. 01

STATE OF LOUISIANA
DEPARTMENT OF NATURAL RESOURCES
HAZARDOUS WASTE MANAGEMENT
P. O. BOX 44396
BATON ROUGE, LOUISIANA 70804

For Dept. Use
Index #
Date

2. WASTE INFORMATION:

HM	SHIPPING DESCRIPTION	HAZARD CLASS	WASTE NUMBER	WEIGHT (TONS)	PACKAGING QTY.	PACKAGING TYPE
X	Lead Sulfate Sludge	ORM-E	G-9356-01			
		NA2991				
		ORM-E				
		NA2991				

3. GENERATOR INFORMATION: Identification Number: G9356 Telephone: 214-494-2461
NAME OF COMPANY: Johnson Controls - Globe Battery Div
ADDRESS: 111 Shiloh Rd Garland Tx ZIP: 75040
SHIPPING LOCATION: 111 Shiloh Rd Garland Texas
CERTIFICATION: This is to certify that the above-named materials are properly classified, described, packaged, marked and labeled, and are in proper conditions for transportation according to the applicable regulations of the Department of Transportation and the Louisiana Department of Natural Resources. EPA# TXT4900133 49
R. N. Parker 6/9/81
Typed Generator Signature Date

4. TRANSPORTER INFORMATION: Identification Number: 278-H Telephone: 713-963-0121
NAME OF COMPANY: Browning Ferris Ind DATE OF PICK UP: 6/10/81 TIME: 2:00 PM
CERTIFICATION: This is to certify that the above-named materials were picked up at date and time above and that to the best of the transporter's knowledge, his portion of the manifest is accurately and correctly filled out. EPA# LAD000618306
Samuel Davis
Transporter Signature TXD-099797199

CERTIFICATION: This is to certify that the above-named materials were delivered without incident to the disposer at the date and time below.
Transporter Signature DATE OF DELIVERY TIME

5. DISPOSER INFORMATION: Identification Number: D529 Telephone: 318-527-6859
NAME OF COMPANY: BFI Calcasieu Disposal Facility
LOCATION WHERE SHIPMENT RECEIVED: Willow Springs Rd West Lake La.
CERTIFICATION: This is to certify acceptance of the hazardous waste, that the waste has been or will be disposed of in accordance with Department of Natural Resources regulations, and that to the best of the disposer's knowledge, his portion is accurately and correctly filled out: EPA# LAD000618256
Disposer Signature Date

6. EMERGENCY INFORMATION:
Immediate Response Information: In case of accident or spill, call Louisiana Department of Public Safety Telephone: (504) 925-6595
Special Handling Instructions:
Comments:

17 006

DELIVERING T.I.N. 61-2766

GLOBE UNION, INC.
GARLAND, TEXAS

Photo # 1-5

Photographer / Witness

RICK WIGAL / HILLOL RAY

Date / Time / Direction

7-8-82 / 10:30 AM / NORTH

Comments: PANORAMA OF THE PROCESS AREA

Photographer / Witness

Date / Time / Direction

Comments: NOT USED

Photographer / Witness

Date / Time / Direction

Comments: NOT USED

GLOBE UNION, INC.
GARLAND, TEXAS

#8

Photographer / Witness

RICK WIGAL/HILLOL RAY

Date / Time / Direction

7-8-82/10:48 AM/(NORTH)

Comments: BAG HOUSE AREA. SCRAP MATERIALS, GLOVES, APRONS ETC. ARE STORED IN DRUMS AND SENT TO BFI CALCASIEU FACILITY, WILLOW SPRINGS ROAD, WEST LAKE, LOUISIANA FOR DISPOSAL

#9

Photographer / Witness

RICK WIGAL/HILLOL RAY

Date / Time / Direction

7-8-82/10:48 AM (NORTH)

Comments: BAG HOUSE AREA

#6

Photographer / Witness

RICK WIGAL/HILLOL RAY

Date / Time / Direction

7-8-82/10:35AM/EAST

Comments: CITY OF GARLAND COLLECTS WATER SAMPLE FROM THIS MANHOLE, BY REMOVING THE LID.

GLOBE UNION, INC.
GARLAND, TEXAS

#10

Photographer / Witness
RICK WIGAL / HILLOL RAY

Date / Time / Direction
7-8-82 / 10:55AM / WEST

Comments: LOADING-UNLOADING AREA. (CONCRETE SURFACE)

#11

Photographer / Witness
RICK WIGAL / HILLOL RAY

Date / Time / Direction
7-8-82 / 10:55AM / WEST

Comments: LOADING-UNLOADING AREA. (CONCRETE SURFACE)

#12

Photographer / Witness
RICK WIGAL / HILLOL RAY

Date / Time / Direction
7-8-82 / 10:55AM / WEST

Comments: LOADING-UNLOADING AREA. (CONCRETE SURFACE)

GLOBE UNION, INC.
GARLAND, TEXAS

#13

Photographer / Witness
RICK WIGAL/HILLOL RAY

Date / Time / Direction
7-8-82/11:00AM/NORTH

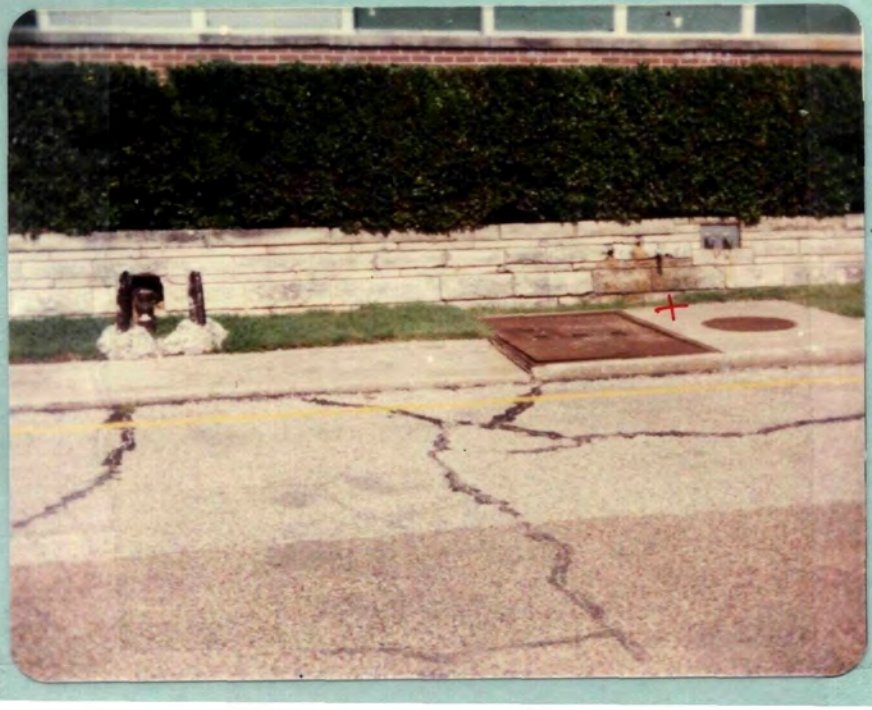
Comments: LEAD OXIDE HAULED IN BY RAIL FROM MEXICO

#14

Photographer / Witness
RICK WIGAL/HILLOL RAY

Date / Time / Direction
7-8-82/11:00AM/NORTH

Comments: LEAD OXIDE HAULED IN BY RAIL FROM MEXICO



#7

Photographer / Witness
RICK WIGAL/HILLOL RAY

Date / Time / Direction
7-8-82/10:40AM/West

Comments: LUNCH ROOM SEWER LINE (See + Marks on photo) CONNECTED TO THE MANHOLE. SMALL CRACKS ON CONCRETE FLOOR

#15

GLOBE UNION, INC.
GARLAND, TEXAS

Pg. 5 of 5

Photographer / Witness

RICK WIGAL/HILLOL RAY

Date / Time / Direction

7-8-82/12:00 Noon/South

Comments: ENTRANCE TO THE MAIN OFFICE

Photographer / Witness

Date / Time / Direction

Comments: NOT USED

Photographer / Witness

Date / Time / Direction

Comments: NOT USED

EPA

POTENTIAL HAZARDOUS WASTE SITE
FINAL STRATEGY DETERMINATION

REGION	SITE NUMBER
6	TX 8389

File this form in the regional Hazardous Waste Log File and submit a copy to: U.S. Environmental Protection Agency; Site Tracking System; Hazardous Waste Enforcement Task Force (EN-335); 401 M St., SW; Washington, DC 20460.

I. SITE IDENTIFICATION

A. SITE NAME	B. STREET	
GLOBE UNION, INC.	1111 SHILOH RD. P.O BOX 401729	
C. CITY	**D. STATE**	**E. ZIP CODE**
GARLAND	TX	75040

II. FINAL DETERMINATION

Indicate the recommended action(s) and agency(ies) that should be involved by marking 'X' in the appropriate boxes.

RECOMMENDATION	ACTION AGENCY				
	MARK 'X'	EPA	STATE	LOCAL	PRIVATE
A. NO ACTION NEEDED TXD980620642	X	X			
B. REMEDIAL ACTION NEEDED, BUT NO RESOURCES AVAILABLE (If yes, complete Section III.)					
C. REMEDIAL ACTION (If yes, complete Section IV.)					
D. ENFORCEMENT ACTION (If yes, specify in Part E whether the case will be primarily managed by the EPA or the State and what type of enforcement action is anticipated.)					

E. RATIONALE FOR FINAL STRATEGY DETERMINATION

SITE IS A MANUFACTURING FACILITY FOR STORAGE BATTERIES. THE CITY OF GARLAND CONDUCTS REGULAR INSPECTIONS AND MONITORS THE PLANT EFFLUENT BY COLLECTING AND ANALYZING SAMPLES EVERY MONTH. CITY OFFICALS ARE SATISFIED WITH THE GLOBE UNION, INC. OPERATION.

F. IF A CASE DEVELOPMENT PLAN HAS BEEN PREPARED, SPECIFY THE DATE PREPARED (mo., day, & yr.)	G. IF AN ENFORCEMENT CASE HAS BEEN FILED, SPECIFY THE DATE FILED (mo., day, & yr.)
	-

H. PREPARER INFORMATION

1. NAME	2. TELEPHONE NUMBER	3. DATE (mo., day, & yr.)
A.L. GARDNER GAW-SE	214/767-3274	8-2-82

III. REMEDIAL ACTIONS TO BE TAKEN WHEN RESOURCES BECOME AVAILABLE

List all remedial actions, such as excavation, removal, etc. to be taken as soon as resources become available. See instructions for a list of Key Words for each of the actions to be used in the spaces below. Provide an estimate of the approximate cost of the remedy.

A. REMEDIAL ACTION	B. ESTIMATED COST	C. REMARKS
	$	
	$	
	$	
	$	
	$	
	$	
	$	
	$	
D. TOTAL ESTIMATED COST	$	

EPA Form 2070-5 (10-79)

DEC

Continue On Reverse

185180

Continuation Sheet

IV. REMEDIAL ACTIONS

A. SHORT TERM/EMERGENCY ACTIONS *(On Site and Off-Site)*: List all emergency actions immediate control, e.g., restrict access, provide alternate water supply, etc. See instructio the actions to be used in the spaces below.

1. ACTION	2. ACTION START DATE (mo, day, & yr)	3. ACTION END DATE (mo, day, & yr)	4. ACTION AGENCY (EPA, State, Private Party)	5. COST
				$
				$
				$
				$
				$
				$

B. LONG TERM STRATEGY *(On Site and Off-Site)*: List all long term solutions, e.g., excavat wells, etc. See instructions for a list of Key Words for each of the actions to be used in the

1. ACTION	2. ACTION START DATE (mo, day, & yr)	3. ACTION END DATE (mo, day, & yr)	4. ACTION AGENCY (EPA, State Private Party)	5. COST
				$
				$
				$
				$
				$
				$

C. MANHOURS AND COST BY ACTION AGENCY

1. ACTION AGENCY		2. TOTAL MAN-HOURS FOR REMEDIAL ACTIVITI
a. EPA		
b. STATE		
c. PRIVATE PARTIES		
d. OTHER (Specify)		

Reference 18

SMOKE HANDLING IN A LEAD SMELTER

by

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Smoke in General

Smoke is the term commonly used to refer to dust, fume and gas which are natural by-products of all smelting operations. Strictly speaking, the term "gas" should be limited to material which carries no solids or liquids in suspension. "Fume", as differentiated from "dust", refers to material which has been volatilized or sublimed and then condenses as the gases become cooler. "Dust" is any solid particle small enough to be carried by the gas current.

Smoke is produced from three sources in the lead smelting operation:

1. Sintering
2. Blast Furnace Smelting
3. Hygiene Ventilation

Sintering is the process in which the sulfur content of the lead concentrates is burned off, and at the same time the material is agglomerated into porous lumps for feed to the blast furnace. The burning of sulfur is the source of SO_2 gas in the process smoke.

Smelting is the melting and reduction of the sintered material in a furnace, using coke as a fuel and an air blast to support combustion.

Hygiene ventilation is the collection of fume and dust produced at several intermediate stages of both the sintering and smelting operations.

Gases produced in the various operations are eventually discharged into the atmosphere but before this is done it is necessary to:

1. Remove the suspended particulate matter.
2. Cool the gases as much as practical for condensation of fume.
3. Remove or dilute SO_2.

In practice dust and fume are mixed and collected together in a single product commonly called "dust", even though the bulk of the

material is a true fume.

Subsequent treatment of the recovered dust will depend upon the composition of the product. Many smelters have by-product plants incorporated in the operation for recovery of fume values such as cadmium, zinc, selenium, etc.

The principal gases found in lead smelter smoke are nitrogen, water vapor, carbon dioxide and sulfur dioxide. Sulfur dioxide is the only one of these gases which can be harmful to vegetation or cause irritation to humans. It is for this reason that treatment and final disposal of SO_2 is important in smelting operations.

History of Dust and Fume Recovery

In the United States lead was first mined and smelted in 1621 at Falling Creek, Virginia. However, it was not until 1720, at Mine La Motte in southeastern Missouri, that lead smelting was carried out on a commercial basis.

The smelting was done in crude furnaces consisting of enclosed stalls with inclined floors. Galena was charged on top of a wood fire and the melted lead trickled down the inclined hearth and was collected in a basin. This type of furnace operation continued until 1836, when the first Scotch Hearth was introduced from England.

The Scotch Hearth employed an air blast to reduce lead from a charge of Galena and charcoal or fine coal. The hearth furnaces, with various improvements, predominated in smelting lead in the Mississippi Valley of Missouri and Illinois and the tri-state area for the next 80 years.

The hearth furnaces were limited in their application to coarse, clean, high grade lead feed. Therefore, with the discovery of the silver bearing lead deposits in the West between 1865 and 1880 and the limitations of the hearth furnaces, the lead blast furnace came into prominence and has now replaced all other types of lead furnaces in the United States.

In the early days no attempt was made to collect or recover the dust and fume from smelting operations. Hearth furnaces, under the best of conditions, produced large amounts of dust and fume amounting to 25-30% of the ore feed. During the 1860's some smelting plants started use of long flues and settling chambers from the hearths to a single stack in an effort to recover dust and fume.

The first successful fume recovery was accomplished by bag filtering in 1876 at the Lone Elm smelter in Joplin.

By the turn of the century some combination of flue, settling chamber and bag filter arrangement was common on all hearth operations.

Blast furnace operations utilized a flue system only, as the lead content of the charge was low (10-20%) and the furnaces operated with cold tops which resulted in a dust fall of only 2-3% with little or no fume produced.

Bag filtering was used only if the values of the recovered dust and fume would pay for the installation and operating cost of a baghouse.

By 1906 the concentration of lead blast furnaces in urban areas had come to such a point that local laws were passed to restrict emission of fume and dust to the atmosphere. For example, there was a total of 20 blast furnaces operating within a 20 mile radius in the Salt Lake Valley, 10 in Leadville, Colorado and 7 in the city limits of Denver.

As a result, in order to comply with state and local laws as well as to be protected against possilbe damage suits, all the lead smelting plants went to bag filtering of furnace fumes.

About the same time that baghouses were coming into general use for fume recovery, Dr. F. G. Cottrell developed and patented a process for the recovery of fume by means of electrostatic charges, commonly known as the Cottrell process.

The first commerical application of this process was for the recovery of sulfuric acid mist at the Selby smelter in 1906.

The Cottrell process was not limited to handling the relatively chemically inert and cool gases as was the baghouse, but could effectively remove fume from hot corrosive gas. Therefore, it soon became universally used in the copper smelters for the recovery of fume from roaster, reverbs and converters, as well as having widespread use in the recovery of fume from roasting and sintering operations in the lead smelters.

By 1920 the effective recovery of fume and dust in the smelting industry had been accomplished through use of baghouses and Cottrell plants. However, there still remained the problem of sulfur dioxide produced in the roasting and sintering operations. Although dust and fume recovery of over 99% was possible, SO_2 passed freely through baghouses and Cottrell treaters. Most smelters attempted to remedy the SO_2 problem by passing the filtered gas into a common flue and discharging it into the atmosphere through high stacks.

This method of SO_2 abatement was only partially successful as evidenced by the steady increase of smelter stack heights, which increased from 200' in 1910 to over 800' today.

By 1930 a great deal of work had been done on studies for the removal of SO_2 from smelter gases. Many methods were proposed,

but as none were of sufficient commercial value to warrant an elaborate treatment plant, especially from lean gas containing less than two percent SO_2, little progress was made.

The copper smelters at Garfield, Utah; Anaconda, Montana; and Ducktown, Tennessee; started producing limited amounts of sulfuric acid from a portion of the gas for use directly in their plants.

The first production of sulfuric acid from a lead smelter was at the Selby Plant of the American Smelting and Refining Company during the 1940's. This was accomplished by recirculating part of the gas from a down draft sintering machine back through the sinter bed to obtain a gas strength of 4-5% of SO_2. However, in this methods only a relatively small amount of the sulfur burned was recovered as sulfuric acid.

With the development of updraft sintering at Port Pirie, Australia about 1950, it became possible to recover up to 90% of the sulfur burned as sulfuric acid without any recirculation of gas, and the problem of SO_2 emission from lead smelters was well on the way to being solved.

Recovery and Utilization of SO_2

Most lead smelters in the United States dilute the SO_2 gas by combining the cleaned process gases into a common flue and discharging it to the atmosphere through a tall stack. Normally, wind currents will diffuse and dilute the SO_2 content to such an amount so as to be harmless at ground level.

However, with the ever increasing public emphasis on elimination of air pollution, it is apparent that emissions of SO_2 gas and particulate matter to the atmosphere will not be tolerated.

Particulate matter, such as dust and fume in smelter smoke, present no problem as recovery by filtration in baghouses and retreatment of the recovered product are relatively straightforward procedures.

However, the SO_2 in the gas from the sintering operation presents a complex problem. Not only must the SO_2 be removed from the gas, but it must be in the form of a disposable product.

One practical approach, as far as smelter operations are concerned, is to make sulfuric acid from the SO_2 -bearing gas produced in the roasting operation. As the roasting of lead concentrates is carried out entirely on sintering machines this type of operation causes several problems in the acid plant; namely, discoloration of the product acid by unburned organic flotation reagents in the concentrate, and the grade or strength of product acid from varying SO_2 concentrations in the gas.

The latter can be controlled, but the discoloration of the acid has restricted the use of acid produced from a sintering operation. Although there are several methods by which the black acid can be partically clarified, none will result in a colorless acid such as is produced from the burning of sulfur, and as a result the only commercial outlet for this acid has been in the fertilizer industry.

In spite of the problems presented, the Amax-Homestake group decided in 1965 that air pollution control was imperative and as a result a sulfuric acid plant was included in the basic design of the new Missouri smelter in order to reduce to a minimum air pollution from SO_2.

The design of the sulfuric acid plant at Missouri Lead Operating Company's smelter is to produce 200 tons of sulfuric acid per day from an updraft lead sintering machine delivering a gas analyzing as follows:

	% Range Vol.
SO_2	4-7
O_2	4-9
CO_2	3-4
N_2	84-85
SO_3	.05-.2
Dust Content	25 grains/scf
Temp.	400° - 665° F
Moisture Content	25% by Vol.

Vessel sizing; for 25,000 scfm dry gas, with gas cooling system sized to maintain a water balance for the production of 66° Be' acid with gas strength of 4% SO_2 at 21,000 scfm.

Acid Plant Operation

Essentially the sulfuric acid process consists of three principal steps:

1. Purification and cooling of the SO_2 laden gas from the sinter machine.
2. Conversion of the purified SO_2 gas to SO_3.
3. Absorption of the SO_3 in sulfuric acid.

The SO_2 gas from the sinter machine contains dust and metallic fume impurities which are removed by filtering the gas through bags in a six compartment baghouse. The hot filtered gas contains excessive water vapor which must be removed by cooling in order to produce a high strength acid. This is accomplished in a tower packed with ceramic rings in which cold weak sulfuric acid is used to scrub the gas passing through the tower.

The cool gas is then passed through an electrostatic precipitator where any remaining fume and dust are removed along with any acid mist. The gas is now optically clear and is passed through a drying tower, where a counter current stream of 66° Be' acid removes all of the remaining water vapor.

The clean dry gas leaving the drying tower is then forced through the remainder of the plant by the pressure side of the main blower.

The conversion of the SO_2 in the gas takes place in a converter which is a steel tank containing separated layers of vanadium pentoxide catalyst. The catalyst accelerates the reaction between SO_2 and oxygen to form SO_3.

As the SO_2 is being converted to SO_3 considerable heat is evolved which increases the gas temperature. In order to obtain efficient conversion the temperature range must be controlled carefully. This is accomplished by adjusting the flow of gas through a series of external heat exchangers by means of manually controlled valves.

The SO_2 gas produced in the converter does not combine directly with water, but must be combined indirectly by absorbing it in 98% sulfuric acid. This operation is carried out in the absorbing tower.

The acid in the absorbing tower is strengthened by the absorption of SO_3 while the acid circulating over the drying tower is diluted by the water in the SO_2 gas. Acid strengths are maintained by cross circulation of both acids through their respective pump tanks. The constant transfer of acids containing SO_3 and water increases the amount of acid in the system. The cross flows are adjusted so that this excess acid is maintained at 66° Be', which represents the production and is pumped to storage.

Recovery of Dust and Fume

Due to the low sulfur content of a lead blast furnace feed, little or no SO_2 is formed in the smelting operation. Most of the sulfur combines with copper and iron to form a matte or dross with lead bullion or remains in the slag.

The smoke produced in the blast furnace operation consists principally of oxides of lead and some zinc, along with carbon dioxide, nitrogen and water vapor. The dust loading varies considerably depending upon the condition of the blast furnace. Normal dust and fume content is in the range of 0.2 to 5.0 grains/cu.ft. of gas, however, this will increase appreciably if furnace conditions are such that a "blow-hole" is formed or the furnace is being operated with a low charge column.

In either case, not only is the dust loading increased but also the temperature of the gas rises, which will exceed 1200° F at times. The temperature is controlled by the addition of cooling air, high pressure water sprays or combination of both. The variations in dust loading and gas volumes are handled more efficiently in a baghouse than in any other type of dust and fume recovery equipment.

Our baghouse is designed to handle not only the smoke from two lead blast furnaces and a dross reverb, but also the hygiene ventilation around these furnaces, as well as the dust produced at the discharge end of the sintering machine and primary crushers. Overall dust and fume recovery is in excess of 99% and there is no visible plume of "flag" from the stack.

The baghouse is a Wheelabrator, two section type, with 7 compartments per section. Each compartment contains 416 bags, 8" diameter x 20' long.

The baghouse has a capacity of 450,000 cfm at 230°F and operates under a pressure of from 2.5 to 6.0 ins water.

Filtering ration with one section out and handling the maximum volume of 450,000 cfm is 2.1 cu. ft. of gas to 1 sq. ft. of cloth area.

Gases from the various sources are combined in a centrally located cooling chamber where they can be cooled to 230° F, if necessary, by means of outside air and a water spray system.

Two Sturtevant 6' x 12' double inlet, draft fans, each rated at 235,00 cfm at 230° F and 12' W.G. move the gas from the cooling chamber to the baghouse. With this arrangement it is possible to operate only one half of the baghouse if conditions allow.

The baghouse operation is fully automatic. Temperature is controlled primarily by the addition of atmospheric air through a damper located in the cooling chamber. A series of high pressure sprays are also installed to supplement the air cooling in cases of extreme temperature.

Shaking of the bags in each compartment for the removal of dust is set on a five minute time interval. A timer actuates the individual inlet dampers and bag shaking mechanism.

Dust is removed from hoppers under each compartment continuously by means of screw conveyors.

In order to reduce dust losses and minimize localized hygiene problems caused by blowing dust, all dust recovered in the baghouses is transported in closed drag conveyors to a 25 ton surge bin. From this bin the dust is then fed into a drum mixer where it is moistened and blended with fine product from the sinter machine.

The preceding has been a general description of the smoke problem in the lead smelting industry and the approach used by the Missouri Lead Operating Company in its solution. This does not mean that there are no other means of treating the smoke problem, but to attempt to cover all phases of smoke handling would require much more time than is presently available.

Reference 19

United States Environmental Protection Agency
Office of Air Quality Planning and Standards Research Triangle Park NC 27711
EPA-450/2-89-022 December 1990
Air

EPA

REVIEW OF THE NATIONAL AMBIENT AIR QUALITY STANDARDS FOR LEAD:

ASSESSMENT OF SCIENTIFIC AND TECHNICAL INFORMATION

OAQPS STAFF PAPER

19 001

Preface

Though this document was finalized in December 1990, it does not incorporate information from all the potentially relevant studies of lead health effects or exposures that were published after March 1989. However, this document does reflect the complete Lead Criteria Document, comprised of: 1) the Air Quality Criteria for Lead, 1986; 2) the Addendum to the Air Quality Criteria for Lead, 1986; and 3) the Supplement to the 1986 Addendum to the Air Quality Criteria for Lead, 1990.

This report has been reviewed by the Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, and approved for publication. Mention of trade names or commercial products is not intended to constitute endorsement or recommendation for use.

REVIEW OF THE NATIONAL AMBIENT AIR QUALITY STANDARDS FOR LEAD: ASSESSMENT OF SCIENTIFIC AND TECHNICAL INFORMATION

OAQPS STAFF PAPER

Air Quality Management Division
Office of Air Quality Planning and Standards
U.S. Environmental Protection Agency
Research Triangle Park, N.C. 27711

December 1990

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Helpful comments were also submitted by independent scientists, and by environmental and industry groups including the Environmental Defense Fund, the Lead Industries Association, and the International Lead and Zinc Research Organization.

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EXECUTIVE SUMMARY

This paper evaluates and interprets the available scientific and technical information that the EPA staff believes is most relevant to the review of primary (health) and secondary (welfare) National Ambient Air Quality Standards (NAAQS) for lead and presents staff recommendations on revising the standards. Review of the NAAQS is a periodic process instituted to ensure the scientific adequacy of air quality standards and is required by Section 109 of the 1977 Clean Air Act Amendments. The assessment in this staff paper is intended to help bridge the gap between the scientific review contained in the EPA criteria document "Air Quality Criteria for Lead", its 1986 Addendum and 1990 Supplement, the "Review of National Ambient Air Quality Standards for Lead: Exposure Methodology and Validation" and the judgments required of the Administrator in setting ambient standards for lead. The staff paper is, therefore, an important element in the standards review process and provides an opportunity for public comment on proposed staff recommendations before they are presented to the Administrator.

Human exposure to lead occurs through multiple pathways including: paint pigments, solder in food cans and plumbing, and airborne emissions from motor vehicles and a variety of stationary lead point sources. Over the past decade, there has been a marked decline in lead exposure. Significant dietary declines have resulted from the gradual phaseout of lead in solder and reductions in deposition of atmospheric lead. Additional exposure reductions are expected due to the impact of new drinking water regulations and the continued shrinking leaded gasoline market.

Total lead emissions to air have dropped 94% between 1978 and 1987 resulting in an air lead level of 0.1 to 0.3 $\mu g/m^3$ in most U.S. cities without a major lead point source. Most of

this is directly attributable to the lead-in-gasoline phasedown. Analysis indicated the largest single year drop in average air lead concentrations (42%) occurred between 1985 and 1986 when the lead content in gasoline shifted from 1.0 grams/gallon at the start of 1985, to 0.5 grams/gallon in July 1985, and finally to 0.1 grams/gallon in January 1986. The decline in air lead attributable to leaded gasoline is expected to continue as the leaded gasoline market shrinks.

While these downward trends are encouraging, several important sources of lead exposure persist. The focus of this review is on areas near stationary sources of lead emissions. Although such sources in the past have not made a significant contribution (as compared to lead-in-gasoline) to the overall lead pollution across large, urban or regional areas, lead emissions from such sources can have a significant impact on a local scale; air, and especially soil and dust lead concentrations have been associated with elevated levels of lead absorption in children and adults in numerous lead point source community studies. Exceedances of the current NAAQS (1.5 $\mu g/m^3$) are found only in the vicinity of nonferrous smelters or other point sources of lead.

Primary Standard

The staff has reviewed scientific and technical information on the known and potential health effects of lead cited in the Criteria Document, its 1986 Addendum and 1990 Supplement. This includes information on sensitive populations, mechanisms of lead toxicity, health effects of concern, and relationships between blood lead (PbB), the most commonly used index of exposure, and different health effects of concern. Based on this review, the staff derives the following conclusions and recommendations.

1) Everyone is susceptible to toxic effects from lead. The major subgroups of the population who appear to be especially sensitive are young children, middle-aged men, and pregnant women and their fetuses.

2) Although it remains uncertain whether a common underlying mechanism is involved in the diverse functional impairments produced by lead, it does appear that lead affects biological systems directly, rather than through metabolic transformation, and that there may be no biological threshold for effects of lead ions at subcellular or cellular sites of action.

3) The major low-level effects of concern include:

- Heme biosynthesis and related functions
- Neurological development and function
- Reproduction and physical development
- Kidney function
- Cardiovascular function

4) The critical dose-response findings at low PbB levels are as follows:

- Inhibition of the activity of enzymes involved in red blood cell metabolism, ALA-D and Py-5-N, at 10-15 µg/dl and possibly below, with no evident threshold.
- Interference in heme synthesis indicated by elevated EP (erythrocyte protoporphyrin) levels at 12-23 µg/dl in children, depending on their iron status.
- Interference with vitamin D hormone synthesis in children with no apparent threshold down to the lowest levels measured (12 µg/dl);
- Reduced auditory function in children with no apparent threshold down to the lowest measured levels (4-6 µg/dl);
- Altered electrical brain wave activity with no evident threshold down to 15 µg/dl, and possibly lower;

- Deficits in IQ and other measures of cognitive function (e.g., attention span) in children at PbB levels above 30 µg/dl, and small deficits as low as 15 µg/dl (or possibly lower) in socially disadvantaged children;

- Slowed peripheral nerve conduction at PbB as low as 20-30 µg/dl in children;

- Deficits in mental developmental indices in infants with maternal or umbilical cord PbB levels as low as 10-15 µg/dl.

- Low birth weight and decreased gestational age, which may also influence early neurological development, at maternal PbB levels above 12-14 µg/dl;

- Reduction in early childhood growth with no apparent threshold in one study across the range of 5-35 µg/dl; a threshold at 40 µg/dl was identified in another study;

- Small increases in blood pressure in adult men with no apparent threshold from cross-sectional data down possibly, to 7 µg/dl.

5) There is evidence that lead produces renal tumors in lab animals and lead has been classified a probable carcinogen. While this is of concern, the non-cancer effects at low lead exposure levels are the focus of this staff paper.

The lack of an apparent PbB threshold in several studies is supported by the fact that many of the biochemical changes, or mechanisms, that appear to underlie lead toxicity (e.g., altered enzyme activity, membrane receptors, calcium homeostasis) have been observed at the lowest experimental dosages administered, often with no discernible threshold. There is a great deal of uncertainty regarding the point at which subtle molecular changes individually or collectively, become significant enough that they should be regarded as constituting "adverse" effects for purposes of standard setting under the Clean Air Act. However, such effects clearly become more pronounced (and likely), and broaden

to cause more severe disruptions of the normal functioning of many organ systems, as PbB levels increase. This continuum of effects, from biochemical responses, cellular dysfunction and morphological changes, to organ system alterations and clinical toxicity, makes it difficult to identify clearly what PbB level constitutes an appropriate "threshold", if any, below which there are no significant risks of adverse effects.

The approach taken in this staff paper is to identify those effects that individually or collectively represent an adverse pattern that should be avoided. For children, the collective impact of the effects at PbB levels above 15 µg/dl can be seen as representing a clear pattern of adverse effects worthy of avoidance. At levels of 10-15 µg/dl, there appears to be a convergence of evidence of lead-induced interference with a diverse set of physiological functions and processes, particularly evident in several independent studies showing impaired neurobehavioral function and development. The available data do not indicate a clear threshold at 10-15 µg/dl, but rather suggest a continuum of health risks down to the lowest levels measured. The effects of lead below this range become increasingly difficult to detect and their significance more difficult to determine. For purposes of comparing the relative protectiveness of alternative lead NAAQS, the staff has estimated the percentages of children with PbB levels above 10 and above 15 µg/dl.

While the dose-response information on blood pressure changes in men is less clear than the information on children, the same approximate range of PbB levels can also be considered for assessing risks among adult men. In this staff paper, percentages of middle-aged men with PbB levels above 10 and 12 µg/dl are estimated to compare relative protection afforded by alternative NAAQS.

Quantitative analyses of differences in prenatal lead exposures under alternative lead NAAQS are not done in this review. Although it is likely that there is extensive mobilization of lead, like calcium, during pregnancy, there are no biokinetic data available to quantify this dynamic process. Given the sensitivity of the fetus and neonate, potential risks associated with fetal lead exposures must be considered in determining an appropriate margin of safety for the lead standard. There are approximately 140,000 women of child-bearing age living near major lead point sources whose offspring may be at risk.

Other factors that warrant consideration in evaluating the margin of safety are the significance and persistence of observed or potential health effects, the persistence of lead in the body and in accessible environmental reservoirs (i.e., soil), the sensitivity of exposure analyses to alternative assumptions, and the potential carcinogenicity of lead. It should be considered that for groups that have excessive background exposures, children with pica and/or children living in deteriorated lead-paint homes, any reduction in ambient air lead levels is beneficial. Also other groups, not quantified in this paper, (e.g., post-menopausal women) will also benefit from a reduction in ambient lead levels.

Based on scientific and technical reviews, as well as policy considerations, the staff makes the following recommendations with respect to the primary lead standard.

1) The range of standards for consideration for the primary lead NAAQS should be from .5 to 1.5 $\mu g/m^3$. The results of exposure analyses for children living near three lead smelter sites are summarized in Table 1.

TABLE 1. ESTIMATED CHILDREN'S (0-6 YRS.) PbB LEVELS UNDER ALTERNATIVE LEAD NAAQS IN 3 CASE STUDY ANALYSES: 1990-1996*

Case Study (# Children) / PbB Level[a]	Lead NAAQS Level ($\mu g/m^3$) Baseline[b]	1.5 Quarterly[c]	1.5 Monthly[d]	1.25 Monthly[d]	1.0 Monthly[d]	0.75 Monthly[d]	0.5 Monthly[d]
Dallas (241)							
Mean PbB ($\mu g/dl$)	6.9	4.9	4.8	4.8	4.7	4.6	4.5
% > 10 $\mu g/dl$	14.2	2.2	1.9	1.7	1.5	1.4	1.2
% > 15 $\mu g/dl$	1.3	0.08	0.06	0.05	0.04	0.04	0.03
East Helena (217)							
Mean PbB ($\mu g/dl$)	6.2	5.2	5.1	4.9	4.8	4.6	4.4
% > 10 $\mu g/dl$	8.3	2.9	2.6	2.1	1.7	1.4	1.0
% > 15 $\mu g/dl$	0.6	0.1	0.1	0.07	0.05	0.04	0.02
Tampa (10)							
Mean PbB ($\mu g/dl$)	10.1	8.3	7.8	7.4	7.0	6.6	6.3
% > 10 $\mu g/dl$	50.9	29.7	23.4	19.4	15.6	12.1	9.2
% > 15 $\mu g/dl$	12.9	4.6	3.0	2.2	1.5	1.0	0.6

* Assumes soil Pb remains at baseline levels
[a] PbB distributions calculated assuming GSD = 1.42
[b] Baseline scenario represents current conditions for air quality, as well as soil and dust Pb. Dietary intake assumed to be at 1990-1996 levels
[c] Current NAAQS level and averaging time (calendar quarter)
[d] Alternative NAAQS levels with monthly averaging time

2) A monthly averaging period would better capture short-term increases in lead exposure and would more fully protect children's health than the current quarterly average.

3) The most appropriate form of the standard appears to be the second highest monthly averages in a 3-year span. This form would be nearly as stringent as a form that does not permit any exceedances and allows for discounting of one "bad" month in 3 years which may be caused, for example, by unusual meteorology.

4) With a revision to a monthly averaging time more frequent sampling is needed, except in areas, like roadways remote from lead point sources, where the standard is not expected to be violated. In those situations, the current 1-in-6 day sampling schedule would sufficiently reflect air quality and trends.

5) Because exposure to atmospheric lead particles occurs not only via direct inhalation, but via ingestion of deposited particles as well, especially among young children, the hi-volume sampler provides a reasonable indicator for determining compliance with a monthly standard and should be retained as the instrument to monitor compliance with the lead NAAQS until more refined instruments can be developed.

The analyses summarized in Table 1 omit young children who cannot be substantially affected by any changes in atmospheric lead emissions under different standards. These children (e.g., those with excessive pica and/or living in overtly deteriorated lead-paint homes) total several million and require direct parental and public health intervention to reduce their high-level exposures. Nevertheless, any reduction in air lead levels can be expected to have at least a small beneficial effect on these children and should be considered in establishing the lead NAAQS. Similarly, adult women whose blood pressure is affected by ongoing lead exposure, and women experiencing bone

demineralization during osteoporosis (as well as during pregnancy) and increased lead mobilization, will also benefit from any reduction in ambient air lead levels.

The results from Tampa should not be extrapolated since the secondary smelter and battery plant modeled there were surrounded by mainly non-residential areas and thus only 10 children and 20 men live close enough to these point sources to be significantly effected by changes in emissions. Further analyses are necessary to determine whether these results are applicable to other point source areas with small populations nearby.

Because young children are exposed to, absorb, and retain proportionally more environmental lead than other populations, the staff believes they are most responsive to changes in atmospheric lead emissions and provide sensitive indications of relative protection afforded by alternative NAAQS. Any lead standard designed to protect them should also protect other sensitive groups evaluated quantitatively (adult men) or qualitatively (pregnant women/fetus). Case-study analyses of children populations living near Dallas and East Helena smelters indicate that substantial reductions in lead exposure could be achieved through attainment of the current lead NAAQS. Progressively smaller improvements are estimated for the alternative monthly lead NAAQS levels evaluated, ranging from 1.5 $\mu g/m^3$ to 0.5 $\mu g/m^3$.

According to the best estimate analyses, over 99.5% of children living in areas significantly affected by the smelters would have PbB levels below 15 $\mu g/dl$ if the current standard (1.5 $\mu g/m^3$) were achieved. However, the staff believes that evaluation of alternative standards based on children's PbB levels above 10 $\mu g/dl$ is more appropriate given the health risks associated with lead. Reducing the NAAQS levels would reduce the

estimated proportion of children with PbB levels above 10 μg/dl. For the Dallas and East Helena case studies, assuming a GSD value of 1.42, an estimated 8.3-14.2% of nearby children currently exceed 10 μg/dl, whereas a monthly lead NAAQS of 1.5 $\mu g/m^3$ would reduce this fraction to 1.9-2.6%, and a monthly NAAQS of 0.5 $\mu g/m^3$ would reduce it to 1.0-1.2%. Because of unavoidable background exposures to lead in the diet, historically-contaminated soils and dusts, and maternal bone lead stores in utero, no lead air emission standard can keep all children below a PbB of 10 μg/dl. It is estimated that even with zero air lead emissions, 0.7% of children would have PbB levels above 10 μg/dl and there would be a range of average PbBs from 4.2 to 5.2 μg/dl. Compared to a zero air lead scenario, a NAAQS of 0.5 $\mu g/m^3$ appears to minimize the number of children with PbB levels above 10 μg/dl, the range being from 1.0 to 1.2%. The 0.5 $\mu g/m^3$ NAAQS also appears to be a reasonable lower bound for consideration of a revised lead standard because it would keep more than 99.97% of the exposed children below a PbB of 15 μg/dl. Intermediate increments are indicated for lead NAAQS levels of 0.75, 1.0 and 1.25 $\mu g/m^3$.

While the basis for a decision on the lead standard should be the most sensitive population, i.e., young children, the case-study results on adult men indicated small PbB reductions with progressively lower monthly lead NAAQS levels evaluated, beginning with 1.5 $\mu g/m^3$ down to 0.5 $\mu g/m^3$. A PbB threshold for blood pressure effects in men has not been defined. Two PbB levels, 10 and 12 μg/dl, are selected to compare the relative protectiveness of alternative lead NAAQS. The results indicate that a monthly NAAQS between 0.5 and 1.5 $\mu g/m^3$ would result in between 1.4 - 3.5% of non-occupationally exposed men with PbB levels above 10 μg/dl, compared to 7.2-12.1% at current baseline exposures and 0.6% above 10 μg/dl simply because of non-air background exposure. The percentages above 12 μg/dl for this

range of standards are estimated to be 0.3-0.9%, compared to 0.1% due to background exposures.

SECONDARY STANDARD

The staff review of available laboratory and field data indicate that at high concentrations, lead can:

1) affect certain plants (inhibition of photosynthesis, reduced growth, changes in species composition);
2) affect fish (neurological changes);
3) alter the composition of soil microbial communities and inhibit invertebrate activity resulting in delayed decomposition, reduced nutrient supply, and altered soil properties (lower organic content).

Toxicological data suggests that domestic animals and wildlife are as susceptible to the effects of lead as laboratory animals used to investigate human lead toxicity risks.

The available data also raise concerns about the continued accumulation of lead in soil and sediment reservoirs. Due to the persistence of lead in the environment, such accumulations are expected to continue as long as inputs exceed outputs. Thus, even at relatively low deposition rates, lead could affect an ecosystem over time. This concern is primarily directed to urban and stationary source areas that may already be approaching or have exceeded their soil capacity to bind lead.

Until a stronger data base is developed that more accurately quantifies ecological effects of different lead concentrations, the staff recommends that consideration be given to retaining a secondary standard at or below the level of the current secondary standard of 1.5 $\mu g/m^3$. If the level, averaging time, or form is changed for the primary standard, consideration should be given to making a similar change for the secondary standard to facilitate implementation.

REVIEW OF THE NATIONAL AMBIENT AIR QUALITY STANDARDS FOR LEAD: ASSESSMENT OF SCIENTIFIC AND TECHNICAL INFORMATION

OAQPS DRAFT STAFF PAPER

I. INTRODUCTION

A. Purpose

This paper evaluates and interprets the most relevant scientific and technical information reviewed in the EPA document "Air Quality Criteria for Lead" (EPA, 1986a), the 1986 Addendum to the Air Quality Criteria Document for Lead (1986b), and the 1990 Supplement to the Addendum (EPA 1990), that EPA staff believes is most relevant to the review of the primary and secondary National Ambient Air Quality Standards (NAAQS) for lead. This assessment is intended to help bridge the gap between the scientific review contained in the air quality criteria document and the judgments required of the Administrator in setting ambient standards for lead. Particular emphasis is placed on identifying those conclusions and uncertainties in the available scientific literature that the staff believes should be considered in selecting the averaging times, forms, and levels for the primary and secondary standards. While the paper should be of use to all parties interested in the standards review, it is written for those decision makers, scientists, and staff who have some familiarity with the technical discussions contained in the criteria document, the 1986 Addendum, and the 1990 supplement (hereafter referenced as "CD", "CDA" and the "CDA Supplement", respectively).

A critical element to this review is the assessment of lead exposure from multiple sources, including air, and prediction of lead exposures among sensitive populations under alternative standards. A separate staff report (EPA, 1989a) summarizes

relevant information on lead exposure and presents the exposure modeling methodologies that the staff believes should be considered for the lead NAAQS exposure analysis. Using methodologies described and validated in that report, exposure analyses of populations living near stationary lead sources are presented here to better inform the Administrator of the potential impacts of alternative standards.

B. Background

Since 1970 the Clean Air Act, as amended, has provided authority and guidance for the listing of certain ambient air pollutants that may endanger public health or welfare and the setting and revising of NAAQS for those pollutants. Primary standards must be based on health effects criteria and provide an adequate margin of safety to ensure protection of public health. As several judicial decisions have made clear, the economic and technological feasibility of attaining primary standards are not to be considered in setting them, although such factors may be considered to a degree in the development of state plans to implement the standards (D.C. Cir., 1980, 1981). Further guidance provided in the legislative history of the Act indicates that the standards should be set at "the maximum permissible ambient air level . . . which will protect the health of any [sensitive] group of the population." Also, margins of safety are to be provided such that the standards will afford "a reasonable degree of protection . . . against hazards which research has not yet identified" (Committee on Public Works, 1974). In the final analysis, the EPA Administrator must make a policy decision in setting the primary standard, based on his judgment regarding the implications of all the health effects evidence and on the requirement that an adequate margin of safety be provided.

Secondary ambient air quality standards must be adequate to protect the public welfare from any known or anticipated adverse

effects associated with the presence of a listed ambient air pollutant. Welfare effects, which are defined in section 302(h) of the Act, include effects on vegetation, visibility, water, crops, man-made materials, animals, economic values and personal comfort and well-being. In specifying a level or levels for secondary standards the Administrator must determine at which point the effects become "adverse" and base his judgment on the welfare effects criteria.

The current primary standard for lead (to protect public health) is 1.5 micrograms per cubic meter ($\mu g/m^3$), maximum arithmetic mean averaged over a calendar quarter. The current secondary standard for lead (to protect public welfare) is identical to the primary standard. For both primary and secondary standards, lead and its compounds are measured as elemental lead and currently are collected using a high volume air sampler.

C. Approach

The approach used in this paper is to assess and integrate information derived from the criteria review and the OAQPS staff exposure report (EPA, 1989a) in the context of those critical elements that the staff believes should be considered in the review of the primary and secondary standards. Particular attention is drawn to those judgments that must be based on the careful interpretation of incomplete or uncertain evidence. In such instances, the paper states the staff's evaluation of the evidence as it relates to a specific judgment, sets forth appropriate alternatives that should be considered, and recommends a course of action.

Since the original lead NAAQS was established in 1978, the use of lead in gasoline has dropped dramatically. As a result, controlling and monitoring air lead emissions has shifted from an area-wide problem to one of specific, localized sources. Accordingly, the focus of this paper is on the effects of inorganic lead, either airborne or deposited from the air onto

dusts, soils, vegetation, food, and water, from point sources of lead. The multi-media aspects of lead exposure, related to both air and non-air sources, are addressed in the staff exposure report (EPA, 1989a). Hazardous concentrations of lead in and around lead-based painted housing and in soils with historical accumulations will remain persistent problems not significantly diminished by any change in ambient air emissions. Such hazards will require further coordinated public health intervention measures by parents and appropriate governmental activities.

Section II summarizes information on current air lead exposures; information on other routes of exposure is presented and incorporated into exposure modeling methodologies in EPA (1989a). Section III addresses the critical elements in the review of the primary standards including: 1) identification of the most sensitive population groups; 2) mechanisms of toxicity; 3) health effects of concern; and 4) dose-response information relating the health effects of concern to lead exposures. Drawing on information presented in Sections II and III and the OAQPS staff exposure report (EPA, 1989a), Section IV identifies and assesses the critical elements the staff believes should be considered in selecting an averaging time, form, and level of the primary standard. Results from exposure analyses described in the staff exposure report are presented in Section IV that include estimated blood lead distributions in sensitive populations under alternative lead NAAQS. Staff conclusions regarding alternative policy options in each of these areas are also presented.

Section V examines relevant information on the welfare effects of lead and presents the staff recommendation concerning the secondary standard.

II. AIR QUALITY AND LEAD EXPOSURE CONSIDERATIONS

Human exposure to lead occurs through multiple pathways, and can be traced primarily to lead in paint pigments, solder in canned foods and plumbing, and atmospheric emissions from motor vehicles and stationary lead sources. Although airborne lead is a principal starting point of environmental contamination, oral intake of deposited atmospheric lead is often the primary identifiable factor in predicting blood lead levels, particularly in young children. It is necessary, therefore, to assess not only human exposures through direct inhalation of lead containing particles, but also the ingestion of lead deposited onto soil, dusts, vegetation and other environmental surfaces. The principal pathways of human exposure can be seen in Figure 2-1.

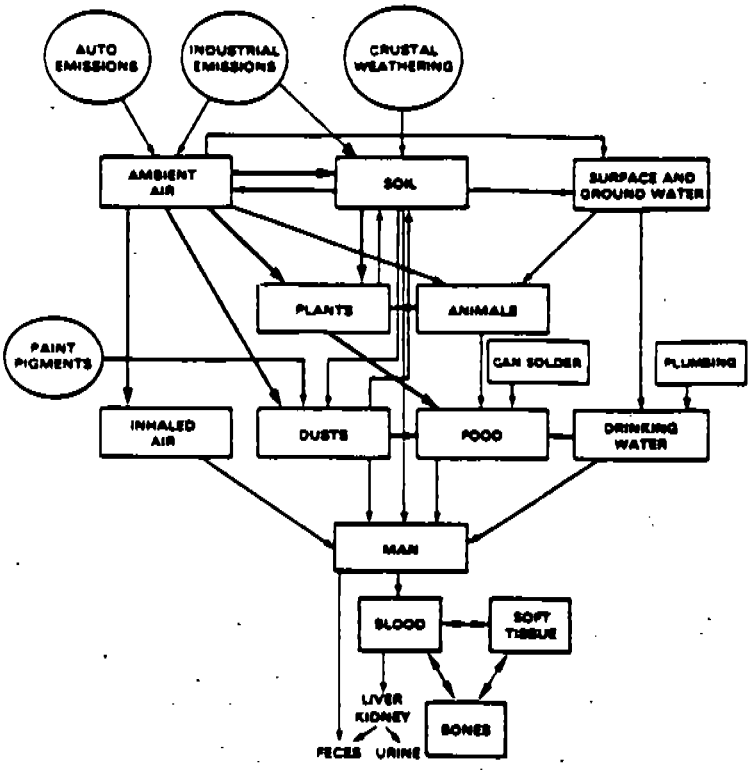

Figure 2-1. PRINCIPAL PATHWAYS OF HUMAN EXPOSURE TO LEAD AND SUBSEQUENT PHYSIOLOGICAL DISTRIBUTION. ADAPTED FROM CD, FIGURE 7-1.

The OAQPS staff exposure report (EPA, 1989a) discusses the relevant information on the principal pathways of lead exposure: airborne lead, and lead in soil, dust, diet, water and paint. As detailed in that report and the CD, there have been marked downward trends in lead exposure from several sources. For example, total lead emissions to air dropped 94% between 1978 and 1987 (see Table 2-1 and Figure 2-2). Most of this decline is attributable to reductions in gasoline lead consumption, which has dropped by about 90% since 1978. This trend will continue as compliance with the 1986 gasoline phasedown regulations progresses, and as the fleet of lead-burning cars shrinks. In addition, lead emissions from stationary sources have been substantially reduced by control programs oriented toward attainment of the particulate matter and lead NAAQS. In 1987, lead emissions from industrial sources (e.g., primary and secondary smelters) dropped by more than one-half from levels reported in the late 1970's (EPA, 1989c). Emissions of lead from solid waste disposal are down 35% since the late 1970's but now represent the second largest category of total air lead emissions behind transportation. If emissions from sewage sludge incineration were included, the two categories would be nearly equal. While aggregate solid waste emissions are relatively high because of the numerous sources, local air quality impacts from individual incinerators are generally low, particularly compared to major stationary industrial sources.

The overall effect of the different control programs has been paralleled by a major reduction in ambient air lead levels, which now average between 0.1 and 0.3 $\mu g/m^3$ in most U.S. cities without major point sources. Recent (1980-1986) air quality data for both point source-oriented sites (predominantly "SLAMS" sites), roadside sites ("NAMS", micro-scale) and other sites (middle-scale, neighborhood), are summarized in Table 2-2 (Battye, 1988a). By 1986, the only quarterly average concentrations over 1.5 $\mu g/m^3$ were recorded at monitors near stationary sources. Twelve counties in the U.S. reported

TABLE 2-1. NATIONAL AIR LEAD EMISSION ESTIMATES, 1978-1987

(thousand metric tons/year)

Source Category	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
Transportation	112.4	94.6	59.4	46.4	46.9	40.7	34.7	15.5	3.5	3.0
Fuel Combustion	6.1	4.9	3.9	2.8	1.7	0.6	0.5	0.5	0.5	0.5
Industrial Processes	5.4	5.2	3.6	3.0	2.7	2.4	2.3	2.3	1.9	2.0
Solid Waste *	4.0	4.0	3.7	3.7	3.1	2.6	2.6	2.8	2.7	2.6
Total	127.9	108.7	70.6	55.9	54.4	46.3	40.1	21.1	8.6	8.1

NOTE: The sums of sub-categories may not equal total due to rounding.
SOURCE: EPA, 1989c
* Does not include lead emissions from sewage sludge incineration which currently amounts to 0.2 - 0.3 thousand metric tons per year.

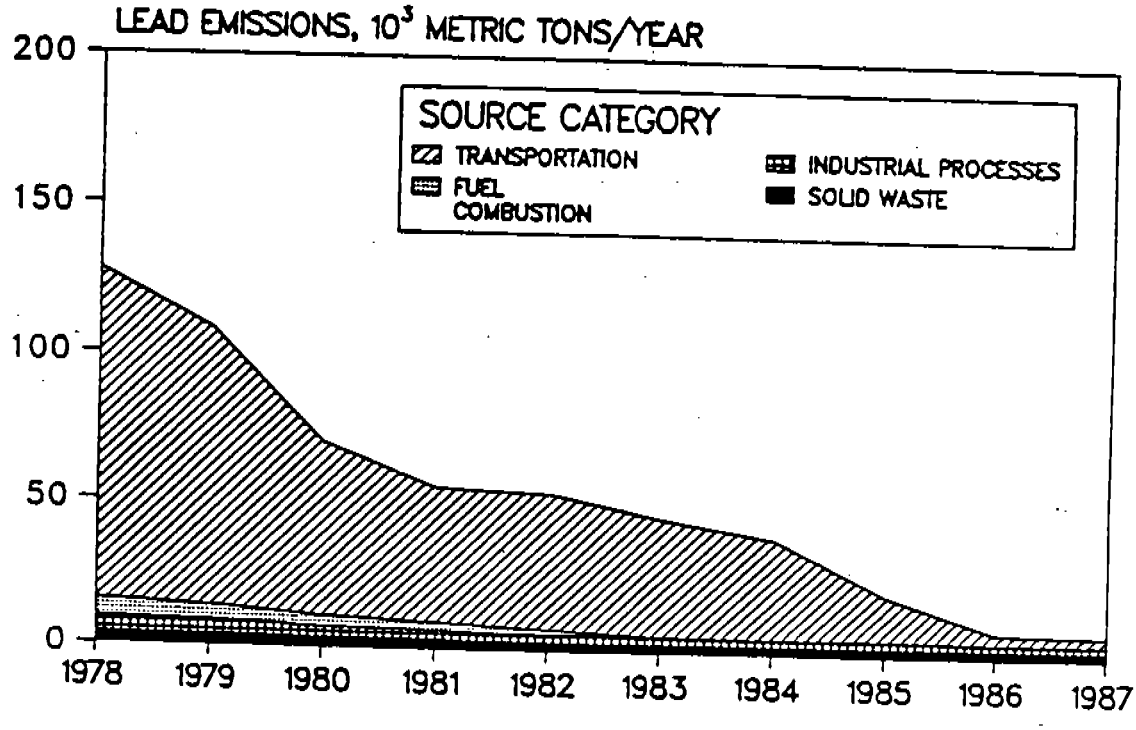

Figure 2-2. NATIONAL TREND IN AIR LEAD EMISSIONS, 1978 - 1987 (from EPA, 1989c)

quarterly averages above 1.5 $\mu g/m^3$ in the 1986-1987 period; 13 more were on the margin of exceeding the NAAQS but either had inadequate numbers of samples or were slightly below the standard level.

Trends in maximum quarterly averages for 97 urban- and 24-point source sites over 10 years (1978-1987) are illustrated in Figure 2-3. Data selected for this trends analysis had to satisfy data completeness criteria of at least 8 out of 10 "valid" years of data in the 1978-1987 period. A year was included as valid if at least 3 of the 4 quarterly averages were available (EPA, 1989d). Some of the dramatic improvement in air quality near point sources is attributable to plant shutdowns. Average air lead trends were also studied over the shorter period 1983-1987 to include more monitoring sites (1989c). This analysis indicated that the largest single year drop in average lead concentrations, 42 percent, occurred as expected between 1985 and 1986, because of the shift from 1.0 grams/gallon of lead in leaded gasoline for the first half of 1985 to 0.5 grams/gallon of lead in July 1985, and finally to 0.1 grams of lead/gallon on January 1, 1986. Average lead concentrations in 1987 declined by 19% from 1986 levels. This trend is expected to continue primarily because the leaded gasoline market will continue to shrink. Some major petroleum companies have discontinued refining leaded gasoline because of the dwindling market.

There have also been significant declines in dietary lead intake as a result of the gradual phaseout of lead solder in canned food manufacturing, and reductions in atmospheric deposition as ambient lead levels have declined (Section II.E; EPA, 1989a). Additional reductions are expected as the recent ban of lead solder in plumbing takes effect and compliance with a revised National Primary Drinking Water Regulation for lead occurs within the next few years. These recent and anticipated changes in nationwide exposures, and other expected future trends in contributions from non-air sources of lead (e.g., contaminated

TABLE 2-2. FREQUENCY DISTRIBUTION OF MAXIMUM QUARTERLY AIR LEAD CONCENTRATIONS ($\mu g/m^3$)[a]

Site type/time frame	Percentage of sites in concentration ranges (concentrations in $\mu g/m^3$) <0.5	0.5-1.0	1.0-1.5	1.5-2.0	>2.0	Mean	Number of site-years
1980 through 1986							
All monitors[b]	77.5	15.4	3.2	1.5	2.3	0.39	3,279
NAMS[c]	76.9	17.2	4.7	1.1	0.2	0.41	471
SLAMS	75.4	16.7	2.8	1.7	3.4	0.38	1,158
Microscale roadside[d]	24.1	37.9	25.9	10.3	1.7	0.74	58
Middle scale	45.7	47.1	7.1	0.0	0.0	0.46	70
Neighborhood scale	68.7	24.3	7.0	0.0	0.0	0.37	115
1986 only							
All monitors	93.0	2.5	1.2	1.6	1.8	0.17	514
NAMS	97.5	1.3	1.3	0.0	0.0	0.14	79
SLAMS	92.9	2.2	0.9	1.3	2.7	0.21	226
Microscale roadside	100.0	0.0	0.0	0.0	0.0	0.18	9
Middle scale	100.0	0.0	0.0	0.0	0.0	0.12	9
Neighborhood scale	94.4	0.0	0.0	5.6	0.0	0.14	18
1987 only							
All monitors	93.0	2.8	1.7	0.4	2.0	0.20	458
NAMS	97.4	0.0	1.3	0.0	1.3	0.20	78
SLAMS	93.1	2.3	1.7	0.0	2.9	0.20	175

[a]Data are from the SAROAD and AIRS systems and represent the number of site-years for which the maximum quarterly concentration fall within the designated ranges. To be included, a valid site-year must have at least three quarters of data with at least 6 observations per quarter.

[b]Includes sites previously classified into categories (e.g., "urban") that do not meet any of the current definitions.

[c]NAMS refers to the National Ambient Monitoring Station network, while SLAMS refers to the State and Local Ambient Monitoring Station network. Each of these two networks includes both roadside and point source monitors; however, in the case of lead, the NAMS network tends to focus on roadside sites, while the SLAMS network incorporates more point sources and other special purpose monitors.

[d]Microscale sites were within 5-15 meters from a major roadway. Middle scale sites had further setbacks and define concentrations up to several city blocks. Neighborhood scale sites define concentrations in more extended areas of uniform land use within cities (0.5-4 km^2). After 1986, data collection at these sites stopped.

Source: Battye (1988a)

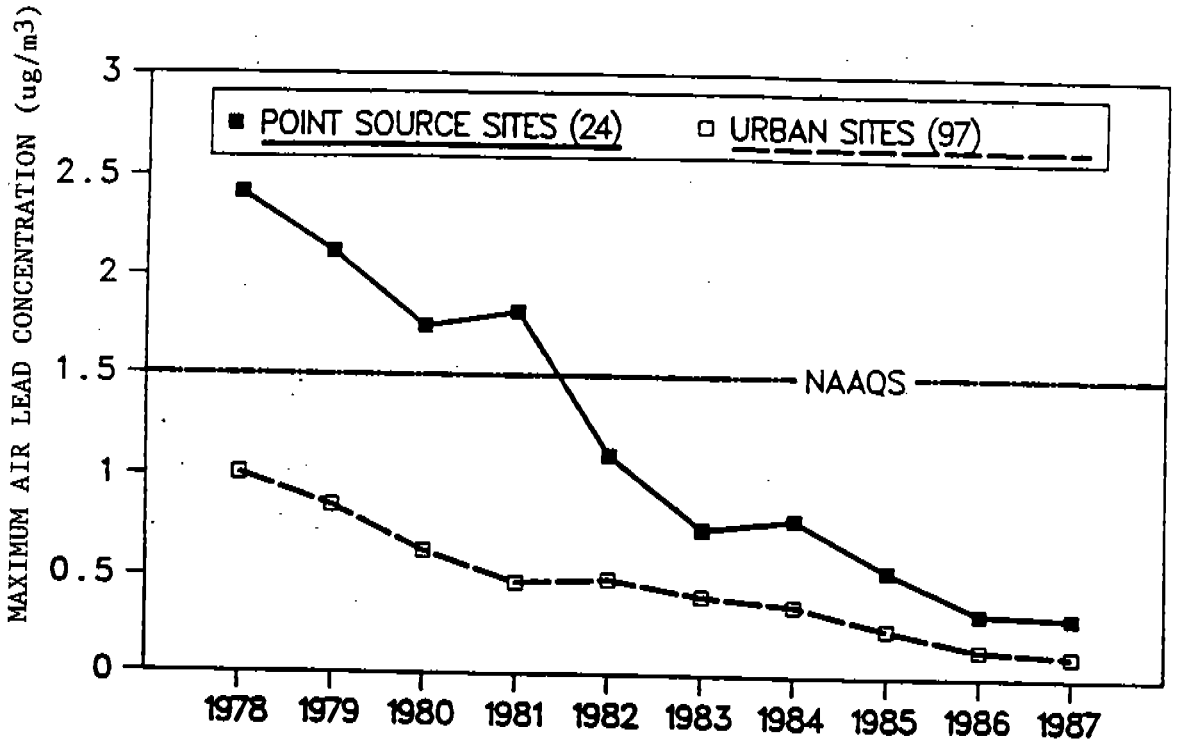

FIGURE 2-3. TRENDS IN MAXIMUM QUARTERLY AIR LEAD CONCENTRATIONS FOR URBAN AND POINT-SOURCE ORIENTED MONITOR SITES (EPA, 1989c)

soils and dusts), are important considerations in estimating lead exposures among sensitive populations under alternative lead NAAQS (see Section IV.C).

While these downward trends are encouraging, several important sources of lead exposure persist. Lead-based paint continues to be the major source of high-dose lead exposure and symptomatic lead poisoning for children in the U.S. As discussed in Section III.A, children excessively exposed to lead-based paint cannot be protected by a lead NAAQS and quantitative exposure analyses for them will not be presented in this paper. Similarly, soils contaminated by a long history of atmospheric lead deposition will remain a potential hazard around roadways and closed industrial facilities and will not be substantially affected by changes in the lead NAAQS.

The focus of this review is on areas near stationary sources of lead emissions. Although such sources in the past have not made a significant contribution (as compared to lead-in-gasoline) to the overall lead pollution across large, urban or regional areas, lead emissions from such sources can have a significant impact on a local scale; air, and especially soil and dust lead concentrations have been associated with elevated levels of lead absorption in children and adults in numerous lead point source community studies (CD, Chapter 11). Figure 2-4 displays the maximum quarterly average air lead concentrations in the nation. Exceedances of the current NAAQS (1.5 $\mu g/m^3$) are found only in the vicinity of nonferrous smelters or other point sources of lead. When assessing the available air quality data, it is important to recognize that up to this time, the focus of the monitoring networks has been on mobile rather than stationary sources of lead. Thus the available data may under-represent or understate stationary source problems.

High lead concentration levels which are found around lead smelters in particular, result mainly from fugitive emissions

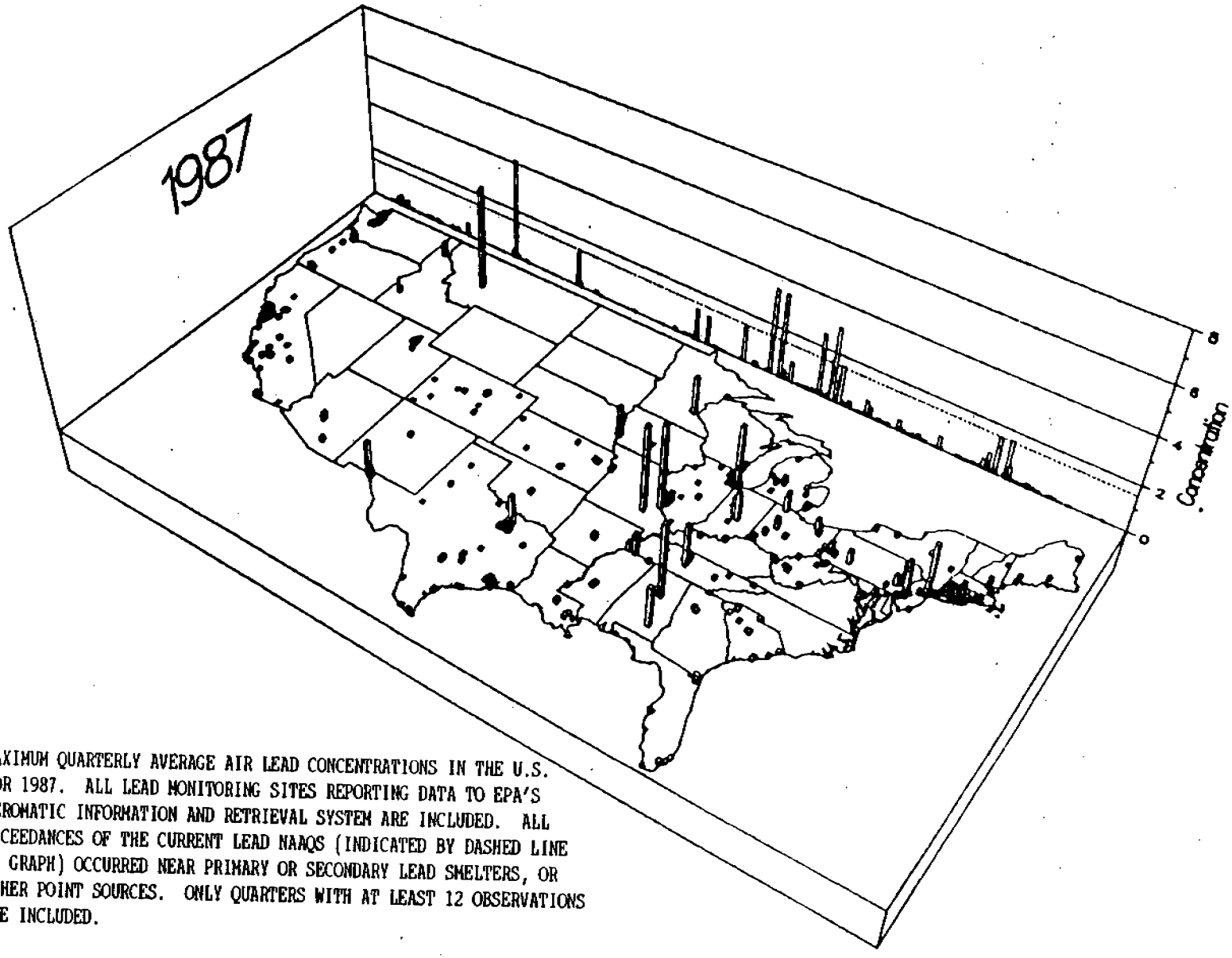

Figure 2-4. MAXIMUM QUARTERLY AVERAGE AIR LEAD CONCENTRATIONS IN THE U.S. FOR 1987. ALL LEAD MONITORING SITES REPORTING DATA TO EPA'S AEROMATIC INFORMATION AND RETRIEVAL SYSTEM ARE INCLUDED. ALL EXCEEDANCES OF THE CURRENT LEAD NAAQS (INDICATED BY DASHED LINE ON GRAPH) OCCURRED NEAR PRIMARY OR SECONDARY LEAD SMELTERS, OR OTHER POINT SOURCES. ONLY QUARTERS WITH AT LEAST 12 OBSERVATIONS ARE INCLUDED.

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predominately made up of large (> 7 micrometers, or μm) lead particles resulting from materials handling, furnace upsets, and furnace charging and tapping operations (Landrigan et al., 1975; Jennett et al., 1977; Battye et al., 1985). Beyond the immediate area (≈2 km) of lead stationary sources, process emissions from stacks, predominant as lead sulfates and oxides with a size range between 1 and 10 μm, become the major source of lead in soils and air (Dorn et al., 1976; Roels et al., 1980; Davidson and Osborn, 1984). A recent study of controlled process emissions from three non-ferrous smelters (1 zinc, 1 lead, and 1 copper smelter) reported that the mass median aerodynamic diameters (MMAD) of process particulate emissions are near 1 μm or less (Bennett and Knapp, 1989).

Size-specific data collected near primary and secondary smelters and battery plants indicate approximately 25% of ambient lead particle mass is less than 2.5 μm MMAD, 20% is between 2.5 and 15 μm, 40% is between 15-30 μm, and 15% is larger than 30 μm (Cohen, 1987). It should be noted, however, that for every lead smelter, refiner, or manufacturer, the particle size distribution will be unique to that facility depending on the proportions and types of fugitive and controlled emissions present.

Because of fugitive emissions and process operating parameters, air quality levels in close proximity of stationary sources can vary significantly day-to-day. While daily sampling data in the vicinity of major sources is sparse, one monitor near (100 meters) a lead refinery in Omaha was operated on a daily basis during 1984. Figure 2-5 illustrates the day-to-day variation in observed air quality levels for the three month period of July, August, and September 1984.

Other months of the year displayed similar variations, but July-September was chosen as representative of a period of usual plant operations. It is interesting to note that despite the high daily peaks, the quarterly average air lead concentration

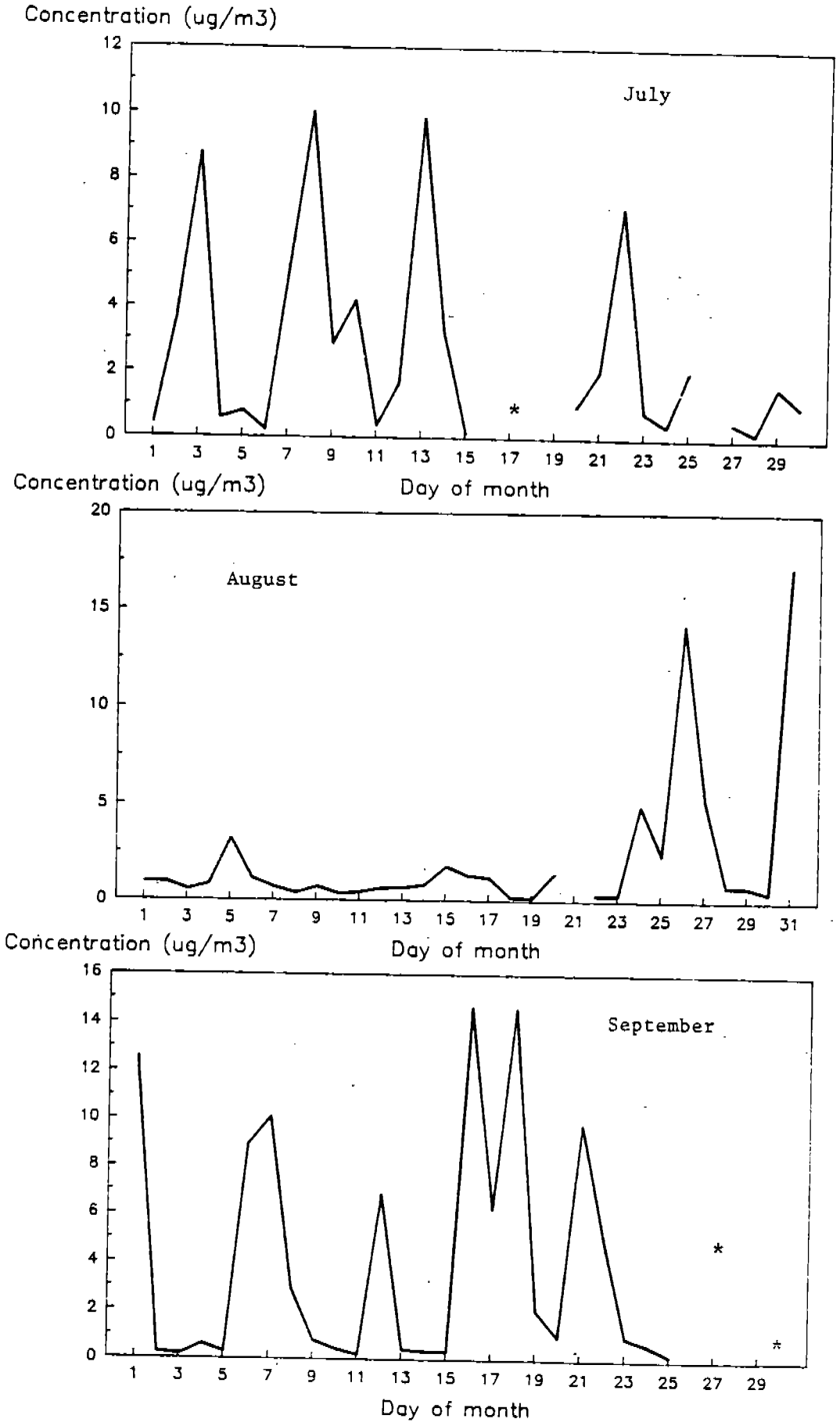

FIGURE 2-5. DAILY VARIABILITY OF AMBIENT LEAD CONCENTRATION AT OMAHA REFINERY, JULY, AUGUST, SEPTEMBER, 1984

* Denotes where data are discontinuous

for the period, composed of 1-in-6 day (1/6) samples, was 1.51 $\mu g/m^3$ which would demonstrate attainment of the current NAAQS. If all of the available daily data are used for this quarter, the average concentration is 2.84 $\mu g/m^3$. The air quality monthly averages, composed of 1/6 day sampling for this quarter are .832, .65, and 3.05 $\mu g/m^3$, respectively. However, when computing monthly averages, the 1/6 day average is not always less than an average computed from all available daily data. Several monthly averages from this data set show larger 1/6 day averages than averages comprised of daily samples. For example, the month of May had a monthly average of 5.07 based on 1/6 sampling and a monthly average of 2.44 based on daily sampling. Three other months that year displayed a similar but less extreme pattern. As this illustrates, the degree of daily variability in air lead levels around major lead point sources, coupled with the available data on particle size distributions, has important implications when considering the appropriate averaging period, form, and sampling methodology for the lead NAAQS. These issues are discussed more fully in Section IV.

III. CRITICAL ELEMENTS IN THE REVIEW OF THE PRIMARY STANDARD

To characterize and assess risks associated with alternative lead NAAQS, information is necessary on: a) sensitive populations; b) mechanisms of lead toxicity; c) health effects of concern; d) relationships between blood lead (i.e., "dose") and different health effects (i.e., "response"); and e) the effects of alternative lead NAAQS on blood lead distributions among the sensitive populations. As part of the current lead NAAQS review, OAQPS staff is estimating blood lead responses under different standards using methods that account for past, current, and future exposures to lead in food, water, soil, dusts, and air, and the cumulative effects of lead in the environment as well as in different tissues within the body. A separate staff report has been prepared to ensure that complex multi-media modeling methodologies are fully documented and reviewed (EPA, 1989a). The exposure methodologies described in that supplemental report have been used to predict, under alternative lead NAAQS, blood lead distributions in populations living near lead point sources. Results of three "case studies" are presented in Section IV.C. This section summarizes information on the other critical elements needed to determine a primary lead NAAQS.

A. Sensitive Population Groups

Lead is harmful to any exposed organism. At least three populations have been identified as especially sensitive: pre-school age children, pregnant women--as exposure surrogates for the fetus, and middle-aged men. Several factors predispose young children to lead-related risks: 1) normal mouthing behavior (e.g., finger licking and immature dietary habits), as well as abnormal ingestion of non-food items ("pica"), which can result in excessive ingestion of lead-contaminated soils and dusts; 2) greater lead absorption and retention rates; 3) greater prevalence of nutritional deficiencies which enhance

gastrointestinal lead absorption; 4) relatively greater proportion of lead body burden in labile pools (e.g., soft tissues) rather than in slow exchange pools (e.g., dense bone matrix) compared to adults; 5) a less developed blood-brain barrier that can allow greater entry of lead into the brain; and 6) an inherently greater physiological sensitivity of developing tissues and organs, as indicated by heightened hematological and neurological responses to lead among children.

Physiological sensitivity to lead is also high during fetal development when the central nervous system is undergoing its most pronounced growth. Persistent effects on neurological function have been observed following in vitro lead exposure in experimental animals. Early developmental impairments associated with fetal exposure have been found in several human longitudinal studies (see Section III.D.2). The pregnant woman is considered sensitive not only because of risks of delivery complications, but because she is the exposure vehicle for the fetus since lead is readily transferred across the placenta. As discussed in the lead exposure staff report (EPA, 1989a), blood lead estimates for pregnant women will not be made under alternative lead NAAQS in this review. This decision was made jointly by EPA staff and the CASAC subcommittee on the lead NAAQS exposure modeling (see Appendix E; EPA, 1989a) because of the lack of biokinetic data for pregnancy that could be used to estimate the distribution of lead among tissues (including fetal) during this complex and dynamic metabolic period. As discussed in Section IV.C., after accounting for the relative contributions to the fetus of maternal bone lead stores versus contemporaneous environmental exposures to young children, it appears reasonable to consider children as the most sensitive group for purposes of this review.

Blood lead has been found in some recent studies to be a small, but significant factor in predicting blood pressure in adult men (see Section III.D.5.), and to a lesser extent in adult women (Schwartz, 1989), including pregnant women (Rabinowitz et

al., 1984). In the largest of these studies, the association was strongest in white males, ages 40-59 years (Pirkle et al., 1985). Because black men are in general more susceptible to blood pressure changes, the impacts of alternative lead NAAQS on blood lead distributions for both white and black middle-aged men will be presented.

Post-menopausal women also appear to be at increased risk due to major changes in mineral metabolism and in bone lead mobilization (Silbergeld et al., 1988); at this time, there are insufficient data to quantify their risks under alternative standards.

Estimated numbers of the three sensitive population subgroups and total populations living around major, operating lead point sources are given in Table 3-1. Populations living within 5 kilometers (km) of 5 primary lead smelters and 1 primary refinery, within 2 km of 23 secondary lead smelters, and within 1 km of 87 lead-acid battery plants were estimated using U.S. Census Bureau-defined block groups or enumeration districts (Battye, 1988b). These distances were selected to include all areas affected by emissions resulting in air lead levels of at least 0.25 $\mu g/m^3$ from the different sources, and not necessarily the high-impact areas. In the exposure modeling discussed in Section IV.C, only populations exposed to air-lead levels at least as high as 0.4 $\mu g/m^3$ are analyzed.

Many more Americans can be identified as especially susceptible to lead toxicity because of excessive exposures to lead in paint, drinking water, and contaminated soil from historical deposition. It is estimated that in 1980, between 6.2 and 13.6 million children under age 7 lived in homes containing hazardous levels of lead in paint surfaces, as defined by CDC, with between 235,000 to 840,000 of them residing in unsound housing conditions (e.g., peeling paint, cracked plaster) (Pope, 1986). Lead-based paint, in combination with poverty, poor

TABLE 3-1. POPULATIONS LIVING NEAR MAJOR U.S. LEAD POINT SOURCES*

SOURCE TYPE (Number Operating)	Total Population	Children[a]	Women of Child-Bearing Age[b]	Adult Men[c]
Primary Smelters and Primary Refinery (6)	136,265	14,649	32,700	13,052
Secondary Smelters (23)	114,301	12,165	27,471	10,965
Battery Plants (87)	322,000	34,269	77,400	30,890

*Distances given in text. Point sources operating as of February, 1988.
[a]Children 0-6 years of age.
[b]In any given year, pregnant women comprise about 7% of all women of child-bearing age (15-44 years).
[c]Adult men 40-59 years of age are focused on because the relationship between blood pressure and PbB appears strongest in that age group. Significant associations have been found, however, for all ages of adult men and women (>20 years of age).

nutrition, and parental stresses and limitations, will continue to be the major source of lead toxicity during the coming decades (Chisolm, 1984; Schneider and Levander, 1986). In addition, as many as 290,000 children may receive enough lead from drinking water via either old plumbing or new lead-soldered plumbing to elevate their blood lead levels to toxic levels (ATSDR, 1988). The numbers of children exposed to potentially hazardous levels of lead in contaminated soils and dusts from historical deposition is difficult to quantify, but likely represents a significant fraction of those living near busy roadways, old housing, and old industrial facilities.

Even the most stringent lead NAAQS cannot be expected to sufficiently reduce health risks in these groups exposed excessively to "non-air" sources of lead and no attempt will be made in this paper to predict their exposures under different air lead scenarios. To abate existing hazards and regulate high intensity exposure sources, better interagency (EPA, FDA, HUD, HHS) coordination to address total lead exposure from multiple sources is needed, as well as a commitment for housing inspection and enforcement, parental education, incentives for property owners, and continued lead screening and research programs.

Although the potential effects of alternative lead NAAQS on some of the other sensitive groups are not evaluated quantitatively, risks related to lead exposure among these groups will be considered in establishing the margin of safety.

B. Mechanisms of Toxicity

The toxicological impact of environmental lead can be the cumulative product of continuous low-level exposure, or of single or repeated acute exposures. Adverse effects are due essentially to the mobile fraction of absorbed lead within the body. A major determinant of toxicity is the distribution of lead among binding proteins and compartments that contain susceptible enzyme systems or other target sites (Raghavan et al., 1981; Silbergeld, 1983).

On a larger scale, the selective accumulation of lead in the heart, kidney cortex, liver, and particularly in the brain during the early stages of pre- and post-natal life may be associated with the sensitivity of these organs to lead. The effects of lead on subcellular structures and processes result in biochemical derangements common to, and affecting, many tissues and organ systems. These biochemical alterations can be linked to the diverse types of lead-based functional disruptions of organ systems that operate in a coordinated, interdependent way.

One molecular basis underlying lead's toxicity in various human tissues is believed to be its ability as a metallic cation to bind with specific biochemical ligands, such as sulfhydryl, amino, and carboxyl groups, which are present in biomolecular substances crucial to normal physiological functions (Moore et al., 1980). Another fundamental mechanism and early manifestation of lead toxicity common to diverse cell types is related to perturbations in intracellular calcium ion homeostasis (Pounds et al., 1982). Lead alters calcium mediated cellular processes and may mimic calcium in binding to various regulatory proteins (Haberman et al., 1983). These disturbances in turn interfere with a constellation of biochemical events, summarized below, which appear to contribute to the more obvious manifestations of lead toxicity.

1. Alteration of enzyme activity

Lead inhibits at least two enzymes in the heme biosynthetic pathway, delta-aminolevulinate dehydrase (ALA-D) and ferrochelatase (Chisolm, 1981), as well as several enzymes and cofactors involved in maintaining the structural integrity of red blood cells and protecting them against oxidation -- Na^+, K^+-activated adenosine triphosphatase (Na^+, K^+ - ATPase), pyrimidine-5′-nucleotidase (Py-5-N), superoxide dismutase, and glutathione (Hasan et al., 1967; Secchi et al., 1973; Angle et al., 1975; Valentine et al., 1976; Levander et al., 1980; Gelman et al., 1978). Altered synthesis of tetrahydrobiopterin and activity of protein kinase C and brain adenyl cyclase (associated with neurochemical receptors; see below) has also been reported

with lead in vitro and in vivo at low concentrations (Purdy et al., 1981; McIntosh et al., 1985; Nathanson and Bloom, 1975; Markovac and Goldstein, 1988a,b).

2. Altered cellular energy metabolism and ion transport

Energy metabolism occupies a central position in all biologic processes. Substantial interference with one or more steps in cellular energetics can have immediate and severe effects on the usual functioning of a cell, tissue, or organ. Mitochondrial structure and a variety of its functions in energy metabolism are very sensitive to lead, particularly in rapidly developing tissues in the young (Bull et al., 1979). Effects including uncoupled oxidative phosphorylation (Goyer and Moore, 1974), inhibited substrate oxidation, and changes in mitochondrial membrane permeability and transport of ions, (especially calcium, sodium, and potassium), occur at levels of lead as low as 15 micromolar in intact cellular systems (Holtzman et al., 1977; Bull, 1980; Van Rossum et al., 1985).

3. Competition with ions for essential binding sites and altered neurochemistry

Lead absorption, distribution, and retention is known to vary depending on dietary intake of calcium, iron, copper, and zinc, as well as other nutrients (e.g., protein, fat, vitamin D) (Mahaffey and Michaelson, 1980). In addition, increased susceptibility to the toxic effects of lead on heme synthesis and on neurological function has been associated with deficiencies in calcium, iron, copper, and zinc (Mahaffey-Six and Goyer, 1970, 1972; Klauder and Petering, 1977; Cerklewski and Forbes, 1976). These metabolic interactions can be expected among elements that share common chemical properties and compete for common metabolic binding sites, such as the mucosal proteins responsible for absorption and transport across the intestinal wall, and on specific intracellular enzymes.

Lead-induced alteration of cellular calcium homeostasis has been observed at lead concentrations as low as 50 micromolar, either by direct competition at receptor binding sites (Barton et

al., 1978; Ong and Lee, 1980; Habermann et al., 1983), or indirectly by reducing energy production and impairing mitochondrial and cell membrane transport "pumps" (Pounds et al., 1982). This could disturb multiple cell functions of different tissues that depend upon calcium as a messenger of hormonal and electrical stimuli, or as a modulator of cyclic nucleotide metabolism (Rasmussen and Waisman, 1983; Rosen, 1983). For example, low levels of lead inhibit the calcium-mediated regulation of pyruvate kinase activity essential to hepatic glycolysis (Pounds et al., 1982), and some calcium-dependent neurotransmission which regulates the propagation of nerve impulses in the brain (Silbergeld et al., 1977; Silbergeld and Adler, 1978), as well as peripheral neuromuscular junctions (Cooper et al., 1984). A wide range of linkages between lead's impact on calcium and energy metabolism, and altered functional activity and developmental delays in the kidney, liver, brain, cardiovascular system, and smooth muscle have been proposed (Bull et al., 1979; McCauley et al., 1979; Silbergeld, 1983; Pounds et al., 1982).

Besides competition with calcium at synaptic binding sites, other mechanisms by which lead at low doses may alter the functioning of neurotransmitter pathways (see CD, Table 12-7) include: 1) inhibition in the brain of the enzymes (Na,K)-ATPase, which helps maintain the ion distribution about the cellular membrane required for neuronal activity (Vallee and Ulmer, 1972), and adenyl cyclase, which regulates cyclic AMP metabolism and synaptic transmission (Nathanson and Bloom, 1975); 2) inhibition of sodium-dependent neurotransmitter uptake (Silbergeld and Goldberg, 1975); 3) impairment of cerebellar and cerebral energy metabolism (Holtzman et al., 1978; Bull et al., 1979); 4) altered metabolism of tetrahydrobiopterin, which helps control the synthesis of the neurotransmitters dopamine and norepinephrine (Purdy et al., 1981; McIntosh et al., 1985); 5) altered GABA neurotransmission, linked to either inhibition of heme synthesis in brain and an accumulation of ALA, altered glutamate metabolism, or lead-induced increase in zinc concentrations in the brain (Sassa et al., 1979; Silbergeld and

Lamon, 1980; Regunathan and Sundaresan, 1985; Baraldi et al., 1985); 6) reduced heme levels in the liver that appear to indirectly alter associated activity in the brain of the amino acid, tryptophan, and the transmitter to which it contributes, serotonin (Litman and Correia, 1983); 7) altered levels of endogenous opiate (e.g., endorphin) and increased sensitivity of brain opiate receptors which may directly affect motor functions (Memo et al., 1981; Baraldi et al., 1985); 8) increased axonal growth and innervation in adrenergic neural pathways in the brain (Freedman et al., 1988); 9) retarded development of other dendritic and axonal connections (Petit and Alfano, 1983) and of neural support cells (Ohnishi and Dyck, 1981; Scott and Lew, 1986).

Most of the above in vitro findings were elicited by micromolar concentrations of lead. Recently, picomolar concentrations of lead were reported to mimic calcium and activate brain protein kinase C, a regulatory enzyme localized in presynaptic terminals and brain microvessels and critical to neurotransmission, neuronal growth and differentiation, and the integrity of the blood-brain barrier (Markovac and Goldstein, 1988a,b). Although this enzyme is only one of several potential mediators of lead toxicity, this finding is important given that cellular concentrations of lead would be expected to be in the picomolar range in humans with typical blood levels today (i.e., 5-25 µg/dl) (Markovac and Goldstein, 1988a). Lead-induced activation of membrane-bound protein kinase C in red blood cells has also been hypothesized to mediate the enhanced vascular reactivity, and in turn, increased blood pressure, associated with lead exposure (Chai and Webb, 1988).

These different effects on neurotransmitter function may reflect either a different accumulation of the metal within distinct anatomical regions or differences in the mechanisms regulating synthesis, release and uptake of the neurotransmitters involved in various brain areas (Collins et al., 1984; Lucci et al., 1981). It is apparent, however, that the type of

neurotransmitter receptor changes induced by lead is determined by the developmental phase during which exposure occurs (Roussouw et al., 1987).

In summary, it remains uncertain whether a common underlying mechanism is involved in the diverse functional impairments produced by lead. It does appear, however, that lead affects biological systems directly rather than through metabolic transformation, and that if present, there may be no biological threshold for effects of lead ions at subcellular or cellular sites of action. The factors that determine the distributions and ultimate availability of lead at these many sites are poorly understood. Thus external exposure levels or internal circulating levels (blood lead concentrations) of lead sufficient to achieve subcellular or cellular concentrations associated with biochemical changes described above remain to be defined.

C. Effects of Concern

Lead is a poison with no known normal function in the body. Lead produces physiological, and ultimately, pathological effects in a variety of tissues and organ systems across a broad range of exposure levels. Evidence for such effects is drawn from in vitro, animal toxicological, and human clinical and epidemiological studies. Based on these data, summarized in the CD (Chapter 12), the 1986 CDA and the 1990 CDA Supplement, relatively low-level effects in the following areas are of primary interest:

1) heme biosynthesis and related functions
2) neurological development and function
3) reproduction and physical development
4) kidney function
5) cardiovascular function

Lead also affects immunological, liver, gastrointestinal, and endocrine functions, and at high dosages produces tumors in

laboratory animals. Information on these effects is generally limited to high exposure levels. The major implications of the available literature and dose-response information related to each of the key effect areas listed above, as well as the potential carcinogenicity of lead, are summarized in Section III.D. as they relate to assessing the risks associated with alternative lead NAAQS.

D. Dose-Response Information

The amount of lead measured in whole blood (PbB) has been the most widely used indicator of lead exposure in the many studies of health effects associated with lead. Although blood lead is only an indirect surrogate of toxicologically active dosages at target sites, and may under-represent total body burden of lead especially after high exposures, it does provide a reliable index of fairly stable exposures and can respond relatively rapidly to short-term changes in lead intake. Future research is expected to increasingly rely on serial blood measurements in combination with <u>in situ</u> bone lead analysis as indices of long-term integrated exposures.

Tables 3-2 and 3-3 summarize the lowest observed effect levels (in terms of PbB levels) that have thus far been credibly associated with health effects of concern observed in children and in adults, respectively. The tables are adapted from Tables 13-7 and 13-8 in the 1986 CD, and have been updated to include more recent data, as evaluated in the 1986 CDA and its 1990 supplement, as well as the 1988 ATSDR Report to Congress. Because of variations in individual biological susceptibility, nutritional status, exposure patterns, and other factors, many people would not experience the stated effects until higher PbB levels while others may respond to even lower levels. Lead affects many levels of physiological and anatomical organization within the body across a wide range of exposure levels. These effects range from biochemical changes in energy metabolism and synaptic neurotransmission, with no apparent threshold on a

TABLE 3-2. SUMMARY OF LOWEST OBSERVED EFFECT LEVELS FOR KEY LEAD-INDUCED HEALTH EFFECTS IN CHILDREN

Lowest Observed Effect Level (PbB)*	Heme Synthesis and Hematological Effects	Neurological Effects	Effects on the Kidney	Developmental Effects
80-100 ug/dl		Encephalopathic signs & symptoms	Chronic nephropathy (aminoaciduria, etc.)	
70 ug/dl	Frank anemia			
60 ug/dl		Peripheral neuropathies		
		↓		
50 ug/dl		?		
40 ug/dl	Reduced hemoglobin synthesis	Peripheral nerve dysfunction (slowed NCV's)		
	Elevated coproporphyrin	CNS cognitive effects (IQ deficits, etc.)		
	Increased urinary ALA	↓		
30 ug/dl		?	Vitamin D metabolism interference	Reduced gestational age & birthweight
15 ug/dl	Erythrocyte protoporphyrin elevation	Altered auditory, electrophysiological responses	↓	Deficits in mental development, growth rate
	↓	↓		↓
10 ug/dl	ALA-D inhibition		?	?
	↓	?		
	Py-5-N activity inhibition			
	↓			
	?			

*PbB = blood lead concentration

Updated from CD Table 13-7

TABLE 3-3. SUMMARY OF LOWEST OBSERVED EFFECT LEVELS FOR KEY LEAD-INDUCED HEALTH EFFECTS IN ADULTS

Lowest observed effect level (PbB)*	Heme Synthesis and Hematological Effects	Neurological Effects	Effects on the Kidney	Reproductive Function Effects	Cardiovascular Effects
100-120 ug/dl		Encephalopathic signs and symptoms	Chronic nephropathy		
80 ug/dl	Frank anemia				
60 ug/dl				Pregnancy complications	
50 ug/dl	Reduced hemoglobin production	Overt subencephalopathic neurological symptoms		Altered Testicular function	
40 ug/dl	Increased urinary ALA and elevated coproporphyrins	Peripheral nerve dysfunction (slowed nerve conduction)		Pre-term delivery	
30 ug/dl					Elevated blood pressure
25-30 ug/dl	Erythrocyte protoporphyrin (EP) elevation in males			?	
15-20 ug/dl	Erythrocyte protoporphyrin (EP) elevation in females				?
<10 ug/dl	ALA-D inhibition				

*PbB = blood lead concentration
Updated from CD Table 13-8

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subcellular molecular level, to severe, irreversible central nervous system damage manifested by mental retardation, encephalopathy (degenerative brain disease), and possibly, death at PbB levels starting between 80 and 100 µg/dl in the most highly susceptible children (EPA, 1986a, p. 12-69). Other overt neurological damage such as peripheral neuropathies, have been observed at PbB levels possibly as low as 40-60 µg/dl (EPA, 1986a, p. 12-108). Clearly adverse effects occur in other organ systems at these elevated levels (60-100 µg/dl) including chronic nephropathy, gastrointestinal symptoms, and frank anemia, which represents an extreme manifestation of reduced hemoglobin synthesis. The focus here will be on the most sensitive targets of low-level lead toxicity: in children, heme synthesis and related functions, neurological function, and mental and physical development; and, the cardiovascular system in adults. Potential carcinogenicity of lead will also be discussed. The PbB levels of concern in evaluating a range of alternative lead NAAQS are discussed in Section III.E.

1. Heme Biosynthesis and Related Functions

Other than some changes in neurochemistry discussed in Section III.B., hematological changes are generally the earliest effects seen in lead exposure. Under normal circumstances, heme biosynthesis is a highly efficient and coordinated pathway, which produces only sufficient amounts of intermediates and, ultimately, heme to service requirements for hemoglobin -- the blood pigment responsible for transporting oxygen to the tissues -- as well as a multitude of functions mediated in most cells by heme-containing proteins. These hemoproteins include myoglobin, the hemoglobin of muscle, and the mitochondrial respiratory pigments, cytochromes, responsible for cellular energetics. As summarized in Table 3-4, moderately elevated lead exposure has been demonstrated to disturb the biosynthetic sequence so as to produce large quantities of redundant intermediates that must then be excreted. More severe lead intoxication may result in the development of anemia due to

TABLE 3-4. SUMMARY OF LEAD'S EFFECTS ON HEME BIOSYNTHESIS AND RELATED SYSTEMS IN CHILDREN

PbB (ug/dl)[1]	Effect	References
≤10-15	Inhibition of ALA-D, Py-5-N, red blood cell ATPase activity	Hernberg and Nikkanen, 1970; Secchi et al., 1973; Wada et al., 1976; Angle and McIntire, 1978; Valentine and Paglia, 1980
≥12	Reduction in vitamin D hormone synthesis	Rosen et al., 1980
~12	Elevated EP in children with iron deficiency	Marcus and Schwartz, 1987
15-18	Accumulation of EP in children with mix of iron status	Roels et al., 1976; Piomelli et al., 1977; 1982; Hammond et al., 1984; Rabinowitz et al., 1986
>20	Impaired globin synthesis	White and Harvey, 1972; Dresner et al., 1982
~23	Elevated EP in children with high iron status	Marcus and Schwartz, 1987
25-30	Significant EP elevation above normal	Roels et al., 1980; Piomelli et al., 1982
>33	Significant interference with vitamin D hormone synthesis comparable to that seen in renal diseases	Rosen and Chesney, 1983; Chesney et al., 1983
18-40	Accumulation of underutilized ALA; possible interference with neuro-transmission	Meredith et al., 1978; O'Flaherty et al., 1980; Nicoll, 1976; Brennan and Cantrill, 1979; Silbergeld et al., 1980, 1982
~40	Reduction in hemoglobin levels	Betts et al., 1973; Rosen et al., 1974; Adenbojo, 1974; Pueschel et al., 1972;
?	Impairment of cytochrome synthesis and function (e.g., liver detoxification cellular energy metabolism)	Alvares et al., 1975; 1976, Meredith et al., 1977; Saenger et al., 1984; Holtzman and Shen Hsu, 1976; Bull et al., 1979
?	Alterations in heme-based neurochemical synthesis and activity and neural tissue development	Litman and Correia, 1983; Whetsell and Kappas, 1981; Whetsell et al., 1984

[1]These levels represent lowest observed effect levels in a significant fraction of children studied. In some cases, no threshold has been detected, as noted by < or > signs. Question mark signifies that the effect has been observed in vitro or in vivo in animals models and extrapolating dosages to children is not not possible at this time.

reduced hemoglobin production and shortened red blood cell survival. Because heme synthesis is a continuous process, most of these effects are reversible upon removal or reduction of lead. However, given: a) there may be long-term functional consequences of even transitory changes in developing tissues in children; b) heme's pervasive role in many organ systems and physiological processes; and c) the sensitivity of heme production to lead, lead's interference in the heme synthetic pathway may have long-lasting implications that must be carefully considered.

As discussed in the CD (Section 12.3), lead interferes with heme synthesis at several points in its metabolic pathway:

1) Activity of the enzyme ALA-D (porphobilinogen synthase), which catalyzes the conversion of ALA to porphobilinogen, is inhibited in red blood cells at PbB levels below 10-15 µg/dl with no clear threshold (Hernberg and Nikkanen, 1970);

2) Accumulations of ALA, which result from inhibited ALA-D activity, have been noted in plasma and urine at PbB levels of 40 µg/dl, and possibly as low as 18 µg/dl. Inhibition of ALA-D activity, and increases in non-utilized ALA appear to occur in brain, kidney, and the liver at roughly the same PbB levels associated with ALA accumulations in plasma (Millar et al., 1970; Secchi et al., 1974; Silbergeld et al., 1982);

3) Lead impairs the transmitochondrial transport of iron and instead of producing heme, the mitochondria accumulate its precursor, protoporphyrin which, lacking iron, is incapable of performing its essential respiratory function. As a result of lead intoxication in newly forming erythrocytes, protoporphyrin (referred to as erythrocyte protoporphyrin or EP) takes the place of heme in the specific pocket of the hemoglobin molecule. As the red blood cells remain in the circulation, zinc is rapidly chelated at the center of the molecule in the site normally

occupied by iron (Piomelli et al., 1982). The resulting zinc protoporphyrin (ZPP) is tightly bound in the available heme pocket for the life of the erythrocyte, normally 120-130 days (Lamola et al., 1975). Impairment of iron utilization for heme synthesis by lead is enhanced by iron deficiency. Persons with both low iron status and PbB levels above 30 µg/dl were approximately 6.5 times as likely to have elevated EP than those with normal iron status in the same PbB range (Mahaffey and Annest, 1986). The interaction of iron status and lead in elevating EP in children should be considered. Several studies have found progressive increases in EP with increasing PbB with an apparent threshold between 15 and 18 µg/dl (Roels et al., 1976; Piomelli et al., 1982; Rabinowitz et al., 1986). Significant EP elevations greater than one and two standard deviations above normal were found in 50% of children with PbB levels of 25-30 and 35 µg/dl, respectively. Some of these studies selected children so as to minimize the number with iron deficiency, although direct data on nutritional status were not available and it is likely that children with different iron stores were grouped together. Data on U.S. children surveyed in NHANES II were reanalyzed to more directly examine the impact of iron status on the dose-response relationships between PbB and EP (Marcus and Schwartz, 1987). While no actual threshold exists in the fitted, non-linear model, the typical estimated EP response increases sharply at about 12 µg/dl in iron-deficient children, and at about 23 µg/dl for children with high iron stores.

The health significance of EP or ZPP accumulation is that it indicates that heme or hemoprotein synthesis in many tissues has been impaired as a result of lead's entry into mitochondria (EPA, 1986a, p. 12-46). Previously, EP elevations at PbB levels around 30 µg/dl were considered to be of concern based on functional disruptions in hemoglobin synthesis at 40 µg/dl and neurobehavioral effects above 50 µg/dl (EPA, 1977). Recent data, however, have provided more information on the extensive impact

of lead on the body heme pool and associated disruptions of many physiological processes (see Figure 3-1). With increasing lead exposure, impairment of heme and hemoprotein synthesis intensifies in different organ systems which can result in reductions in oxygen transport, changes in cellular energetics, interference with neurotransmitter synthesis and function, reduced detoxification of certain drugs and other foreign agents in the liver due to inhibition of cytochrome P-450, impairments in the biosynthesis of 1,25-dihydroxyvitamin D (1,25-OH_2-D) in the kidney, and possibly impairment of the immune system (EPA, 1986a, p. 13-30).

Most of these linkages between the biochemical effects of lead on heme synthesis, and effects on other functions such as neurotransmission, are primarily based on animal or *in vitro* experimental data. It is, therefore, difficult to determine a PbB level of concern for heme-related disturbances in humans. Nevertheless, the common biochemical processes operating across mammalian species suggest the abnormalities in heme synthesis caused by low level lead exposure in humans may also indicate some risk of broader functional impairments.

Of the functional consequences associated with heme reductions and lead's interaction with those processes, perhaps the best quantitative data are available on the negative correlation between PbB levels and circulating levels of the vitamin D hormone, 1,25$(OH)_2$D (Rosen et al., 1980). Synthesis of this hormone, which is the major active form of vitamin D, is mediated by a heme-requiring cytochrome P-450 enzyme system (renal 1-hydroxylase) in the kidney. It is also controlled by the functional integrity of the renal mitochondria, by the ionic (calcium, phosphorous) environment of the extracellular fluid, and by the active uptake of calcium by mitochondria (EPA, 1986a, p. 12-38). Given lead's effects on mitochondria, cellular energetics, cytochrome P-450 function, and ferrochelatase activity in kidneys, it is not surprising that lower 1,25$(OH)_2$D

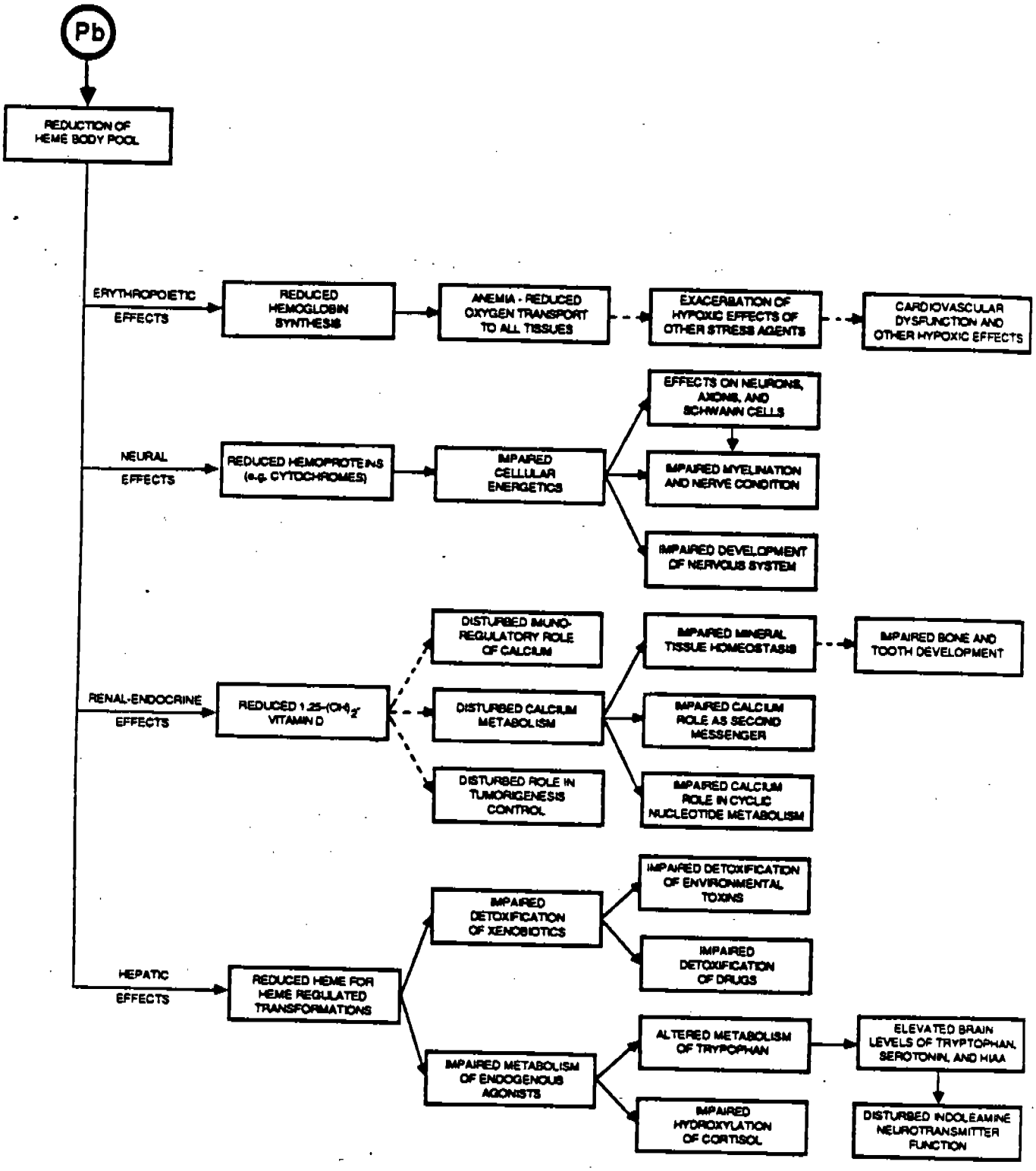

Figure 3-1. Multi-organ impact of reductions of heme body pool by lead. Impairment of heme synthesis by lead results in disruption of wide variety of important physiological processes in many organs and tissues. Particularly well documented are erythropoietic, neural, renal-endocrine, and hepatic effects indicated above by solid arrows (——►). Plausible further consequences of heme synthesis interference by lead which remain to be more conclusively established are indicated by dashed arrows (--►).

Source: Criteria Document (Figure 13-4).

levels occur at PbB levels corresponding to those associated with the onset of EP accumulation in red blood cells. A strong negative correlation between vitamin-D hormone and PbB levels was found over a range of 12-120 µg/dl (Mahaffey et al., 1982) with no apparent threshold. Above 33 µg/dl, the reductions in vitamin D hormone were comparable to these observed in children lacking two-thirds of normal renal function.

The CD concludes that it appears likely that lead-induced reductions in heme underlie this association, and that impaired production of $1,25(OH)_2D$ can have profound and pervasive effects on tissues and cells of diverse type and function throughout the body (EPA, 1986a, p. 12-51). Altered levels of $1,25(OH)_2D$ may affect calcium homeostasis and thus calcium-dependent processes essential to several enzyme systems, the transport of and response to various hormonal and electrical stimuli, and cyclic nucleotide metabolism. In addition, lead may affect the role of $1,25(OH)_2D$ in cell differentiation/maturation, immunoregulation, pancreatic function (e.g., insulin secretion), and mediation of tumorigenesis (EPA, 1986a, pp. 12-40 to 12-42).

At higher levels, lead's interference with heme synthesis and other red blood cell functions (e.g., inhibition of Py-5-N activity which affects membrane stability) may result in anemia. A PbB threshold for apparent reductions in hemoglobin levels in children has been commonly cited at 40 µg/dl (WHO, 1977) although this has not been conclusively established (EPA, 1986a, p. 12-29). Judgments of experts were encoded in 1985-86 in an attempt to address the uncertainty in the dose-response relationship between lead absorption and hematologic dysfunction. These judgments are described in Wallsten and Whitfield (1986) and summarized in Appendix A. Three of four experts assigned at least a 50% chance that some children with a PbB level of 35 µg/dl ($\simeq$5-11%) would have lead-induced anemia and that there would be some children at small risk at even lower levels. A fourth expert felt there was no measurable lead-induced hemoglobin effects at PbB levels below

45-55 µg/dl. Recent analysis of data collected in 1974 from Idaho children living near a lead smelter and rural control areas indicate that hematocrit levels were depressed below normal (an index of anemia) in one-year olds beginning at a PbB level of about 20 µg/dl, and at about 40-50 µg/dl in older children (Schwartz et al., 1989). Although anemia is a serious clinical manifestation, the inhibition of heme synthesis at lower PbB levels has much wider implications for a multitude of organs and physiological systems.

2. Neurological Effects of Lead

The nervous system is a critical target for low-level lead effects. Alterations in neurotransmission and brain mitochondrial function are evident within minutes of exposure for submicromolar lead concentrations in vitro and in vivo. Although the functional significance is difficult to assess and PbB levels at which such effects occur in humans have not yet been determined, these neurochemical changes (e.g., inhibition of acetylcholine release and Na, K-ATPase activity) exhibit continuous dose-response relationships which may form the bases of delayed brain development and disrupted neurobehavioral function (Silbergeld, 1983).

The effects of lead on the nervous system, summarized in Table 3-5, are both structural and functional, involving various regions of the brain and spinal cord (i.e., the central nervous system) as well as the motor and sensory nerves leading to specific areas of the body (i.e., the peripheral nervous system). These effects can result in deterioration of intellectual, sensory, neuromuscular, and/or psychological functions.

a) Acute Effects

Acute encephalopathy (degenerative brain disease) is the most severe consequence of lead intoxication and can abruptly progress to delirium, convulsions, coma, and ultimately death (Cumings et al., 1959). Acute encephalopathy in adults usually

Table 3-5. SUMMARY OF LEAD'S EFFECTS ON THE NERVOUS SYSTEM

Effect	Exposure	References*
Biochemical		
In vitro impairment in rat brain of: synthesis on tetrahydrobiopterin (neurotransmitter cofactor), adenyl cyclase; Na, K-ATPase activity, energy metabolism; activation of protein kinase C	0.001 - 5 uM lead solution	Purdy et al., 1981; Goddard and Robinson, 1976; Taylor et al., 1978; Gmerek al.,1981; Markovac and Goldstein, 1988a,b
Delayed development of rat brain energy metabolism and respiration (in vivo)	0.02% lead salt in drinking water	McCauley et al., 1979; Bull et al., 1977; Bull, 1983
Altered synthesis, release, and/or uptake of several neutotransmitters and cofactors in vivo (dopamine, norepinephrine, serotonin, GABA, tetrahydrobiopterin)	0.2 - 2.0% lead salt in drinking water	Shellenberger, 1984*; Litman and Correla, 1983; McIntosh et al., 1985; Baraldi et al. 1985
Morphological and Functional Development		
Impaired myelin, glial cell development in rat brain.	0.05 - 2.0% lead in diet	Reyners et al., 1979; Widebank et al., 1980; Stephens and Gerber, 1981
Delayed synaptogenesis and neuronal development in young, rat brain	0.1 - 2.0% lead in diet	Petit et al., 1983;* Costa and Fox, 1983; Bull et al., 1983; Roussouw et al. 1987
Delayed development of reflexes and locomotor activity; alterations in social interactions; some persistent learning and behavior deficits,in rats and monkeys exposed in utero or post-natally	>0.001% lead in diet	Brown, 1975; Overmann et al., 1981; Hastings et al., 1979; Bull et al., 1983; Bushnell and Bowman, 1979; Bushnell & Levin, 1987; Cory-Slechta et al., 1985; Rice, 1984, 1985; Winneke et al., 1982b; Barrett and Livesey, 1983
Deficits in early mental development in infants	mean maternal and neonatal PbB 10-15 ug/dl, possibly below	See Table 3-6
Electrophysiological		
Altered electrical activity, neurotransmission in isolated neurons (in vitro)	>1 - 5uM lead solution	Sillman et al., 1982; Taylor et al., 1978; Olson et al., 1984; Cooper et al., 1984; Silbergeld and Adler, 1978
Altered visual and electrical evoked responses, visual acuity, and spatial resolution in young rats, monkeys	0.2% lead in drinking water/diet	Bushnell et al., 1977; Fox et al., 1982; Winneke, 1980
Subtle, alterations of brain electical activity (EEG patterns), auditory function in young children; inconsistent findings on slow-wave potential, visual and auditory evoked potential.	No apparent threshold down to 15 ug/dl PbB and possibly below	Otto et al., 1981, 1982; Otto, 1985; Robinson et al., 1985; Benignus et al., 1981; Burchfiel et al., 1980; Winneke et al., 1984; Schwartz and Otto, 1987
Depressed conduction velocities in sensory and motor nerves of adults and children (conflicting results at similar exposure levels)	>20-30 ug/dl PbB	Seppalainen et al., 1975, 1979, 1983; Schwartz et al., 1988 (Spivey et al., 1980; Triebig et al., 1984)
Motor Nerve Function		
Small deficits in perceptual-motor integration, fine motor coordination and balance in young children	50 - 60 ug/dl PbB, possibly as low as 30 - 40 ug/dl or lower	de la Burde and Choate, 1972, 1975; Landrigan et al., 1975; McBride et al., 1982; Needleman et al., 1979, 1984; Winneke et al., 1982, 1983; Bhattacharya et al., 1988
Conflicting results at similar exposure levels		Rummo, 1974; Rummo et al., 1979; Perino and Ernhart, 1974; Kotok et al., 1977; Winneke et al., 1984

TABLE 3-5. SUMMARY OF LEAD'S EFFECTS ON THE NERVOUS SYSTEM (CONT'D)

Behavioral Disorders		
Symptoms associated with neuropsychiatric disorders (hyperactivity, mental retardation) in children	Effect level not adequately defined	Baloh et al., 1975; Gittleman & Eskenazi, 1983; David et al., 1977, 1983, 1985: Beattie et al., 1975; Moore et al., 1982; Youroukos et al., 1978
Attention (reaction time) deficits and distractability in young children	>30 - 50 ug/dl PbB and possibly as low as 15 - 30 ug/dl	Winneke et al., 1983, 1984; Needleman et al., 1979, 1984; Yule and Landsdown, 1983; Hunter et al., 1983; Hatzakis et al., 1989
Auditory and Language Processing		
Abnormal processing of complex auditory stimuli in infant monkeys	Prenatal and neonatal PbB 50 - 80 ug/dl	Morse et al., 1987
Deficits in motor speech behavior, language comprehension, formulation behaviors, auditory processing and function in children	>30 - 50 ug/dl PbB; no threshold for auditory function	de la Burde and Choate, 1975; Needleman et al., 1979, 1984; Schwartz and Otto, 1987
Cognitive Function		
1 - 4 point deficits in IQ scores on verbal performance, visual-motor perception, short-term memory, general intelligence among young children	>30 - 50 ug/dl PbB; [possibly below 30 ug/dl in socially disadvantaged children]	de la Burde and Choate, 1972, 1975; Rummo, 1974; Rummo et al., 1979; Perino and Ernhart, 1974; Ernhart et al., 1981; Ernhart, 1983, 1984; Needleman et al., 1979, Needleman, 1984; Schroeder et al., 1985; Fulton et al., 1987; Hatzakis et al., 1989 [Harvey et al., 1983, 1984; Winneke et al., 1983; Schroeder and Hawk, 1987]
1 - 2 point, IQ differences due to lead at lower exposure levels in children	15 - 30 ug/dl PbB	Smith et al., 1983; Harvey et al., 1983, 1984; Yule et al., 1983; Yule and Landsdown, 1983; Winneke et al., 1984; Landsdown et al., 1986
Overt Toxicity		
Peripheral nerve damage among chronically exposed adults and children	>40 ug/dl	Lillis et al., 1977; Spivey et al., 1980; Haenninen et al., 1979; Zimmerman-Tansella et al., 1983; Erenberg et al., 1974
Encephalopathy, mental retardation, possibly death among children	>80 - 100 ug/dl	Gant et al., 1938; Smith et al., 1938; Chisolm and Harrison, 1956; Chisolm, 1965; Bradley and Baumgartner, 1958; Rummo et al., 1979

*In some cases, review articles are cited. Refer to CD for more comprehensive referencing

is manifested at PbB levels of approximately 100-120 µg/dl (Chisolm, 1965); this syndrome may be associated with PbB levels between 80 and 100 µg/dl in the most susceptible children (EPA, 1986a, p. 12-69) and can lead to permanent dysfunctions ranging from short attention span to mental retardation.

b) Peripheral Nerve Damage

Peripheral nerve damage (neuropathy) due to high lead exposure has been more commonly found in adults occupationally exposed to lead. Overt symptoms such as muscle tremor, palsy (e.g., "wrist drop") or weakness, muscle and joint pain, and gastrointestinal complaints have been observed in workers with PbB levels exceeding 40 µg/dl (e.g., Lilis et al., 1977; Spivey et al., 1980). Small reductions in conduction velocities of electrically-stimulated sensory and motor nerves (NCVs) have been observed in some apparently asymptomatic workers with PbB levels as low as 30-50 µg/dl (e.g., Seppalainen et al., 1983). It is difficult to draw conclusions from the many studies (more than 30 published) in light of contrasting, negative findings (Spivey et al., 1980; Triebig et al., 1984), as well as a lack of consistency in the nerves examined and in the statistical significance of the effects. Nevertheless, the preponderance of results have been positive, and the most consistently decreased NCVs appear to involve the median motor nerve in the arm. Although lead-induced impairment of nerve conduction may be reversible (peripheral nerves can regenerate), at least in part by a reduction in PbB levels through chelation therapy (Feldman et al., 1977; Araki et al., 1980), electrophysiologic dysfunction in adults is accompanied by alterations in neuromuscular performance (e.g. reduced grip strength and eye-hand coordination) and by subclinical tremor, and reduced visual sensitivity and reactivity (Repko et al., 1979; Baloh et al., 1979). Even small changes in nerve conduction thus may be early warning signals of progressively more serious neuropathy in otherwise undiagnosed lead intoxication (Feldman et al., 1977; Seppalainen and Hernberg, 1980).

Overt, lead-induced peripheral neuropathy has been documented in children with PbB levels above 60 µg/dl (Erenberg et al., 1974), possibly as low as 40 µg/dl (EPA, 1986a, p. 12-108). Unlike the data base for adults, no longitudinal data on nerve conduction are available for children which precludes clear conclusions regarding a threshold for lead-induced neuropathy. Schwartz et al. (1988) reanalyzed cross-sectional data and found a small effect on motor nerve conduction velocity in asymptomatic children at PbB levels beginning at 20-30 µg/dl, with about a 2% slowing in NCV associated with every 10 µg/dl increment in PbB.

c) Effects Associated with Chronic Low-Level Exposures

Besides the severe pathophysiological changes observed in the central nervous system (CNS) associated with childhood lead intoxication, various maladaptive behaviors, neuropsychological deficits, and neuro-anatomical changes have been associated with chronic exposures to relatively low concentrations of lead. Table 3-5 summarizes the numerous biochemical, morphological, and functional effects of lead at low dosages and exposures that have been found in developing nervous systems and the discussion below highlights the key dose-response information.

i) Brain Development: Prospective Studies

Lead readily enters the brain and appears to be selectively deposited in the hippocampus and cortex as well as in non-neuronal elements (e.g., glial cells, endothelial cells of brain capillaries) that are important in the maintenance of "blood-brain barrier" functions (Fjerdingstad et al., 1974; Stumpf et al., 1980). Once deposited, lead is retained in the brain for long periods of time even after external exposure ceases and PbB levels decline (Mykkanen et al., 1979; Goldstein et al., 1974).

The sensitivity of the brain during the period of maximal brain growth and differentiation in the first 2 years of life tends to magnify the severity of the long-term consequences of

any toxin encountered during that period (Dobbing, 1974). The immaturity of specific brain tissues (i.e., hippocampus, cerebellum and neocortex) at birth and their relatively late development suggests that post-natal lead exposure could interfere with mitosis, cellular migration, differentiation of dendritic and axonal processes, synaptogenesis, and myelin production, as well as exerting biochemical and cytotoxic effects (Campbell et al., 1982). While the developing nervous system may possess considerable reserve for functional compensation (involving plasticity, regeneration, and redundancy of neural pathways), specific processes affected by lead apparently may not be reversed, either because lead is not removed from brain cells (Silbergeld, 1983) or because of interruption or damage to neurostructural elements undergoing rapid development at the time of the lead insult.

Rat pups exposed to low levels of lead during the pre-natal or neonatal period show retarded development in cerebral energy metabolic pathways, delayed cerebral cortex synaptogenesis, and reductions in hippocampal morphometric, dendritic, and axonal development (See Table 3-5). These biochemical and morphological disruptions are paralleled by delays in the development of exploratory and locomotor activity, and by learning and behavioral deficits in young, lead-exposed animals (EPA, 1986a, Tables 12-4 and 12-5). Emerging findings from well-conducted, ongoing prospective studies indicating that low levels of <u>in utero</u> or neonatal lead exposure are associated with disturbances in early neurobehavioral development are therefore not surprising.

These studies are reviewed in the CDA and CDA Supplement. Prospective studies have several advantages over cross-sectional or retrospective studies. For example, lead exposure histories can be ascertained and potential confounding variables are better controlled. In addition, efforts were made by the different investigators to use comparable study designs, analytical techniques, and covariate and outcome measures. The study groups

inevitably had different exposure/environmental/socioeconomic profiles, which probably accounts in part for contrasting findings. Numerous combinations of blood lead measures (e.g., maternal, umbilical cord, 3-,6-,12-,24-months, etc.) and mental and psychomotor test measures (e.g., Bayley Mental and Physical Development Indices - MDI and PDI, General Cognitive Index-GCI, etc.) were tested for associations after adjustment for numerous covariates. The many results from the individual studies differ in terms of temporal associations, or lag periods between exposure and outcome measures, statistical significance, and in some cases, direction of effect (PbB positively correlated with some neurological scores in some studies). A generally consistent pattern, however, is evident from these studies linking low-level lead exposure during early development and later neurobehavioral performance. Table 3-6, adapted from Table 13 in the CDA Supplement, summarizes for the most completely documented studies so far, the strongest relationships between different PbB and outcome measures. Other more recent studies provide preliminary results or incomplete analyses that are given less weight in the CDA Supplement (Rothenberg et al., 1989; Graziano et al., 1989a,b; Moore et al., 1989; Fergusson et al., 1988; Winneke et al., 1985 a,b).

Considering the difficulties in assessing neurological function in infants and young children, the different measures used in the prospective studies are generally considered the most reliable and sensitive indicators available. The MDI, for example, reflects the infant's attentiveness and responsiveness to stimuli, rudimentary problem solving, and display of early communicative behavior. While the predictive ability of the MDI is debatable, the correlation between infant MDI scores and childhood test scores are, in general, moderately high, positive, and statistically significant (Davis and Svendsgaard, 1987).

Based on an assessment of earlier results from the Boston, Cincinnati, Cleveland, and Port Pirie studies, the 1986 CDA

TABLE 3-6. SIGNIFICANT EXPOSURE/EFFECT RELATIONSHIPS FROM KEY PROSPECTIVE STUDIES

Study	PbB Measure	PbB Level (ug/dl)	Affected Measure*	Comment
Boston (Bellinger et al., 1985, 1986a,b, 1987, 1988, 1989)	Cord	10-25 (6-7 in "low" SES)	6-,12-,18-,24-month MDI	MDI not related to postnasal PbB. No cord PbB effect at 5 yrs; but risk of persistent effect higher with prenatal PbB >10 ug/dl
	2-yr	mean = 6.8	5-year GCI	
Cincinnati (Dietrich et al., 1986, 1987; 1989a,b; Bornschein et al., 1989; Shukla et al; 1987; Bhattacharya et al., 1988)	Maternal	12-13	3- and 6-month MDI, mediated by birthweight and gestational age	Effect of maternal PbB could range between 7 and 18 ug/dl. No effect of pre- or postnatal PbB by 2 yrs
			Postnatal growth rate	
	Postnatal/10 day	1-29	12-month MDI	
	2-yr	9-49		
			6-yr postural sway	
Cleveland (Wolf et al., 1985; Ernhart et al., 1986, 1987; Morrow-Tlucak and Ernhart, 1987)	Cord	mean = 6.9	12-month MDI via muscle tonus	No effect on birthweight or postnatal growth
			soft signs	
			2-yr language acquisition	
	Maternal/ delivery	mean = 6.8	6-month MDI, PDI, KID	
	6-month	mean = 10.1	6-month KID	
Port Pirie (Vimpani et al., 1989; Baghurst et al., 1987; Wigg et al., 1988; McMichael et al., 1986, 1988)	6-month	avg. = 14	2-yr MDI	Effects on 2-yr MDI marginally significant (p=0.07)
	6-,24-,36-month, and integrated postnatal	avg. = 14-21	4-yr GCI	
	Maternal	>14	Pre-term delivery	
Sydney (Cooney et al., 1989a,b,; McBride et al, 1989)	Maternal/Cord	avg = 8.1-9.1		No consistent significant associations with MDI, PDI, GCI
	6-48 months	avg = 10-16		

*Numerous combinations of PbB measure (e.g., cord, 3-, 6-month, etc.) and outcome measure were tested in these studies; only those found to have significant, negative correlations are listed here (see CDA Supplement). Refer to text and CDA for descriptions of outcome measures: MDI and PDI are Bayley Mental and Physical Development Indices; KID is Kent Infant Development Scale; GCI is McCarthy Scales General Cognitive Index.

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concluded that "these studies taken together suggest that neurobehavioral deficits, including declines in Bayley Mental Development Index scores and other assessments of neurobehavioral function, are associated with prenatal PbB exposure levels on the order of 10 to 15 µg/dl and possibly even lower, as indexed by maternal or cord PbB concentrations" (EPA, 1986b, p. A-48).

The updated assessment from those and other more recent studies in the CDA Supplement concludes that:

> "Various lines of evidence still relate neurobehavioral effects to blood lead levels of '10-15 µg/dl, and possibly lower,' as was previously concluded in the 1986 CDA. Further analyses from the Boston study, which has provided the most direct information bearing on dose-response relationships for neurobehavioral effects, not only supported the 10-15 µg/dl level of concern but indicated that MDI deficits can be detected in relation to cord blood lead levels of 6-7 µg/dl in "lower" SES children (Bellinger et al., 1988). Since the Boston cohort was mostly middle to upper-middle class, "lower" SES merely refers to less than the highest SES levels and is probably in fact much closer to the median of the U.S. population. Although the postnatal lead exposure levels were somewhat higher in the Port Pirie study, analyses of the relationship between postnatal blood lead levels and covariate-adjusted MDI scores provided 'no evidence of a threshold effect' (Wigg et al., 1988). Indeed, restricting the analysis to children with blood lead levels below 25 µg/dl in the Port Pirie study yielded an even stronger association between covariate-adjusted McCarthy GCI scores and integrated postnatal blood lead measures (McMichael et al., 1988)" (EPA, 1990, p. 53).

Recent data from these studies suggest that effects of early lead exposure may be attenuated. Sizable increases in postnatal PbB levels were noted in the Cincinnati, Cleveland, and especially in the Port Pirie studies, but not in the Boston study. None of the first 3 studies showed a significant association between pre- or post-natal PbB and MDI scores at or past 2 years of age. Results from the Boston study suggest that the association between prenatal lead exposure and development only persisted beyond age 2 if postnatal exposure remained at

levels above 10 µg/dl (Bellinger et al., 1989). In the Port Pirie study, the strongest relationship was between MDI and integrated postnatal average lead exposure, suggesting that it is cumulative exposure from pre-birth and early childhood that is critical in affecting subsequent mental development (Vimpani et al., 1989).

Future reports from these studies will perhaps provide insight into the causal linkages involved and help clarify uncertainties, including: (a) which period of exposure (pre- or post-natal, cumulative versus concurrent) is most critical under different conditions; (b) the persistence of the effects given the nervous system's ability of adapting to and even compensating for early developmental insults; and (c) the possibility that important effects are obscured by indirect measures of target dose levels or rapid post-natal changes in lead exposure (see CDA Supplement, pp. 57 to 62). Until then, it must be assumed that any disturbance in a child's developmental potential, even if reversible, can have long-lasting secondary effects. For example, otitis media itself may be transient and fully reversible, but secondary effects on language development in young children may be much longer lived (EPA, 1990, p. 62). Further, the potentially large public health implications of even small neurobehavioral deficits associated with PbB increments warrants minimization of lead exposure from any source. For example, the CDA Supplement notes that the Boston, Cincinnati, and Port Pirie studies found that Bayley MDI scores declined by 2-6 points for approximately every 10 µg/dl increase in PbB level (EPA, 1990, p. 62). An overall 4-point downward shift in a normal distribution of scores such as the MDI or GCI would result in 50% more children scoring below 80 on these exams (Davis and Svendsgaard, 1987).

ii) Behavior and Motor/Communication/Cognitive Functions

1. Animal Data

A variety of behavioral changes, abnormalities and/or developmental delays in motor ability, and deficits in learning, have been observed in young animals following early lead exposure (see Table 3-5). It has been suggested that the animal experiments indicate that lead exposure during early development is associated with an underlying tendency to respond excessively (a behavioral "overreactivity"), whether or not such response is appropriate. This overreactivity facilitates active avoidance and other simple learning tasks but is disruptive in demanding, difficult discrimination learning and complex neuropsychological performance (Overmann, 1977; Winneke et al., 1982; Rice, 1985; Alfano and Petit, 1985).

Interpretation of the animal data is limited given: a) inconsistent measures and results across studies; b) uncertainties in comparing "learning" impairments and behavioral measures (e.g., locomotive activity) across species; c) possible confounding effects of nutrition, route of exposure, litter size, maternal care, and differential species and strain-sensitivity (CD, pp. 12-110 to 12-117); and d) uncertainties in relating external and internal exposure indices across species. Despite these limitations, it is likely that lead-induced effects observed in animal studies at least qualitatively parallel altered neurobehavioral function seen in children.

2. Cross-Sectional Data on Children

Since 1979, when Needleman et al. reported small but significant deficits in IQ, attention span, and auditory and speech processing in apparently normal children at lower exposure levels than had previously been suspected, over 20 cross-sectional studies from 9 countries have been published along with numerous reviews (e.g., Rutter, 1980; Bellinger and Needleman, 1982; Smith, 1985; EPA, 1986a, 1989b).

Determining the subtle interactive effects of low level lead exposure on children's neuropsychological development in relation to social (especially caregiving), genetic, nutritional, and other influential variables over time, while controlling for experimental and analytical biases has proved to be difficult. Problems encountered in the conduct and interpretation of childhood lead studies are discussed in the CD (pp. 12-53 to 12-56).

Based on five methodological criteria (adequate markers of lead exposure, sensitive measures of neurobehavioral function, appropriate subject selection, control of confounding covariates, and appropriate statistical analysis), the criteria document has identified a group of neurobehavioral studies that "were conducted rigorously enough to warrant at least some consideration here" (EPA, 1986a, p. 12-72).

There have been mixed findings regarding lead's association with children's scores on standardized IQ tests, which measure some combination of literacy, information, academic capacity, and intelligence (Flynn, 1984). Several well-controlled studies have found effects that are clearly statistically significant, whereas others have found "non-significant" but borderline effects. It is important to note that: 1) the definition of "statistical significance" ($p < 0.05$) is somewhat arbitrary and should not be used to totally exclude results that may have important public health implications; and 2) given the likely subtle nature of the behavioral or neural effects probable at low levels of lead exposure, the differential maturation patterns and sensitivities among different brain processes, and the many other factors that play a larger role in an individual's developmental trajectory, one would not expect to find striking differences in every study, especially in those that use standardized but non-specific measures of intelligence or academic capacity.

The criteria document concludes that:

"none of the available studies on the subject, individually, can be said to prove conclusively that significant cognitive (IQ) or behavioral effects occur in children at PbB levels < 30 µg/dl. Rather, the collective neurobehavioral studies can probably now be most reasonably interpreted as being clearly indicative of likely associations between neuropsychologic deficits and low level lead exposures in young children resulting in PbB levels ranging to as low as 30-50 µg/dl. The magnitude of average observed IQ deficits appears to be approximately 5 points at mean PbB levels of 50-70 µg/dl and about 4 points at mean PbB levels of 30-50 µg/dl (CD, p. 13-35). Although such IQ deficits are relatively small on average, such shifts in the mean can make a substantial difference in the percentage of children with IQ's in the extremes of the population distribution (i.e., below 80 and above 125) and may impact the intellectual development, school achievement, and social development of the affected children sufficiently so as to be regarded as adverse" (EPA, 1986a, p. 13-36).

Figure 3-2 illustrates that an apparently small shift (4 points) in IQ in the mean of a normal distribution may result in

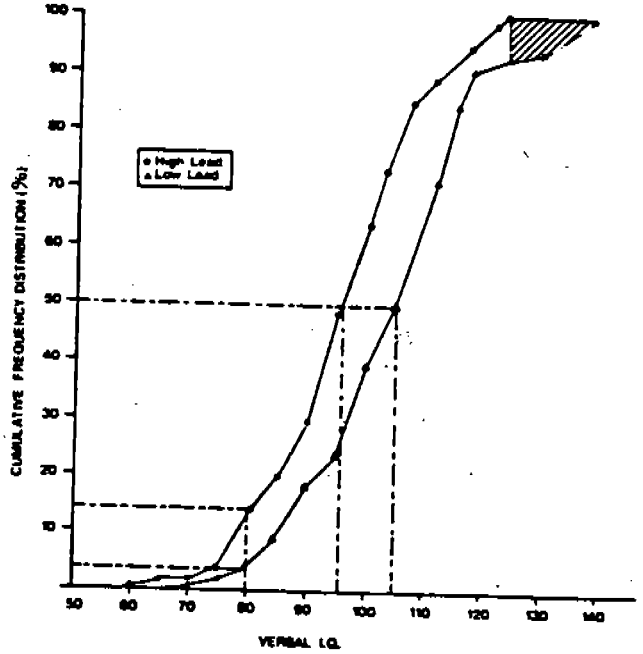

FIGURE 3-2. CUMULATIVE FREQUENCY DISTRIBUTION OF VERBAL IQ SCORES IN SUBJECTS WITH LOW OR HIGH LEAD LEVELS (Source: Needleman et al., 1982)

a nearly four-fold increase in the likelihood of children having severe deficits (IQ < 80), along with an approximately three-fold reduction in the likelihood of children attaining superior function (IQ > 125).

Associations at lower exposure levels have been more difficult to disentangle from other factors. In European children estimated to have PbB levels between 15 and 30 µg/dl, small deficits in IQ and attentiveness have been observed, although no consistent, statistically significant associations have been found (Smith et al., 1983; Harvey et al., 1983, 1984; Yule et al., 1984; Hunter et al., 1983; Winneke et al., 1983, 1984). The criteria document concluded from these studies that "the possibility of small neuropsychologic deficits being associated with lead exposure in apparently asymptomatic children at the exposure levels studied (i.e., 15-30 µg/dl) cannot be completely ruled out, given the overall pattern of results obtained with the cross-sectional study designs employed by Winneke and the British investigators. Small, 1-2 point differences in IQ, seen in some of their studies between control and lead exposure groups might in fact be due to lead effects masked by much larger effects of socioeconomic factors, home environment, or parental IQ" (EPA, 1986a, p. 12-98).

Four recent cross-sectional studies have found continuous exposure-response relationships across the following measured PbB ranges: 7.4 - 63.9 µg/dl, mean = 23.7 µg/dl (with IQ and reaction time performance; Hatzakis et al., 1989); 3.3 - 34.0 µg/dl, mean = 11.5 µg/dl (with British Ability Scales of perceptual, short-term memory, and language functions; Fulton et al., 1987); 6 - 59 µg/dl (with IQ; Schroeder et al., 1985); 6 - 47 µg/dl, mean = 20.8 µg/dl (with IQ; Schroeder and Hawk, 1987). The latter 3 studies found linear relationships with no detectable thresholds. The cohort of 3-7 year-old, low SES children studied by Schroeder et al. (1985) were followed up 5 years later after PbB levels declined (all were below 30 µg/dl); after covariate adjustment, the relationship between PbB and IQ was not significant.

Smaller cross-sectional studies recently reported either consistent findings at moderate-high exposure levels (Faust and Brown, 1987; PbB levels between 30 and 60 µg/dl), or no significant associations among children with lower exposure levels, for example: 5.4 - 21.5 µg/dl, mean = 10.8 µg/dl (with Bayley MDI; Wolf et al., 1987); mean PbB = 11.5 µg/dl (with IQ; Vivoli et al., 1989).

Given the experimental problems encountered in studying subtle, low-level lead effects on children's neurobehavior, it is important to recognize the limits of evaluating studies in isolation. Although results from several studies failed to attain statistical significance individually at the $p = 0.05$ level, in nearly all studies children with higher lead exposures consistently showed lower mean IQs (after covariate adjustment). Simply tallying "positive and negative" studies according to whether the observed association achieved some "arbitrary level of significance" in an attempt to seek a consensus summary is misleading (Pocock and Smith, 1987; Needleman and Bellinger, 1989). For example, two apparently contradictory studies (Fulton et al, 1987, discussed above; and Pocock et al., 1987, who found no significant association between tooth lead and IQ) were compared in terms of their regression coefficients and confidence intervals and were shown to have considerable overlap (Pocock and Smith, 1987). Needleman and Bellinger (1989) integrated recent studies on lead-IQ relationships in children (<12 years of age) into a meta-analysis whereby each study is treated as a subject in a study of studies, and then combined effects are computed. Criteria for selection of the studies were based on adequate information regarding statistical analyses and methodology. Thirteen studies were included; the joint probability was found to be less than 3 in a trillion (2.97×10^{-12}) that the observed pattern of results (lower IQ in higher lead exposure groups) could have been due to chance if there were really no effect. Only if the studies were consistently biased towards finding an effect would the robustness of this result be questionable.

Actually, these studies subtract out variance due to lead (i.e., "overcontrol"). For example, adjusting for covariates such as maternal IQ or maternal caregiving, which negatively correlate with prior lead exposure, likely removes some "transgenerational" influences of lead (Needleman and Bellinger, 1989).

Results of encoding experts' probability judgments on lead-induced IQ decrements, summarized in Appendix A, provide additional insight. The encodings were done in 1984 and 1985 before several key studies were published. According to five of the six experts, risks of small but measurable IQ deficits exist at PbB levels as low as 15 µg/dl in children living in households with incomes in the lowest 15th percentile. Three of the experts felt that there would be some risk of very small lead-induced IQ deficits in low SES children with PbB levels as low as 5 µg/dl.

In addition to IQ decrements, PbB levels in the 30-50 µg/dl range, and possibly lower, may be associated with deficits in auditory and language processing, motor coordination, postural equilibrium, appropriate social behavior, and the ability to focus attention (de la Burde and Choate, 1972, 1975; Needleman et al., 1979; Winneke et al., 1983; Bhattacharya et al., 1988). The degree to which lead's effects on neuropsychological performance at these levels persist into later life remains to be established. One study followed the academic performance of a subset of the children initially evaluated by Needleman et al. (1979) and found that grade retention was clearly associated with past dentine lead levels, while the relationship between other outcomes and past dentine levels were either marginally - (e.g., IQ scores, classroom behavior) or statistically non-significant (e.g., teacher ratings) (Bellinger et al., 1984).

iii) Electrophysiological Effects and Altered Auditory Function

As discussed earlier, in addition to its varied effects on neuronal development and chemically-mediated synaptic transmission, lead impairs peripheral nerve conduction

velocities, at levels possibly as low as 20-30 µg/dl. Similarly, lead exposure affects brain morphology and metabolism, interferes with neurotransmission in central nervous system tissue (e.g., cerebellum, retina) (Palmer et al., 1981; Fox and Sillman, 1979; Sillman et al., 1982), and depresses conduction velocities in the visual pathways of rats accompanied by persistent decreases in visual acuity and spatial resolution (Fox et al., 1977; Cooper et al., 1980; Winneke, 1980; Impelman et al., 1982; Fox and Wright, 1982). Neurological assessments of adult workers indicate that a wide range of lead levels may be associated with impaired function in the visual-motor and auditory systems (Repko and Corum, 1979; Haenninen et al., 1978).

Electrical activity in the brain, determined by electroencephalograms (EEG), is disrupted in animals and humans suffering from lead intoxication (Cooper et al., 1980). More subtle abnormalities in brain wave patterns have been associated with PbB levels in children (along with IQ decrements; Burchfiel et al., 1980) in the range of 30-50 µg/dl, with no evident threshold down to 15 µg/dl, or somewhat lower (Benignus et al., 1981; Otto et al., 1981, 1982, 1985). The functional significance of many of the electrophysiological changes observed below 30 µg/dl (i.e., slow wave potentials, synchronized EEG amplitudes, visual evoked potentials) has not been established, although some changes persisted for at least two years (Otto et al., 1982). Inconsistent or unexpected findings across studies at PbB <30 µg/dl (e.g., decreased evoked potential latencies with increased PbB) (Winneke et al., 1984; Otto et al., 1985; Baumann et al., 1987) require clarification but may indicate hyper-excitability of the peripheral and central nervous system. This would be compatible with symptoms of cognitive impairment associated with lead such as attention deficits, learning disorders, and developmental delays.

The effects on hearing or nerve conduction in the auditory pathway that have been related to lead exposure in children may also be indicative of subtle, but potentially important

neurological impairment. Slowed nerve conduction in the auditory pathway (i.e., increased latencies of brainstem auditory evoked potentials [BAEP]) was directly related to increased PbB levels in children 6-12 years old across the range of 6 to 59 µg/dl (Otto et al., 1985). Attempts to replicate these findings in an independent group of children 3 to 7 years old found that the latency of BAEP waves, as well as hearing threshold at 2000Hz, increased with the maximal PbB levels found in the children's medical records, from 6 to 56 µg/dl (Otto, 1985; Robinson et al., 1985).

Probability of elevated hearing thresholds in 4 different frequencies (500-400Hz) increased significantly with increasing PbB in an analysis of 4,500 children and adolescents (4-19 years of age) studied in NHANES II (Schwartz and Otto, 1987). An association with PbB was apparent across the entire exposure range down to the lowest levels measured (4 µg/dl) after adjustment for covariates including history of recent and chronic ear infections or other disorders. The age at which a child first sat, walked, and spoke also appeared to be associated with PbB levels above 11.5 µg/dl.

Given that lead exposure may impair hearing and the peripheral segment of the auditory pathway, and that a hearing loss occurring in early childhood that remains undetected may result in speech and learning impairments as the child develops, the implications of these findings should be pursued as part of understanding lead's putative role in subtle performance deficiencies among pre-school and school-age children. The preliminary nature of these auditory function results must be emphasized, however, and until comprehensive longitudinal, audiometric, electrophysiological, and speech measurements in children are done, it will be difficult to resolve this issue.

In summary, there have been some inconclusive findings and contrasting interpretations regarding lead's effects on specific

neurobehavioral indicators and functions (e.g., verbal performance, emotional reactivity, perceptual-motor integration, short-term memory, attention, electrical activity in the brain) and the mechanisms involved. The overall evidence, however, indicates that lead is associated with neurological impairment in some children with PbB levels between 30 and 50 µg/dl and that effects on certain behavioral and electrophysiological measures which may have some small, but potentially important and persistent effects on neurological function, support a continuous dose-effect gradient down to exposure levels as low as 15-30 µg/dl PbB, or perhaps, somewhat lower (CD, p. 12-157).

The CDA supplement concludes that "a blood lead concentration of 10-15 µg/dl, and possibly lower, remains the level of concern for impaired neurobehavioral development in infants and children. Given the fact that such effects have been associated with blood lead measures in pregnant women, umbilical cords, and infants up to at least 2 years of age, there is no apparent distinction at present as to whether this level of concern applies to only fetuses or infants or preschool-age children. Thus, a blood lead level of 10-15 µg/dl, and possibly lower, ought to be avoided in pregnant women, fetuses, infants, and young children, although it is recognized that pregnant women per se are not necessarily a population at risk" (EPA, 1990, p. 55).

3. Effects on Reproduction and Physical Development

Lead compounds have been used as an abortifacient and severe lead poisoning has been shown to be accompanied by miscarriages, stillbirths, and reduced fertility (Oliver, 1911). In female animals, relatively low-level lead exposure has been shown to affect pubertal progression and hypothalamic-pituitary-ovarian-uterine functions, as evidenced by ovarian abnormalities (Hilderbrand et al., 1973; Der et al., 1974), and delays in vaginal opening (Grant et al., 1980; Kimmel et al., 1980) and first conception (Maker et al., 1975). In addition, the ability

of the placenta to support fetuses is compromised in mice exposed to relatively low lead levels (Maisin et al., 1975; Jacquet et al., 1976). Newborn rodents and monkeys whose mothers were exposed to lead during pregnancy showed compromised growth (Reiter et al., 1975), congenital malformations in the spinal cord (Carpenter and Ferm, 1977; Jacquet and Gerber, 1979) and delayed neurological development (see previous section).

Pregnant women who lived in homes with excessive drinking water lead concentrations (>800 ppm) bore a significantly higher proportion of retarded infants (Beattie et al., 1975). Premature births, lower birth weight, and premature rupture of membranes have been associated with maternal PbB of 30-40 µg/dl and above in women who worked in or lived near lead smelters (Fahim et al., 1976; Nordstrom et al., 1978). Women in another smelter community, all with PbB at 14-20 weeks gestation below 32 µg/dl, also had increased risk of pre-term delivery (<37th week) as well as late fetal death (beyond 20th week of pregnancy) (McMichael et al., 1986). Mothers whose pregnancies terminated actually had lower PbB levels than average suggesting the possibility of greater lead transfer to the fetus in those cases, consistent with earlier findings (Wibberly et al., 1977).

In newborn children with umbilical cord PbB levels >6.3 µg/dl, an increased incidence in minor (but not major) congenital anomalies (e.g., benign cysts and minor skin defects) was reported after covariate control, although no single anatomic defect was individually associated with lead (Needleman et al., 1984). The longitudinal study of Ernhart et al. (1986), involving a smaller group, failed to find such an association, with average maternal and cord PbB levels of 5.8 and 6.5 µg/dl, respectively.

Significant reductions in gestational age and birth weight have been found to be related to increased maternal or cord PbB in some prospective studies (Moore et al., 1982--mean PbB 12-14 µg/dl; Rothenberg et al., 1989--mean PbB = 15 µg/dl;

Dietrich et al., 1984--apparent threshold at about 13 µg/dl) whereas other studies have reported non-significant, or inconsistent effects (Bellinger et al., 1986a; Ernhart et al., 1986; McMichael et al., 1986). Differences in the age of the mothers, racial make-up, sample sizes, and lead exposure levels, as well as analytical approaches, could underlie the varying results of these different studies (EPA, 1990, p. 57).

As discussed earlier, Dietrich et al. (1984) concluded that the neurobehavioral deficits associated with fetal lead exposure were in part mediated by the observed reductions in gestation and birth weight. Based on subsequent, preliminary analyses of this cohort, these investigators suggest that high prenatal lead exposure (>8 µg/dl) interacts with high postnatal exposure to yield lower than expected growth rates during the first 15 months (Shukla et al., 1987; Bornschein et al., 1989). Although preliminary, these findings lend support to cross-sectional analyses finding small but significant decreases in stature with increased PbB. Schwartz et al. (1986) found that at 59 months, the mean PbB of children surveyed in NHANES II (≈ 16.0 µg/dl) was associated with about a 1.5% reduction in height, weight, and chest circumference, with no apparent threshold across the measured PbB range (5-35 µg/dl). Dentine lead was significantly associated with growth in Danish children between 6 and 10 years of age with low level exposure (Lyngbye et al., 1987). Lauwers et al. (1986) studied children with higher exposures who lived in a lead smelter area and found reduced growth at PbB levels above 40 µg/dl. Despite the uncertainties regarding dose-response relationships, these findings on childhood growth are highly plausible given lead's interactions with heme-dependent enzymes, calcium metabolism, bone formation, and hormonal control (e.g., Rosen et al., 1980; Rosen, 1983; Sandstead et al., 1969).

Male reproductive function is also affected by lead. Sperm abnormalities, reduced fertility, and altered testicular function have been observed in lead-exposed animals and in some industrial workers with PbB levels above 40-50 µg/dl (EPA, 1986a, pp. 12-219).

Although there are inconsistencies, available data suggest that low level exposure to mothers and fathers, may increase the risk of early developmental delays and deficits and reproductive abnormalities. OSHA concluded in 1978 that men and women planning to have children should maintain PbB at or below 30 µg/dl. The 1990 CDA Supplement concludes that "it is difficult, however, to derive a definitive dose-response relationship for fetal outcomes from the available data, although some indications point to a level of concern starting in the region of 10-15 µg/dl. The average maternal blood lead levels in the studies where the pre-term delivery effect was clearest (Port Pirie and Glasgow) were in the 10-15 µg/dl range, in contrast to somewhat mixed findings in the Cincinnati, Boston, and Cleveland studies where the maternal or cord blood lead levels averaged below 10 µg/dl. A similar pattern seems to hold for birth weight as well. The strongest evidence of a birthweight effect comes from the Cincinnati study, with some of their analyses suggesting that this effect could start in the region of 12-13 µg/dl, but possibly extending from 7 to 18 µg/dl. However, other studies provide no support for this conclusion, and so it is considered an open issue awaiting more definitive resolution" (EPA, 1990, pp. 57-58).

4. Effects on the Kidney

Excessive exposure to lead can cause renal disease (see CD, Section 12.5). At low dosages, lead disturbs heme-mediated generation in the kidney of the hormonal metabolite of vitamin D, critical to calcium metabolism (see Section III.D.1). Lead also affects renal mitochondrial structure (e.g., swelling) and other functions (e.g., altered respiratory rates, oxidative phosphorylation and synthesis of proteins and nucleic acids) (Goyer, 1968; Fowler et al., 1980, 1981 a,b; Silbergeld et al., 1982). Lead's interference with these biochemical processes in the kidney, particularly energy metabolism, might account for the transient decreases in renal tubular reabsorptive processes, as indicated by hyperaminoaciduria, glycosuria, and hyperphosphaturia, at PbB levels ranging from 40 to more than

100 µg/dl, and possibly as low as 30 µg/dl (See CD, Sections 12.5.2 and 12.5.3; p. 12-170). The effects of chronic, low-level lead exposure on renal dysfunction in children have not been adequately studied, mainly because there is no good method to easily detect an early renal effect of lead.

There is limited evidence that elevated lead absorption contributes to renal disease in association with gout and hypertension (Emmerson, 1973; Batuman et al., 1981; Wedeen, 1982). The mild hypertension associated with chronic low-level lead exposure however, may be related to lead's ability to directly alter vascular reactivity (Webb et al., 1981; see following section).

5. Effects on the Cardiovascular System

Symptoms consistent with cardiac disease, such as degenerative changes in heart muscle (Kline, 1960), abnormal electrocardiograms (ECG) (Silver and Rodriquez-Torres, 1968) and increased cerebrovascular mortality (Dingwall-Fordyce and Lane, 1963; McMichael and Johnson, 1982; Fanning, 1988) have been associated with high human lead exposures. Cardiotoxicity has been reproduced in experimental animals acutely exposed to high concentrations of lead. Effects include depression in contractility, increased susceptibility to norepinephrine-induced arrhythmias (exaggerated in neonates), and decreased cardiac protein phosphorylation (Kopp et al., 1980; Williams et al., 1977 a,b). It appears that effects may persist in immature rats even after cessation of lead exposure (Williams et al., 1977b).

Chronic administration of lead resulting in PbB levels as low as 40 µg/dl caused structural changes in the myocardium of mice, and ECG abnormalities that are likely due to nerve conduction disturbances (Khan et al., 1977, Kopp et al., 1980). Besides affecting cardiac output, low levels of lead exposure have produced increased vascular responsiveness to contractile agents such as noradrenaline, and sustained elevations in

systolic blood pressure in rats with PbB levels around 40 µg/dl (and possibly lower) (Webb et al., 1981; Victery et al., 1982; Perry and Erlanger, 1979; Aviv et al., 1980; Kopp, 1980). These changes may be linked to depressed energy metabolism (Kopp, 1980), or to altered nerve transmission by increased intracellular calcium concentrations (mediated by impaired sodium-potassium cotransport or activation of protein kinase C) resulting in increased vascular reactivity in arteriolar smooth muscle to vasoconstrictive agents such as norepinephrine and angiotensin (Victery et al., 1982; Rasmussen, 1983; Skocynska et al., 1986; Chai and Webb, 1988; Moreau et al., 1988; Weiler et al., 1988). These studies suggest possible mechanisms by which lead may contribute to hypertension in humans.

Excessive amounts of mobilizable lead have been measured in patients with hypertension (Batuman et al., 1983) and evidence of increased hypertension has been found among men occupationally exposed to high levels of lead (> 50-60 µg/dl) (Inglis et al., 1978; Lilis et al., 1977; Kirkby and Gyntelberg, 1985; de Kort et al., 1987; Cooper, 1988), although there have been contrasting findings in similar populations (Richet et al., 1966; Cramer and Dahlberg, 1966; Parkinson et al., 1987; Selevan et al., 1988). After covariate adjustment, lead exposure has been associated with hypertension prevalence (Beevers et al., 1976; Kromhout and Coulande, 1984) and small increases in blood pressure in some community studies (Moreau et al., 1982; Pocock et al., 1984; Pirkle et al., 1985; Weiss et al., 1988; Neri et al., 1988; Sharp et al., 1988; Schwartz, 1989), but not in others (Staessen et al., 1984; Elwood et al., 1988; Grandjean et al., 1989). Rabinowitz et al. (1984b) reported that umbilical cord PbB was significantly associated with both mother's blood pressure at delivery and the presence of pregnancy hypertension in a sample of 3200 live births in Boston with a mean cord PbB of 6.9 µg/dl.

Weiss et al. (1988) followed changes in blood pressure among 89 Boston policeman over 5 years. Despite the small sample, the

longitudinal nature of the data overcomes many limitations associated with cross-sectional studies and provides a sensitive measure to detect a subtle effect. Time-series and bootstrap analysis indicated a significant association between PbB above 30 µg/dl (but not below) and subsequent elevation in systolic (but not diastolic) pressure. Another longitudinal study of lead foundry workers also found a significant association but results are confounded by cadmium exposures (Neri et al., 1988).

Some of the largest cross-sectional studies, involving as many as 7300 adult men (Pocock et al., 1984; Pirkle et al., 1985; Schwartz, 1985a,b; 1986a,b; E.I. Dupont de Nemours, 1986a,b) and subsequent reanalyses, are focused on in the 1986 CDA (pp. A-10 to A-18) and 1990 CDA Supplement. The quantitative results of these studies are summarized in Table A-3 of the CDA and Table 1 of the CDA Supplement.

Although the investigators in these studies originally published divergent conclusions, reassessment using comparable statistical approaches (comparing covariate-adjusted regression coefficients) on these, as well as 2 other "negative studies" on over 1700 Welsh men and women (Elwood et al., 1988), revealed substantially overlapping confidence intervals and a consistent indication of at least a weak positive association (Pocock et al., 1988; Figure 1, CDA Supplement). Based on the their analysis, Pocock et al. concluded that a mean increase of 1.45 mm Hg in systolic blood pressure appears to occur for every doubling of PbB concentration. This supports the earlier conclusion in the 1986 CDA (p. A-17) that the analyses in Table A-3 (Table 1 in the CDA Supplement) represented the best estimates of the association (i.e., generally in the range of 2.0-5.0 mm Hg/log PbB for systolic and 1.4-2.7 mm Hg/log PbB for diastolic blood pressure). The consensus among leading experts at the 1987 International Symposium on Blood Lead-Blood Pressure Relationships was similar: that a doubling of PbB was associated with about a 1-2 mm change in blood pressure, on average (Victery et al., 1988).

The NHANES II analyses initially focused on white males aged 40 to 59 years to avoid the collinearity between blood pressure and blood lead evident at lower ages, and because data relating cardiovascular disease to blood pressure are less extensive for non-whites (Pirkle et al., 1985). Lead was found to be a significant, but weaker, predictor of blood pressure in additional analyses on all men ages 20-74, both black and white (Schwartz, 1988), and in adult women ages 20-74. A threshold below which blood lead was not significantly related to blood pressure could not be found in that study across a range of adjusted PbB levels between 7 and 34 µg/dl. It is of interest to note that the dose-response relationships found by Pirkle et al. (1985) suggest a large initial effect, leveling off at higher PbB levels, which is consistent with the biphasic blood pressure response to PbB levels found in rats (Victery et al., 1982) and with the saturable, lead-induced accumulation of calcium in cells (Pounds et al., 1982). This may account for the inconsistent epidemiologic findings in persons with mild to moderate elevations of blood lead.

Because of the complex inter-relationships among the multiple environmental, dietary, medical, socio-economic, and genetic factors that influence blood pressure, all of which may not be measurable, results from even the recent large studies must be interpreted cautiously. Nevertheless, the CDA Supplement concludes that the new information emerging since 1986 substantiates the main conclusions stated in the CDA at that time:

> "Sufficient evidence exists from both the four large-scale general population studies discussed above (NHANES II, BRHS, and the two Welsh studies) and numerous other smaller-scale studies to conclude that a small but positive association exists between blood lead levels and increases in blood pressure. Quantitatively, the relationship appears to hold across a wide range of PbB values, extending possibly down to as low as 7 µg/dl for middle-aged men, and furthermore, an estimated mean increase of about 1.5-3.0 mm Hg in systolic blood pressure appears to occur for every doubling of blood lead concentration in adult males and

> something less than 1.0-2.0 mm Hg for adult females. The plausibility of these relationships observed in epidemiologic studies of human populations being of a causal nature is supported by controlled experimental animal studies demonstrating increased blood pressure effects clearly attributable to lead, with an apparent biphasic dose-response relationship being involved." (EPA, 1990, pp. 22-23)

As noted by Tyroler (1988) and other discussants at the 1987 Symposium mentioned above, despite the seemingly small elevations in blood pressure when viewed from the clinical perspective of each individual, any increase in blood pressure carries with it increased risk (albeit very small) for stroke, heart attack, and/or associated mortality. Projections of potential lead effects on such outcomes were modeled by Pirkle et al. (1985). The CDA Supplement concludes that:

> "projections of potential lead effects on such outcomes, as were modelled by Pirkle et al. (1985) and discussed in the 1986 Addendum, are not unreasonable in view of the potentially very large public health impacts; however, much caution must be exercised in accepting the validity of any specific quantitative estimates derived from such projections in view of the uncertainties associated with the selection of the specific coefficients used for (1) blood-lead-blood pressure relationships and (2) relationships between blood pressure increases and more serious cardiovascular outcomes." (EPA, 1990, p. 23)

Recent reanalyses of NHANES II data help to illustrate the possibility of detecting indications of small increased risks in the general population. Schwartz (1989) found a direct relationship between PbB levels and electrocardiogram (ECG) abnormalities, indicative of left ventricular hypertrophy. Such ECG abnormalities represent an early indicator of cardiovascular disease that is much more common than frank myocardial infarctions. It remains to be determined to what extent these observations are due to a lead-induced increase in blood pressure or to some other lead-related pathogenic mechanism (EPA, 1990; p. 19).

6. Possible Genotoxicity/Carcinogenicity

Dose-related increases in renal tumors (Azar et al., 1973; van Esch et al., 1962; Hass et al., 1967) and tumors in endocrine organs (Zawirska and Medras, 1968) have been reported in rats administered dietary lead acetate or lead subacetate. Other studies have found no indication of tumors at either low doses or short duration exposures in rats and mice (Kanisawa and Schroeder, 1969; Stoner et al., 1976; Koller et al., 1985) or high doses in hamsters (van Esch and Kroes, 1969). Data on other chemical forms of lead are either lacking (e.g., lead chloride), or are limited, but suggestive of carcinogenic potential (lead phosphate via injection, Roe et al., 1965; lead oxide via tracheal instillation with benzo[a]pyrene, Kobayashi and Okamato, 1974; lead napthenate via skin painting, Baldwin et al., 1964). Evidence for tumors at other sites other than kidneys is uncertain (Hass et al., 1967; Blakely et al., 1987).

Since lead is capable of transforming cells directly in culture (DiPaolo et al., 1978; Casto et al., 1979) and affecting DNA-to-DNA and DNA-to-RNA transcription (Sirover and Loeb, 1976; Robinson et al., 1984), lead may serve as an initiator of carcinogenic activity. Lead's potential to induce chromosomal aberrations (CD, Table 12-21) may be indicative of its ability to initiate carcinogenic activity but contradictory results have been reported (EPA, 1986a, Table 12-22). In addition, lead may be a promoter of carcinogenesis, as indicated by its ability to increase DNA, RNA, and protein synthesis (Choie and Richter, 1974, a,b), and to enhance the development of renal tumors in rats previously treated with a known carcinogenic initiator (Hiasa et al., 1983; Shirai et al., 1984). Lead's sequestration in the form of "inclusion bodies" in kidney cell nuclei may be linked to its carcinogenic effects (EPA, 1986a, p. 12-244).

An evaluation of these results by EPA (1989b) concludes that: (a) the evidence for carcinogenicity of lead in animals is adequate, although positive responses were generally seen only at

high doses (above a cumulative dose of 1 gram); (b) because several different lead compounds including organic and inorganic ones have been shown to be capable of inducing kidney cancer, and all lead compounds tested are capable of increasing the body burden of lead, from a qualitative weight of evidence perspective, all lead compounds are considered to be potentially carcinogenic; (c) most experiments administered lead in the food, although positive results were reported using other routes. Although no inhalation cancer bioassays are available, there is ample evidence for the bioavailability of lead via inhalation. Lead is therefore considered to be potentially carcinogenic by any route.

Epidemiological studies of lead-exposed workers and children suggest lead may induce chromosomal aberrations that may be associated with certain forms of cancer (Grandjean et al., 1983; Dalpra et al., 1983). Little can be reliably concluded from the conflicting occupational findings on kidney tumor incidence and excess cancer mortality (e.g., Cooper and Gaffey, 1975; Cooper, 1985; McMichael and Johnson, 1982; Sheffet et al., 1982; Selevan et al., 1988; Cantor et al., 1986), although the significant elevations in respiratory and digestive tract cancer in workers exposed to lead and other agents warrant concern (EPA, 1986a, p. 12-225). These latter findings should not be over-interpreted given differences in age distributions among the populations studied and inadequate controls for factors such as smoking, diet, ethnicity, geographical location, and simultaneous exposures to other heavy metals such as arsenic and chromium, which are proven carcinogens. Furthermore, these studies provide no specific information on the long-term lead exposure levels or the lead compounds to which workers were exposed.

The criteria document concludes that:

"Since lead acetate can produce renal tumors in some experimental animals, it seems reasonable to conclude that at least that particular lead compound should be regarded and treated as a human carcinogen (as per recommendations of the International Agency for Research on Carcinogenicity). However, this statement is qualified by noting that lead has

been seen to increase tumorigenesis rates in animals only at relatively high concentrations, and therefore does not seem a potent carcinogen. In vitro studies further support the genotoxic and carcinogenic role of lead, but also indicate that lead is not potent in these systems" (EPA, 1986a, p. 12-289).

Since the IARC recommendations were published in 1980, an EPA assessment (EPA, 1990) recommends that lead be classified as a probable human carcinogen in a tentative weight-of-evidence "Group B2". Evidence on potential carcinogenicity from human studies is considered "inadequate" and the evidence from animal studies is considered "sufficient" according to EPA's guidelines for Carcinogen Risk Assessment (EPA, 1990). This classification includes all lead compounds since all can be absorbed from both the respiratory and gastro-intestinal tracts, and in some cases, from the skin. Although the mechanism through which lead induces chromosomal aberrations and mutations is unknown, the pattern of responses suggests that lead compounds may not directly damage the genetic material, but rather may act through an indirect mechanism, such as activation of cellular transformation or tumor promotion (EPA, 1989b).

Although there are animal dose-response data that could be used to describe the carcinogenic potency of lead, the Agency staff feels that any such calculation would be highly uncertain. A variety of complicating factors influence lead-induced cancer, such as the route of exposure, nutrition, and bioavailability of different chemical forms. The preliminary evaluation of lead carcinogenicity concludes that while pharmacokinetic models have been developed to assess non-cancer health effects in humans, comparative models across species would be needed to extrapolate from high-dose animal studies to project human cancer risks at low-level environmental exposures, and that sufficient information is not available to incorporate many of the factors into a credible exposure-response model for humans (EPA, 1989b). Based on qualitative characterization, this assessment placed lead in potency Group 3 ("low"), as defined in EPA guidelines for evaluating potential carcinogenicity (EPA, 1986b). Combining the

weight of evidence (B2) and the potency ranking, lead receives a "hazard" ranking of "low" relative to other potential carcinogens.

The potential carcinogenicity of lead raises concern; available data, however, do not indicate substantial risks that can be anticipated at current exposure levels. It is recommended that for purposes of revising the lead NAAQS, attention be focused on the non-cancer effects of lead which represent significant risks at relatively low exposure levels. However, the staff believes that the potential carcinogenicity of lead should be considered in determining an adequate margin of safety.

E. Summary of Health Risks Associated with Different Blood Lead Levels of Concern

This section presents a brief staff assessment of how the dose-response information summarized previously may be applied in determining PbB levels of concern for sensitive populations in assessing the relative protectiveness of alternative lead NAAQS.

Lead exposure across a broad range of exposure levels has been associated with a continuum of effects ranging from subtle molecular changes to clear pathological effects. The critical findings at low PbB levels are as follows:

(1) Inhibition of ALA-D and Py-5-N activity at 10-15 µg/dl and possibly below, with no evident threshold;

(2) Elevated EP levels at 12-23 µg/dl in children, depending on their iron status. Elevated EP indicates interference with heme or hemoprotein synthesis in many tissues, which can result in reductions in oxygen transport, changes in cellular energetics, interference with neurotransmitter synthesis and

function, reduced detoxification in the liver, and impaired vitamin D metabolism;

(3) Interference with vitamin D hormone synthesis in children with no apparent threshold down to the lowest levels measured (12 µg/dl);

(4) Reduced auditory function in children with no apparent threshold down to the lowest measured levels (4-6 µg/dl);

(5) Altered electrical brain wave activity with no evident threshold down to 15 µg/dl, and possibly lower;

(6) Deficits in IQ and other measures of cognitive function (e.g., attention span) in children at PbB levels above 30 µg/dl, and small deficits as low as 15 µg/dl (or possibly lower) in socially disadvantaged children;

(7) Slowed peripheral nerve conduction at PbB as low as 20-30 µg/dl in children;

(8) Deficits in mental developmental indices in infants with maternal or umbilical cord PbB levels as low as 10-15 µg/dl. The CDA Supplement concludes that a PbB concentration of 10-15 µg/dl, and possibly lower, remains the level of concern for impaired neurobehavioral development in infants and children (EPA, 1990, p. 55);

(9) Low birth weight and decreased gestational age, which may influence early neurological development, at maternal PbB levels above 12-14 µg/dl;

(10) Reduction in early childhood growth with no apparent threshold in one study across the range of 5-35 µg/dl; a threshold at 40 µg/dl was identified in another study;

(11) Small increases in blood pressure in adult men with no apparent threshold from cross-sectional data down possibly, to 7 µg/dl.

Evidence that lead is a potential, weak carcinogen is also of concern although the focus here will remain on the non-cancer effects at low exposure levels.

The lack of an apparent PbB threshold in several studies is supported by the fact that many of the biochemical changes, or mechanisms, that appear to underlie lead toxicity (e.g., altered enzyme activity, membrane receptors, calcium homeostasis) have been observed at the lowest experimental dosages administered, often with no discernible threshold. There is a great deal of uncertainty regarding the point at which subtle molecular changes individually or collectively, become significant enough that they should be regarded as constituting "adverse" effects for purposes of standard setting under the Clean Air Act. However, such effects clearly become more pronounced (and likely), and broaden to cause more severe disruptions of the normal functioning of many organ systems, as PbB levels increase. This continuum of effects, from biochemical responses, cellular dysfunction and morphological changes, to organ system alterations and clinical toxicity, makes it difficult to identify clearly what PbB level constitutes an appropriate "threshold", if any, below which there are no significant risks of adverse effects.

One approach would be to simply state, as the American Academy of Pediatrics does, that since lead has no biologic value, the "ideal" PbB level is 0 µg/dl (AAP, 1987). This may be a correct public health goal, and adopting it as the basis for revising the lead NAAQS would avoid the problems inherent in addressing the kinds of uncertainties discussed above. However, the Clean Air Act does not instruct the Administrator to eliminate all conceivable health risks that might result from atmospheric lead, regardless of their likelihood, extent, or

significance, simply because there are uncertainties in the relevant scientific data. Instead, it requires him to weigh the available evidence, including the uncertainties, and set NAAQS which, in his judgment, will protect public health against "adverse" effects with an adequate margin of safety. Accordingly, the staff believes it is appropriate to assess the implications for public health of potential effects at PbB levels above zero and to examine the degree of protection that would be afforded by alternative NAAQS.

The approach taken here is to identify those effects that individually or collectively represent an adverse pattern that should be avoided. For children, the collective impact of the effects at PbB levels above 15 µg/dl can be seen as representing a clear pattern of adverse effects worthy of avoidance. Such levels provide relatively little margin from those currently defined by CDC as requiring environmental or medical intervention (> 25 µg/dl along with elevated EP levels). At levels of 10-15 µg/dl, there appears to be a convergence of evidence of lead-induced interference with a diverse set of physiological functions and processes, particularly evident in several independent studies showing impaired neurobehavioral function and development. While the available data do not indicate a clear threshold at 10-15 µg/dl, but rather suggest a continuum of health risks down to the lowest levels measured, the effects of lead below this range become increasingly difficult to detect and their significance more difficult to determine. For purposes of comparing the relative protectiveness of alternative lead NAAQS, the staff has estimated the percentages of children with PbB levels above 10 and above 15 µg/dl (see Section IV.C).

While the dose-response information on blood pressure changes in men is less clear than the information on children, the same approximate range of PbB levels can also be considered for assessing risks among adult men. Percentages of middle-aged men with PbB levels above 10 and 12 µg/dl are estimated to compare relative protection afforded by alternative NAAQS.

Quantitative analyses of differences in prenatal lead exposures under alternative lead NAAQS are not done in this review (see Section III.A). Although fetal sensitivity to lead is high, it appears that young children are significantly more responsive to a lead NAAQS; therefore, the analyses that focus on young children likely provide appropriate estimates of relative risks among alternative standards. Risks associated with fetal lead exposures will be considered in determining an appropriate margin of safety.

To further focus the evaluation of alternative lead NAAQS in Section IV.C., the following factors should be considered: (1) young children are most exposed and absorb a greater proportion of lead; (2) lead accumulates and persists not only in the skeleton but in target organs such as the immature brain; (3) peak exposure generally occurs during the period of maximal neurological growth and differentiation such that any effects on the "hardwiring" of neural networks in the brain may be irreversible. Given these considerations, the staff recommends that of the different sensitive populations and PbB levels of concern, greatest attention be placed on the percentages of young children with PbB levels above 10 μg/dl.

IV. FACTORS TO BE CONSIDERED IN SELECTING A PRIMARY STANDARD FOR LEAD

This section, drawing upon the previous evaluation of scientific information from the criteria document and other information sources, outlines the key factors that should be considered by the Administrator in designating appropriate criteria for averaging time, sampling frequency, monitoring options, and in establishing the level of the lead primary standard. Preliminary staff conclusions and recommendations regarding the most appropriate policy options in each of these areas are presented.

A. Averaging Time

When the lead standard was proposed in 1977, the averaging time for the primary lead NAAQS was specified as a calendar month due to studies which showed an equilibration period of approximately 60 days before steady state PbB levels in adults adjust to changes in air lead concentration (Rabinowitz et al., 1973; Griffin et al., 1975). A month averaging time was considered appropriate because of the greater risk of exposure of young children (FR Vol. 42, No. 240, 1977). Subsequently, EPA promulgated the current NAAQS with a calendar quarter averaging time based on the conclusion that an air lead level of 1.5 $\mu g/m^3$ as a ceiling would be safe for indefinite exposure of young children, and that the slightly greater possibility of elevated air lead levels within the quarterly period was not significant for health (FR Vol. 43, No. 194, 1978). The risk of shorter term exposures to air lead concentrations elevated above a quarterly-averaged standard that might go undetected was considered in the 1978 standard decision to be minimized because 1) based on the ambient air quality data available at that time, the possibilities for significant, sustained excursions were considered small, and 2) it was determined that direct inhalation of air lead is a relatively small component of total airborne lead exposure (FR Vol. 43, No. 194, 1978).

Since promulgation of the lead NAAQS in 1978, the air lead problem has changed in scope from a nationwide, primarily auto emission problem to one related to point source emissions. Point source emissions accounted for 63 percent of total lead emissions in 1987 (EPA, 1989c) and will reach an even higher fraction as gasoline lead emissions continue to decline. Therefore, the 1978 standard decision rationale is no longer as directly relevant to the remaining issues surrounding air lead emissions. The following assessment of additional health and exposure information available since 1978 and other evidence suggests that a monthly averaging time would be more appropriate than a calendar quarter.

1. Biological Kinetics of Lead and Potential Health Impacts Associated with Short-Term (Days-Weeks) Exposures

Lead is absorbed from the environment through the lungs (direct inhalation) and through the gastro-intestinal tract (ingestion). See Chapter 10 of the CD and exposure report (EPA, 1989a) for complete discussions of lead biokinetics and multi-media exposure. Once lead is absorbed into blood plasma through the alveoli or through the gut lumen, it is quickly ionized and is distributed from plasma to the red blood cells, kidney, liver, skeleton, brain, and other tissues. The following discussion summarizes the most relevant information from studies on adults and on children.

a) Adult Data

The initial uptake of lead from plasma to the red blood cells is very rapid, occurring within a few minutes to tens of minutes (Campbell et al.; 1984; Chamberlain, et al., 1983; De Silva, 1981). Ingested lead appears in urine in less than one hour (Chamberlain et al., 1978). Analysis of data from studies on exposure to lead isotope tracers (Rabinowitz et al., 1973, 1976; Griffin et al., 1975; De Silva, 1981) show that lead is absorbed into peripheral tissues in adults within a few days (Marcus, 1985a,b,c; Chamberlain, 1985).

The relevance of the rapid transfer of lead via blood plasma into target tissues is difficult to assess. Most animal and human studies of lead toxicity use measures of lead exposure which reflect accumulations over time (such as blood and tooth lead), and thus do not readily allow effects of different exposure patterns to be distinguished. It is generally accepted, however, that acute exposures to very high lead levels (i.e. from ingestion of paint chips) can result in immediate changes in blood lead and overt toxicity. Data are available on the effects of intense inhalation exposures on a direct precursor of lead toxicity, impaired heme synthesis. PbB levels and ALA-D activity in workers experiencing occupational lead exposure (e.g., as high as 2-4 mg/m^3 air lead) for the first time were significantly altered after only a few days of exposure (e.g., from 12 to 40 µg/dl PbB in 3 weeks), and concentrations of urinary lead and urinary ALA changed significantly after about two weeks (Tola et al., 1973). Hemoglobin and hematocrit levels were significantly lower in the workers at the end of the observation period (about 3 months). After a brief massive exposure of a British worker, zinc EP became highly elevated within one week. Similar results were seen under controlled conditions in which single experimental lead exposures were followed by a rapid (10-20 days) and significant elevation in EP in adult men and women (Stuik, 1974; Cools et al., 1976; Schlegel and Kufner, 1979).

While lead uptake and the onset of potential toxicity may occur rapidly during increased exposure, there is long-term retention of lead in tissues, and reductions in exposure do not cause an equally rapid reduction in either body burden or toxicity. Accumulation of mobilizable pools of lead in the skeleton and other tissues create an endogenous source of lead that is only slowly eliminated. Even soft tissues such as kidney, liver, and the brain retain lead on the order of months, and lead in bone may be retained for many years. Thus, the rapid intake of lead during periods of increased exposure is of

critical concern in determining an averaging time for the lead NAAQS.

b) Data on Children

The experimental data cited above are all based on adults, mostly males, and while valuable, should not be directly extrapolated to children. Children are kinetically different from adults, with a proportionally larger volume of blood and a much smaller but rapidly developing skeleton (especially dense cortical bone which retains most of the adult body burden of lead). Children also absorb lead from the environment at a greater rate, as they have greater gastrointestinal absorption of ingested lead and a more rapid ventilation rate than do adults. Blood lead concentrations change substantially during childhood (Rabinowitz et al., 1984a). These changes reflect the washout of in utero lead and the exposure of the child to changing patterns of food and water consumption, and changes in exposure to leaded soil and dust in his or her environment. Thus, an important consideration in determining an averaging time for the lead NAAQS is how quickly a child responds to changes in exposure.

As noted earlier, clinical studies with adult male volunteers showed that PbB changed to a new equilibrium level after 2 or 3 months of exposure, with a half-life of lead in blood of 18-28 days (Rabinowitz et al., 1973, 1976; Griffin et al., 1975). Few direct measurements have been made on the equilibration period for blood lead in children, although the higher metabolic rates in children would be expected to produce a more rapid turnover rate of red blood cells, along with lead, in their blood compared to adults (Chamberlain, et al., 1978) and would thus be more sensitive to changes in lead exposure. Limited, but informative, data on lead biokinetics in children are available:

(1) Ryu et al. (1983) measured lead balance in infants exposed to controlled concentrations of lead in formula and in milk. Blood lead and lead content of food were measured at 28-

day intervals. Blood lead levels in these infants appeared to equilibrate so fast that no estimate of the kinetic parameters was possible.

(2) A preliminary estimate by Duggan (1983), based on earlier input-output studies in infants (Ziegler et al., 1978) gave a PbB half-life (= mean life * log(2)) of 4 to 6 days. Duggan's method has many assumptions and uncertainties. An alternative method, allometric scaling based on surface area, suggests that if a 70 kg adult male has a blood lead mean life of 30 days, then a 7 kg infant should have a blood lead mean life of about 8 days.

(3) A biomathematical model has been developed by Harley and Kneip (1985) and modified for use by OAQPS (EPA, 1989a). This biokinetic model is based on controlled lead exposure studies on infant and juvenile baboons, believed to constitute a valid animal model for human growth and development. Data on human growth patterns were subsequently used to calibrate the model. Validation and application of the model is discussed in the staff exposure report (EPA, 1989a) and in Section IV.C. Annual changes of kinetic parameters such as the transfer rates for blood-to-bone, blood-to-liver, liver-to-gastrointestinal tract, and growth of blood, tissue, and skeleton are included. The model predicts a mean residence time for lead in blood of 2-year-old children as 8 days.

(4) A population of poor, urban children with pretreatment PbB concentrations greater than 50 µg/dl received chelation therapy and were than followed prospectively for the next 2 to 2 1/2 years (Chisolm et al., 1985). Following therapy, blood lead levels increased within one month to varying degrees, depending on the housing conditions the children returned to, and stabilized after three months. Individual records showed that PbB levels usually increased in 3 months by approximately 10 µg/dl in children who moved from lead-free or renovated housing to old housing with some lead-paint hazards and that PbB levels decreased in a similar fashion in those who moved in the opposite way. The authors conclude that such observations suggest that

PbB is "quite sensitive to changes in exposures to lead" (Chisolm et al., 1985).

(5) A more rapid equilibration rate for blood lead in children is indicated by regression analyses of NHANES II data in which individual children's PbB levels most closely correlated with the previous month's gasoline lead consumption compared to the current month and second previous month's gasoline lead use (the third previous month's gasoline lead coefficients were not significant) (Schwartz, 1985). A one month-lagged gasoline lead also best fit blood lead in regression analyses of New York and Chicago screening data (Schwartz, 1985) and of cord blood lead in Boston (Rabinowitz et al., 1984b). In addition, for the prevalence of children then reported (1976-1980) to have lead toxicity (PbB > 30 μg/dl) in CDC quarterly screening reports and in NHANES II, a greater portion of the variance was explained by one month-lagged gasoline lead, compared to concurrent or previous gasoline lead use (Schwartz 1985).

Based on the above data, it appears that increased lead exposure may produce increases in steady state PbB levels in children much sooner than the 60 days observed in adults, and that such changes may not reflect those occurring in the levels of toxicologically active, or mobile, lead throughout the body, particularly if exposure is in the form of intermittent pulses. Although it is difficult to specify a precise temporal pattern of lead exposure most critical in determining health risks, there is some cause for concern regarding the current 3-month averaging time. This concern is based on the following findings: 1) based on limited occupational and experimental studies, exposures < 2 weeks to high levels of lead result in significant changes in heme biosynthesis; effects on other physiological processes associated with similar short-term exposures, and effects of short-term exposures more typical of ambient conditions remain to be studied; 2) lead accumulates in the body and is only slowly removed, therefore repeated exposures to small amounts over many months may produce elevated PbB levels (CDC, 1985); 3) the

mean-life of lead in blood in adults is approximately 30 days and the toxicologically active fraction of blood lead appears to respond quickly to changes in exposure; 4) the rate of equilibration in children is expected to be much faster than in adults due to their overall higher metabolic rate. This would result in children being more responsive to short-term exposures; and 5) based on NHANES II and gasoline lead data, children's PbB, levels and the number of children with elevated lead levels, appear to respond to monthly variations in air lead emissions.

In summary, it appears that a monthly standard would be a more appropriate averaging time than the current quarterly standard, especially around point sources where emissions may vary significantly from day to day (see section II and section IV.B.). Not only would a monthly standard, when compared to a quarterly standard set at the same level, better capture significant excursions in lead exposure, it would also reduce average long-term air lead levels and deposition since controls would be necessary to meet the standard in months with increased emissions, and would thereby reduce the number of children with long-term elevated blood lead levels.

B. Form of the Standard and Sampling Frequency

1. Form of the Standard

Any ambient standard is defined not only by its averaging time and level, but by the characteristic way attainment of that standard is determined, i.e., its form. The method of judging attainment of the current lead NAAQS is deterministic--the maximum arithmetic mean average over a calendar quarter is not to exceed 1.5 $\mu g/m^3$. Although other NAAQS have adopted statistical forms to determine compliance, the staff recommends maintaining a deterministic form for the lead NAAQS due to the unique properties of lead contamination and exposure around point sources.

Several alternative forms of a revised NAAQS for lead have been examined, all of which emphasize peak monthly average

concentrations (Frank and Faoro, 1989). The analyses were conducted independent of a specific concentration level for the standard over a computed three calendar year attainment period. This procedure is consistent with the multi-year formats adopted for the ozone and particulate matter NAAQS. The forms considered are presented in Table 4.1. Associated with these forms are rules by which attainment is judged. For example, with the second highest monthly average form, at most one monthly value in a 3-year period would be permitted to exceed the stated level of the NAAQS.

In order to evaluate the statistical characteristics of each form, two types of analyses were conducted. First, a computer simulation was performed using generated daily lead concentrations over a three-year period. This permitted the examination of a wide range of possible data sets with identical, known characteristics. The second type of analysis involved the examination of actual lead data observed at point source-oriented sites. This provided additional perspective for currently monitored situations.

All of the comparisons were based on a design value, also referred to as the design concentration. This design value reflects the amount of air pollution control necessary to attain a standard. As used in this evaluation, as the design value increases, the stringency of the form being evaluated increases. The results were presented as relative values normalized to the expected maximum monthly average concentration (option 3). Using a reference indicator, the conclusions are independent of the concentration level selected for the standard.

Lead concentration distributions derived from actual point source-oriented monitoring sites were used as generating models for the simulation. Daily air quality data in the vicinity of an ASARCO refinery in Omaha and a lead oxide manufacturer in Philadelphia were used to estimate the underlying distributions.

TABLE 4-1. ALTERNATIVE STANDARD FORMS CONSIDERED AND THEIR RELATIVE STRINGENCY[a]

Alternative Forms	Computation Scheme	Average Design Value (ug/m^3)	Ratio to Reference
(1) Maximum monthly average	Choose maximum monthly average in a 3-year period	3.89	1.11
(2) Expected maximum calendar month	Compute average over 3 years for each calendar month (i.e., average all January's, all February's, etc.) to reflect the highest of these three averages	2.97	0.85
(3) Expected maximum month[b]	Choose maximum monthly average in each calendar year within the 3-year period; average these three values	3.51	1.0
(4) Expected highest 3 months	Compute average of the 3 highest monthly averages over 3 years	3.60	1.03
(5) 2nd highest monthly average	Choose the 2nd highest monthly average value from 3 years of data	3.54	1.01
(6) Maximum 2nd highest monthly average	Choose the 2nd highest monthly average per calendar year; choose the maximum of these three values. Note: standard could be violated each year of the 3-year period considered	3.09	0.88

[a]Based on multiple simulations of daily air quality over 3 years for a site near the Omaha lead refinery (see text).

[b]Reference Indicator

The simulation analyses based on 100 sets of 1080 values, each set representing 3 years of simulated lead data, were used to examine the relative stringency among the alternative forms and the potential effects of incomplete sampling (Frank & Faoro, 1989).

The first simulation analysis examined the relative stringency of each potential form of the standard in terms of average design values. The average design values produced for the alternative 3-year forms ranged from 2.97 to 3.89 $\mu g/m^3$, (see Table 4-1) with the maximum monthly average yielding the highest value (most stringent) and the expected maximum calendar month yielding the lowest value (least stringent). The maximum second highest monthly average per year produces a relatively low value of 3.09 $\mu g/m^3$. The other three alternatives yielded similar values which were each within 3% of the reference indicator. Among these three "middle" indicators, the simplest form is the second maximum month in three years. This standard allows a single exceedance of a monthly average lead level in a three year period.

In order to confirm the stringency findings from the first simulation analysis, actual lead data from point source monitoring sites which had violations of the present lead standard during the 1985-1987 time period were analyzed for comparisons among the six alternative forms of a revised lead NAAQS. Ten sites from 7 different states were used. These sites included the ASARCO refinery and the Philadelphia lead oxide manufacturer, along with other primary and secondary lead smelters. In order to compute the design value statistics from available data, two out of the three years had to be available. The empirical results from the 10 sites confirmed the relative stringency findings developed from the computer simulation. The average design values for these 10 lead sites ranged from 5.34 $\mu g/m^3$ for the maximum monthly average (Option 1) to 2.96 $\mu g/m^3$ for the expected maximum calendar month (Option 2). The

design value for the 2nd highest monthly average of 4.13 $\mu g/m^3$ (Option 5) was again only 1% greater than the expected maximum monthly average of 4.08 $\mu g/m^3$ (Option 3).

Among the alternative forms examined, the form based on the second highest monthly average in three years (Option 5) is recommended for a revised lead NAAQS. It is easy to comprehend, does not involve any complex statistical calculations, and produces design values comparable to the expected maximum monthly average. As stated previously, with the second highest monthly average form, at most one monthly value in a three year period would be permitted to exceed the stated level of the NAAQS. The exceedances could occur in adjacent months or in separate years. While this form is obviously less stringent than the form which does not permit any exceedances in a three year period (Option 1), it allows for explicit discounting of one "bad" month which may be caused, for example, by unusual meteorology. This approach is more stringent than the alternative maximum second highest month per year form (Option 6) in which one monthly exceedance is allowed each year. The staff therefore recommends that the standard be stated deterministically, in terms of a three-year period with no more than one monthly average exceedance.

2. Sampling Frequency and Monitoring Options

In reaching a decision on the standard, the averaging period, form, method of collection, and frequency with which ambient air lead samples are collected should be considered. Given the normal operation of the current one-in-six day lead sampling schedule, even with suggested 75% data capture, it is clear that 4-6 samples collected in the course of a month would not provide a statistically valid estimate of the actual air quality for the period (Thrall et al., 1984; Frank and Faoro, 1989). Consequently, in changing to a monthly average lead NAAQS, it would be necessary to increase the frequency of ambient air lead sampling, especially during periods and in areas of relatively high, variable air quality.

Because attainment is recommended to be based on peak monthly averages, (i.e., second highest monthly average in three years) the precision of the monthly average lead concentrations is critical. This is because, with imprecision, peak values selected from a set of data tend to be overestimated. One source of imprecision is measurement error. Another source is incomplete sampling. Although, averages of measurement concentrations have less measurement error than individual 24-hour samples, these errors still persist with small sample sizes. With one in six day (1/6) or even every other day (1/2) sampling (coupled with the inevitable missing samples), monthly averages would be based on few values. For example, there would be at most 5-6 values with 1/6 sampling. Consequently, such averages would be highly variable (imprecise), causing the potential for misleading monthly average concentrations. The peak values selected from these highly variable monthly averages could therefore yield overestimates of the true peak average concentrations.

Data from the ASARCO refinery based simulations, used to test the stringency of the alternative sample forms presented earlier, were also used to examine the effects of incomplete sampling on design values (Frank and Faoro, 1989). This analysis revealed a design value bias. Design values for each of the alternative forms considered increased with less than complete sampling. For example, evaluating option 1 (maximum monthly average), using every day sampling, produced a design concentration value of 3.89 $\mu g/m^3$. This same option evaluated with 1/2 and 1/6 sampling produced average design values of 4.64 $\mu g/m^3$ and 6.46 $\mu g/m^3$ respectively. This resultant bias could cause true attainment sites, which are close to the level of the standard and exhibit large variability in daily concentrations, to appear to be in nonattainment.

A striking example of the expression of this bias is seen in a simple evaluation of air lead data from the ASARCO refinery

presented in Table 4.2 below. The 1/6 day average for the month presented is 5.07 $\mu g/m^3$ a value based on 5 samples. However, the average of the 31 available daily values is 2.44 $\mu g/m^3$. Other months within this year demonstrated the same bias.

TABLE 4.2 DAILY AIR LEAD DATA FROM A LEAD REFINERY (MAY 1984)

DATE	AIR LEAD ($\mu g/m^3$)	DATE	AIR LEAD ($\mu g/m^3$)
1	1.22	21	6.45
2	0.21	22	0.46
3	0.19	23	5.82
4	1.03	24	8.44*
5	0.60	25	0.12
6	1.03*	26	0.58
7	0.24	27	0.07
8	0.21	28	0.05
9	0.70	29	0.24
10	1.25	30	8.24*
11	0.34	31	14.71
12	6.54*		
13	0.36		
14	0.35		
15	0.32		
16	6.99		
17	6.15		
18	1.11*		
19	0.58		
20	1.18		

*denotes the normal 1/6 day sample

Further simulation analyses using a variety of lead concentration distributions confirmed this bias and showed that large overestimates in design concentrations are possible with 1/6 sampling, and that moderate overestimates are still possible even with 1/2 sampling. It should be noted that this bias occurs in general, but not always.

Nevertheless, since attainment is judged on the highest monthly averages, it is imperative that these values be as precise as possible. Therefore, complete data sampling is

recommended in order to judge attainment/nonattainment for a revised monthly lead NAAQS when a site's maximum monthly readings approach the standard level. This is especially a concern around point sources which can have high daily variability in lead concentrations (see Figure 2-5). Analyses suggest that complete data sampling and highest data capture would only be needed when the design value is within a factor of 2 of the NAAQS level; this will maintain errors of attainment/nonattainment misclassification below 5 percent (Frank and Faoro, 1989). To maximize precision of the monthly average concentrations, general minimum data completeness criteria (e.g., 75 percent) would also be needed and should be explicitly stated in the NAAQS. Nevertheless, attainment or nonattainment could still be determined with less precise estimates for those cases in which the true peak averages were sufficiently far from the level of the NAAQS. At non-point source sites, such as roadside and non-industrial neighborhood sites where lead concentrations are below the current standard, incomplete sampling (i.e., 1/6) would be sufficient to show the long-term aggregate national trends.

The current reference method for the determination of lead in ambient air is based on the collection of suspended particulate matter on a glass fiber filter using a high-volume air sampler, and subsequent analysis of the collected sample for lead uses atomic absorption spectrometry. Samples are collected over 24-hour sample periods and analyzed, either individually or after compositing over a calendar month or quarter, to determine the average lead concentration for the calendar quarter. Several equivalent methods for lead have also been approved for use by state and local agencies under the provisions of FR Vol. 52 No. 126 July 1987; however, all use the high-volume sampler (hi-vol) for sample collection.

During the recent reviews of the air quality criteria for particulate matter and lead, attention was focused on the limitations of the high-volume sampler. Characterization of the

sampler by Wedding et al. (1977), McFarland and Rodes (1979) has demonstrated that the sampler flowrate and shelter geometry favor collection of particles up to 25-50 μm (aerodynamic diameter), depending on wind speed and direction. The sampling effectiveness for large particles is also substantially affected by wind speed and monitor inlet orientation.

The extent to which the hi-vol sampler will efficiently collect lead in ambient air may be estimated if the sampling characteristics of the sampling device and the size distribution of lead in the air are known. Available data characterizing the size distribution of lead in the atmosphere are somewhat limited and suspect due to inadequate sampling methodology. The large wind-generated lead particles, which are of most concern from a sampling viewpoint, and their contribution to the total size distribution of lead in the atmosphere have not been studied to any extent. Nevertheless, the hi-vol's ability to collect particles suspended in air can be reasonably estimated if some assumptions are made concerning the distribution of lead particles in the atmosphere.

Using the particle size distribution specified in the PM_{10} methodology requirements (FR Vol. 52 No. 126 July 1987), one can demonstrate that the hi-vol sampler should provide an "acceptable" measure of lead in ambient air. A hypothetical particle size distribution can be characterized by a fine mode mass median diameter of 0.5 μm, a coarse mode mass median diameter of 14 μm, fine and coarse mode geometric standard deviations of 2.0, a coarse to fine mass ratio of 3.0, and a total concentration of 300 $\mu g/m^3$. This distribution is believed to be an extreme case and somewhat representative of particle size distributions in the western states where frequent high winds and wind gusts are common. By assuming that lead is distributed everywhere in an identical fashion, the collection efficiency for lead can be estimated by integrating the product of the hi-vol's sampling effectiveness and the size distribution. In such an analysis (Purdue, 1988), of three wind speed scenarios, scenarios, the sampler was estimated to collect 85-90% of the total

mass of lead particles in the distribution. Even for a worst-case scenario, 80 percent collection was demonstrated.

The effectiveness of the hi-vol as compared with the PM_{10} sampler has been evaluated in the field. A study at the East Helena lead smelter used co-located PM_{10} and hi-vol samplers (Sternberg, 1988). Analysis of 22 sampling days showed the hi-vol captured, on average, twice as much lead (mass) than the PM_{10} sampler (Brion, 1988). The average percentage of lead of the total particulate weight for both samplers was comparable.

The reason for this observed phenomenon is clear. The PM_{10} sampler, by design, excludes particles larger than respirable size that the hi-vol collects. Given that exposure to lead occurs not only via direct inhalation, but via ingestion of deposited particles as well, especially among young children, the hi-vol provides a more complete measure of the total impact of ambient air lead.

Despite its shortcomings, the staff believes the high-volume sampler will provide a reasonable indicator for determination of compliance with a monthly lead standard. The measurement technology is in place, the monitor is relatively simple and inexpensive to operate, and it's continued use for compliance monitoring will result in historical continuity in the lead air quality data base.

C. Level of the Standard

This section presents a staff assessment of the degree of health protection that would be provided by alternative air lead scenarios and how this information may be used in decision-making on the level of the lead NAAQS. The presentation also outlines a qualitative assessment of the key factors that affect the margin of safety associated with alternative standards.

1. Evaluation of Alternative Lead NAAQS from Case-Study Results

a) Approach

As discussed earlier, blood lead (PbB) has been the common measure used in evaluating health risks associated with lead exposure. To assess the degree of protection provided by alternative lead NAAQS, the chosen approach is to predict distributions of PbB levels in sensitive populations living near lead point sources under different air lead scenarios. As discussed in Section III.E., it is difficult to specify a threshold PbB level below which there are no significant risks of any adverse effects; percentages of children with PbB levels above 10-15 µg/dl will be examined to evaluate alternative standards (see Section III.E).

Exposure results of 3 case-studies are presented below. Children with excessive exposures to paint lead hazards are excluded (see Section III.A). The methodologies used for the case-studies are fully described in the supplemental staff exposure report (EPA, 1989a).

For children, an uptake/biokinetic model is used; for adult men, a hybrid model of two other methodologies ("aggregate" and "disaggregate" models) that accounts for long-term resorption of bone lead is used. All of the exposure methodologies account for the fact that air lead contributes both directly (via inhalation) and indirectly (via ingestion of deposited particles onto soils, dusts, and crops) to total exposure, along with several other sources (e.g., solder in plumbing and food cans, historically-contaminated soils, old paint). Adjustment is made for recent and continuing downward trends in gasoline, canned foods, and drinking water. The aggregate and disaggregate models require an assumption that dust and soil lead concentrations are approximately in equilibrium with air lead levels, and that current air lead exposures reflect historical levels. These latter two approaches were also developed for young children.

risks. For example, approximately 60,000 children between the ages of 0 and 7 years live near major U.S. lead point sources. Therefore, even a 1% difference in the proportion of children above 10 μg/dl corresponds to about 600 children. Also, recognition of the limitations of any exposure modeling effort to fully and correctly simulate reality is important. The staff believes, however, that the uptake/biokinetic model does provide plausible and useful results for several reasons, including: a) The model's mathematical assumptions and numerical parameters combine plausible biological hypotheses with the full range of available and reliable animal experimental data, results of human experimental studies, and environmental lead data; b) Results of different validations of the model indicate good concordance between observed and predicted PbB levels in children living near lead point sources; and c) Of the 3 modeling approaches developed in EPA (1989a), it is not only the most flexible but the most conservative in terms of public health protection. To illustrate, using the midpoint estimates (for air and non-air exposures) of the 3 models, and a constant air lead exposure to 1.0 $\mu g/m^3$ results in a PbB level in a 2-year child in 1990 of: 10.9 μg/dl (uptake/biokinetic model); 8.7 μg/dl (aggregate model); 7.2 μg/dl (disaggregate model).

An effects threshold for increased blood pressure in men has not been defined; several studies have failed to find one while one longitudinal study suggests a threshold of 30 μg/dl (Section III.D.5). For analytical purposes of comparing alternative lead NAAQS, PbB levels of 10 and 12 μg/dl will be used to compare relative effects of alternative NAAQS on adult men. While the basis for a decision on the lead NAAQS should be on the most sensitive population (young children), the results in Table 4-4 indicate substantial reductions in PbB levels in men through attainment of the current NAAQS, and that the range of monthly lead NAAQS analyzed for children (0.5-1.5 $\mu g/m^3$) would be associated with corresponding improvements in adult men exposures compared to baseline conditions.

distributions are consistently lognormal and can be calculated using geometric standard deviations (GSDs) from point source and other population surveys. A range of GSD values (1.30-1.53) is derived from available data on children living near lead point sources (EPA 1989a); results calculated from the lower and upper bound GSD values are presented to reflect the uncertainty in this parameter. The midpoint value of 1.42 is considered to be a reasonable best estimate (EPA 1989a) and emphasis is placed on results using this GSD. A GSD value of 1.37 derived from the NHANES II survey is used for adults (EPA, 1989a).

As noted earlier, no attempt is made here to specifically assess exposures to lead in children with excessive "pica" behavior (i.e., abnormal tendency to repeatedly ingest non-food items) because of an absence of data that could quantify such highly variable intakes, or who are excessively exposed to lead in paint from deteriorating housing conditions. Such children cannot be effectively protected from the hazards of lead in their environment by a lead NAAQS (see Section III.A). Nevertheless, the data used for the exposure analyses implicitly include high exposure conditions.

The uptake/biokinetic model uses data on indoor and outdoor dust and soil lead concentrations measured in various locations where children were exposed. As best that can be determined from the studies, these data do not include measurements from in and around homes where peeling paint, holes in the walls, or other unsound conditions were reported. However, to the extent that the studies appeared to have sampled populations and dwellings representative of the study areas, a heterogeneous mix of homes including older homes with lead-based paint (but no overt hazards) are represented and appear suitable to represent average or "typical" lead exposures. [Data from homes with identified lead paint hazards are excluded from analysis; see Appendix A, EPA, 1989a]. In addition, where applicable, available data was used on the full range of "typical" rates of dirt ingestion

through inadvertent hand-to-mouth activity in children. Finally, the uptake/biokinetic model uses GSD values derived from blood lead distributions measured in a variety of childhood populations living near different lead point sources to capture the range of exposure variability to the fullest extent possible. Given these factors, the staff believes that the exposure analyses presented below reflect a wide range of biological, sociodemographic, and behavioral variability among children who live near point sources including, in part, those living in lead-painted homes (but without overt hazards such as chipping or flaking walls), and those who ingest higher than average amounts of soil and dust.

b) Case-Study Analyses

Populations living near a secondary smelter in Dallas, a secondary smelter and a battery recycling plant in Tampa, and a primary lead smelter in East Helena, Montana comprise the case-study groups. PbB levels in children living near the East Helena smelter were measured in 1983, along with lead in household dust, yard soil, drinking water, and ambient air. These data were used in a successful validation of the uptake/biokinetic model (Section VI, EPA, 1989a).

Air lead concentrations around the point sources were estimated by the Industrial Source Complex Model (ISC) that accounts for source sampling data on emissions, dry atmospheric deposition, background lead concentrations (i.e., mobile sources, re-entrained soil, local minor point sources), and site-specific meteorological data. Air lead levels generated by ISC were found to reliably predict average concentrations in the East Helena validation study. Modeled air quality was used to determine the geographic ranges for analysis; only those people living within an area that the source(s) impacted air lead by a concentration above 0.4 $\mu g/m^3$ were included (roughly 1-3 km radius depending on the source). Predicted air lead concentrations and populations were assigned by block group (or in the case of East Helena, enumeration district), as defined by census data. Soil and

household dust lead concentrations were estimated for the uptake/biokinetic model using relationships derived from available data collected near a wide range of point sources (Appendix B, EPA, 1989a). This approach allows estimation of effects, if any, of historical or possible future changes in air lead levels on soil and dust lead concentrations. Dietary lead intake estimates were derived from historical and current data and future projections of the Multiple Source Food Model, originally developed in the 1986 CD, and updated to include more recent information (Appendix A, EPA, 1989a).

Additional considerations related to the uptake/biokinetic modeling results presented in this section are:

(1) Several parameters in the model were assigned lower and upper bound values defined by the ranges of available data of comparable reliability and relevance. These parameters include time spent outdoors, volume of air respired, absorption efficiency of dietary lead in the gastrointestinal tract, soil and dust lead levels associated with different air lead concentrations, and the amount of dirt typically ingested by children (Appendix A; EPA, 1989a). Midpoint estimates of these parameters are considered best estimates and are incorporated into analyses presented here. Results using the full range of values are presented in Appendix B.

(2) As noted above, the midpoint GSD value of 1.42 is considered a best estimate for point source PbB distributions. Results based on lower and upper bound GSD values of 1.30 and 1.53 are also presented.

(3) Two alternative assumptions were made regarding the response of soil lead levels to future changes in air lead standards: a) that soil lead levels equilibrate to changing air lead levels within a few years. Under this assumption, a different soil lead level would exist for each air lead

concentration in the model between 1990 and 1996. Each soil lead level could be specified by the equilibrated air lead:soil lead relationships derived from mainly cross-sectional data summarized in Appendix B of the staff exposure report (EPA, 1989a) or; b) baseline soil lead levels in 1990, which are the result of long-term deposition, will remain constant for at least six years after a new standard is implemented. The staff, with concurrence from the CASAC Subcommittee that reviewed the lead NAAQS exposure analysis, believes that the latter assumption is more realistic and results presented here reflect a "fixed soil lead" scenario (with varying house dust lead levels). For a given standard, PbB levels are predicted higher under this scenario than under a variable soil lead scenario, although relative differences between standard alternatives are less using this approach.

Blood lead distributions are predicted for non-occupationally exposed middle-aged men assuming a blood lead:inhaled air lead slope of 1.8 $\mu g/dl$ per $\mu g/m^3$ (the weighted average derived from various clinical and epidemiology studies, incorporating a long-term bone resorption factor of 30%; EPA, 1989a, Section V.A), and an average background PbB contribution from non-air sources of 4.4 $\mu g/dl$ (for white men) and 5.3 $\mu g/m^3$ (for black men) (see EPA, 1989a, Appendix C).

c) Case-Study Results

Table 4-3 summarizes case-study results for children, born in 1990 and modeled up to their 7th birthdays, living within areas of significant impact (air lead >0.4 $\mu g/m^3$) near point sources in East Helena, Dallas, and Tampa under alternative lead NAAQS. Percentages above selected PbB levels within the estimated distributions are presented. Other points of the distribution can be calculated; for example, percentages of children above 25 $\mu g/dl$, the CDC definition of undue lead absorption for medical intervention. Because children with pica and with exposures to lead paint hazards are excluded from the

TABLE 4-3. ESTIMATED CHILDREN'S (0-6 YRS.) PbB LEVELS UNDER ALTERNATIVE LEAD NAAQS IN 3 CASE STUDY ANALYSES: 1990-1996*

Case Study (# Children) / PbB Level[a]	Baseline[b]	Lead NAAQS Level ($\mu g/m^3$) 1.5 Quarterly[c]	Monthly[d] 1.5	1.25	1.0	0.75	0.5
Dallas (241)							
Mean PbB ($\mu g/dl$)	6.9	4.9	4.8	4.8	4.7	4.6	4.5
% > 10 $\mu g/dl$	14.2	2.2	1.9	1.7	1.5	1.4	1.2
% > 15 $\mu g/dl$	1.3	0.08	0.06	0.05	0.04	0.04	0.03
East Helena (217)							
Mean PbB ($\mu g/dl$)	6.2	5.2	5.1	4.9	4.8	4.6	4.4
% > 10 $\mu g/dl$	8.3	2.9	2.6	2.1	1.7	1.4	1.0
% > 15 $\mu g/dl$	0.6	0.1	0.1	0.07	0.05	0.04	0.02
Tampa (10)							
Mean PbB ($\mu g/dl$)	10.1	8.3	7.8	7.4	7.0	6.6	6.3
% > 10 $\mu g/dl$	50.9	29.7	23.4	19.4	15.6	12.1	9.2
% > 15 $\mu g/dl$	12.9	4.6	3.0	2.2	1.5	1.0	0.6

* Assumes soil Pb remains at baseline levels (see text)

[a] PbB distributions calculated assuming GSD = 1.42

[b] Baseline scenario represents current conditions for air quality, as well as soil and dust Pb. Dietary intake assumed to be at 1990-1996 levels

[c] Current NAAQS level and averaging time (calendar quarter)

[d] Alternative NAAQS levels with monthly averaging time

analysis, very few, and in most cases no children, were estimated to have such high levels.

The results for Tampa should not be extrapolated since the secondary smelter and battery plant modeled there were surrounded by mainly non-residential areas. According to the overlay of air dispersion estimates onto block group census data, only 10 children and 20 men live close enough to those point sources to be significantly affected by changes in emissions. Further analyses are necessary to determine whether these results for Tampa are applicable to other point source areas with small populations living nearby.

The results indicate that significant reductions in exposure in all 3 case-study areas could be achieved through attainment of the current NAAQS. Progressive but smaller improvements are indicated for alternative monthly standards, beginning with the current level down to 0.5 $\mu g/m^3$.

The level of protection that should be provided by a lead NAAQS is difficult to specify. The current standard was set in 1978 so that 99.5% of all children (including those with pica) would have PbB levels below 30 µg/dl, which at that time was CDC's definition of lead toxicity for screening programs, and which was considered to provide an adequate margin of safety from clearly adverse effects (e.g., anemia). Since then, a PbB of 15 µg/dl has been associated with risks of several health effects in children, including newborns (see Section III.D), and may provide a small margin of safety from adverse effects. According to the analyses using the best estimate GSD value, a monthly NAAQS between 0.5 and 1.5 $\mu g/m^3$ would keep more than 99.9% of the non-pica children, living without lead-paint hazards near the Dallas and E. Helena smelters, below a PbB of 15 µg/dl.

A NAAQS at 0.5 $\mu g/m^3$, according to the best estimate Dallas and E. Helena case-studies, would protect 99.97% of affected

children from 15 μg/dl PbB and keep 98.8 - 99.0% below 10 μg/dl PbB. A PbB of 10 μg/dl obviously provides a relatively greater margin of safety than 15 μg/dl, although it cannot be considered devoid of any risks of some health effect, however uncertain in terms of functional or "clinical" significance (see Section III.D). No NAAQS can adequately protect all children, even non-pica children living without lead paint hazards, from PbB levels above 10 μg/dl. EPA's exposure analysis estimated that by 1990, non-air contributions to children's total lead exposure (excluding excessive paint lead) would result in a range of PbBs from 4.2 to 5.2. The lower bound was used in their analyses (EPA, 1990). Assuming a GSD of 1.42, this mean increment attributable to non-air lead sources alone would be associated with 0.7% of children above 10 μg/dl, (and 0.02% above 15 μg/dl). Reducing the NAAQS would reduce the estimated proportion of children with PbB levels above 10 μg/dl. For the East Helena and Dallas case studies, an estimated 8.3-14.2% of children currently exceed 10 μg/dl, whereas a monthly NAAQS of 1.5 $\mu g/m^3$ would reduce this fraction to 1.9-2.6%, and a monthly NAAQS of 0.5 $\mu g/m^3$ would reduce it to 1.0-1.2%. Given that a lead NAAQS of 0.5 $\mu g/m^3$ would appear to minimize the number of additional children with PbB levels over 10 μg/dl compared to a "zero air lead" scenario (an additional 0.3-0.5%), and would keep more than 99.97% below 15 μg/dl, it can be considered as a reasonable lower bound for a revised lead NAAQS.

According to the best estimate analyses using a GSD of 1.42, intermediate NAAQS levels (0.75, 1.0, 1.25 $\mu g/m^3$) would be associated with an additional 0.7-1.4% of children above 10 μg/dl over what would be expected with zero air lead emissions, and a total of 99.95-99.96% below 15 μg/dl (0.063-0.066% increase over "zero air lead" scenario).

Interpretation of the above results must consider that although the differences among standard alternatives appear small, they are in fact, significant in terms of population

risks. For example, approximately 60,000 children between the ages of 0 and 7 years live near major U.S. lead point sources. Therefore, even a 1% difference in the proportion of children above 10 μg/dl corresponds to about 600 children. Also, recognition of the limitations of any exposure modeling effort to fully and correctly simulate reality is important. The staff believes, however, that the uptake/biokinetic model does provide plausible and useful results for several reasons, including: a) The model's mathematical assumptions and numerical parameters combine plausible biological hypotheses with the full range of available and reliable animal experimental data, results of human experimental studies, and environmental lead data; b) Results of different validations of the model indicate good concordance between observed and predicted PbB levels in children living near lead point sources; and c) Of the 3 modeling approaches developed in EPA (1989a), it is not only the most flexible but the most conservative in terms of public health protection. To illustrate, using the midpoint estimates (for air and non-air exposures) of the 3 models, and a constant air lead exposure to 1.0 $\mu g/m^3$ results in a PbB level in a 2-year child in 1990 of: 10.9 μg/dl (uptake/biokinetic model); 8.7 μg/dl (aggregate model); 7.2 μg/dl (disaggregate model).

An effects threshold for increased blood pressure in men has not been defined; several studies have failed to find one while one longitudinal study suggests a threshold of 30 μg/dl (Section III.D.5). For analytical purposes of comparing alternative lead NAAQS, PbB levels of 10 and 12 μg/dl will be used to compare relative effects of alternative NAAQS on adult men. While the basis for a decision on the lead NAAQS should be on the most sensitive population (young children), the results in Table 4-4 indicate substantial reductions in PbB levels in men through attainment of the current NAAQS, and that the range of monthly lead NAAQS analyzed for children (0.5-1.5 $\mu g/m^3$) would be associated with corresponding improvements in adult men exposures compared to baseline conditions.

TABLE 4-4. ESTIMATED MEN'S (40-59 YRS.) PbB LEVELS UNDER ALTERNATIVE LEAD NAAQS IN 3 CASE STUDY ANALYSES*

Case Study (# Men) / PbB Level[a]	Baseline[b]	Lead NAAQS Level ($\mu g/m^3$) 1.5 Quarterly[c]	1.5 Monthly[d]	1.25 Monthly[d]	1.0 Monthly[d]	0.75 Monthly[d]	0.5 Monthly[d]
Dallas (131)							
Mean PbB (µg/dl)	6.3	5.5	5.4	5.3	5.2	5.1	5.0
% > 10 µg/dl	7.2	2.8	2.5	2.1	1.9	1.5	1.4
% > 12 µg/dl	2.1	0.7	0.5	0.4	0.4	0.3	0.3
East Helena (173)							
Mean PbB (µg/dl)	6.9	5.8	5.7	5.6	5.5	5.4	5.3
% > 10 µg/dl	12.1	4.2	3.5	3.3	2.8	2.5	2.1
% > 12 µg/dl	4.0	1.0	0.9	0.7	0.7	0.5	0.4
Tampa (17)							
Mean PbB (µg/dl)	6.6	5.8	5.6	5.4	5.2	5.1	4.8
% > 10 µg/dl	9.2	4.2	3.3	2.3	1.9	1.5	1.0
% > 12 µg/dl	2.8	1.0	0.7	0.5	0.4	0.3	0.2

* Weighted averages of white and non-white men.
[a] PbB distributions calculated by assuming GSD = 1.37
[b] Baseline scenario represents current air quality; non-air contributions assumed to be at 1996 levels
[c] Current NAAQS level and averaging time (calendar quarter)
[d] Alternative NAAQS levels with monthly averaging time

According to the case-study analyses, a monthly NAAQS between 0.5 and 1.5 $\mu g/m^3$ would result in between 1.4 - 3.5% of non-occupationally exposed middle-aged men with PbB levels above 10 $\mu g/dl$ (compared to 7.2 - 12.1% at current baseline air and 1990 non-air exposures); percentages above 12 $\mu g/dl$ would be 0.3-0.9%.

As seen for children, even with zero air lead emissions, average PbB in adult men is expected to be about 4.5 $\mu g/dl$ in 1990; with 0.6% above 10 $\mu g/dl$ and 0.1% above 12 $\mu g/dl$. In other words, a NAAQS of 0.5 $\mu g/m^3$ would increase the number of men in these analyses above 10 $\mu g/dl$ by only 0.4-0.5%; a 1.5 $\mu g/m^3$ NAAQS would increase this fraction by 1.9-2.9%.

No estimates are derived for pregnant women. Although the fetus is highly sensitive to lead, direct and indirect contributions from atmospheric lead via the mother is limited compared to young children. The staff recommends that the analytic focus remain on young children as the most "sensitive" in terms of the present standard review. As discussed in the staff exposure report, approximately 95% of adult body lead burden is sequestered in bone. Fetal exposures in most cases can therefore be expected to be dominated by maternal bone lead stores from past, higher-level exposures compared to current ones (EPA, 1989a). Given this and the fact that children are exposed to, absorb, and retain proportionally more lead from the environment than women, it can be concluded that a lead NAAQS will influence children's exposures more than fetal exposures.

As discussed earlier, the effects of mobilization of skeletal lead sequestered from past exposures, during pregnancy, on transplacental transfer of lead to the fetus cannot be quantified at this time. It is possible, however, to gain some insight into what might be expected in the future under alternative standards. The available data indicate that any PbB: air slope used for adult women would be similar to that used for

adult men. Furthermore, the non-air background contributions to PbB are estimated to be lower in adult women compared to men (EPA, 1989a; Section V.A. and Appendix C).

Given this, the case study results for adult men would be expected to be reasonable upper bound surrogates for those that would be derived for adult women. This suggests that the small improvements in PbB levels between future lead NAAQS in the range of 0.5-1.5 $\mu g/m^3$ estimated for adult men could also be expected for adult women. Thus, it can be anticipated that in the future, changes in atmospheric lead will have a relatively small impact on maternal bone lead stores, and consequently on fetal exposures. In contrast, young children are much more responsive, indirectly and directly, to changes in atmospheric lead emissions and provide the most sensitive indications of the relative protection afforded by alternative NAAQS.

While the fetus may not be the most responsive or "sensitive" subgroup of the population in assessing the future impacts of alternative lead NAAQS, the fact remains that there are now approximately 140,000 women of childbearing age living near major lead point sources whose offspring may be at risk from past lead exposures. A conservative approach to the decision on the lead NAAQS would benefit the future generation born to women who are children today.

2. Factors to Consider in Evaluating Margin of Safety for the Lead NAAQS

a) The Significance and Persistence of Observed or Anticipated Health Effects

Little controversy exists that high-level lead exposures are associated with adverse health effects. There is substantial concern regarding several health effects associated with low-level lead exposure as well:

(1) The significance of alterations in the heme synthetic pathway may be questioned given the physiological reserve capacity of ALA-D activity, for example, and that effects on EP elevation are reversible. Given that disturbances in heme formation can extend throughout multiple organ systems and physiological functions (e.g., neurotransmission, vitamin D metabolism), however, even low-level disturbances have potentially long-term effects;

(2) The relatively small effect on children's IQ attributable to lead at low-moderate exposures, compared to other socio-hereditary influences, (≈ 4 IQ point deficit at 30-50 μg/dl; 1-2 points at 15-30 μg/dl) indicates nevertheless, potentially large population impacts. For example, Needleman et al. (1982) calculated that a 4 point decrement in the mean IQ of a normal population distribution would be associated with a three-fold increase in the number of children with severe deficits (IQ < 80), along with a 5% reduction in the number of children who attain superior function (IQ > 125). Although there is some evidence that low-level lead (<30 μg/dl) effects on IQ may be reversible (Hawk et al., 1986), follow-up investigation of a subset of the children initially evaluated by Needleman et al. indicated that grade retention was significantly associated with past lead exposure (Bellinger et al., 1984);

(3) The small but significant impacts of lead on auditory function may have long-lasting consequences in some children by interacting with lead-induced effects on, or resulting in, delays or deficits in language acquisition and processing, attention, and learning;

(4) Definitive conclusions about the persistence and ultimate impact of low-level effects on infant mental and physical development, due to prenatal and neonatal exposures, must await further results of ongoing longitudinal studies. Some data suggest that children with early neurobehavioral deficits

are able to catch up later on in childhood (Dietrich et al., 1989b), and that natural over-production of neural cells pre-and post-natally may compensate for structural perturbations. However, as stated in the ATSDR (1988; page IV-23) report, "research in developmental and physiological psychology has shown that the actualization of behavioral capabilities requires appropriate periods of functional neural activity for proper development. Thus, even transient, or in themselves, reversible deficits during early development may have potentially serious and long-lasting sequelae. Given the complex interactions that figure into the psychosocial development of children, attempts to compensate for lead-induced deficits in one area of a child's development may affect other areas of development";

(5) Linkages have been drawn from animal experiments between the persistence of lead-induced effects on neurobehavior and neurological biochemistry and morphology, and the accumulation and retention of lead in the brain. This illustrates that, even if effects appear to be reversible, as long as absorbed lead remains in soft tissues or is available from long-term storage, continuing risk of lead toxicity remains.

b) Persistence of Lead in the Environment

Atmospheric lead deposits on soils, crops, and street and playground surfaces. Soil lead, which serves as a continuous source of outdoor and indoor (household) dusts as well as a direct exposure route for young children, is relatively insoluble and immobile and can continue to accumulate indefinitely. The persistence of lead in soil, and its movement into accessible dusts has been taken into account in the uptake/biokinetic model. Nevertheless, the long-term presence of atmospheric lead in the environment, once deposited, beyond the time-frame addressed in the exposure analyses, should be considered in evaluating the margin of safety of alternative NAAQS.

c) Sensitivity of Exposure Results

The full range of available and reliable data were used to estimate PbB distributions of populations exposed under alternative lead NAAQS. Wherever possible, best estimates were derived from the data to use for various input parameters. Where lower and upper bound parameter values could not be distinguished in terms of reliability or relevance, midpoint estimates were chosen. As with any modeling exercise, the results are sensitive to the required assumptions. Appendix B presents results of the analyses on children with either all upper bound assumptions or all lower bound assumptions. The upper bound results indicate much higher percentages of children above PbB cutoffs (e.g., 10 and 15 μg/dl) for a given standard. While the case-study results presented in this section should not be considered as precise and absolute predictions, the staff believes they adequately represent the relative impacts associated with alternative lead NAAQS. Further refinements can be made as additional data become available.

d) Groups Not Evaluated

Young children have the highest rates of lead exposure and absorption and any lead standard derived to protect them should also protect other sensitive groups evaluated quantitatively (adult men) or qualitatively (pregnant women/fetus). The analyses summarized in this section omit young children who cannot be substantially affected by any changes in atmospheric lead emissions under different standards. These children (e.g., those with pica and/or living in deteriorated lead-paint homes) total several million and require direct parental and public health intervention to reduce their high-level exposures (see Section III.A). Nevertheless, any reduction in air lead levels can be expected to have at least a small beneficial effect on these children and should be considered in establishing the lead NAAQS. Similarly, adult women whose blood pressure is affected by ongoing lead exposure, and women experiencing bone

demineralization during osteoporosis (as well as during pregnancy) and increased lead mobilization, will also benefit, however slightly, from any reduction in ambient air lead levels.

D. Summary of Staff Conclusions and Recommendations

The major staff conclusions and recommendations made in Sections IV.A-C are briefly summarized below:

1) A monthly averaging period would better capture short-term increases in lead exposure and would more fully protect children's health than the current quarterly average.

2) The most appropriate form of the standard appears to be based on the second highest monthly average. This form would be nearly as stringent as a form that does not permit any exceedances and allows for discounting of one "bad" month in 3 years which may be caused, for example, by unusual meteorology.

3) With a revision to a monthly averaging time, complete data is needed, except in areas, like roadways remote from lead point sources, where the standard is not expected to be violated. In those situations, the current 1-in-6 day sampling schedule would sufficiently reflect air quality and trends.

4) Because exposure to atmospheric lead particles occurs not only via direct inhalation, but ingestion of deposited particles as well, especially among young children, the hi-volume sampler provides a reasonable indicator for determination of compliance with a monthly lead standard and should be retained as the instrument to monitor compliance with the lead NAAQS.

5) Because young children are exposed to, absorb, and retain proportionally more environmental lead than other populations, they are most responsive to changes in atmospheric lead emissions and provide the most sensitive indications of relative protection afforded by alternative NAAQS. Case-study analyses of children populations living near Dallas and East Helena smelters indicate that substantial reductions in lead exposure could be achieved through attainment of the current lead NAAQS. Progressively smaller improvements are estimated for the alternative monthly lead NAAQS levels evaluated, ranging from 1.5 $\mu g/m^3$ to 0.5 $\mu g/m^3$.

A PbB concentration in the range of 10-15 µg/dl is considered the level of concern for infants and children, and is used to compare the relative protection provided by alternative standards. According to the best estimate analyses, over 99.9% of children living in areas significantly affected by the smelters would have PbB levels below 15 µg/dl. The staff believes that evaluation of alternative standards based on children's PbB levels above 10 µg/dl is more appropriate given the health risks associated with lead. Reducing the NAAQS levels would reduce the estimated proportion of children with PbB levels above 10 µg/dl. For the Dallas and East Helena case studies, an estimated 8.3-14.2% of children currently exceed 10 µg/dl, whereas a monthly lead NAAQS of 1.5 $\mu g/m^3$ would reduce this fraction to 1.9-2.6%, and a monthly NAAQS of 0.5 $\mu g/m^3$ would reduce it to 1.0-1.2%. Because of unavoidable background exposures to lead in the diet, historically-contaminated soils and dusts, and maternal bone lead stores <u>in utero</u>, no standard can keep all children below a PbB of 10 µg/dl. It is estimated that even at zero air lead emissions, 0.7% of children would have PbB levels above 10 µg/dl. For example, Dallas and East Helena results indicate that a monthly lead NAAQS of 1.5 $\mu g/m^3$ would result in an additional 1.2-1.9% of children with PbB levels above 10 µg/dl over what would be expected with zero air lead emissions. A NAAQS of 0.5 $\mu g/m^3$ would appear to minimize the

number of additional children with PbB levels above 10 μg/dl compared to a zero air lead scenario and appears to be a reasonable lower bound for consideration of a revised lead standard. Intermediate increments are indicated for lead NAAQS levels of 0.75, 1.0 and 1.25 $\mu g/m^3$.

6) While the basis for a decision on the lead standard should be the most sensitive population, i.e., young children, the case-study results on adult men indicated small PbB reductions with progressively lower monthly lead NAAQS levels evaluated, beginning with 1.5 $\mu g/m^3$ down to 0.5 $\mu g/m^3$. A PbB threshold for blood pressure effects in men has not been defined. Two PbB levels, 10 and 12 μg/dl, are selected to compare the relative protectiveness of alternative lead NAAQS. The results indicate that a monthly NAAQS between 0.5 and 1.5 $\mu g/m^3$ would result in between 1.0 - 3.5% of non-occupationally exposed men with PbB levels above 10 μg/dl, compared to 7.2-12.1% at current baseline exposures and 0.6% above 10 μg/dl simply because of non-air background exposure. The percentages above 12 μg/dl for this range of standards are estimated to be 0.3-0.9%, compared to 0.1% due to background exposures.

7) Fetal exposures are not evaluated quantitatively in the case-study exposure analyses. While young children are the most responsive population in terms of the lead NAAQS, and represent the appropriate group to focus on in the exposure analyses, the sensitivity of the developing nervous system in the fetus, and uncertainties regarding other possible fetal effects, require consideration in determining the appropriate margin of safety that should be provided by a lead NAAQS.

8) Other factors that should be considered in evaluating the margin of safety are the significance and persistence of observed or potential health effects, the persistence of lead in the body and in accessible environmental reservoirs (i.e., soil),

the sensitivity of the exposure analyses to alternative assumptions, the potential carcinogenicity of lead, and groups beside the fetus that have not been evaluated quantitatively because any lead NAAQS, no matter how stringent, could not remedy their excessive background exposures (e.g., children with pica or living with lead-paint hazards), or because there are insufficient data to quantify their risks at this time (e.g., post-menopausal women).

V. CRITICAL ELEMENTS IN THE REVIEW OF THE SECONDARY STANDARD

This section includes a discussion of information drawn from the criteria document that appears most relevant to the review and possible revision of the current secondary NAAQS for lead. It focuses on field and laboratory studies that have identified potential effects of lead in terrestrial and aquatic ecosystems.

A. Effects in Terrestrial Ecosystems

Anthropogenic emissions of lead deposit on terrestrial ecosystems via wet and dry deposition. After initial deposition on vegetation and other surfaces, the migration and distribution of lead in the soil reservoir depends on a number of environmental factors including precipitation, surface adsorption, and ion exchange reactions (Zimdahl and Skogerboe, 1977; Miller & McFee, 1983; Camerlynck & Kiekens, 1982). Once in the soil reservoir, lead is relatively insoluble and immobile (NAS, 1980; Nriagu, 1978) and is not readily removed by such mechanisms as leaching and stream run-off (EPA 1986a, pp. 6-29, 8-8). As a result, lead accumulates in the soil reservoir even when the deposition rate is relatively low.

When examining the potential impact of lead on terrestrial ecosystems, a distinction must be made between total soil lead content and the available or potentially available fractions. The fraction of soil lead that may be biologically available includes the potentially available lead (exchangeable forms determined by chemical extraction) and the actually available water soluble forms (lead in soil moisture) (EPA, 1986a, p. 6-29). The generally low solubility of lead and the apparently small percentage (1-12%) of total soil lead that is exchangeable (Camerlynck and Kiekens, 1982; Miller and McFee, 1983; Hughes, 1981; Atkins et al., 1982) suggest that the bioavailability of lead for plants is quite limited. The potential effect of acid precipitation to increase the relative mobility of lead in soil

(Tyler, 1978; Hutchinson, 1980) is of clear concern as a mechanism that may increase the bioavailability of this heavy metal.

Given the varying capacity of different soil types to immobilize lead under different environmental conditions (Zimdahl and Skogerboe, 1977), and the limited usefulness of chemical extraction studies to provide reliable estimates of exchangeable soil lead fractions, it is difficult to determine the percentage of total soil lead that is biologically available (actual or potential).

The major concern regarding deposition of atmospheric lead onto plant surfaces is its eventual entry into the human food chain. Effects on plants may also occur directly through foliar uptake or indirectly via root uptake from the nutrient medium (soil moisture) (Facchetti and Geiss, 1982; Lindberg and Harriss, 1981). Although 90% or more of lead taken up via the roots may remain tightly bound in the roots (Koeppe, 1981), field and laboratory studies provide evidence that some lead is translocated to physiologically active tissues in vascular plants (CD, pp. 8-18 to 8-19). While the relative significance of foliar uptake has not been clearly determined, it is potentially high since surface deposition of lead is estimated to account for 90% of total plant lead (CD, p. 8-42). Elevated lead burdens in plants near smelters and along roadsides, for example, have been attributed primarily to surface deposition (Getz et al., 1977; Nriagu, 1978; Smith, 1976).

Experimental data on lead-induced effects in plants indicate that: (1) at relatively low concentrations, ranging from 2-10 μg Pb/g hydroponic solution, inhibition of photosynthesis, alteration in enzyme activity, and reduction in growth can occur. Factors such as length of treatment (exposure), chemical form of lead, level of nutrients in solution, and age and species of plant can influence the experimental results (Koeppe, 1981;

Paivoke, 1979); (2) high concentrations of total soil lead are necessary before physiological effects in plants are observed. For example, Khan and Frankland (1983) report significant growth reduction in radish plants with exposure to 1000 µg Pb/g soil and complete growth inhibition at 5000 µg Pb/g soil; and (3) lead tolerant plant communities appear near roadsides and stationary source emissions (Antonovics et al., 1971; Atkins et al., 1982). Potential changes in species composition in these areas have implications for the long-term effect of lead on ecosystem function and stability. Atkins et al. (1982) suggest that selection pressure due to even low total soil lead concentrations (112 µg Pb/g soil), resulted in the evolution of lead tolerance in a roadside grass.

Available data suggest that the impact of lead in terrestrial ecosystems may be evident first in the components of the soil and litter microcosm (e.g., fungi and bacteria) that play a critical role in the decomposition of organic matter and in nutrient cycling (Tyler, 1972; Doelman and Haanstra, 1979a; Babich and Stotgky, 1979). In the presence of lead (1500 µg Pb/g soil), the composition of microbe communities may shift to more lead-tolerant populations (Doelman and Haanstra, 1979b) and, at soil lead concentrations found near roadways and stationary sources (750-2000 µg Pb/g soil), soil microbial activity may be sufficiently reduced to inhibit the decomposition and nitrification processes (Smith, 1981; Doelman and Haanstra, 1979a; Liang and Tabatabai, 1978). However, Crist et al. (1985) reported no inhibition during the early stages of leaf-litter decomposition for the range of lead concentrations evaluated, i.e., 0 to 1000 µg Pb/g leaf added as lead sulfate. Subtle changes in ecosystem structure and function have been attributed to lead contamination. Friedland et al. (1984) suggest that the increase in percent organic matter in a New England forest may have resulted from the accumulation of lead and other trace metals that inhibited decomposition. In other more heavily contaminated areas, reduced abundance and altered composition of

microflora populations have been observed accompanied by accumulation of litter and alterations in soil parameters (Jackson and Watson, 1977; Bisessar, 1982; Williams et al., 1977c).

Although these field observations suggest inhibitory effects of lead on microbial activity in certain heavily contaminated areas, quantitative assessment is limited by the lack of adequate controls for confounding effects of other stationary source emissions (including other metals) and of environmental influences (e.g., temperature, moisture). Further, the long-term significance of lead-induced changes in soil microbial populations is unclear and depends on whether the ecosystem has the ability to compensate for such perturbations. Nevertheless, the critical role of soil microbes in terrestrial ecosystem processes (decomposition and nutrient cycling) indicates the need for additional research to more clearly define the potentially serious effects of lead on microbial activity.

Decreased soil invertebrate abundance has also been observed in lead-contaminated soils (Watson et al., 1976; Williams et al., 1977c; Bisessar, 1982).

Very few field studies reporting lead exposures, body burdens and associated effects in wildlife are available. With the exception of cattle and waterfowl, incidence rates of lead poisoning in terrestrial fauna are generally unavailable (Forbes and Sanderson, 1978; Botts, 1977) and difficult to verify. Sources of these exposures have typically included lead wastes, paint and spent lead shot (unrelated to airborne lead emissions), and contaminated forage near lead smelters (NAS, 1980; Forbes and Sanderson, 1978).

Lead burdens in animals are elevated relative to natural background levels (EPA, 1986a, pp. 8-33, 8-34), and have been correlated with proximity to roadways and lead point sources

(e.g., mining sites, smelters) (Williamson and Evans, 1972; Quarles et al., 1974; NAS, 1980; Clark, 1979; Beresford et al., 1981; Kisseberth et al., 1984).

When assessing the effects of lead on domestic animals and wildlife, it is important to consider the more subtle effects that are not readily discernible in field observational studies, but found on laboratory experiments such as alterations in neurobehavior and reproduction and development. Because of species differences in susceptibility (Forbes and Sanderson, 1978) and a lack of sufficient quantitative exposure/uptake/response data in natural habitats, results from controlled animal studies have not been extrapolated to animals in natural environments. Nevertheless, the available data indicate that domestic animals and wildlife are at least as sensitive to lead as those studied in laboratories.

B. Effects in Aquatic Ecosystems

Although lead is readily complexed in natural water systems (EPA, 1986a, p. 6-34), concentrations exceeding 100 µg Pb/l (lead in solution) have been reported for surface waters receiving urban runoff and sewage and industrial effluents (NAS, 1980). Freshwater ecosystems function as potential sinks for lead loading (McNurney et al., 1977; Getz et al., 1977), with the sediment as the primary collection site (Rickard and Nriagu, 1978). As a result, the soluble fraction comprises only a small percentage of the total lead burden (Rickard and Nriagu, 1978; Wershaw, 1976). The solubility and sedimentation of lead depends on a number of physical, chemical and biological factors (EPA, 1986a, p. 8-14), and the retention of lead within the sediment is influenced by the substrate type (McNurney et al., 1977; Wershaw, 1976; Newman and McIntosh, 1982). Over the past century, a trend of increasing deposition of lead in the sediments of freshwater systems has been observed (EPA, 1986a, p. 5-1, Figure 5-1), with elevated lead concentrations observed in sediments draining urban areas relative to rural areas (McNurney et al., 1977; Getz et al.,

1977). Some reversal of this trend has been observed in river and ocean sediments in and around the U.S., likely a result of recent, significant reductions in atmospheric lead emissions (Alexander and Smith, 1988; Rabinowitz, 1989). For example, Trefry et al. (1985) reported a 40% decrease in lead transport by the Mississippi River in the decade since the regulation of lead additives in gasoline.

Lead in the sediment can become a source of soluble lead even after the discontinuation of lead inputs (Wershaw, 1976). Increased availability of waterborne lead to aquatic biota is most pronounced in water bodies in which complexed lead in the sediment remains at the water-sediment interface (Getz et al., 1977).

Water lead concentrations as low as 19-30 µg/L have been associated with increased mortality and impaired reproduction) in aquatic invertebrates (Borgmann et al., 1978; Biesinger and Christensen, 1972). Vertebrates (fish) appear even more sensitive. Hematological and neurological changes have been observed in fish exposed under laboratory conditions to concentrations between 8-12 µg Pb/l. The neurological effects include black tails, an early indicator of spinal deformity, and spinal curvature, which increases mortality and prevents successful reproduction (Hodson et al., 1978a,b). Effects observed at these lower levels may have been enhanced by the relatively soft water conditions used in the experiments (Hodson, 1979). In 1985, the U.S. EPA Office of Water Regulations and Standards published new ambient water quality criteria for lead to protect aquatic life. These criteria concentrations are expressed as a function of water hardness and indicate the need to consider the influence of this chemical water quality parameter on the bioavailability and toxicity of lead. For example, at hardnesses of 50, 100, and 200 mg/l as $CaCO_3$ the 4-day average criteria concentrations of lead for freshwater systems are 1.3, 3.2, and 7.7 µg/l, respectively, and the one-

hour average concentrations are 34, 83, and 200 µg/l (50 FR 30791).

C. Staff Conclusions and Recommendations

The available laboratory and field data indicate that at high concentrations, lead can: 1) affect certain plants (e.g., inhibition of photosynthesis, reduced growth, changes in species composition), and fish (e.g., neurological changes); and 2) alter the composition of soil microbial communities and inhibit invertebrate activity resulting in delayed decomposition, reduced nutrient supply, and altered soil properties (e.g., lower organic content). A qualitative assessment of the available field studies and animal toxicological data suggests that domestic animals and wildlife are as susceptible to the effects of lead as laboratory animals used to investigate human lead toxicity risks.

The available data also raise concerns about the continued accumulation of lead in soil and sediment reservoirs. Due to the persistence of lead in the environment, such accumulations are expected to continue as long as inputs exceed outputs. Thus, even at relatively low deposition rates, lead could affect the ecosystem over time. This concern is primarily directed to urban and stationary source areas that may already be approaching or have exceeded their soil capacity to bind lead.

In summary, while the available data are limited and do not provide clear quantitative relationships, they generally support the need for limiting lead emissions to protect against potential ecosystem effects. Indications are that the emission reductions achieved since promulgation of the current standards in 1978, particularly when coupled with reductions achieved by the phasedown of lead in gasoline (gasoline combustion in the early 1980's accounted for 85-90% of total airborne lead emissions), may have mitigated or delayed the potential risk of lead-induced ecosystem effects occurring in many areas of the country. In urban centers, along roadsides, and in the immediate vicinity of

major stationary sources that have experienced a long-term, historical accumulation of lead, and where the natural soil sinks for lead may be approaching or have exceeded their capacity to bind lead, the more sensitive components of the ecosystem (e.g., soil microbes) may remain at some risk that is difficult to quantify at present.

Until a stronger data base is developed that more accurately quantifies ecological effects of different lead concentrations, the staff recommends that consideration be given to retaining a secondary standard at or below the level of the current secondary standard of 1.5 $\mu g/m^3$. If the level, averaging time, or form is changed for the primary standard, consideration should be given to making a similar change for the secondary standard to facilitate implementation.

APPENDIX A. SUMMARY OF PROBABILITY ENCODING ON LEAD-INDUCED HEALTH EFFECTS

The scientific information describing dose-response relationships for lead, as with most environmental pollutants, is generally limited and incomplete. There is a large variation in people's susceptibility to air pollution-induced health effects, and scientific evidence is rarely conclusive in establishing a causal relationship for health effects resulting from pollutant exposure, especially if these effects involve a latency period or other contributing factors. Given the precautionary nature of the Clean Air Act and the need to protect public health with an adequate margin of safety, it is important to characterize, as explicitly as possible, the range and implications of uncertainties in the data base as part of the ambient standard review. One way to address uncertainties in the scientific knowledge about a particular health effect is to obtain probability distributions based on expert judgments. Obtaining, or encoding these judgments involves interviewing experts to assess their judgments concerning the probability that a certain fraction of the sensitive population would suffer a particular adverse health effect at a given exposure level. Probability judgments can be used to describe an individual's assessment of the likelihood of an event based on the current state of information, which includes both his or her judgments or interpretations of existing studies and theories and the quantitative data available. Because different experts will have different judgments, it is also important not to merge these judgments into a single average, but rather to present to the decision makers the range of risks based on the range of judgments, and thereby also identify the range and form of disagreement among experts.

In 1984-1985, probability distributions representing the judgments of experts on two health effects were formally and directly assessed using the technique of probability encoding.

Detailed results of the encoded judgments and their application to compute health risks in children living near representative lead point sources are provided in Wallsten and Whitfield (1986). The report also describes the methods used to elicit the judgments. These methods were reviewed in 1985 by CASAC who found them to be sound.

Of the numerous health effects of lead, reductions in hemoglobin levels and IQ decrements were chosen for probability encoding. It must be emphasized that although there is considerable uncertainty regarding the dose-response functions for these two effects, particularly at low lead levels, these endpoints are not the most sensitive indicators of lead toxicity, nor are they necessarily the most critical in terms of public health. Because this exercise was EPA's first application of formal risk assessment procedures in reviewing a NAAQS, it was important to select health endpoints: a) that could be readily quantifiable in common measurement units (in contrast to classroom behavior, for example); b) that could be readily understood in terms of their medical significance (in contrast to changes in ALA or nerve conduction velocity, for example); and c) for which exist a sufficient number of qualified experts who span the range of respected opinion and interpretation (unlike for example,lead-induced changes in vitamin D metabolism for which few experts can be identified).

Since only a finite number of PbB levels can be presented for encoding,it is necessary to interpolate between levels in order to use the judgments in risk assessments. Such interpolations were made by fitting suitable probability distributions to the encoded values for both hemoglobin and IQ effects (see Wallsten and Whitfield, 1986, for a detailed description). The present discussion utilizes the functions fit to each individual's probabilistic judgments to present a summary of the quantitative results for both hemoglobin and IQ. The functions provide an accurate representation of the underlying encoded values, both because goodness of fit was excellent and

because each expert endorsed the output of the respective functions as representing his or her judgments.

A. Encoding Judgments on Lead-Induced Hemoglobin Decrements

Of five experts selected, probability judgments of four were encoded with respect to the frequency of lead-induced hemoglobin levels below either 9.5 or 11.0 grams per deciliter (g/dl) in homogeneously exposed populations of young children. The fifth expert (Expert B) felt uncomfortable with the notion of judgmental probability encoding and declined to have his judgments encoded. The experts were given the option of considering separately the population of children in the age groups 0-3 and 4-6 years, because of the age-related differences in iron deficiency.

It is generally agreed that for children a hemoglobin level of about 12 g/dl is normal and about 9 g/dl is anemic. Thus, of the two levels specified, a hemoglobin concentration of 9.5 g/dl would be much more likely to be considered as an adverse health effect. Although both hemoglobin levels are sufficiently low to warrant concern, there would likely be extensive debate over whether a hemoglobin level of 11 g/dl would necessitate preventative measures in terms of a lead air quality standard. In the interests of brevity and of focusing in on the more critical effects, results are summarized here only for the judgments regarding 0-3 year olds (the more sensitive age group), and for the dose-response function for hemoglobin levels less than or equal to 9.5 g/dl (See Figure A-1). [Expert C, believes that a single dose-response function applies to children in the 0-6 year age range; with his concurrence, his judgments were reproduced in both the 0-3 and 4-6 year age groups.]

The following discussion regarding Figures A-1 and A-2 is extracted directly from Wallsten and Whitfield (1986):

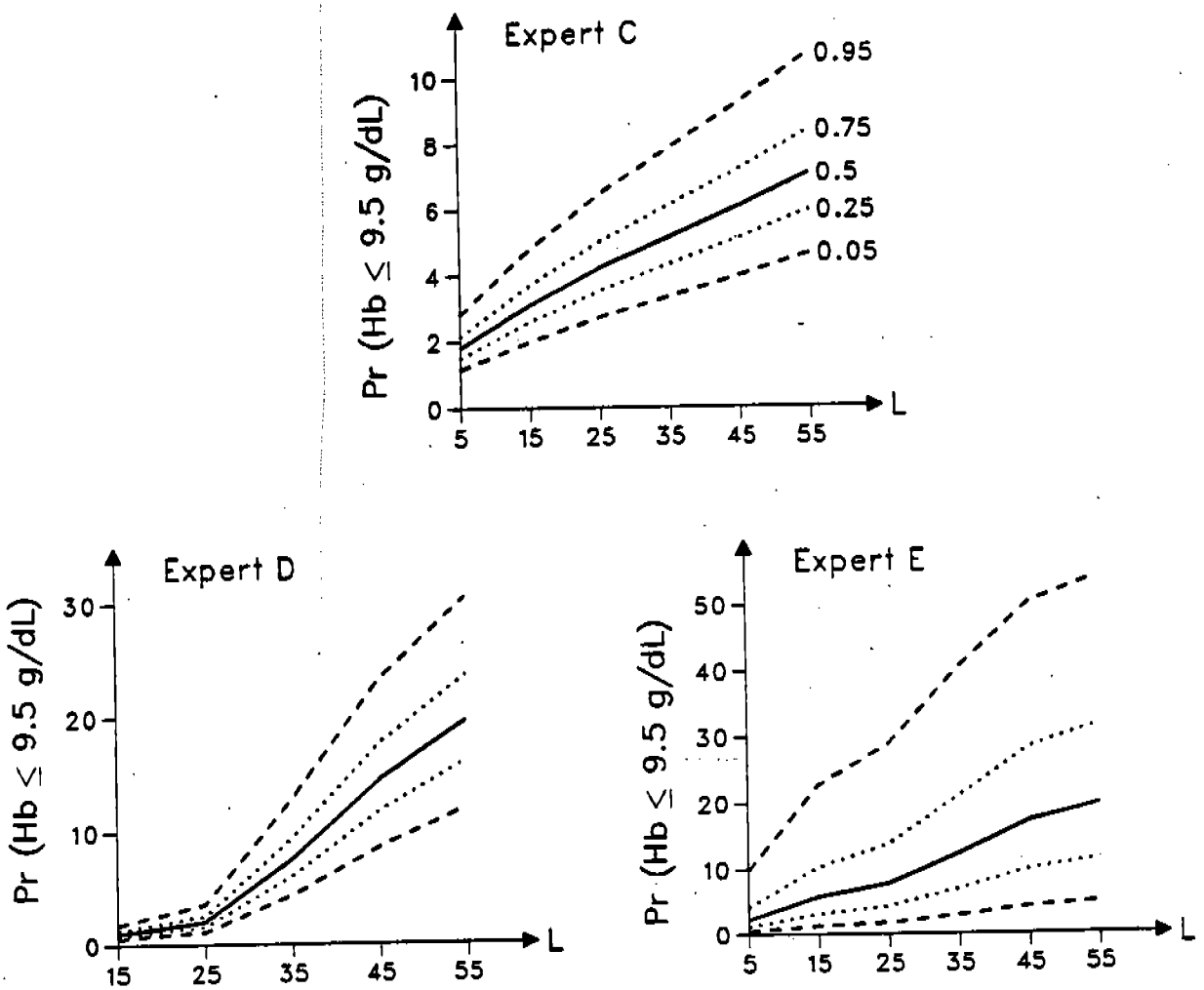

Figure A-1. Probabilistic Judgments of Experts Regarding Lead-Induced Hemoglobin Levels ≤ 9.5 g/dl in children aged 0-3 years. Blood lead (L) is on abscissa (in ug/dl) (from Wallsten and Whitfield, 1986).

The graphs are analogous to the usual dose-response functions found in the literature, except, of course, they are based on probabilistic judgments rather than on direct data. The dark, central curve in each panel shows the median judged dose-response curve for each expert. In other words, for a given panel, according to that expert, at each blood lead level there is a 0.50 probability that the true response rate is above the indicated value and a 0.50 probability that the true response rate is below it.

The two lighter lines on either side of the median curve contain the central 50% credible interval. Thus, according to the expert in a particular panel, at each blood lead level there is a 0.25 probability that the true response rate is below the lower light curve, a 0.50 probability that it is between the two light curves, and a 0.25 probability that it is above the upper one. In a similar manner, the dashed curve contains the 90% credible interval.

The more tightly packed are a family of functions in a panel, the less uncertainty does an expert indicate in his judgments. Thus, Figure A-1 gives a rather complete representation of each expert's probabilistic judgments.

Figure A-2 is less complete, but provides a convenient means of comparing judgments across experts. The axes are the same as in Figure A-1. The vertical bars at each lead level represent each expert's central 90% credible interval for response rate, and the symbol within each bar indicates the median judgment at that lead level.

It must be borne in mind that these judgments are with respect to lead-induced response rates over and above any base response rate due to iron deficiency and other factors. Thus, levels of uncertainty, as well as differences or similarities of opinion reflected here, are focused solely on the effects of lead on hemoglobin.

Note first that expert A did not feel that there was a measurable lead-induced hemoglobin effect at PbB levels below 45-55 µg/dl, and therefore judgments at 9.5 g/dl are not shown for him; indeed, his median judgment for the percentage of children

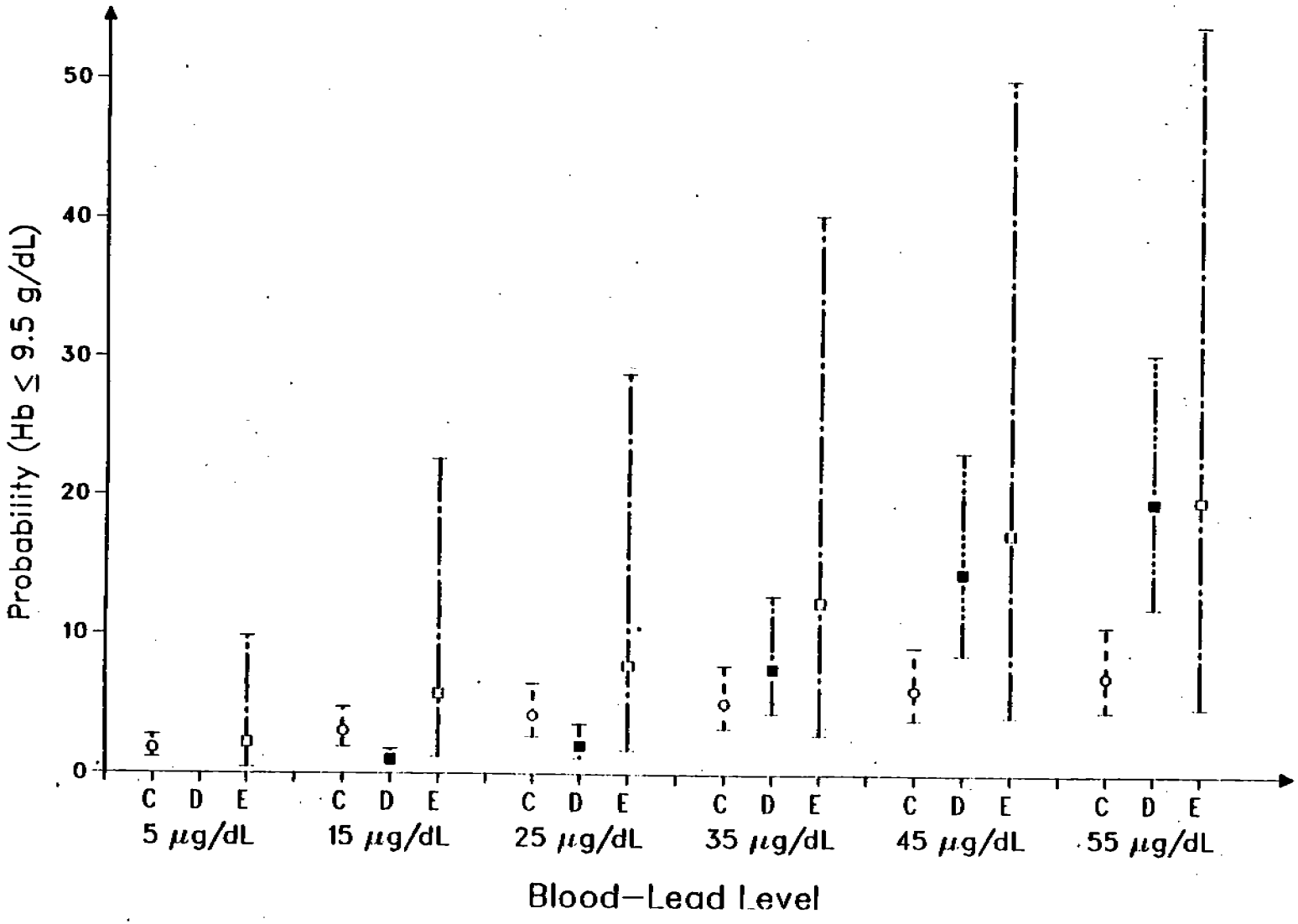

Figure A-2. Comparison of judgments of Experts C, D, and E regarding the probability of hemoglobin levels ≤ 9.5 g/dl, in children ages 0-3 years at different blood-lead levels. The vertical bars at each blood-lead level represent each expert's 90% credible interval for response rate and the symbols indicate the median judgment at that blood-lead level (from Wallsten and Whitfield).

age 0-3 years with hemoglobin levels below 11 g/dl at PbB = 45 µg/dl is 3%, and this rises to a most likely rate of 17% at PbB = 75 µg/dl.

There is overlap in the judgments of experts C, D, and E, although not to the degree as for their judgments regarding hemoglobin levels below 11.0 g/dl which are not displayed here. For example, these experts judged with a probability of 0.9 that the following fraction of children 0-3 years old which would have hemoglobin levels below 9.5 g/dl with PbB of 35 µg/dl were within the following ranges: 3-8% (Expert C); 4-13% (Expert D); 3-41% (Expert E). At a PbB of 25 µg/dl, the corresponding range of the fraction of children affected with a probability of 0.9 are:3-6% (Expert C); 1-4% (Expert D); 2-29% (Expert E). For a PbB of 15 µg/dl, these 0.9 credible intervals are: 2-5% (Expert C); 1-2% (Expert D);1-23% (Expert E). For a PbB of 5 µg/dl, the following range of fractions of children 0-3 years would have hemoglobin levels below 9.5 g/dl with 0.9 probability: 1-3% (Expert C); 0 (Expert D); 0-10% (Expert E).

Considering the median judgments (i.e., the response rate for which there is a 0.5 probability that the actual rate is either above or below the indicated value), C and E agree in estimating the most likely response rate at 5 µg/dl to be 2%, while D is most certain that the response rate is 0. Expert C's median response rate judgment increases relatively slowly with increased PbB, while that of expert D increases relatively quickly. As a result, at PbB = 55 µg/dl, D and E agree that the most likely response rate is 20%, while C considers it to be 7%.

Of these 3 experts, expert E expresses considerable uncertainty in his judgment about the dose-response function, while experts C and D express much less. Note also that the judgment of expert D suggests a slight threshold between PbB levels 25 and 35 µg/dl, but that the judgments of the other two

do not suggest a threshold for hemoglobin levels below 9.5 g/dl in 0-3 year olds.

The corresponding judgments for lead-induced hemoglobin levels at or below 11.0 g/dl, and for children 4-6 years old, are not displayed here. Expert A judged that blood lead below 45 μg/dl would not cause hemoglobin levels to drop as low as 11.0 g/dl. As with 9.5 g/dl, the judgments of experts C, D, and E for 11.0 g/dl tend to overlap, but the degree of similarity displayed is greater than at the low hemoglobin level.

None of these 3 experts' judgments suggest a threshold above which blood lead would result in a hemoglobin level below 11.0 g/dl. According to their median judgments, the best estimate of response rate for 0-3 year olds, hemoglobin $\leq$ 11.0 g/dl, is between 2% and 7% at PbB = 5 μg/dl, rising to between 14% and 26% at PbB = 55 μg/dl. The judgments for children 4-6 years of age followed the same patterns as for children 0-3 years, with all the experts judging smaller probabilities of effects in the older group. Detailed results can be found in Wallsten and Whitfield (1986).

B. Encoding Judgments on Lead-Induced IQ Decrements

It should be noted again that IQ was chosen not because it is the only,nor necessarily the best, measure of cognitive ability, nor is it being considered as a surrogate for other suspected lead-related central nervous system and behavioral effects that have been explored (e.g., brain wave activity, sensory motor, perceptual and attentional deficits, negative classroom behaviors). Rather, IQ decrement emerged as most appropriate to consider because of its acknowledged functional significance, its easy specification, and the amount of data on its relationship to lead exposure.

It must also be emphasized that the encodings were conducted prior to publication of several important studies or IQ effects in children (e.g., Schroeder et al., 1985; Hawk et al., 1986; Fulton et al., 1987; see section III.D.2.c). Although these recent studies tend to support earlier data, interpretation of the encoded judgments here must recognize their time context.

The probability judgments of six experts were encoded with respect to the outcomes of a hypothetical, ideal experiment in which a very large number of subjects were randomly assigned at conception to various exposure groups and were exposed to (or sheltered from) lead until their seventh birthdays. Although each child's lead uptake would not be constant due to changes with age, physiology and behavior, the hypothetical experimental conditions were specified such that at their third birthdays, all children in each group have the same measured PbB level. Environmental lead levels necessary to yield a given PbB level at age 3 in a particular child were specified as remaining constant through the seventh birthday, at which time the WISC-R IQ test was administered. The very large numbers of subjects per group eliminated any concern about sampling error, and the random assignment of subjects to conditions eliminated any concern about complex analyses of covariance. Each group was assumed to differ only in terms of exposure to lead.

Probabilistic judgments were encoded regarding: (a) the mean IQ decrement for each exposure group (5, 15, 25, 35, 45, and 55 µg/dl on their 3rd birthday) relative to a lead-free control group; (b) the mean IQ of the control group; and (c) the within-group IQ standard deviation. Judgments about control group mean IQ values and within-group standard deviations were necessary to derive probabilistic estimates about the lead-induced increase in percent of children at each lead level whose IQ scores are below a specified IQ value of interest. Detailed results, including the encoded judgments, mathematical functions fit to those judgments, goodness of fit measures, and derived subjective

probabilities about dose-response functions, are given in Wallsten and Whitfield (1986). For brevity, summaries of results for IQ decrements only are presented here.

The experts were given the option of considering possible interactive effects of socio-economic status and lead on IQ (based on findings from several studies discussed in the CD and this staff paper) by considering low SES children living in households with incomes in the lowest 15th percentile separate from the remainder of the population. All the experts, except F, believe that at the doses under consideration, lead interacts with variables that contribute to SES level. Therefore, all except Expert F provided separate judgments for the two SES levels.

Figure A-3 summarizes the judgments of all six experts regarding mean IQ decrements for the low SES group. The following discussion regarding the figure is extracted directly from Wallsten and Whitfield (1986).

> Each person's judgments are shown in a separate panel. Blood lead is on the abscissa and mean IQ decrement (mean control group IQ minus mean exposed group IQ) is on the ordinate.
>
> The dark, central curve in each panel shows the median judged IQ decrement for each lead level. In other words, for a given panel, according to that expert there is a 0.50 probability that the actual mean IQ decrement would be greater than the indicated value, and a 0.50 probability that it would be less. The successively lighter pairs of curves that bracket the median curve represent central 50%, 90%, and 95% credible intervals.
>
> Figure A-4 allows a comparison of judgments across the experts. The axes are the same as in Figure A-3. The vertical bars at each lead level represent each expert's central 90% credible interval, and the symbols are his or her median judgments.
>
> Expert F consistently judged the IQ effects of lead to be less than did the other experts, and evidenced considerably less uncertainty about the magnitude of

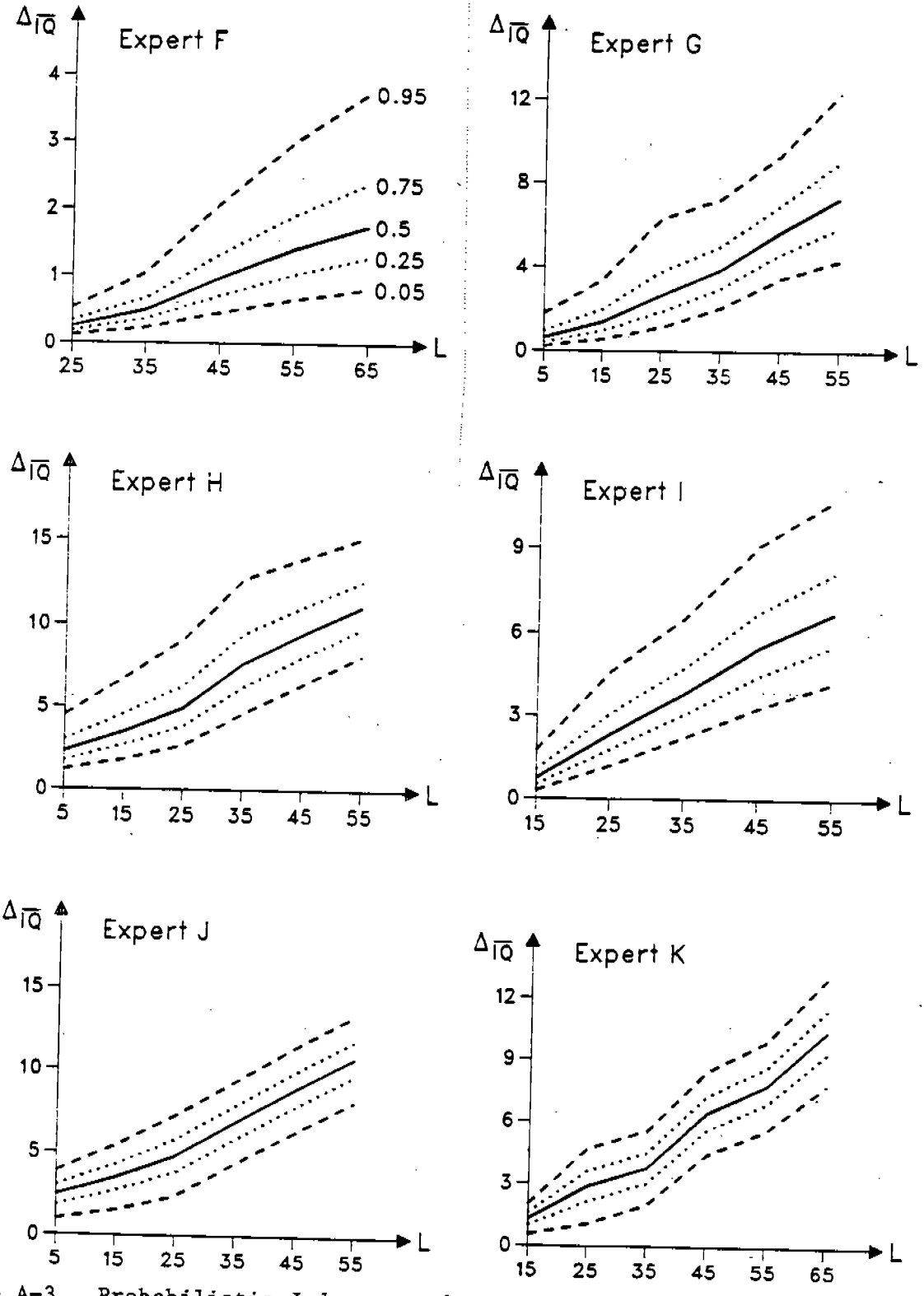

Figure A-3. Probabilistic Judgments of Experts Regarding Mean, Lead-Induced IQ Decrements for Low SES Group. Blood lead (L) is on abscissa (in ug/dl) and mean IQ decrement (mean control group IQ minus exposed group IQ) is on the ordinate of each panel (from Wallsten and Whitfield, 1986).

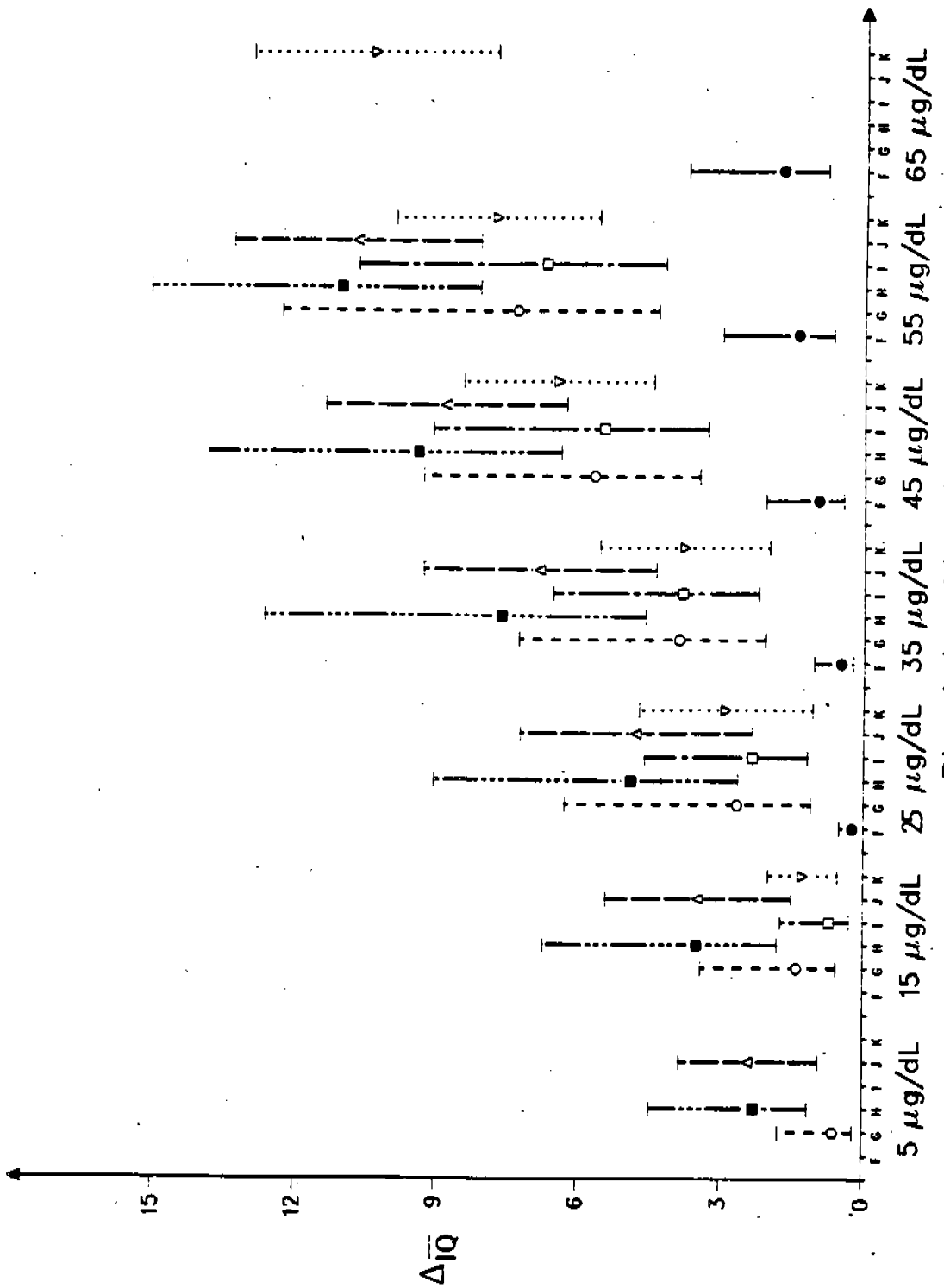

Figure A-4. Comparison of judgments across experts regarding mean IQ decrements for low SES group. The vertical bar at each, blood-lead level represents each expert's central 90% credible interval, and the symbols indicate the median judgment at that blood-lead level (from Wallsten and Whitfield, 1986).

these effects than did the others. F was certain that there is no IQ effect of lead up to at least 15 µg/dl. At 25 µg/dl, the median judged IQ decrement is about a 0.25 point, and this increases to a median judged IQ decrement of just under 2 points at 65 µg/dl. According to F, at 25 µg/dl, the IQ decrement exceeds approximately 0.5 point with probability 0.05, while at 65 µg/dl, it exceeds 3.7 points with the same probability.

There are overriding similarities in the judgments of the other experts, although there are also small, consistent differences among them. Thus, only G, H, and J give any credibility to there being IQ effects as low as 5 µg/dl, while I does so at 15 µg/dl, and K does at 25 µg/dl. The judgments of H and J are consistently very close, as are those of G, I, and K, which as a group are somewhat lower than those of and H and J. Considering the five sets of judgments, the median judged IQ decrement at 5 µg/dl ranges from 0 to 2.4 points. The median judged IQ decrement at 55 µg/dl is from about 7 to 11 points. According to the judgments of G, H, and J, with probability 0.05, the IQ decrement exceeds 1.8 to 4.5 points at 5 µg/dl, while according to all 5 experts, it exceeds 9.9 to 15.1 points at 55 µg/dl with the same probability.

Considering intermediate PbB levels, Expert F judged a probability of 0.5 that the mean IQ decrement at a PbB level of 35 µg/dl in low SES children would be 0.5 points. Corresponding median judged IQ decrements at 35 µg/dl for the other experts are: 1.5 (Expert G); 8.4 (Expert H); 3.6 (Expert I); 7.0 (Expert J); 4.0 (Expert K). The median judged IQ decrements at 25 µg/dl for low SES children are: 0.25 (Expert F); 2.7 (Expert G); 4.9 (Expert H); 2.3 (Expert I); 4.8 (Expert J); 2.9(Expert K). At a PbB level of 15 µg/dl, the median judged IQ decrements for low SES children are according to these experts: 0 (Expert F); 1.4 (Expert G); 3.5 (Expert H); 0.7 (Expert I); 3.5 (Expert J); 1.3 (Expert K).

As with hemoglobin, credible intervals were calculated for each expert's judgments. For example, the 0.9 credible interval is a set of mean IQ decrement values such that there is a 0.9 probability of the true value falling within it. The 0.9

credible intervals concerning mean IQ decrements for the low SES children for different PbB levels are as follows:

45 µg/dl: 0.45-2.07 (Expert F); 3.5-9.3 (Expert G); 6.4-13.9 (Expert H);3.3-9.1 (Expert I); 6.3-11.4 (Expert J); 4.4-8.4 (Expert K).

35 µg/dl: 0.23-1.05 (Expert F); 2.1-7.3 (Expert G); 4.6-12.7 (Expert H);2.2-6.5 (Expert I); 4.4-9.3 (Expert J); 2.0-5.5 (Expert K).

25 µg/dl: 0.11-0.52 (Expert F); 1.1-6.3 (Expert G); 2.6-9.0 (Expert H);1.2-4.6 (Expert I); 2.3-7.2 (Expert J); 1.1-4.7 (Expert K).

15 µg/dl: 0 (Expert F); 0.6-3.5 (Expert G); 1.8-6.7 (Expert H);0.3-1.7 (Expert I); 1.5-5.4 (Expert J); 0.5-1.8 (Expert K).

5 µg/dl: 0 (Expert F); 0.2-1.8 (Expert G); 1.2-4.5 (Expert H); 0 (Expert I); 0.9-3.9 (Expert J); 0 (Expert K).

Judgments about mean IQ decrement for the high SES group are not displayed here, although all the experts, except F, felt that the risks of lead effects on IQ would be smaller in the high SES children. Also, as with the low SES population, F consistently judged the IQ effect to be less than did the other experts. From 25 µg/dl on, the judgments of the others overlap, with, as before, those of H and J being very similar and somewhat greater than those of G, K, and I, which themselves are similar. Only H gave any credibility to the existence of an IQ effect at 5 µg/dl, G, I,and J did so at 15 µg/dl, and F and K concur at 25 µg/dl (Wallsten and Whitfield, 1986).

Considering all the experts simultaneously, the median judged IQ decrement at 15 µg/dl in the high SES group ranges from 0 to 2.4 points;at 55 µg/dl, it ranges from 1.4 to 7.9 points.

According to G, H, I, and J, with probability 0.05 it exceeds 1 to 7 points at 15 µg/dl, while according to all the experts it exceeds 4 to 11.5 points at 55 µg/dl with probability 0.05.

C. DISCUSSION

Considering the scientific debate that has prevailed about the IQ effects of lead, the degree of consensus reflected in the results is notable. This is particularly so, since the experts were selected so as to span the credible range of opinion. For both health endpoints, encoding subjective probabilities from the scientific experts about specific, well-defined scientific outcomes eliminated or minimized disagreements about definitions, policy, and other matters. The remaining differences, evidenced in the preceding results, are mainly due to differing interpretations of, and extrapolations from, the scientific evidence.

As discussed previously, the health endpoints that were assessed using probability encoding should not be considered the individual effects most crucial to a determination of the appropriate maximum acceptable PbB level. Further, the encodings were conducted in 1985-86 prior to publication of several important studies on IQ effects in children; these studies tend to support earlier data. Several of the experts assigned fairly high probabilities that potentially important hemoglobin and IQ decrements could occur in children with PbB levels starting at 25 µg/dl. Judgments of some of the experts suggest that effects on IQ and hemoglobin could occur at and below 15 µg/dl. In general the judgments tend to support that the range of 10-15 µg/dl is appropriate for evaluating in Section IV.C the health protection provided by alternative lead NAAQS.

APPENDIX B. EXPOSURE CASE STUDIES: SENSITIVITY ANALYSES

This appendix presents results of sensitivity analyses of the three case studies on children described in Section IV.D.2. Populations of children living near a Dallas secondary smelter, the East Helena primary smelter, and a secondary smelter and battery plant in Tampa were modeled from birth up to their seventh birthdays, 1990-1996. Blood lead distributions under alternative lead NAAQS are estimated using the uptake/biokinetic model which accounts for age-specific differences in exposure, absorption, and physiological distribution of lead from food, water, soil and housedusts, as well as air; behavioral and biological variability not captured by the model parameters is accounted for through use of empirically-derived measures of blood lead variance (GSDs). Several parameters were assigned lower and upper bound values that span the range of credible estimates derived from available data. These include time spent outdoors per day, volume of air respired per day, percent absorption in the gastrointestinal tract of ingested lead in diet, concentrations of lead in soil and housedust associated with different air lead concentrations, the amount of dirt typically ingested by children daily, and the GSD value that best represents variability in childhood lead exposure around lead point sources.

The results presented for children in Section IV.D.2 incorporate midpoint estimates of those parameter values with lower and upper bounds. Tables B.1 and B.2 summarize blood lead distributions estimated by the uptake/biokinetic model using either all lower bound values or all upper bound values. While the staff believes that the results in Section IV.D.2 are better representations of future scenarios, the results shown here illustrate the extremes in possibilities. Sensitivity analyses that focus on altering only one or two parameters at a time are possible but are not shown here in the interest of space. Results of any such analysis, using the same range of estimates, would be intermediate to the results in the following two tables.

TABLE B-1. LOWER BOUND SENSITIVITY ANALYSIS: CHILDREN'S PbB LEVELS IN 3 CASE STUDIES*

Case Study (# Children) / PbB Level[a]	Lead NAAQS Level (µg/m³) Baseline[b]	1.5 Quarterly[c]	Monthly[d] 1.5	1.25	1.0	0.75	0.5
Dallas (241)							
Mean PbB (µg/dl)	4.9	3.8	3.8	3.7	3.7	3.6	3.6
% > 10 µg/dl	0.3	0.01	0.01	0.01	0.01	0.005	0.004
% > 15 µg/dl	0.001	0	0	0	0	0	0
East Helena (217)							
Mean PbB (µg/dl)	4.0	3.6	3.5	3.4	3.4	3.3	3.2
% > 10 µg/dl	0.03	0.004	0.003	0.002	0.002	0.001	0.001
% > 15 µg/dl	0	0	0	0	0	0	0
Tampa (10)							
Mean PbB (µg/dl)	6.5	5.6	5.4	5.2	5.0	4.8	4.7
% > 10 µg/dl	5.3	1.4	0.9	0.6	0.4	0.3	0.2
% > 15 µg/dl	0.08	0.009	0.005	0.003	0.001	0.001	0

* Assumes lower bound values for parameters specified in text.
[a] PbB distributions calculated by assuming GSD = 1.30.
[b] Baseline scenario represents current conditions for air quality, as well as soil and dust. Dietary intake assumed to be at 1990-1996 levels.
[c] Current NAAQS and averaging time (calendar quarter).
[d] Alternative NAAQS levels with monthly averaging time.

TABLE B-2. UPPER BOUND SENSITIVITY ANALYSIS: CHILDREN'S PbB LEVELS IN 3 CASE STUDIES*

Case Study (# Children) / PbB Level[a]	Lead NAAQS Level (µg/m³) Baseline[b]	1.5 Quarterly[c]	1.5 Monthly[d]	1.25 Monthly[d]	1.0 Monthly[d]	0.75 Monthly[d]	0.5 Monthly[d]
Dallas (241)							
Mean PbB (µg/dl)	8.9	6.1	5.9	5.8	5.7	5.6	5.5
% > 10 µg/dl	38.8	12.0	10.8	10.1	9.3	8.6	7.9
% > 15 µg/dl	10.8	1.7	1.4	1.3	1.1	1.0	0.9
East Helena (217)							
Mean PbB (µg/dl)	8.3	6.7	6.6	6.4	6.1	5.9	5.6
% > 10 µg/dl	32.7	17.7	16.6	14.5	12.6	10.9	8.6
% > 15 µg/dl	8.1	3.0	2.7	2.2	1.8	1.4	1.0
Tampa (10)							
Mean PbB (µg/dl)	13.6	11.0	10.1	9.6	9.0	8.4	7.9
% > 10 µg/dl	76.6	58.7	51.3	46.1	40.3	34.4	28.7
% > 15 µg/dl	41.0	23.1	17.9	14.7	11.6	8.8	6.5

* Assumes upper bound values for parameters specified in text.
[a] PbB distributions calculated by assuming GSD = 1.53.
[b] Baseline scenario represents current conditions for air quality, as well as soil and dust. Dietary intake assumed to be at 1990-1996 levels.
[c] Current NAAQS and averaging time (calendar quarter).
[d] Alternative NAAQS levels with monthly averaging time.

APPENDIX C: CASAC CLOSURE REPORT

EPA U.S. Environmental Protection Agency Washington, DC EPA-SAB-CASAC-90-002

Report of the Clean Air Scientific Advisory Committee (CASAC)

Review of the OAQPS Lead Staff Paper and the ECAO Air Quality Criteria Document Supplement

A SCIENCE ADVISORY BOARD REPORT JANUARY 1990

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

OFFICE OF
THE ADMINISTRATOR

January 3, 1990

Honorable William K. Reilly
Administrator
U.S. Environmental Protection Agency
401 M Street, SW
Washington, DC 20460

RE: National Ambient Air Quality Standards for Lead

Dear Mr. Reilly:

I am pleased to transmit the advice of the Clean Air Scientific Advisory Committee (CASAC) concerning the National Ambient Air Quality Standards (NAAQS) for Lead. The CASAC has reviewed and offered comments directly to EPA Staff on the EPA Air Criteria Document update, "Supplement to the 1986 EPA Air Quality Criteria for Lead - Volume I Addendum (Pages A1 - A67)", and the Office of Air Quality Planning and Standards (OAQPS) staff position paper "Review of the National Ambient Air Quality Standards for Lead: Assessment of Scientific and Technical Information", both dated March 1989.

The Committee previously reached closure on the 1986 Air Quality Criteria Document and Criteria Document Supplement. At a meeting held on April 27, 1989, CASAC reviewed and was prepared to close on the 1989 Criteria Document Addendum and the 1989 Staff Position Paper, but withheld closure pending receipt and consideration of additional public comments. The public comment period, scheduled to close 30 days following the CASAC meeting, was extended through June 12, 1989, providing the interested public further time to prepare comments. The additional comments received as a result of the extended comment period were provided to the Committee and taken into consideration before reaching closure. The Committee concludes that these EPA documents, along with the 1986 documents previously closed upon, provide a scientifically balanced and defensible summary of our current knowledge of the

effects of this pollutant, providing an adequate scientific basis for EPA to retain or revise primary and secondary NAAQS for airborne lead.

As part of this review process, the Committee considered and approved the CASAC Exposure Subcommittee review of the August 1988 EPA document "Review of the National Ambient Air Quality Standards for Lead: Exposure Analysis Methodology and Validation". That approval is formally contained in the CASAC report transmitted to you in April 1989 (EPA-SAB-CASAC-89-018, April 1989).

In November 1988, the CASAC formed an ad hoc Joint Study Group with the Science Advisory Board (SAB). The broad charge to this Study Group included assessment of the weight of evidence classification of lead and lead compounds as carcinogens; review of lead-related health effects and exposure issues which cut across EPA organizational lines; and an assessment of how the scientific information concerning lead is applied to standard setting and other regulatory decisions in the Agency. The report of that Joint Study Group, based on their March 30, 1989 and April 28, 1989 meetings, is contained in their report (EPA-SAB-EC-90-001, December 1989), transmitted to you separately.

A key point of the Joint Study Group Report is the contrasting nature of the data base for central nervous system versus carcinogenic effects. The carcinogenic risk assessment is based primarily on induction of kidney tumors in rodents administered large quantities of lead. Use of these data for human risk assessment involves two extrapolations: from rodents to people, and from high doses to the low doses encountered in ambient exposures of lead. In contrast, central nervous system effects are observed directly in people and at exposures at or near the levels of exposure relevant to setting the standard. Thus, and unless, more quantifiable and relevant scientific evidence is available on the carcinogenicity of lead, the Committee feels it appropriate to give primary consideration to nervous system effects in setting the national ambient air quality standard for lead.

During the course of the CASAC meeting several recommendations were made to the EPA Staff as to actions that can be taken that will provide an improved basis for setting the NAAQS for lead. These include calculation of the distribution of blood lead levels estimated to result from achieving an air lead concentration of

0.25 ug/m^3. In addition, it was suggested that it would be appropriate to evaluate the estimated distribution of effects on childrens intelligence at a given level of lead exposure.

While the Committee is willing to further advise you on the lead standard, we see no need, in view of the extensive comments provided, to review any proposed changes prior to their publication in the Federal Register. The public comment period following publication will provide sufficient opportunity for the Committee to provide any additional comment or review, if needed.

The attached report contains the detailed analysis and recommendations of the CASAC concerning its closure on the Criteria Document Addendum and the EPA Staff Position Paper for airborne lead. In considering the CASAC's recommendations for the lead NAAQS it is important to recognize that air is just one source of exposure to lead; reducing the total population risk from lead will require a concerted effort to reduce lead intake from all sources.

We appreciate the opportunity to provide advice on this important issue and look forward to your response to our recommendations.

Sincerely,

Roger O. McClellan, D.V.M.
Chairman, Clean Air Scientific
Advisory Committee

U.S. Environmental Protection Agency
Science Advisory Board

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15. SUPPLEMENTARY NOTES

16. ABSTRACT

This paper evaluates and interprets the updated scientific and technical information that EPA staff believes is most relevant to the review of the primary (health) and secondary (welfare) national ambient air quality standards for lead. This assessment is intended to bridge the gap between the scientific review in the EPA criteria document and the judgements required of the Administrator in setting the ambient air quality standards for lead.

The major recommendations of the staff paper are: (1) the range of standards under consideration should be from 0.5 to 1.5 ug/m^3; (2) a monthly averaging period would better reflect children's responsiveness to lead exposures than a quarterly averaging period; (3) the most appropriate form of the standard is the second highest monthly average in a 3 year span; (4) with a monthly averaging period, more frequent sampling is needed in areas with point sources; and (5) the hi-volume sampler should be retained to monitor compliance with the lead NAAQS.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Lead Air Pollution	Air Quality Standards	

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
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Texas Water Commission

INTEROFFICE MEMORANDUM

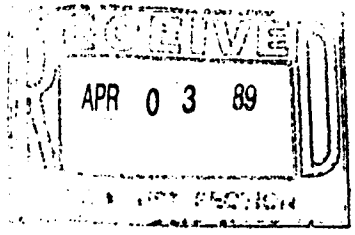
TO : UST Technical Support Unit
Attention: Allan Martinez

THRU : Brenda Price, UST Coordinator,
Field Operations Division

FROM : Crockett Howard, EQS
District 4 - Duncanville

SUBJECT: Inspection of UST Construction Activity

DATE: 3/17/89



INSPECTION DATE(S) 2/17/89

SUMMARY OF INSPECTION Two 10,000 Gal diesel tanks were removed. Corrosion holes were observed in both tanks. Soil analysis indicate relatively high concentrations of TPH exist in soils surrounding the tank pit

COMMENTS

PERSONNEL PRESENT ON SITE DURING INSPECTION Lamb, Jones, Chemco Inc

VIOLATIONS OBSERVED LUST

ATTACHMENTS Construction Checklist, LUST IR, Lab Analysis

Signed Crockett Howard Approved Sid Stocum

4/3/89

Texas Water Commission
UST Construction Checklist

GENERAL FACILITY & SITE INFORMATION

1. **Type of Activity:** REMOVAL

2. **Facility Name:** JOHNSON CONTROLS
   Location: 1111 SHILOH RD
   City: GARLAND **Co:** DALLAS
   Telephone: (214) 494-2461
   UST Fac. No. (if known): 34225

3. **Owner:** JOHNSON CONTROLS
   Representative: DAVID COOPER
   Title: MGR OF ENGINEERING
   Address: BOX 461729
   City/St/Zip: GARLAND, TX 75046
   Telephone: (214) 494-2461

4. **Consultant:** NA
   Representative:
   Title:
   Address:
   City/St/Zip:
   Telephone:

5. **UST Contractor:** CHENCO INC
   Representative: LARRY CORNETT
   Title: CONSTRUCTION SUPERVISOR
   Address: 2343 CARTWRIGHT
   City/St/Zip: DALLAS, TX 75212
   Telephone: (214) 631-4492

6. **Facility/Site Description:**
   Type Facility: MANUFACTURING FACILITY **Facility Status:** OPEN
   Locale: CITY **Prevailing Land Use:** INDUSTRIAL/COMMERCIAL
   Nearby Surface Features (roads, rivers, etc.) LOCATED IN NORTH WEST CORNER OF SHILO RD & MARQUIS
   Adjacent/Nearby Buildings or Structures: GARAGE TO NORTH
   Geological/Hydrogeological Features: CLAYS TO 10 FT – TAYLOR FORMATION ENCOUNTERED 10 FT –

7. **Planning Materials:**
   Construction Plans:
   Project Specifications:
   Equipment Operating Instructions:
   As-Built Plans On-Site:
   Closure Plan:
   Other (specify):
   Copies Filed with TWC:

8. **Remarks:**

ABANDONMENT AND REMOVAL INFORMATION

1. **Type of Activity:** ⊛ NA Abandonment-in-Place; ✓ Removal
2. **No. of Tanks Involved:** 2. **Written closure plan:** No.
3. **Reason(s) for Removing from Service:** NEW SYSTEM HAS BEEN INSTALLED, CLOSING OUT OCD TANK FARM

4. **Tank Information:**

	Tank 1	Tank 2	Tank NA	Tank NA
Last Product Stored	GASOLINE	DIESEL		
Last Date Used (est.)	JUN. 1989	JAN. 1989		
Age (if known)	27	27		
Capacity (gallons)	8000	8000		
Material	STEEL	STEEL		
Manufacturer	⊛⊛ UK	UK		
Sgl. or Dbl. Wall	SGL	SGL		
Exterior Coating	BITUMINOUS	BITUMINOUS		
Interior Lining	NA	NA		
Cath. Protection	NO	NO		
Condition/Appearance	POOR	POOR		

Remarks: CORROSION HOLES WERE OBSERVED IN BOTH TANKS

5. **Procedures for Abandonment-in-Place.**

Product Removal/Disposal: _____

Extent of Excavation: _____

Preparation of Piping, Fill Tubes, Tanks, etc. _____

Method(s) of Purging Vapors: _____

Procedures & Materials for Tank Filling: _____

Remarks: _____

⊛ NOT APPLICABLE
⊛⊛ UNKNOWN

6. Procedures for UST removal.

Product Removal/Disposal: PUMPED AND USED IN NEW INSTALLATION.

Extent of Excavation: NORMAL TANK HOLE DIMENSIONS

Preparation of Piping, Fill Tubes, etc.: PIPING & FILLS REMOVED BEFORE TANK EXTRACTION

Tank Removal/Temp. On-Site Storage: NA

Method(s) of Purging Vapors: NONE

Tank Disposal/Destination: PERRY ALEXANDER, GRAND PRAIRIE

Remarks: NA

7. Inspection/Assessment of Tank Pit and Site.

Leaks/Spills: ANALYTICAL RESULTS INDICATE ELEVATED TPH LEVELS AT THE SITE. BTEX CONCENTRATIONS DO NOT APPEAR TO BE OF GREAT SIGNIFICANCE.

Removal of free product/contaminated groundwater or soil: SOILS HAVE BEEN TAKEN TO AN APPROVED LANDFILL

Soil/Water Sampling Procedures: NO GROUNDWATER ENCOUNTERED - SOIL SAMPLES COLLECTED FROM SIDE WALLS, BOTTOM AND BACKFILL - ANALYZED FOR BTEX & TPH

LUST Reported to UST Enforcement Unit (Name & Date): 3/15/89

Remarks: NA

8. Additional Information: NA SEE LAB ANALYSIS

CODE FOR LAB REPORT B-1 = BACKFILL

C-1 = CENTER BOTTOM

N-1 = NORTH WALL

W-1 = WEST WALL

E-1 = EAST WALL

S-1 = SOUTH WALL

SwL SOUTHWESTERN LABORATORIES, INC.
J/c
Construction materials testing, analytical chemistry and geotechnical engineering
P.O. Box 224227 • 2575 Lone Star Drive • Dallas, Texas 75222 • 214/631-2700

February 27, 1989 File No. _____ Johnson Controls C.H.

Report of: Analysis of Soil

Reported to: Chenco, Incorporated
Attn: Larry Jones
2343 Cartwright
Dallas, Texas 75212

Date received: 2/17/89

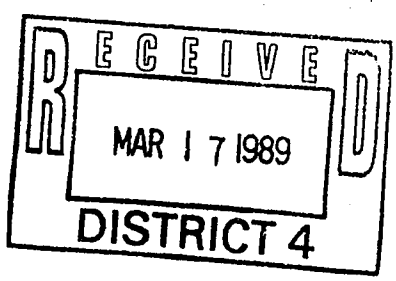
Identification: P.O. #2281-125 Job #8203

	B-1	C-1	N-1	S-1	E-1	W-1	Detection Limit	Eptox Limit
Benzene, mg/kg	*0.02	*0.02	*0.02	*0.02	*0.02	*0.02	0.02	
Toluene, mg/kg	*0.02	0.36	0.40	*0.02	*0.02	0.78	0.02	
Ethyl Benzene, mg/kg	1.77	1.26	0.73	0.49	*0.02	0.99	0.02	
Xylene, mg/kg	6.65	7.14	4.42	1.33	1.75	3.13		
Total Petroleum Hydrocarbons, mg/kg	8050	3060	1760	5200	1640	694		
Eptox Chromium, mg/kg	*0.05	*0.05	*0.05	*0.05	*0.05	*0.05	0.05	5.0 mg/L
Eptox Lead, mg/L	*0.5	*0.5	*0.5	*0.5	*0.5	*0.5	0.5	5.0 mg/L

*None detected, less than

Methods: EPA SW846 #5030 & #8020
EPA 600/4-79 #418.1

Analyst: LP, RZ, LWG



Distribution of report:
1C: Chenco, Incorportatd

Respectfully submitted,

SOUTHWESTERN LABORATORIES, INC.

Per: Richard Beale
Richard Beale, Manager
Environmental and Analytical Services

Lab. No. D-29365 :sf

Samples are discarded 30 days after reports are mailed unless prior arrangements are made in writing. A storage fee will apply on samples held over 30 days. Our letters and reports are for the exclusive use of the client to whom they are addressed. The use of our name must receive our prior written approval. Our letters and reports apply to the sample tested and/or inspected, and are not necessarily indicative of the qualities of apparently identical or similar products

CL

COORD. OFFICE (UST Corr. Act., UST Enf., UST Contracts, or DFO)

TEXAS WATER COMMISSION

LEAKING UNDERGROUND STORAGE TANK

INCIDENT REPORT

92789
LUST ID. NO.

SOL.WST.REG.NO. (if applicable)

WK No 3500

STATUS INFORMATION

UST REG #: 34225 LUST PRIORITY: III

LUST DISCOV DATE: 2/17/89 TWC NOTIF DATE: 2/17/89

REPORTED BY: CROCKETT HOWARD PHONE: (214) 298-6128

REPRESENTING: TWC

REPORTED TO: N/A

SUBSTANCES RELEASED

PETROLEUM PRODUCT(S) RELEASED: DIESEL / GASOLINE EST.VOL. UK gal.s

HAZARDOUS SUBSTANCE RELEASED: N/A EST.VOL. N/A gal.s

RELEASE DETECTION METHOD: (Routine Monitor, Tank Test, Visual Observation, Other)

COMMENTS: HOLES OBSERVED IN TWO USTS. PETROLEUM VAPORS DETECTED IN SOILS OF BOTTOM & SIDE WALLS.

LOCATION OF RELEASE

NAME OF FACILITY: JOHNSON CONTROLS

FACILITY ADDRESS: 1111 SHILOH RD PHONE: (214) 494-2461

FACILITY CITY: GARLAND COUNTY: DALLAS (57) (Code #) ZIP: 75046

OTHER LOCATION INFO: T.P. LOCATED IN NORTHWEST CORNER OF THE JUNCTION OF SHILO RD & MARQUIS

RESPONSIBLE PARTY

TANK OWNER/COMPANY: JOHNSON CONTROLS

MAILING ADDRESS: BOX 461729

CITY: GARLAND STATE: TX

PHONE: (214) 494-2461 ZIP CODE: 75046

CONTACT (NAME/TITLE): DAVID COOPER, MGR OF ENGINEERING

AFFECTED WATERS

GROUNDWATER AFFECTED?: (Yes, (No), Unknown) SURFACE WATER AFFECTED?: (Yes, (No), Unknown)

GROUNDWATER STATUS: (Usable, Unusable, (Unknown)) SURFACE WATER STATUS: _____

COMMENTS: NO GROUNDWATER ENCOUNTERED DURING EXCAVATION

RELEASE DATA

RELEASE ORIGIN: ((Tank), Lines, (Overfill), Intentional Release; Specify if other)

RELEASE CAUSE: ((Corrosion), Equip. Failure, (Human Error), Improper Installation, Other)

AFFECTED MEDIA: ((Soil), Subsurface Utilities, Habitations, Other)

RELEASE DESCRIPTION: SOIL ANALYSIS INDICATE SURROUNDING SOILS HAVE BEEN IMPACTED. UP TO 8050 ppm TPH DETECTED.

ANTICIPATED HAZARDS

HAZARDS/THREATS DESCRIPTION: NONE

TWC DIRECTIVES/TO WHOM: SAMPLE BACKFILL, BOTTOM AND SIDEWALLS FOR TPH & BTEX. DISPOSE SOILS AT AUTHORIZED SITE. LARRY JONES, CHEVRON; DAVID COOPER, JOHNSON CONTROLS

INITIAL AND CURRENT RESPONSE/BY WHOM: ANALYSIS HAS BEEN COMPLETED. SITE ASSESSMENT TO DETERMINE EXTENT OF CONTAMINATION WILL BEGIN IN NEAR FUTURE

MANAGEMENT DATA

INSPECTION BY TWC: 2/17/89 (Yes or No/Date) INSPECTOR NAME/OFFICE: CROCKETT HOWARD

UST COORDINATOR: Chris Chandler DIST. COORDINATOR: CROCKETT HOWARD

OTHER AUTHORITIES INVOLVED: CARCHASIA WATER QUALITY

ERU NOTIFICATION: ____ (Check when complete) REFERRAL DATE: _____

SIGNED BY: Crockett Howard DATE SIGNED: 3/17/89

APPROVED BY (Optional): Sal Sousa DATE APPROVED: 3/27/89

Revised 10/88

TEXAS WATER COMMISSION

92798 cc

B. J. Wynne, III, Chairman
Paul Hopkins, Commissioner
John O. Houchins, Commissioner

Allen Beinke, Executive Director
Michael E. Field, General Counsel
Brenda W. Foster, Chief Clerk

RECEIVED
MAR 28 89

March 20, 1989

MAR 23 89

CERTIFIED MAIL NO. P 156 349 629
RETURN RECEIPT REQUESTED

Mr. David Cooper
Manager of Engineering
Johnson Controls
P.O. Box 461729
Garland, Texas 75046

Re: Subsurface Release of Diesel at Johnson Controls, 1111 Shiloh Road, Garland (Dallas County), Texas (Facility No. 34225)

Dear Mr. Cooper:

On February 17, 1989, Mr. Crockett Howard, of this Office, contacted Mr. Larry Jones of Chenco Inc. and conducted an underground storage tank removal inspection at the above-referenced facility. During the removal, corrosion holes were observed in both tanks removed from the site. Petroleum vapors were also detected in soils in the immediate vicinity of the tank pit. Subsequent chemical analysis conducted on these soils indicates a release of diesel has occurred from the tank system. Based on this information, it appears further subsurface investigation at the site is required.

The Texas Water Commission (TWC) is responsible for protecting state waters as well as public health and safety from impacts that may result when a release occurs from an underground storage tank system. Section 26.351(b) of the Texas Water Code requires the owner or operator of an underground storage tank system to immediately abate any releases of a regulated substance and remove the resulting contamination. In order to determine the degree of remediation necessary to address this incident, you are requested to perform a contamination assessment study and provide your findings in a detailed report to this office. This report must include the following information:

(1) A description of the release including the cause, the volume lost, and all measures taken to abate and contain it.

3/28/89

(2) A determination of the vertical and horizontal extent of subsurface contamination and an account of the procedures utilized to support this determination. The term "subsurface contamination" includes not only the presence of free product, but also any dissolved-product contamination of groundwater and residual contamination of soils.

(3) A site characterization which provides a description of the local soil, geology, and groundwater conditions. If any groundwater is threatened or has already been impacted, you must also provide a water-table gradient map and a water well inventory. This inventory must locate, on a current U.S.G.S. topographic map, all water wells within a one-half mile radius of the site and provide all available information pertaining to each well. It is also necessary that you provide copies of all State of Texas Water Well Reports (Form No. WWD-012) for any installed monitor wells as is required under the Texas Water Well Driller's Act.

(4) A site map drawn to scale indicating the location of the entire underground storage tank system and all nearby buried utilities, structures, and roads. This map should also provide the location of any excavated areas and the collection points for all soil and water samples.

(5) Laboratory reports providing the results of all sample analyses and a description of sample collection and analytical procedures. Only EPA-approved methods will be accepted for the collection and analysis of samples utilized to determine waste classifications and final cleanup levels.

(6) An account of the disposition of contaminated soils and water, recovered product, or any associated wastes. If wastes are transported off-site for disposal or recycling, copies of signed receipts from the receiving facility as well as any requested uniform hazardous waste manifests must be included.

(7) A city or county map depicting the facility's location and photographs documenting observable impacts, excavations, stockpiled soils, and any on-site treatment activities.

(8) Finally, based upon the results of the assessment, a proposal for the completion of site remediation.

Please note that you are required to notify Mr. Howard of this Office at least 48 hours in advance of any significant on-site remediation activities including excavation and soil borings.

Also be advised that TWC approval must be granted before you may initiate any on-site treatment to reduce contaminant levels of affected soils and/or water. Additionally, all vapor emissions that might be associated with this release or your response activities must be controlled and monitored to protect human health and safety.

We request that a response to this letter describing your activities to date and including a schedule for the expeditious submittal of the complete site assessment study and remediation proposal be provided to this Office within 30 days following receipt of this letter. You are encouraged to secure the services of a qualified environmental consultant knowledgeable in hydrogeology to assist you in addressing this incident.

If you have any questions or require guidance regarding this matter, please contact Mr. Howard of my staff at (214) 298-6171. Your cooperation will be appreciated.

Sincerely,

Charles D. Gill
District Manager

KH:jp

cc: Keith Copeland, TWC Corrective Action Unit

1.0 Project Summary

On February 14, 1995, EnTech Environmental, (EnTech), was contracted by Mr. Rick Williams, Site Engineer for Johnson Controls, Inc., located at 1111 South Shiloh Road, Garland, Texas to remove one 20,000 gallon diesel underground storage tank (UST). After the initial contract between Johnson Controls, Inc., and EnTech was completed, a 30 day notification was then submitted to the Texas Natural Resource Conservation Commission (TNRCC) and a removal date of the UST was set for March 15, 1995.

The UST was formerly used to store diesel fuel for fueling trucks at the site. No adverse conditions were encountered prior to, during or after the removal of the 20,000 gallon diesel UST system. The UST system was removed as part of the beginning stages of the demolition of the subject facility.

As a certified TNRCC corrective action specialist (#RCAS00083), EnTech provided consulting, technical and supervisory services for the project. In addition, EnTech also performed all field sampling activities in accordance with current TNRCC and the city of Garland guidelines concerning the removal of USTs.

Prior to the tank removal, the interior of the UST was cleaned. Fluids generated during the cleaning activities were removed and disposed by American Waste Company. The UST was then tested with an explosiometer to insure that the atmosphere within the tank contained oxygen levels less than 5%. On March 15, 1995, the 20,000 gallon UST was pulled and labeled with proper warnings before transported off site.

The sampling plan for the tank excavation assessment included a total of eleven (11) samples which were collected from the excavation and fuel islands and placed in laboratory-supplied sample containers, (4 oz. wide mouth glass jars with teflon lids for soils and 750 ml. glass bottles with teflon lids for liquids) placed on ice and submitted to Anachem, an Allen, Texas based analytical laboratory for analysis. The samples were submitted and analyzed for Benzene, Toluene, Ethyl Benzene or Xylenes (BTEX) and Total Petroleum Hydrocarbons (TPH), Lead and pH.

Table 1 below depicts the analytical summary results.

Table 1:

Sample Location	Sample ID	Matrix	BTEX	TPH
Stockpile	95107-1	Soil	<10.0 ug/Kg	300 mg/Kg
Excavation	EXNW-95107-3	Soil	<2.0 ug/Kg	25 mg/Kg
Excavation	EXN-95107-4	Soil	<2.0 ug/Kg	<10 mg/Kg
Excavation	EXSE-95107-5	Soil	<2.0 ug/Kg	<10 mg/Kg
Excavation	EXSW-95107-6	Soil	<2.0 ug/Kg	<10 mg/Kg
Excavation	EXE-95107-7	Soil	<2.0 ug/Kg	70 mg/Kg
Excavation	EXW-95107-8	Soil	<2.0 ug/Kg	<10 mg/Kg
Pump Island 2	EX-9	Soil	<2.0 ug/Kg	25 mg/Kg
Pump Island 1	EX-10	Soil	29.7 ug/Kg	10 mg/Kg
Stockpile	95107-11	Soil	2.4 ug/Kg	<10 mg/Kg
EX Water From Pit	EX-12	Liq.	9.5 ug/L	124 mg/L

Other Sample Analysis:

Sample Location	Sample ID	Matrix	Lead	pH
EX Water From Pit	EX-12	Liq.	<0.050 mg/L	7.1

During the interim period of waiting for analytical and directives from the TNRCC, storm water had accumulated in the excavation. Subsequently, the water was sampled for BTEX, TPH, Lead and pH. Once determined to be "clean", a permit for discharging the storm water from the excavation to the city of Garland's sanitary sewer system was obtained. Approximately 50,000 to 60,000 gallons were discharged from the excavation

In addition to the removal of the UST, a monitor well that was located in the tank bed was also removed after consulting with Ms. Martha Britton, Field Investigator for the TNRCC PST Division, Duncanville, Texas. On March 29, 1995, Ms. Britton advised EnTech that the monitor well would have no further purpose if subsurface investigations and tank monitoring projects were completed. Upon that advice, the monitor well was removed.

A site drawing was drafted to indicate the location of the former UST system, the areas of excavation, sample locations and the layout of all associated piping. The site drawing is located in appendix 7.5.

4.0 Recommendations & Conclusion

As a result of the extraction of the 20,000 diesel UST system, no adverse subsurface conditions were encountered to the extent that remediation would be required. However, the accumulation of storm water in the excavation did result in delaying the closure of the excavation by several days pending analytical. Approximately 50,000 to 60,000 gallons of water was pumped and treated on site prior to being discharged to the city of Garland sanitary sewer system.

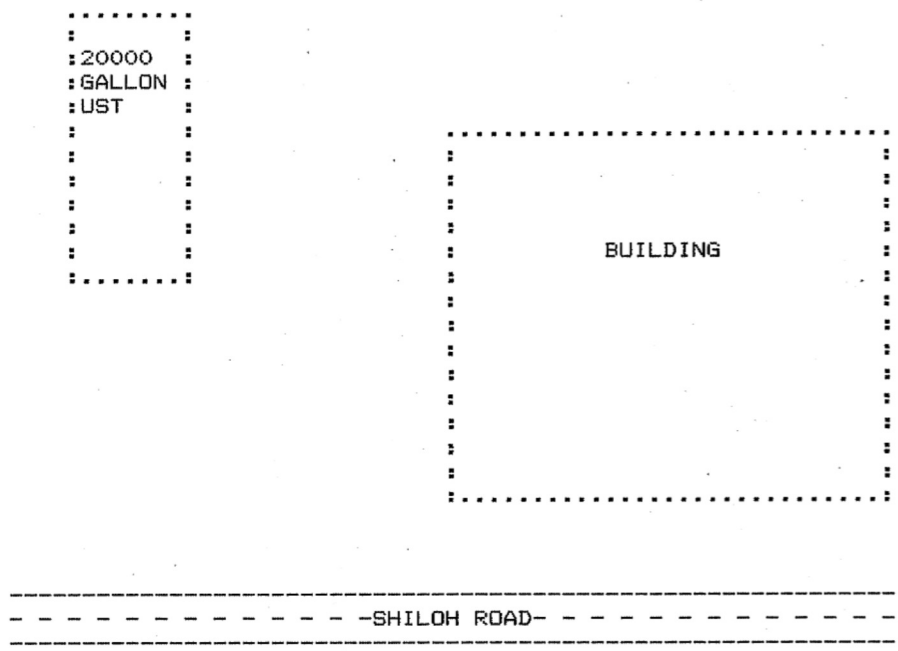
Results of all soil and water samples analyzed were well below the TNRCC action level of 500 ppm. All fill material that was excavation from the tank bed when the UST system was extracted was placed back in the excavation in addition to the 165 yards of clean fill material that was brought in to complete the backfilling of the excavation.

No recommendations regarding this project are forth coming.

SITE SKETCH FOR:

JOHNSON CONTROL CO.
1111 S. SHILOH ROAD
GARLAND, TEXAS

W
S + N
E



FOR USE IN TEXAS

Please Mail Completed Form To: UST Registration Section, PST Division
Texas Water Commission
P.O. Box 13087 - Capitol Station
Austin, TX 78711-3087

Facility ID Number (If known)

Tax ID Number (Optional)

Owner ID Number (If known)

I. OWNER INFORMATION

Owner Name: RICK WILLIAMS

Mailing Address: 1111 S. SHILOH RD.

City: GARLAND | State: TX | Zip Code: 75046

County: DALLAS

Contact Person: CHARLES DAIGLE | Telephone: (214) 690-4094

TYPE OF OWNER
- Private or Corporate: ☒
- State Government: ☐
- Local Government: ☐
- Federal Government: ☐

Location of Records (If off-site)

Address, City, State

Custodian of Records | Telephone: ( )

II. FACILITY INFORMATION

Facility Name: JOHNSON CONTROL

Physical Address: 1111 S. SHILOH ROAD

City: GARLAND | State: TX | Zip Code: 75046

County: DALLAS

Contact Person: CHARLES DAIGLE | Telephone: (214) 690-4094

TYPE OF FACILITY (mark all that apply)
- Retail: ☐
- Wholesale: ☐
- Fleet Refueling: ☒
- Farm or Residential: ☐
- Industrial, Chemical, or Manufacturing Plant: ☐
- Aircraft Refueling: ☐
- Indian Land: ☐
- Other (please specify):

Number of Underground Tanks at This Facility: 0

Number of Aboveground Tanks at This Facility: 0

III. REGISTRATION STATUS

If this is the first time that this facility has been registered, or if you are not sure if it has been registered, mark here: ORIGINAL FORM ☐

If this is an amendment (e.g. ownership change, location name change or UST status change) to a form that was previously filed with the TWC, mark here: AMENDED FORM ☒

NOTE: If this is an amendment to a UST form that has already been filed with the Texas Water Commission, briefly explain the change in the space provided (attach additional sheets if necessary). Please include dates, names, addresses, phone numbers and any other pertinent information.

PERMANENTLY REMOVED FROM THE GROUND ONE (1) 20000 GALLON UST

IV. FINANCIAL RESPONSIBILITY

COMPLIANCE DATE (mark one)

Sept. 29, 1989 ☐ Oct. 26, 1989 ☐ April 26, 1990 ☐ Oct. 26, 1990 ☐

FINANCIAL RESPONSIBILITY MECHANISM (mark all that apply)
- Letter of Credit: ☐
- Trust Fund: ☐
- Insurance or Risk Retention Group: ☐
- Surety Bond: ☐
- Guarantee: ☐
- Self Insured: ☐
- PST Remediation Fund: ☐
- Standby Trust Fund: ☐
- Other (please specify):

V. INSTALLER CERTIFICATION

NOTE: This section must be completed and signed by the Installer. Leave blank if no installation activity is involved.

I certify that the information provided concerning recent installations is true to the best of my belief and knowledge:

Was tank testing completed during and after installation? ☐ Yes ☐ No

Installation Company Name (print): _____ Contractor's Registration Number: _____

Installer's Name (print): _____ Installer's License Number: _____

Installer Signature: _____ Date Signed: _____

VI. OWNER CERTIFICATION

I certify under penalty of law that I have personally examined and am familiar with the information submitted in this and all attached documents, and based on my inquiry of those individuals immediately responsible for obtaining the information, I believe that the submitted information is true, accurate, and complete.

Owner or Owner's Authorized Representative (print): DON L. HUNT Title (print): OSS/AWC

Signature: DL Hunt Date Signed: 3-15-95

WC-0724 (12-29-89)

TANK STATUS

Tank Installation Date *(month/year)*	UKN 2000			
Tank Capacity *(gallons)*				
1. Currently in Use	1. ☐	1. ☐	1. ☐	1. ☐
2. Temporarily Out of Service *(date)*	2. / /	2. / /	2. / /	2. / /
Emptied *(Yes/No)*	☐Y ☐N	☐Y ☐N	☐Y ☐N	☐Y ☐N
3. Permanently Abandoned In-place *(date)* (must be filled with sand or concrete, etc.)	3. / /	3. / /	3. / /	3. / /
4. Permanently Removed from the Ground *(date)*	4. 03/14/AS	4. / /	4. / /	4. / /

UST CONSTRUCTION AND CONTAINMENT (mark all that apply) ☒

1. Single Wall
2. Double Wall
3. External Jacket System
4. Excavation/Trench Liner System
5. Piping System:
   - a. Pressurized
   - b. Suction
   - c. Gravity
6. Other *(please specify)*

	Tank	Piping	Tank	Piping	Tank	Piping	Tank	Piping
1.	☒	☒	☐	☐	☐	☐	☐	☐
2.	☐	☐	☐	☐	☐	☐	☐	☐
3.	☐	☐	☐	☐	☐	☐	☐	☐
4.	☐	☐	☐	☐	☐	☐	☐	☐
5.		a. ☐ b. ☐ c. ☐		a. ☐ b. ☐ c. ☐		a. ☐ b. ☐ c. ☐		a. ☐ b. ☐ c. ☐
6.								

MATERIAL OF CONSTRUCTION

1. Steel
2. Fiberglass-Reinforced Plastic (FRP)
3. Composite (steel w/FRP laminate)
4. Concrete
5. Other *(please specify)*

	Tank	Piping	Tank	Piping	Tank	Piping	Tank	Piping
1.	☐	☐	☐	☐	☐	☐	☐	☐
2.	☒	☒	☐	☐	☐	☐	☐	☐
3.	☐		☐		☐		☐	
4.	☐	☐	☐	☐	☐	☐	☐	☐
5.								

RELEASE DETECTION (mark all that apply) ☒

1. Vapor Monitoring
2. Groundwater Monitoring
3. Monitoring Above Excavation Liner
4. Automatic In-Tank Monitoring & Inventory Control
5. Interstitial Monitoring for Double Wall UST's
6. Tightness Testing
7. Inventory Control
8. Unknown/None
9. Line Leak Detectors
10. Other *(please specify)*

	Tank	Piping	Tank	Piping	Tank	Piping	Tank	Piping
1.	☐	☐	☐	☐	☐	☐	☐	☐
2.	☐	☐	☐	☐	☐	☐	☐	☐
3.	☐	☐	☐	☐	☐	☐	☐	☐
4.	☐		☐		☐		☐	
5.	☐	☐	☐	☐	☐	☐	☐	☐
6.	☐	☐	☐	☐	☐	☐	☐	☐
7.	☐		☐		☐		☐	
8.	☒	☒	☐	☐	☐	☐	☐	☐
9.		☐		☐		☐		☐
10.								

SUBSTANCE STORED

1. Empty
2. Gasoline
3. Diesel
4. Kerosene
5. Used Oil
6. New Oil
7. Other Petroleum Product *(please specify)*
8. Hazardous Substance
   - a. Name of Principal CERCLA Substance
   - b. Chemical Abstract Service (CAS) No.
   - c. Mixture of Hazardous Substances
9. Mixture of Petroleum & Hazardous Substance
10. Other *(please specify)*

1.	☐	4. ☐	1. ☐	4. ☐	1. ☐	4. ☐	1. ☐	4. ☐
2.	☐	5. ☐	2. ☐	5. ☐	2. ☐	5. ☐	2. ☐	5. ☐
3.	☒	6. ☐	3. ☐	6. ☐	3. ☐	6. ☐	3. ☐	6. ☐
7.			7.		7.		7.	
8.			8.		8.		8.	
a.			a.		a.		a.	
b.			b.		b.		b.	
c.	☐		c.	☐	c.	☐	c.	☐
9.	☐		9.	☐	9.	☐	9.	☐
10.			10.		10.		10.	

SPILL AND OVERFILL PREVENTION (mark all that apply) ☒

1. Tight-Fill Fitting
2. Spill Container/Liquid-Tight Sump
3. Automatic Overfill Device:
   - a. Shut-Off Valve
   - b. Flow Restrictor Valve
   - c. High Level Alarm
4. Unknown/None

1.	☐	1. ☐	1. ☐	1. ☐
2.	☐	2. ☐	2. ☐	2. ☐
3.		3.	3.	3.
a.	☐	a. ☐	a. ☐	a. ☐
b.	☐	b. ☐	b. ☐	b. ☐
c.	☐	c. ☐	c. ☐	c. ☐
4.	☒	4. ☐	4. ☐	4. ☐

CORROSION PROTECTION (mark all that apply) ☒

1. External Coatings:
   - a. Painted (e.g. asphaltic)
   - b. Dielectric (e.g. coal tar epoxy)
   - c. Fiberglass-Reinforced Plastic
   - d. Taped/Wrapped Piping
2. Internally Lined Tank (e.g. epoxy resin)
3. Cathodic Protection System
4. Composite Tank (steel w/FRP laminate)
5. Noncorrodible Material Construction
6. Electrical Isolation
7. Unknown/None

	Tank	Piping	Tank	Piping	Tank	Piping	Tank	Piping
1.								
a.	☐	☐	☐	☐	☐	☐	☐	☐
b.	☐	☐	☐	☐	☐	☐	☐	☐
c.	☐	☐	☐	☐	☐	☐	☐	☐
d.		☐		☐		☐		☐
2.	☐		☐		☐		☐	
3.	☐	☐	☐	☐	☐	☐	☐	☐
4.	☐		☐		☐		☐	
5.	☐	☐	☐	☐	☐	☐	☐	☐
6.	☐	☐	☐	☐	☐	☐	☐	☐
7.	☒	☒	☐	☐	☐	☐	☐	☐

SITE CLOSURE REQUEST FORM

I. GENERAL INFORMATION

LPST ID No.: 92788 Facility ID No.: _____

Responsible Party: Johnson Controls

Facility Name: Johnson Controls Inc.

Facility Street Address: 1111 Shiloh Rd

Facility City: Garland County: Dallas

What is the current use of site? (indicate all that apply):
☒ Residence ☐ School or Day Care center ☐ Commercial/Industrial ☐ Recreational ☐ Agricultural

What is the anticipated future use of the site? (indicate all that apply):
☐ Residence ☐ School or Day Care center ☐ Commercial/Industrial ☐ Recreational ☐ Agricultural

Adjacent property use (indicate all that apply):
☐ Residence ☐ School or Day Care Center ☐ Commercial/Industrial ☐ Recreational ☐ Agricultural

Distance to nearest off-site residence from property line: _____ feet in _____ direction.
Distance to nearest school or day care center from property line: _____ feet in _____ direction.

II. CLOSURE SCREENING INFORMATION

Based on the *Limited Site Assessment Report* form or the Risk-Based *Assessment Report Form* (TNRCC-0562), the site is a **Priority** 4 site.

☐ Yes ☒ No Have non-aqueous phase liquids (NAPL) ever been present at this site? If yes, is NAPL present now (thickness ≥0.1 feet)? ☐ Yes ☐ No Thickness: _____ feet. If NAPL is currently present, stop here and do not submit this form for case closure. Initiate or continue activities necessary for the removal of all recoverable NAPL at the site.

☐ Yes ☐ No Has the source of the release been abated? If yes, specify date and abatement methods: _____

☐ Yes ☐ No Has groundwater been affected?

☐ Yes ☐ No Has a receptor survey been conducted?

☐ Yes ☐ No Has a water well inventory been conducted?

☐ Yes ☐ No Have vapor impacts to buildings or utility lines ever been associated with this release? If Yes, specify the measures taken to abate the impact and indicate the latest date that an impact was noted:

☐ Yes ☐ No Have subsurface utilities ever been affected with NAPL or vapors by this release? If Yes, indicate the latest date that an impact was noted: _____

☐ Yes ☐ No Do contaminant concentrations show a consistent decreasing or low static trend? If No, is the contaminant plume increasing in size? ☐ Yes ☐ No If Yes, stop here, do not submit this form, and initiate activities to control plume migration. If the contaminant concentrations are not decreasing, provide justification: _____

20 018

III. RELEASE ABATEMENT/REMEDIATION

Date Release Discovered: _____

Substance(s) released: (check all that apply) ☐ Gasoline ☐ Alcohol-blended fuel (Type and percentage of alcohol: _____)
☐ Diesel ☐ Used Oil ☐ Jet Fuel (type: _____) ☐ Aviation Gasoline ☐ Other: (be specific) _____

Source of Release (specify all that apply):
☐ Spills/overfills ☐ Piping leaks ☐ Dispenser leaks ☐ Tank corrosion ☐ Other: _____

If not already provided in *Release Report Form* (TNRCC-0621), indicate number of tanks currently and formerly located at this site (attach pages as necessary):

	Type (UST/AST)	Product Type	Size (approx. gal)	Date Removed from Service
Current:				
Former:	1	diesel	20,000	3-15-1996

☒ Yes ☐ No Were native soil samples collected from beneath the UST **and** the piping? If No, explain why not: _____

☐ Yes ☐ No Were native soil samples collected from beneath the dispensers? If No, explain why not: _____

☐ Yes ☒ No Was a new UST system installed? If Yes, indicate the date, number of tanks and their contents: _____

☐ Yes ☒ No Are there any open excavations at the site? If Yes, state size, location, purpose, and status for each of the excavations: _____

Type(s) of soil remediation and time periods the remediation method was operational (indicate all that apply):
☒ Excavation 3-14-96 to 4-12-96 (dates), and
- ☐ Aboveground Bioremediation _____ to _____ (dates), or
- ☐ Thermal Treatment _____ to _____ (dates), or
- ☐ Disposal 3-15-96 to _____ (dates).

☐ Soil Vapor Extraction _____ to _____ (dates).
☐ In-Situ Bioremediation _____ to _____ (dates).
☐ None

Type(s) of groundwater remediation and time periods the remediation method was operational (indicate all that apply):
☐ Groundwater Pump and Treat _____ to _____ (dates)
☐ Air Sparging/SVE _____ to _____ (dates)
☐ In-Situ Bioremediation _____ to _____ (dates)
☐ Other: _____ _____ to _____ (dates)
☒ None

III. RELEASE ABATEMENT/REMEDIATION (Continued)

☐ Yes ☐ No Were copies of all receipts and manifests to document disposition of all wastes submitted to the TNRCC? If No, attach copies to this form.

Measured total volume of NAPL recovered: _____ gallons.

Estimated total volume of soil treated/removed: _____ cubic yards (exclude soil cuttings removed from borings).

Estimated total volume of groundwater treated/removed: _____ gallons (if known).

Estimated pounds of hydrocarbons removed or treated from soil (if known): _____

Estimated pounds of hydrocarbons removed or treated from groundwater (if known): _____

Estimated percent of total contaminants removed or treated (if known): _____

IV. SOIL DATA VALIDATION

Are there now affected surface soils (contamination exceeding health-based target concentrations) present within 2 feet below the ground surface? ☐ Yes ☐ No unknown. contaminated soil was mixed with clean soil to backfill into the tank hole

Type of surface cover over affected surface soil area:

☒ Paved [☐ Asphalt or ☐ Concrete] Percent of affected soils covered? _____ ☐ Unpaved

☐ Other: _____

Is there public access to the affected surface soil area? ☐ Yes ☐ No

Number of borings converted to monitor wells: _____ Number of borings **not** converted to monitor wells: _____

☐ Yes ☐ No Was the vertical and horizontal extent of soil impacts defined (to health-based target concentrations horizontally and to groundwater or nondetect vertically) by the borings?

☐ Yes ☐ No Are shallow (0-15 feet below ground surface) soils affected (contaminant levels exceed health-based target concentrations) on adjacent properties (including right-of-way properties).

☐ Yes ☐ No Were all soil sample collection, handling, transport, and analytical procedures conducted in accordance with TNRCC and EPA requirements? If No, provide justification: _____

☐ Yes ☐ No Were all regulated soil wastes properly disposed of, treated, or reused in accordance with TNRCC requirements? If No, describe the location(s) and status of wastes yet to be disposed: _____

MAXIMUM SOIL CONCENTRATION LEVELS

Soil Contaminants	Sample Date	Sample Location	Depth (in feet below ground surface)	Analytical Method	Maximum Concentration* (mg/kg)	Target Cleanup Goals** (indicate source of target cleanup goals: 1990 or 1994 [Plan A or B] guidance)
Benzene						
Toluene						
Ethylbenzene						
Total Xylenes						
Total BTEX						
TPH						
Other						
Other						

* Enter maximum soil analytical results for soils remaining beneath the site (take into account all available data, including information obtained during the release determination (tank removal from service, minimal site assessment, etc)).

** If Plan A cleanup goals were used, provide the potential groundwater beneficial use category and a justification of how it was determined in Section VI.

1990 cleanup goals may be used only if all activities necessary to meet those goals were completed by November 8, 1995.

V. GROUNDWATER DATA VALIDATION

Is groundwater at the site impacted? ☐ Yes ☐ No one Groundwater monitoring well was dogged under TNRCC approval.

Did the assessment document that groundwater was not impacted? ☐ Yes ☐ No If No or unsure, provide justification for not determining whether there is a groundwater impact:_____

Total number of monitoring wells installed: _____ Number of monitor wells remaining at the site:_____

Will the remaining wells be used in the future? ☐ Yes ☐ No If No, they must be plugged in accordance with 30 TAC Chapter 338.

Measured total dissolved solids (TDS) concentration in groundwater: _____ mg/l. From which monitor well was this sample collected? _____

Measured groundwater yield at the site: _____ gallons/day.

Measured groundwater depth at the site ranges between _____ and _____ feet below the top of well casing.

Time period of groundwater monitoring at the site (dates): _____ to _____.

Total number of groundwater monitoring events: _____.

What type of aquifer is impacted? (unconfined, confined, semi-confined):_____.

Distance from maximum plume concentration point to nearest existing downgradient well location (not monitor well): _____ ft. in _____ direction (Input ">0.5 mile" if there is no well within 0.5 mile downgradient)

Are any water supply wells impacted or immediately threatened? ☐ Yes ☐ No
If Yes, specify type of well: ☐ Drinking water ☐ Non-drinking water

Are there any existing water wells located within the area of affected groundwater? ☐ Yes ☐ No
If Yes, specify type of well: ☐ Drinking water ☐ Non-drinking water

Has surface water been affected? ☐ Yes ☐ No

Will the groundwater contaminants likely discharge to a surface water body? ☐ Yes ☐ No

What is the potential impact of affected groundwater discharge on surface water?
☐ Current impact ☐ Discharges within 500 ft. ☐ Discharges within 500 to 0.25 miles
☐ No potential discharge

☐ Yes ☐ No Were groundwater sample collection, handling, transport, and analytical procedures conducted and documented in accordance with TNRCC requirements? If no, provide justification:_____

V. GROUNDWATER DATA VALIDATION (Continued)

☐ Yes ☐ No Is the extent of groundwater contamination defined (to MCL concentrations)? If No, provide justification for not defining the plume:_____

_____

☐ Yes ☐ No Have groundwater impacts from this release been detected on adjacent properties? If No, is off-site migration probable? ☐ Yes ☐ No Is there documentation that off-site migration has **not** occurred? ☐ Yes ☐ No

☐ Yes ☐ No Was the static groundwater level above the top of the well screen in any monitor wells during any of the last 4 monitoring events? If Yes, provide a statement of validity regarding these samples:

_____

_____

☐ Yes ☐ No Have groundwater samples from all monitor wells met the target cleanup goals for the last four consecutive sampling events?

☐ Yes ☐ No Was all recovered contaminated groundwater properly disposed of, treated or recycled in accordance with TNRCC requirements? If No, what is the status of the waste?:_____

_____

MAXIMUM GROUNDWATER CONCENTRATIONS

Groundwater Contaminants	Sample Date	Sample Location	Laboratory Method	Maximum Concentration* (mg/l)	Target Cleanup Goals** *(indicate source of target cleanup goals: 1990 or 1994 [Plan A or B] guidance)*
Benzene					
Toluene					
Ethylbenzene					
Total Xylenes					
Total BTEX					
TPH					
Other_____					
Other_____					

* Enter maximum groundwater analytical results from the most recent 12 months of monitoring.

** 1990 cleanup goals may be used only if all activities necessary to meet those goals were completed by November 8, 1995.

20 023

VI. JUSTIFICATION FOR CLOSURE

Please provide a brief summary supporting this request for site closure, including footnoted discussions for the above entries as necessary. Include discussions providing necessary justifications for any site conditions which deviate from the specific requirements of TNRCC rules and policies, including the document *Risk-Based Corrective Action for Leaking Storage Tank Sites*. Provide documentation to justify case closure, including information which addresses the potential for future exposure, the existence of impervious cover or other actions which may prevent exposure or limit infiltration, the absence of receptors, etc.

1. The BTEX Concentration levels are below cleanup levels.
2. [TPH] in stockpile was 388 ppm. However, it was mixed with clean soil and all backfilled the tank hole
3. The tank hole was covered by concrete and this creates incomplete exposure pathway
4. The [TPH] in pit water was 124 mg/L which is higher than TNRCC benchmark level. But it is assumed that the water with storm water and drained into the City of Garland sewer line under city's supervision
5. Therefore, this site could be closed!

20 024

VII. REPORT PREPARATION

I certify that the results of the investigation detailed in this document are valid and representative of site conditions. All activities were conducted in accordance with accepted industry standards/practices and that the work adhered to TNRCC guidance and rules and State of Texas laws. I certify that this document is complete and that the information contained in this document is accurate and representative of site conditions. I certify that I am aware that misrepresentation of any of the above claims is a violation of 30 TAC 334.453(b)(1)(E) and that this violation may result in the disciplinary actions set forth in 30 TAC 334.453 and/or 334.463 and 334.465. **I certify that the site has met all requirements for closure and that closure is appropriate.**

Project Manager:_____ CAPM No.:_____ Expiration date:_____

Company:_____

Address:_____ City:_____ State:_____ Zip:_____

Telephone No.:_____ Fax No.:_____

Signature:_____ Date:_____

I certify that the results of the investigation detailed in this document are valid and representative of site conditions. All activities were conducted in accordance with accepted industry standards/practices and that the work adhered to TNRCC guidance and rules and State of Texas laws. I certify that this document is complete and that the information contained in this document is accurate and representative of site conditions. I certify that I am aware that misrepresentation of any of the above claims is a violation of 30 TAC 334.453(b)(1)(E) and that this violation may result in the disciplinary actions set forth in 30 TAC 334.453 and/or 334.463 and 334.465. **I certify that the site has met all requirements for closure and that closure is appropriate.**

Corrective Action Specialist:_____ CAS No.:_____ Expiration date:_____

Company:_____

Address:_____ City:_____ State:_____ Zip:_____

Telephone No.:_____ Fax No.:_____

Signature:_____ Date:_____

I certify that I have reviewed this report for accuracy and completeness. I understand that I am responsible for addressing this matter.

Name of Responsible Party contact:_____

Telephone No.:_____ Fax No.:_____

Signature:_____ Date:_____

THE FOLLOWING ITEMS MUST BE SUBMITTED WITH THIS FORM:

- A site map illustrating the locations of the entire UST and/or AST system (including piping, dispensers, observation wells, etc.), all soil borings and monitoring wells, subsurface utilities, and surface water within 500 feet.
- A copy of the latest groundwater gradient map (if monitor wells were completed).
- Summary tables of all soil, groundwater and surface water analytical results, including samples collected from any tank removal from service activities, tank system repair activities, and those collected from borings and monitor wells. The tables must clearly identify the sample number and sampling locations.
- Copies of any manifests, other waste receipts, or other documents necessary for case closure that were not previously submitted.

Youngmoo Kim
(214) 665-6788

Summary of Review to recommend closure approval

Johnson Controls, Inc. LPST No. 92788

1. 20,000 gallon diesel tank was removed on March 15, 1995 - cleaned and disposed to Hughes Tank Company.
2. BTEX Values are below detection limits for all (10) soil samples.
3. The concentration of TPH in stockpile was 388 ppm which is above TNRCC Target level. However, stockpile soil of unknow volume was pulled back into the tank hole with ≈ 165 yd^3 clean fill material. The concrete was poured into the hole to close. — This gives Incomplete exposure pathway. The stockpile was better analyzed for PAHs since the tank was used diesel storage.
4. The TPH concentration of Ex. Water from pit #12 was 124 mg/L above TNRCC level. However, the water with Storm water was assumed to drain into city of Garland sewer line under city's supervision.
5. 1 remain Groundwater MW was plugged under TNRCC approval.
6. Therefore, the site can be approved for closure.

NO DATE

Texas Natural Resource Conservation Commission

INTEROFFICE MEMORANDUM

TO : FILE **DATE:** April 16, 1996

THRU : Chet Clarke, Section Manager
Responsible Party Remediation Section
Petroleum Storage Tank Division
cwc Chris Chandler, RPR Section

FROM : Youngmoo Kim, EPA Case Reviewer

SUBJECT : File Closure of Subsurface Hydrocarbon Contamination at the Johnson Control Inc. facility, 1111 S. Shiloh Road, Garland (Dallas County) Texas, (LPST ID No. 92788)

One 20,000 gallon diesel fuel tank was removed from the ground on March 15, 1995. Samples collected from the tankhold, piping chase, and from under the dispenser indicated contaminant levels of nondetectable benzene, less than 30 ppb BTEX, and less than 70 ppm TPH. Rainwater which entered the tankhold during the removal activities was removed and discharged to the city's sanitary sewer system. Stockpiled backfill, with contaminant levels of 388 ppm TPH and nondetectable BTEX, was placed back into the excavation and the area was completed with concrete.

Based on the remaining low contaminant levels, I recommend that this case be assigned final status.

Chandler
for Youngmoo Kim

92788.clo

cc: Sam Barrett, TNRCC Region 4 Field Office

4-16-96

92788

Barry R. McBee, *Chairman*
R. B. "Ralph" Marquez, *Commissioner*
John M. Baker, *Commissioner*
Dan Pearson, *Executive Director*

TEXAS NATURAL RESOURCE CONSERVATION COMMISSION

Protecting Texas by Reducing and Preventing Pollution

May 31, 1996

Mr. Richard D. Williams
Johnson Controls
5757 North Green Bay Avenue
Milwaukee, Wisconsin 53209-4408

Re: Leaking Petroleum Storage Tank (LPST) Case Closure of Subsurface Hydrocarbon Contamination at the Johnson Controls facility, 1111 South Shiloh Road, Garland (Dallas County) (LPST ID No. 92788, Facility ID No. 34225)

Dear Mr. Williams:

This letter confirms the completion of corrective action requirements for the release incident at the above-referenced facility. Based upon the submitted information and with the provision that the documentation provided to this agency was accurate and representative of site conditions, we concur with your recommendation that the site has met the closure requirements. No further corrective action is necessary.

For any subsequent release from an underground or aboveground storage tank at this site, the deductible will be increased in accordance with Section 26.3512 of the Texas Water Code. Additionally, if any storage tanks are operated at this site, the owner or operator must now secure financial assurance to cover the deductible in accordance with the appropriate provisions of Title 30, Sections 334.91-334.109 of the Texas Administrative Code.

If there is to be any other necessary site restoration activities to complete site closure, complete a *Final Site Closure Report* and submit the report to both the local TNRCC Regional Field Office and to the Central Office in Austin to document actual site closure. For sites which are eligible for reimbursement through the Petroleum Storage Tank Remediation Fund, written preapproval should be obtained prior to initiation of site closure activities. Reimbursement claims for activities that are not preapproved will not be paid until all claims for preapproved work are processed and paid.

Please note that the *Final Site Closure Report*, if necessary, will be the last submittal associated with this case. This letter signifies the completion of corrective action associated with the release. No subsequent TNRCC correspondence will be issued in response to the *Final Site Closure Report*.

5/31/96

Please note that all correspondence must include the LPST ID Number and must be submitted to both the local TNRCC Regional Field Office and to the Central Office in Austin.

Should you have any questions, please contact Ms. Chris Chandler of my staff at 512/239-2200. **Please reference the LPST ID Number when making inquiries.** Your cooperation in this matter has been appreciated.

Sincerely,

for Chandler
Chet Clarke, Manager
Responsible Party Remediation Section
Petroleum Storage Tank Division

92788.fnn

cc: Sam Barrett, TNRCC Region 4 Field Office
(1019 N. Duncanville Rd., Duncanville, Tx 75116-2201)

Reference 21

TEXAS
Health and Human Services

Texas Department of State Health Services

Assessment of the Occurrence of Cancer

Census Tracts 185.01 and 186.00
Garland, Texas
2000-2015

June 19, 2018

Prepared by the
Texas Department of State Health Services

Investigation# 18001

Table of Contents

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Executive Summary

Community concern prompted the Environmental and Injury Epidemiology and Toxicology Unit (EIET) and Texas Cancer Registry (TCR) of the Texas Department of State Health Services (DSHS) to examine the occurrence of cancer in two census tracts (185.01 and 186.00) in Garland, Texas.

DSHS followed the Centers for Disease Control and Prevention (CDC) and Council of State and Territorial Epidemiologists (CSTE) 2013 guidelines and agency protocol to investigate the occurrence of 8 types of all-age cancers in a geographic area selected in collaboration with community members. In accordance with these guidelines, the purpose of this assessment was to determine whether the observed number of cancer cases is statistically significantly greater than expected. It was not intended to determine the cause of the observed cancers or identify possible associations with any risk factors.

DSHS staff analyzed TCR data available for a 16-year period spanning from 2000 through 2015. United States Census data was used to estimate the population in the selected geographic area, which consisted of two census tracts. To evaluate the occurrence of cancer in the area investigated, the number of observed cancer cases was compared to what would be expected for the area based on cancer rates in Texas. Standardized incidence ratios (SIRs) were calculated as the number of observed cases divided by the number of expected cases in the area of concern for the 16-year period (2000-2015). A 95 percent confidence interval (CI) was calculated for each SIR to determine statistical significance.

The number of all-age bladder, breast, kidney, chronic myeloid and lymphocytic leukemia, lung, liver, pancreatic, and colon cancer was within the range of what is expected based on cancer rates in Texas.

Background

Community concern expressed to the Texas Department of State Health Services (DSHS) prompted the agency's Environmental and Injury Epidemiology and Toxicology Unit (EIET) and Texas Cancer Registry (TCR) to examine the occurrence of cancer in two census tracts (185.01 and 186.00) in Garland, Texas.

The Centers for Disease Control and Prevention (CDC) and Council of State and Territorial Epidemiologists (CSTE) define a cancer cluster as a greater than expected number of cancer cases that occurs within a group of people in a geographic area over a defined period of time[1]. DSHS followed the CDC and CSTE 2013 Guidelines for Investigating Suspected Cancer Clusters and Responding to Community Concerns[1] and agency protocol[2] to investigate the occurrence of cancer in this community.

The CDC and CSTE guidelines include four steps[1]. The first step is to collect information about the community's concerns. The second step, reported here, is to determine whether the observed number of cancer cases is statistically significantly greater than expected. It is important to note that the data and statistical analysis conducted at this step cannot determine if cancers observed in the community are associated with environmental, lifestyle, or other risk factors.

The guidelines also provide additional steps that can be followed when appropriate. The third step is to evaluate the feasibility of performing an epidemiologic study to examine if exposure to a specific risk factor is associated with the suspected cancer cluster, and the fourth step is to conduct an epidemiologic study, if deemed feasible in step three. Many factors are considered in making the determination to progress to steps three or four. The CDC and CSTE guidelines state, "only a small fraction of cancer cluster inquiries might meet the statistical and etiological criteria to support a cluster investigation through all the steps outlined…."[1]

Methods

Consistent with the CDC and CSTE guidelines, DSHS collaborated with the community to select the geographic area, time frame, and cancers to be included in this analysis. The following cancer types were included in the analysis: breast, bladder, colon, chronic myeloid and lymphocytic leukemia,

[1] Centers for Disease Control and Prevention, *Investigating Suspected Cancer Clusters and Responding to Community Concerns.* MMWR, 2013. 62: p. 22.
[2] Texas Department of State Health Services, *Protocol for Responding to Community Cancer Cluster Concerns.* Updated January 15, 2016. Available from: http://www.dshs.texas.gov/epitox/CancerClusters/Protocol-for-Responding-to-Community-Cancer-Cluster-Concerns.pdf.

kidney, liver, lung, and pancreas. The following cancer types could not be analyzed because there were <6 cases: brain, Hodgkin lymphoma, testis, and soft tissue. The geographic area investigated was selected to encompass the entire area of concern. The two census tracts comprising the area investigated are shown in Figure 1.

This document outlines the results from step two of the CDC and CSTE guidelines, and only addresses the question, "Is there a statistically significant excess of cancer in the area of investigation?"

Data Sources

For each cancer type, the number of cases observed from 2000 through 2015 in the area included in the investigation was obtained from the TCR (Incidence – Texas, 1995-2015, SEER*Prep 2.5.3). The TCR is responsible for the collection, maintenance, and dissemination of high-quality Texas population-based cancer data, and meets national CDC timeliness and data quality standards, as well as North American Association of Central Cancer Registry certification standards. All-age cancers were defined according to Site Recode ICD-O-3/WHO 2008 Definitions[3]. Statewide cancer rates for the same time period were also obtained from the TCR.

Population estimates for 2000 through 2015 were calculated using linear interpolation based on population counts obtained from the United States Decennial Census[4] for the years 2000 and 2010. This method, outlined by the United States Census Bureau[5], assumed population growth occurred in a linear manner.

Statistical Analysis

To determine if a statistically significant excess of cancer existed in the area investigated, the number of observed cancer cases was compared to what would be expected for the area based on cancer rates in Texas. Characteristics such as race, sex, and age are closely related to cancer. To ensure that differences between the numbers of observed and expected cancer cases are not simply due to differences in these demographic characteristics, the expected numbers of cancer cases were calculated by multiplying the age-, sex-, and race-specific cancer incidence rates of Texas residents (reference population) by the number of people in the corresponding demographic groups in the area of investigation.

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[3] National Cancer Institute, Surveillance, Epidemiology and End Results Program. Site Recode ICD-O-3/WHO 2008 Definition. Available online: http://seer.cancer.gov/siterecode/icdo3_dwhoheme/index.html

[4] United States Census Bureau. *American FactFinder*. 2012; Available from: http://factfinder2.census.gov/faces/nav/jsf/pages/index.xhtml.

[5] US Census Bureau. *Methodology for the Intercensal Population and Housing Unit Estimates: 2000 to 2010*. 2012; Available from: http://www.census.gov/popest/methodology/2000-2010_Intercensal_Estimates_Methodology.pdf.

Standardized incidence ratios (SIRs) were calculated to determine if an excess of cancer exists in the area. The SIR is the number of observed cases compared to (divided by) the number of expected cases for each cancer type. A SIR greater than 1.00 indicates that the observed number of cases of a specific cancer type is higher than expected and a SIR less than 1.00 indicates that the observed number of cases of a specific cancer type is lower than expected.

Few, if any, communities will have exactly the same rate as the average state rate for a similar population; most will be higher or lower. Therefore, 95 percent confidence intervals (CI) were calculated for the SIRs to determine if the observed number of cases was statistically significantly different than expected. If a 95 percent CI (range) includes 1.00, no statistically significant excess (or reduction) of cancer is indicated. If a 95 percent CI does not contain 1.00, the SIR is outside the expected range and is statistically significant. When using a 95 percent CI, 5 percent of SIR values calculated is expected to be statistically significantly higher or lower than the state average due to random chance alone.

In all cases, when results are described as significant or not significant, DSHS is referring only to statistical significance, with the understanding that all cases of cancer are significant to the individual, the family, and friends of the individuals who are affected.

Results

Table 1 presents the number of observed cases, the number of expected cases, the SIRs, and the corresponding 95 percent CIs for each cancer type evaluated in the area of investigation. The number of bladder, breast, kidney, chronic myeloid and lymphocytic leukemia, lung, liver, pancreas, and colon cancer was within the range of what is expected based on cancer rates in Texas.

Table 1. Standardized Incidence Ratios (SIRs) and 95 percent Confidence Intervals (CIs) for Selected Cancers in Census Tracts 185.01 and 186.00, Garland, Texas, 2000-2015.

Cancer Type	Observed	Expected	SIR	95% CI
Bladder	31	21.8	1.43	(0.97, 2.02)
Breast	83	79.6	1.04	(0.83, 1.29)
Chronic Myeloid/ Lymphocytic Leukemia	7	9.1	0.77	(0.31, 1.59)
Colon	42	38.3	1.10	(0.79, 1.48)
Kidney	30	20.5	1.46	(0.99, 2.09)
Liver	7	8.9	0.79	(0.32, 1.63)
Lung	88	78.8	1.12	(0.90, 1.38)
Pancreatic	17	14.2	1.20	(0.70, 1.92)

Discussion

Consistent with the second step of the CDC and CSTE guidelines for investigating suspected cancer clusters, the primary purpose of this step (assessment) is to determine whether the observed number of cases is statistically significantly greater than expected[1]. It is not intended to determine the cause of the observed cancers or identify possible associations with any risk factors.

The assessment step in a cancer cluster investigation has several inherent limitations, and results should be interpreted with these limitations in mind. Cancer is not a single disease, but rather many different diseases. Different types of cancers vary in etiologies (causes or origins) and may not share the same predisposing factors. Cancers may be associated with a variety of factors such as genetics, lifestyle, and socioeconomic status. Because cancer is common, cases might appear to occur with alarming frequencies within a community even when the number of cases is within the expected rate for the population.

Additionally, cancer incidence data are based on residence at the time of diagnosis. As people move, it becomes more difficult to determine whether living in the area of investigation is associated with an excess of cancers, because residential history is not tracked. Latency (the time period elapsed between exposure and illness onset) adds to the complexity of this step in the investigation. For most adult cancers, a period of 10 to 40 years can elapse between the beginning of an exposure to a cancer-causing agent and the development of a clinically diagnosable case of cancer. It is possible that

former residents who developed cancer no longer lived in the area at the time of diagnosis, and these cases would not be included in this assessment. It is also possible that new people have moved into the area and then were diagnosed with cancer; these cases are included in this assessment.

Conclusion

The number of bladder, breast, kidney, chronic myeloid and lymphocytic leukemia, lung, liver, pancreas, and colon cancer was within the range of what is expected based on cancer rates in Texas. Community members were also concerned about cancers that could not be included in this analysis because there were fewer than six cases in the TCR data. Therefore, upon request, DSHS will update this analysis to include those cancers when new TCR data become available.

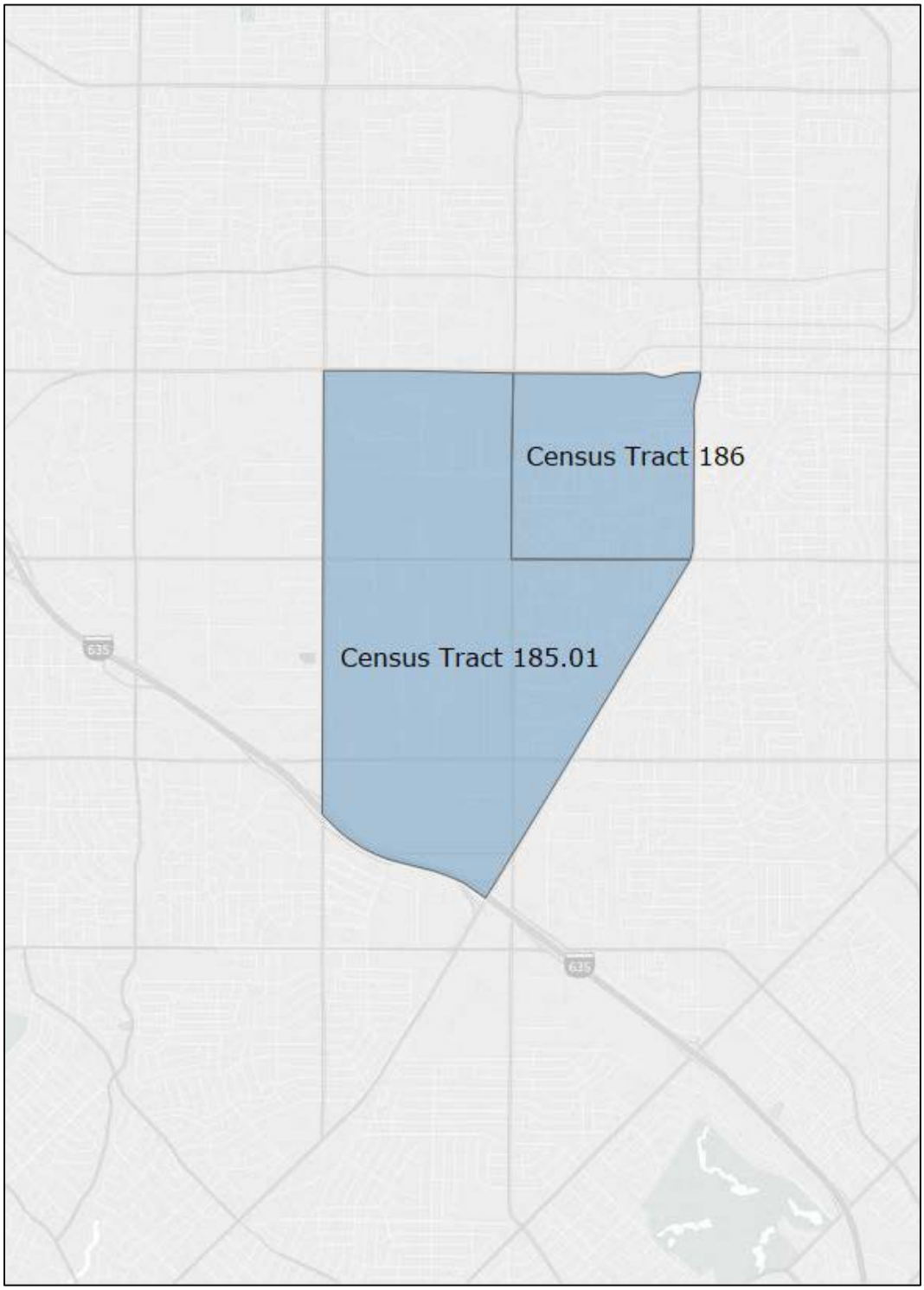
Additional Information

For additional information about cancer clusters, visit the Centers for Disease Control and Prevention, "About Cancer Clusters," web page at http://www.cdc.gov/nceh/clusters/about.htm.

For additional information on cancer risk factors, visit the American Cancer Society, "What Causes Cancer?" web page at http://www.cancer.org/cancer/cancercauses/index.

Questions or comments regarding this investigation may be directed to Emily Hall, MPH, Epidemiologist, Environmental & Injury Epidemiology & Toxicology Unit, at 512-776-3723 (email: emily.hall@dshs.state.tx.us).

Figure 1. Selected Census Tracts (2010) for Garland, TX.



Reference 22

TELEPHONE MEMO TO THE FILE

(Please complete with typewriter or black pen)

ATTACHMENT

Call To: Debbie Hastings / Env. Engineer
Tina La Ford, Environmental Mgr

Call From: Region 4 Office / SF

Date of Call: 1/9/96

File No.: TXD 980626642 / SWR # 34361

Phone No.: (414) 228-2745 / 2459

Subject: Site Status Verification

Globe Union, Inc. AKA: Johnson Controls Battery Group, Inc.
1111 Shiloh Road, Garland, Tx 75046 (SWR # 34361)

Information for File: Contacted Ms. Debbie Hastings, Env. Eng and Tina La Ford, Env. Manager, Corporate Office located at 5757 N. Green Bay Ave, Milwaukee, Wis 53201 concerning status of the former lead-acid battery manufacturing facility located at 1111 Shiloh Road, Garland, Tx. Ms. Hastings stated the facility stopped production in April 1995 and closed in July 1995. All processing/manufacturing equipment has been removed from the building and distributed to other plants located in the country. The company has notified the TNRCC Central Office of above intentions and only the I & HW NOR is still active pending disposition of remediated wastes. I requested copies of all correspondence be forwarded to the Region 4 I & HW office, ATTN: Sam Barrett, address/phone provided, so that the Region office can be informed of pending close activities.

TWC-0225B (Rev. 09-01-85)

Signed: JD Thoyan 1/9/96

Reference 23

From:	Kendrick, Bret
To:	Stephen Ellis
Subject:	FW: Meadowlark Williams concerned citizens group
Date:	Friday, March 1, 2019 9:06:12 AM

My latest communication with Mr. Phillips.

From: Don Phillips <da.phillips12@gmail.com>
Sent: Thursday, January 31, 2019 4:48 PM
To: Kendrick, Bret <kendrick.bret@epa.gov>
Subject: Re: Meadowlark Williams concerned citizens group

Thank you for your response.
Regretably we have found the TCEQ to be somewhat obstinate in dealing with us. Hopefully you can get more consideration from them. The Texas House Committee on Environmental Regulations has contacted me and requested that we keep them apprised of our interactions with the TCEQ.
Also we have met with a representative of Garland subsequent to our meeting with them and they have committed to assist in the testing of these areas.
In regards to the dispersal of lead contaminated water and the 5 lead smelters that ran 24 hrs a day while this company manufactered from Globe Union / Johnson controls , please refer to the cancer study by the state of Texas and note that Kidney/bladder cancer and Brain cancer are about 1/3 higher than expected. Lead toxicity affects the brain and renal system more than any other body systems.
U.S. Foods has consistently poisoned the right of way for a number of years and we are requesting testing of the right of way to determine what was used and who and how it was applied .
Thank you for your attention to this .

On Thu, Jan 31, 2019, 1:58 PM Kendrick, Bret <kendrick.bret@epa.gov> wrote:

> Mr. Phillips,
>
> The EPA Region 6 office re-opened on Monday, January 28 following the end of the partial government shutdown. We are in receipt of your e-mail message below providing clarification on the areas that are of most concern to the Meadowlark Williams concerned citizens group.
>
> Previous e-mails from you identify specific concerns regarding the Globe-Union/Johnson Controls plant and the US Foods facility. However, I am not aware of any specific concerns with regards to the Valspar facility located at the corner of Forest and Shiloh or the vacant field adjacent to the Resistol hat factory. If you could provide me with specific concerns regarding these areas, that would be helpful.
>
> Based on your previous e-mails, specific concerns with the Globe-Union/Johnson Controls facility include the past discharges of waste water (containing spent lead battery acid) into the surrounding area, and the presence of a couple of buried barrels that were observed in the creek

directly behind the facility. Your specific concern with the US Foods facility is related to the over application of herbicides that killed 6-inch diameter trees and completely destroyed the vegetation along their (U.S. Foods') fence line and the City right-of-way. Please clarify if this is correct.

EPA will schedule a meeting with the Texas Commission on Environmental Quality (TCEQ) to discuss your concerns and to gain an understanding of the operations, permits, and compliance history for each of the facilities identified (Valspar, Globe-Union/Johnson Controls, and US Foods). Following our meeting with the TCEQ, we will contact you to further discuss your concerns.

Thank you,

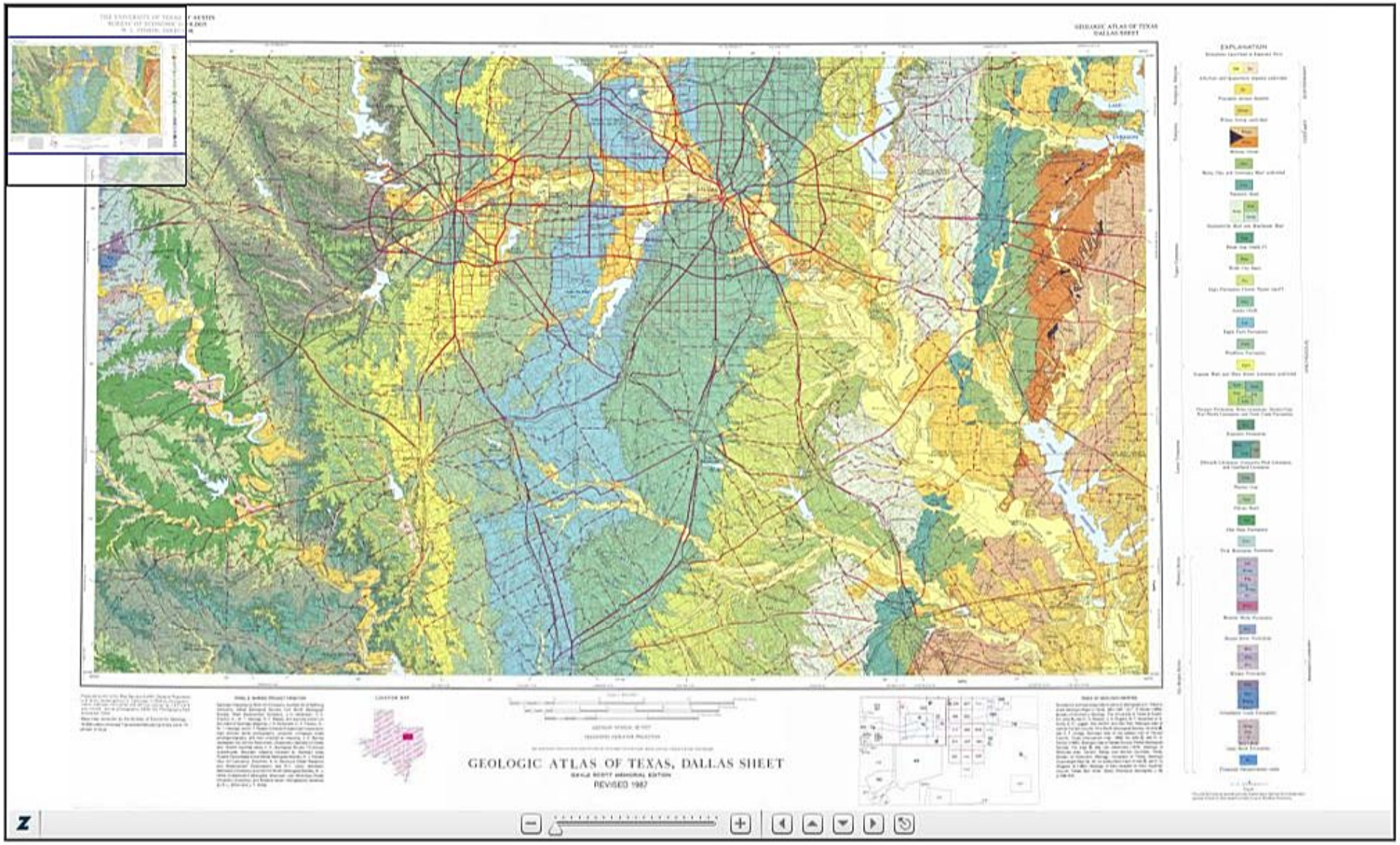
Bret Kendrick
Site Assessment Manager
Superfund Division
U.S. EPA, Region 6
Tel: (214) 665-2240
Fax: (214) 665-6660

From: Don Phillips <da.phillips12@gmail.com>
Sent: Thursday, January 17, 2019 6:48 PM
To: Villarreal, Chris <villarreal.chris@epa.gov>
Subject: Meadowlark Williams concerned citizens group

Good afternoon Chris ,
I wanted to up date you now that we have had our meeting with the city of Garland. The city Administration was very receptive to the information we gave them regarding our concerns for the presence of toxins. They have agreed to allocate funds to do some testing in relation to any testing your organization will do.
In our last meeting we took the map that you sent us and we have settled on the area that are of the most concern. That would include Valspar paint color. at the corner of Forest and Shiloh , the old Globe Union /Johnson Controls plant , and the alleyway adjacent to US Foods or alternatively the vacant field adjacent to Resistol hat factory. I will anxiously await your response concerning the proposed soil testing of these sites.
Thank you

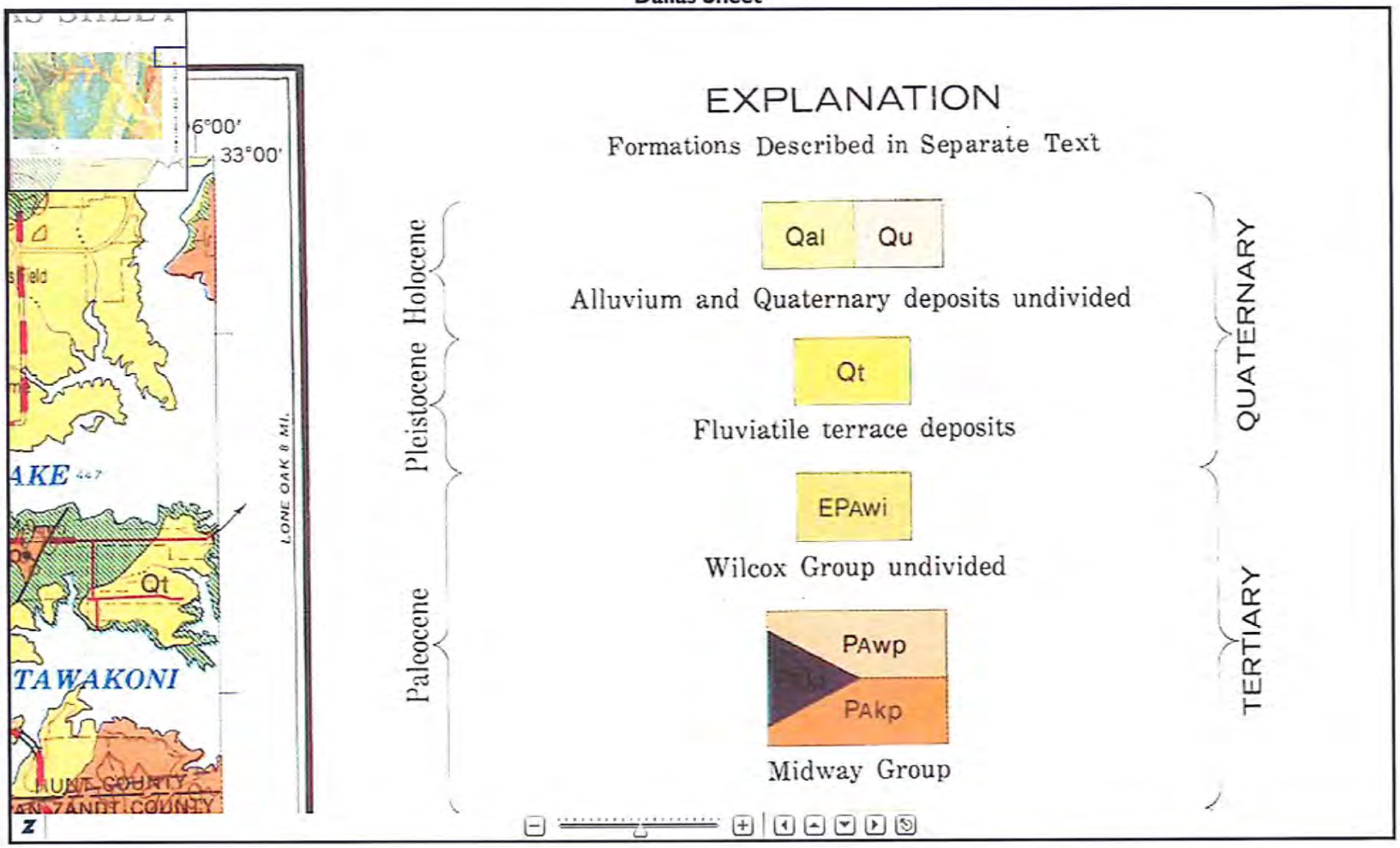
Reference 24

Dallas Sheet



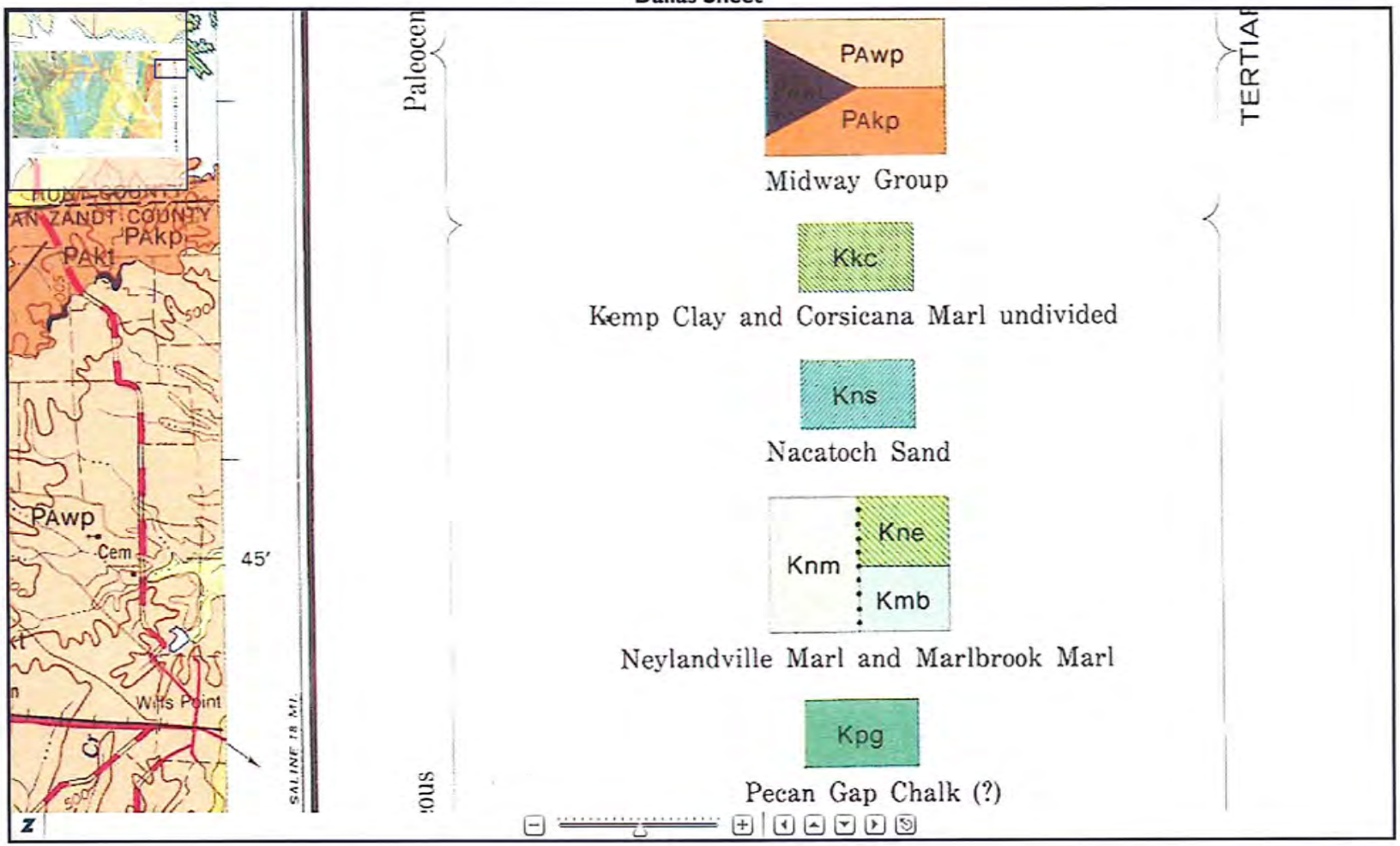
Duck Creek
Garland
78
Temco-Garland
613
Site
Hudson
614
244
Rowlett
MKT
OFT
Ko

Dallas Sheet



24 003

Dallas Sheet



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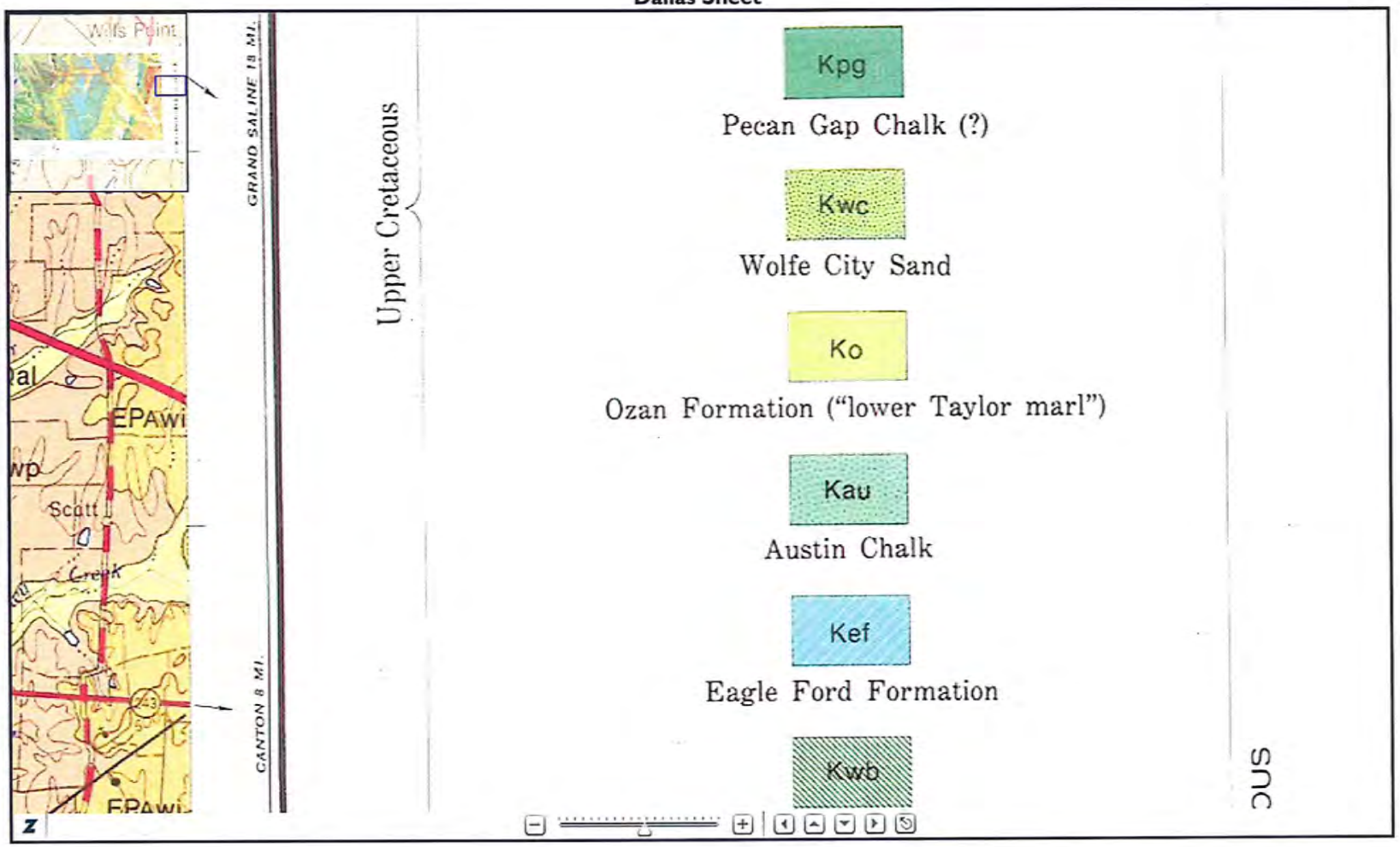

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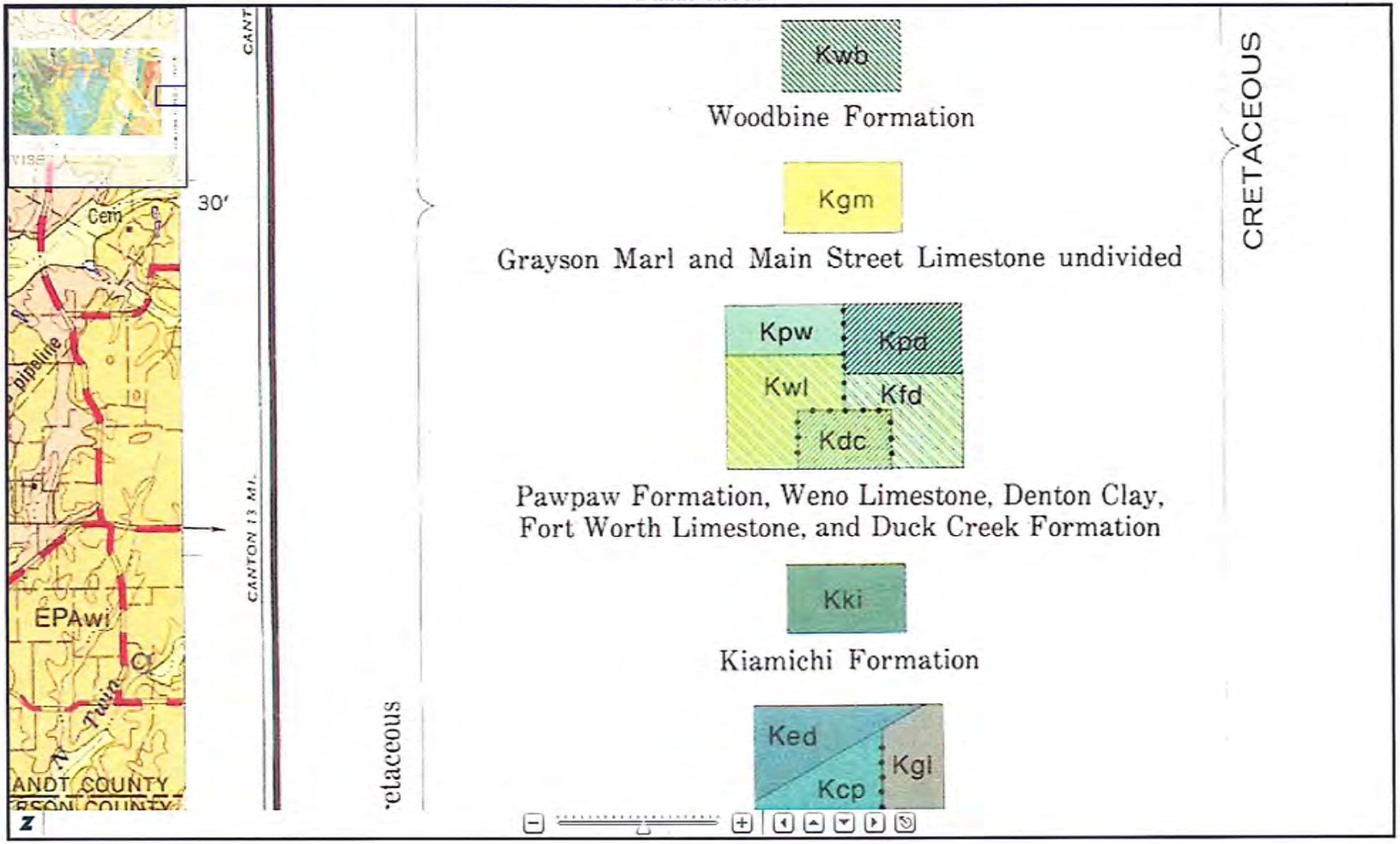

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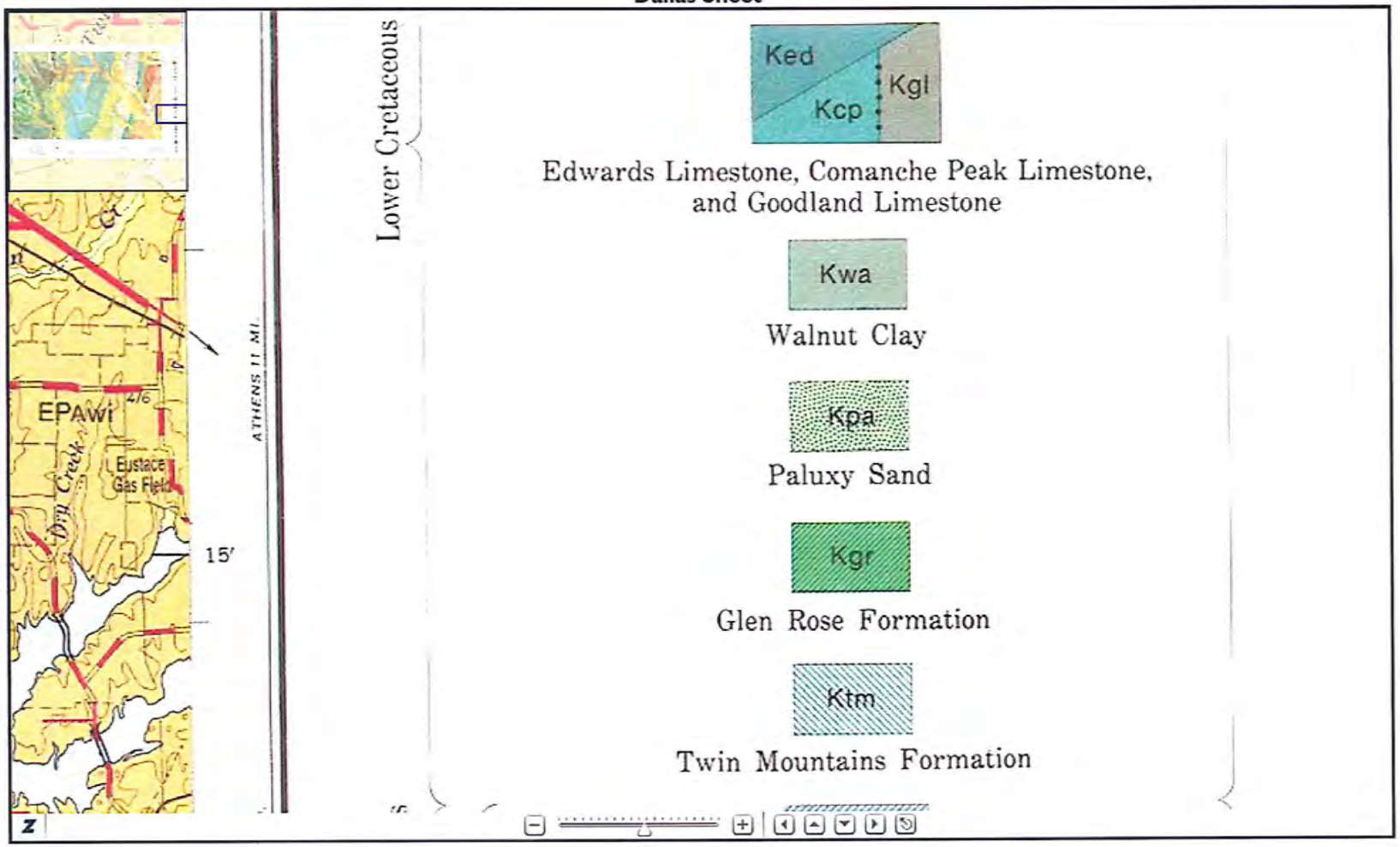

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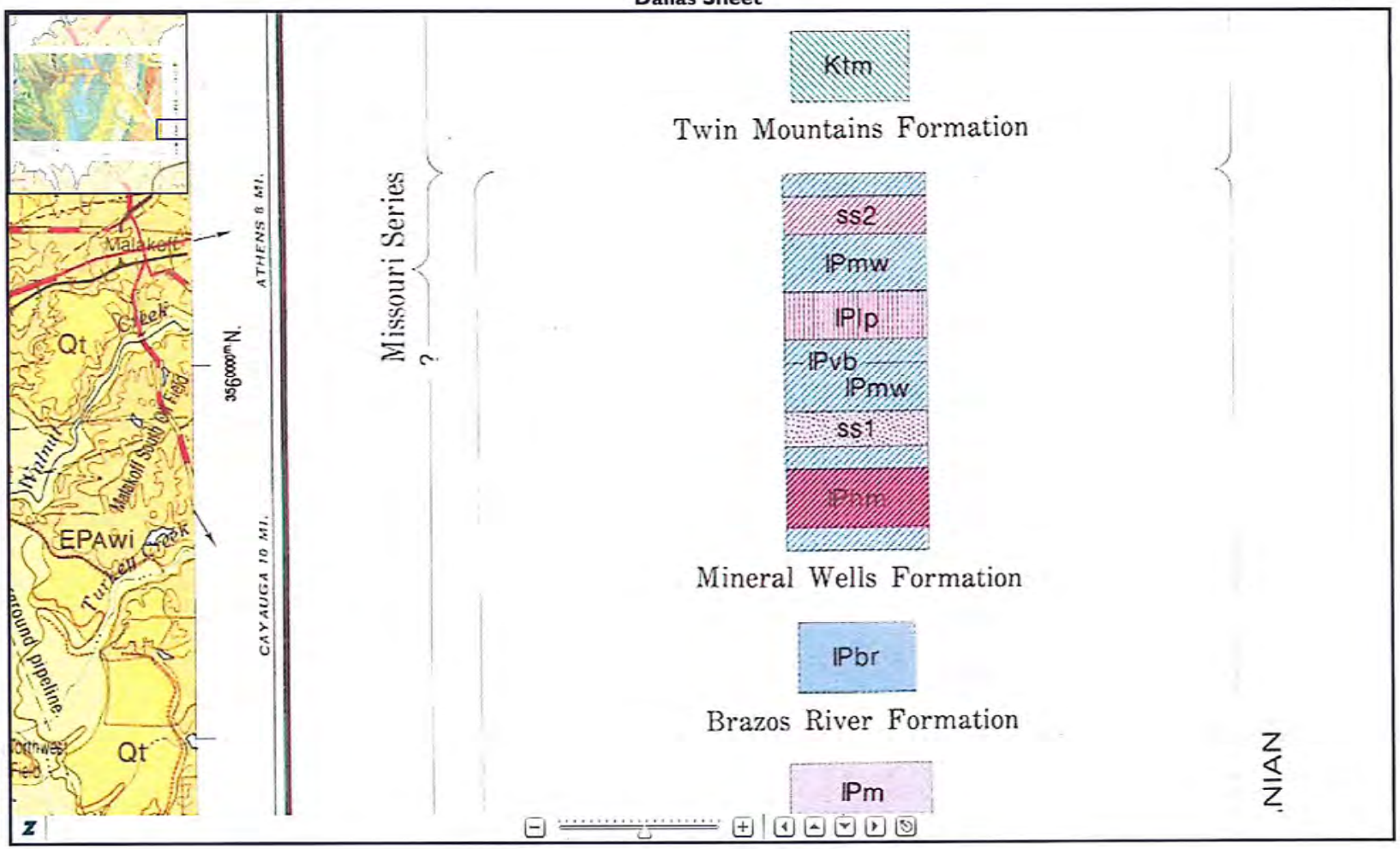
Dallas Sheet



24 008

Dallas Sheet

MAPPING

n bibliography in "Index to
1," by T. E. Brown (1963),
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); for area **C,** see G. H.
County, Dallas Geological
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Denton Counties, Texas,
rsity of Texas, Geologic

Des Moines Series

PENNSYLVANIAN

IPm
IPdv
IPm

Mingus Formation

IPbc
IPgr
IPbb2
IPbb1

Grindstone Creek Formation

IPmb
IPlb
ls
IPkf ? IPdb

Lazy Bend Formation

24 009

Dallas Sheet

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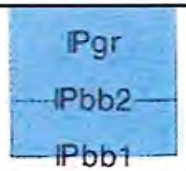
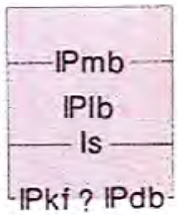
maps of area **E,** see P. N.
Gossett oil field, Kaufman
troleum Geologists, v. 38,



Grindstone Creek Formation



Lazy Bend Formation

Unnamed Pennsylvanian rocks

Fault

Tics with ball indicate downthrown side; dashed where inferred; short dashes show position of fault in Ham Gossett oil field at top of Woodbine Formation.

THE UNIVERSITY OF TEXAS AT AUSTIN
BUREAU OF ECONOMIC GEOLOGY

TO ACCOMPANY MAP—DALLAS SHEET—
GEOLOGIC ATLAS OF TEXAS

GEOLOGIC ATLAS OF TEXAS
DALLAS SHEET

GAYLE SCOTT MEMORIAL EDITION

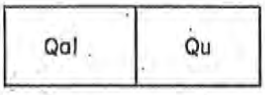
VIRGIL E. BARNES, Project Director

1972
Revised 1988

EXPLANATION

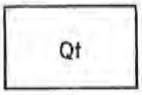
Holocene
Pleistocene
Eocene and Paleocene
Paleocene

QUATERNARY
TERTIARY



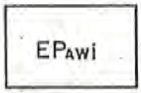
Alluvium and Quaternary deposits undivided

Alluvium, Qal, flood-plain deposits including indistinct low terrace deposits; gravel, sand, silt, silty clay, and organic matter. Quaternary deposits undivided, Qu, mostly colluvium with some alluvium and alluvial fan deposits



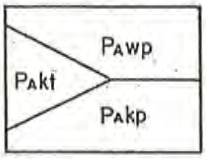
Fluviatile terrace deposits

Gravel, sand, silt, and clay; contiguous terraces of different ages separated by solid line



Wilcox Group undivided

Mostly mudstone with various amounts of sandstone, lignite, ironstone concretions, locally glauconitic in uppermost and lowermost parts. Mudstone, massive to thin bedded, interbedded with laminae of silt and very fine sand, pale brown to yellowish brown in upper part, medium to dark gray in lower part, weathers yellowish brown. Sandstone, medium to fine grained, moderately well sorted, cross-bedded, lenticular in upper part, units a few inches to 30 feet thick in lower part, light gray to pale yellowish brown and yellowish brown to moderate brown. Lignite mostly near middle of formation, seams 1–20 feet thick, brownish black. Abundant plant fossils, a few marine megafossils. Thickness 1,000–1,500 feet



Midway Group

Includes Wills Point Formation, PAwp, *Tehuacana Member of Kincaid Formation,* PAkt, *and Pisgah and Littig Members of Kincaid Formation undivided,* PAkp

Wills Point Formation, PAwp, *clay, silty, sandy, silt and sand more abundant upward, slightly glauconitic near base, 10-inch rosette limestone bed below middle, massive, poorly bedded, grades upward to mudstone and sand of Wilcox Group, light gray to dark gray; weathers medium gray to yellowish gray, topographically featureless; thickness 550± feet*

Tehuacana Member of Kincaid Formation, PAkt, *limestone, silty, slightly glauconitic, hard, white to light gray, interbedded with light gray marl, thickness up to 30 feet, outcrop discontinuous, absent south of Trinity River*

Pisgah and Littig Members of Kincaid Formation undivided, PAkp, *sand and clay. Sand, glauconitic, argillaceous, poorly sorted, medium gray to greenish gray, some hard sandstone beds near top; clay, sandy, silty, phosphatic pebbles and nodules present in lower part, medium gray to dark gray; weathers to yellow and yellowish brown soil. Thickness 150± feet*

Upper Cretaceous

Kkc

Kemp Clay and Corsicana Marl undivided

Mostly clay, calcareous, locally silty, compact, thinly laminated, subconchoidal fracture, medium dark gray; weathers light gray and fissile; some interbeds of fine-grained sandstone near base; marine megafossils; thickness 300–400 feet.

Kns

Nacatoch Sand

Quartz sand, fine grained, poorly sorted, friable, silty, glauconitic, local lenses of silty clay, compact, light gray to greenish gray; thin calcareous sandstone beds in upper and lower parts; marine megafossils; thickness 250± feet.

Knm | Kne / Kmb

Neylandville Formation and Marlbrook Marl

Neylandville Formation and Marlbrook Marl undivided, Knm, *south of Rockwall County; where subdivided includes from top down Neylandville Formation,* Kne, *and Marlbrook Marl,* Kmb

Neylandville Formation, Kne, *clay, calcareous, silty, sandy, sand content increases upward, medium gray; weathers light gray, forms irregular topography; thickness 125± feet*

Marlbrook Marl ("upper Taylor marl"), Kmb, *clay, calcareous, variable amount of silt and glauconite, silt content increases upward, disseminated pyrite, locally phosphate nodules and phosphatized marine megafossils, blocky, conchoidal fracture, light to dark gray; weathers light gray with poor fissility; marine megafossils; thickness 350± feet*

Kpg

Pecan Gap Chalk (?)

Marl and clay, very sandy and silty, medium gray; thickness up to 40 feet, feathers out southward northeast of Rockwall

Kwc

Wolfe City Formation

Marl, sand, sandstone, and mudstone. In Navarro County, marl, sandy and silty, interbedded with thin sandstone beds and massive sandstone; medium gray. Grades northward into an upper fine-grained sand and silt unit, calcareous, medium yellowish gray; and a lower mudstone unit, calcareous, dark gray, weathers medium gray. Marine megafossils. Thickness 75–300 feet, thins northward

CRETACEOUS

Upper Cretaceous

Lower Cretaceous

CRETACEOUS

Ko

Ozan Formation ("lower Taylor marl")

Clay, calcareous, silt and sand content increases upward, montmorillonitic, blocky, conchoidal fracture, medium gray; some glauconite, phosphate pellets, hematite nodules, and pyrite nodules; some very thin limestone lenses locally in lower part; weathers light brownish gray with poor fissility, grades upward to Wolfe City Formation; marine megafossils; thickness 500± feet

Kau

Austin Chalk

Upper and lower parts, chalk, mostly microgranular calcite, massive, some interbeds and partings of calcareous clay, thin bentonitic beds locally in lower part, lower part forms westward-facing scarp; light gray. Middle part, mostly thin-bedded marl with interbeds of massive chalk, locally burrowed, marcasite-pyrite nodules common, light gray. Weathers white, marine megafossils scarce, thickness 300–500 feet, thins southward

Kef

Eagle Ford Group undivided

North of Hill County, shale, sandstone, and limestone; shale, bituminous, selenitic, with calcareous concretions and large septaria; sandstone and sandy limestone in upper and middle parts, platy, burrowed, medium to dark gray; in lower part bentonitic; hard limestone bed marks base in Ellis and Johnson Counties; locally forms low cuesta; thickness 200–300 feet

Kwb

Woodbine Formation

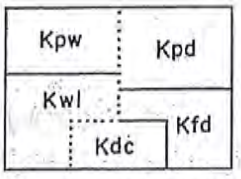
Sandstone, some clay and shale. Upper part, mostly sandstone, fine grained, well sorted, in part tuffaceous, ripple marked, large scale cross-bedding, reddish brown; near top some sandstone with large discoid concretions, medium to coarse grained, friable; some shale, jarositic, gray, fissile; some marine megafossils, oyster reefs locally. Middle part, mostly sandstone, fine grained, cross-bedded; some interbeds of clay, carbonaceous, in part sandy, gray to brown. Lower part, interbedded sandstone and clay; sandstone, fine grained, very thinly bedded to massive, some beds of ironstone and ironstone conglomerate, white, red, brown; clay, sandy, gray to brown; channeled locally. Thickness 175–250 feet, thickens northward

Kgm

Grayson Marl and Main Street Limestone undivided

Mostly Grayson Marl, *mostly calcareous clay and marl, blocky, yellowish gray and medium gray; some 0.25–1.0-foot limestone beds in upper one-third, very fine grained, fossiliferous; weathers yellowish brown, forms gentle slope; thickness 60–100 feet, thins northward.*

Main Street Limestone, *medium grained, chalky, some 6–8-foot units of calcareous shale, thin bedded to massive, distinctly bedded to wavy bedded and nodular, yellowish gray; weathers light gray to white; thickness 20–35 feet, thins northward*



Pawpaw Formation, Weno Limestone, Denton Clay, Fort Worth Limestone, and Duck Creek Formation

Pawpaw Formation and upper limestone unit of Weno Limestone undivided, Kpw, *south of Fort Worth area;* Pawpaw Formation, Weno Limestone, and Denton Clay undivided, Kpd, *in Fort Worth area and northward;* middle shale and lower limestone units of Weno Limestone, Denton Clay, Fort Worth Limestone, and Duck Creek Formation undivided, Kwl, *south of Fort Worth area;* Fort Worth Limestone and Duck Creek Formation undivided, Kfd, *in Fort Worth area and northward; and* Duck Creek Formation, Kdc, *mapped separately in Parker County and western Tarrant County*

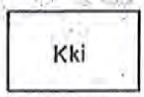
Pawpaw Formation, *claystone, mudstone, and sandstone. Claystone and mudstone, massive, slightly selenitic. Sandstone, fine to very fine grained, platy, ripple cross-laminations, light olive gray to medium gray. Forms grass-covered slopes. Marine megafossils. Thickness 10–25 feet, thins southward*

Weno Limestone, *consists of upper limestone, middle alternating clay and limestone, and lower limestone units. Upper limestone, aphanitic, in part bioclastic, soft and chalky to hard and compact, massive, light gray and yellowish gray; weathers gray and yellowish brown, forms a topographic bench; marine megafossils; thickness 2–20 feet, thins northward. Middle unit:In Tarrant County—mostly calcareous clay, massive, some lenses of sand-size shell debris, olive brown to olive gray; marine megafossils are oysters and molds of small pelecypods. In southwestern Johnson County—alternating limestone and clay; limestone, aphanitic, bioclastic, in part burrowed, some sparry bioclastic limestone, beds pinch and swell, 0.1–1.0 foot thick, medium gray, weathers yellowish brown; clay, calcareous, medium to dark gray, weathers yellowish gray and yellowish brown. fossils include pelecypods, ammonites, echinoids, vertebrate bones, and lignitized wood; thickness 15–45 feet, thins southward. Lower limestone, aphanitic, in part sandy, fossiliferous, burrowed to south, massive, progressively more resistant southward, forming scarp, light gray, medium gray where sandy, weathers yellowish brown, thickness 1–5 feet, thins northward. Thickness from about 60 feet in Tarrant County to about 25 feet in northern Hill County*

Denton Clay, *alternating clay, marl, and limestone, total limestone in unit remains about constant as amount of clay and marl varies. Clay, calcareous, considerable shell debris, locally burrowed, a few irregular calcareous concretions, units 1–3 feet thick, marine megafossils are* Anomia, Gryphaea, *and pelecypod molds. Marl, ranges from calcareous clay to aphanitic argillaceous limestone, soft, yellowish brown, weathers dusky brown. Limestone aphanitic,* Gryphaea*-bearing beds 0.1–0.6 foot thick, locally pinch and swell, dark gray, weathers dusky brown; marine megafossils are* Gryphaea, Pecten, *and* Anomia. *Thickness 0–25 feet, thins southward*

Fort Worth Limestone, *limestone and clay. Limestone, aphanitic to biosparite, burrowed, beds 0.2–2 feet becoming thicker and more massive southward, light to medium gray; weathers yellowish brown; marine megafossils are* Pecten, *oysters, echinoids, and ammonites. Clay, calcareous, in units 0.1–5 feet thick, medium gray to yellowish brown; weathers yellowish brown, forms low rolling hills. Thickness 25–35 feet*

Duck Creek Formation, Kdc, *limestone, aphanitic, in part bioclastic, locally burrowed, pyrite nodules up to 0.2 foot, beds 0.2–2 feet thick, pinch and swell, medium gray to yellowish gray; weathers dark gray with yellowish-brown patches, locally forms topographic benches; marine megafossils are* Gryphaea *and ammonites; thickness 30–100 feet, thins southward*

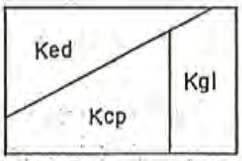


Kiamichi Formation

Clay and limestone in alternating units 0.1–5 feet thick; some sandstone. Clay, calcareous, olive brown, weathers yellowish brown, constitutes about two-thirds of formation. Limestone mostly aphanitic and bioclastic, locally burrowed, medium gray to yellowish gray; weathers yellowish brown. Sandstone, fine grained, moderately well sorted, calcareous, burrowed, beds 0.1–0.2 foot thick, medium gray; weathers yellowish brown. Marine megafossils are Gryphaea; *some* Pecten *in sandstone. Thickness 20–50 feet, thins southward*

Lower Cretaceous

CRETACEOUS

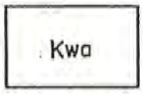


Edwards Limestone, Comanche Peak Limestone, and Goodland Limestone

Edwards Limestone, Ked, *in thicker sections consists of an upper scarp-forming rudistid facies, a middle aphanitic to biosparite fossiliferous limestone, and a lower bioclast-packed aphanitic to sparry limestone with individual corals, light gray to yellowish gray; weathers various shades of gray with moderate brown patches; thickness up to 40 feet, gradually merges with Comanche Peak Limestone or Goodland Limestone in the vicinity of the northern Hood County line*

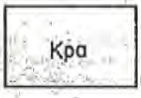
Comanche Peak Limestone, Kcp, *limestone and some clay. Limestone mostly aphanitic, bioclastic to fossiliferous, soft, a few harder* Gryphaea-*bearing beds about 25 feet above base form benches, light to medium gray; weathers various shades of gray, locally mottled yellowish brown; marine megafossils are gastropods, ammonites, echinoids,* Pecten, Lima, Gryphaea, *and* Exogyra texana. *Clay, calcareous, intergradational with nodular limestone, beds 1–5 feet thick, medium to dark gray, weathers yellowish brown, fossiliferous. Thickness 90± feet*

Goodland Limestone, Kgl, *intergradational laterally with Comanche Peak Limestone and differs from it chiefly in that the Goodland is more coarsely nodular, contains fewer and thinner clay beds, and massive resistant limestone beds are more numerous; upper 5 feet, massive, bioclast-packed aphanitic limestone and limestone composed of oolites in sparry calcite; thickness 90± feet*



Walnut Clay

Clay and limestone about equally abundant. Limestone, aphanitic; in part bioclastic, Gryphaea*-bearing, beds 0.1–1 foot thick; in part nodular, grades laterally into either resistant, bench-forming,* Gryphaea*-bearing limestone or calcareous clay; medium to dark gray, weathers yellowish brown. Clay, fossiliferous, calcareous, olive brown, weathers yellowish brown. Thickness 30± feet*



Paluxy Formation

Sandstone, mudstone, and limestone. Sandstone, fine to very fine grained, friable to calcite cemented, cross-beds common, in part massive, locally burrowed, light gray to greenish gray; weathers yellowish brown to dusky brown. Mudstone, sandy, massive, locally burrowed, greenish gray, olive green, and medium gray; weathers yellowish brown and red brown. Limestone locally in upper 40–50 feet, sandy, fossiliferous, beds 0.5–2 feet thick, yellowish gray; weathers mottled dark gray and yellowish brown. Thickness 95–105 feet

Glen Rose Formation

Limestone, alternating with units composed of variable amounts of clay, marl, and sand. Limestone, distinctly bedded, in part with variable amounts of clay, silt, and sand, soft to hard, various shades of brownish yellow and gray. Gradational to Paluxy Formation above and Twin Mountains Formation below, bench-forming beds included in the Glen Rose Formation. Thickness 40–200 feet, thins northward

Lower Cretaceous

Missouri Series

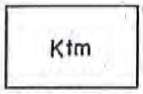
Des Moines Series

?

Strawn Group

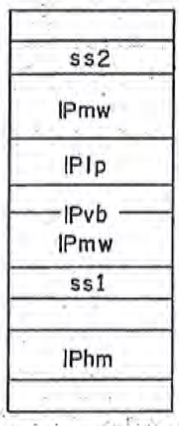
CRETACEOUS

PENNSYLVANIAN



Twin Mountains Formation

Upper part claystone, middle part sandstone above claystone, lower part mostly sandstone, some claystone and conglomerate. Sandstone, fine to medium grained in middle part, medium to coarse grained in lower part, sorting best in middle part, friable, locally large scale cross-bedding, mostly light gray, some light brown near middle. Claystone, silty, mostly gray, locally in upper part green, yellow, red. Conglomerate, pebbles of chert and quartz, argillaceous, sandy, gray, brown. Thickness about 150 feet



Mineral Wells Formation

Mineral Wells Formation, IPmw, *shale, sandstone, conglomerate, and limestone;* sandstone, ss2, Lake Pinto Sandstone, IPlp, Village Bend Limestone, IPvb, sandstone, ss1, *and* Hog Mountain Sandstone, IPhm, *mapped separately. Shale, calcareous, locally contains sandstone and a few thin limestone beds, gray to black, a few plant fossils*

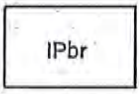
Sandstone, ss2, *fine to coarse grained, thin bedded to massive, brown, thickness 10 feet, feathers out southwestward on Abilene Sheet*

Lake Pinto Sandstone, IPlp, *medium to fine grained, locally conglomeratic, thick bedded, brown, thickness 20–40 feet*

Village Bend Limestone, IPvb, *fine grained, locally sandy, thick bedded, yellow gray, weathers to small blocks, marine megafossils, forms laterally discontinuous lentils, thickness up to 3 feet*

Sandstone, ss1, *locally conglomeratic, thickness about 30–40 feet, feathers out southwestward near Mineral Wells on Abilene Sheet*

Hog Mountain Sandstone, IPhm, *fine to medium grained, thick bedded to flaggy, brown, thickness about 25 feet. Thickness of exposed part of Mineral Wells Formation 400–500 feet, overlapping Cretaceous rocks cover upper third and other portions of formation including Turkey Creek Sandstone and Dog Bend Limestone, which are exposed on the Abilene Sheet immediately to the west*



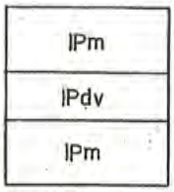
Brazos River Formation

Sandstone, conglomerate, and mudstone; sandstone, coarse grained, ferruginous, cross-bedded, thick bedded to massive, reddish brown; mudstone, silty, gray, local lenses; conglomerate, angular pebbles of chert up to 1.5 inches in size, some clay ironstone, variegated, ferruginous cement common; thickness 100 feet

Des Moines Series

Strawn Group

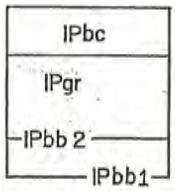
PENNSYLVANIAN



Mingus Formation

Mingus Formation, IPm, *shale and sandstone;* Dobbs Valley Sandstone, IPdv, *mapped separately. Shale, sandy, poorly bedded, gray to buff*

Dobbs Valley Sandstone, IPdv, *medium grained, locally calcareous, commonly massive, reddish brown, some interbedded sandy shale, thickness about 45 feet. Thickness of exposed part of* Mingus Formation *about 200 feet; overlapping Cretaceous rocks cover lower part of formation including Santo Limestone; the Goen Limestone feathers out above the Dobbs Valley Sandstone a few miles to the west before reaching the Dallas Sheet*

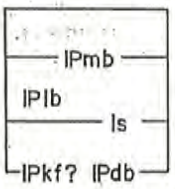


Grindstone Creek Formation

Grindstone Creek Formation, IPgr, *shale, sandstone, and limestone;* Buck Creek Sandstone, IPbc, *and* Brannon Bridge Limestones, IPbb2 *and* IPbb1, *mapped separately. Shale, in part sandy, locally contains thin coal beds and sandstone lentils, gray*

Buck Creek Sandstone, IPbc, *coarse grained, massive, reddish brown, forms prominent scarp. Thickness about 30 feet*

Brannon Bridge Limestones, IPbb2 *and* IPbb1, *fine grained, some interbedded shale, dark chert lenses in* IPbb2, *bedding uneven, indistinct to medium, gray, units up to about 15 feet thick, form distinct scarps and broad dip slopes; about 10 feet of shale separates the two limestone units. Thickness of exposed part of* Grindstone Creek Formation *about 225 feet; overlapping Cretaceous rocks cover upper part of formation; a third and higher Brannon Bridge Limestone feathers out a few miles to the west within the Abilene Sheet*



Lazy Bend Formation

Lazy Bend Formation, IPlb, *shale, sandstone, and limestone;* Meek Bend Limestone, IPmb, unnamed limestone, ls, Dennis Bridge Limestone, IPdbr, *and* Kickapoo Falls Limestone, IPkf, *mapped separately. Shale, in part sandy, in part silty, local coal beds, and unmapped limestone lentils*

Meek Bend Limestone, IPmb, *fine grained, bedding thin flaggy to massive, gray, marine megafossils; thickness about 12 feet, exposed only in small creek west of Brazos River, well exposed on Abilene Sheet to the west*

Limestone, ls, *fine grained, locally grades into sandstone, medium to thin bedded, gray to brown, marine megafossils; thickness up to 6 feet, outcrop discontinuous and poorly exposed*

Dennis Bridge Limestone, IPdb, *fine grained, massive at base to thin bedded at top, gray to light brown, marine megafossils; thickness 10 feet, exposed at south end of Dennis Bridge over Brazos River and vicinity, approximately equivalent to Kickapoo Falls Limestone*

Kickapoo Falls Limestone, IPkf, *fine grained, thick to medium bedded, upper part nodular, light gray, mottled dark gray, marine megafossils and algae; thickness up to 12 feet, approximately equivalent to Dennis Bridge Limestone, outcrop confined to Kickapoo Creek inlier. Thickness of* Lazy Bend Formation *275 feet*

Des Moines Series

Strawn Group

PENNSYLVANIAN

IPu

Unnamed Pennsylvanian rocks

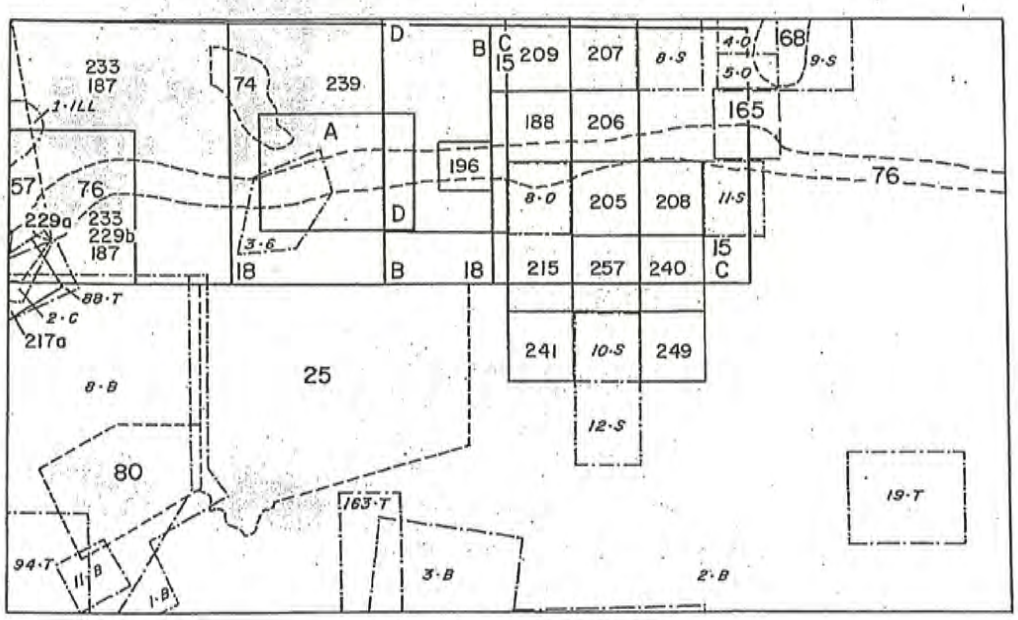
Shale, limestone, and sandstone. Shale, locally sandy and silty, some thin sandstone beds and impure limestone lentils, gray to deep dull red; thickness exposed beneath Cretaceous overlap about 75 feet, comprises rocks cropping out beneath Dennis Bridge and Kickapoo Falls Limestones, best exposed along Kickapoo Creek, downstream from Kickapoo Falls crossing

Geologic mapping by Shell Oil Company, Humble Oil and Refining Company, Dallas Geological Society, Fort Worth Geological Society, Shell Development Company, J. H. McGowen, C. V. Proctor, Jr., W. T. Haenggi, D. F. Reaser, and sources shown on the Index of Geologic Mapping. Paleozoic mapping by L. F. Brown, Jr., and J. L. Goodson. J. H. McGowen, C. V. Proctor, Jr., W. T. Haenggi, and D. F. Reaser compiled the geologic mapping on high altitude aerial photographs, compiled unmapped areas photogeologically, and field checked all mapping. V. E. Barnes remapped, but did not field check, Quaternary deposits of Dallas and Tarrant Counties using U.S. Geological Survey 7.5-minute topographic quadrangles. Geologic mapping reviewed by Geologic Atlas Project Committees of the Dallas Geological Society, R. J. Cordell (Sun Oil Company), Chairman, E. G. Wermund (Mobil Research and Development Corporation), and R. L. Laury (Southern Methodist University); and the Fort Worth Geological Society, W. J. Nolte (Independent Geologist), Chairman, Leo Hendricks (Texas Christian University), and Edward Heuer. Geology scribed by J. W. Macon and Barbara Hartmann.

Extensive revision in the southeastern part of the Dallas Sheet relied on mapping furnished by Humble Oil and Refining Company. Where needed, V. E. Barnes remapped the Quaternary deposits of the sheet using U.S. Geological Survey 7.5-minute topographic quadrangles. The revision of the Dallas Sheet was scribed by John T. Ames.

INDEX OF GEOLOGIC MAPPING

Numbers in outlined areas refer to items in bibliography in "Index to Areal Geologic Maps in Texas, 1891–1961," by T. E. Brown (1963), Bureau of Economic Geology, University of Texas, Austin. For area A, see O. D. Weaver, J. A. Rogers, W. F. Buckthal, A. E. Kurie, E. R. Leggat, Dan McGill, and Ray Rall, Geologic map of central Tarrant County, Fort Worth Geological Society; for area B, see C. F. Dodge, Geologic map of the eastern half of Tarrant County, Texas (manuscript map, 1966); for area C, see G. H. Norton (1965), Geologic map of Dallas County, Dallas Geological Society; for area D, see Leo Hendricks (1976), Geology of Midcities area, Tarrant, Dallas, and Denton Counties, Texas: The University of Texas at Austin, Bureau of Economic Geology Geologic Quadrangle Map 42; for area E, see P. N. Wiggins, III (1954), Geology of Ham Gossett Oil Field, Kaufman County, Texas: American Association of Petroleum Geologists Bulletin, v. 38, p. 306–318.



Reference 25

TEXAS DEPARTMENT OF WATER RESOURCES

REPORT 269

OCCURRENCE, AVAILABILITY, AND CHEMICAL QUALITY OF GROUND WATER IN THE CRETACEOUS AQUIFERS OF NORTH-CENTRAL TEXAS

VOLUME 1

By

Phillip L. Nordstrom, Geologist

April 1982

25 001

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25 007

OCCURRENCE, AVAILABILITY, AND CHEMICAL QUALITY OF GROUND WATER IN THE CRETACEOUS AQUIFERS OF NORTH-CENTRAL TEXAS

SUMMARY AND CONCLUSIONS

The study area consists of approximately 15,500 square miles (40,145 km^2) and lies within the Red, Sulphur, Sabine, Trinity, and Brazos River basins. The region includes all or parts of Collin, Cooke, Dallas, Delta, Denton, Ellis, Fannin, Grayson, Hood, Hunt, Johnson, Kaufman, Lamar, Montague, Navarro, Parker, Red River, Rockwall, Tarrant and Wise Counties.

The Trinity Group of Cretaceous age is the largest and most prolific aquifer in the study area. The aquifer consists of the Antlers, Paluxy, and Twin Mountains Formations. The Antlers is a coalescence of the Paluxy and Twin Mountains in the northern part of the study area where the Glen Rose Limestone is absent. The Trinity Group aquifer ranges in thickness from about 100 feet (30 m) in the outcrop area to about 1,200 feet (366 m) near the downdip limit of fresh to slightly saline water. The transmissibility is highly variable with average values ranging from 3,700 (gal/d)/ft or 45,900 (l/d)/m in the Paluxy and in the Antlers near Sherman to over 10,000 (gal/d)/ft or 124,000 (l/d)/m in most downdip areas of the Twin Mountains and in the Antlers near Gainesville. A wide range in permeabilities is also encountered, but an overall value of 50 $(gal/d)ft^2$ or 2,040 $(l/d)/m^2$ is average. Artesian storage coefficients range from 0.0001 to 0.00025 and specific yields range from 15 to 25 percent in the outcrop.

Chemical quality in the Trinity Group aquifer updip from the fresh to slightly saline water limit is suitable for most public supply and industrial uses. Irrigation is usually limited to the outcrop area and quality is fair for most crops. Generally, water from wells on or near the outcrop is harder than ground water downdip and it also contains high iron concentrations in some areas. The Twin Mountains Formation contains high dissolved solids in an area centered in southeastern Wise County and is generally of poor quality along the Parker and Tarrant Counties boundary line.

Yields of wells completed in the Trinity Group aquifer increase in a downdip direction with wells producing up to 1,900 gal/min (120 l/s). Yields of wells completed on or near the outcrop are low, with maximum yields of 50 gal/min (3.2 l/s) not uncommon. Wells in the Antlers and Twin Mountains Formations have much higher yield averages than wells producing from the Paluxy Formation. However, the areal extent of groundwater production is larger in the Paluxy than in the Antlers and Twin Mountains. Paluxy wells have been developed in 16 of the 20 counties as compared to only 14 counties for the Antlers and Twin Mountains.

Water-level declines have been recorded in the Trinity Group since water-level records began in the first part of the 20th century. Significant cones of depression have formed in the Antlers around Gainesville and Sherman. The large cone of depression in the Dallas-Fort Worth metroplex involves both the Paluxy and Twin Mountains. Static water levels in this area have reached the top of the Paluxy and dewatering of the aquifer has begun, while static water levels in the Twin Mountains have reached 1,000 feet (305 m) below the land surface. Declines of over 20 feet (6 m) per year is not uncommon in the area along the Dallas and Tarrant counties boundary line. The abandonment of many Trinity wells in this area has alleviated the problem somewhat, but the large quantity of ground water pumped from surrounding areas will cause a continuation of the trend in water-level declines. Diminishing yields, lowering of pumps, and high lifting costs will continue to plague ground-water users. Water levels outside the influence of heavily pumped areas are also experiencing declines, but at a slower rate.

Total pumpage for public supply, industrial, and irrigation purposes from the Antlers, Twin Mountains, and Paluxy Formations in 1976 was, respectively 8,870 acre-feet (10.9 hm^3), 38,600 acre-feet (47.5 hm^3), and 10,000 acre-feet (12.3 hm^3). With the additional pumpage of ground water for domestic and livestock

purposes, the Trinity Group aquifer yielded over 66,000 acre-feet (81.4 hm^3) of water to wells in the study area. The total average annual ground-water availability for the Trinity Group in the study area to the year 2030 is 63,000 acre-feet (77.7 hm^3) which includes an annual effective recharge of 51,000 acre-feet (62.9 hm^3). The large discrepancy in pumpage and effective recharge emphasizes the fact that the Trinity Group aquifer is overdeveloped. Further development of ground water at present pumpage rates will continue to lower the piezometric surface and deplete storage that cannot be replenished.

The Woodbine Group provides water for all purposes to approximately half of the counties covered in this study. The group is divided into three water-bearing parts-upper, middle, and lower-which vary considerably in productivity and quality. The upper Woodbine contains water of extremely poor quality in downdip locales and contains excessive iron concentrations along the outcrop. In general, water from this part is sealed off in all wells except those used for irrigation, where iron content is not important. The middle Woodbine generally contains water of good quality; however, high iron concentrations occur in some areas. Yields are moderate and water from this part is utilized in most wells. The lower Woodbine is the most productive and contains good quality water. High yields are characteristic in this part from the outcrop downdip to the slightly saline limit which is approximately 2,000 feet (610 m) below land surface.

Total thickness of the Woodbine ranges from 230 feet (70 m) near the outcrop to 700 feet (21 3 m) near the downdip limit of fresh to slightly saline water. The net sand thickness is less than 350 feet (10 7 m) with most of this occurring in the lower Woodbine. The average artesian coefficient of storage is 0.00015 where the Woodbine is under artesian conditions, and the specific yield is about 15 percent. Transmissibility values in downdip areas average 4,700 (gal/d)/ft or 58,400 (l/d)/m and permeability values average 44 (gal/d)/ft^2 or 1,790 (l/d)/m^2.

Chemical quality deteriorates rapidly in well depths below 1,500 feet (457 m). In areas between the outcrop and this depth, quality is considered very good overall as long as ground water from the upper Woodbine is sealed off. Water is classified as soft with most chemical analyses showing total hardness as calcium carbonate below 60 mg/l.

Yields of wells completed in the Woodbine averaged 160 gal/min (10 l/s) with measured quantities of as much as 1,170 gal/min (74 l/s). The average specific capacity calculated from production tests was 2.9 (gal/min)/ft or 0.60 (l/s)/m. Wells operating under artesian conditions are experiencing declines in water levels. Declines of a few feet (less than a meter) per year to over 10 feet (3 m) per year have been recorded. Declines in the Sherman area (Grayson County) are steepest and are depicted as a cone of depression on water-level maps. The steady decline is a result of low permeabilities in water-bearing sands and large withdrawals by ground-water users.

Approximately 16,000 acre-feet (19.1 hm^3) of ground water was pumped from the Woodbine in 1976 from wells in the study region. Public supply pumpage accounted for 8,560 acre-feet (10.6 hm^3) in 1976, while industrial and irrigation users added over 2,500 acre-feet (3.08 hm^3) each to this quantity. The average annual ground-water availability as effective recharge is 24,500 acre-feet (30.2 hm^3) over the entire aquifer. This maximum quantity is based on uniform use along the entire aquifer after water levels have been lowered to a maximum of 400 feet (122 m) below the land surface. Water levels will continue to decline in heavily pumped areas. However, at the present withdrawal rate, when considered collectively, the aquifer is in no immediate danger of overdevelopment.

Information was collected on several minor water-bearing formations within the study region and all pertinent data have been included in this report. The minor aquifers included in the study are the Paleozoic rocks undifferentiated, Blossom Sand, Nacatoch Sand, and alluvium. The primary use of these aquifers is for domestic and livestock purposes although several municipalities pump from them. The Paleozoic rocks provide water mainly in Montague County with smaller usage in Wise, Parker, and Hood Counties. The Blossom and Nacatoch Sands of Cretaceous age provide ground water to wells along the eastern portion of the study area. Minor amounts of water are pumped from the alluvium along the Red River for irrigation and livestock needs.

Wells completed in the Nacatoch and Blossom Sands produce up to 500 gal/min (32 l/s) for public supply use in local areas. In regions of heavy pumpage such as around Clarksville in Red River County and Commerce in Hunt County, water levels are declining steadily. A total of 2,700 acre-feet (3.33 hm^3) of water was pumped from these aquifers in 1976 for public supply and industrial purposes. Domestic and livestock usage probably exceeds this amount. The estimated average annual amount of ground water available as effective recharge from both aquifers is about 1,620 acre-feet (2 hm^3). Annual water-level declines are a direct result of the deficit between pumpage and effective recharge.

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INTRODUCTION

Purpose and Scope

The general purpose of this study was to determine the ground-water resources of the Cretaceous aquifers in north-central Texas, with emphasis on the Woodbine and Trinity Groups. Field investigations were conducted during the period from January 1975 to August 1978. Aquifers comprising the Trinity Group consist of the Antlers, Paluxy, and Twin Mountains Formations which are the most important water-bearing units in the study region. The study area is shown on Figure 1.

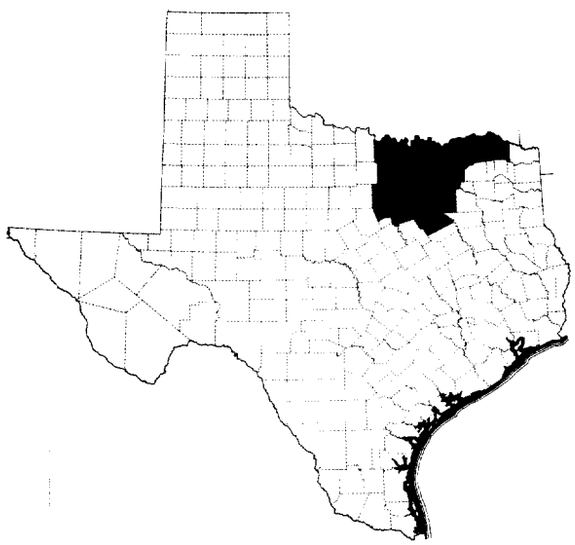

Figure 1.—Location of Study Area

The primary purpose of this study was to determine the occurrence, availability, quality, and quantity of ground water used for municipal, industrial, and irrigation purposes from the Woodbine and Trinity Groups of Cretaceous age. The secondary purpose was to include data on minor aquifers being utilized within the study region such as the Paleozoic rocks undifferentiated, Blossom Sand, Nacatoch Sand, and alluvium.

The general scope of this investigation included the collection, compilation, and analysis of data relating to ground water from the Cretaceous aquifers in north-central Texas, and the presentation of these data, results of analyses, and conclusions in a published report. The report consists of two volumes. Volume 1 contains interpretive information presented as text and related figures and tables. Volume 2 contains supporting basic data including well location maps, records of wells, water-level measurements, and chemical analyses of water.

The scope, although directed toward the quantitative aspects of water availability, also included collection and use of chemical-quality data, surface and subsurface geological data, study of ground-water contamination by oil and gas field operations in the west and northwest part of the study area, and review of previous work by federal and state agencies.

Location and Extent

The study region has an areal extent of 15,500 square miles (40,145 km^2) and represents 5.8 percent of the State's total area. It is bounded on the north by the Red River, on the west by the physical limit of the Cretaceous rocks, and on the east by the downdip limit of fresh to slightly saline water. For the purpose of this report, usable ground water is considered to be water that contains less than 3,000 milligrams per liter (mg/l) dissolved solids. The region includes all or parts of Collin, Cooke, Dallas, Delta, Denton, Ellis, Fannin, Grayson, Hood, Hunt, Johnson, Kaufman, Lamar, Montague, Navarro, Parker, Red River, Rockwall, Tarrant, and Wise Counties and lies within the Red, Sulphur, Sabine, Trinity, and Brazos River basins.

Physiography

The portion of Texas defined by the boundaries of the study area has been divided into a number of distinct physiographic subdivisions, which are also coincidental with the geologic units. The topography of a dissected region is determined chiefly by the nature of the underlying parent rock. According to Fenneman (1938) and Fenneman and Johnson (1946), the study area can be divided into six north-south trending belts which are clearly marked by distinctive soil, plant, and topographic characteristics. These belts, from west to east, are: the Osage Plains, the Western Cross Timbers, the Grand Prairie, the Eastern Cross Timbers, the Black Prairie, and the East Texas Timber Belt.

The Osage Plains is underlain by rocks of Paleozoic age and forms the western boundary of the study region. Its contact with the Western Cross Timbers coincides with the outcrop of Cretaceous rocks.

The Western Cross Timbers is underlain by the Trinity Group and also, in the south western part of the study area, by the Walnut Formation. This belt is characterized by a rolling to hilly topography that is

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dissected into steep hills and deep ravines. The very sandy soil supports a heavy growth of post oak and blackjack oak.

The Grand Prairie is underlain by alternating limestones and marls of the Washita and Fredericksburg Groups. The intervening marls form low escarpments that connect successive uplands and produce a "cuesta" topography. The surfaces of the terraces slope gently eastward, broken only by the westward-facing escarpments. The thin mantle of light brown to black loamy soil is well drained and its characteristics differ depending on the nature of the underlying material. The broad, gently rolling, grass-covered plain is usually treeless except for isolated clumps of upland timber.

The Eastern Cross Timbers coincides with the narrow belt of the Woodbine Group outcrop and is characterized by low, rounded, wooded hills along the western margin and gentle slopes along the eastern margin. It is well d ssected by streams leaving some areas quite rugged in appearance. The soil is reddish sand with iron concretions and some clay. The surface supports a dense growth of timber, consisting chiefly of post oak and blackjack oak.

The remaining Cretaceous formations and the Midway Group form the base of the Black Prairie. It is characterized by a relatively flat to gently undulating surface that slopes gently to the east. The Black Prairie is poorly drained constituting the famous blackland soil and relatively treeless.

A small part of the study region falls within the East Texas Timber Belt which is underlain by the Wilcox and has a sandy, slightly hummocky surface.

Land-surface elevations range from 1,450 feet (442 m) in the west to 250 feet (76 m) above mean sea level in the northeast. The 20-county area lies within the Red, Sulphur, Sabine, Trinity, and Brazos River basins. Drainage is to the southeast.

Climate

The climate of the region covered by this report is characterized by long, hot summers and short, mild winters. The average minimum temperature for January, the coldest month, ranges from 32°F (0°C) in the northwest to 36°F (2°C) in the southeast. The average maximum temperature for July, the hottest month, is 96°F (36°C) throughout most of the study area. The annual mean free air temperature for the period 1931-70 averaged 65" F (18°C).

The average annual precipitation ranges from 30 inches (76 cm) in the northwest to 45 inches (114 cm) in the northeast. These figures are based on National Weather Service records for the 77-year period 1900-76, and are illustrated on Figure 2 along with average monthly precipitation for periods of record at selected stations.

The average annual gross lake surface evaporation for the period 1940-70 ranges from 78 inches (198 cm) in the north-central area to 61 inches (155 cm) in the southeast.

Population

According to the 1978-79 Texas Almanac, the estimated 1975 populatior for the study region is over 2.75 million people, which is an average of 180 people per square mile (69.5 per km^2). This represented about 25 percent of the State's population. More than 85 percent of the people in this region lived in urban areas having 2,500 or more inhabitants. Some of the urban areas are Bonham, Clarksville, Cleburne, the Dallas-Fort Worth metroplex, Decatur, Denton, Gainesville, Granbury, Greenville, Lewisville, McKinney, Paris, Plano, Sherman, Waxahachie, and Weatherford. The remaining inhabitants lived in rural areas or smaller communities.

Economy

The general economy is varied. Principal manufacturing plants are in or near large cities; however, some plants in smaller cities process local products. Manufacturing, transportation, business, and insurance are of primary importance in the Dallas-Fort Worth area. About one-third of the counties in the study region produce petroleum products. Cooke and Montague Counties have produced about 475 million barrels of oil since the mid-1920's. Agricultural economy, which averages about 230 million dollars per year, consists of cattle and poultry raising and dairy products with grain, grain sorghums, peanuts, cotton, and soybeans the principal crops. Industrial activities include the operation of sand and gravel pits, the production of clay and manufacture of brick and tile products, the production of cement materials, and the manufacture of cement.

Previous Investigations

Portions of the study region have been previously discussed in numerous publications related to geology

and ground-water resources, and these are listed in the selected references. Some of the investigations leading to these publications were conducted by the U.S. Geological Survey, Texas Department of Water Resources, Bureau of Economic Geology of the University of Texas, private concerns, and educational institutes.

Reports have been published on the geology of Cooke, Denton, Grayson, Johnson, and Parker Counties and on the ground-water resources of Dallas, Ellis, Grayson, Johnson, Montague, Navarro, Parker, and Tarrant Counties. Most of these publications were published prior to 1960.

Acknowledgements

Recognition is extended to the property owners within the study region for supplying information concerning their water wells and permitting access to their properties; and to all water well drillers, city officials, water superintendents, and officials of independent water companies for information, assista-ce, and cooperation rendered throughout the investigation. Cooperation of federal and other state agencies is also gratefully acknowledged. Special thanks are extended to J. L. Myers Co., Layne Texas Co., and Henry Millican for the extensive use of their water-well records and electric logs.

The author also thanks Dan Muller and Bob Price of the Texas Department of Water Resources who made many useful suggestions concerning the ground-water availability estimates and to Loyd Walker for his review and editing of the manuscript. General supervision in the preparation of this report was furnished by C. R. Baskin, Director, Data and Engineering Services Division, and Tommy R. Knowles, Chief of the Data Collection and Evalution Section.

Method of Investigation

The fieldwork for this investigation began in January 1975 and ended in April 1978. Office work, which consisted mainly of assembling data and writing the report, started concurrently with the fieldwork and was completed in August 1978.

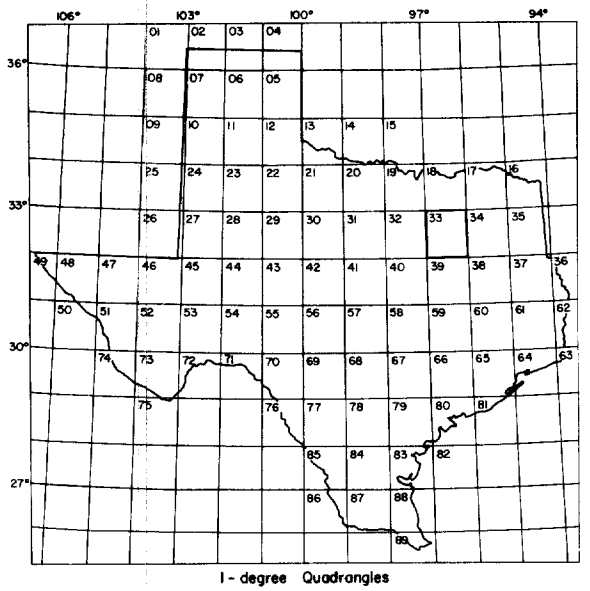
Fieldwork consisted of conducting a complete inventory of municipal, industrial, and irrigation water wells; conducting an inventory of historical pumpage; collect ng past and present water levels; collecting data on well construction, yields, pumping rates, and pumping levels; collecting drillers' logs, mechanical logs, and well completion data; determining elevations of wells having water level or stratigraphic data; conducting power and yield tests on selected irrigation wells; mapping surface geology; determining the chemical quality of ground water by using available analyses and collecting water samples for analysis, where needed; and determining the magnitude and extent of ground-water contamination in the outcrop area. Office work included constructing geologic cross-sections; tabulating water-well records, water levels, and chemical analyses; preparing well-location maps; constructing geologic maps of net sand thickness, structure, piezometric surface, chemical quality, surface geology, transmissibility, and water-level decline; and tabulating historical pumpage and projecting future water demands based on population, economic growth, and precipitation.

Well-Numbering System

The systematic well numbering used in this report was originally developed by the Texas Water Commission and is now in use statewide. It was designed to identify, facilitate the location of, and avoid duplication of numbers on all wells used in any Department report, investigation or study. The system is based on division of the State into one-degree quadrangles of latitude and longitude and the repeated division of these quadrangles into smaller ones as shown in Figure 3.

Each one-degree quadrangle is subdivided into sixty-four 7 1/2-minute quadrangles, and these quadrangles are further subdivided into nine 2 1/2-minute quadrangles. Each one-degree quadrangle has an assigned number. The 7 1/2-minute quadrangles are numbered consecutively from left to right, beginning with quadrangle number 01 in the upper left-hand corner of the one-degree quadrangle. The 2 1/2-minute quadrangles within each 7 1/2 minute quadrangle are numbered similarly. The wells are numbered consecutively, beginning with 01, within each 2%minute quadrangle. From left to right, the first and second digits of a well number identify the one-degree quadrangle in which the well belongs; the third and fourth digits, the 7 1/2-minute quadrangle; and the fifth digit, the 2 1/2-minute quadrangle. The sixth and seventh digits identify the particular well in the 2 1/2-minute quadrangle.

On the well location maps in this report, the one-degree quadrangles are identified with large open-block numbers. The 7 1/2-minute quadrangles are numbered in the upper left-hand corner or as near to that position as possible in the cases where a part of the quadrangle falls outside the county. The three-digit numbers near the wells identify the 2 1/2-minute quadrangle and the well within that quadrangle.



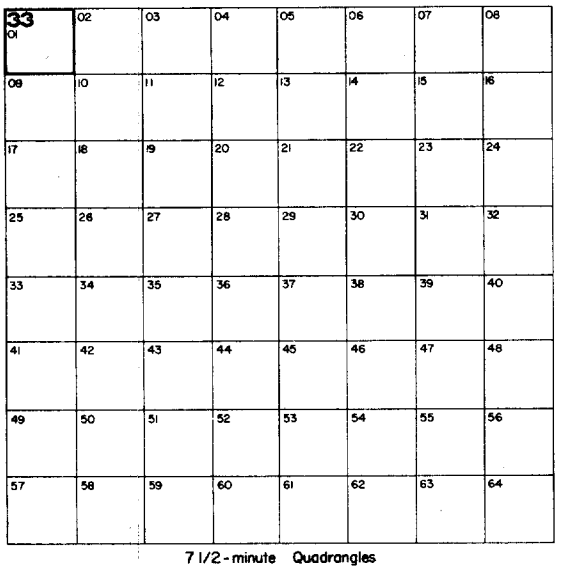
Location of Well HR-33-01-604

33 1 - degree quadrangle

01 7 1/2 - minute quadrangle

6 2 1/2 - minute quadrangle

04 Well number within 2 1/2-minute quadrangle



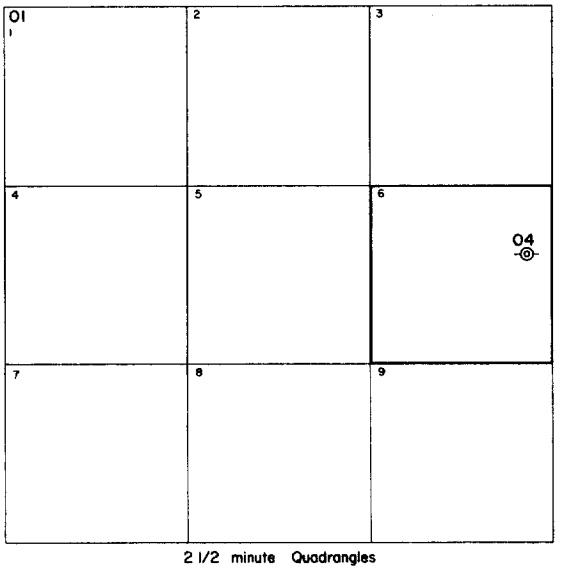


Figure 3.—Well-Numbering System

In addition to the seven-digit well number, a two letter prefix is used to identify the county. The prefixes for the 20 counties in this report are:

Prefix	County	Prefix	County
DT	Collin	KT	Grayson
HA	Cooke	LY	Hood
HR	Dallas	PH	Hunt
HU	Delta	PX	Johnson
HW	Denton	RA	Kaufman
JK	Ellis	RT	Lamar
JS	Fannin	TR	Montague
TY	Navarro	WL	Rockwall
UP	Parker	XU	Tarrant
WB	Red River	ZR	Wise

Well HR-33-01-604, shown on Figure 3, is in Dallas County (HR); 1-degree quadrangle 33; 7½-minute quadrangle 01; 2½-minute quadrangle 6; and was the fourth well inventoried in that 2½-minute quadrangle.

METRIC CONVERSIONS TABLE

For those readers interested in using the International System (SI) of Units, the metric

equivalents of English Units of measurements are given in parentheses in the text. The English units used in this report may be converted to metric units by the following conversion factors:

Multiply English units	BY	To obtain SI units
acres	0.4047	square hectometers (hm^2)
acre-feet (acre-ft)	.001233	cubic hectometers (hm^3)
cubic feet per second (ft^3/s)	28.32	liters per second (l/s)
feet (ft)	.3048	meters (m)
feet per mile (ft/m)	.189	meters per kilometer (m/km)
gallons (gal)	3.785	liters (l)
gallons per minute (gal/min)	.06309	liters per second (l/s)
gallons per minute per foot [(gal/min)/ft]	.207	liters per second per meter [(l/s)/m]
gallons per day per square foot [(gal/d)/ft^2]	40.74	liters per day per square meter [(l/d)/m^2]
gallons per day per foot [(gal/d)/ft]	12.418	liters per day per meter [(l/d)/m]
inches (in)	2.54	centimeters (cm)
miles (mi)	1.609	kilometer (km)
square miles (mi^2)	2.590	square kilometers (km^2)

To convert degrees Fahrenheit ($^\circ F$) to degrees Celsius ($^\circ C$) use the following formula:

$$^\circ C = (^\circ F - 32)(0.556)$$

GEOLOGY AS RELATED TO THE OCCURRENCE OF GROUND WATER

Geologic History

Paleozoic

During most of the Paleozoic era, a sedimentary basin existed throughout much of central and north-central Texas which received sediments consisting of sandstone, limestone, carbonaceous shales, and other marine sediments. 'Sediments were deposited in this basin until late Pennsylvanian time when the Llano Uplift and the Ouachita Fold Belt caused a regional tilting to the west and faulting in the immediate uplift area. The Pennsylvanian-Cretaceous unconformity shows a tremendous period of emergence and erosion. During Permian time, the basin shifted to the west and only the northwest corner of the study area received sediments, while the remainder of the area underwent extensive erosion.

Cretaceous

During the Triassic and Jurassic periods of the early Mesozoic era, withdrawal of the seas from the north-central Texas area along with subsidence in the Gulf Coast embayment led to a reversal of drainage direction. This resulted in an extensive truncation of Pennsylvanian strata in the Fort Worth basin and surrounding area. By the close of Jurassic time, Paleozoic rocks had been reduced to an almost flat-featureless plain, or peneplain, upon which marine sediments were deposited along an oscillating shoreline during the Cretaceous period.

Two major invasions of the seas during the Cretaceous period are represented by the Comanche and Gulf Series. During late Cretaceous (Gulf Series), a general uplift occurred to the west and the seas withdrew gullfward covering only the eastern portion of the study area.

Tertiary and Quaternary

At the close of the Cretaceous period, noted by uplifting of the western area and subsidence of the coastal area, sediments of Tertiary and Quaternary age were deposited. The repeated transgression and regression of the sea resulted in an alternating sequence of marine and continental deposits. Throughout Tertiary time, except for minor periods of subsidence, the land surface was eroded and modified by streams. During Quaternary time, the streams deposited alluvial sediments. The older sediments are represented by terrace deposits above the alluviated valleys of present streams.

General Stratigraphy

Stratigraphic units that supply fresh to slightly saline water to wells in the study region range in age from Paleozoic to Recent. The most important

water-bearing formations in north-central Texas are of Cretaceous age.

The Cretaceous System is composed of two series, Gulf and Comanche, and each is divided into groups. The Gulf Series is divided into the following five groups: Navarro, Taylor, Austin, Eagle Ford, and Woodbine. The Comanche Series is divided into the following three groups: Washita, Fredericksburg, and Trinity.

The Taylor and Eagle Ford Groups consist predominantly of shale, limestone, clay, and marl and yield only small amounts of water in localized areas. The Navarro and Austin Groups consist of chalk, limestone, marl, clay, and sand and, except for the Nacatoch and Blossom Sands, yield only small amounts of water locally. The Nacatoch Sand of the Navarro Group and the Blossom Sand of the Austin Group yield small to moderate supplies of water to limited areas. The Woodbine Group is the only important aquifer of the Gulf Series in the area covered by this report. It consists of sand, sandstone, and clay and is capable of yielding small to large amounts of water. The Woodbine Group is discussed in detail in the sections covering the stratigraphy of the water-bearing formations and the occurrence and the availability of ground water.

Both the Washita and Fredericksburg Groups of the Comanche Series consist predominantly of limestone, shale, clay, and marl and yield only small amounts of water to localized areas. The Trinity Group is the principal water-bearing group of rocks in the region and is divided into the Paluxy, Glen Rose, Twin Mountains, and Antlers Formations. The Paluxy consists of sand and shale and is capable of yielding small to moderate amounts of water. The Glen Rose is predominantly a limestone and yields small quantities of water only to localized areas. The Twin Mountains is composed of conglomerate, sand, and shale. It is the principal water-bearing formation of Cretaceous age in the region and yields moderate to large amounts of water. The name Antlers Formation is applied north of the Glen Rose pinch-out, where the Paluxy and Twin Mountains coalesce to form one unit. Water-bearing members of the Trinity Group are discussed in detail in the sections covering stratigraphy of the water-bearing formations and occurrence and availability of ground water.

The relationship, approximate maximum thickness, brief description of lithology, and summary of water-bearing properties of the stratigraphic units are shown in Table 1. Outcrop areas of the various formations are illustrated on the geologic outcrop map (Figure 16). The altitude of the top of the formations and their net sand thicknesses are shown on Figures 18 through 22, 27, and 29.

Geologic cross-sections are profiles portraying an interpretation of a vertical section of the earth. Five geologic cross-sections were constructed; two are strike sections and three are dip sections. Dip sections are constructed approximately perpendicular to the strike of the beds and parallel to the dip of the beds, while strike sections are constructed parallel to the strike of the beds. These five geologic: sections, illustrated on Figures 35 through 39, show the structure and stratigraphic relationships of the geologic units.

Structure

Pennsylvanian and Permian rocks in the outcrop along the west edge of the study area dip westward and northwestward at about 40 feet per mile (7.6 m/km). Permian beds probably extend not much farther eastward than Montague County. The Pennsylvanian sediments, which underlie the Cretaceous rocks in most of the remaining area, thicken from the outcrop eastward into the Fort Worth basin. The axis of this basin and many of the other major structural features in or near the report area are shown on Figure 4.

The Cretaceous System forms a southeastward-thickening wedge extending across the area into a structural feature known as the East Texas basin. Thickness of these rocks ranges from zero in the west to nearly 7,500 feet (2,286 m) in the southeast. Regional dip is east and southeast at rates of about 15 to 40 feet per mile (2.8 to 7.6 m/km). The dip rate increases to as much as 300 feet per mile (57 m/km) on the southeastward-plunging ridge called the Preston anticline. This anticline and an associated trough to the south (Sherman syncline) have caused a change in the regional outcrop pattern as shown on the geologic map (Figure 16).

Tertiary System beds dip regionally southeastward from the Mexia-Talco fault system, which extends in a northerly direction along the eastern margin of the report area, at a rate of about 100 feet per mile (19 m/km). Deviations from this dip rate occur locally due to the faulting. These beds attain a thickness of approximately 250 feet (76 m) within the area of study. However, just outside the area of investigation in southern Navarro County they reach a maximum thickness in excess of 1,000 feet (305 m).

Quarternary deposits occur along the floodplains of the Brazos, Red, Sulphur, and Trinity Rivers and

Table 1.—Stratigraphic Units and Their Water-bearing Properties

Yield, in gallons per minute (gal/min): small, less than 100 gal/min; moderate, 100—1,000 gal/min; large, more than 1,000 gal/min.

Era	System	Series	Group	Stratigraphic units	Approximate maximum thickness (feet)	Character of rocks	Water-bearing characteristics
Cenozoic	Quaternary	Recent		Alluvium	75	Sand, silt, clay and gravel.	Yields small to large amounts of water to wells along the Red River
		Pleistocene		Fluviatile terrace deposits			
	Tertiary	Eocene	Wilcox		100	Fine to medium sand with silt and clay	Yields small quantities of water to wells in the eastern part of the area.
		Paleocene	Midway		150	Gray, calcareous clay, in part silty to sandy	Do.
Mesozoic	Cretaceous	Gulf	Navarro	Kemp Clay Corsicana Marl	300	Fossiliferous clay and hard limy marl	Not known to yield water to wells in the area.
				Nacatoch Sand	500	Fine sand and marl, fossiliferous	Yields small to moderate quantities of water near the outcrop.
			Taylor	Marlbrook Marl Pecan Gap Chalk Wolfe City - Ozan Formations	1,500	Clay, marl, mudstone, and chalk	Yields small quantities of water to shallow wells.
			Austin	Gober Chalk Brownstown Marl Blossom Sand Bonham Formation	700	Chalk, limestone, and marl; fine to medium sand, fossiliferous	Yields small to moderate quantities of water to wells in the northeastern part of the area; very limited as an aquifer.
			Eagle Ford		650	Shale with thin beds of sandstone and limestone	Yields small quantities of water to shallow wells.
			Woodbine		700	Medium to coarse iron sand, sandstone, clay and some lignite	Yields moderate to large quantities of water to municipal, industrial and irrigation wells.
		Comanche	Washita	Grayson Marl - Mainstreet Limestone Pawpaw Formation - Weno Limestone - Denton Clay Fort Worth - Duck Creek Kiamichi Formation	1,000	Fossiliferous limestone, marl, and clay; some sand near top	Yields small quantities of water to shallow wells.
			Fredericksburg	Edwards Limestone Comanche Peak Formation — Goodland Limestone Walnut Formation	250	Limestone, clay, marl, shale, and shell agglomerates	Do.
			Trinity	Antlers Formation: Paluxy Formation	900 — 400	Fine sand, sandy shale, and shale	Yields small to moderate quantities of water to wells.
				Antlers Formation: Glen Rose Formation	900 — 1,500	Limestone, marl, shale, and anhydrite	Yields small quantities of water in localized areas.
				Antlers Formation: Twin Mountains Formation	1,000	Fine to coarse sand, shale, clay, and basal gravel and conglomerate	Yields moderate to large quantities of water to wells.
Paleozoic				Paleozoic rocks undifferentiated		Sandstone, limestone, shale and conglomerate	Yields small quantities of water in the western part of the area.

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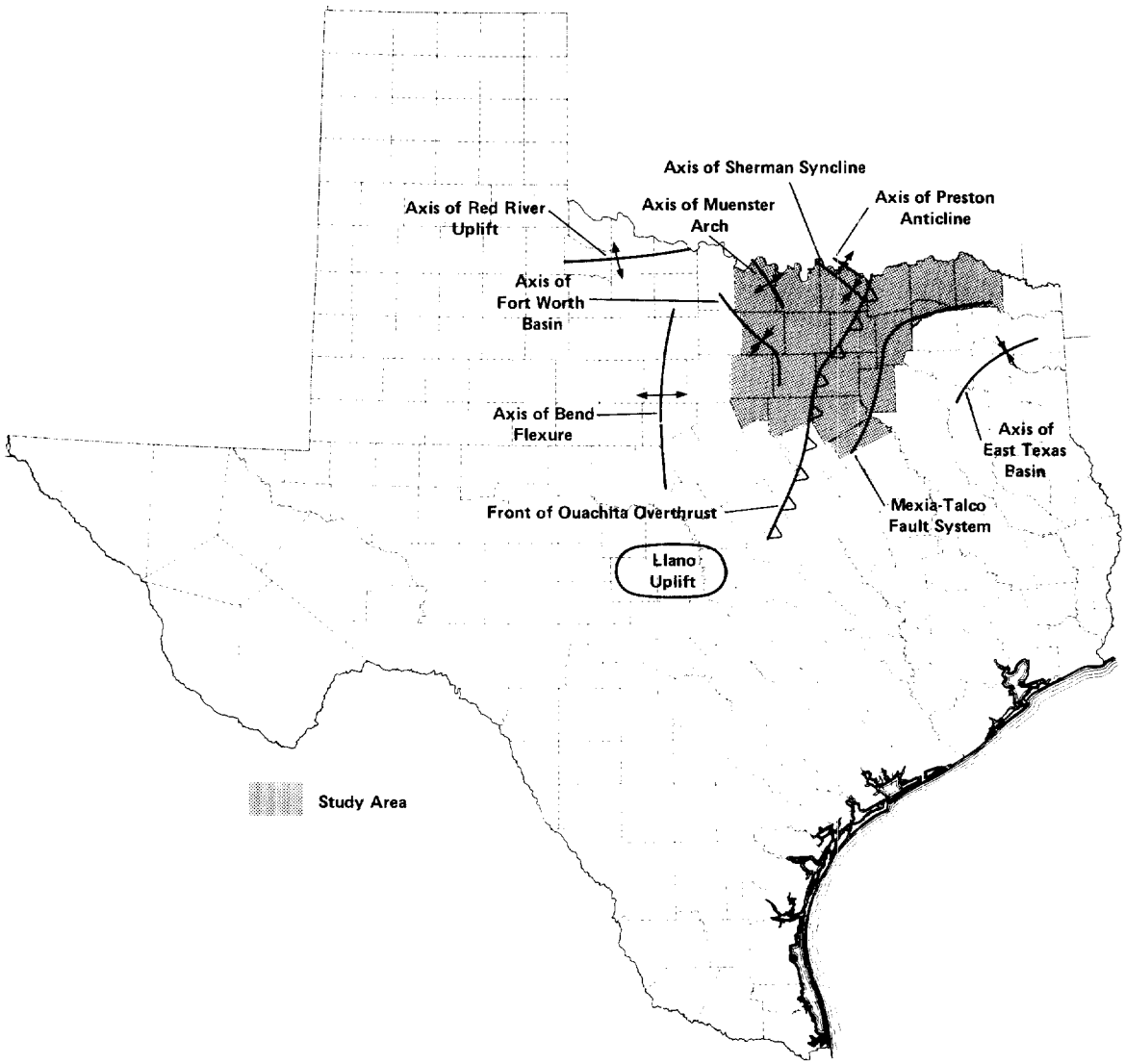

Figure 4.—Major Structural Features From the Llano Uplift to the Red River

many of their main tributaries. Terraces, which represent remnants of older floodplain deposits of these drainage systems, occur at higher elevations along some of the rivers, particularly the Red River. Alluvial deposits are reported to be as thick as 70 feet (21 m) in Fannin County. Generally, the alluvial deposits are irregular in thickness and areal extent. Regional slope of these deposits is probably less than 5 feet per mile (0.9 m/km) and generally east and southeast in the direction of slope of the land surface. Locally, the direction will vary according to the direction of stream or river flow.

STRATIGRAPHY OF THE WATER-BEARING FORMATIONS

Paleozoic Rocks

Paleozoic rocks crop out in the western part of the study area in Hood, Montague, Parker, and Wise Counties (Figure 16). The occurrence of ground water with acceptable quality in these rocks is generally limited to the outcrop and adjacent area. Figure 17 shows the approximate altitude of the base of

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Cretaceous rocks, which is the top of the Paleozoic in the western part of the study area.

Of the many pre-Cretaceous rocks cropping out along the western edge of the study region, only the Wichita Group of the Permian System and several formations in the Cisco and Strawn Groups of the Pennsylvanian System yield water in any appreciable quantity and of good quality.

The Wichita Group crops out in the northwest third of Montague County and consists of fossiliferous limestone, shale, and sandstone. Sandstone is more abundant in the lower part of the group, however, the amount of sand diminishes downdip. For this reason, wells pumping ground water from this lower sandstone are located on or very near the outcrop. The rocks dip gently toward the west or northwest.

The Cisco Group crops out in the southwest corner of Montague County and underlies the Wichita Group to the north. The Cisco Group consists of alternating beds of shale, sandstone, limestone, and conglomerate. As in the Wichita Group, there is less sand downdip than in the outcrop. In the study area, rocks of Pennsylvanian age generally dip toward the west or northwsst at a rate of approximately 50 feet per mile (9.5 m/km) and are overlain by the Trinity Group of Cretaceous age to the east.

The Strawn Group crops out in the western portion of Parker County. The Garner Formation of the Strawn Group in the northern part of the outcrop is the only source of water for wells in this part of the study area. Ground water is derived from the Brazos River Conglomerate Member of the Garner Formation, and the town of Whitt in Parker County has the only public supply system that taps this source. Numerous domestic and livestock wells utilize ground water from both the Cisco and Strawn Groups.

Antlers Formation

The Antlers Formation is the lateral equivalent of the Twin Mountains and Paluxy Formation. In the northwestern part of the study region, north of the updip limit of the Glen Rose Formation (Figure 16), the elastic sand and clay of the Twin Mountains and Paluxy Formarions coalesce to form a single unit, the Antlers Formation (Figure 36 and 37).

The Antlers crops out mainly in Cooke, Montague, and Wise Counties. The Antlers dips to the southeast at an average rate of 20 feet per mile (3.8 m/km) near its outcrop to 70 feet per mile (13.3 m/km) near its southeastern limit. In parts of Grayson County on the south flank of the Preston anticline, the dip is southward in excess of 300 feet per mile (56.8 m/km).

A typical section of Antlers consists of a basal conglomerate and gravel overlain by a fine white to gray, poorly consolidated sand in massive-crossbedded layers interbedded with layers of red, purple, or gray clay in discontinuous lenses scattered throughout the formation. A middle section of Antlers contains considerably more clay beds than the upper or lower sections, and to the south, near the updip limit of the Glen Rose Formation, limestone beds also occur. Massive beds near the base and top of the Antlers probably correspond to the Twin Mountains and Paluxy Formations in the southern part of the study area. Fine white to yellow pack sand with thin beds of multicolored clay resting on a basal layer of gravel characterize a section on the outcrop.

Total thickness of the Antlers varies from about 400 feet (122 m) near the outcrop to about 900 feet (274 m) near the updip limit of the Glen Rose Limestone in southeast Grayson County. Well HA-19-22-704 in Cooke County shows a total thickness of 550 feet (167 m) while well KT-18-28-404 in Grayson County reveals a total thickness of 870 feet (265 m). The thickness gradually increases from west to east as illustrated on Figure 38. The approximate altitude of the top of the Antlers is shown on Figure 18.

Twin Mountains Formation

The Twin Mountains Formation outcrops in the western part of the study region in Hood, Parker, and Wise Counties. The Twin Mountains overlies Paleozoic rocks throughout the study region and is the lower member of the Trinity Group. The Twin Mountains underlies the Glen Rose Formation where the Glen Rose is present. In Wise, Denton, Cooke, and Grayson Counties, where the Glen Rose is absent, the Twin Mountains is equivalent to the lower unit of the Antlers Formation.

Originally the basal Cretaceous bed was named the Travis Peak Formation, but the name was changed to the Twin Mountains Formation in north-central Texas (Fisher and Rodda, 1966). The Travis Peak contains conglomerates of pebble-size and cobble-size limestone and dolomite, calcareous sands and silts, and impure limestones in central Texas. In contrast, the Twin Mountains sequence in north-central Texas consists mainly of medium- to coarse-grained sands, red and gray

silty clays, and siliceous conglomerates of chert, quartzite, and quartz pebbles.

The Twin Mountains consists of a basal conglomerate of chert and quartz, grading upward into coarse- to fine-grained sand interspersed with varicolored shale. The sand strata are more thickly bedded in the lower part of the formation than in the upper and middle and can be correlated to the Hosston Formation to the south. It is in this lower massive sand that the majority of wells are completed. Varicolored shale and clay, predominantly red, occur throughout the formation. The shale grades vertically and laterally into sandy shale and sand, making correlations over long distances almost impossible. The upper part of the Twin Mountains also contains a considerable percentage of sand and sandstone strata but less than the lower part due to the increased interbedding of shale and clay. Few wells are developed in the upper part of the formation.

Beds dip toward the east from 30 feet per mile (5.7 m/km) near the outcrop to 95 feet per mile (18 m/km) near the downdip limit of fresh to slightly saline water as illustrated on the geologic cross sections and Figure 19 which shows the approximate altitude of the top of the Twin Mountains. Thickness varies considerably over the study region, generally increasing downdip and ranging from less than 200 feet (61 m) near the outcrop to 860 feet (262 m) in oil test HR-33-28-401. However, data on cross section C-C' (Figure 37) indicate that maximum thickness at the downdip limit of fresh to slightly saline water should reach approximately 1,000 feet (305 m).

The Twin Mountains Formation is the most important source of ground water for a large part of the study region anc yields moderate to large quantities of fresh to slightly saline water to municipal and industrial wells. In 1974, over 41,000 acre-feet (50.6 hm^3) of water was pumped from this aquifer for municipal and industrial uses.

Paluxy Formation

The Paluxy Formation is the upper member of the Trinity Group south of the Glen Rose pinch-out. It crops out in Hood, Parker, Tarrant, and Wise Counties and forms the surface of the Western Cross Timbers belt. The dip is easterly at an average rate of 30 feet per mile (5.7 m/km) near the outcrop, increasing to 80 feet per mile (15.2 m/km) near the downdip limit of fresh to slightly saline water as illustrated on the geologic sections and on Figure 18, which shows the approximate altitude of the top of the Paluxy and the extent of the outcrop in the study area.

The Paluxy is composed predominantly of fine- to coarse-grained, friable, homogeneous, white quartz sand interbedded with sandy, silty, calcareous, or waxy clay and shale. In general, coarse-grained sand is in the lower part. The Paluxy grades upward into fine-grained sand with variable amounts of shale and clay. The sands are usually well sorted, poorly cemented, and crossbedded. Pyrite and iron nodules are often associated with the sands and frequently contribute a red stain to the individual beds. In some areas along the outcrop, high iron concentrations are present in ground-water analyses.

Thickness of the Paluxy varies considerably throughout the study region. From a maximum thickness nearing 400 feet (122 m) in the northern part of the study area, the Paluxy thins to the south and southeast to less than 100 feet (30 m) with a net sand thickness of less than 40 feet (12 m). This thickness change is shown on the geologic sections and on Figure 20, which shows the approximate net thickness of sand and the downdip limit of fresh to slightly saline water.

The Paluxy Formation is an important aquifer in the study region and during 1974, produced over 10,000 acre-feet (12.3 hm^3) of water for municipal and industrial use and provided water to many domestic and livestock wells. Water wells tapping the Paluxy aquifer yield small to moderate quantities of fresh to slightly saline water.

Woodbine Group

The Woodbine Group is the basal rock unit of the Gulf Series of Cretaceous age in the study area. It crops out in Cooke, Dallas, Denton, Grayson, Johnson, and Tarrant Counties with a northeast-southwest strike. In the northern part of Texas, the outcrop parallels the Red River in a west-east strike, cropping out in Fannin, Lamar, and Red River Counties (Figure 16). The regional dip is to the southeast at an average rate of 35 feet per mile (6.63 m/km) near the outcrop and up to 75 feet per mile (14.2 m/km) near the downdip limit of fresh to slightly saline water as illustrated on the geologic sections and on Figure 21, which shows the approximate altitude of the top of the Woodbine.

In the southern part of the study area, the Woodbine is composed of friable, ferruginous, fine-grained sand and sandstone with interbedded shale, sandy shale, and laminated clay. The upper part of the Woodbine displays a marked increase in shale and clay, while the lower portion exhibits a more sandy make-up. Ripple marks and large-scale crossbedding are prevalent throughout the entire Woodbine Group.

25 019

In the northern part of the study area, the Woodbine is generally divided into a lower, middle, and upper part, which drillers refer to as first, second, and third Woodbine. These three parts can be readily distinguished on individual electric logs of wells located between Dallas and Sherman but are difficult to trace accurately as a unit over long distances along the strike or in the downdip area.

The upper Woodbine is mostly a fine-grained, well sorted, crossbedded, reddish-brown sandstone with concretions and some gray shale. The middle Woodbine is a reddish sandstone with interbedded gray to brown clay and some shale. The lower Woodbine is an interbedded, red-brown to white sandstone (sometimes exhibiting massive beds) with ironstone and sandy, gray to brown clay. It yields the largest quantity of water that is low in dissolved iron. The upper Woodbine yields limitec amounts of water that contains large concentrations of iron.

The total thickness of the Woodbine ranges from 230 feet (70 m) near the southern extent of the outcrop to about 700 feet (213 m) near the downdip limit of fresh to slightly saline water in Fannin County. Regionally, the formation thickens downdip and toward the northeast. The change in thickness is shown on the geologic sections and on Figure 22, which shows the approximate net thickness of sand containing fresh to slightly saline water.

The Woodbine Group is an extremely important aquifer over a large portion of the study area, yielding over 8,500 acre-feet (10.5 hm^3) per year of water to public supply wells in nine of the 20 counties in this study.

Blossom Sand

The Blossom Sand of the Austin Group crops out in central Fannin, Lamar, and Red River Counties. The strike of the outcrop is east-west and ends in central Fannin County where the Blossom merges laterally into marl and chalk. The outcrop extends out of the study area into Bowie County to the east. The occurrence of usable quality water in the Blossom is generally limited to the Red River basin and the northern part of the Sulfur River basin. The dip is to the south averaging about 85 feet per mile (16.1 m/km).

The Blossom Sand consists of brown to light gray, unconsolidated, glauconitic, ferruginous, fine to medium sand interbedded with sandy and chalky marl. Most of the formation contains impermeable sandy clay or marl and chalk, with only about 25 percent sand. The amount of sand decreases westward near the town of Bonham.

The Blossom thickens southward downdip and eastward along the strike. Total thickness varies from zero in central Fannin County to about 400 feet (122 m) in southern Red River County. In some areas, the sand beds at the top and base of the formation approach a thickness of 50 feet (15 m). However, due to the impervious nature of the intervening beds, the sands are probably not hydrologically connected.

Nacatoch Sand

The Nacatoch Sand of the Navarro Group crops out in Delta, Hunt, Kaufman, Lamar, Navarro, and Red River Counties within the study region. It dips southward at about 80 feet per mile (15.2 m/km). In the western part of the outcrop, numerous faults of the Luling-Mexia-Talco fault system cut the formation.

The Nacatoch Sand consists of light gray, unconsolidated, massive, glauconitic, calcareous sand and marl. Approximately half of the formation is composed of sand, but individual beds vary considerably in extent and thickness laterally.

Thickness of the Nacatoch varies from 500 feet (152 m) in the eastern part of Red River County, decreasing westward along the strike, to about 350 feet (107 m) in parts of Delta and Hunt Counties. There is little change in thickness from the outcrop to the downdip limit of fresh to slightly saline water.

CHEMICAL QUALITY OF GROUND WATER AS RELATED TO USE

General Chemical Quality of Ground Water

All ground water contains minerals carried in solution, the type and concentration of which depend upon the surface and subsurface environment, rate of ground-water movement, and source of the ground water. Precipitation is relatively free of minerals until it comes in contact with the various constituents which make up the soils and component rocks of the aquifer. As a result of the water's solvent power, minerals are dissolved and carried into solution as the water moves through the aquifer. The concentration depends upon the solubility of the minerals present, the length of time water is in contact with the rocks, and the amount of dissolved carbon dioxide the water contains.

25 020

Concentrations of dissolved minerals in ground water generally increase with depth where circulation has been restricted due to various geologic conditions. Restricted circulation retards the flushing action of the fresh water moving through the aquifers, causing the water to become highly mineralized. In addition to natural mineralization, man can adversely alter the chemical quality of ground water by permitting highly mineralized water to enter fresh-water strata through inadequately constructed wells, by seepage from oil-field brine disposal pits, and disposal of animal wastes, sewage, or various industrial waste into fresh-water strata or into aquifer recharge areas.

The principal chemical constituents found in ground water are calcium, magnesium, sodium, iron, carbonate, bicarbonate, sulfate, chloride, and minor amounts of silica, potassium, manganese, nitrate, fluoride, and boron. Concentrations of these ions or chemical constituents are commonly reported in milligrams per liter (mg/l). The source, significance, and range in concentration of mineral constituents and properties of natural waters for the various aquifers in the study area are given in Table 2. Chemical analyses of water from selected wells in the study region are given in Table 4, Volume 2. Figure 23 shows the sulfate, chloride, and dissolved-solids content in water from selected wells in the Trinity and Woodbine aquifers.

Salt water is produced from oil and gas fields mainly in the norlhern half of the study area. Oil and gas wells which are not properly cemented opposite fresh to slightly saline water-producing formations and improper disposal of salt water can cause contamination of water-supply sources. Presently the area between Springtown in Parker County, and Decatur in Wise County, is experiencing apparently contaminated water in wells due to the improper completion of existing oil and gas wells. The main problem with this type of contamination is that the water may remain polluted long after the source of contamination is removed due to the slow rate of movement exhibited by ground water. Checks to insure continued good quality of ground water are now being made through a network of wells periodically sampled in each water-bearing formation. Comparisons of the relative concentrations of chemical constituents in native ground water, apparently contaminated ground water, and a typical oil-field brine are illustrated on Figure 5.

Quality Criteria or Standards

The degree and type of mineralization of ground water determines its suitability for municipal, industrial, irrigation, and other uses. Several criteria for water-quality requirements have been developed through the years which serve as guidelines in determining the suitability of water for various uses. Subjects covered by the guidelines are bacterial content; physical characteristics, including color, taste, odor, turbidity, and temperature; and the chemical constituents. Water-quality problems associated with the first two subjects can usually be alleviated economically. The neutralization or removal of most of the unwanted chemical constituents is usually difficult and often very costly.

Total dissolved-solids content is usually the main factor which limits or determines the use of ground water. Winslow and Kister (1956, p. 5) used an excellent, and very applicable, general classification of waters based on the dissolved-solids concentration in parts per million (ppm). The classification is as follows:

Description	Dissolved-Solids Content (ppm)
Fresh	Less than 1,000
Slightly saline	1,000 to 3,000
Moderately saline	3,000 to 10,000
Very saline	10,000 to 35,000
Brine	More than 35,000

In recent years, most laboratories have begun reporting analyses in mlg/l (milligrams per liter) instead of ppm. These units, for practical purposes, are identical unless the dissolved-solids concentration of water reaches or exceeds 7,000 units (ppm or mg/l). The concentrations of chemical constituents reported in this report, other than for oil-field brines, are in mg/l (Tables 8, IO, 12, and 14). Most of the chemical concentrations are below 7,000 mg/l and therefore the units are interchangeable. For the more highly mineralized waters, a density correction should be made using the following formula:

$$\text{parts per million} = \frac{\text{milligrams per liter}}{\text{specific gravity of the water}}$$

Municipal

As the first step in setting national standards for drinking water quality under the provisions of the Safe Drinking Water Act of 1974, the U.S. Environmental Protection Agency (1975) issued drinking water regulations on December 10, 1975. These standards

Table 2.–Source, Significance, and Range in Concentration of Dissolved-Mineral Constituents and Properties of Water

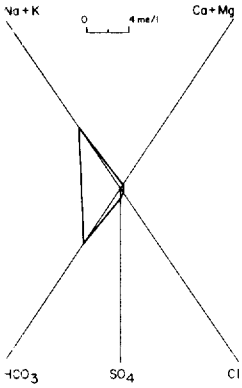
(Adapted from Doll and others, 1963, p. 39-43)

Only analyses representative of native ground water were used. Analyses are in mg/l except percent sodium, specific conductance, pH, and SAR.

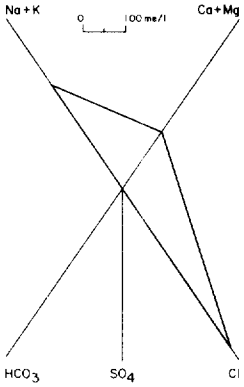
Constituent or property	Source or cause	Significance	Range in concentrations, by aquifer																	
			Antlers			Paluxy			Twin Mountains			Woodbine			Blossom			Nacatoch		
Silica (SiO_2)	Dissolved from practically all rocks and soils, commonly less than 30 mg/l. High concentrations, as much as 100 mg/l, generally occur in highly alkaline waters.	Forms hard scale in pipes and boilers. Carried over in steam of high pressure boilers to form deposits on blades of turbines. Inhibits deterioration of zeolite type water softeners.	3		72	1	–	76	0	–	102	0	–	79	3	–	13	5	–	65
Iron (Fe)	Dissolved from practically all rocks and soils. May also be derived from iron pipes, pumps, and other equipment.	On exposure to air, iron in ground water oxidizes to reddish-brown precipitate. More than about 0.3 mg/l stain laundry and utensils reddish-brown. Objectionable for food processing, textile processing, beverages, ice manufacture, brewing, and other processes. Texas Department of Health (1977) drinking water standards state that iron should not exceed 0.3 mg/l. Larger quantities cause unpleasant taste and favor growth of iron bacteria.	0	–	58.5	0	–	10.0	0	–	17.2	0	–	26.9	0	–	.2	0	–	.1
Calcium (Ca) and Magnesium (Mg)	Dissolved from practically all soils and rocks, but especially from limestone, dolomite, and gypsum. Calcium and magnesium are found in large quantities in some brines. Magnesium is present in large quantities in sea water.	Cause most of the hardness and scale-forming properties of water; soap consuming (see hardness). Waters low in calcium and magnesium desired in electroplating, tanning, dyeing, and in textile manufacturing.	0 and 0	– and –	256 142	0 and 0	– and –	250 205	0 and 0	– and –	266 82	0 and 0	– and –	405 89	2 and 1	– and –	15 3	1 and 0	– and	16 9
Sodium (Na) and Potassium (K)	Dissolved from practically all rocks and soils. Found also in oil field brines, sea water, industrial brines, and sewage.	Large amounts, in combination with chloride, give a salty taste. Moderate quantities have little effect on the usefulness of water for most purposes. Sodium salts may cause foaming in steam boilers and a high sodium content may limit the use of water for irrigation.	7 and 5	– and	580 22.5	5 and 1	– and	1,050 10.0	5 and 0	– and	760 20.0	5 and 1	– and	1,390 20.0	49 and 3.4	– and	813 4.8	9 and 1	– and	663 10.0
Bicarbonate (HCO_3) and Carbonate (CO_3)	Action of carbon dioxide in water on carbonate rocks such as limestone and dolomite.	Bicarbonate and carbonate produce alkalinity. Bicarbonates of calcium and magnesium decompose in steam boilers and hot water facilities to form scale and release corrosive carbon dioxide gas. In combination with calcium and magnesium, cause carbonate hardness.	54	(HCO_3) –	790	122	(HCO_3) –	822	35	(HCO_3) –	700	40	(HCO_3) –	1,210	123	(HCO_3)	784	27	(HCO_3) –	740
Sulfate (SO_4)	Dissolved from rocks and soils containing gypsum, iron sulfides, and other sulfur compounds. Commonly present in some industrial wastes.	Sulfate in water containing calcium forms hard scale in steam boilers. In large amounts, sulfate in combination with other ions gives bitter taste to water. Texas Department of Health (1977) drinking water standards recommend that the sulfate content should not exceed 300 mg/l.	10	–	600	4	–	1,711	4		940	3	–	1,460	52	–	458	0	–	320
Chloride (Cl)	Dissolved from rocks and soils. Present in sewage and found in large amounts in oil-field brines, sea water, and industrial brines.	In large amounts in combination with sodium, gives salty taste to drinking water. In large quantities, increases the corrosiveness of water. Texas Department of Health (1977) drinking water standards recommend that the chloride content should not exceed 300 mg/l.	2	–	590	0	–	815	3	–	980	4	–	1,633	29	–	762	6	–	580
Fluoride (F)	Dissolved in small to minute quantities from most rocks and soils. Added to many waters by fluoridation of municipal supplies.	Fluoride in drinking water reduces the incidence of tooth decay when the water is consumed during the period of enamel calcification. However, it may cause mottling of the teeth, depending on the concentration of fluoride, the age of the child, amount of drinking water consumed, and susceptibility of the individual (Maier, 1950, p. 1120-1139).	0	–	4.2	0		8.0	0	–	16.0	0		7.9	.3	–	2.6	0	–	3.0
Nitrate (NO_3)	Decaying organic matter, sewage, fertilizers, and nitrates in soil.	Concentration much greater than the local average may suggest pollution. Texas Department of Health (1977) drinking water standards suggest a limit of 45 mg/l (as NO_3) or 10 (as N). Waters of high nitrate content have been reported to be the cause of methemoglobinemia (an often fatal disease in infants) and therefore should not be used in infant feeding (Maxcy, 1950, p. 271). Nitrate shown to be helpful in reducing inter-crystalline cracking of boiler steel. It encourages growth of algae and other organisms which produce undesirable tastes and odors.	0	–	90	0		135	0	–	170	0		294	.2	–	4.2	0		11.0

Table 2.–Source, Significance, and Range in Concentration of Dissolved-Mineral Constituents and Properties of Water–Continued

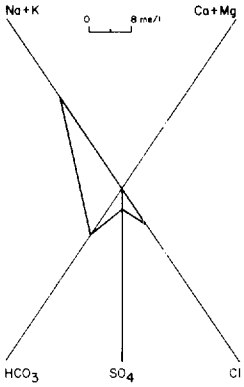
Constituent or property	Source or cause	Significance	Range in concentrations, by aquifer																	
			Antlers			Paluxy			Twin Mountains			Woodbine			Blossom			Nacatoch		
Boron (B)	A minor constituent of rocks and of natural waters.	An excessive boron content will make water unsuitable for irrigation. Wilcox (1955, p. 11) indicated that a boron concentration of as much as 1.0 mg/l is permissible for irrigating sensitive crops; as much as 2.0 mg/l for semitolerant crops; and as much as 3.0 mg/l for tolerant crops. Crops sensitive to boron include most deciduous fruit and nut trees and navy beans; semitolerant crops include most small grains, potatoes and some other vegetables, and cotton; and tolerant crops include alfalfa, most root vegetables, and the date palm.	3	–	1.3	0.3	–	3.0	0.1	–	1.9	0	–	5.7				0.4	–	0.9
Dissolved solids	Chiefly mineral constituents dissolved from rocks and soils	Texas Department of Health (1977) drinking water standards recommend that waters containing more than 1,000 mg/l dissolved solids not be used if other less mineralized supplies are available. For many purposes the dissolved-solids content is a major limitation on the use of water. A general classification of water based on dissolved-solids content, in mg/l, is as follows (Winslow and Kister, 1956, p. 5): Waters containing less than 1,000 mg/l of dissolved solids are considered fresh; 1,000 to 3,000 mg/l, slightly saline; 3,000 to 10,000 mg/l, moderately saline; 10,000 to 35,000 mg/l, very saline; and more than 35,000 mg/l, brine.	208	–	1,870	200		3,008	133	–	2,002	72	–	3,494	182	–	2,031	97	–	1,711
Hardness as $CaCO_3$	In most waters nearly all the hardness is due to calcium and magnesium. All of the metallic cations other than the alkali metals also cause hardness.	Consumes soap before a lather will form. Deposits soap curd on bathtubs. Hard water forms scale in boilers, water heaters, and pipes. Hardness equivalent to the bicarbonate and carbonate is called carbonate hardness. Any hardness in excess of this is called noncarbonate hardness. Waters of hardness up to 60 mg/l are considered soft; 61 to 120 mg/l, moderately hard; 121 to 180 mg/l, hard; more than 180 mg/l, very hard.	1	–	1,160	2		1,400	1	–	914	0	–	940	6	–	47	2	–	56
Sodium-adsorption ratio (SAR)	Sodium in water.	A ratio for soil extracts and irrigation waters used to express the relative activity of sodium ions in exchange reactions with soil (U.S. Salinity Laboratory Staff, 1954, p. 72, 156). Defined by the following equation: $$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}},$$ where Na^{+}, Ca^{++}, and Mg^{++} represent the concentrations in milliequivalents per liter (me/l) of the respective ions.	.1	–	98.1	.1	–	85.6	.2	–	73.2	.2	–	129.5	3.1		117.2	.7	–	75.0
Residual sodium carbonate (RSC)	Sodium and carbonate or bicarbonate in water.	As calcium and magnesium precipitate as carbonates in the soil, the relative proportion of sodium in the water is increased (Eaton, 1950, p. 123-133). Defined by the following equation: $$RSC = (CO_3^{--} + HCO_3^{-}) - (Ca^{++} + Mg^{++})$$ where CO_3^{--}, HCO_3^{-}, Ca^{++}, and Mg^{++} represent the concentrations in milliequivalents per liter (me/l) of the respective ions.	0	–	13.8	0	–	132	0	–	11.1	0	–	19.2	1.1		12.6	0	–	11.8
Specific conductance (micromhos at 25°C)	Mineral content of the water.	Indicates degree of mineralization. Specific conductance is a measure of the capacity of the water to conduct an electric current. Varies with concentration and degree of ionization of the constituents.	338	–	2,646	345	–	5,280	201		4,030	139	–	6,060	315	–	3,590	527	–	2,680
Hydrogen ion concentration (pH)	Acids, acid-generating salts, and free carbon dioxide lower the pH. Carbonates, bicarbonates, hydroxides, phosphates, silicates, and borates raise the pH.	A pH of 7.0 indicates neutrality of a solution. Values higher than 7.0 denote increasing alkalinity; values lower than 7.0 indicate increasing acidity. pH is a measure of the activity of the hydrogen ions. Corrosiveness of water generally increases with decreasing pH. However, excessively alkaline waters may also attack metals. The Texas Department of Health (1977) recommends a pH greater than 7.	6.1	–	9.4	6.6	–	10.4	6.8	–	9.3	6.1	–	9.4	7.6	–	8.9	6.2	–	9.1
Percent Sodium	Sodium in water.	A ratio (using me/l) of the sodium ions to the total sodium, calcium, and magnesium ions. A percent Na exceeding 50 percent is a warning of a sodium hazard. Continued irrigation with this type of water will impair the tilth and permeability of the soil.	5.2	–	100	2.1		100	6.7	–	100	3.8		100	20.0	–	99.5	34.4	–	99.6



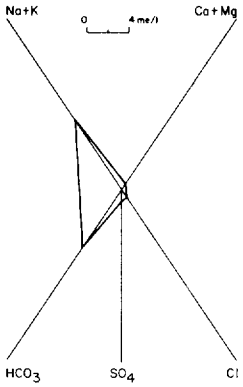
Native Ground Water
Well HA-19-21-902
Depth: 683ft. (208m)
Aquifer: Antlers



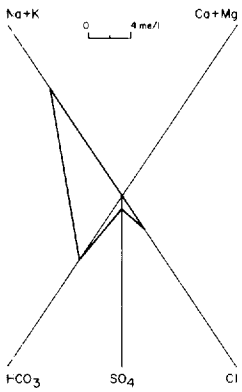
Apparently Contaminated Water
Well TR-19-13-701
Depth: 324ft. (99m)
Aquifer: Antlers



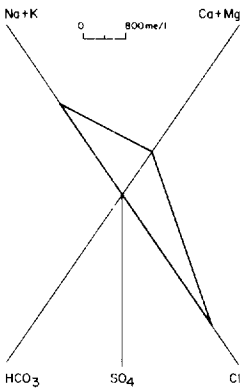
Native Ground Water
Well HR-33-27-202
Depth: 3,669ft. (1,118m)
Aquifer: Twin Mountains



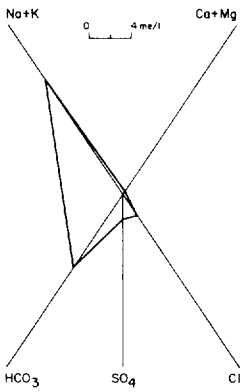
Native Ground Water
Well LY-32-34-602
Depth: 225ft. (69m)
Aquifer: Twin Mountains



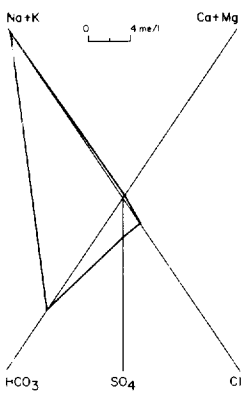
Native Ground Water
Well PH-17-41-902
Depth: 580ft. (177m)
Aquifer: Nacatoch Sand



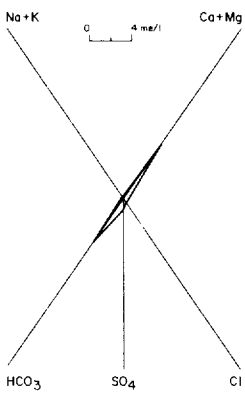
Illinois-Bend Field
Brine produced from Pennsylvanian
Montague County



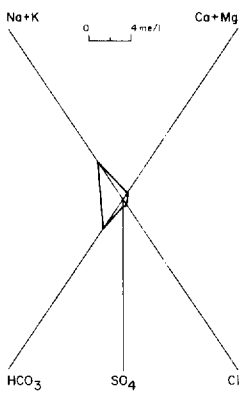
Native Ground Water
Well RT-17-21-710
Depth: 168ft. (51m)
Aquifer: Blossom Sand



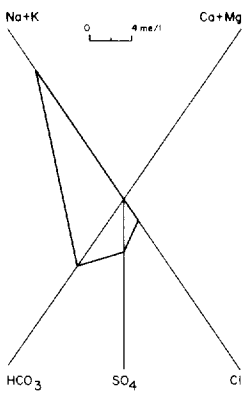
Native Ground Water
Well WB-17-22-902
Depth: 2,025ft. (617m)
Aquifer: Paluxy



Native Ground Water
Well UP-32-11-801
Depth: 231ft. (70m)
Aquifer: Paluxy



Native Ground Water
Well HW-18-33-809
Depth: 280ft. (85m)
Aquifer: Woodbine



Native Ground Water
Well JS-18-32-501
Depth: 1,660ft. (506m)
Aquifer: Woodbine

Distance along each axis shows concentration of ions (in milliequivalents per liter) expressed as a percentage of the total concentration of dissolved solids.

Figure 5

Diagrams of Chemical Analyses of Ground Water and a Typical Oil-Field Brine

apply to all of the public water systems of Texas and became effective June 1977. The responsibility for enforcement of these standards was assumed by the Texas Department of Health on July 1, 1977. Minor revision of the standards became effective on November 30, 1977.

As defined by the Texas Department of Health, municipal systems are classified as follows:

1. A "public water system" is any system for the delivery to the public of piped water for human consumption, if such a system has 4 or more service connections or regularly serves at least 25 individuals daily at least 60 days out of the year.

2. A "community water system" is any system which serves at least 4 or more service connections or regularly serves 25 permanent type residents for at least 180 days per year.

3. A "non-community water system" is any public water system which is not a community water system.

Standards which relate to municipal supplies are of two types: (1) primary and (2) secondary. Primary standards are devoted to constituents and regulations affecting the health of consumers. Secondary standards are those which deal with the esthetic qualities of drinking water. Contaminants for which secondary maximum contaminant levels are set in these standards do not have a direct impact on the health of the consumers, but their presence in excessive quantities may discourage the use of the water.

Primary Standards

Primary standards for dissolved minerals apply to community water systems and are as follows:

Contaminant	Maximum concentration (mg/l)
Arsenic (As)	0.05
Barium (Ba)	1.0
Cadmium (Cd)	.OlO
Chromium (Cr6)	.05
Lead (Pb)	.05
Mercury (Hg)	.002
Selenium (Se)	.Ol
Silver (Ag)	.05
Nitrate (as NO_3)	45
Nitrate (as N)	10

Except for nitrate content, none of the above contaminant levels for toxic minerals applies to non-community water systems. The maximum of 10 mg/l nitrate as nitrogen (about 45 mg/l nitrate as NO_3) applies to community and non-community systems alike.

Maximum fluoride concentrations are applicable to community water systems and they vary with the annual average of the maximum daily air temperature at the location of the system. These are shown in the following tabulation:

Temperature (^{0}F)	Ternperature (^{o}C)	Maximum concentration (mg/l)
63.9 to 70.6	17.7 to 21.4	1.8
70.7 to 79.2	21.5 to 26.2	1.6
79.3 to 90.5	26.3 to 32.5	1.4

Maximum contaminant limits for organic chemicals, as specified, apply to community water systems and are as follows:

Constituent	Maximum concentration (mg/l)
1. Chlorinated hydrocarbons:	
Endrin (1,2,3,4,10,10-hexachloro-6,7,-epoxy-1,4,4a,5,6,7,8,8a-octahydro-1,4-endo, endo-5,8-dimethano napthalene).	0.0002
Lindane (1,2,3,4,5,6 hexachloro-cyclohexane, gamma isomer).	.004
Methoxychlor (I,1,l-Trichloro-2,2-bis [p-methoxyphenyl] ethane).	.I
Toxaphene ($C_{10}H_{10}$ &Cl_8-Technical chlorinated camphene, 67-69 percent chlorine).	005
2. Chlorophenoxys:	
2,4-D (2,4-Dichlorophenoxyacetic acid).	.I
2,4,5-TP Silvex (2,4,5-Trichlorophenoxypropionic acid).	.0l

Maximum levels for coliform bacteria, as specified by the Texas Department of Health, apply to

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community and non-community water systems. The limits specified are basically the same as in the 1962 Public Health Service Standards which have been widely adopted in most states.

In addition to the previously stated requirements, there are also stringent rules regarding general sampling and the frequency of sampling which apply to all public water systems. Additionally, community water systems are subject to rigid radiological sampling and analytical requirements.

Secondary Standards

Recommended secondary standards applicable to all public water systems are given in the following table:

Constituent	Maximum level
Chloride (Cl)	300 mg/l
Color	15 color units
Copper (Cu)	1 .O mg/l
Corrosivity	non-corrosive
Foaming agents	.5 mg/l
Hydrogen sulfide (H_2S)	.05 mg/l
Iron (Fe)	.3 mg/l
Manganese (Mn)	.05 mg/l
Odor	3 Threshold Odor Number
pH	> 7.0
Sulfate (SO_4)	300 mg/l
Dissolved solids	1,000 mg/l
Zinc (Zn)	5.0 mg/l

The above secondary standards are recommended limits, except for water systems which are not in existence as of the effective date of these standards. For water systems which are constructed after the effective date, no source of supply which does not meet the recommended secondary standards may be used without written approval by the Texas Department of Health. The determining factor will be whether there is an alternate source of supply of acceptable chemical quality available to the area to be served.

After July 1, 1977, for all instances in which drinking water does not meet the recommended limits and is accepted for use by the Texas Department of Health, such acceptance is valid only until such time as water of acceptable chemical quality can be made available at reasonable cost to the area in question from an alternate source. At such time, either the water which was previously accepted would have to be treated to lower the constituents to acceptable levels, or water would have to be secured from the alternate source.

Domestic and Livestock

Ideally, waters used for rural domestic purposes should be as free of contaminants as those used for municipal purposes; however, this is not economically possible. At present, there are no controls placed on private domestic or livestock wells. In general, the chemical constituents of waters used for domestic purposes should not exceed the concentrations shown in the following table, except in those areas where more suitable supplies are not available (Texas Department of Health, 1977).

Substance	Maximum concentration (mg/l)
Chloride (Cl)	300
Fluoride (F)	1.6 *
Iron (Fe)	.3
Manganese (Mn)	.05
Nitrate (as; N)	10
Nitrate (as NO_3)	45
Sulfate (SO_4)	300
Dissolved solids	1,000

'Maximum fluoride limit based on annual average of maximum daily air temperature range of 70.7 to 79.Z°F (21.5 to 26.2°C).

Many areas of north-central Texas do not have and cannot obtain domestic water supplies which meet the above recommended standards; however, supplies which do not meet these standards have been used for long periods of time without any apparent ill effects to the user. It is not generally recommended that water used for drinking purposes contain more than a maximum of 2,000 mg/l dissolved solids; however, water containing somewhat higher mineral concentrations has been used where water of better quality was not available.

Generall'y, water used for livestock purposes is subject to the same quality limitations as those relating to drinking water for humans; however, the tolerance limits of the v8ars chemical constituents as well as the dissolved-solids concentration may be considerably higher for livestock than that which is considered satisfactory for human consumption. The type of animal, the kind of soluble salts, and the respective amount of soluble salts determine the tolerance limits (Heller, 1933, p. 22). In the western United States, cattle may tolerate drinking water containing nearly 10,000 mg/l dissolved solids providing these waters contain mostly sodium and chloride (Hem, 1970, p. 324). Waters containing high concentrations of sulfate are usually considered undesirable for livestock use.

Many investigators recommend an upper limit of dissolved solids near 5,000 mg/l as necessary for maximum growth and reproduction. Hem (1970, p. 324) cited a publication of the Department of Agriculture of the state of Western Australia as recommending the following maximum upper limits for dissolved-solids concentration in livestock water.

Animal	Maximum dissolved-solids concentration (mg/l)
Poultry	2,860
Hogs	4,290
Horses	6,435
Cattle (dairy)	7,150
Cattle (beef)	10,100
Sheep (adult)	12,900

Water having concentrations of chemical constituents in excess of the Texas Department of Health's standards may be objectionable for many reasons. Brief explanations for these objections, as well as the significance of each constituent, are given in Table 2.

Industrial

The chemical quality of ground water from the Cretaceous aquifers is generally favorable for industrial use throughout most of the study region. The tolerance in chemical quality of water for industrial use differs widely for different industries and different processes. Suggested water-quality tolerances are presented in Table 3.

Irrigation

The chemical composition of ground water is important in determining its usefulness for irrigation in that it should not adversely affect the productivity of the land. The extent to which chemical quality limits the suitability of ground water for irrigation depends on the nature, composition, and drainage of the soil and subsoil; the amounts of water used and methods of application; the kinds of crops grown; and the climate of the region, including the amounts and distribution of rainfall.

The characteristics of an irrigation water that seem to be most important in determining its quality are: 1) total concentration of soluble salts; 2) relative proportion of sodium to other principal cations (magnesium, calciurr, and potassium); 3) concentration of boron or other elements that may be toxic; and 4) under some conditions, the bicarbonate concentration as related to the concentration of calcium plus magnesium. These have been termed the salinity hazard, the sodium (alkali) hazard, the boron hazard, and the bicarbonate ion hazard (U.S. Salinity Laboratory Staff, 1954, p. 69-82; Wilcox, 1955, p. 11-12; and Lyerly and Longenecker, 1957, p. 13-15).

For purposes of diagnosis and classification, the total concentration of soluble salts (salinity hazard) in irrigation water can be adequately expressed in terms of specific conductance. Specific conductance is the measure of the ability of the ionized organic salts in solution to conduct an electrical current, and is usually expressed in terms of micromhos per centimeter at 25°C (77°F). In general, water having a conductance below 750 micromhos per centimeter is satisfactory for irrigation insofar as salt content is concerned, although salt-sensitive crops may be adversely affected by irrigation water having a conductance in the range of 250 to 750 micromhos per centimeter. Water in the range of 750 to 2,250 micromhos per centimeter is widely used, and satisfactory crop growth is obtained under good management (U.S. Salinity Laboratory Staff, 1954).

In the past, the sodium hazard had been expressed simply as the percent sodium and was divided into the following three classes: (a) water with a percent sodium less than 60, excellent to good; (b) water with a percent sodium between 60 and 75, good to injurious, and (c) water with a percent sodium greater than 75, injurious to unsatisfactory. A better measure of the sodium hazard of water for irrigation is the sodium-adsorption ratio (SAR) which is used to express the relative activity of sodium ions in exchange reactions with soil. The SAR is easily computed from the data determined in the usual water analysis by using the equation found in Table 2.

When the SAR and the specific conductance of a water are known, the classification of the water for irrigation can be determined by graphically plotting these values on the diagram shown in Figure 6. Low sodium water (SI) can be used for irrigation on almost all soils with little danger of the development of harmful levels of exchangeable sodium. Medium-sodium water (S2) will present an appreciable sodium hazard in certain fine-textured soils having high cation-exchange capacity under low leaching conditions. This water may be used on coarse-textured or organic soils having good permeability. High-sodium water (S3) may produce harmful levels of exchangeable sodium in most soils and will require special soil management. Very high sodium water (S4) is generally unsatisfactory for irrigation unless special action is taken, such as addition of gypsum

Table 3.--Water-Quality Tolerances for Industrial Application[1]

(Allowable Limits in Milligrams Per Liter Except as Indicated)

Industry	Turbidity	Color	Color $+O_2$ consumed	Dissolved oxygen (ml/l)	Odor	Hardness	Alkalinity (as $CaCO_3$)	pH	Total solids	Ca	Fe	Mn	Fe+Mn	Al_2O_3	SiO_2	Cu	F	CO_3	HCO_3	OH	$CaSO_4$	Na_2SO_4 to Na_2SO_3 ratio	General[2]
Air Conditioning[3]	--	--	--	--	--	--	--	--	--	--	0.5	0.5	0.5	--	--	--	--	--	--	--	--	--	A, B
Baking	10	10	--	--	--	(4)	--	--	--	--	.2	.2	.2	--	--	--	--	--	--	--	--	--	C
Boiler feed:																							
0-150 psi	20	80	100	2	--	75	--	8.0+	3,000-1,000	--	--	--	--	5	40	--	--	200	50	50	--	1 to 1	--
150-250 psi	10	40	50	.2	--	40	--	8.5+	2,500-500	--	--	--	--	.5	20	--	--	100	30	40	--	2 to 1	--
250 psi and up	5	5	10	0	--	8	--	9.0+	1,500-100	--	--	--	--	.05	5	--	--	40	5	30	--	3 to 1	--
Brewing:[5]																							
Light	10	--	--	--	Low	--	75	6.5-7.0	500	100-200	.1	.1	.1	--	--	--	1	--	--	--	100-200	--	C, D
Dark	10	--	--	--	Low	--	150	7.0+	1,000	200-500	.1	.1	.1	--	--	--	1	--	--	--	200-500	--	C, D
Canning:																							
Legumes	10	--	--	--	Low	25-75	--	--	--	--	.2	.2	.2	--	--	--	--	--	--	--	--	--	C
General	10	--	--	--	Low	--	--	--	--	--	.2	.2	.2	--	--	--	1	--	--	--	--	--	C
Carbonated beverages[6]	2	10	10	--	0	250	50	--	850	--	.2	.2	.3	--	--	--	.2	--	--	--	--	--	C
Confectionary	--	--	--	--	Low	--	--	(7)	100	--	.2	.2	.2	--	--	--	--	--	--	--	--	--	--
Cooling[8]	50	--	--	--	--	50	--	--	--	--	.5	.5	.5	--	--	--	--	--	--	--	--	--	A, B
Food, general	10	--	--	--	Low	--	--	--	--	--	.2	.2	.2	--	--	--	--	--	--	--	--	--	C
Ice (raw water)[9]	1-5	5	--	--	--	--	30-50	--	300	--	.2	.2	.2	--	10	--	--	--	--	--	--	--	C
Laundering	--	--	--	--	--	50	--	--	--	--	.2	.2	.2	--	--	--	--	--	--	--	--	--	--
Plastics, clear, undercolored	2	2	--	--	--	--	--	--	200	--	.02	.02	.02	--	--	--	--	--	--	--	--	--	--
Paper and pulp:[10]																							
Groundwood	50	20	--	--	--	180	--	--	--	--	1.0	.5	1.0	--	--	--	--	--	--	--	--	--	A
Kraft pulp	25	15	--	--	--	100	--	--	300	--	.2	.1	.2	--	--	--	--	--	--	--	--	--	--
Soda and sulfite	15	10	--	--	--	100	--	--	200	--	.1	.05	.1	--	--	--	--	--	--	--	--	--	--
Light paper, HL-Grade	5	5	--	--	--	50	--	--	200	--	.1	.05	.1	--	--	--	--	--	--	--	--	--	B
Rayon (viscose) pulp:																							
Production	5	5	--	--	--	8	50	--	100	--	.05	.03	.05	< 8.0	< 25	< 5	--	--	--	--	--	--	--
Manufacture	.3	--	--	--	--	55	--	7.8-8.3	--	--	.0	.0	.0	--	--	--	--	--	--	--	--	--	--
Tanning[11]	20	10-100	--	--	--	50-135	135	8.0	--	--	.2	.2	.2	--	--	--	--	--	--	--	--	--	--
Textiles:																							
General	5	20	--	--	--	20	--	--	--	--	.25	.25	--	--	--	--	--	--	--	--	--	--	--
Dyeing[12]	5	5-20	--	--	--	20	--	--	--	--	.25	.25	.25	--	--	--	--	--	--	--	--	--	--
Wool scouring[13]	--	70	--	--	--	20	--	--	--	--	1.0	1.0	1.0	--	--	--	--	--	--	--	--	--	--
Cotton bandage[13]	5	5	--	--	Low	20	--	--	--	--	.2	.2	.2	--	--	--	--	--	--	--	--	--	--

1/ American Water Works Association, 1950.
2/ A--No corrosiveness; B--No slime formation; C--Conformance to Federal drinking water standards necessary; D--NaCl, 275 mg/l.
3/ Waters with algae and hydrogen sulfide odors are most unsuitable for air conditioning.
4/ Some hardness desirable.
5/ Water for distilling must meet the same general requirements as for brewing (gin and spirits mashing water of light-beer quality; whiskey mashing water of dark-beer quality).
6/ Clear, odorless, sterile water for syrup and carbonization. Water consistent in character. Most high quality filtered municipal water not satisfactory for beverages.
7/ Hard candy requires pH of 7.0 or greater, as low value favors inversion of sucrose, causing sticky product.
8/ Control of corrosiveness is necessary as is also control of organisms, such as sulfur and iron bacteria, which tend to form slimes.
9/ Ca $(HCO_3)_2$ particularly troublesome. $Mg(HCO_3)_2$ tends to greenish color. CO_2 assists to prevent cracking. Sulfates and chlorides of Ca, Mg, Na should each be less than 300 mg/l (white butts).
10/ Uniformity of composition and temperature desirable. Iron objectionable as cellulose adsorbs iron from dilute solutions. Manganese very objectionable, clogs pipelines and is oxidized to permanganates by chlorine, causing reddish color.
11/ Excessive iron, manganese, or turbidity creates spots and discoloration in tanning of hides and leather goods.
12/ Constant composition; residual alumina 0.5 mg/l.
13/ Calcium, magnesium, iron, manganese, suspended matter, and soluable organic matter may be objectionable.

to the soil (Lyerly and Longenecker, 1957, p. 14-15). Low-salinity water (C1) can be used for irrigation of most crops on most soils with little likelihood that soil salinity will develop. Medium-salinity water (C2) can be used if a moderate amount of leaching occurs. High salinity water (C3) cannot be used on soils with restricted drainage. Very high-salinity water (C4) is not suitable for irrigation under ordinary conditions.

Boron is necessary for plant growth, but is highly toxic and unsuitable for irrigation at concentrations only slightly more than optimum. Scofield (1936, p. 286) suggests the following permissible limits of boron for irrigation water:

Classes of water

Rating	Grade	Sensitive crops (mg/l)	Semitolerant crops (mg/l)	Tolerant crops (mg/l)
1	Excellent	< 0.33	< 0.67	< 1.00
2	Good	.33 to .67	.67 to 1.33	1.00 to 2.00
3	Permissible	.67 to 1.00	1.33 to 2.00	2.00 to 3.00
4	Doubtful	1.00 to 1.25	2.00 to 2.50	3.00 to 3.75
5	Unsuitable	> 1.25	> 2.50	> 3.75

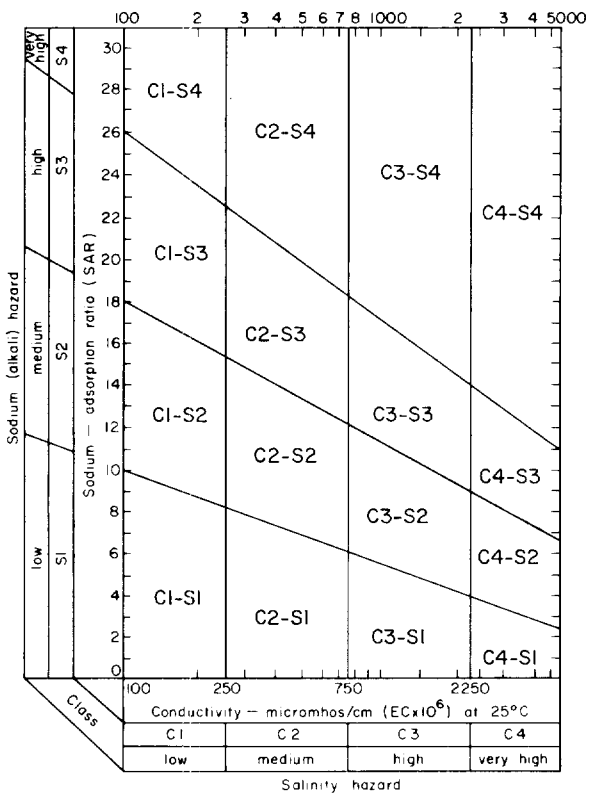

Figure 6.—Diagram for the Classification of Irrigation Waters (After United States Salinity Laboratory Staff, 1954, p. 80)

In water having high concentrations of bicarbonate, there is a tendency for calcium and magnesium to precipitate as the water in the soil becomes more concentrated. Due to this reaction, the relative proportion of sodium in the water is increased in the form of sodium carbonate. Using this residual sodium carbonate (RSC) concept, it was concluded by the U.S. Department of Agriculture that water having more than 2.50 milliequivalents per liter (me/l) RSC is not suitable for irrigation purposes. Water containing 1.25 to 2.50 me/l RSC is marginal, and water containing less than 1.25 me/l is safe. The method of calculating RSC is found in Table 2.

In appraising the quality of an irrigation water, first consideration must be given to salinity and sodium hazards. Then consideration should be given to independent characteristics such as boron and bicarbonate, either of which may change the quality rating. The use of water of any quality must take into account such factors as drainage and management practices.

Most irrigation wells in the study area are scattered over the Trinity and Woodbine outcrops with only a few areas of concentrated activity. Occasionally deeper wells are found downdip from the outcrop and are used primarily to irrigate golf courses. Approximately 5,000 acre-feet (6.17 hm^3) of water was pumped for irrigation purposes in 1977 from Cretaceous formations in the

study area, with about 55 percent of the water from the Woodbine Group. The largest concentration of irrigation wells is located on the Woodbine outcrop in an area bounded by western Grayson County, the eastern edge of Cooke County, and the northeastern corner of Denton County. Approximately 80 irrigation wells operate in this area and several produce as much as 900 gpm (56.8 l/s). Several smaller irrigation well developments are located in Parker and Hood Counties (Twin Mountains) and in Wise County (Antlers). There are also irrigation wells in Fannin County producing from the alluvium along the Red River, but not enough water-quality data were collected for inclusion in this study.

OCCURRENCE AND DEVELOPMENT OF GROUND WATER

Antlers Formation

The Antlers combines the ground-water availablity of both the Paluxy and Twin Mountains Formations to the south (Table I). Small-capacity wells tap the upper part of the Antlers while large production wells pump from either the lower section or the entire aquifer.

The primary source of ground water in the Antlers Formation is precipitation on the outcrop. The average annual precipitation on the outcrop is about 32 inches (81.3 cm), and the mean annual temperature is about 64^0F (18^0C). Surface-water seepage from lakes and streams on the outcrop is also a source of ground water. Water in the outcrop area is unconfined and therefore under water-table conditions. Downdip from the outcrop, the water in confined under hydrostatic pressure and is under artesian conditions.

Recharge to the sandy portion of the 650 square miles (1,684 km^2) of Antlers outcrop is less than 1 inch (2.5 cm) of precipitation per year. The rate of movement of water through an aquifer depends upon the permeability, porosity, and hydraulic gradient. The average rate of movement of water in the Antlers is about 1 to 2 feet (0.3 to 0.6 m) per year (Baker, 1960, p. 37). Ground water moves slowly downdip in an east-southeast direction. Water-level measurements indicate the present gradient of the piezometric surface is 7 to 24 feet per mile (1.3 to 4.5 m/km) except for local fluctuations and around areas of heavy
In areas of heavy pumping, a cone of depression forms and the direction of ground-water movement is toward these points of discharge from all directions. Altitudes of water levels about 1955 and about 1976 are shown on Figures 24 and 25. Cones of depression can be seen around the cities of Gainesville and Sherman.

Wells tap the Antlers in the outcrop area of Montague and Wise Counties and in the downdip areas of Cooke, Denton, and Grayson Counties. Discharge from the Antlers occurs naturally through the pumpage of water wells. In 1976, approximately 10,760 acre-feet (13.3 hm^3) of water was pumped from the Antlers in this area.

Table 4 shows the results of pumping tests conducted in the study region, including the aquifer coefficients of storage, permeability, transmissibility, and specific capacities. The locations of the tests and the coefficients of transmissibility and permeability are shown on Figure 26. Test results were obtained from existing literature and data reported by well drillers. Permeability coefficients were computed by dividing the transmissibility of the well by its screened interval. Net sand thicknesses throughout the aquifer are illustrated on Figure 27..

Transmissibility values were considerably higher for wells tested in Cooke County than in Grayson County. Results of the eight tests conducted on wells in the vicinity of Gainesville showed a range of transmissibilities of 5,800 to 17,879 (gal/d)/ft, or 72,000 to 222,000 (l/s)/m, with an average value of 9,970 (gal/d)/ft, or 123,800 (l/s)/m. In contrast with this area, the range of transmissibilities of nine tests conducted in the Sherman vicinity was 1,860 to 4,727 (gal/d)/ft, or 23,100 to 58,700 (l/s)/m, with an average value of 3,735 (gal/d)/ft, or 46,400 (l/s)/m. Similarly, the coefficients of permeability around Gainesville averaged about 53 (gal/d)/ft^2, or 2,200 (l/s)/m^2 while in the Sherman area, the average was 24 (gal/d)/ft^2, or 978 (l/s)/m^2.

Only two coefficient of storage values, both in Sherman, were determined by the U.S. Geological Survey in 1945. An approximate value of 2.5 X 10^{-4} seems representative for this area. The average artesian storage coefficient was estimated by multiplying the average net saturated sand thickness, in feet, by 10^{-6} per foot, which is proper for most confined aquifers (Lohman, 1972, p. 8).

The specific yield of the Antlers is on the order of 20 to 25 percent as estimated by seismic methods (Duffin and Elder, 1979). The yields from the Antlers range from less than 20 (1.3 l/s) to 920 gal/min (58 l/s), with an average of 200 gal/min (13 l/s) for the 119 measured wells. Yields were highest around Gainesville and Sherman because these wells penetrate the total thickness of the aquifer and are screened opposite all

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Table 4.—Results of Pumping Tests

Aquifer: Kca, Antlers Formation; Kcpa, Paluxy Formation; Kct, Trinity Group; Kctm, Twin Mountains Formation; Kgbl, Blossom Sand of Austin Group; Kgna, Nacatoch Sand of Navarro Group; Kgw, Woodbine Group.

Coefficient of transmissibility values shown are the averages from drawdown and recovery test data.

Well	Aquifer	Test Date	Screened from (ft)	Interval to (ft)	Yield (gal/min)	Coefficient of Transmissibility [(gal/d)/ft]	Coefficient of storage	Coefficient of Permeability [(gal/d)/ft^2]	Specific Capacity [(gal/min)/ft]
				Collin County					
DT-18-44-202	Kgw	Apr. 6, 1976	1,300	1,526	150	1,885	--	17	1.1
50-501	Kctm	Sept. 18, 1953	2,266	2,515	1,940	20,683	--	83	11.3
502	do	Mar. 20, 1954	2,378	2,640	1,845	21,486	--	82	12.2
504	Kcpa	July 26, 1973	1,333	1,652	238	1,263	--	6	1.0
51-301	Kctm	Oct. 22, 1952	3,110	3,410	690	29,724	--	99	7.7
				Cooke County					
HA-19-23-401	Kca	Aug. 29, 1942	--	--	385	5,800	--	--	2.0
503	do	Aug. 23, 1942	660	910	340	9,250	--	44	5.0
		Aug. 17, 1960	660	910	580	12,303	--	67	5.0
805	do	Aug. 4, 1971	629	893	818	10,972	--	54	8.2
901	do	May 8, 1952	723	890	375	8,316	--	55	1.7
903	do	May 30, 1960	767	927	320	17,879	--	--	18.5
906	do	Mar. 5, 1965	754	961	800	6,414	--	43	3.7
31-302	do	Mar. 28, 1959	726	978	720	8,818	--	53	4.8
				Dallas County					
HR-33-01-301	Kctm	May 7, 1957	2,017	2,260	1,254	20,130	--	100	9.7
02-102	do	May 27, 1975	2,245	2,455	1,697	17,256	--	102	7.1
09-102	do	June 27, 1973	1,930	2,120	759	13,905	--	99	5.9
402	do	May 20, 1965	1,922	2,074	708	17,076	--	112	6.3
403	do	Apr. 3, 1972	1,924	2,077	754	12,141	--	80	6.2
507	do	Oct. 10, 1972	2,102	2,240	759	13,085	--	106	5.5
508	do	Jan. 14, 1972	1,999	2,145	703	17,718	--	124	7.7
701	do	May 4, 1965	1,880	2,039	708	8,400	--	53	6.1
908	Kcpa	Nov. 29, 1965	1,375	1,504	317	6,118	--	62	2.8
10-501	Kctm	Nov. 14, 1948	2,567	2,734	1,014	17,000	9×10^{-5}	102	--
805	do	Nov. 14, 1948	2,534	2,735	511	16,300	8×10^{-5}	81	4.1
831	Kcpa	Nov. 17, 1948	--	--	166	2,890	2×10^{-5}	--	0.7
17-115	Kctm	Oct. 19, 1953	1,900	2,065	480	12,500	2×10^{-4}	76	--
802	do	Mar. 31, 1969	2,394	2,518	638	3,660	--	31	2.8
18-201	do	Apr. 11, 1955	2,620	2,883	750	12,300	5×10^{-5}	47	--
803	do	Nov. 6, 1973	2,904	3,088	1,051	13,242	--	--	6.9
26-104	do	June 4, 1964	2,604	2,745	650	7,692	--	55	3.4
105	do	Aug. 5, 1968	2,644	2,814	715	10,397	--	61	4.1
27-205	do	Sept. 29, 1964	3,322	3,442	300	3,593	--	30	3.3
602	Kgw	June 1, 1965	1,288	1,352	170	4,700	--	78	4.2
				Delta County					
HU-17-42-806	Kgna	Oct. 14, 1965	422	525	200	2,300	--	29	1.0
807	do	Nov. 15, 1965	507	620	254	2,563	--	28	1.2
808	do	Dec. 8, 1965	425	525	200	2,151	--	26	1.0
				Denton County					
HW-18-33-703	Kca	May 10, 1957	1,372	1,514	167	4,900	--	35	--
57-602	Kctm	Nov. 19, 1974	2,235	2,390	795	12,369	--	--	10.2
19-47-901	Kctm, Kcpa	July 8, 1960	770	1,184	888	6,900	--	28	3.4
55-305	Kctm	Dec. 15, 1948	1,029	1,130	450	4,150	5×10^{-5}	46	--
56-101	co	Dec. 1, 1948	1,082	1,214	450	4,150	5×10^{-5}	23	--
103	co	Dec. 1, 1951	1,055	1,200	450	5,020	--	34	5.0
104	Kct	May 14, 1957	624	1,142	670	3,000	--	19	5.1
64-905	Kctm	Jan. 20, 1972	1,690	1,892	560	8,963	--	47	6.4
906	Kcpa	Mar. 27, 1972	853	944	236	5,197	--	84	0.7
32-07-205	Kctm	June 17, 1974	1,291	1,391	510	12,680	--	127	4.8

25 031

Table 4.—Results of Pumping Tests—Continued

Aquifer: Kca, Antlers Formation; Kcpa, Paluxy Formation; Kct, Trinity Group; Kctm, Twin Mountains Formation; Kgbl, Blossom Sand of Austin Group; Kgna, Nacatoch Sand of Navarro Group; Kgw, Woodbine Group.

Coefficient of transmissibility values shown are the averages from drawdown and recovery test data.

Well	Aquifer	Test Date	Screened from (ft)	Interval to (ft)	Yield (gal/min)	Coefficient of Transmissibility [(gal/d)/ft]	Coefficient of storage	Coefficient of Permeability [(gal/d)/ft^2]	Specific Capacity [(gal/min)/ft]
				Ellis County					
JK-32-40-608	Kctm	Feb. 10, 1976	2,290	2,390	250	5,442	–	65	2.9
901	Kcpa	June 2, 1965	1,230	1,338	79	3,140	–	32	2.7
33-33-101	Kctm	June 6, 1965	2,175	2,335	450	5,900	–	39	3.0
34-702	do	Mar. 14, 1948	–	–	617	8,960	8×10^{-5}	–	2.6
703	do	do	–	–	504	8,800	9×10^{-5}	–	–
35-503	Kgw	June 2, 1965	1,330	1,390	120	11,300	–	183	3.9
41-203	Kctm	Jan. 25, 1975	2,410	2,540	160	16,547	–	165	3.1
49-602	Kgw	May 17, 1957	839	929	201 *	1,320	–	22	0.8
				Fannin County					
JS-18-01-201	Kgw	Aug. 1, 1957	1,096	1,240	740	14,000	–	75	9.3
39-702	do	June 23, 1975	1,464	1,606	300	1,371	–	14	3.8
				Grayson County					
KT-18-10-406	Kgw	Aug. 20, 1958	–	–	132	16,700	–	167	7.0
802	do	Aug. 15, 1958	189	345	145	7,870	–	84	2.2
11-802	do	Mar. 27, 1958	241	341	73	2,250	–	43	2.2
17-901	Kca	May 9, 1957	1,388	1,519	330	4,600	–	23	3.2
20-701	Kgw	July 14, 1945	721	788	249	2,400	–	42	–
702	do	do	725	776	260	2,190	9×10^{-5}	43	–
703	Kca	do	1,965	2,136	360	2,420	1×10^{-4}	17	–
704	Kgw	do	541	580	260	2,420	2×10^{-4}	22	–
705	do	do	726	785	260	2,320	1.9×10^{-4}	39	–
706	do	do	724	786	260	2,340	1.8×10^{-4}	38	–
709	Kca	do	1,382	2,084	360	3,440	2×10^{-4}	11	–
801	Kgw	Aug. 9, 1966	650	980	608	6,710	–	24	5.1
802	Kca	Jan. 17, 1967	1,510	2,214	567	4,288	–	11	3.4
804	Kgw	May 5, 1970	570	1,034	708	4,938	–	21	3.4
25-601	Kca	Apr. 8, 1957	1,355	–	110	4,500	–	23	4.2
27-801	Kgw	Oct. 10, 1973	630	934	554	2,389	–	14	2.1
802	Kca	Oct. 27, 1975	1,594	2,454	608	3,081	–	8	1.8
803	do	July 12, 1976	–	–	638	4,727	–	–	2.6
28-102	do	Jan. 28, 1959	1,590	2,420	602	4,690	–	97	3.5
103	Kgw	do	832	1,012	602	5,950	–	40	4.7
402	do	May 4, 1970	840	969	457	3,442	–	33	3.1
403	do	June 7, 1972	794	1,064	402	2,976	–	27	2.2
404	Kca	Mar. 8, 1972	1,700	2,450	510	1,860	–	5	3.4
702	Kgw	Apr. 21, 1954	908	1,054	105	7,920	–	78	2.0
29-902	do	Mar. 26, 1958	1,109	1,189	80	2,394	–	30	2.2
35-402	do	Mar. 24, 1958	655	730	52	14,700	–	178	1.5
36-502	do	July 31, 1957	1,165	1,400	250	7,900	–	99	2.7
503	Kca	July 29, 1970	2,010	2,290	250	1,100	–	6	0.6
				Hunt County					
PH-17-41-901	Kgna	Nov. 9, 1943	374	412	285	2,670	–	70	5.1
902	do	Nov. 7, 1943	375	435	285	2,660	–	44	9.3
				Johnson County					
PX-32-30-502	Kcpa	May 10, 1960	472	586	134	1,573	–	26	1.3
37-901	Kctm	Apr. 21, 1958	961	1,245	423	4,600	–	19	1.7
38-309	do	Jan. 8, 1969	1,135	1,425	164	1,948	–	8	–
901	do	Oct. 5, 1964	1,522	1,575	100	4,761	–	110	0.5
39-702	Kcpa, Kctm	May 4, 1947	766	1,634	296	4,568	–	26	2.8
45-302	Kctm	Feb. 19, 1945	898	1,204	472	4,509	–	43	2.6
304	do	Jan. 25, 1938	941	1,251	405	4,656	–	28	1.5
601	do	Apr. 12, 1955	895	1,165	560	7,400	–	31	2.8
47-802	Kcpa	Mar. 24, 1955	802	846	84	6,517	–	148	1.7
803	Kgw	Nov. 16, 1966	187	210	47	2,208	7×10^{-5}	56	–
806	do	do	182	204	47	1,837	–	84	1.0
54-101	Kctm	Dec. 6, 1966	1,137	1,215	168	4,247	–	55	1.8

25 032

Table 4.—Results of Pumping Tests—Continued

Aquifer: Kca, Antlers Formation; Kcpa, Paluxy Formation; Kct, Trinity Group; Kctm, Twin Mountains Formation; Kgbl, Blossom Sand of Austin Group; Kgna, Nacatoch Sand of Navarro Group; Kgw, Woodbine Group.

Coefficient of transmissibility values shown are the averages from drawdown and recovery test data.

Well	Aquifer	Test Date	Screened from (ft)	Interval to (ft)	Yield (gal/min)	Coefficient of Transmissibility [(gal/d)/ft]	Coefficient of storage	Coefficient of Permeability [(gal/d)/ft^2]	Specific Capacity [(gal/min)/ft]
Red River County									
WB-17-24-803	Kgbl	Dec. 3, 1969	465	530	164	1,316	–	21	1.3
32-201	do	Aug. 9, 1960	523	600	630	4,100	6×10^{-5}	54	–
203	do	Aug. 10, 1960	510	602	630	3,690	3×10^{-5}	41	–
39-508	Kgna	Aug. 16, 1972	150	270	349	6,330	–	53	3.6
Tarrant County									
XU-32-07-602	Kctm	May 15, 1972	1,500	1,573	602	6,667	–	92	4.1
13-701	Kcpa	Mar. 24, 1954	–	–	100	3,100	3.4×10^{-4}	–	–
703	do	do	–	–	–	7,500	–	72	3.3
901	do	May 27, 1955	–	–	60	4,100	7.4×10^{-5}	–	–
14-609	Kctm	Dec. 4, 1954	958	1,090	361	6,860	–	69	2.8
701	do	Dec. 3, 1953	867	964	247	3,250	6.2×10^{-5}	34	–
702	do	Aug. 12, 1954	855	952	236	2,900	7.6×10^{-5}	30	–
15-104	Kcpa	May 19, 1961	575	692	164	13,808	–	138	3.0
105	do	Apr. 26, 1961	434	549	107	2,934	–	28	1.3
207	do	Apr. 24, 1961	538	677	101	1,536	–	18	0.7
15-401	Kcpa	Mar. 17, 1954	460	522	80	2,660	1.2×10^{-4}	37	0.7
412	Kctm	June 10, 1955	1,059	1,225	412	3,580	–	28	3.4
413	Kcpa	Aug. 1, 1961	511	624	105	3,126	–	35	2.0
507	Kctm	Jan. 12, 1965	1,232	1,428	717	9,756	–	60	6.4
512	do	June 9, 1966	1,219	1,350	708	9,147	–	70	4.0
601	do	Mar. 20, 1955	1,179	1,450	793	11,789	–	85	5.0
902	Kcpa	June 4, 1954	668	809	408	6,150	–	49	3.1
16-503	Kgw	Mar. 22, 1951	236	266	15	2,740	–	91	1.2
21-204	Kcpa	Aug. 11, 1962	280	375	107	3,312	–	42	1.3
405	do	Mar. 12, 1960	193	248	126	2,867	–	60	1.6
502	do	Mar. 25, 1960	209	270	105	2,164	–	48	1.4
22-601	do	Apr. 9, 1953	209	270	52	4,250	1.8×10^{-4}	–	–
702	do	Aug. 17, 1953	380	450	80	3,350	–	70	1.9
901	Kctm	June 18, 1972	1,108	1,335	455	6,231	–	47	4.5
907	Kcpa	June 19, 1965	507	580	108	10,937	–	150	2.7
909	Kctm	Aug. 1, 1966	1,042	1,280	556	8,925	–	72	4.7
910	Kcpa	July 31, 1962	488	586	125	2,005	–	25	1.2
23-101	Kctm	Aug. 21, 1945	1,154	1,334	260	11,000	6×10^{-5}	74	2.8
102	do	Nov. 7, 1950	1,180	1,340	768	8,837	–	59	3.9
103	do	Jan. 8, 1954	–	–	259	7,400	4×10^{-5}	37	3.9
104	do	Aug. 25, 1948	1,210	1,330	240	7,850	5×10^{-5}	65	2.5
106	do	do	1,239	1,359	473	10,000	–	83	3.4
108	do	Jan. 11, 1954	1,305	1,423	260	9,000	7×10^{-5}	95	–
401	do	Feb. 15, 1951	1,004	1,326	705	9,800	–	54	2.9
404	Kctm	Jan. 21, 1971	1,064	1,350	708	1,525	–	–	3.8
603	Kcpa	May 5, 1954	628	776	465	3,900	–	43	1.0
802	Kctm	May 26, 1966	1,408	1,580	503	16,795	–	125	4.6
24-101	do	Sept. 16, 1942	1,567	1,751	450	12,500	–	68	4.5
202	Kcpa	Feb. 26, 1954	888	1,058	402	6,300	–	45	3.2
31-605	Kctm	Apr. 2, 1955	1,592	1,708	390	6,700	–	69	2.7

25 033

fresh water-bearing sands. The specific capacity of a well is generally expressed as the ratio of the yield in gallons per minute (liters per second) to the drawdown in feet (meters). A word of caution must be used in comparing specific capacities of wells. The method of well completion is an important function of specific capacity. For example, a gravel-walled and screened well of the same diameter and in the same location as a well with either torch-slotted or gun-perforated casing would have a considerably higher specific capacity. Specific capacir es of 63 wells that obtain water from the Antlers Formation in the study region ranged from 0.3 to 8.5 (gal/min)/ft or 0.06 to 1.8 (l/s)/m, with an average of 2.7 (gal/min)/ft or 0.56 (l/s)/m.

Except for water levels in wells on or near the outcrop, static levels have been steadily declining over the years. Long-range declines have averaged up to 7 feet (2 m) per year, with as much as 10 ft/yr (3 m/yr) during recent measurements in developed areas. Figure 28 shows the approximate change in water levels in Antlers wells from about 1955 to about 1976. Hydrographs showing long-term water-level changes under water table and artesian conditions are illustrated by Figures 7 and 8.

Long-range declines in the water table seem to increase from west to east, parallel to the Red River in a line from Muenster in Cooke County, to Sherman in Grayson County. The water level in well HA-19-21-903 in Muenster declined 133 ft (41 m) in 37 years; well HA-19-23-905 in Gainesville declined 146 ft (45 m) in 40 years; well KT-18-17-902 in Whitesboro lowered 209 feet (64 m) in 42 years; and well KT-18-20-709 declined 228 ft (69 m) in 32 years. Along this strike, water levels have fallen from 3.6 ft/yr (1 m/yr) in western Cooke County to 7.1 ft/yr (2 mlyr) in central Grayson County. Wells outside the influence of large centers of pumpage also show declines but not near as severe, with deficits of only a few feet per year (less than one meter per year).

Water levels in the vicinity of Gainesville are near the top of the Antlers, while pumping levels there drop about 100 feet (30 m) below the top. The static level in a well at Era, in southern Cooke County, is 200 feet (61 m) below the top of the Antlers. Pumping levels in most of the large-capacity wells in Cooke County are below the top of the formation. However, due to the influence of the Preston anticline and the Sherman syncline, the top of the Antlers at the city of Sherman is about 1,480 feet (451 m) below land surface. Consequently, static water levels there are about 1,000 feet (305 m) above the top of the formation and pumping levels are about 700 feet (213 m) above the top of the Antlers.

Of the estimated 82,000 acre-feet (101hm^3) of water pumped from the Woodbine and Trinity Group aquifers in 1976, only 13 percent or 10,670 acre-feet (13.2 hm^3) was pumped from the Antlers. Most of this ground water is utilized for municipal purposes. About 70 percent of the large-capacity Antlers wells inventoried for this study were public supply wells and accounted for 77 percent of the total pumpage from the Antlers. Public supply pumpage increased from 4,920 acre-feet (6.07 hm3) in 1955 to 8,260 acre-feet (10.2 hm^3) in 1976. The estimated amounts of ground water pumped from the Antlers for irrigation and for public supply and industrial purposes are shown in Tables 5 and 6. Domestic wells pumped an estimated 1,800 acre-feet (2.22 hm^3) of water from the Antlers in 1975.

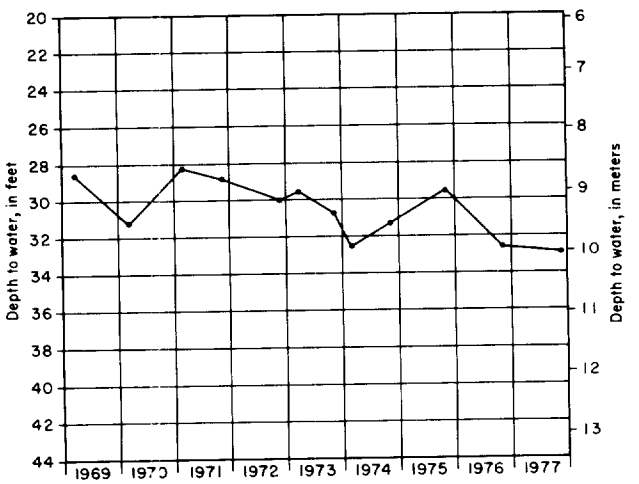
The development of the Antlers as a public supply source began in the city of Sherman with a 2,300 foot (701 m) well located near well KT-18-20-715. It was drilled in 1889 and produced 200 gal/min (12.6 l/s). Sherman had two more deep wells drilled in 1921 and 1923, respectively. Gainesville and Valley View in Cooke County had wells in production in 1912. By 1940, most of the larger towns in Cooke and western Grayson County were obtaining water from the Antlers.

Grayson County is the largest user of public supply water from the Antlers aquifer, pumping 4,627 acre-feet (5.71 hm^3) of water in 1976. Cooke County is second with a total use of 2,803 acre-feet (3.46 hm^3). The city of Sherman used 3,735 acre-feet (4.61 hm^3) in 1976 which is 45 percent of the total amount of ground water pumped from the Antlers for public-supply purposes. The city of Gainesville is the second largest individual user with a total of 1,916 acre-feet (2.36 hm^3) pumped in 1976. These two cities accounted for over 68 percent of the water pumped for public supply use from the Antlers in 1976.

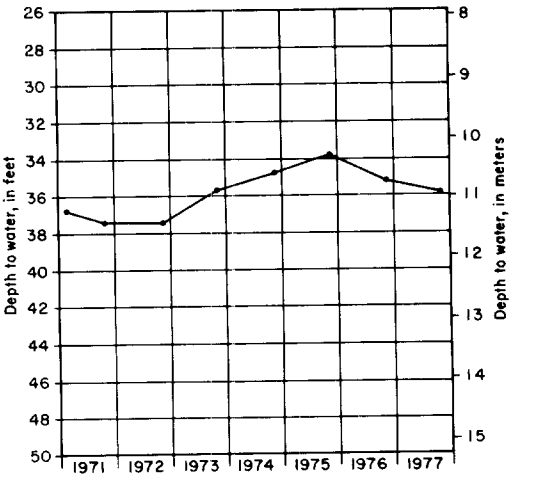
Only 29 industrial wells were located and many are no longer in use. Many industries purchase their water from municipalities. In 1976, ground water pumped from the Antlers for industrial use amounted to only 287 acre-feet (0.354 hm^3). Table 6 shows the amount of industrial pumpage from 1955 to 1976, by county. The largest amount used in a year was 845 acre-feet (1.04 hm^3) pumped in 1959. Wise County had the most pumpage in 1976 with 144 acre-feet (0.188 hm^3), all attributed to one industry. Cooke County produced 113 acre-feet (0.139 hm^3) for industrial purposes in 1976.

Irrigation is mostly confined to wells located on the Antlers outcrop in Wise, Montague, and Cooke Counties. Only 28 irrigation wells were inventoried, and

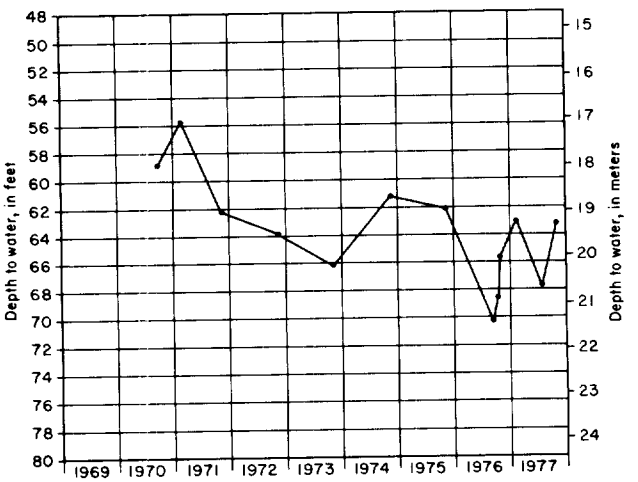
25 034



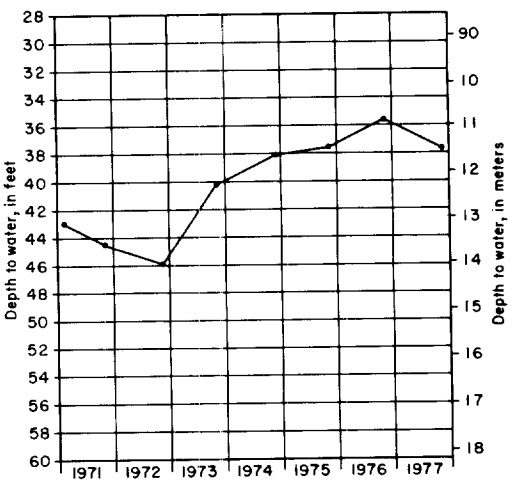
Hood County
Well LY-31-32-901
depth: 46ft. (14m)
Twin Mountains Formation



Montague County
Well TR-19-20-201
depth: 128ft. (39m)
Antlers Formation



Parker County
Well UP-32-18-201
depth: 96ft. (29m)
Paluxy Formation

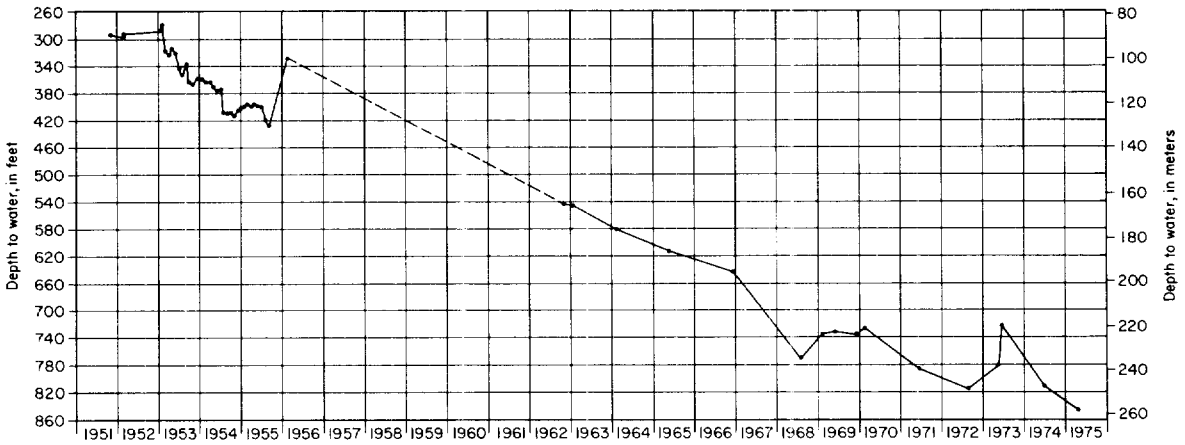


Denton County
Well HW-18-41-201
depth: 210ft. (64m)
Woodbine Group

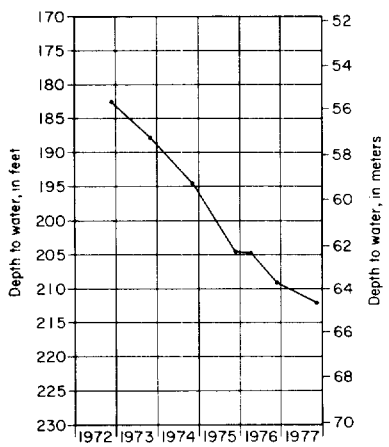
Figure 7

Hydrographs of Water Levels Under Water-Table Conditions

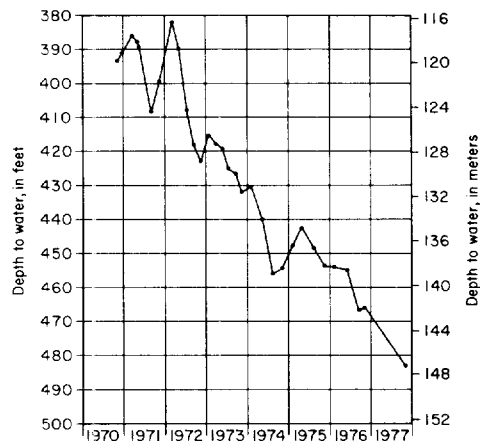
25 035



Tarrant County
Well XU-32-15-601
depth: 1,483ft.(452m)
Twin Mountains Formation



Grayson County
Well KT-18-33-301
depth: 923ft. (281m)
Antlers Formation



Dallas County
Well HR-33-19-101
depth: 3,076ft. (938m)
Twin Mountains Formation

Figure 8

Hydrographs of Water Levels in Wells Completed in the Antlers and Twin Mountains Formations Under Artesian Conditions

25 036

Table 5.-Estimated Use of Ground Water for Irrigation, 1970-77

Includes irrigation of commercial landscapes as well as crops. Amounts are in acre-feet.
Water-bearing units: Kgw, Woodbine Group; Kcpa, Paluxy Formation; Kctm, Twin Mountains Formation; Kca, Antlers Formation

County	Aauifer	1970	1971	1972	1973	1974	1975	1976	1977
Cooke	Kgw	88	88	88	88	88	88	221	234
	Kca	175	215	275	279	279	279	278	242
Dallas	Kgw	40	40	40	188	228	285	293	347
	Kcpa	23	23	23	23	23	23	70	89
	Kctrn	285	278	350	353	270	124	371	435
Denton	Kgw	255	255	473	506	566	546	554	50.
	Kctrn	0	150	212	212	341	357	708	762
Grayson	Kgw	890	1,000	1,281	1,313	1,313	1,012	1,158	1,225
Hood	Kctrn	0	57	75	200	200	223	223	199
Johnson	Kgw	0	41	41	41	41	41	41	41
	Kcpa	55	83	83	83	83	83	83	83
Parker	Kcpa	0	0	3	3	3	3	3	3
	KCirl.	0	20	26	28	36	28	30	34
Tarrant	Kgw	83	83	83	129	314	314	340	363
	Kcpa	258	258	275	294	163	163	163	186
	Kctm	99	99	99	99	99	99	99	99
Wise	Kca	8	19	120	135	135	135	45	76
	Kctm		—	–	–	–	–	16	16
Totals	Kgw	1,356	1,507	2,006	2,265	2,550	2,286	2,607	2.717
	Kcpa	336	364	384	403	272	272	319	361
	Kctm	384	604	762	892	946	831	1,447	1,545
	Kca	183	234	395	414	414	414	323	318
		2,259	2,709	3,547	3,974	4,182	3,803	4,696	4,941

production in 1977 accounted for 318 acre-feet (0.392 hm^3). Most of the wells are of small capacity, and there is currently no extensive ground-water irrigation pumpage from the Antlers. The estimates of pumpage are based on power and yield tests and the results of these tests are given in Table 7.

The water provided by the Antlers in the north-northwest part of the study area is excellent for most purposes. Ground water derived from the outcrop is mostly hard to very hard, while water from downdip locations is generally soft. Approximately one-third of the analyses taken had over 60 mg/l hardness as calcium carbonate, with many analyses in Montague and northern Wise Counties containing over 300 mg/l. High iron concentrations near the outcrop are also encountered, with 27 samples exceeding the 0.3 mg/l limit. Of the more than 280 water samples taken from the Antlers, only 26 had dissolved-solids concentrations over 1,000 mg/l and none had more than 2,000 mg/l. Less than 5 percent of the samples contained excess amounts of chloride and sulfate. Two dozen analyses contained fluoride concentrations exceeding the 1.6 mg/l acceptable level for this area. Results of chemical analyses on water from irrigation wells completed in the outcrop showed very low sodium hazard but medium to high salinity hazard. Residual sodium carbonate for all samples was zero. Table 8 shows the range of constituents in ground water from selected wells in the Antlers Formation.

Recharge to the Antlers also occurs on the outcrop in Oklahoma, and well records in northern Grayson County indicate that the Trinity is also being recharged by Lake Texoma. Static and pumping levels in Grayson County are still well above the top of the formation, but higher lifting costs from deeper pumping levels will probably be the limiting factor in development here.

Development of the Antlers in Cooke County is only in the lower section of the aquifer, and although both static and pumping levels are below the top of the upper section, or Paluxy equivalent, the levels are still well above the top of the lower section, or Twin Mountains equivalent. Based on this and pumping levels that are hundreds of feet above the screened intervals, the Antlers is in no immediate danger of being dewatered.

Table 6.--Estimated Use of Ground Water for Public Supply and Industrial Purposes From the Antlers Formation, 1955-76

Use: PS, public supply; Ind, industrial. Values are in acre-feet.

County	Use	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	Totals
Cooke	PS	2,649.2	2,682.4	2,289.4	2,073.7	2,052.7	1,896.8	2,019.8	2,770.9	2,732.3	2,124.6	1,859.5	2,051.6	2,107.3	2,061.9	2,497.8	2,909.6	2,929.3	3,373.3	2,952.1	2,864.3	2,650.4	2,802.8	54,351.7
	Ind	422.8	422.8	422.8	202.9	656.0	144.4	154.0	152.3	108.2	78.7	55.3	55.4	55.7	45.6	45.2	66.3	146.6	152.8	152.1	106.2	131.2	112.6	3,889.9
Denton	PS	191.6	240.0	254.8	220.1	226.8	235.9	231.6	243.9	293.7	271.2	260.3	279.5	329.3	312.8	339.0	386.2	405.8	457.1	431.3	514.0	526.2	619.2	7,270.3
Grayson	PS	1,647.8	2,050.8	1,890.1	1,812.0	1,848.1	1,869.1	1,928.8	2,137.0	2,646.7	2,626.2	2,687.4	2,661.4	2,728.7	2,934.1	3,461.4	3,832.3	4,352.5	4,504.0	4,488.0	4,544.6	4,221.2	4,627.1	65,499.3
	Ind	18.0	18.0	18.0	54.4	55.0	36.5	36.5	43.2	62.1	77.9	72.2	73.8	73.8	73.9	73.9	73.5	51.7	61.2	58.1	67.6	32.1	31.1	1,162.5
Montague	PS	114.2	153.1	89.1	69.1	83.8	87.0	95.9	95.8	116.8	109.8	108.5	111.0	120.2	125.3	133.2	138.5	134.7	152.4	141.9	143.6	132.3	145.4	2,601.6
Wise	PS	316.8	343.7	405.1	364.6	331.2	367.3	312.7	432.9	528.8	475.4	460.0	322.0	114.5	67.5	107.7	108.8	64.2	65.7	63.9	64.9	66.6	65.3	5,449.6
	Ind	96.8	96.8	96.8	164.2	134.4	171.0	168.3	165.4	76.5	154.1	153.9	153.9	153.5	152.4	152.4	153.0	152.7	137.5	132.6	116.2	117.9	143.6	3,043.9
Totals	PS	4,919.6	5,470.0	4,928.5	4,539.5	4,542.6	4,456.1	4,588.8	5,680.5	6,318.3	5,607.2	5,375.7	5,425.5	5,400.0	5,501.6	6,539.1	7,375.4	7,886.5	8,552.5	8,077.2	8,131.4	7,596.7	8,259.8	135,172.5
	Ind	537.6	537.6	537.6	421.5	845.4	351.9	358.8	360.9	246.8	310.7	281.4	283.1	283.0	271.9	271.5	292.8	351.0	351.5	342.8	290.0	281.2	287.3	8,096.3
	PS and Ind	5,457.2	6,007.6	5,466.1	4,961.0	5,388.0	4,808.0	4,947.6	6,041.4	6,565.1	5,917.9	5,657.1	5,708.6	5,683.0	5,773.5	6,810.6	7,668.2	8,237.5	8,904.0	8,420.0	8,421.4	7,877.9	8,547.1	143,268.8

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Table 7.--Power-Yield Tests From Selected Irrigation Wells

Method of Distribution: OD, irrigation well pumping into earthen or concrete tank; D, irrigation well pumping directly to the field through sprinkler lines; OD-EB, irrigation well pumping into earthen or concrete tank, and an electric booster pumping water from the tank to the field through sprinkler lines.

Test Number	Well	Date of Test	Method of distribution	Length of Test		Pump Horsepower		Yield in gal/min		Total kwh used	Gals/ kwh	Kwh/ hr	Remarks
				Hours	Minutes	Well	Booster	Well	Sprinkler				
						Dallas County							
1	HR-33-02-203	Sept. 7, 1976	OD	4	00	125	--	470	--	--	--	--	
2	303	do	OD	4	00	20	--	85	--	96	213	24	
						Denton County							
3	HW-18-41-501	Aug. 12, 1976	D	7	00	20	--	--	185	120	648	17.1	
4	19-55-606	Oct. 8, 1976	OD	31	20	20	--	107	--	280	720	8.9	
	606	Aug. 4, 1976	OD	21	30	20	--	105	--	148	910	6.9	
						Grayson County							
5	KT-18-17-601	Aug. 11, 1976	OD	3	00	15	--	182	--	41	799	13.7	
6	18-407	Aug. 10, 1976	D	2	20	5	--	55	--	12.2	632	5.2	
7	408	do	D	2	00	10	--	80	--	17.1	842	8.6	
8	409	do	D	1	45	3	--	45	--	4.8	985	2.8	
9	410	do	D	17	25	1.5	--	35	--	29.6	1,236	1.7	
10	412	Aug. 11, 1976	D	4	00	3	--	32	--	13	591	3.3	
11	413	do	D	4	00	3	--	80	--	15.7	1,223	3.9	
12	414	do	OD	4	00	.5	--	8.5	--	4.1	498	1.0	
13	415	Aug. 10, 1976	D	17	35	2	--	60	--	45.2	1,400	2.6	
14	701	Aug. 11, 1976	OD	2	30	20	--	230	--	45.1	765	18	
15	25-606	Aug. 12, 1976	D	2	00	25	--	--	195	45.7	512	22.8	
16	610	Sept. 15, 1976	D	3	00	20	--	--	175	58.2	541	19.4	
17	33-501	Aug. 6, 1976	D	2	12	40	--	--	301	83	478	37.8	
18	602	Aug. 17, 1976	D	0	56	25	--	--	218	26	470	28	
						Hood County							
19	LY-32-26-902	Aug. 23, 1976	OD	4	00	30	--	300	--	100	720	25	
20	903	do	OD	3	45	30	--	170	--	100	383	26.7	
21	27-703	do	OD-EB	4	00	30	50	150	--	270	133	67.5	
22	34-112	Aug. 24, 1976	OD	3	20	10	--	145	--	35	829	10.5	
						Parker County							
23	UP-32-17-512	July 21, 1976	OD	0	30	5	--	105	--	1.5	2,100	3	
24	516	do	OD	0	22	5	--	105	--	2	1,155	5.4	
						Tarrant County							
25	XU-32-07-907	Oct. 19, 1977	OD	2	42	5	--	48	--	36	572	13.3	Three wells pump into earthen tank. All on one meter.
	908					3		40					
	913					5		40					
26	15-903	Sept. 14, 1976	OD	2	30	5	--	20	--	17	177	6.8	
27	904	do	OD	2	30	5	--	20	--	13	232	5.2	
28	22-607	Sept. 15, 1976	OD	3	08	20	--	108	--	52.8	385	16.9	
29	23-607	do	OD	2	30	3	--	39	--	10	578	4	
30	608	do	OD	2	30	3	--	56	--	9	927	3.6	
						Wise County							
31	ZR-19-34-703	Aug. 26, 1976	D	3	00	10	--	--	95	86.6	200	28.9	Three wells on three meters pumping through one sprinkler line.
	33-901					15							
	902					5							
32	34-701	do	D	3	30	3	--	--	80	39.1	430	11.2	Five wells on three meters pumping through one sprinkler line.
	702					3							
	42-101					5							
	102					1							
	103					1							

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Table 8.--Range of Constituents in Ground Water From Selected Wells in the Antlers Formation

Analyses given are in milligrams per liter except percent sodium, specific conductance, pH, SAR, and RSC.

Single values appear where only one analysis or value was available.

Constituent or property	Montague County	Cooke County	Grayson County	Denton County	Wise County
Silica (SiO_2)	5 - 32	8 - 57	3 - 72	11 - 18	10 - 40
Iron (Fe)	.2- 15	0 - 1.7	0 - 58.5	0 - .1	--
Calcium (Ca)	19 - 256	1 - 127	1 - 253	0 - 7	3 - 235
Magnesium (Mg)	5 - 82	0 - 15	0 - 39	0 - 8	1 - 142
Sodium (Na)	13 - 200	10 - 432	9 - 580	181 - 310	7 - 149
Bicarbonate (HCO_3)	54 - 504	315 - 700	151 - 790	234 - 502	142 - 540
Sulfate (SO_4)	21 - 304	19 - 130	11 - 600	46 - 108	10 - 419
Chloride (Cl)	7 - 434	2 - 484	8 - 590	10 - 67	5 - 394
Fluoride (F)	.1- 1.2	0 - 2.8	.1- 4.2	.1- 1.5	.1- .9
Nitrate (NO_3)	0 - 90	0 - 7.0	0 - 3.7	0 - 4.0	0 - 30
Boron (B)	.1	.3- 1.3	0 - 1.2	--	.1
Dissolved solids	358 -1,238	221 -1,202	269 -1,870	335 - 602	201 -1,587
Total hardness ($CaCO_3$)	20 - 930	1 - 374	1 - 770	1 - 43	7 -1,160
Percent sodium (%)	6.7- 93.7	5.5- 99.5	5.8- 99.6	92.5- 100	5.2- 96.5
pH	6.8- 8.7	7.2- 9.4	6.1- 9.1	8.1- 9.3	6.9- 8.6
Sodium-adsorption ratio (SAR)	.2- 16	.2- 60	.2- 98.1	14.5- 69.7	.1- 19.0
Residual sodium carbonate (RSC)	0 - 6.7	0 - 11.2	0 - 13.8	3.3- 8.2	0 - 5
Specific conductance (micromhos at 25°C)	599 -2,110	594 -2,080	448 -2,646	720 -1,030	338 -2,300

As previously stated, the water table is declining by as much as 7 feet (2 m) per year, reflecting the fact that more water is removed annually from the Antlers than is recharged. With the large saturated sand thicknesses available and proper use of well construction and spacing, no problems seem likely in the immediate future as far as Antlers ground-water availability is concerned.

According to Baker (1960, p. 65), the amount of fresh-water sand decreases northward in Grayson County, chiefly as a result of increasing amounts of salt water in the northern part of the county. The lower part of the Antlers contains saline water in the vicinity of the Preston anticline; therefore, the upper part of the Antlers or the Woodbine should be developed for ground water in this area.

Twin Mountains Formation

The Twin Mountains provides moderate to large quantities of fresh to slightly saline water to wells in nine of the twenty counties included in this study. The outcrop covers approximately 370 square miles (958 km^2) and lies within Hood, Parker, and Wise Counties. As illustrated on the geologic map (Figure 16), this basal Cretaceous aquifer forms the western boundary of this study. Data on the Twin Mountains were obtained prirnarily through the inventory of over 600 public supply, industrial, and irrigation wells located in the study area.

The primary source of ground water in the Twin Mountains is precipitation falling on the outcrop. Other minor sources include surface-water seepage from ponds, lakes, and streams cutting the outcrop. The average annual precipitat ion is about 30 inches (76cm). However, probably less than 1 inch (2.5cm) per year is available for recharge.

Ground water in the Twin Mountains usually occurs under water-table conditions in or near the outcrop, while ground water downdip from the outcrop is under artesian conditions. The lower sands and shales of the Twin Mountains are the hydrologic equivalent of the basal portion of the Antlers. Water-level maps for the Antlers and the Twin Mountains Formations have been combined and are shown on Figures 24, 25 and 28.

The average rate of movement of water in the Twin Mountains is estimated to be less than 2 feet (1m) per year. Ground water moves slowly downdip in an easterly direction except for local changes. Water-level measurements indicate the present hydraulic gradient is extremely variable due to the large cone of depression surrounding the Dallas-Fort Worth metroplex, but in areas beyond this influence, a gradient of approximately 22 feet per mile (4.2 m/km) is average. Altitudes of water levels about 1955 and about 1976 are shown on Figures 24 and 25.

Water is discharged naturally from the Twin Mountains by springs and evapotranspiration and artificially by pumpage. In 1976, over 40,000 acre-feet (49.3 hm^3) of ground water was pumped from the Twin Mountains in the study area.

The coefficients of transmissibility, permeability, and storage for the Twin Mountains Formation are shown in Table 4. This table was compiled from existing literature and from data supplied by well drillers. Transmissibility and permeability values are also represented graphically on Figure 26. Permeability coefficients were computed by dividing the transmissibility of the well by its screened interval. Aquifer test results on 58 Twin Mountains wells were analvzed.

Review of the test results, illustrated on Figure 26, show that transmissibility values are generally higher in the central, northern, and eastern sections of the study area. The range of transmissibility was 1,950 to 29,700 (gal/d)/ft, or 24,200 to 369,000 (I/d)/m. The average for tests in Dallas County was 12,700 (gal/d)/ft, or 158,100 (I/d)/m; tests in Tarrant County was 8,450 (gal/d)/ft, or 105,000 (I/d)/m; and tests in the Johnson-Ellis County area was 6,480 (gal/d)/ft, or 80,500 (I/d)/m. Permeability values ranged from 8 to 165 (gal/d)/ft^2, or 326 to 6,720 (I/d)/m^2, with an average value of 68 (Ngal/d)/ft^2, or 2,770 (I/d)/m^2. Storage coefficients were obtained from 14 tests and ranged from 5 X 10^{-4} to 4 X 10^{-5} with an average value of 1 X 10^{-4}, or 0.0001. The specific yield in the outcrop is on the order of 15 percent as estimated by seismic methods (Duffin and Elder. 1979).

Yields of wells completed in the Twin Mountains range from 10 to 1,940 gallons per minute (gal/min) (0.63 to 122 I/s), with an average yield of 286 gal/min (18 I/s) for the 525 wells measured. Yields were considerably lower on or near the outcrop than yields of wells further downdip. Well yields generally increase from the southern part of the study area to the northern part. Both Collin and Dallas Counties have average well yields in excess of 700 gal/min, (44 I/s), while Hood, Parker, and Wise Counties average less than 100 gal/min (6.3 I/s). Denton, Ellis, and Tarrant Counties each average about 300 gal/min (19 I/s). Since many of the wells measured were of small capacity, improperly developed, or did not penetrate the full thickness of the aquifer, well yields are probably greater than the stated averages.

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Specific capacities of 233 wells screened in the Twin Mountains range from 0.3 to 12.2 or 0.06 to 2.53 (l/s)/m, and averaged 3.3 (gal/min)/ft, or 0.68 (l/s)/m. Specific capacities are generally higher in the northern and eastern parts of the study area.

Wells completed in the Twin Mountains outcrop have not experienced water-level declines other than the normal seasonal fluctuations. Water levels in wells east of the outcrop are declining steadily. The changes in water levels are illustrated on Figure 28 and by hydrographs (Figures 7 and 8). Long-range declines average over 20 feet (6 m) per year in eastern Tarrant and western Dallas Counties, corresponding to the center of the cone of depression as illustrated by the water-level maps (Figures 24 and 25). In areas outside this influence, water levels are declining 9 (3 m) to 17 (5 m) feet annually.

The large cone of depression depicted on Figure 25 is centered in the area between Euless in Tarrant County and Grand Prairie in Dallas County. Static water levels in several wells have reached the 1,000 foot (305 m) level and pumps are set as low as 1,500 feet (457 m) below the land surface. Yields have diminished and pumping-lift costs have risen. Lowering of pumps is a common occurrence. Several large ground-water users in this area, namely Euless, Bedford, and Arlington, have changed to surface-water supplies. This resultant decrease in pumpage may help alleviate the water-level declines now being experienced.

Wells which are not in the immediate vicinity of the cone of depression have also experienced large annual declines. A well at Everman in Tarrant County, had a water-level decline of 530 feet (162 m) over a 26-year period. The level in a well at Lancaster in Dallas County, declined 362 feet (110 m) in a 23-year period, and at Flower Mound in Denton County, a decline of 160 feet (49 m) in less than 9 years has occurred. Water-level declines are commonplace and are about average over most of the study area.

About half the ground water from the Woodbine and Trinity Group aquifers, over 40,000 acre-feet (49.3 hm^3), was pumped from the Twin Mountains in 1976. Public-supply use accounted for over 31,000 acre-feet (38.2 hm^3), more than the total public-supply use for all other aquifers in the study area combined. Almost all municipal, industrial, and irrigation wells were inventoried for this study. Data on 613 wells were tabulated and compiled within the record of wells. In areas where no large capacity wells exist, livestock or domesr'c wells were inventoried to provide more complete coverage. The estimated amount of ground water pumped from the Twin Mountains is shown in Tables 5 and 9. Domestic wells pumped an estimated 1,200 acre-feet (1.48 hm^3) of water from the Twin Mountains in 1975.

Public-supply wells accounted for 31,120 acre-feet (38.4 hm^3) of water from the Twin Mountains in 1976. This amount is double the quantity pumped in 1960. The greatest amount pumped during a single year was 32,468 acre-feet (40.0 hm^3) in 1974. Over the years, Dallas County pumpage has steadily increased, with almost 18,000 acre-feet (22.2 hm^3) pumped in 1976. Tarrant County increased each year until 1972, when Arlington, Bedford, and Euless changed to surface water. The amount of ground water pumped from the Twin Mountains in Tarrant County declined from 12,688 acre-feet (15.6 hm^3) in 1972 to only 6,080 acre-feet (7.50 hm^3) in 1976. Table 9 shows the public supply and industrial pumpage from 1955 to 1976.

Data were collected on 437 public-supply wells completed in the Twin Mountains. Of this amount, 105 are located in Tarrant County. Dallas, Denton, and Hood Counties average 70 wells each. Many of the wells inventoried in Tarrant and Dallas Counties have been abandoned. The largest individual user of ground water is Grand Prairie, pumping approximately 6,706 acre-feet (8.26 hm^3) in 1976. The four largest users are all in Dallas County, including Grand Prairie, Irving (4,812 acre-feet) (5.93 hm^3), Carrollton (2,080 acre-feet) (2.56 hm^3), and Lancaster (I ,348 acre-feet) (1.66 hm^3). These four cities had a 1976 total pumpage of almost 15,000 acre-feet (18.5 hm^3), which is about half of all the ground water pumped from the Twin Mountains for public-supply purposes in the study area. Grand Prairie and Irving are both situated near the center of the cone of depression previously mentioned. When Arlington, Bedford, and Euless were operating wells, an additional 5,000 acre-feet (6.17 hm^3) of ground water was also pumped from near the center of the cone.

Use of ground water for industrial purposes has diminished over the last 12 years. As shown in Table 9, approximately 6,000 acre-feet (7.40 hm^3) was pumped in 1976, just about one-half the amount, used in 1964. The inventory of wells resulted in the location of 113 industrial wells in the study area, many of which are now abandoned. About 70 percent of the industrial wells inventoried are located in Dallas and Tarrant Counties.

Ground-water irrigation constitutes only a small portion of the pumpage from the Twin Mountains. According to Table 5, approximately 1,545 acre-feet (1.90 hm^3) was pumped for irrigation purposes in 1977. Most of the water was used to irrigate golf courses and lawns. Irrigation of crops is limited to the outcrop area

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Table 9.--Estimated Use of Ground Water for Public Supply and Industrial Purposes From the Twin Mountains Formation, 1955-76

Use: PS, public supply; Ind, industrial. Values are in acre-feet.

County	Use	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	Totals
Collin	PS	1,205.9	1,012.8	326.8	309.1	302.6	22.1	24.6	24.6	30.9	64.4	63.1	64.3	102.7	106.7	120.6	127.8	134.4	171.8	177.2	205.8	185.3	193.2	4,976.1
	Ind	1,739.8	1,723.2	1,707.8	1,525.9	1,079.3	1,734.5	1,646.1	2,019.8	1,859.4	2,689.0	2,019.9	1,967.1	1,821.2	1,730.8	1,968.8	2,250.8	2,241.8	2,012.5	1,808.0	770.0	339.0	451.0	37,088.7
Dallas	PS	10,481.6	10,573.2	7,451.8	7,918.5	7,888.0	6,103.5	7,232.6	7,323.5	7,882.5	8,239.2	8,126.3	8,875.7	9,391.0	8,755.5	9,440.7	10,095.1	9,451.4	11,108.4	11,817.4	13,263.8	13,569.2	17,848.2	214,837.1
	Ind	6,414.6	6,414.6	6,414.6	4,928.3	5,635.5	5,075.2	5,111.7	5,450.1	6,230.3	5,898.8	5,606.3	5,774.0	5,626.7	4,641.3	5,002.0	4,585.9	4,055.4	4,792.3	3,907.6	4,441.6	2,309.0	2,232.5	110,348.3
Denton	PS	3,271.5	3,762.5	3,552.8	674.1	381.0	374.8	418.6	505.4	618.2	609.8	586.3	718.6	927.3	1,081.2	1,325.5	1,576.9	1,846.6	2,558.3	2,434.5	3,148.5	2,237.1	1,389.4	33,998.9
Ellis	PS	1,384.9	1,586.6	1,041.8	1,172.9	1,005.2	162.7	199.0	177.3	194.3	302.2	214.9	329.8	438.6	411.0	793.1	856.6	1,014.7	1,268.8	1,184.1	1,409.9	1,463.5	1,490.0	18,121.9
	Ind	--	--	--	--	--	220.0	220.0	220.0	220.0	220.0	270.0	420.0	420.0	445.0	462.5	638.5	788.1	868.4	1,052.7	1,042.8	1,013.3	1,011.9	9,533.2
Hood	PS	111.6	196.0	236.4	267.4	366.0	387.2	367.1	199.2	410.3	447.0	415.2	373.1	364.2	343.8	407.4	479.2	601.0	758.4	773.9	899.4	1,080.7	1,092.5	10,677.0
	Ind	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	41.5	43.2	84.7
Johnson	PS	2,211.0	2,580.0	2,307.6	1,937.1	2,452.9	2,144.3	2,568.2	2,632.7	2,533.1	2,413.2	1,221.8	628.7	942.5	993.9	1,150.8	1,448.6	1,583.0	1,955.0	1,806.2	2,487.5	2,397.6	2,581.4	43,177.1
	Ind	--	--	--	--	--	76.1	260.9	260.9	260.9	182.3	182.3	271.9	271.9	271.9	271.9	271.9	709.6	708.3	708.3	797.7	698.0	747.6	6,952.4
Parker	PS	808.0	910.8	972.6	17.0	13.0	16.0	51.0	50.9	66.5	68.2	242.7	247.3	262.8	280.7	332.1	389.8	472.4	488.2	443.2	478.1	483.5	358.1	7,454.9
	Ind	161.3	161.3	161.3	145.2	80.9	161.3	177.4	168.0	168.0	168.0	168.0	168.0	168.0	159.0	187.2	236.0	240.6	219.4	18.4	18.4	4.1	4.3	3,144.1
Tarrant	PS	6,193.8	6,191.6	6,844.5	5,927.4	6,217.2	6,026.4	5,710.7	6,112.2	7,824.4	8,001.7	9,881.0	9,366.6	10,850.1	10,928.3	12,254.2	11,298.7	10,891.2	12,688.3	10,623.4	10,493.0	6,591.0	6,079.5	186,995.2
	Ind	3,654.7	3,654.7	3,654.7	3,597.9	2,773.3	2,546.9	2,532.3	2,894.1	2,904.9	3,150.0	2,973.6	3,006.0	2,962.1	3,079.1	2,915.9	2,697.4	1,593.6	1,710.6	1,742.2	1,534.6	1,512.1	1,415.1	58,105.8
Wise	PS	90.3	90.3	90.3	90.3	37.0	34.4	32.6	29.1	19.1	44.6	21.6	22.3	40.2	36.7	22.9	22.9	68.2	84.5	74.0	81.9	75.5	87.8	1,198.5
	Ind	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	64.3	80.7	161.3	80.7	387.0
Totals	PS	25,758.6	26,903.8	22,824.6	18,313.8	18,644.9	15,271.4	16,604.4	17,254.9	19,578.7	20,190.3	20,774.9	20,626.4	23,339.4	22,937.8	26,047.3	26,295.6	26,062.9	31,081.7	29,333.9	32,467.9	30,003.4	31,120.1	521,436.7
	Ind	11,970.4	11,953.8	11,936.4	10,197.3	9,569.0	9,804.0	9,948.5	11,012.9	11,636.5	12,108.1	11,220.1	11,607.0	11,269.9	10,327.1	10,808.3	10,680.5	9,629.1	9,911.5	9,301.5	8,685.8	6,078.3	5,986.3	225,644.2
	PS and Ind	37,729.0	38,857.6	34,763.0	28,511.1	28,213.9	25,075.4	26,552.8	28,267.8	31,215.2	32,298.4	31,995.0	32,233.4	34,609.3	33,264.9	36,855.6	36,976.1	35,692.0	40,993.2	38,635.4	41,153.7	36,081.7	37,106.4	747,080.9

25 043

in Hood, Parker, and Wise Counties. Forty-seven irrigation wells that were inventoried accounted for 16 percent of the 1977 pumpage from the Twin Mountains.

The Twin Mountains Formation is the most prolific of the Cretaceous aquifers in the study area with about 55 percent of the total quantity of ground water utilized for municipal and industrial purposes. The quality of water is generally not as good as from the Paluxy or Antlers. However, higher well-yields allow some sacrifice in chemical quality. Approximately 700 analyses of water samples from the Twin Mountains have been tabulated and included in Table 10 which shows the range of constituents and properties of the water from representative wells. About 22 percent of these analyses contained dissolved-solids concentrations in excess of 1,000 mg/l.

Similar to the other Cretaceous aquifers in this study, the ground water from wells drilled on the outcrop of the Twin Mountains is hard and contains high concentrations of dissolved iron. In the downdip area, about 9 percent of the samples contain dissolved iron concentrations in excess of the recommended limit of 0.3 mg/, and about 83 percent of'the water is soft. The maximum allowable level for fluoride in the study area is 1.6 mg/l according to Drinking Water Standards adopted by the Texas Department of Health. Over 230 analyses contained fluoride levels exceeding 1.6 mg/l. Most of the other constituent levels were close to the maximum. Therefore, the main problems related to water quality for this aquifer are excessive fluoride and dissolved-solids concentrations. The downdip limit of fresh to slightly saline water is encountered about 60 to 75 miles (97 to 121 km) east-southeast of the outcrop in the majority of the study area (Figure 25). This distance is considerably less in the northern part of the study area where the outcrop trends eastward in the vicinity of Red River.

Since there are no concentrated areas of ground-water irrigation on the Twin Mountains outcrop, not enough chemical-quality data could be obtained to present a detailed classification of irrigation waters. Generally speaking, the Twin Mountains irrigation wells that are scattered through northeastern Hood County showed a very high sodium hazard, medium to high salinity hazard, and RSC levels classified as unsuitable for irrigation. Limited use of these wells accompanied with crop rotation and good management is necessary for continued good land productivity.

Irrigation wells, located near Brock in Parker County and completed on the Twin Mountains outcrop, were sampled and the results showed a low sodium hazard, medium salinity hazard, and zero RSC. The quality of water from 30 wells was suitable for irrigation use, but well yields limited extensive development.

Figure 29 shows the net sand thickness of fresh to slightly saline water-bearing sand in the Twin Mountains. Net sand thickness generally increases downdip in an easterly direction. Thickness increases from less than 100 feet (30 m) near the outcrop to over 400 feet (122 m) near the downdip limit of fresh to slightly saline water.

Areas for future development would have to be outside the Dallas-Fort Worth metroplex cone of depression. Even outside this influence, water levels are dropping over 10 feet (3 m) per year. There are several areas where waier quality restricts development of wells for irrigation use as previously noted and depicted on Figure 23. Wells tapping the Twin Mountains aquifer in areas downdip from the outcrop and in areas where quality is not a problem can expect a steady decline in water levels and yields.

Paluxy Formation

The Paluxy yields small to moderate amounts of fresh to slightly saline water to public supply, industrial, domestic and livestock wells in 16 of the 20 counties included in this study. The majority of the Paluxy outcrop occurs in Hood, Parker, Tarrant, and Wise Counties as illustrated on the geologic map (Figure 16) and occupies about 650 square miles (1,684 km^2).

The primary source of recharge to the Paluxy is precipitation on the outcrop. Secondary sources include recharge from streams flowing across the outcrop and surface-water seepage from lakes. The Brazos and Trinity River systems and Eagle Mountain Reservoir are a few examples. The average annual precipitation on the outcrop is about 31 inches (79 cm). Only a small fraction of the amount is available as effective recharge since there is much runoff and evapotranspiration.

Water in the outcrop area is under water-table conditions and water levels remain fairly constant with only normal seasonal fluctuations. In downdip areas, water is under artesian conditions, and is confined under hydrostatic pressure from overlying formations. The average rate of movement of water in the Paluxy amounts to less than 2 feet (0.6 m) per year in an easterly direction except in downdip areas of heavy pumpage where cones of depression have occurred and movement is towards the center of the pumped wells. Water-level measurements indicate that the present hydraulic gradient is approximately 27 feet per mile

Table 10.--Range of Constituents in Ground Water From Selected Wells in the Twin Mountains Formation

Analyses given are in milligrams per liter except percent sodium, specific conductance, pH, SAR, and RSC.

Single values appear where only one analysis or value was available.

Constituent or property	Collin County	Dallas County	Denton County	Ellis County	Hood County	Johnson County	Parker County	Tarrant County	Wise County
Silica (SiO_2)	10 - 21	4 - 40	7 - 38	2 - 79	0 - 102	8 - 28	9 - 48	5 - 79	8 - 27
Iron (Fe)	0 - .8	0 - 9.4	0 - 8.8	.1- .9	0 - 3.6	0 - .4	0 - 17.2	0 - 2.6	.1- 1.3
Calcium (Ca)	3 - 21	0 - 36	0 - 34	2 - 26	1 - 192	1 - 17	1 - 266	1 - 114	1 - 182
Magnesium (Mg)	1 - 4	0 - 56	0 - 11	0 - 25	0 - 35	0 - 8	1 - 79	0 - 11	1 - 82
Sodium (Na)	228 - 620	150 - 666	170 - 760	241 - 532	8 - 283	192 - 305	5 - 442	141 - 670	34 - 600
Bicarbonate (HCO_3)	293 - 538	185 - 640	244 - 680	360 - 646	240 - 590	356 - 483	35 - 700	288 - 659	303 - 550
Sulfate (SO_4)	73 - 504	19 - 940	38 - 335	70 - 500	4 - 339	41 - 251	4 - 519	21 - 579	24 - 263
Chloride (Cl)	28 - 740	36 - 364	10 - 090	67 - 383	3 - 258	13 - 93	7 - 306	14 - 650	8 - 680
Fluoride (F)	.2- 3.6	.2- 16.0	0 - 3.4	1.1- 3.0	.1- 3.2	.1- 2.7	0 - 3.9	0 - 7.0	.1- 1.5
Nitrate (NO_3)	0 - 2.0	0 - 3.9	0 - 5.2	0 - 5.0	0 - 162	0 - 3.0	0 - 170	0 - 5.9	.4- 44.0
Boron (B)	--	.1- 1.0	.3- 1.0	.4- 1.1	.1- .8	.4- .7	.1- 1.0	.2- 1.9	.2- .7
Dissolved solids	590 -1,612	420 -2,002	307 -1,973	554 -1,408	265 -1,366	382 - 844	133 -1,735	381 -1,735	387 -1,654
Total hardness ($CaCO_3$)	11 - 65	8 - 230	1 - 60	2 - 110	6 - 600	4 - 28	9 - 914	5 - 302	5 - 770
Percent sodium (%)	93.2- 98.5	80.1- 99.2	88.4- 100	77.7- 98.9	6.7- 99.5	87.0- 99.3	8.5- 99.1	12.8- 99.3	18.6- 98.7
pH	8.0- 8.8	7.7- 9.1	7.2- 9.3	7.8- 9.2	6.9- 8.9	7.9- 9.0	7.0- 8.8	7.4- 9.1	6.8- 8.8
Sodium-adsorption ratio (SAR)	21.8- 57.7	5.4- 66.0	11.1- 73.2	9.2- 63.8	.2- 64.1	11.2- 65.0	.2- 56.5	.4- 72	.8- 38.0
Residual sodium carbonate (RSC)	4.3- 7.9	0 - 10.2	2.3- 10.6	2.6- 10.1	0 - 9.3	5.6- 7.7	0 - 11.1	0 - 10.1	0 - 8.5
Specific conductance (micromhos at 25°C)	1,040 -2,790	510 -3,108	610 -4,030	1,000 -2,310	451 -1,960	780 -1,420	201 -2,270	607 -3,317	706 -2,880

25 045

(5.1 m/km). Altitudes of water levels about 1955 and about 1976 are shown on Figures 30 and 31.

Discharge from the Paluxy occurs naturally through springs and evapotranspiration and artificially through pumpage from water wells. In 1976, approximately 13,550 acre-feet (16.7 hm^3) was pumped from the Paluxy for municipal, industrial, irrigation, and domestic purposes. Livestock use would probably add several thousand acre-feet (several cubic hectometers) more to this quantity.

Table 4 shows the results of pumping tests conducted in the study area. Test results were obtained from existing literature or from data supplied by well drillers. A total of 25 Paluxy public-supply wells were tested and transmissibilities determined. Permeabilities were determined by dividing the transmissibility of the well by its screened interval. No tests were conducted on the outcrop, under water-table conditions.

Transmissibility values in 25 tests range from 1,263 to 13,808 (gal/d)/ft, or 15,700 to 171,500 (I/d)/m, with an overall average of 3,700 (gal/d)/ft, or 45,900 (I/d)/m. Only three tests exceeded 6,600 (gal/d)/ft, or 82,000 (I/d)/m, while nine tests fell below 3,000 (gal/d)/ft, or 37,300 (I/d)/m. Generally, the net sand thickness increases from less than 50 feet (15 m) in the southwest portion of the study area to 190 feet (58 m) in Denton County. Coefficients of permeability at 25 well locations were highly variable. A range of 6 to 150 (gal/d)/ft^2, or 244 to 6,110 (I/d)/m^2, was encountered with an overall average of 50 (gal/d)/ft^2, or 2,040 (I/d)/m^2. Of the 18 aquifer tests conducted in Tarrant County, two transmissibilities were extremely high and probably not representative. Eliminating the two high results, the average transmissibility for 16 tests is 3,580 (gal/d)ft, or 44,500 (I/d)/m, and the average permeability is 44 (gal/d)/ft^2, or 1,790 (l/d)/m^2. Permeabilities probably increase from the outcrop in a downdip direction and from south to north, corresponding to increasing sand thicknesses. Storage coefficients were determined at five sites, four of which are in Tarrant County. Values range from 0.00002 to 0.00034 with an average of 0.00014. This value is probably applicable to most of the study area. The specific yield in the outcrop is on the order of 15 to 20 percent as estimated by seismic methods (Duffin and Elder, 1979).

Yields of wells completed in the Paluxy ranged from 10 to 482 gal/min (0.63 to 30 l/s). A total of 344 wells were measured with an average yield of 97 gal/min (6.1 l/s). Lower yields were obtained in wells completed on or near the outcrop, while wells in downdip areas had significantly larger yields due mainly to the larger available heads. The following table lists counties that use water from the Paluxy aquifer extensively.

County	Number of Wells Measured	Average Yield (gal/min)	Number of Wells Tested	Average Specific Capacity [(gal/min)/ftl
Collin	9	132	3	2.39
Dallas	37	189	13	2.13
Denton	27	84	12	1.85
Johnson	19	68	6	1.08
Parker	21	45	13	1.35
Tarrant	214	84	95	1.56

Many of the wells do not penetrate the entire aquifer and are not designed for maximum production. Well completion techniques and pump capacities also affect production. Therefore, yields of many wells are somewhat less than the maximum yields that could be developed. Four flowing wells were measured in Red River County near the Red River and had an average yield of 300 gal/min (19 l/s). Several wells in Fannin, Lamar, Kaufman, Rockwall, and Ellis Counties were measured and yields of at least 100 gal/min (6.3 l/s) were obtained. The specific capacities of 152 wells screened in the Paluxy sand ranged from 0.3 to 5.4 (gpl/min)/ft, or 0.06 to 1.1 (l/s)/m, and averaged 1.64 (gal/min)/ft, or 0.34 (l/s)/m. The specific capacities increase toward the east in a downdip direction. Variations over short distances are due mainly to well construction and to lithologic changes.

25 046

Changes in water levels of wells completed in the Paluxy aquifer are illustrated by hydrographs (Figures 7 and 9) and a water-level decline map (Figure 32) showing approximate declines in the vicinity of Dallas and Tarrant Counties from about 1955 through about 1976. There are no long-range declines in the outcrop of the Paluxy or adjacent to it. The aquifer is under water-table condtions in this region and observation wells show minor fluctuations from year to year. However, the Lake Worth-White Settlement-Benbrook area of Tarrant County lies adjacent to the outcrop and due to heavy pumpage of the Paluxy, declines of several feet (meters) per year have been observed. Substantial withdrawals of water in the Tarrant County vicinity are reflected in the large cone of depression illustrated on Figure 31. The cone is at its deepest point in the Euless area of Tarrant County where the static water level of the Paluxy declined over 350 feet (107 m) in the last 20 years. The abandonment of Paluxy public-supply wells in this area during recent years should reflect rising water levels in the near future. The steady decline exhibited throughout the study area downdip from the outcrop is a result of the low permeability of the water-bearing sands and the large amount of ground water used for public supply and domestic purposes.

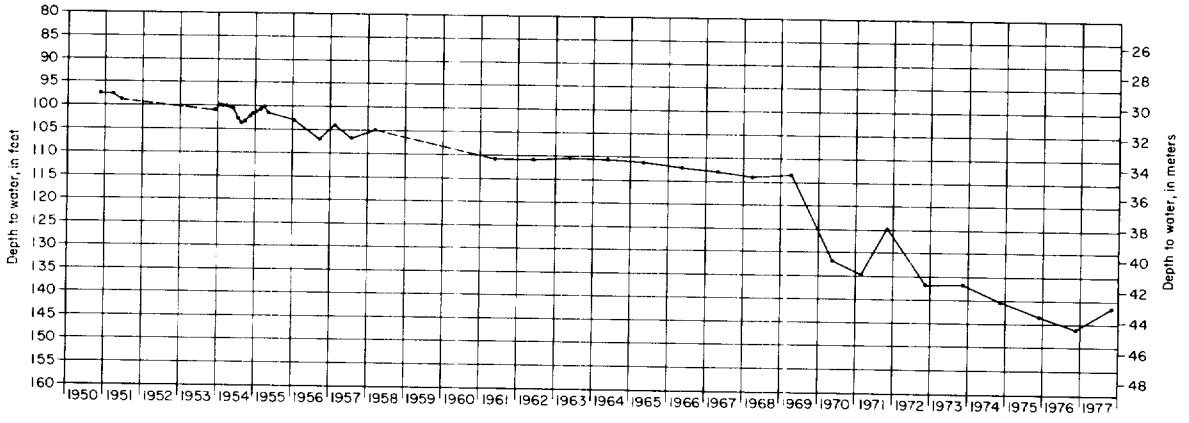
Approximately 15,000 acre-feet (18.5 hm^3) of water was withdrawn from the Paluxy in 1976, which is about 17 percent of the total amount pumped from the Woodbine and Trinity Group aquifers for the year. Municipal pumpage accounted for over half of this amount while domestic use accounted for about 24 percent. An attempt was made to inventory all large-capacity Paluxy wells developed for public supply, industry, and irrigation purposes. Of the 650 wells inventoried, 480 were used for public supply, and of this amount, approximately 40 percent are no longer in use. The estimated amount of ground water pumped from the Paluxy is shown in Tables 5 and 11.

Public-supply wells pumped 8,320 acre-feet (10.3 hm^3) of ground water from the Paluxy in 1976. Development of the Paluxy, especially in Tarrant County, began at the turn of the century and by the 1950's. large quantities of water were being withdrawn. In 1955, Tarrant County used 5,628 acre-feet (6.94 hm^3) for public supply, and Dallas County pumped 1,718 acre-feet (2.12 hm^3). This accounted for 88 percent of the public-supply pumpage from the Paluxy for the year. According to Table 11, Dallas and Tarrant Counties pumped 72 percent of the ground water used for public-supply in 1976. The concentrated pumpage in these two counties has resulted in the large cone of depression located in eastern Tarrant County. Of the 480 Paluxy public-supply wells inventoried, 285 were located in Tarrant County and 105 of these have been abandoned. Many of the cities near the center of the cone of depression have abandoned Paluxy wells due to diminishing well yields and declining water levels. Pumping levels in some wells fall below the top of the screened interval. Dewatering of the aquifer in this area has been taking place for the last 25 years. Municipalities using large amounts of ground water in 1976 include the cities of Benbrook, acre-feet (1.34 hm^3); Grand Prairie, 900 acre-feet (1.11 hm^3); Colleyville, 433 acre-feet (0.533 hm^3); and White Settlement, 420 acre-feet (0.517 hm^3). Domestic pumpage for 1976 is estimated at 3,550 acre-feet (4.38 hm^3).

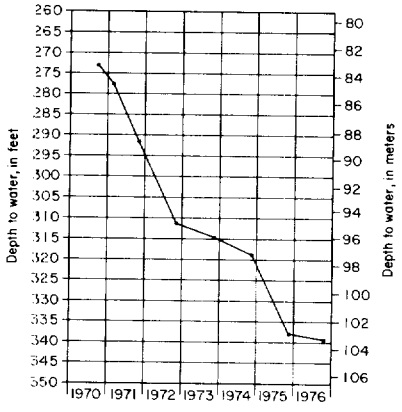
Industrial use accounted for 1,365 acre-feet (1.68 hm^3) in 1976. Of the 126 Paluxy industrial wells inventoried, 80 were located in Tarrant County and pumped 643 acre-feet (0.793 hm^3) in 1976. About one-fourth of these wells are no longer used. Only 18 industrial wells were developed in Dallas County but production in 1976 amounted to 519 acre-feet (0.640 hm^3). The most ground water pumped in any one year for industrial purposes from the Paluxy was in 1973 when 2,035 acre-feet (2.51 hm^3) was withdrawn.

Only minor amounts of water for irrigation purposes are pumped from the Paluxy, with about 361 acre-feet (0.445 hm^3) used in 1977 from 44 wells, Most of these wells are located in Dallas, Parker, Red River, and Tarrant Counties. The wells are widely scattered and are primarily used for watering golf courses and greenbelt areas around industries. Four flowing wells in Red River County were inventoried; one well was flowing in excess of 400 gal/min (25 l/s).

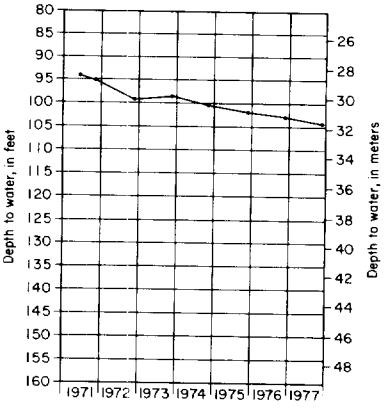
Wells completed in the Paluxy have water with chemical quality that is generally better than water from other Cretaceous aquifers in the study area. Over 600 analyses were collected or obtained from other sources, providing an adequate chemical quality network with the exception of the northeastern area. Most of the minor deficiencies found in Paluxy water exist on or near the outcrop, hardness and higher iron concentrations occur. Approximately 25 percent of the analyses show hardness as $CaCO_3$ exceeding the 60 mg/l level, and many exceed the 120 mg/l and 180 mg/l level. About 40 analyses had iron concentrations in excess of the recommended level of 0.3 mg/l. Only 7 percent of the analyses had more than 1,000 mg/l dissolved-solids and only 9 analyses had concentrations in excess of 2,000 mg/l. Fluoride levels increase in the downdip part of the aquifer, with rnost of the water exceeding 1.6 mg/l near the downdip limit of fresh to slightly saline water. Only a few water wells tap the Paluxy in Fannin, Lamar, and Red River Counties; however, they contain water of good quality. 'Well yields and construction costs limit Paluxy well development in this area. Table 12



Tarrant County
Well XU-32-21-501
depth: 227ft.(69m



Denton County
Well HW-18-57-901
depth: 1,308ft.(399m)



Lamar County
Well RT-17-29-601
depth: 2,644ft.(806m)

Figure 9

Hydrographs of Water Levels in Wells Completed in the Paluxy Formation Under Artesian Conditions

25 048

Table 11.--Estimated Use of Ground Water for Public Supply and Industrial Purposes from the Paluxy Formation, 1955-76

Use: PS, public supply; Ind, industrial. Values are in acre-feet.

County	Use	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	Totals
Collin	PS	134.1	156.8	100.0	112.3	96.0	127.7	112.8	114.4	133.9	108.3	109.0	128.0	158.5	132.3	157.6	176.2	186.2	204.1	229.6	264.6	258.5	281.3	3,482.2
	Ind	154.7	154.7	154.7	138.1	150.0	156.5	162.7	159.6	159.6	161.1	165.7	153.4	147.3	7.2	59.0	117.4	107.3	124.8	309.1	242.7	183.1	203.2	3,371.9
Dallas	PS	1,718.3	1,723.3	1,285.7	1,668.8	1,549.9	1,555.2	1,472.5	1,390.4	1,570.8	1,413.8	1,221.0	1,083.7	1,084.7	1,106.7	1,223.4	1,219.8	1,340.9	1,283.1	1,094.6	849.6	1,255.0	1,238.0	29,349.4
	Ind	947.2	947.2	1,100.6	742.0	992.2	898.2	785.3	831.4	765.9	704.0	836.0	849.1	903.7	769.1	786.9	756.5	781.1	1,034.2	971.5	938.4	579.4	518.5	18,438.4
Delta	PS	--	--	--	--	--	--	--	--	--	2.2	12.9	21.5	40.6	51.2	61.7	69.6	71.6	71.6	67.6	81.7	96.3	64.7	713.2
Denton	PS	203.8	193.0	227.8	240.9	275.7	526.1	395.1	363.5	398.7	458.8	489.2	460.9	485.1	573.3	593.2	446.7	476.5	607.1	626.0	747.2	539.9	469.9	9,798.4
	Ind	8.5	9.2	9.2	46.3	50.0	60.0	48.1	55.7	41.5	45.3	45.0	60.3	61.3	56.7	40.1	1.7	2.7	2.8	--	--	--	--	644.4
Ellis	Ind	--	--	--	--	--	--	--	--	--	--	--	--	--	119.0	119.0	119.0	119.0	117.8	156.1	183.2	181.7	175.2	1,290.0
Fannin	PS	--	--	--	--	--	--		--	19.9	46.7	46.2	68.5	76.0	66.9	70.8	76.3	83.0	87.1	100.7	257.9	372.6	345.2	1,717.8
Johnson	PS	348.6	401.8	386.6	389.6	397.5	437.3	520.8	510.9	556.7	469.9	449.8	532.7	401.9	440.4	851.0	572.7	378.5	357.8	340.9	393.7	385.1	473.2	9,995.9
Kaufman	PS	92.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	92.1
Lamar	PS	--	--	--	--	--	--	--	--	--	--	9.0	29.4	34.7	48.3	63.9	62.3	94.0	104.7	92.0	95.8	131.9	100.5	866.5
Parker	PS	2.5	2.5	2.5	2.5	2.5	3.0	3.0	3.7	3.9	6.3	11.8	27.0	36.4	51.7	76.1	75.5	112.1	138.4	140.1	197.5	213.1	277.3	1,389.4
Red River	PS	--	--	--	--	--	--	--	5.0	25.0	26.0	28.0	30.0	30.0	30.0	33.2	43.5	54.7	55.4	56.2	57.7	58.0	67.8	600.5
Rockwall	PS	143.4	139.7	59.2	8.4	3.3	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	354.0
Tarrant	PS	5,627.7	5,631.9	5,804.1	5,795.5	5,916.2	6,349.8	6,880.5	7,763.4	8,945.2	8,050.4	7,887.9	6,831.4	7,214.4	7,050.8	7,891.1	6,871.7	6,135.5	6,346.1	5,608.0	5,197.0	4,789.8	4,724.3	143,312.7
	Ind	720.2	720.2	720.2	825.1	827.2	808.1	802.8	797.1	908.6	791.5	603.0	681.8	888.0	774.3	957.2	745.1	591.1	613.9	753.6	590.1	518.3	642.6	16,280.0
Wise	PS	48.9	32.4	36.7	58.8	61.4	63.4	43.2	37.3	42.2	23.0	24.9	69.6	72.2	74.4	75.2	61.9	79.6	69.0	81.0	96.4	85.3	98.8	1,335.6
	Ind	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	.9	.4	.4	.9	.4	3.0
Totals	PS	8,319.4	8,281.4	7,901.6	8,276.8	8,302.5	9,062.5	9,427.9	10,188.6	11,696.3	10,605.4	10,289.7	9,282.7	9,634.5	9,745.0	11,250.0	9,795.2	9,131.6	9,442.4	8,592.8	8,421.8	8,367.2	8,316.2	204,297.7
	Ind	1,830.6	1,831.3	1,984.7	1,751.5	2,019.4	1,922.8	1,798.9	1,843.8	1,875.6	1,701.9	1,649.7	1,744.6	2,000.3	1,607.3	1,843.2	1,620.7	1,482.2	1,776.6	2,034.6	1,771.6	1,281.7	1,364.7	38,737.7
	PS and Ind	10,150.0	10,112.7	9,886.3	10,028.3	10,321.9	10,985.3	11,226.8	12,032.4	13,571.9	12,307.3	11,939.4	11,027.3	11,634.8	11,352.3	13,059.4	11,415.9	10,613.8	11,219.0	10,627.4	10,193.4	9,648.9	9,680.9	243,035.4

25 049

Table 12.--Range of Constituents in Ground Water From Selected Wells in the Paluxy Formation

Analyses given are in milligrams per liter except percent sodium, specific conductance, pH, SAR, and RSC.

Single values appear where only one analyses or value was available.

Constituent or property	Collin County	Dallas County	Denton County	Ellis County	Hood County	Johnson County	Lamar County	Parker County	Red River County	Tarrant County	Wise County
Silica (SiO_2)	1 - 26	3 - 76	3 - 23	13 - 14	10 - 21	9 - 41	16 - 21	10 - 54	7 - 17	1 - 30	10 - 21
Iron (Fe)	0 - .5	.1- 3.6	0 - .9	--	2.6	0 - 1.7	.2- .5	0 - 10.0	0 - 1.0	0 - 9.9	0.2
Calcium (Ca)	1 - 8	0 - 129	0 - 58	5 - 7	68 - 157	1 - 79	3 - 7	2 - 225	3 - 109	0 - 120	5 - 250
Magnesium (Mg)	0 - 3	0 - 24	0 - 18	1 - 4	2 - 23	0 - 21	1 - 5	1 - 205	1 - 33	0 - 43	2 - 18
Sodium (Na)	245 - 340	30 -1,050	42 - 770	466 - 696	7 - 44	17 - 408	401 - 486	5 - 194	22 - 729	11 - 740	7 - 409
Bicarbonate (HCO_3)	470 - 691	122 - 695	293 - 790	666 - 710	256 - 447	296 - 710	620 - 820	192 - 620	131 - 822	177 - 689	295 - 497
Sulfate (SO_4)	73 - 125	21 -1,711	15 - 494	354 - 864	13 - 74	5 - 280	143 - 192	11 - 167	4 - 191	6 -1,080	31 - 421
Chloride (Cl)	18 - 110	16 - 307	5 - 399	54 - 74	5 - 65	7 - 66	72 - 197	0 - 815	10 - 680	5 - 117	6 - 240
Fluoride (F)	.2- 1.9	.4- 4.0	0 - 3.9	5.4- 7.0	.2- .5	.1- 8.0	3.4- 4.6	0 - 3.2	.1- 6.2	0 - 4.5	.1- 1.1
Nitrate (NO_3)	.2- 2.5	0 - 4.6	0 - 3.2	.4- 3.2	0 - 69	0 - 5.7	.4- 3.5	.4- 135	0 - 2.0	0 - 10.0	.4- 31
Boron (B)	--	2.1	3.0	--	--	.3- 1.4	--	.1- .2	.3	.1- .6	--
Dissolved solids	615 - 847	257 -3,008	310 -2,076	1,250 -1,999	282 - 586	280 -1,071	1,012 -1,237	264 -1,870	200 -1,840	264 -2,176	316 -1,050
Total hardness ($CaCO_3$)	5 - 30	4 - 423	2 - 214	15 - 36	227 - 487	3 - 251	11 - 34	9 -1,400	12 - 350	2 - 401	21 - 699
Percent sodium (%)	95.5- 99.3	29.4- 99.6	30.2- 100	97.5- 98.4	5.6- 24.0	12.9- 99.1	96.4- 98.6	3.5- 97.1	24.0- 98.8	7.1- 99.5	21 - 97.7
pH	8.2- 8.9	7.2- 9.2	7.1- 10.4	8.0- 8.4	6.6- 7.9	7.4- 9.3	8.1- 9.0	6.8- 8.7	7.3- 8.5	7.1- 9.2	6.9- 8.3
Sodium-adsorption ratio (SAR)	23.0- 74.1	1.0- 85.6	1.2- 75.7	49.8- 52.0	.2- 1.0	.4- 52.2	30.8- 57.0	.1- 21.5	.8- 57.6	.2- 68.8	.1- 39.1
Residual sodium carbonate (RSC)	7.4- 10.8	0 - 10.4	.9- 12.1	10.2- 11.3	0 - .3	0 - 11.3	9.6- 13.2	0 - 6.6	0 - 13.2	0 - 10.0	0 - 7.7
Specific conductance (micromhos at 25°C)	1,029 -1,260	451 -3,280	540 -3,770	1,900 -2,970	470 - 905	485 -1,700	1,040 -2,272	461 -3,110	345 -3,180	427 -3,193	518 -1,790

shows the range of constituents and properties of water from representative wells in the Paluxy Formation.

Figure 20 shows the net sand thickness of fresh to slightly saline water-bearing sand in the Paluxy. Net sand thicknesses increase from less than 50 feet (15 m) in Johnson County to 190 feet (58 m) in Denton County. Ordinarily, the most favorable areas for development of ground water would be where the saturated sand is greatest. However, due to the heavy pumpage over the past 30 years, most areas are already overdeveloped and water levels are declining at an alarming rate. The only area that seems available for increased development would be in areas of Fannin and Lamar Counties. The six public supply wells in these counties are located in an area where water from the Woodbine is saline. Well yields in excess of 100 gal/min (6.3 l/s) with pumping levels below 300 feet (91 m) are encountered.

Any Paluxy wells developed in the area of the cone of depression in eastern Tarrant County can expect pumping levels, and in some areas static water levels, to be below the top of the aquifer. Pumps are usually set near the base of the formation. Outside this area and downdip from the outcrop, water levels are declining from 4 to 12 feet (1 to 4 m) per year. Correct spacing of wells is a prerequisite throughout the study region. Any additional development of the Paluxy will result in further lowering of the artesian head in areas where the water levels are still above the formation top. In sone areas, additional development will result in dewatering of the aquifer.

Woodbine Group

The Woodbine Group is an important aquifer in the study region. The outcrop extends in a south-north direction through the center of the report area and then trends to the east parallel to the Red River. The Woodbine dips eastward where it reaches a maximum thickness of about 700 feet (213 m) and has a maximum depth of 2,500 feet (762 m) below land surface. The areal extent of the outcrop and the approximate altitude to the top of the Woodbine are illustrated on Figure 21.

The primary source of ground water in the Woodbine is rainfall on the outcrop area. This area receives an annual rainfall of from 33 inches (84 cm) in the south to 37 inches (94 cm) in the north. Other sources of ground water include surface-water seepage from lakes and streams, such as Lake Grapevine, Garza-Little Elm Reservoir, and the Trinity River tributaries.

Water occurs in saturated sand beds under both water-table and artesian conditions. Water-table conditions occur in or near the outcrop while artesian conditions prevail downdip.

Recharge to the Woodbine occurs in the outcrop area, about 1,200 square miles (3,108 km^2), which consists of a permeable, sandy soil conductive to infiltration of rainfall and seepage from streams. The quantity of recharge to the Woodbine is estimated to be equivalent to less than one inch of precipitation per year on the sandy portion of the outcrop. The movement of water follows an east-southeast direction from the outcrop, generally paralleling the dip of the beds. According to Baker (1960). the average rate of water movement in the Woodbine is estimated to be about 15 feet per year (4.6 m/yr). The hydraulic gradient varies from over 30 feet per mile (5.7 m/km) to less than 13 feet per mile (2.5 m/km) within the study area except for minor local variations and for cones of depression around areas of excessive ground-water pumpage. The hydraulic gradient and a large cone of depression around the city of Sherman are illustrated on Figure 33, which also shows the approximate altitude of water levels in the Woodbine aquifer about 1976.

Discharge from the Woodbine occurs naturally through springs and seeps, evaporation, and transpiration by plants. Evapotranspiration is greatest in the summer and where vegetation is dense. Pumpage of wells constitutes most of the water artificially discharged from the aquifer and includes some flowing wells along the Red River portion of the outcrop. In 1976, about 20,500 acre-feet (25.3 hm^3) of ground water was pumped from the Woodbine in the region.

The coefficients of storage, permeability, and transmissibility and the specific capacity for the Woodbine are shown on Table 4. Aquifer test locations and results are shown on Figure 26. The table was compiled from existing literature and from tests conducted by water-well drillers. Data from aquifer tests were analyzed by using the modified Theis nonequilibrium formula in conjunction with a computer program which provides a means of computing transmissibility from the water-level recovery of a step-drawdown test. The permeability coefficients were computed by dividing the transmissibility by the effective sand thickness. Specific capacities of wells were determined by dividing the yield by the total water-level drawdown measured in the well.

The specific yield was estimated using seismic methods (Duffin and Elder, 1979) in the outcrop under

water-table conditions and is on the order of 15 percent. Downd p, where the aquifer is under artesian conditions, the average coefficient of storage is approximately 0.00015, or 1.5×10^{-4} The coefficient of storage is dimensionless and indicates the volume of water that an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface.

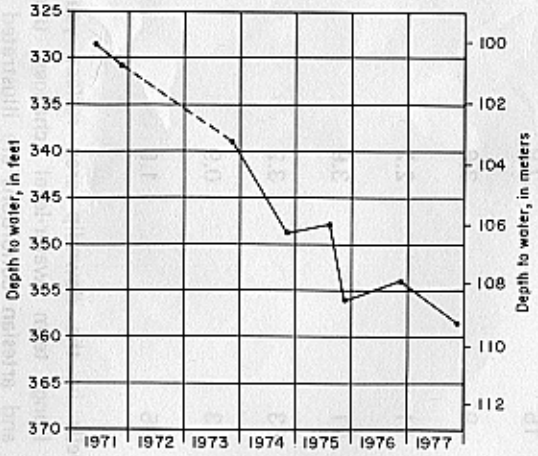
Generally, the more permeable sands of the Woodbine occur on or near the outcrop, where permeability coefficients range from 84 to 167 gallons per day per square foot [(gal/d)/ft^2], or 3,400 to 6,800 liters per day per square meter [(l/d)/m^2]. Farther downdip, a range of 14 to 183 (gal/d)/ft^2, or 570 to 7,500 (l/d)/m^2, was encountered with an average coefficient of permeability of 44 (gal/d)/ft^2, or 1,800 (l/d)/m^2.

Transmissibility values are estimated to be considerably higher along the outcrop where water-table conditions exist. Two tests were conducted on irrigation wells completed in the outcrop in Grayson County and even though the tests were of short duration and thus not completely accurate, values of 7,870 and 16,700 gallons per day per foot [(gal/d)/ft], or 97,800 and 207,400 liters per day per meter [(l/d)/m], were obtained. The 24 remaining tests conducted mainly on public supply wells and utilizing data provided by the well driller showed a range of 1,320 to 14,700 (gal/d)/ft or 16,400 to 182,500 (l/d)/m and an average value of 4,700 (gal/d),lft, or 58,400 (l/d)/m, can be expected. In 1945, the U.S. Geological Survey conducted five pumping tes-ts (drawdown and recovery) on several Woodbine wells owned by the city of Sherman and obtained an average transmissibility of 2,400 (gal/d)/ft, or 29,800 (l/d)/m, and an average coefficient of permeability of 37 (gal/d)/ft^2, or 1,500 (l/d)/m^2.

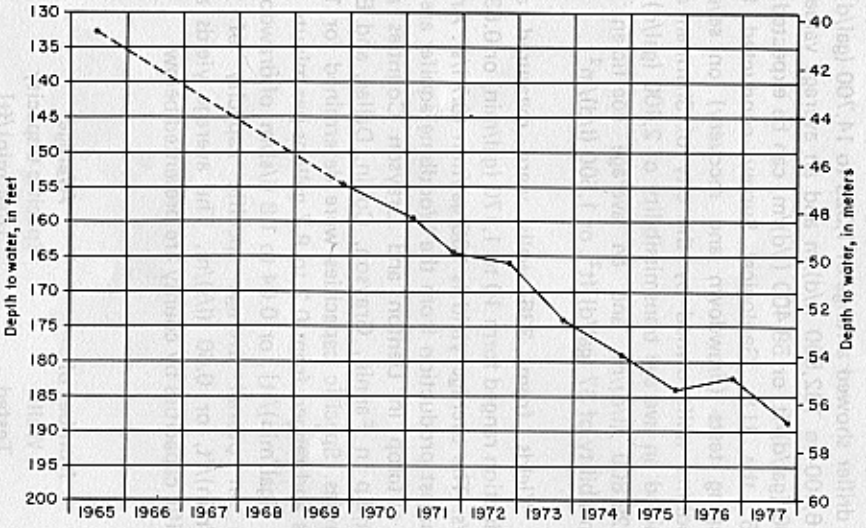
Yields from 336 wells were measured and production ranged form 10 to 1,170 (gal/min) or 0.63 to 74 l/s. The average yield is 106 gal/min (6.7 l/s). Areas of largest production from the Woodbine aquifer are on the outcrop in Denton and Grayson Counties and downdip in Fannin, Grayson, Collin, Dallas, and Ellis Counties. Specific capacities were determined for 139 wells and ranged from 0.2 to 8.7 gallons per minute per foot [(gal/min)/ft], or 0.04 to 1.8 (l/s)/m, of drawdown with an overall average specific capacity of 2.9 (gal/min)/ft, or 0.60 (l/s)/m. The average yields and specific capacities by county are presented below:

County	Number of Wells Measured	Average Yield (gal/ min.	Number of Wells Tested	Average Specific Capacity [(gal/min)/ft]
Collin	20	139	8	2.7
Cooke	8	124	2	1.6
Dallas	67	111	15	2.8
Denton	20	215	9	3.6
Ellis	24	177	11	2.2
Fannin	34	214	21	3.9
Grayson	108	223	5'3	3.2
Johnson	12	51	3	0.9
Tarrant	37	45	15	1.5

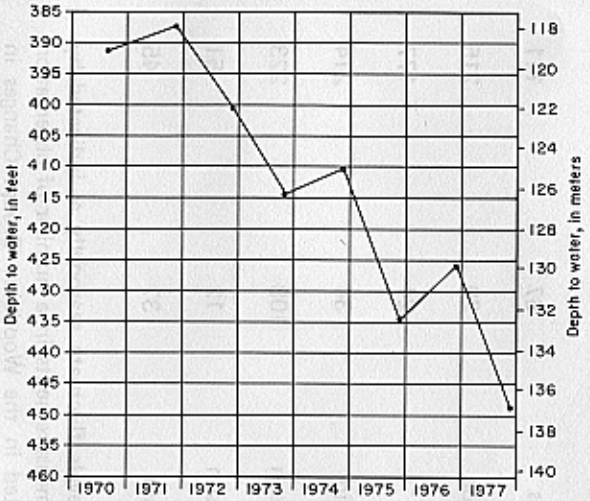
Water levels fluctuate seasonally as indicated by the periodic measurements in a number of observation wells completed in the Woodbine Group. Changes in water levels are illustrated by hydrographs. Water levels in the outcrop seem to recover to static level each year whereas wells in the downdip area reflect yearly declines. Long term water-level changes under water-table and artesian conditions are illustrated by Figures 7 and 10. The approximate altitude of water levels in Woodbine wells around 1955 is shown on Figure 34.



Lamar County
Well RT-17-27-201
depth: 1,675 ft. (511m)



Ellis County
Well JK-32-48-501
depth: 367 ft. (112m)



Grayson County
Well KT-18-27-701
depth: 613 ft. (187m)

Figure 10
Hydrographs of Water Levels in Wells Completed in the Woodbine Group Under Artesian Conditions

25 053

In February 1959, well KT-18-20-714 (Grayson County) had a water level of 342 feet (104 m) below ground level. This same well was measured in February 1972 and the static water level had declined to 428 ft (130 m). In April 1977, the water level was 536 feet (163 m) resulting in a net decline of 194 ft (59 m) in just 18 years, or 10.8 feet per year (3.29 m/yr). In Ellis County, well JK-32-48-501 declined 56 feet (17 m) in 12 years, while well JK-33-26-802, further downdip, dropped 138 feet (42 m) in 15 years. However, there are some areas downdip that are not experiencing large declines. For example, well DT-18-50-901 in Collin County declined about 5 feet (1.8 m) in 5 years.

As would be expected, the greatest declines are found in areas where large quantities of water are pumped for industrial and public-supply purposes. This fact, coupled with the low permeability of the water-producing sands, has resulted in a steady decline in the water table. In some downdip areas, especially in the southern part of the study region, the static water level has already dropped below the top of the Woodbine.

Since the initial years of the 20th century, the Woodbine aquifer has been characterized by ever-increasing development. The primary uses of ground water from Woodbine wells are for domestic, livestock, and public-supply purposes. Initial large increases in industrial-water use was followed by a generally, constant reported usage over the last 25 years. The development of ground water for irrigation purposes is relatively new, beginning about 10 years ago with large withdrawals. The increase in production from the Woodbine in the study area is due primarily to the increase in population and in irrigation activities.

In 1976, about 13,750 acre-feet (17.0 hm^3) of ground water was pumped from the Woodbine for public supply, industrial, and irrigation purposes in the study area. This accounts for approximately 20 percent of the ground water pumped from the Woodbine and Trinity Group aquifers for these uses.

Increase in population and home modernization in towns and cities have created a constantly increasing demand for water over the years. This demand is illustrated by Figure 11, which shows the amount of ground water used for public-supply purposes from 1955 to 1976 from the Woodbine and Trinity Group aquifers. The estimated use of ground water from the Woodbine for public supply and industrial purposes from 1955-76 is shown, by county, in Table 13.

In 1976, Grayson County pumped about 4,870 acre-feet (6.01 hm^3) of ground water from the Woodbine for public-supply use. This represents about 57 percent of the 8,560 acre-feet (10.6 hm^3) withdrawn by all counties in the study area. Fannin County was second with about 1,000 acre-feet (1.23 hm^3) of pumpage. The largest, municipal ground-water user is the city of Sherman. In 1933, Sherman pumped 426 acre-feet (0.525 hm^3) from the Woodbine, increasing to 609 acre-feet (0.751 hm^3) in 1943; 1,102 acre-feet (1.36 hm^3) in 1955; 1,795 acre-feet (2.21 hm^3) in 1965; and 3,448 acre-feet (4.25 hm^3) in 1976, which is about 40 percent of the total Woodbine ground-water use in the study region for the year. Many large ground-water users have changed to surface-water supplies, thus decreasing the amount of water pumped from the Woodbine. This decrease is more than offset by the increase in ground-water use by water-supply corporations and smaller, growing towns. A total of 377 public-supply wells were inventoried for this study, which includes those municipal wells no longer in use.

In 1976, approximately 2,581 acre-feet (3.18 hm^3) of ground water was pumped for industrial purposes from the Woodbine, which is about 25 percent of the total quantity of water pumped for industry from the Woodbine and Trinity Group aquifers. About 115 industrial wells were inventoried for this study, most of which are located in Dallas County, where over 50 percent of the industrial pumpage occurs. Industrial pumpage has remained fairly constant with only minor fluctuations occurring from 1955 to 1976, as illustrated on Figure 12 and in Table 13. Some of the declines in industrial usage may be misleading because many businesses purchase ground water from cities where it is reported as municipal pumpage.

In 1977, approximately 135 irrigation wells pumped 2,717 acre-feet (3.35 hm^3) of ground water for irrigation purposes from the Woodbine Group. The irrigation pumpage represents about 20 percent of the total ground water pumped from the Woodbine during 1976 in the study region. This pumpage was principally from Grayson and northern Denton Counties, which accounted for 64 percent of the irrigation pumpage. Irrigation ground-water pumpage in these and adjacent counties for the period 1970-77 is illustrated on Table 5. In most cases, these wells are pumped from 4 to 6 weeks annually and the water is generally used to irrigate peanuts and grasses.

The quantity of ground water used for irrigation was determined in part on power and yield tests conducted on selected irrigation wells, and in part on using measured yields in conjunction with the owner's estimate of the time the irrigation well was pumped annually. The results and data collected from the power and yield tests are given in Table 7. The industrial and municipal use was determined by compiling the data on

25 054

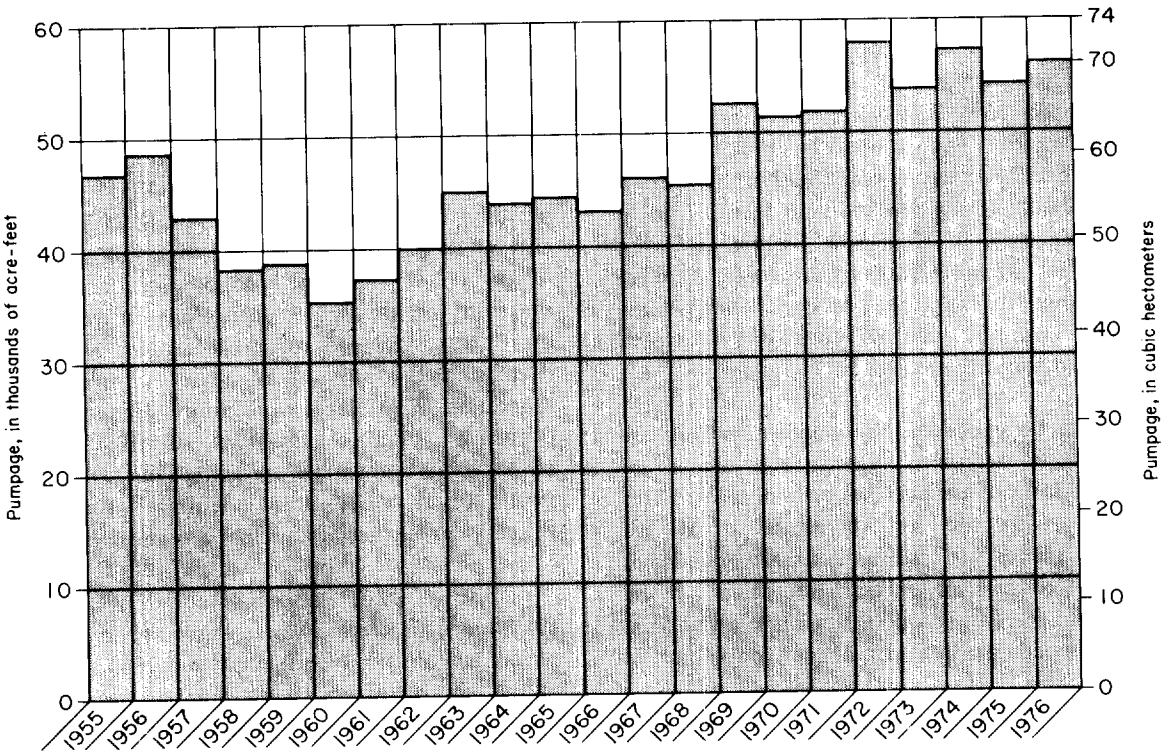


Figure 11.—Public Supply Ground-Water Pumpage From the Woodbine and Trinity Group Aquifers, 1955-76

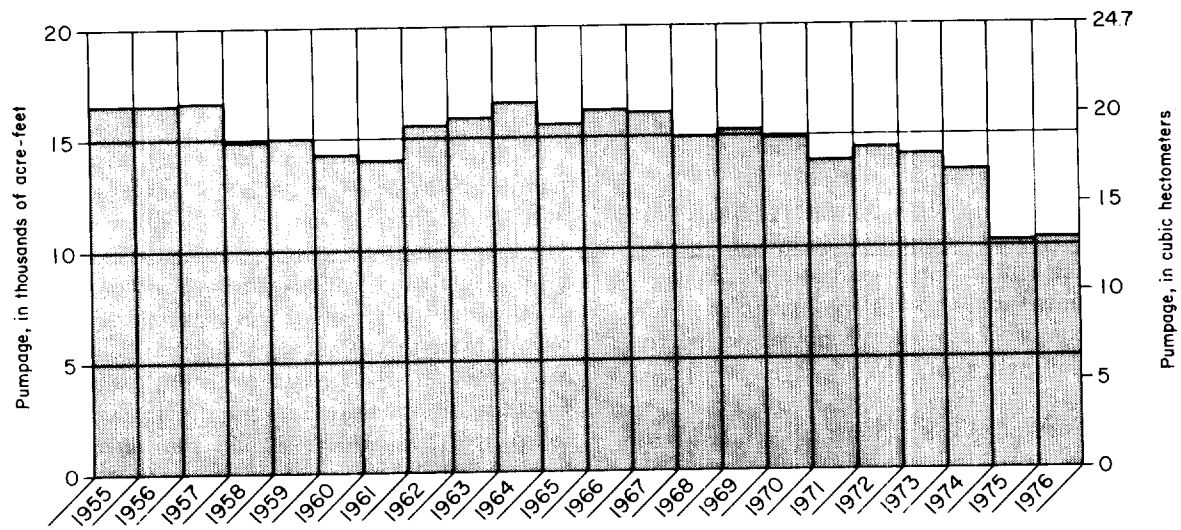


Figure 12.—Industrial Ground-Water Pumpage From the Woodbine and Trinity Group Aquifers, 1955-76

returned questionnaires mailed annually by the Department to the various surface- and ground-water users.

There was little irrigation ground-water use prior to 1965. However, since 1965, many wells have been drilled and ground-water withdrawals continue to rise. The amount of water pumped from the Woodbine for irrigation doubled during the years 1970 to 1977.

Water quality in wells completed on or near the outcrop of the Woodbine is fresh and of good quality

Table 13.--Estimated Use of Ground Water for Public Supply and Industrial Purposes From the Woodbine Group, 1955-76

Use: PS, public supply; Ind, industrial. Values are in acre-feet.

County	Use	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	Totals
Collin	PS	716.2	696.0	301.3	327.6	312.3	267.7	242.9	195.7	237.4	242.6	247.5	309.9	365.9	360.9	406.1	487.7	616.7	739.9	664.6	741.3	809.0	599.6	9,888.8
	Ind	--	--	--	--	--	--	--	--	--	--	--	--	--	--	100.1	42.9	34.0	34.0	34.0	34.0	34.0	34.0	347.0
Dallas	PS	1,819.6	1,828.0	1,686.0	1,448.5	1,560.4	1,556.2	1,344.4	1,436.6	1,483.3	1,350.1	1,454.0	1,457.5	1,576.8	1,429.5	1,412.0	1,159.8	989.6	891.6	896.7	910.6	887.0	835.5	29,413.7
	Ind	1,596.1	1,596.1	1,596.1	1,441.7	1,221.0	1,119.0	1,070.7	1,577.1	1,031.2	1,327.3	1,632.6	1,463.1	1,390.5	1,332.6	913.1	1,009.7	1,005.2	1,158.3	1,088.5	1,214.7	1,187.2	1,326.0	28,297.8
Denton	PS	--	--	--	1.0	1.0	95.0	61.9	64.0	86.4	112.2	118.4	123.2	129.2	161.2	156.7	81.9	46.7	73.1	63.3	75.3	137.1	193.0	1,780.6
	Ind	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1.6	1.6	4.7	57.7	7.2	72.8
Ellis	PS	1,558.0	1,530.0	1,616.6	1,420.7	1,298.1	1,317.8	1,328.4	1,314.0	1,376.4	1,406.7	1,534.0	1,190.7	539.6	528.1	569.4	614.1	656.7	763.4	724.8	825.3	860.8	716.2	23,629.8
	Ind	--	--	--	--	--	140.0	140.0	140.0	280.0	280.0	280.0	280.0	280.0	336.0	336.0	336.0	336.0	471.2	624.6	732.6	726.8	700.4	6,419.6
Fannin	PS	1,380.6	1,494.7	1,335.2	1,397.4	1,484.5	1,378.2	1,417.1	1,394.8	1,503.8	1,518.9	1,494.4	1,563.6	1,479.8	1,127.5	1,962.0	1,091.4	1,827.9	1,843.7	874.4	997.5	927.5	993.4	30,468.3
	Ind	--	--	--	--	--	40.0	90.0	90.0	90.0	90.0	95.0	95.1	159.6	198.2	83.8	82.2	143.7	122.9	118.3	120.3	125.0	117.1	1,861.3
Grayson	PS	1,862.3	2,037.6	1,866.6	2,004.2	2,131.5	1,864.4	2,010.7	2,237.6	2,563.2	2,560.6	2,729.3	3,059.6	3,233.8	3,436.9	4,038.8	4,195.2	4,360.7	4,365.3	4,432.5	4,630.5	4,474.5	4,872.0	68,967.8
	Ind	593.7	593.7	593.7	1,033.0	1,318.4	888.6	630.6	592.5	730.9	758.6	798.6	760.2	732.4	745.6	760.8	730.5	573.3	495.1	530.5	429.5	337.9	395.9	15,024.0
Hunt	PS	28.0	39.3	46.0	33.6	37.0	39.9	34.2	36.3	43.2	44.6	45.4	55.3	64.9	78.7	87.8	105.9	102.6	126.0	116.0	129.6	134.6	131.3	1,560.2
Johnson	PS	112.3	66.6	59.0	87.3	75.4	100.4	64.8	58.0	58.3	65.8	66.0	86.8	66.5	64.6	85.1	67.6	70.8	74.9	70.9	65.2	158.7	72.4	1,697.4
Kaufman	PS	132.6	100.7	100.7	84.0	81.4	80.7	76.7	61.4	67.5	67.5	22.1	--	--	--	--	--	--	--	--	--	--	--	875.3
Lamar	PS	--	--	--	--	--	--	--	--	--	3.5	20.7	10.6	11.5	13.1	15.0	11.6	10.2	13.2	13.4	13.6	17.9	19.7	174.0
Navarro	PS	183.0	147.6	159.8	179.7	158.9	119.3	99.1	126.8	120.9	116.3	108.6	112.0	161.6	128.9	97.4	102.2	100.7	171.5	101.5	105.4	110.4	112.1	2,823.7
Tarrant	PS	80.0	80.0	80.0	64.0	79.3	65.4	65.4	80.0	90.0	90.0	81.6	81.8	85.7	2.5	3.7	6.2	8.6	6.8	7.7	7.4	7.0	14.3	1,087.4
	Ind	1.2	1.2	1.2	1.8	1.3	1.5	1.2	1.1	1.0	.8	.9	.8	.3	.1	--	.3	167.0	50.3	.3	.3	.3	--	233.1
Totals	PS	7,872.6	8,020.5	7,251.2	7,048.0	7,219.8	6,885.0	6,745.6	7,005.2	7,630.4	7,578.8	7,922.0	8,031.0	7,715.3	7,327.9	8,830.0	7,919.6	8,787.2	9,069.4	7,965.8	8,501.7	8,524.5	8,559.5	172,411.0
	Ind	2,191.0	2,191.0	2,191.0	2,476.5	2,540.7	2,189.1	1,932.5	2,400.7	2,133.1	2,456.7	2,807.1	2,599.2	2,562.8	2,616.8	2,197.8	2,205.6	2,263.2	2,333.4	2,397.8	2,536.1	2,468.9	2,580.6	52,271.6
	PS and Ind	10,063.6	10,211.5	9,442.2	9,524.5	9,760.5	9,074.1	8,678.1	9,405.9	9,763.5	10,035.5	10,729.1	10,630.2	10,278.1	9,944.7	11,027.8	10,125.2	11,050.4	11,402.8	10,363.6	11,037.8	10,993.4	11,140.1	224,682.6

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with the exception of high iron concentrations occurring in the upper Woodbine sands or in improperly completed wells. This iron contamination can be alleviated by insur ng that the well penetrates the entire Woodbine Group, or at least to the middle of the Woodbine, and cementing off the upper member of the group. It is not uncommon for water from wells in the upper part of the Woodbine to contain iron concentrations in excess of 3.0 mg/l. Water from 9 wells contained concentrations greater than 10 mg/l. Water quality deteriorates rapidly downdip from the outcrop with concentrations increasing in sodium, chloride, and bicarbonate. The downdip limit of fresh to slightly saline water (Figure 33) occurs approximately 35 miles (56 km) downdip from the outcrop. Along the outcrop, well water contains an average dissolved-solids content of 550 mg/l, while water from areas farther downdip approach the 2,000 mg/l level. Of the more than 800 analyses tabulated, 325 (40 percent) exceeded 1,000 mg/l, and 90 (11 percent) contained more the 2,000 mg/l dissolved solids. Only 90 samples exceeded 300 mg/l chloride and 263 (32 percent) of the analyses exceeded 300 mg/l sulfate. High nitrate levels are not naturally found in the Woodbine and only a few, shallow dug wells exceeded 45 mg/l. Over 80 percent of the analyses collected had a total hardness as calcium carbonate of less than 60 mg/l, giving the water a general classification as soft. Table 14 shows the range of constituents in ground water from selected wells in the Woodbine Group.

The specific conductance of irrigation waters from the northern Woodbine outcrop ranges from 298 to 1,720 micromhos per cubic centimeter (cm^3) at 25°C (77°F). The five samples containing over 750 micromhos per cm^3 were taken in the Sadler area of Grayson County. Other water samples in this vicinity were between 600 and 750 micromhos per cm^3. The remaining 28 samples showed an average specific conductance of 470 micromhos per cm^3, well below the 750 level.

The diagram for the classification of irrigation waters from the Woodbine (Figure 13) shows that the sodium hazard is low, with an SAR ranging from 0.4 to 7.8. Only two samples fell into the medium catagory while the major ty of samples had an SAR below 2. According to classification by percent sodium, all but five samples were below 60 percent and only three exceeded 75 percent.

Of the 33 samples taken, only 13 were tested for boron. The range was from 0 to 0.4, giving the water in this area an excellent rating for even sensitive crops. RSC was calculated for all samples and a range of 0 to 2.6 was determined. Only four samples had an RSC in excess of 0.9 me/l and of these, three were considered marginal and one not safe. The wells from which these samples were taken are pumped about 4 to 6 weeks per year and the water is generally used to irrigate peanuts and grasses.

Blossom Sand

The Blossom Sand aquifer crops out in central Fannin County and extends eastward through Lamar and Red River Counties. Its thickness can range up to about 400 feet (122 m). In general, ground water from the Blossom is fairly high in dissolved-solids content (120 to 2,030 mg/l) and is soft.

Only four of the eleven municipal wells found in the study area are in operation. The largest ground-water user is the city of Clarksville, Red River County. Yields range from 45 to 500 gal/min (2.8 to 31.5 l/s). Specific capacities average slightly more than 1 (gal/min)/ft, or 0.21 (l/s)/m. Several pumping tests conducted on wells in Clarksville showed an average transmissibility of 3,800 (gal/d)/ft, or 47,200 (l/d)/m, and an average

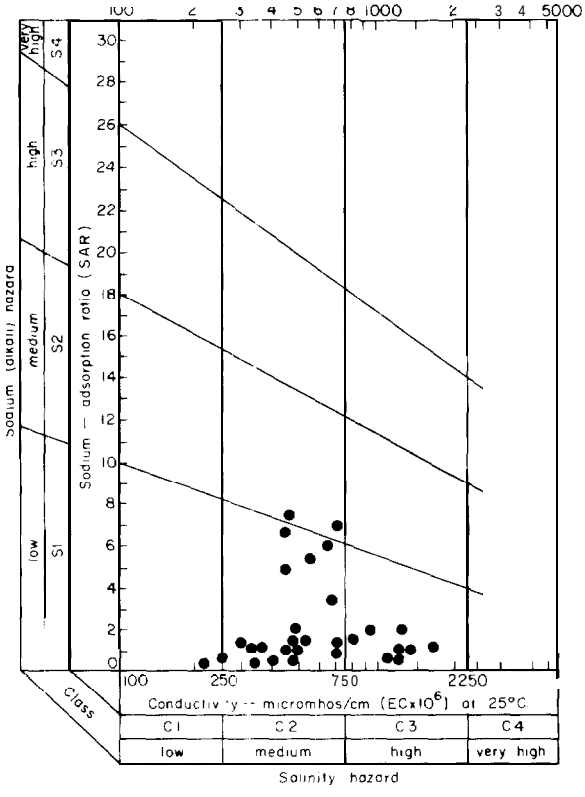

Figure 13.-Diagram for the Classification of Irrigation Waters Showing Quality of Water From Wells Completed in the outcrop of the Woodbine Group (After United States Salinity Laboratory Staff, 1954, p. 80)

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Table 14.--Range of Constituents in Ground Water From Selected Wells in the Woodbine Group

Analyses given are in milligrams per liter except percent sodium, specific conductance, pH, SAR, and RSC.

Single values appear where only one analysis or value was available.

Constituent or property	Collin County	Dallas County	Denton County	Ellis County	Fannin County	Grayson County	Johnson County	Kaufman County	Lamar County	Navarro County	Tarrant County
Silica (SiO_2)	5 - 49	5 - 59	0 - 33	8 - 29	1 - 79	3 - 40	8 - 27	6 - 68	15 - 39	11 - 18	6 - 21
Iron (Fe)	0 - 3.4	0 - 6.5	.1- 21.2	0 - .9	0 - 4.7	0 - 18.0	0 - 7.2	0 - .7	9	.1- 5.8	.4- 13.0
Calcium (Ca)	1 - 52	0 - 105	0 - 269	0 - 14	0 - 34	0 - 230	3 - 405	6 - 28	2 - 34	3 - 11	1 - 194
Magnesium (Mg)	0 - 35	0 - 24	0 - 101	0 - 11	0 - 53	0 - 89	1 - 89	2 - 26	1 - 9	1 - 5	0 - 22
Sodium (Na)	150 -1,370	113 - 930	15 - 790	208 -1,200	151 -1,318	9 -1,070	53 - 447	897 -1,356	20 - 405	570 -1,390	5 - 408
Bicarbonate (HCO_3)	246 -1,130	165 -1,050	77 - 800	370 -1,060	317 -1,150	54 - 850	79 - 580	1,100 -1,210	52 - 590	705 -1,170	40 - 529
Sulfate (SO_4)	37 - 479	44 - 824	17 - 530	16 - 586	30 - 406	3 -1,460	60 - 580	269 - 453	5 - 157	69 - 520	4 - 560
Chloride (Cl)	12 - 640	10 - 610	12 - 492	17 -1,310	13 -1,633	4 - 910	18 - 139	543 -1,210	47 - 155	127 -1,420	7 - 154
Fluoride (F)	.6- 4.0	0 - 5.7	.1- 4.1	0 - 7.9	0 - 4.6	.1- 3.0	.3- 2.0	1.8- 4.7	.1- 1.9	2.1- 6.1	.1- 2.5
Nitrate (NO_3)	0 - 7	0 - 31.0	.2- 294	0 - 50.0	0 - 7.0	0 - 20.0	0 - 56	.4- 14.0	.4- 2.4	.2- 11.0	.4- 44
Boron (B)	--	.1- 4.2	.3	1.5- 4.8	--	0 - 1.7	.7- .8	--	--	5.7	.3
Dissolved solids	377 -2,611	338 -2,430	141 -2,133	429 -3,032	386 -3,256	106 -3,386	367 -1,234	2,563 -3,480	161 -1,038	1,522 -3,494	72 -1,220
Total hardness ($CaCo_3$)	2 - 108	3 - 359	2 - 510	4 - 450	1 - 303	0 - 940	13 - 700	24 - 177	8 - 120	11 - 50	4 - 550
Percent sodium (%)	91.9- 99.3	67.9- 99.7	18.9- 100	42.8- 100	90.4- 99.6	9.9- 99.6	27.8- 98.6	91.7- 99.1	30 - 98.9	98.0- 99.1	9.8- 98.3
pH	7.5- 9.2	6.9- 8.9	6.6- 9.1	7.1- 8.8	7.5- 8.9	6.5- 9.4	6.4- 8.5	8.0- 8.2	6.1- 8.3	7.5- 8.5	6.4- 9.1
Sodium-adsorption ratio (SAR)	13.0- 93.9	5.3- 129.5	.7- 76.6	3.1- 103.6	21.3- 88.4	.3- 101.1	1.8- 51.8	29.3- 109.2	.9- 56.4	58.1- 98.0	.2- 38.5
Residual sodium carbonate (RSC)	3.8- 17.8	1.0- 16.0	0 - 12.6	5.7- 17.0	5.0- 18.4	0 - 13.5	0 - 9.2	17.5- 19.2	0 - 9.5	11 - 18.4	0 - 8.3
Specific conductance (micromhos at 25°C)	609 -4,710	697 -3,549	220 -3,844	895 -3,616	624 -2,760	162 -4,020	551 -1,830	4,860	251 -1,650	2,055 -6,060	139 -1,750

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permeability of 45 (gal/d)/ft^2, or 1,830 (l/d)/m^2. The coefficient of storage was calculated to be 4.5 X10^{-5}.

Public-supply pumpage within the study area was 561 acre-feet (0.692 hm^3); all but 1 acre-foot (0.001 hm^3) was withdrawn by the city of Clarksville. Water levels have declined since development at Clarksville began in 1905 which indicates pumpage exceeds effective recharge (Baker and others, 1963).

Nacatoch Sand

The outcrop of the Nacatoch Sand extends in a northerly direction from Limestone to Hunt County where it trends to the northeast and passes through Red River County into Bowie County. It ranges in thickness from 350 feet (107 m) to 500 feet (152 m). The depth to the top of the aquifer is about 800 feet (244 m) along the southward extent of the fresh to slightly saline water line near the boundary of Red River and Bowie Counties.

Of the 52 public-supply wells and 5 industrial wells located in the study area which were completed in the Nacatoch, 20 are no longer used. Yields measured in municipal and industrial wells ranged from 20 gal/min (1.3 l/s) to 500 gai,'min (31.5 l/s) with an average of 135 gal/min (8.5 I/s). Specific capacities obtained from 15 wells ranged from 0.3 to 9.3 (gal/min)/ft, or 0.06 to 1.9 (l/s)/m. Several pumping tests conducted on Nacatoch wells owned by the city of Commerce (Table 4) showed an average transmissibility of 2,500 (gal/d)/ft, or 31,000 (l/d)/m, and coefficients of permeability ranging from 26 to 53 (gal/d)/ft^2, or 1,060 to 21,200 (l/d)/m^2.

Flowing wells exist in Red River and Bowie Counties. Dissolvea-solids content generally ranges from 100 to 1,700 mg/l. A total of 50 chemical analyses were obtained from inventoried wells and included in this study.

Pumpage has steadily increased over the years and water levels have declined since development began in 1914 (Baker and others, 1963). Municipal and industrial pumpage increased from 687 acre-feet (0.47 hm^3) in 1955 to 1,591 acre-feet (1.96 hm^3) in 1965, and to 2,135 acre-feet (2.63 hm^3) in 1975.

AVAILABILITY OF GROUND WATER

Methods Used to Determine Availability

The procedural steps used to appraise the ground-water availability of the Trinity and Woodbine aquifers were to review pertinent publications and then select an evaluation method or combination of methods to derive the average annual ground-water availability. These methods generally fell into three basic catagories, namely; (I) steady-state flow under the supposition that water levels did not change with time and natural recharge balanced discharge; (2) rate of depletion of ground-water that is recoverable from storage; and (3) circumstances requiring geohydrological judgements or assumptions. In general, only fresh to slightly saline ground water containing less than 3,000 mg/l dissolved solids was evaluated. A discussion of methodologies developed to appraise the ground water available in the study area follows.

Steady-State Flow Methods

Although steady-state flow does not generally happen in nature, the concept that it is approximated in nature is beneficial to the development of analyical methods used to evaluate the available ground water in an aquifer. If so, the discovery by Henri Darcy in 1856 that the rate of water flowing through sand is proportional to the hydraulic gradient is applicable here (Lohman, 1972). This relation is known as Darcy's Law, and Bennett (1976) states that it "relates specific discharge, or discharge per unit area, to the gradient of hydraulic head. It is the fundamental relation governing steady-state flow in porous media." Darcy's Law may be expressed by the equation:

$$q = Q/A = -K\, dh/dl.$$

where q is the specific discharge per unit area, Q/A; Q is the rate of discharge or flow, A is the cross-sectional area through which the discharge or flow passes and is normal to the direction of flow; K is the hydraulic conductivity or permeability of the porous medium; and dh/dl is the head gradient or hydraulic gradient. Values for the parameters of discharge, Q; applicable area, A; permeability, K; and the hydraulic gradient, dh/dl were obtained by the best procedures depending on the form of the available data.

The trough method is a geometric application of Darcy's Law and is used to evaluate the sustainable annual yield or annual effective recharge available from an artesian (confined) aquifer (Klemt and others, 1975, p. 11-12). This steady-state flow method assumes the lowering of water levels to the top of the aquifer downdip from the outcrop to a maximum of 400 feet (112 m) below land surface, but not below the top of the aquifer. The trough axis would be an imaginary line connecting innumerable points of discharge along which the top of the aquifer is approximately the same depth below land surface, roughly parallel to the outcrop of

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the aquifer. The quantity of water that the aquifer will transmit under the hydraulic gradients established between the recharge area and the innumerable points of discharge along an approximate line of discharge, provides an index to the aquifer's maximum effective recharge capability if the water is available as precipitation.

Rate of Depletion of Ground Water That is Recoverable From Storage

The methodology used to determine the depletion rate of recoverable ground-water storage differs for artesian and water-table aquifers. In the case of the Trinity aquifer, the amount of artesian storage proposed for development was determined by constructing a present thickness map of the recoverable artesian storage zone, computing the total volume in the depletion zone, and multiplying it by the storage coefficient. With due consideration given to the transmission capacity of the Trinity aquifer and to pumping lift costs, the lowering of water levels by innumerable discharge points lying in the area between the aquifer outcrop and the downdip limit of fresh to slightly saline water was limited to a maximum level of 100 feet (30 m) above the top of the aquifer (Figure 14). The annual storage depletion rate was calculated by dividing the recoverable storage by 53 years which is the depletable or planning period to the year 2030 (Texas Water Development Board, 1977, Vol. 1, p. 1 l-65). This depletion rate was then added to the annual effective recharge to give the average annual ground-water availability.

Circumstances Requiring Geohydrological Judgements or Assumptions

In order to make a determination of ground-water or assumptions availability utilizing the methodologies just discussed, it was necessary to make certain judgements or assumptions based on unique aquifer attributes. For example, a judgement was made as to whether or not the transmission capacity of the aquifer was compatible to the effective recharge which is based on a percentage of the mean annual precipitation. Judgements or assumptions employed in these methods will become more explicit in the Trinity and Woodbine aquifer discussions which follow.

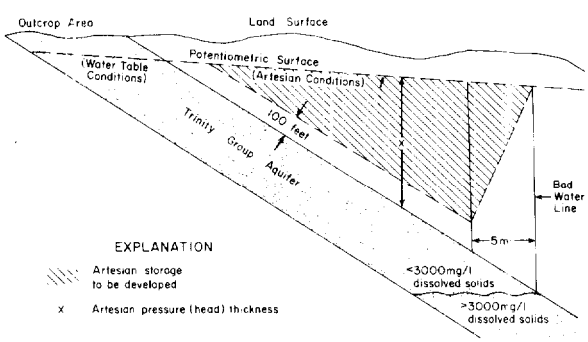

Figure 14.-Diagrammatic Cross Section Through a Confined Aquifer Showing Depletable Artesian Ground-Water Storage

Trinity Group

The ground water available for future development was determined collectively for the Antlers, Paluxy, and Twin Mountains Formations and called the Trinity Group aquifer (Table 1). The annual effective recharge or transmission capacity of the Trinity Group aquifer in the study area was determined using the trough method. The methodology is based on pumpage under assumed conditions and is related mainly to the ability of the aquifer to transmit water to the areas of pumpage. To compute the amount of water available from the Trinity Group aquifer, several assumptions had to be made.

It was assumed that water levels in the outcrop would not decline. An imaginary line of discharge was constructed approximately parallel to the outcrop where the depth to the top of the Trinity Group was 400 feet (122 m) below land surface. The line of discharge was approximately 135 miles (217 km) long, extending from Johnson County west of Cleburne, through Fort Worth in Tarrant County, through Denton County west of Denton, and through Grayson County east of Gainesville. All the recharge was assumed to occur in the middle of the outcrop along a line parallel to the strike. The line of discharge averages 13 miles (21 km) from the assumed line source of recharge. Pumping along the line of discharge will lower water levels to the top of the Trinity Group, which is 400 feet (122 m) below land surface. The hydraulic gradient under which ground water is being transmitted through the aquifer is the difference in the altitude of the water level in the outcrop and the altitude of the top of the Trinity where it is 400 feet (122 m) below land surface divided by the distance between these points of altitude, which is approximately 13 miles (21 km). It was also assumed that recharge along the outcrop will be uniformly transmitted to the line of discharge and that the slope of the piezometric surface will be constant after drawdown to the 400-foot (122 m) level. The average coefficient of transmissibility used for the Trinity Group aquifer was 11,000 (gal/d)/ft or 136,600 (l/d)/m.

Using these assumptions and provided that sufficient water is available as recharge, it was

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determined that approximately 1.5 percent of the average annual precipitation falling on the outcrop, or approximately 51,000 acre-feet (62.9 hm^3), can be transmitted through the Trinity Group aquifer to the line of discharge. This is the computed amount of water that can be pumped annually by wells located downdip from the outcrop in the study area. The 1.5 percent was judged to be acceptable since effective recharge for the Trinity Group in North Texas is probably not greater than 5 percent.

The thickness of artesian storage was determined by using a geologic structure map of the top of the Trinity Group aquifer and the 1977 water-level observation well measurements. The thickness equals the distance between the potentiometric surface and 100 feet (30 m) above the top of the aquifer (Figure 14). The top of the Trinity Group is represented by the Antlers Formation in the northern part of the study area and by the Paluxy Formation south of the Antlers. Contouring of the recoverable artesian storage area was limited as follows: (1) within 5 miles (8 km) of the downdip limit of fresh to slightly saline water; (2) within 5 miles (8 km) of the Texas-Oklahoma border; and (3) where 100 feet (30 m) of artesian head was present above the top of the Trinity Group aquifer. The area of recoverable artesian storage was determined by using a planimeter. The area was multiplied by the thickness of artesian storage and then by the coefficient of storage to give the volume of recoverable storage. A conservative artesian storage coefficient of 1×10^{-4} was used. In January 1977, it was estimated that slightly more than 646,000 acre-feet (797 hm^3) of ground water in the study area could be withdrawn from storage.

The total annual ground-water availability of the Trinity Group aquifer was determined by dividing the volume of recoverable storage by 53 years (January 1, 1977 through December 31, 2029) and adding it to the annual effective recharge. The total annual ground-water availability for the Trinity Group aquifer in the study area to the year 2030 is about 63,000 acre-feet (77.7 hm^3) which consists of 51,000 acre-feet (62.9 hm^3) of annual effective recharge and 12,000 acre-feet (14.8 hm^3) of recoverable storage.

Woodbine Group

In calculating the estimated transmission capacity of the Woodbine aquifer, the following assumptions were made: (a) pumpage would draw water levels down to the top of the aquifer where it is 400 feet below land surface; (b) ground water passes through a vertical section of the aquifer which is 180 miles long and located 5 to 10 miles downdip from the outcrop along a line through Ellis, Dallas, Denton, Collin, Grayson, Fannin, and Lamar Counties; (c) the average transmissibility for the aquifer is 4,700 (gal/d)/ft or 58,365 (l/d)/m.

Based on the above assumption, approximately 24,500 acre-feet (30.2 hm^3) of water can theoretically be transmitted by the Woodbine aquifer in the study area to pumping wells downdip from the outcrop. This amount of water can be pumped annually and is less than 5 percent of the estimated average annual precipitation of 35 inches available to the outcrop area as recharge.

Nacatoch and Blossom Sands

The methodology used to appraise the annual ground-water availability of the Nacatoch and Blossom Sands was a comparison of pumpage and water-level trends.

In regions of heavy pumpage around Clarksville in Red River County and Commerce in Hunt County, water levels have declined steadily. These annual water-level declines are a direct result of pumpage exceeding the effective recharge. After analyzing water-level data presented by Baker and others (1963), it is estimated that the average annual ground-water availability, as effective recharge, within the study area for both of the aquifers is 1,619 acre-feet (2 hm^3). This includes an annual effective recharge for the Nacatoch Sand of 994 acre-feet (1.23 hm^3) and 625 acre-feet (0.771 hm^3) for the Blossom Sand.

WELL CONSTRUCTION

Well construction in the study region is generally based on water requirements and economics. Some of the well designs used to produce ground water from the sand and gravel aquifers in the study area are illustrated on Figure 15.

Within the Trinity Group outcrop area, irrigation wells producing from the Antlers, Paluxy, and Twin Mountains Formations are generally of medium to high capacity (15-470 gal/min) (0.95-30 l/s), cased, and gravel packed. The casing is usually slotted opposite the desired water-bearing unit. Irrigation wells completed in the Woodbine Group are of high capacity (30-900 gal/min) (1.9-57 l/s); however, in some areas of the outcrop, the lower Woodbine is non-(productive, and yields are small (IO-50 gal/min) (0.63-13.2 l/s). Other than the high capacities, completion of wells in the Trinity and Woodbine Groups are similar. The diameter of the well

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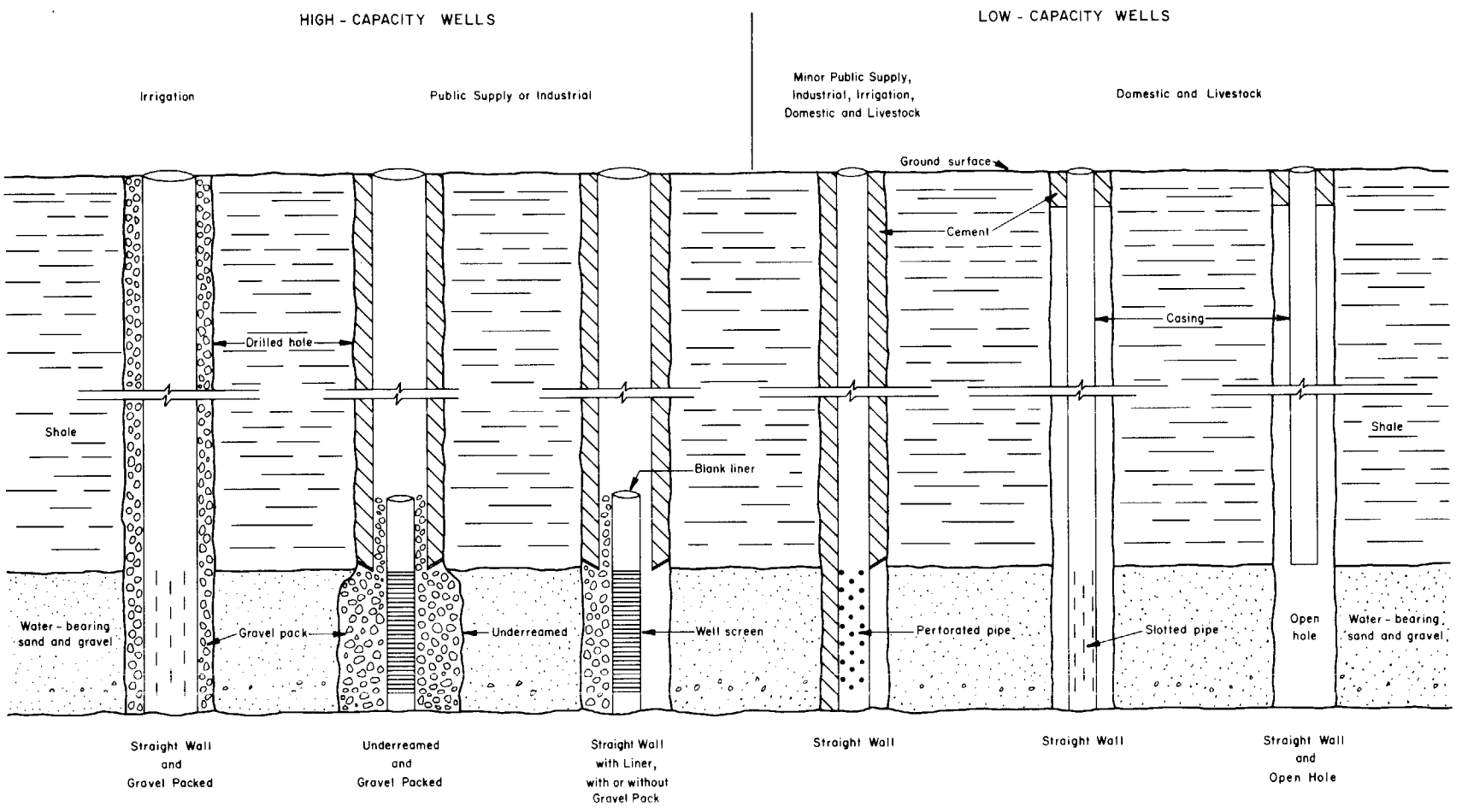

Figure 15

Diagrams of Well Construction

casing varies with the formation and the pumping capacity. In general, the most common size of casing is between 6 and 8 inches (15 and 20 cm). High-capacity Woodbine irrigation wells fall in the 12- to 16-inch (30.5- to 40.6-cm) diameter range. A number of high-capacity Twin Mountains wells in Hood County are 10 inches (25 cm) in diameter.

Generally, public supply and industrial wells are straight walled, cased, and may be cemented from the surface to the top of the desired water-bearing unit. Casing is either slotted or perforated opposite the water-producing interval or selectively screened with intervening blank liner. Large-capacity wells are often underreamed and Gravel packed. Small-capacity wells, in some cases, are cemented from top to bottom and the casing is gun perforated opposite the water-bearing strata. Open-hole completions are rarely found in large-capacity wells in this area. Usually a large diameter casing is used at tne surface and cemented into place to restrict seepage of surface water into the bore hole. Generally, the casing opposite the water-bearing strata ranges from 3 to 12 inches (7.6 to 30 cm) in diameter.

Domestic and livestock wells are generally straight walled, cased from top to bottom, slotted or perforated, and cemented around the top of the casing. In some areas, the wells are gravel packed, and in others, the casing extends only to the top of the producing beds and left as an "open hole" type completion. Casing used in these small-capacity wells generally ranges from 3 to 8 inches (7.6 to 20 cm) in cliameter.

Improperly completed wells can lead to problems such as insufficient yield and poor water quality, which may not only be a problem affecting the well in question, but can also result in contamination of wells in the surrounding area. One of the most common problems occurring in the study region involves water from the Woodbine that is used for domestic purposes. The upper part, and sometimes the middle part, of the Woodbine aquifer contains water that is high in dissolved iron. An iron concentration of more than the recommended upper limit of 0.3 mg/l will stain laundry, utensils, and plumbing fixtures reddish brown and also impart an unpleasant taste. To eliminate this problem, the upper strata, and in some areas the middle strata, of the Woodbine are cemented off and the wells are completed in the lower Woodbine, which contains better quality water. Wells completed in this part also have a higher capacity.

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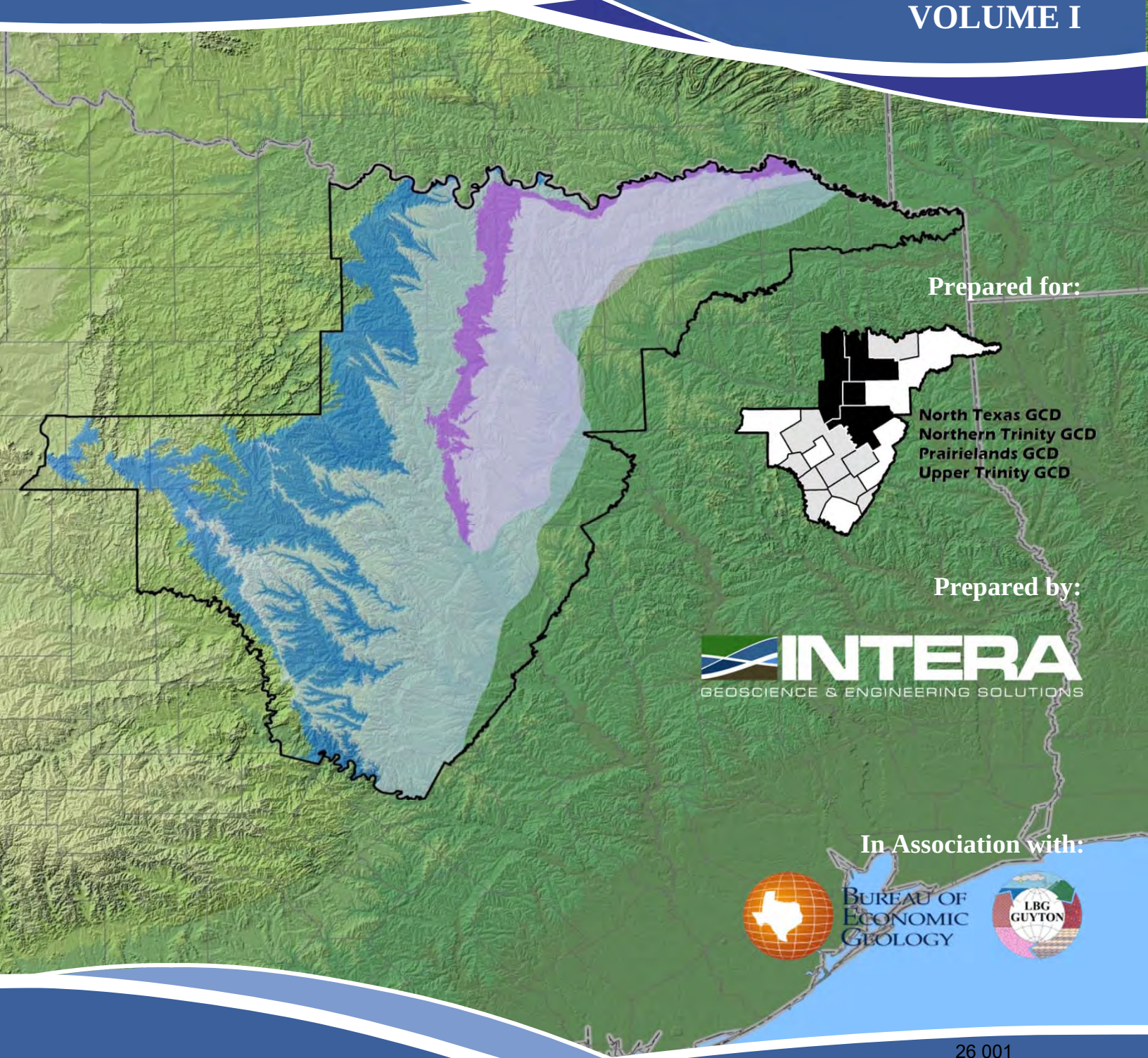
Updated Groundwater Availability Model of the Northern Trinity and Woodbine Aquifers

FINAL MODEL REPORT

VOLUME I



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Prairielands GCD
Upper Trinity GCD

Prepared by:

INTERA
GEOSCIENCE & ENGINEERING SOLUTIONS

In Association with:

Bureau of Economic Geology

LBG Guyton

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AUGUST 2014

FINAL REPORT
Updated Groundwater Availability Model of the Northern Trinity and Woodbine Aquifers

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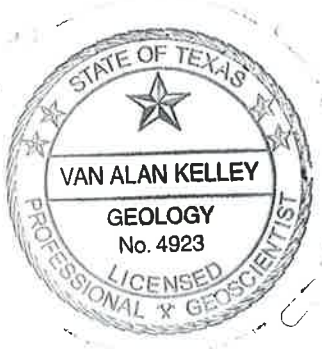

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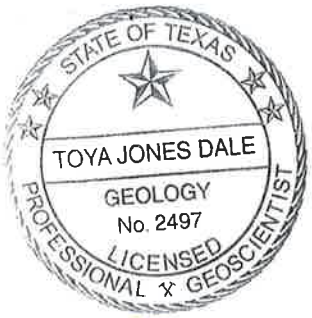

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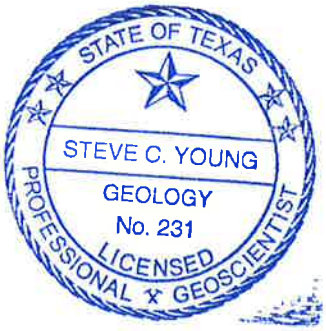

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Executive Summary

This report documents the development of a three-dimensional groundwater model for the northern Trinity and Woodbine aquifers. The model also includes the Washita/Fredericksburg groups as a confining layer separating the northern Trinity Aquifer from the overlying Woodbine Aquifer. The Trinity Aquifer is a major aquifer in Texas [George and others, 2011; Texas Water Development Board (TWDB), 2012] and the northern portion is a major water resource for a large portion of north-central Texas and growing population centers along the Interstate 35 corridor from the Dallas-Fort Worth Metropolitan Area to Austin. The northern Trinity Aquifer generally coincides with the portion of the Trinity Group located north of the Colorado River. The northern Trinity Aquifer outcrops in a broad area in Texas along its western extent from Montague County in the north, as far west as Eastland and Callahan counties, and south to Travis County. North of the Brazos River, the northern Trinity Aquifer is overlain by the Woodbine Aquifer, designated as a minor aquifer in Texas by the TWDB (George and others, 2011; TWDB, 2012). The Woodbine Aquifer is named for the Cretaceous-age Woodbine Group. In Texas, this aquifer generally outcrops in a band parallel to and east of the northern Trinity Aquifer outcrop and is an aquifer from the Texas-Oklahoma border south to northern McLennan County. The eastern extent of the northern Trinity and Woodbine aquifers is defined by the TWDB to be an arc extending from middle of Red River County in northeast Texas through western Kaufman County south to northwestern Bastrop County.

Both the northern Trinity and Woodbine aquifers were deposited in a variety of terrestrial and marine depositional environments. This variety in depositional environments resulted in a complex system of aquifers that can be mapped in the subsurface but have wide variation in lithology from sand and gravel dominated systems to shale and limestone. This large degree of variability has led to a very complex geologic nomenclature. However, persistent stratigraphic layers are physically continuous across the study area while their thickness and dominant lithology may change. This study defines five distinct aquifers/formations within the northern Trinity Aquifer from oldest to youngest; the Hosston Aquifer, the Pearsall Formation, the Hensell Aquifer, the Glen Rose Formation, and the Paluxy Aquifer. The aquifers are comprised of interbedded sands and shales and potable water quality can be found over most of the study

area with the exception of the Paluxy Aquifer. The Paluxy Aquifer only extends as far south as northern McLennan County.

The Washita/Fredericksburg groups are situated between the northern Trinity Aquifer and the Woodbine Aquifer and constitute what is generally considered a confining unit but can produce potable groundwater. The Edwards Balcones Fault Zone (BFZ) Aquifer, designated as a major aquifer (George and others, 2011; TWDB, 2012), is situated within the Washita/Fredericksburg groups in Travis, Williamson, and Bell counties. The Woodbine Aquifer is the youngest aquifer included in this model and is predominantly a sandstone with interbedded shale. The Woodbine Group is an aquifer from the Texas-Oklahoma state line in the north to northernmost McLennan County in the south where it thins and becomes predominantly shale. Potable water quality is found in the Woodbine Aquifer outcrop and in some areas the subcrop. Water quality is variable in the confined portions of the aquifer downdip of the outcrop.

This report documents the updated northern Trinity and Woodbine aquifers groundwater availability model (GAM) which is a redevelopment of the original northern Trinity and Woodbine aquifers GAM developed by Bené and others (2004). This updated northern Trinity and Woodbine aquifers GAM was developed using the groundwater simulation code MODFLOW-NWT. MODFLOW is a three-dimensional finite-difference groundwater flow code that is supported by enhanced boundary condition packages to handle recharge, evapotranspiration (ET), streams, springs, and reservoirs. The updated northern Trinity and Woodbine aquifers GAM is divided into eight model layers. Model Layer 1 represents the shallow surficial flow system in the outcrop areas of the northern Trinity Aquifer, Washita/Fredericksburg groups, and Woodbine Aquifer as well as the younger formations overlying the Woodbine and Washita/Fredericksburg groups east of the Woodbine Aquifer and Washita/Fredericksburg groups outcrops. Model Layers 2 through 8 represent the Woodbine Aquifer, Washita/Fredericksburg groups, Paluxy Aquifer, Glen Rose Formation, Hensell Aquifer, Pearsall Formation, and Hosston Aquifer, respectively. The model grid cells are quarter-mile by quarter-mile squares throughout the model domain, which has 1,412 columns and 1,124 rows for a total of 12,696,704 grid cells for the eight model layers. The model grid origin (lower left-hand corner) is located at GAM coordinates 19,067,743 feet north and

6,169,014 feet east. The model is oriented with the x-axis 65 degrees counter-clockwise of east-west to directly overly the grid for the 2004 northern Trinity and Woodbine aquifers GAM.

The first phase of work in the model development was the development of the conceptual model for the northern Trinity and Woodbine aquifers. A conceptual model is a description of the physical processes governing groundwater flow in an aquifer system. During development of the conceptual model, data was collected and interpreted for all the important hydrogeological features that govern groundwater flow in the aquifers including hydrostratigraphy, hydraulic properties, hydraulic heads, recharge, mechanisms of natural discharge, and pumping and information regarding flowing wells. The data collected, the interpretation of that data, and how the data were used to define the conceptual understanding of the northern Trinity and Woodbine aquifers is discussed in detail in this report. The data are also publically available so that future investigators can build on the data and the interpretation of that data.

The more significant contributions of the analyses performed in support of the aquifers conceptual model are hydrostratigraphy, properties, water quality, and pumping. The northern Trinity and Woodbine aquifers are a complex aquifer system with significant variability in aquifer and formation properties in the study area.

The study used 1,302 geophysical logs to correlate stratigraphic boundaries and interpret lithologies. Stratigraphic unit boundaries were defined in outcrop and traced into the subsurface using advanced modern well log correlation techniques. Lithology was interpreted at the scale of 2 to 3 feet creating a high resolution three-dimensional lithologic data set of the aquifers. Net sand and percent sand maps were developed as well as maps of the dominant depositional environments for each aquifer/formation. This stratigraphic framework provided the basis for developing initial model hydraulic properties.

This study collected, analyzed, and/or reviewed over 1,000 long-term (24 hours or longer) aquifer pumping tests collected from the Texas Commission on Environmental Quality (TCEQ) Public Water Supply well records and literature and over 29,000 specific capacity tests obtained from TCEQ well driller's reports. An assessment of the quality of the hydraulic tests resulted in 450 good aquifer pumping tests and 16,000 good specific capacity tests. Hydraulic conductivity values were estimated using multiple datasets including values available from the literature.

A conceptual geohydrostratigraphic (GHS) model was used for estimating hydraulic properties for the aquifers and formations in the northern Trinity and Woodbine aquifers. The GHS model combined depositional and lithological information interpreted in this study with aquifer pumping test data collected and analyzed to provide a framework for estimating hydraulic properties for each aquifer/formation in the model. The GHS model was used to provide an initial, regional set of aquifer parameters for model calibration and to guide the adjustment of aquifer parameters during model calibration. This approach enabled the use of the larger lithologic dataset to estimate aquifer properties across the model domain.

Several methods were used to estimate recharge including water balance methods, the chloride mass balance method, and stream hydrograph separation analyses. Stream hydrograph separation analysis (sometimes referred to as base flow analysis) was conducted on 36 stream gages and associated watersheds intersecting outcrops of the northern Trinity Aquifer, Washita/Fredericksburg groups, and Woodbine Aquifer. These data were used to develop a recharge model for the northern Trinity and Woodbine aquifers. The recharge rate estimated for the outcrop areas of the northern Trinity and Woodbine aquifers in the study area averaged 1.6 inches per year and ranged from a high of 7.2 inches per year in southwestern Arkansas to a low of 0.25 inches per year in Taylor County, Texas. Because the recharge model is fundamentally based upon precipitation, recharge varies spatially and temporally as a function of climate (precipitation). The recharge model also takes into account the effects of urbanization through the historical period.

This study reviewed the relevant literature discussing water quality of the northern Trinity and Woodbine aquifers and developed maps of total dissolved solids (TDS), chloride, and hydrogeochemical facies to better describe and understand the hydrodynamics of the aquifers. The hydrogeochemical facies analysis suggested that the outcrop areas of the northern Trinity and Woodbine aquifers are an active recharge zone with a strong similarity in groundwater chemistry (calcium-magnesium facies) across aquifers and formations suggesting a well-connected shallow groundwater system. The extent of TDS concentration less than or equal to 1,000 mg/L was mapped for each of the aquifers. It is important to note that the model includes significant portions of the northern Trinity and Woodbine aquifers that would be classified as brackish groundwater (greater than 1,000 mg/L and less than 10,000 mg/L).

Pumping was estimated for the northern Trinity and Woodbine aquifers in Texas from 1890 through 2012. A variety of sources and methods were used to estimate pumping in the period prior to 1980. Because flowing wells were an important source of aquifer discharge prior to the 1930s, a literature review was performed to locate flowing wells and obtain estimates of flow rates where available. After 1980, pumping was estimated using water use survey data from the TWDB and metered data made available by Groundwater Conservation Districts (GCDs) in the study area. Groundwater production increased significantly from the late 1930s through 1980 and is still increasing to date but at a slower rate than that prior to 1980. It is estimated that approximately 260,000 acre-feet of groundwater was pumped from the aquifers/formations in the study area in 2012 (this includes the Edwards BFZ Aquifer).

This updated northern Trinity and Woodbine aquifers GAM was developed using a modeling protocol that is standard to the groundwater modeling industry and has been adopted by the TWDB in their GAM Program. This protocol is based upon industry standards and American Society for Testing and Materials standard guides. The GAM protocol includes: (1) the development of a conceptual model for groundwater flow in the aquifers, including defining physical limits and properties, (2) model design, (3) model calibration, (4) sensitivity analysis, and (5) reporting. The conceptual model is a description of the physical processes governing groundwater flow in the aquifer system. Model design is the process used to translate the conceptual model into a physical model, which in this case is a numerical model of groundwater flow. This involves organizing and distributing model parameters, developing a model grid and model boundary conditions, and determining the model integration time scale. Model calibration is the process of modifying model parameters so that observed field measurements (e.g., water levels in wells) can be reproduced.

The updated GAM for the northern Trinity and Woodbine aquifers was calibrated to predevelopment conditions representing, as closely as possible, conditions in the aquifers prior to significant development and to transient aquifer conditions from predevelopment through 2012. The steady-state model and transient model are combined into the same model to ensure consistent model parameterization between the models and to allow the steady-state hydraulic heads to set the initial transient hydraulic heads. The generally accepted practice for groundwater calibration includes performance of a sensitivity analysis, which was performed as

part of model calibration. Sensitivity analyses were performed on both the steady-state and transient portions of the model to offer insight into the uniqueness of the model and the impact of uncertainty in model parameter estimates.

The steady-state model represents a period of long-term equilibrium between aquifer recharge and aquifer discharge. Simulating steady-state conditions is important in overall model calibration because it ensures that the model of the aquifers is physically plausible in ways a transient model cannot. The transient model calibration period extends predevelopment from 1890 through 2012. An effort was made to include as many water-level observations as possible and to simulate, to the degree possible, the significant regional water-level declines that resulted from initial development and the practice of allowing wells to freely flow and the historical onset of significant groundwater development in the 1940s and 1950s. Relative to the 2004 northern Trinity and Woodbine aquifers GAM, this updated GAM extends the calibration period 90 years prior to 1980 and 12 years past 2000.

Both the steady-state and transient calibrations adequately reproduce aquifer hydraulic heads within their bounds of uncertainty and within engineering best practices and consistent with the standards required in previous TWDB GAMs (TWDB, 2014). Steady-state targets included water-level measurements from 96 well locations in the northern Trinity and Woodbine aquifers. By comparison to the transient model (27,490 water-level targets) there is a distinct lack of water-level data for the steady-state model. To help better constrain the steady-state model, several other metrics were used to guide calibration. These included a comparison to the number and location of flowing wells and the location and extent of the artesian zone as reported in the literature. Particle tracking was performed to qualitatively evaluate whether groundwater age dates were within reason given the observed water quality within the aquifers.

The adjusted mean absolute error (i.e., mean absolute error divided by the range in observed hydraulic heads) is 9.1 percent for the steady-state model, which is within the acceptable GAM standard of 10 percent for the adjusted mean absolute error. The mean error for the steady-state model is 12.0 feet, indicating that the model simulates hydraulic heads slightly higher than the hydraulic head targets. This is considered acceptable because the hydraulic head targets were

expected to be biased low due to reductions in hydraulic heads prior to early water-level measurements.

Out of a total of 420 flowing well locations included in the model, 304 exhibit artesian conditions within the Hensell Aquifer and an additional 47 wells exhibit flowing conditions in the Hosston Aquifer. This qualitative check indicates that the steady-state model is consistent with regard to the artesian conditions observed at the turn of the 20th century. Groundwater age contours were calculated based on particle tracking for 30,000 and 100,000 years in the Hensell and Hosston aquifers and both were qualitatively consistent with the extent of freshwater.

The calibrated average recharge to the northern Trinity and Woodbine aquifers (including the Fredericksburg and Washita groups) totals 1,766,567 acre-feet per year (AFY) which is approximately 4.4 percent of precipitation model wide. Water discharges from the northern Trinity and Woodbine aquifers through ephemeral streams (54.1 percent of net inflow), perennial streams (41.7 percent of net inflow), riparian ET (3.0 percent of net inflow), net upward cross-formational flow to the overlying younger formations (0.8 percent of net inflow), and to springs (0.1 percent of net inflow). It is important to note that only 0.8 percent of the entire water budget gets to the confined downdip aquifers and discharges through diffuse discharge to the overlying younger formations or through the Mexia-Talco Fault Zone. This is a low percent of the predevelopment water balance. However, particle tracking shows that the groundwater velocities downdip are reasonable. Under predevelopment conditions, the northern Trinity and Woodbine aquifers were full and almost all recharge was rejected back to the surface through discharge to surface processes. Development altered this condition as can be seen in the transient model results.

The northern Trinity and Woodbine aquifers transient model simulates the period from 1890 through 2012. Calibration targets included water-level measurements, long-term hydrographs of water levels, which document transient water-level trends over time, and streamflow measurements. There were 27,490 individual water-level measurements used in the calibration period. Wells selected for hydrograph comparisons were chosen from the entire historical period from 1890 to 2012. The many hydrographs that show evidence of drawdown indicate that drawdown began occurring long before 1980, after which the most reliable pumping estimates

are available from the TWDB water use survey data. These early water-level declines motivated the inclusion of pre-1980 water-level measurements in the transient calibration. Transient water-level data with at least five measurements over a period of years were selected as long-tern hydrographs for comparison to model results. This yielded 706 hydrographs. The model streamflows were compared to available base flow estimates.

The transient model performs well at reproducing transient hydraulic heads across the historical calibration period. The model hydraulic head residuals (defined as the simulated hydraulic head minus the observed hydraulic head) show no systematic bias, with a relatively even distribution around zero. The calibration statistics for all layers meet the GAM requirement of a model simulated mean absolute error divided by the range in observed hydraulic heads of less than 10 percent. Typically, GAMs look at calibration statistics for the period from 1980 through the latest date of pumping estimates from the TWDB water use survey data because those data are considered to have the least pumping uncertainty. The mean absolute error from 1980 to 2012 ranges from 38.3 to 56.2 feet across all model layers. The mean absolute error divided by the range in observed hydraulic heads ranges from 1.8 to 5.2 percent for all model layers.

Calibration statistics for the transient period from 1890 through 1949 and from 1950 through 1979 were also calculated. Much fewer calibration targets exist for the pre-1950 time period. The mean absolute error ranges from 28.3 to 74.1 feet for the pre-1950 period and from 34.2 to 64.2 feet for the period between 1950 and 1980. The mean absolute error divided by the range is less than 10 percent in all units, with the exception of the Washita/Fredericksburg groups prior to 1950, when it is 14.5 percent.

Analysis of the transient water budget provides insight into the current conditions within the deep confined portions of the northern Trinity Aquifer. As pumping rapidly increases from 1940 through 1980 in the deeper confined portions of the aquifer downdip of the outcrop, the amount of groundwater flowing to the deep aquifer increases by a factor of four. Early on, a large fraction of deep pumping is supplied by aquifer storage. However, by 1980, capture from the updip portions of the northern Trinity aquifer supplies greater than 60 percent of the groundwater pumped at depth. By 2010, it is estimated that storage contributes less than 15 percent to the groundwater pumped at depth.

The results from this study suggest that this aquifer behavior is the result of the very low vertical conductivities of the northern Trinity and Woodbine aquifers and the low aquifer storage coefficients. The result is that deep pumping quickly depletes available storage with very large water-level declines. At this point, the groundwater must be supplied by capture of water that would normally discharge at ground surface in the outcrop. This is a very inefficient process because it would likely take tens, if not hundreds, of years for the deepest wells to benefit from the discharge capture of the shallower groundwater. The net result is that water levels keep declining even as the rate of groundwater use stabilizes.

The purpose of this model update was to make improvements to the original 2004 GAM by Bené and others (2004), including incorporation of data collected after the 2004 GAM was developed and results from recent studies in the region, and implementation of the model at a scale that better bridges the gap between regional models and a model that can be used at the scale of a typical GCD for pursuit of their groundwater management objectives. This study provides a model that has been calibrated across the entire period of record through 2012, which is a benefit to GCDs, Groundwater Management Area (GMA) 8, and stakeholders. This study provides significant advancement in the hydrogeological framework and understanding of these aquifers. The updated GAM and the information collected and interpreted to support the study provide GCDs with the best available science to inform final rule making, groundwater management within GCD boundaries, and joint planning. The data collected and made public from this study provides a wealth of knowledge to support GCDs in local-scale hydraulic calculations with analytic tool to address such issues as well spacing.

Development of this updated GAM was unique in Texas in that the entire effort was organized and funded by four GCDs in GMA 8. Desiring to make improvements and updates to the 2004 northern Trinity and Woodbine aquifers GAM and to enhance understanding of the aquifers, the North Texas, Northern Trinity, Prairielands, and Upper Trinity GCDs entered into an inter-local agreement in 2012 to support and fund this updated GAM for the northern Trinity and Woodbine aquifers in GMA 8. This work was performed in a public process similar to that used by the TWDB in their GAM Program. A Technical Advisory Committee made up of technical representatives from the GCDs within GMA 8, the TWDB, and the United States Geological

Survey were appointed and utilized throughout development of this updated GAM to ensure, for one, that local hydrological conditions were accurately incorporated into the model.

Through consultation with the Contract Management Committee and the Contract Manager, INTERA was requested to perform three predictive simulations with the updated GAM to support the GMA 8 joint planning process. Those runs are documented in Kelley and Ewing (2014).

2.0 Study Area

The location of the study area, as defined by the active model boundary, for the update of the northern Trinity and Woodbine aquifers GAM is shown in Figure 2.0.1. This area includes a large portion of central and north-central Texas, a narrow band in southeastern Oklahoma, and a small portion of southwestern Arkansas. The outcrop and downdip boundaries of the northern Trinity and Woodbine aquifers in the study area are shown in Figure 2.0.2. In Texas, these boundaries are defined by the Texas Water Development Board (TWDB) (George and others, 2011; TWDB, 2012). The spatial extent of the aquifers has been extended beyond the official TWDB boundaries into Oklahoma and Arkansas based on surface geology and estimated downdip extents. The active model boundary is defined on the west and north as the contact between northern Trinity Group formations and the underlying Paleozoic-age strata, on the south by the Colorado River, and on the east by the approximate center line of the Mexia-Talco Fault Zone. The eastern boundary in Arkansas connects the eastern extent of the northern Trinity Group with the center line of the Mexia-Talco Fault Zone.

In Texas, the northern Trinity Aquifer extends across much of the central and north-central portions of the state (see Figure 2.0.2). The outcrop consists of a north-south trending band from Montague County in the north to Travis County in the south. The outcrop width varies across this band, which exists in parts of 26 counties in Texas, and is widest in the area of Callahan, Eastland, Comanche, Erath, and Somervell counties. The outcrop extends into Oklahoma and Arkansas as a relatively narrow band trending east-west. The downdip portion of the northern Trinity Aquifer lies to the east and south of the outcrop area and exists in 39 counties.

In Texas, the Woodbine Aquifer is located in the north-central portion of the State (Figure 2.0.2). The aquifer outcrops in a north-south trending band from Cooke and Grayson counties in the north to McLennan County in the south and as a narrow, east-west trending band from Grayson County in the west to Red River County in the east. The aquifer outcrops in parts of 11 Texas counties. The downdip portion of the Woodbine Aquifer lies to the east and south of the outcrop area and exists in 13 Texas counties.

Roadways, cities, and towns located in the study area are shown in Figure 2.0.3. The largest urban area in the study area is the Dallas-Fort Worth Metroplex. In general, urban areas lie along the Interstate 35 corridor in Texas from Austin to the Dallas-Fort Worth Metroplex and along U.S. 82 in the northern part of Texas and U.S. 75 from Dallas north to Sherman and Denison, Texas. Figure 2.0.4 shows the locations of rivers and lakes/reservoirs in the study area. Numerous small streams and rivers are located in the study area as well as five major rivers, which, from north to south, are the Red, Sabine, Trinity, Brazos, and Colorado rivers. Numerous large and small lakes/reservoirs are also located in the study area.

Figures 2.0.5 and 2.0.6 show the surface outcrop and downdip subcrop of the Texas major and minor aquifers, respectively, that are present in the study area. In addition to the northern Trinity Aquifer, major aquifers are the northern segment of the Edwards Balcones Fault Zone (BFZ) Aquifer and small portions of the Carrizo Aquifer outcrop and subcrop. In addition to the Woodbine Aquifer, minor aquifers include the entire Blossom Aquifer, the majority of the Nacotoch Aquifer, portions of the Brazos River Alluvium Aquifer, an insignificant portion of the Queen City Aquifer outcrop and subcrop, and small portions of the Marble Falls Aquifer outcrop, Hickory Aquifer subcrop, and Ellenburger-San Saba Aquifer outcrop and subcrop.

Portions of six RWPGs are located in the study area as shown on Figure 2.0.7. They are Region D (North East Texas), Region B, Region C, Brazos G, Region F, and Region K (Lower Colorado). Six GCDs and portions of nine other GCDs are located in the study area. Figure 2.0.8 and Table 2.0.1 provide the locations of and list, respectively, these GCDs. The study area includes most of GMA 8 and small portions of GMAs 6, 11, and 12 (Figure 2.0.9). River authorities in the study area include the Red River Authority, Sulphur River Basin Authority, Sabine River Authority, Trinity River Authority, Brazos River Authority, and Lower Colorado River Authority (Figure 2.0.10). The study area includes portions of six river basins (Figure 2.0.11). These are the Red, Sulphur, Sabine, Trinity, Brazos, and Colorado river basins.

Table 2.0.1 Texas GCDs in the study Area.

GCDs Located in the Study Area	GCDs Located Partially in the Study Area
Clearwater UWCD	Brazos Valley GCD
North Texas GCD	Central Texas GCD
Northern Trinity GCD	Fox Crossing WD
Prairielands GCD	Lost Pines GCD
Red River GCD	Middle Trinity GCD
Southern Trinity GCD	Neches & Trinity Valleys GCD
	Post Oak Savannah GCD
	Saratoga UWCD
	Upper Trinity GCD

UWCD – Underground Water Conservation District

Table 2.0.2 River basins and approximate river length and river basin area in the study area.

River Basin	Approximate River Length (miles)	Approximate River Basin Area (square miles)
Brazos	259	13,860
Colorado	145	1,879
Red	1,010	9,634
Sabine	23	542
Sulphur	56	2,267
Trinity	199	9,455

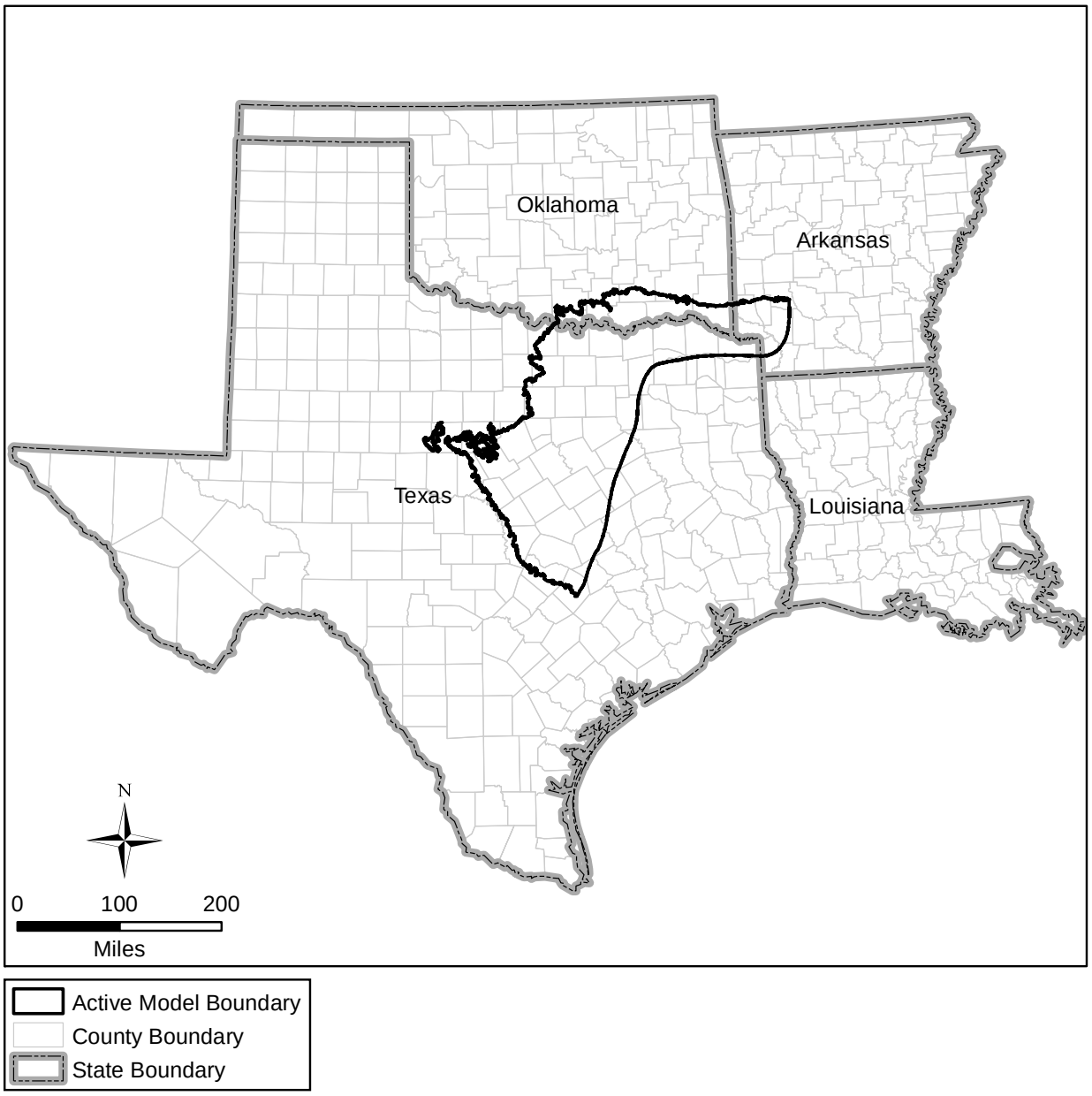


Figure 2.0.1 Study area for the updated northern Trinity and Woodbine aquifers GAM.

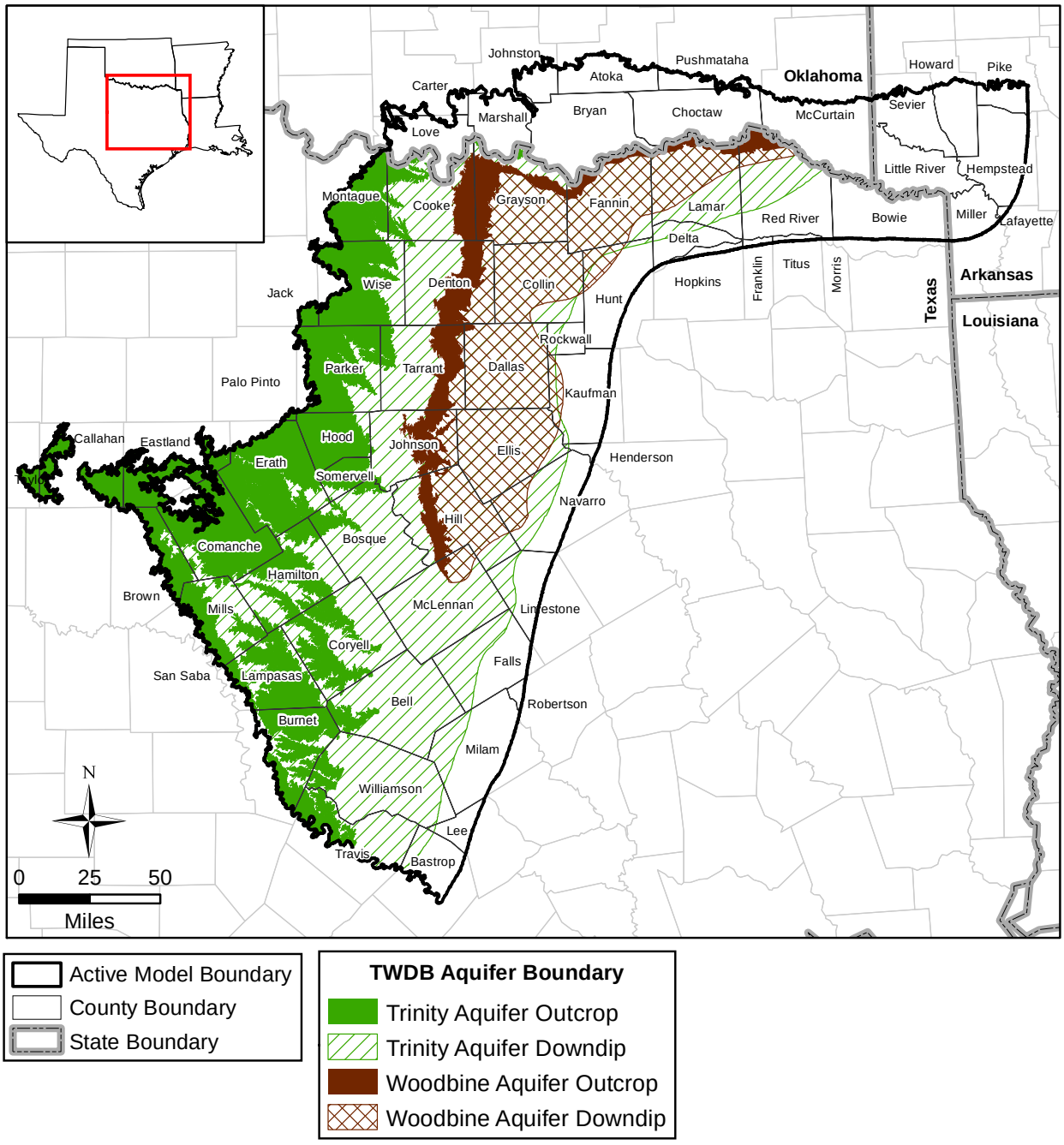


Figure 2.0.2 **Boundaries for the northern Trinity and Woodbine aquifers in the study area as determined by the TWDB in Texas (TWDB, 2006a, b, 2012) and extrapolated into Oklahoma and Arkansas.**

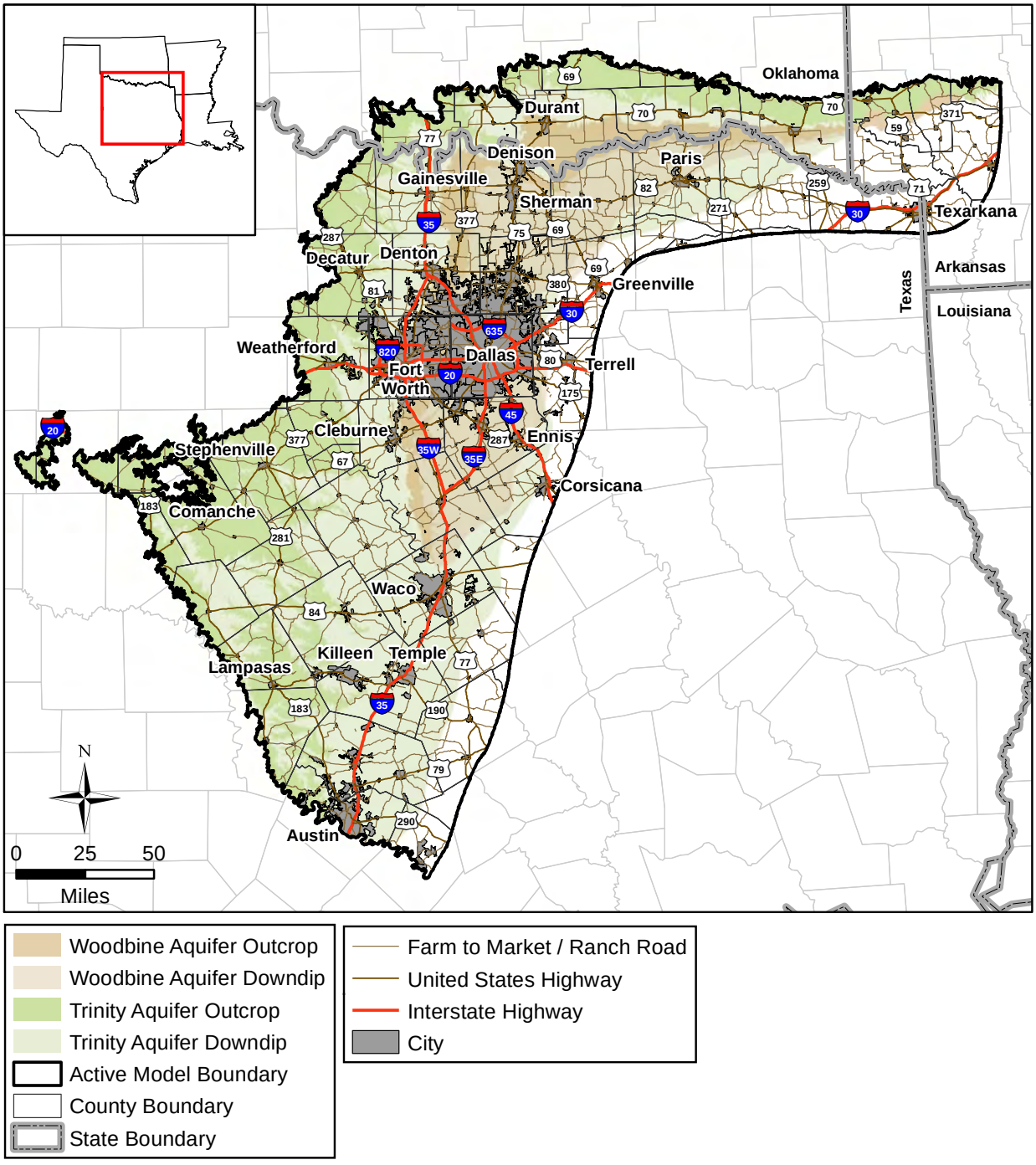


Figure 2.0.3 Cities and major roadways in the study area.

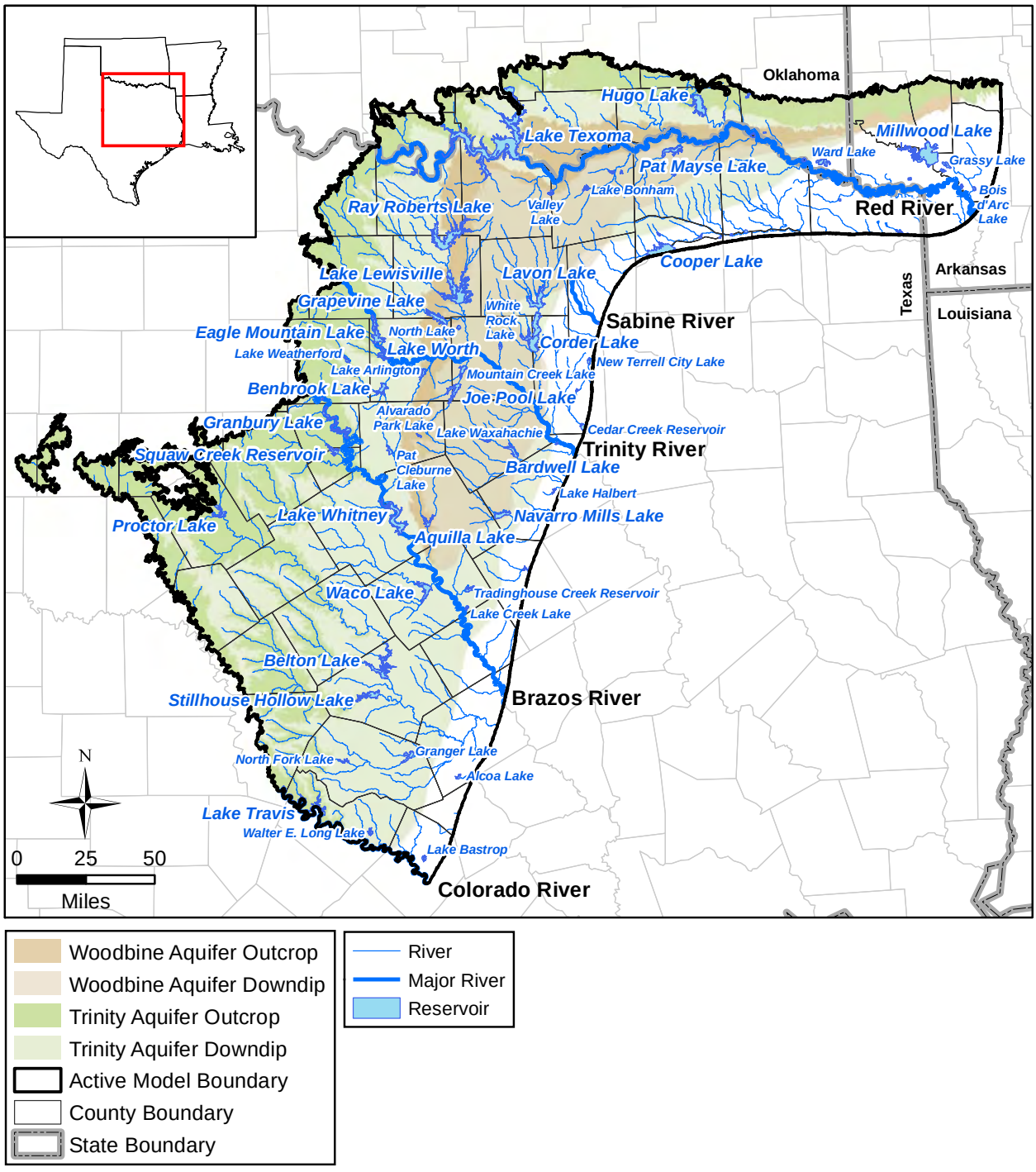


Figure 2.0.4 Rivers, streams, lakes, and reservoirs in the study area.

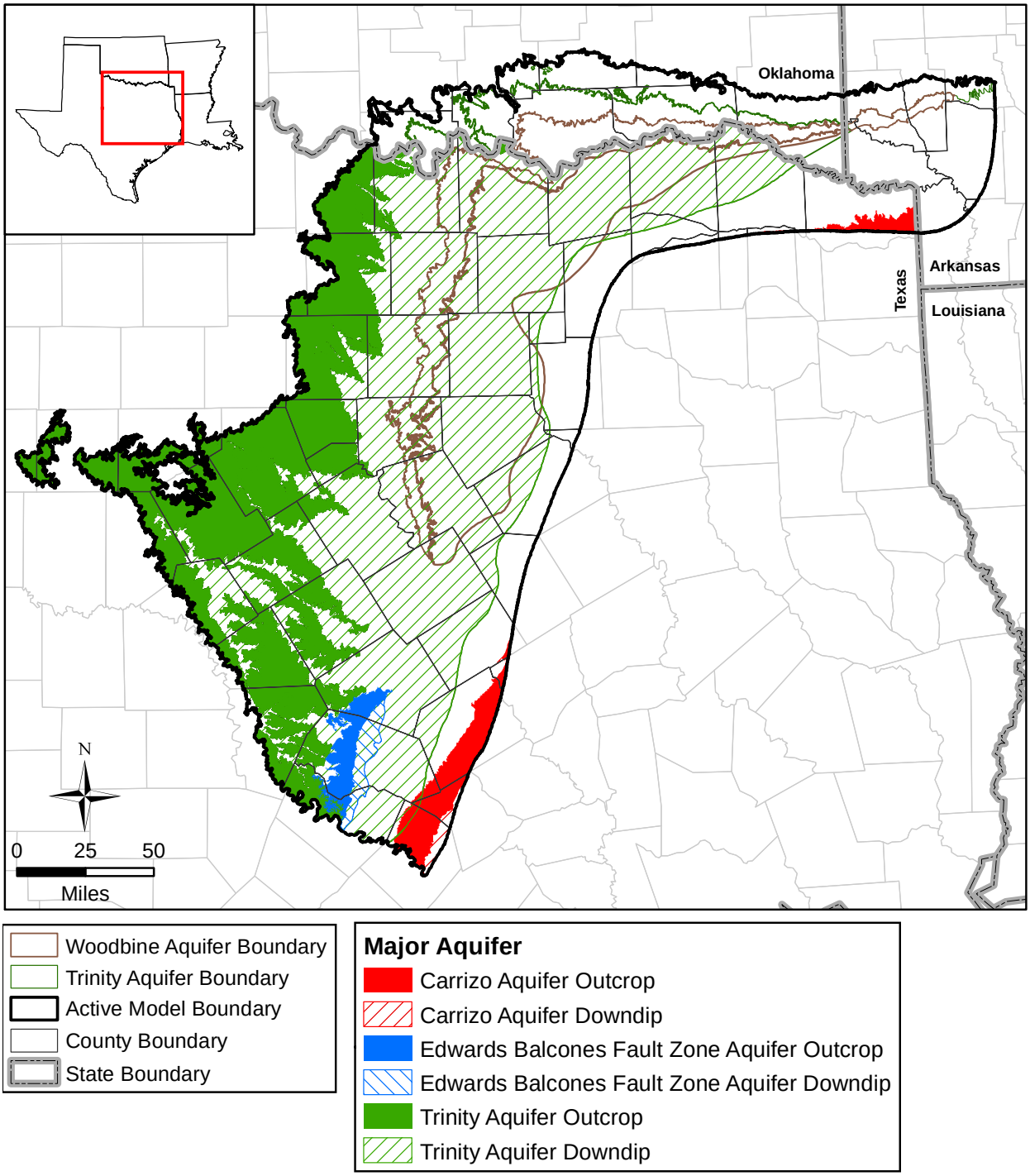


Figure 2.0.5 Major Texas aquifers in the study area (TWDB, 2006a, 2012).

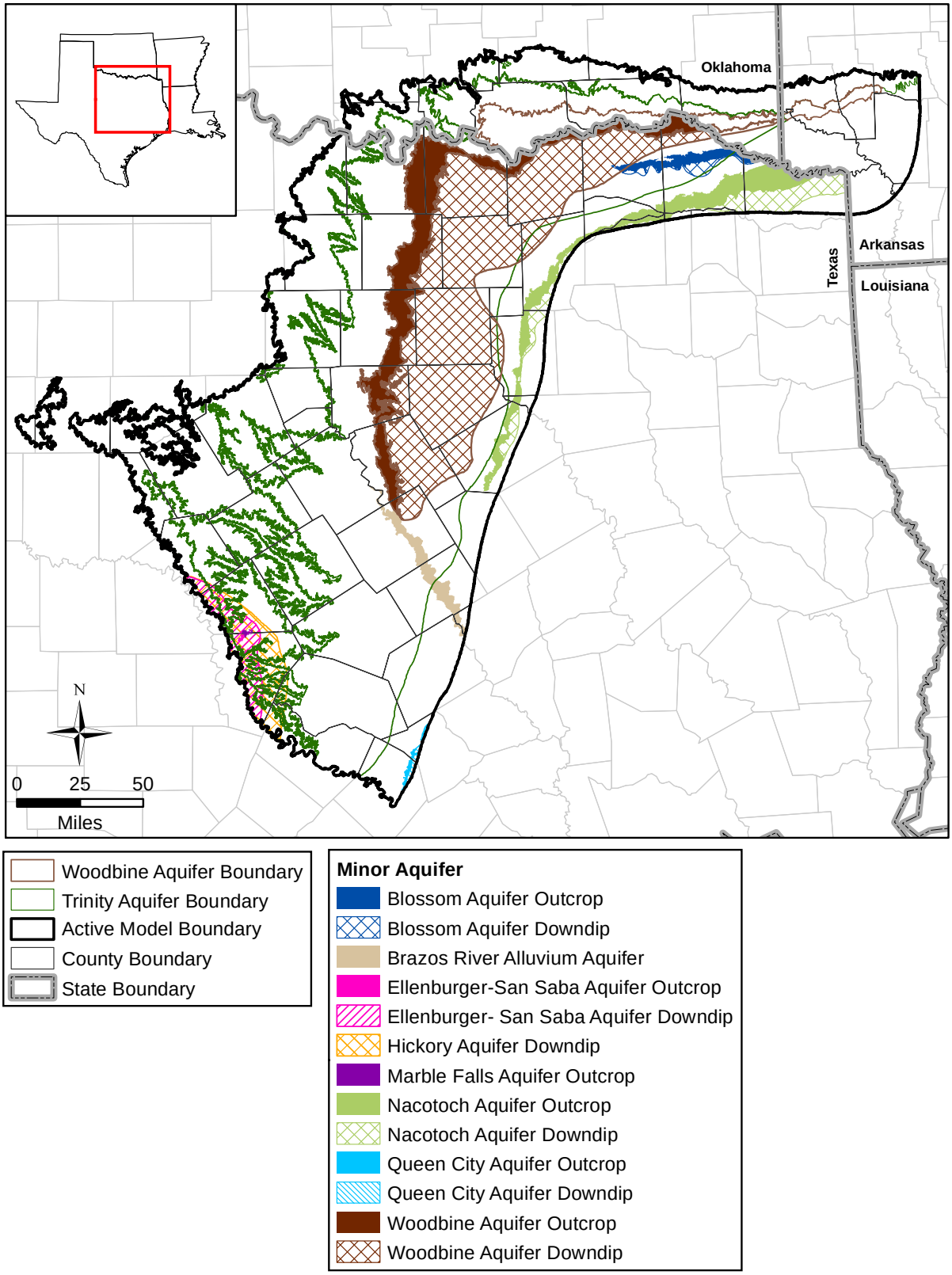


Figure 2.0.6 Minor Texas aquifers in the study area (TWDB, 2006b, 2012).

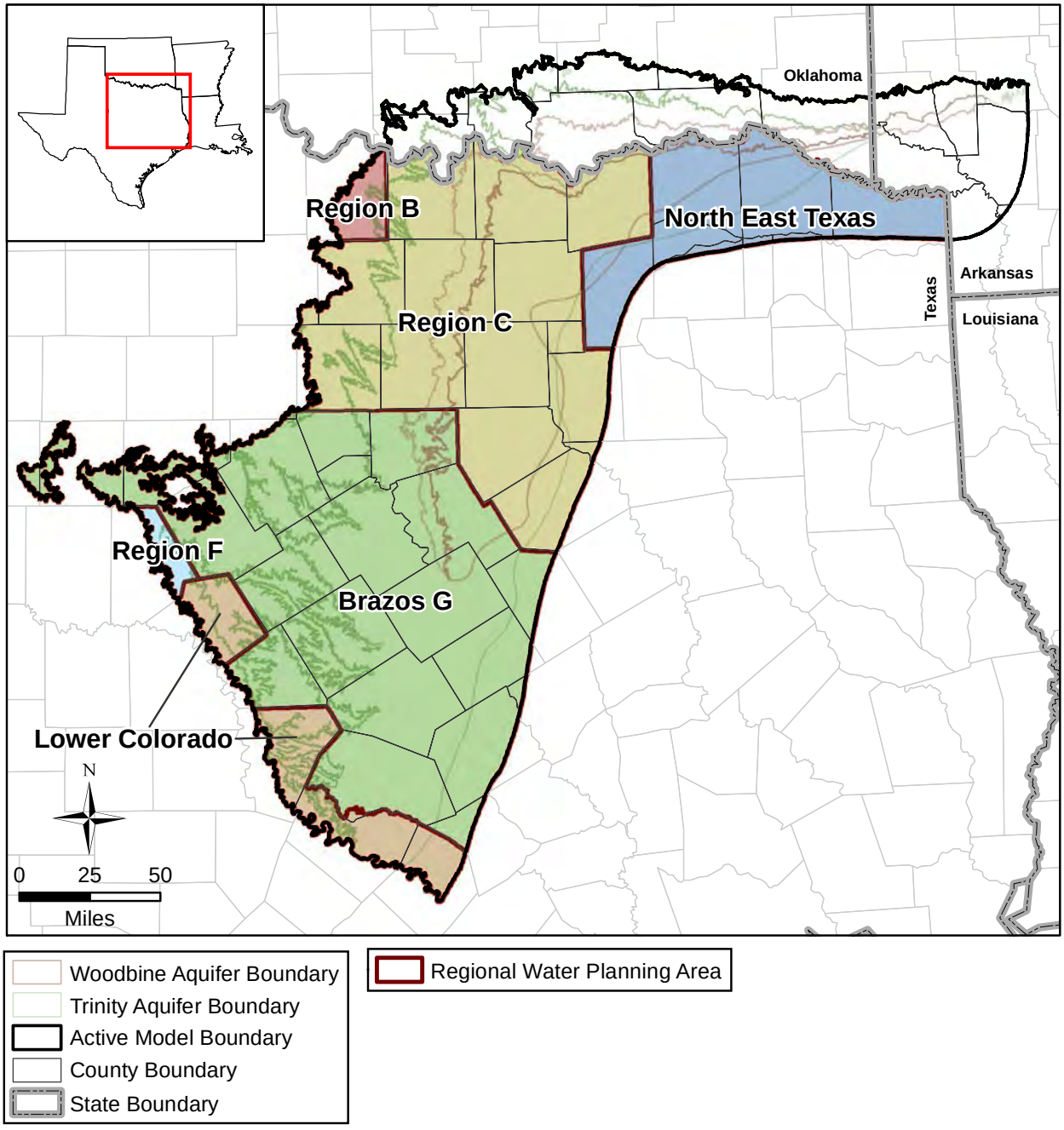


Figure 2.0.7 Texas RWPGs in the study area (TWDB, 2008).

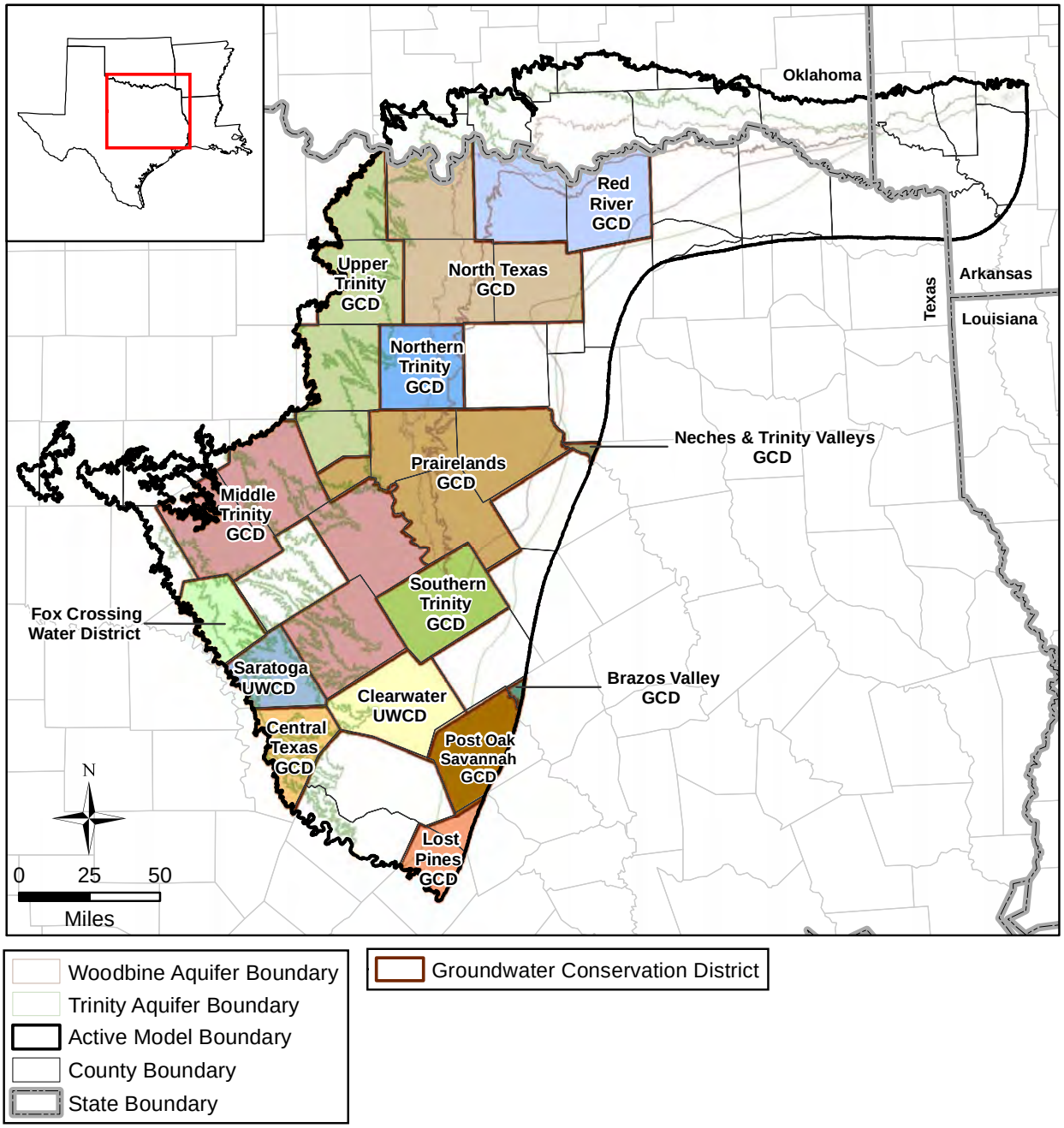


Figure 2.0.8 Texas GCDs in the study area (TWDB, 2010a).

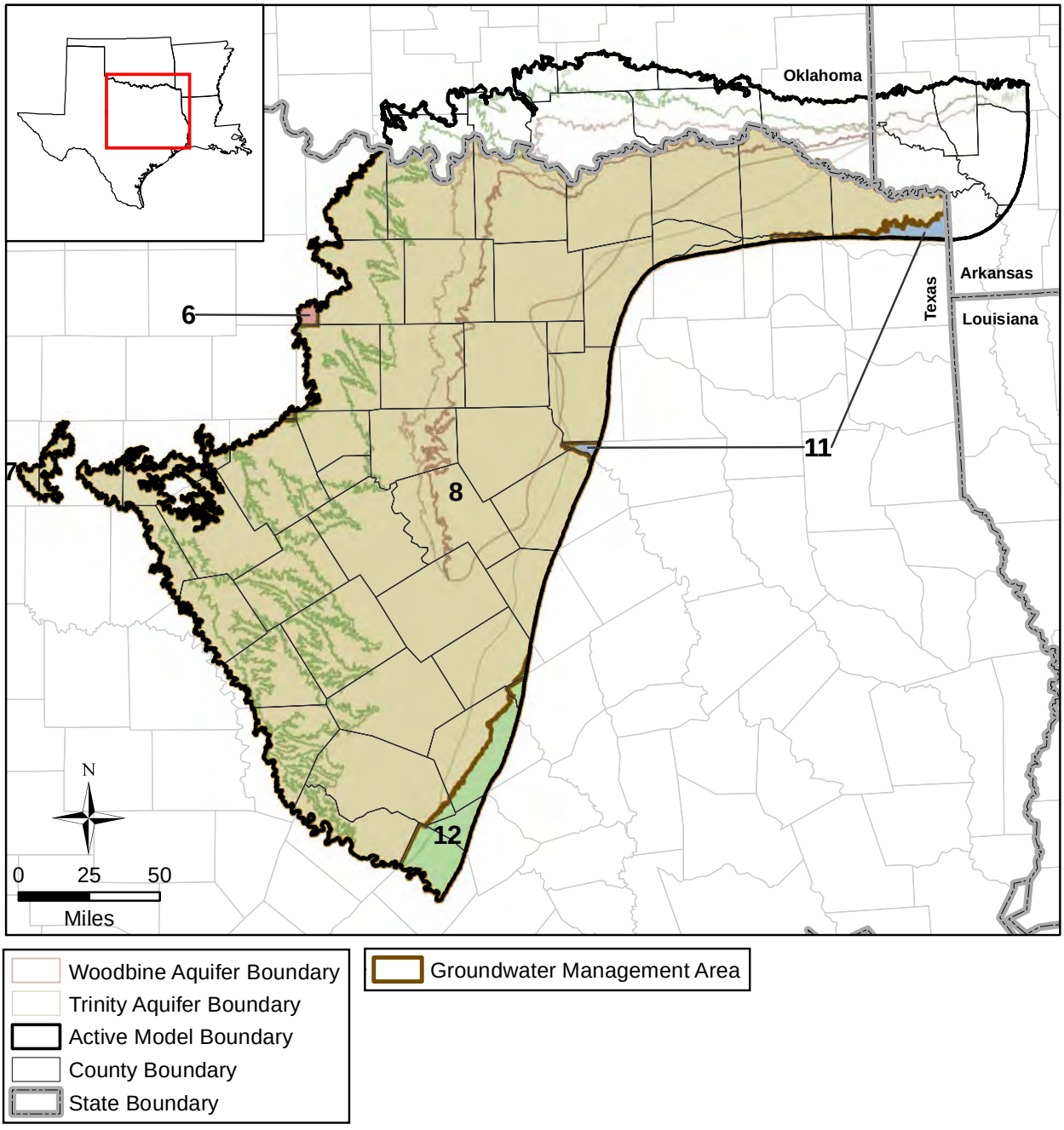


Figure 2.0.9 Texas GMAs in the study area (TWDB, 2007b).

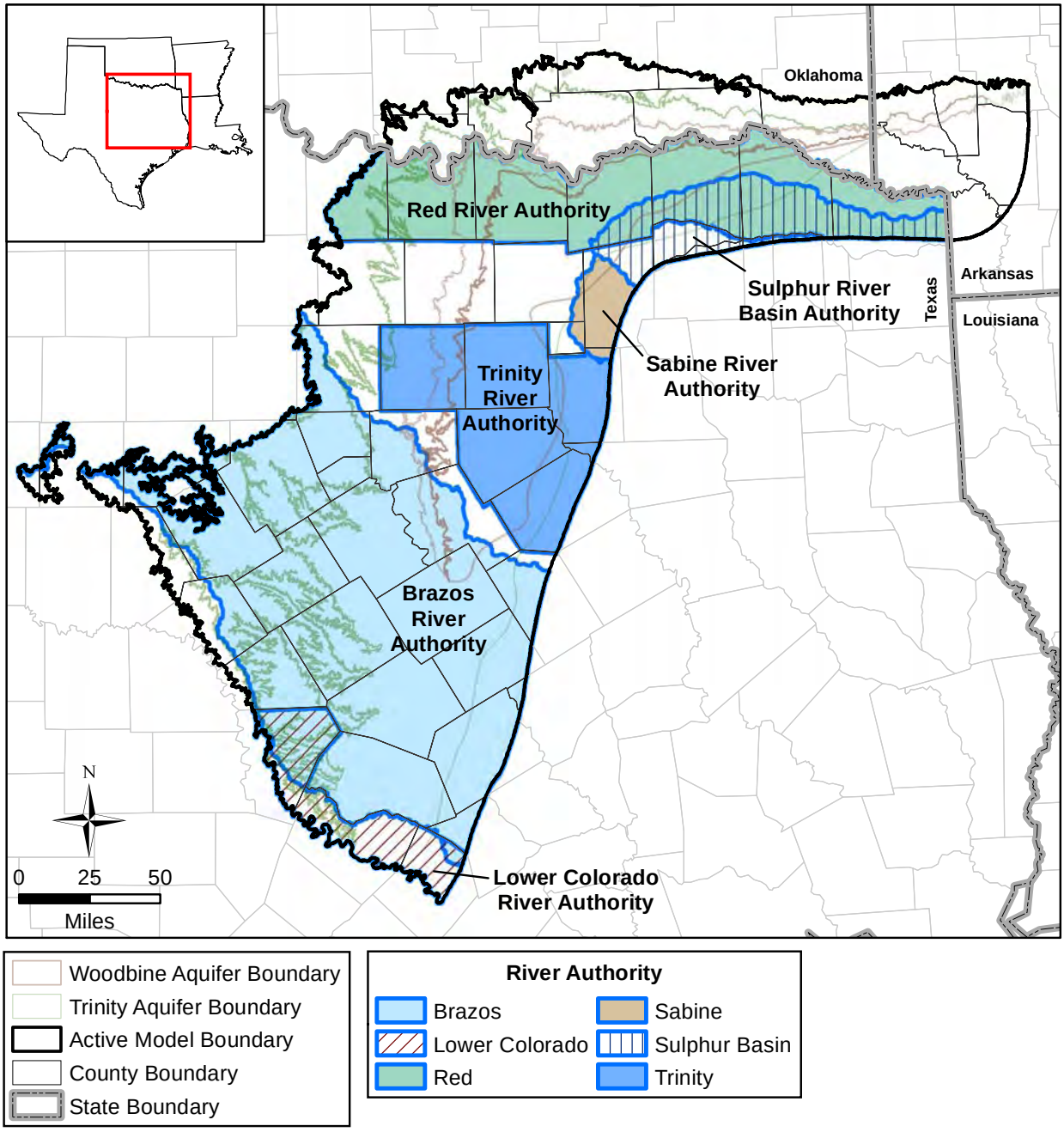


Figure 2.0.10 Texas river authorities in the study area (TWDB, 1999).

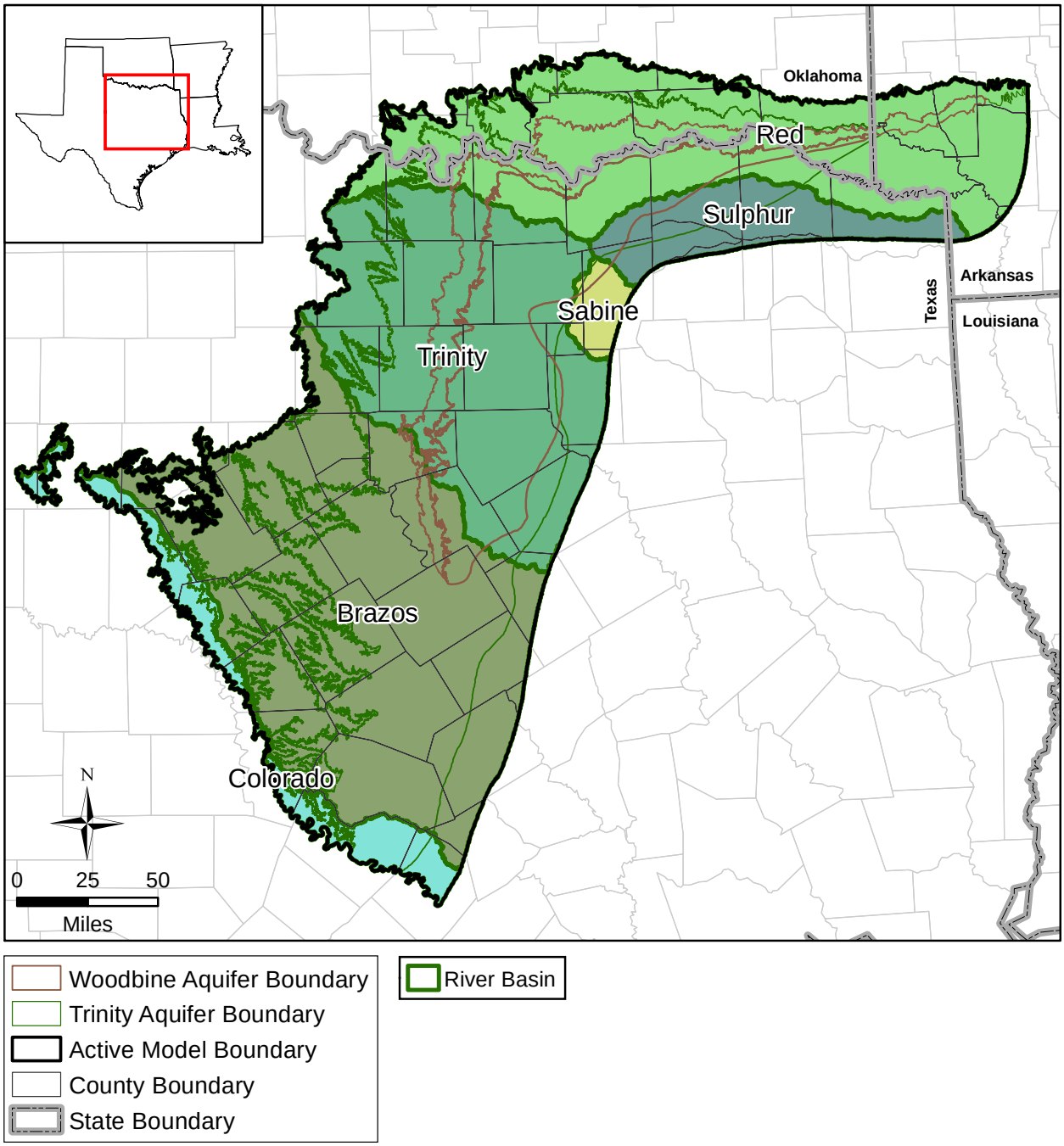


Figure 2.0.11 Major river basins in the study area (TWDB, 2010b; Oklahoma Water Resources Board, 2013; U.S. Department of Agriculture, 2013).

2.2 Geology

The rocks and sediments that comprise the northern Trinity and Woodbine aquifers are contained in the northern Trinity and Woodbine groups deposited during the geologic time period known as the Cretaceous Period, which lasted from about 145 to 65 million years ago. Cretaceous-age strata are exposed at the surface across broad areas of Texas. The geologic units that make up the northern Trinity and Woodbine groups extend from the Colorado River near Austin north to southern Oklahoma and into far southwestern Arkansas. Cretaceous-age stratigraphic units in north and central Texas lie on the northwestern margin of the Gulf of Mexico Basin. Through geologic time, the Gulf of Mexico Basin has progressively filled from the margins toward the center until achieving the shoreline configuration that exists today. Cretaceous-age strata are the oldest part of the Gulf of Mexico Basin fill that is still exposed at the surface.

The Cretaceous-age sediments were unconformably deposited on an erosional surface of Paleozoic-age strata of predominantly Permian and Pennsylvanian age and dip and thicken towards the East Texas Basin to the east. This indicates that the basin was subsiding during the Cretaceous Period while the sediments were being deposited. The sediments deposited during the Cretaceous Period are subdivided, from oldest to youngest, into the Trinity, Fredericksburg, Washita, Woodbine, Eagle Ford, Austin, Taylor, and Navarro groups (Hill, 1901) (Table 2.2.1). For the aquifers considered in the current study, only the Trinity through Woodbine groups are of interest. As discussed in Section 4.1, the sediments of the northern Trinity and Woodbine groups were deposited in a variety of terrestrial and marine depositional environments including coastal plain fluvial and interfluve, deltaic shoreline, and marine shelf environments. This complexity in depositional environments resulted in a complex system of formations that can be mapped in the subsurface but have a wide variation in lithology from sand and gravel dominated systems to shale and off shore limestone units. This large degree of variability has led to a very complex geologic nomenclature (see Table 2.2.1).

As previously noted, the Cretaceous-age strata were deposited unconformably on Paleozoic-age strata, which were deposited on the eastern shelf of the Permian Basin. The Paleozoic-age sediments underlying the northern Trinity Group are comprised, from oldest to youngest, of the Strawn, Canyon, Cisco, Bowie, and Wichita groups. The Strawn Group is primarily a fluvial-

deltaic system comprised of several sandstone units inter-layered with shales. The Canyon Group is a fluvial-deltaic system composed of sandstones and shales, but which also has limestones reflecting a lower energy depositional environment. The Cisco Group is composed of fluvial-deltaic and marine deposits. The Cisco Group contains many intermittent sandstone units that are poorly mapped and extensive limestone units (Brown and others, 1990). The Bowie Group represents a continental depositional facies and is typically composed of more coarse grained sediments than the underlying Cisco Group. The Wichita Group is also a continental deposit and is composed of highly heterogeneous deposits of sand, gravel, and shale. The Paleozoic-age strata generally dip in a westerly direction, while the northern Trinity Group dips to the east-southeast.

The nomenclature of the formations in the northern Trinity Group varies across the study area as shown in Table 2.2.1. In the northern and western portions of the study area, the northern Trinity Group consists of the undifferentiated sediments of the Antlers Formation. Nordstrom (1982, 1987) describes the Antlers Formation as consisting of an upper sand and sandstone with some clay lenses; a middle section composed of sandy clay with sandstone, siltstone, and clayey sand streaks; and a lower section of conglomerate, gravel, sand, and sandstone, with some clay lenses.

In the central and southern portions of the study area, the northern Trinity Group is divided into three formations: the uppermost Paluxy Formation and a middle Glen Rose Formation in both portions and lower Twin Mountains and Travis Peak formations in the central and southern portions, respectively (see Table 2.2.2). Fisher and Rodda (1966) make a distinction between the differences in the facies in the portion of the northern Trinity Group located below the Glen Rose Formation. They describe a more clastic facies in the central portion of the study area (the Twin Mountains Formation) and a more carbonate facies in the southern portion of the study area (the Travis Peak Formation).

The Travis Peak Formation consists of three units. The lowermost unit is the Hosston/Sligo Member. These two members of the Travis Peak Formation were deposited generally at the same time but the Sligo Member consists of finer grained sediments that were deposited in an off shore or marine environment generally in the eastern portions of the study area near the Mexia-Talco Fault Zone. The Hosston Member is a bedded sandstone with high sand percentages

(greater than 60 percent) across its extent. The entirety of the Hosston Member in the study area was deposited in a fluvial coastal plain depositional environment. In the west, this lower unit is named the Sycamore Member and "is a conglomerate consisting of limestone and dolomite pebbles with a calcareous cement" (Klemt and others, 1975).

The middle unit of the Travis Peak Formation consists of the Pearsall/Cow Creek/Hammett Members. These members are carbonate and clay rich sediments deposited primarily in a marine shelf environment and composed of limestone and shale in the southern part of the study area transitioning to deltaic and coastal plain sediments to the north. The Cow Creek Member (predominately limestone) and Hammett Member (predominately shale) occur to the east. The limestones of the Cow Creek Member thin and gradually pinch out to the west. Where this occurs, shale in the Cow Creek Member and the shale of the Hammett Member coalesce to form the Pearsall Member (Klemt and others, 1975).

The Pearsall Member is overlain by the Hensell Member of the Travis Peak Formation, which Hill (1901) identified as the uppermost sand of the Travis Peak Formation. Like the Hosston Member, the Hensell Member is predominantly a sandstone unit with nearly its entire extent being composed of at least 50 percent sandstone or greater. Bené and others (2004) point out that the Hensell Member differs from other Cretaceous-age sandstone units in the northern Trinity Group in that it does not thicken toward the East Texas Basin. The Hensell Member was deposited primarily in coastal plain and deltaic environments with lower energy marine shelf depositional environments in the far east of the study area near the Mexia-Talco Fault Zone.

In the central portion of the study area, the Travis Peak Formation is called the Twin Mountains Formation based on the nomenclature change recommended by Fisher and Rodda (1966). The Hosston, Pearsall, and Hensell members of the Travis Peak Formation tend to become more dominantly sand to the north and comprise the members of the Twin Mountains Formation.

The Glen Rose Formation is a limestone unit that conformably overlies the Twin Mountain and Travis Peak formations and was deposited on an extensive shallow-marine shelf. The formation is composed of dense, finely crystalline limestone with inter-bedded shale, sandy-shale and anhydrite.

The Paluxy Formation, composed of upper sands in the northern Trinity Group, was deposited in a coastal plain environment in the northeast and western portions of the study area and transitions in central Texas to a deltaic shoreline depositional environment and to a marine shelf environment in the southern study area. As a result, the thickest net sand is found in the northeast and northern portions of the formation and essentially no sand is found in the southernmost portion of the formation. Where the Paluxy Formation is predominantly a sand unit, it is characterized as being composed of fine-grained, friable quartz sand, which is poorly cemented and exhibits cross bedding (Klemt and others, 1975).

The northern Trinity Group is overlain by the Fredericksburg and Washita groups (see Table 2.1.1 and Figure 2.2.3). The nomenclature of these two groups is complex. In general, they are composed of limestone, dolomite, marl, and shale (Leggat, 1957). The Fredericksburg and Washita groups comprise a significant percentage of the land surface (outcrop) in the central and southern portion of the study area (see Figure 2.2.2) and separate the northern Trinity and Woodbine groups.

The Woodbine Group was deposited in late Cretaceous time. Both a sand facies and a shale facies are found in the Woodbine Group. The sand facies occurs in the outcrop and in the subsurface in and north of Hill County. The shale facies occurs in the subsurface south of Hill County. In general, the sand facies of the Woodbine Group consists of sand and sandstone with some interbedded shale and clay. Typically, the lower portion of the Woodbine Group contains less clay and shale than the upper portion of the group. The sand facies of the Woodbine Groups was deposited in a deltaic shoreline depositional environment. This portion of the group is composed of two members; the lower Dexter Member and the upper Lewisville Member. The shale facies of the Woodbine Group is referred to as the Pepper Shale. The Woodbine Group is unconformably overlain by shale of the Eagle Ford Group.

Figures 2.2.1 and 2.2.2 show the generalized surface geology for the northern and southern portions of the study area, respectively. The relationship between the terminology used on these figures and the stratigraphic column is provided in Table 2.2.1. Figure 2.2.3 shows structural cross sections of the stratigraphic units in north and central Texas (George and others, 2011;

Bené and others, 2004; Nordstrom, 1982; Klemt and others, 1975). On this figure, the unit identified as “Younger formations” corresponds to Tertiary- and Quaternary-age sediments.

Table 2.2.1 Stratigraphic column for the study area.

Period	Group	North and West	Central		South		Terminology for Generalized Surface Geology in Figures 2.2.1 and 2.2.2
		Formation	Formation	Member	Formation	Member	
Quaternary	differentiation not necessary for this study						Alluvium
Tertiary	differentiation not necessary for this study						Tertiary System
Cretaceous	Navarro	differentiation not necessary for this study					Cretaceous above the Woodbine Group
	Taylor	differentiation not necessary for this study					
	Austin	differentiation not necessary for this study					
	Eagle Ford	differentiation not necessary for this study					
	Woodbine	Lewisville	Lewisville		Pepper Shale		Woodbine Group
		Dexter	Dexter				
	Washita	Grayson Marl	Buda, Del Rio		Buda, Del Rio		Washita Group
		Mainstreet, Pawpaw, Weno, Denton	Georgetown		Georgetown		
		Fort Worth, Duck Creek					
	Fredericksburg	Kiamichi	Kiamichi		Kiamichi		Fredericksburg Group
		Goodland	Edwards		Edwards		
			Comanche Peak		Comanche Peak		
		Walnut Clay	Walnut Clay		Walnut Clay		

Table 2.2.1, continued

Period	Group	North and West	Central		South		Terminology for Generalized Surface Geology in Figures 2.2.1 and 2.2.2
		Formation	Formation	Member	Formation	Member	
Cretaceous (continued)	Trinity	Antlers	Paluxy		Paluxy		Antlers Formation (north and west) or Paluxy Formation (central and south)
			Glen Rose		Glen Rose		Antler Formation (north and west) or Glen Rose Formation (central and south)
			Twin Mountains	Hensell	Travis Peak	Hensell	Antlers Formation (north and west) or Hensell Member (south)
				Pearsall		Pearsall/ Hammett/ Cow Creek	Antlers Formation (north and west), Twin Mountains Formation (central), Travis Peak Formation (south), or Cow Creek Member (south)
				Hosston		Sycamore /Hosston/ Sligo	Antlers Formation (north and west), Twin Mountains Formation (central), Travis Peak Formation (south), or Sycamore Member (south)
Permian	Wichita	differentiation not necessary for this study					na
	Bowie	differentiation not necessary for this study					
Pennsylvanian	Cisco	differentiation not necessary for this study					
	Canyon	differentiation not necessary for this study					
	Strawn	differentiation not necessary for this study					

na - Permian- and Pennsylvanian-age groups do not outcrop in the study area

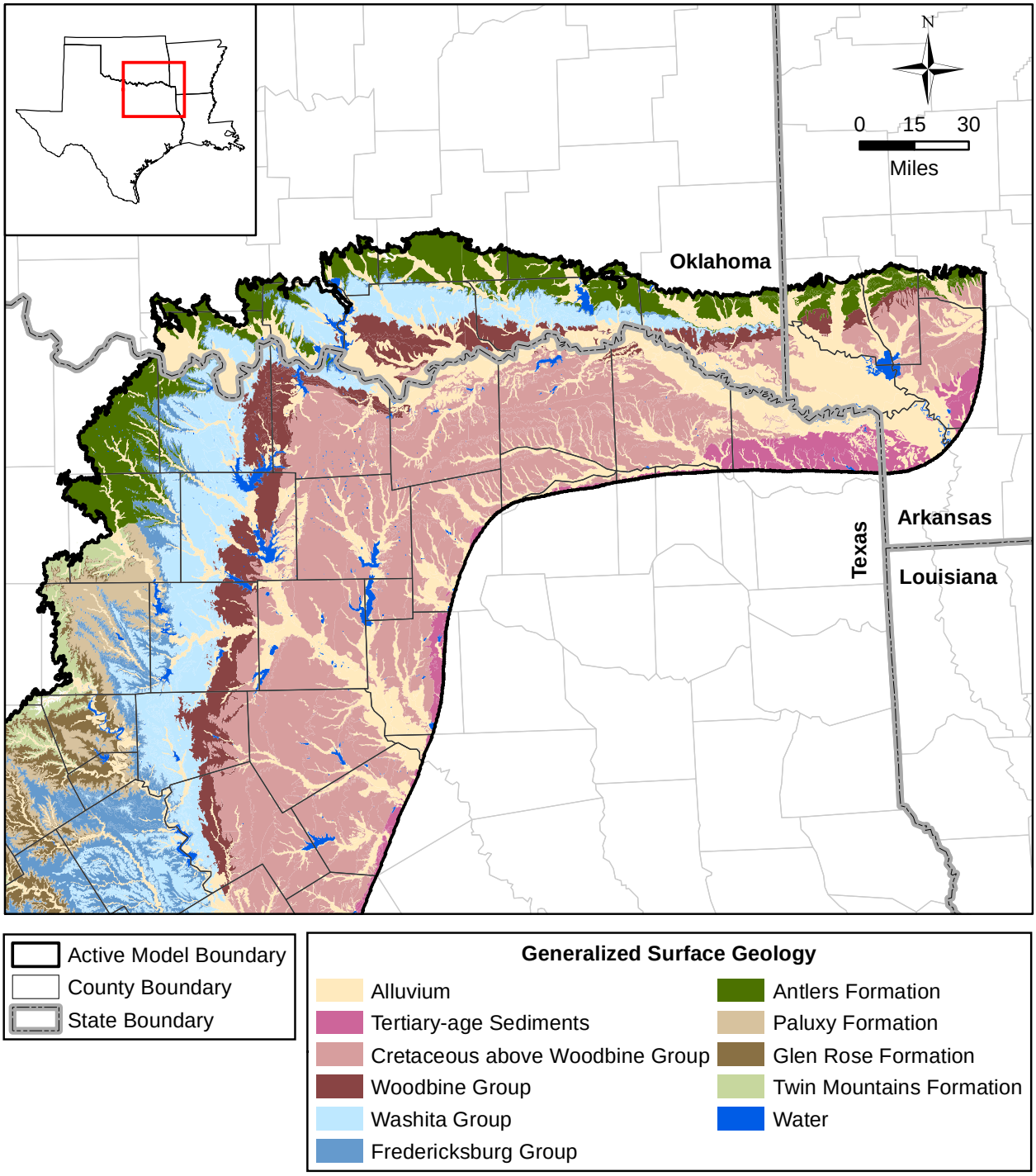


Figure 2.2.1 Generalized surface geology for the northern portion of the study area (Bureau of Economic Geology, 2012).

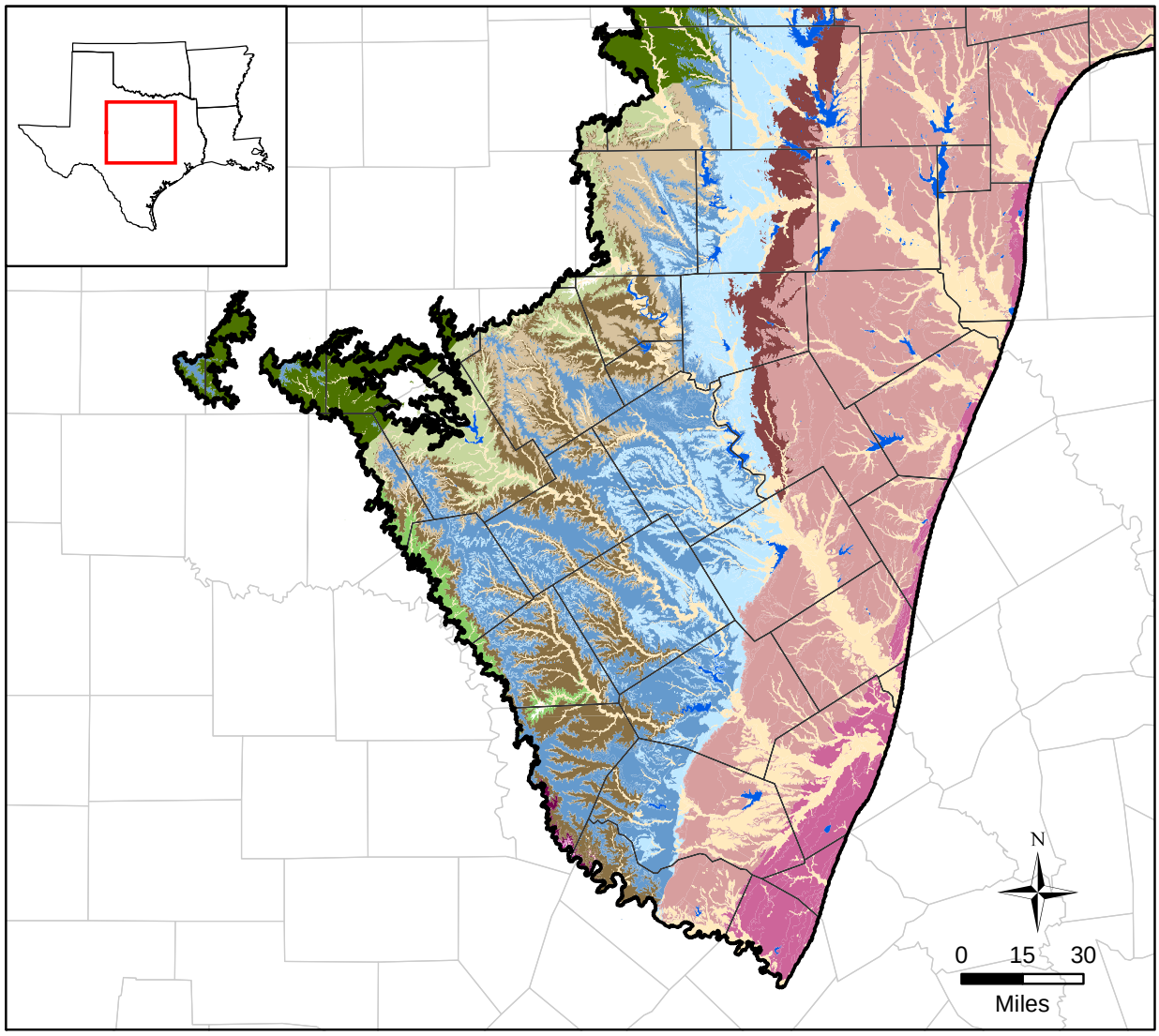


Figure 2.2.2 Generalized surface geology for the southern portion of the study area (Bureau of Economic Geology, 2012).

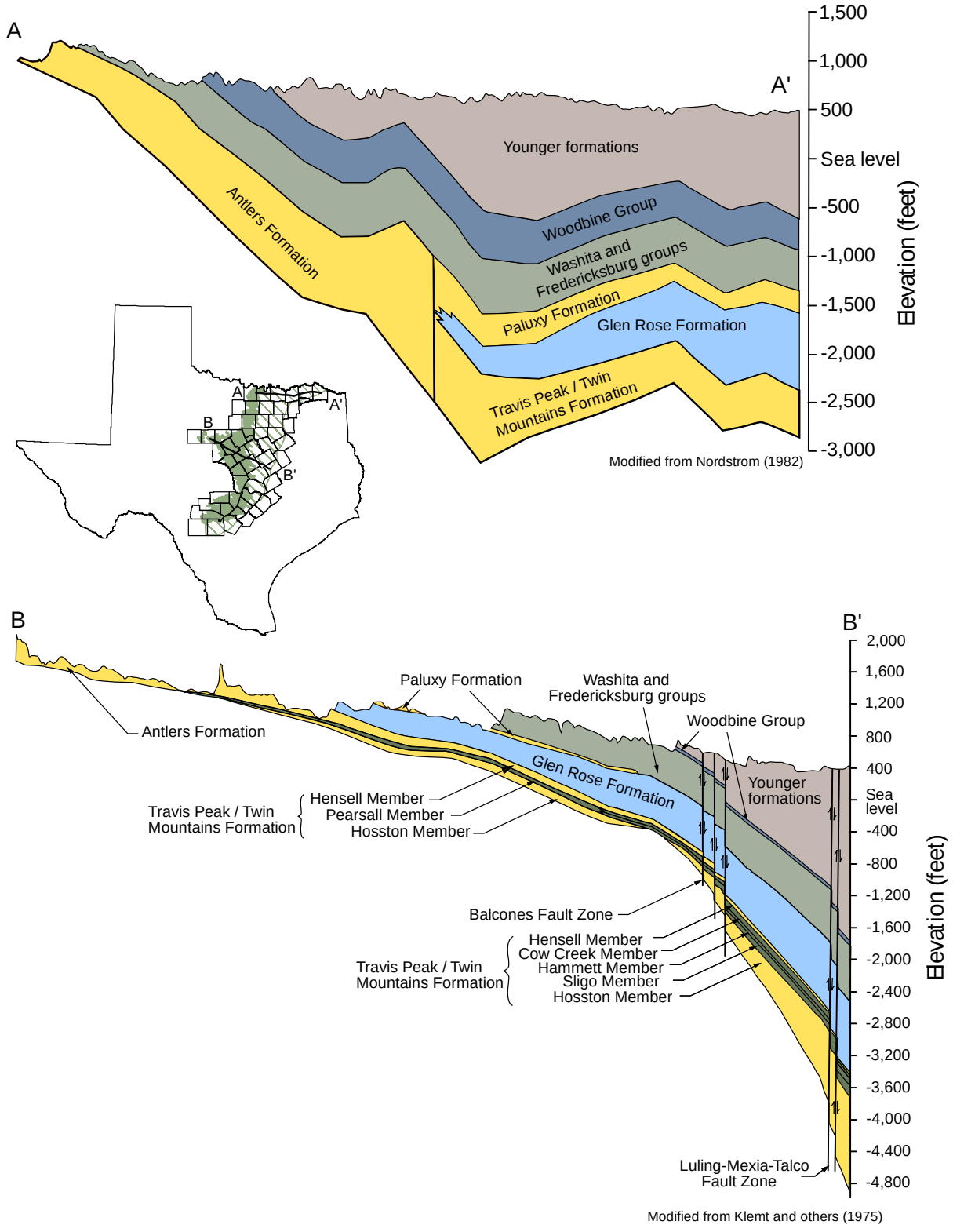


Figure 2.2.3 Cross sections of the stratigraphic units in the study area (after George and others, 2011; Bené and others, 2004; Nordstrom, 1982; Klemt and others, 1975).

4.0 Hydrogeologic Setting

This section details the data compilation and analyses used to support development of the conceptual model for the northern Trinity and Woodbine aquifers. This information, in total, defines the hydrogeologic setting and it includes a discussion of hydrostratigraphy, hydraulic properties, hydraulic heads, water quality, recharge, natural aquifer discharge, and pumping.

4.1 Hydrostratigraphy of the Northern Trinity and Woodbine Aquifers

In this subsection, the hydrostratigraphy of the northern Trinity and Woodbine aquifers is discussed, including structure, lithology, and depositional environment. In addition, this subsection includes an introductory discussion of water quality based on geophysical log analyses. The analysis of water quality is expanded in Section 4.4 through the analysis of groundwater quality samples from wells.

4.1.1 Introduction

The rocks and sediments that host the northern Trinity and Woodbine aquifers formed during the geologic time period known as the Cretaceous Period, which lasted from about 145 to 65 million years ago. Cretaceous-age strata are exposed at the surface across broad areas of Texas (Figure 4.1.1). The most abundant rock type in the Cretaceous-age strata in Texas is limestone, which covers the Edwards Plateau (see Figure 2.1.1) and much of central Texas. Light colored limestone road cuts are a common sight along highways in these areas. However, with the exception of the limestone of the Edwards BFZ Aquifer, the most important aquifers in the study area are composed of sand and sandstone of Cretaceous age. Sandstones in the Trinity Group form major aquifers in the Hill Country, Edwards Plateau, and north-central Texas and minor aquifers under the High Plains of west Texas. Sandstones in the Woodbine Group and Nacatoch and Blossom formations host minor aquifers in northeast Texas (George and others, 2011). The focus of the northern Trinity and Woodbine aquifers GAM are the sand-dominated aquifers in the geologic formations of the northern Trinity and Woodbine groups in central and north-central Texas north of the Colorado River (Figure 4.1.2).

Cretaceous-age stratigraphic units in north-central Texas lie on the northwestern margin of the Gulf of Mexico Basin. To the west are Paleozoic-age strata, which were deposited in the Fort Worth and Permian basins (Figure 4.1.1). These older oceanic basins existed prior to the

opening of the Gulf of Mexico. To the east are younger Tertiary- and Quaternary-age strata, which record sedimentary infilling of the Gulf of Mexico Basin. Through geologic time, the Gulf of Mexico Basin has progressively filled from the margins toward the center until achieving the shoreline configuration that exists today (Figure 4.1.3). Cretaceous-age strata are the oldest part of the Gulf of Mexico Basin fill exposed at the surface. Freshwater aquifers occupy only the uppermost few thousand feet of Cretaceous-age strata.

4.1.2 Previous Studies

R.T. Hill conducted the first geologic and hydrogeologic studies of the Trinity and Woodbine groups and aquifers in Texas (Hill, 1891, 1894, 1901). Hill named the various formations and established their stratigraphic relationships to each other. The nomenclature for Cretaceous-age formations is complex and varies between outcrop and subsurface and from north to south (Figure 4.1.2). This complication arises from lithologic and stratigraphic variability, as formations thin, thicken, or merge together. Lithologies change from limestone-dominated in the south to sandstone-dominated in the north. Fisher and Rodda (1966, 1967) revised Trinity Group stratigraphy based on the distribution of limestone in the Glen Rose Formation and lithologic changes that occur between outcrop and subsurface. A comprehensive volume of papers on lower Cretaceous-age stratigraphy (Hendricks, 1957) further documented lithology, paleontology, and stratigraphy, defining three geologically distinctive regions in north and central Texas (Figure 4.1.2). Subsequent studies focused on depositional patterns of sandstone in the Trinity Group (Boone, 1968; Hall, 1976; Caughey, 1977). The understanding of stratigraphy and depositional environments for the Woodbine Group was refined by Dodge (1968, 1969) and Oliver (1971). Nordstrom (1982) in the north and Klemt and others (1975) in the south provide two key hydrogeologic studies relating stratigraphic and lithologic variability to aquifer development.

4.1.3 Overview of Hydrostratigraphy

Stratigraphy and lithology are fundamental properties of aquifers and primary controls on groundwater flow rates and volumes and on groundwater quality and chemical composition. This section describes the stratigraphy and lithology of the formations of the northern portion of the Trinity Group and the Woodbine Group as these properties relate to aquifer development. Stratigraphy is essentially the arrangement of layers in sedimentary rocks. Sediments (gravel, sand, silt, and clay particles) are typically transported by currents in rivers and oceans and

deposited in horizontal layers. Depositional layering is preserved in stratified rocks, imparting directionality to rock properties. Hydraulic conductivity, for example, is commonly much greater in the horizontal direction than in the vertical direction. Lithology is also more persistent in the horizontal direction. A sandstone formation, such as the Hosston Formation, extends laterally across many counties relatively unchanged, but in the vertical direction, sandstone in the Hosston Formation changes to shale abruptly across a stratigraphic boundary only a few feet thick. These properties of stratified rocks result in a system composed of lithologically contrasting layers (aquifers and aquitards) that extend from shallow recharge areas to deeply buried areas, providing conduits for regional groundwater flow.

Lithologic changes in the horizontal direction, although more gradational than vertical changes, result in regional differences in formation properties. Based on geologic variations, the northern Trinity Group can be divided into five regions in the study area based on stratigraphic and lithologic similarities (Figure 4.1.4). Stratigraphic layers are physically continuous across the regions, but layer thicknesses, lithologies, and formation names, as well as corresponding aquifer names, change. Figure 4.1.5 shows a cross section composed of typical digital geophysical logs transecting Regions 1 through 5. The digital logs show the spontaneous potential curve on the left and a resistivity (short normal) curve on the right.

Region 1 encompasses the western and northwestern portions of the study area in Texas as well as Oklahoma and Arkansas (see Figure 4.1.4). In this region, the northern Trinity Group consists of undifferentiated sandstones and shales referred to as the Antlers Formation, which is an aquifer in this region and locally referred to as the Antlers Aquifer. Region 2 lies south and east of Region 1. In this region, limestones of the Glen Rose Formation separate the sandstones in the upper portion of the northern Trinity Group from the undifferentiated sandstones and shales in the lower portion of the northern Trinity Group. In this region, the upper sandstones are referred to as the Paluxy Formation and make up the Paluxy Aquifer and the undifferentiated lower sandstones and shales are referred to as the Twin Mountains Formation. The water-bearing sandstones in the Twin Mountains Formation are locally referred to as the Twin Mountains Aquifer. Region 3 is stratigraphically similar to Region 2, the main distinctions being a somewhat arbitrary name change and more shale and limestone in the lower portion of the northern Trinity Group. In Region 3, the upper sandstones are also referred to as the Paluxy

Formation and make up the Paluxy Aquifer and the undifferentiated sandstones, shales, and limestones in the lower portion of the northern Trinity Group are referred to as the Travis Peak Formation. The water-bearing sandstones in the Travis Peak Formation are locally referred to as the Travis Peak Aquifer.

In Regions 4 and 5, located in the southern portion of the study area, the Glen Rose Formation is thicker than in Regions 2 and 3 and the stratigraphic layers in the lower portion of the northern Trinity Group can be differentiated into individual formations. In these two regions, the stratigraphy above the Glen Rose Formation is also referred to as the Paluxy Formation. These two regions are distinguished by the presence of sandstone in the Paluxy Formation in Region 4, which makes up the Paluxy Aquifer, and the absence of sandstone in the Paluxy Formation in Region 5, corresponding to an absence of the Paluxy Aquifer.

In Region 4, the stratigraphy of the northern Trinity Group underlying the Glen Rose Formation (i.e., the Twin Mountains Formation) is divisible into sandstones of the Hensell and Hosston members separated by limestones and shales of the Pearsall Member. In Region 5, the stratigraphy of the northern Trinity Group underlying the Glen Rose Formation (i.e., the Travis Peak Formation) is also divided into three units. The upper unit consists of sandstones of the Hensell Member. The middle unit consists of the Pearsall/Cow Creek/Hammett members. The limestones of the Cow Creek Member and shales of the Hammett Member occur to the east and coalesce to form the Pearsall Member in the west. The lower unit consists of limestones and dolomites of the Sycamore Member in the outcrop area to the west, sandstones of the Hosston Member to the east and downdip, and shales of the Sligo Member, which overly the Hosston Member in the vicinity of the Mexia-Talco Fault Zone. In both Regions 4 and 5, the sandstones of the Hensell and Hosston members are referred to as the Hensell and Hosston aquifers, respectively.

The Woodbine Group is separated from the northern Trinity Group by the limestone and shale of the Washita/Fredericksburg groups (Figures 4.1.5 and 4.1.6). Across the entire study area, sandstones are rare to absent in the Washita/Fredericksburg groups. In the south (Bell, Williamson, and Travis counties), the Fredericksburg Group includes the Edwards BFZ Aquifer (Jones, 2003). The Woodbine Group is not present west or north of its outcrop, which extends

through the middle of the study area (Figure 4.1.4). In the southern portion of Region 4 and all of Region 5, sandstone is absent in the Woodbine Group (Figure 4.1.5).

For the model, the Woodbine, Washita/Fredericksburg, and northern Trinity groups in the study area were divided into seven layers based on significant differences in geologic properties. These are the Woodbine Aquifer, Washita/Fredericksburg groups, Paluxy Aquifer, Glen Rose Formation, Hensell Aquifer, Pearsall Formation, and Hosston Aquifer (Figure 4.1.6). Generally, the layering differentiates between sandstone-dominated layers that are aquifers and shale- and limestone-dominated layers that are typically confining units. Shales have low hydraulic conductivities and include soluble mineral salts that decrease groundwater quality. Most limestones in the study area possess similar properties. Sand and sandstone, in contrast, typically have high hydraulic conductivities and are composed of relatively insoluble quartz and feldspar grains. The presence of seven contrasting layers does not occur everywhere in the study area. For example, in Region 1 there are only two or three contrasting layers; the sandstones of the Antlers Formation, the shale and limestone of the Washita/Fredericksburg groups, and the sandstone of the Woodbine Group, where present. In fact, all seven contrasting layers are present together only in portions of Region 4. Vertically adjacent model layers can have similar hydraulic properties, and subdividing a thick sandstone sequence, such as the Antlers Formation, adds resolution to the model.

For modeling purposes, all seven layers shown in Figure 4.1.6 were extended throughout the study area. This was done because it was not feasible to distinguish the complex nomenclature used across the study area in the model and the groundwater code used requires that model layers be continuous over the entire model domain. The nomenclature for Region 4 was selected for use because it has the greatest number of divisions that require implementation as individual layers in the model. Mapping of the model layers to the Antlers, Twin Mountains, and Travis Peak aquifers in Regions 1, 2, and 3, respectively, can be done using the cross section in Figure 4.1.5 and the chart in Figure 4.1.6. For example, the Paluxy Aquifer maps to the upper sands of the Antlers Aquifer in Region 1 and the Hosston Aquifer maps to the lower sands of the Travis Peak Aquifer in Region 3, the lower sands of the Twin Mountains Aquifer in Region 2, and the lower sands of the Antlers Aquifer in Region 1. The layer terminology shown in Figure 4.1.6 is used throughout the remainder of this report.

4.1.4 Structural Features

Structural geology deals with structural changes to sedimentary rocks after deposition in horizontal layers. Most rock formations have been structurally deformed by compressive forces within the Earth's crust or by subsidence. Subsidence of the Gulf of Mexico Basin caused Cretaceous-age formations to tilt (dip) toward the southeast (Figure 4.1.3). Formations at land surface in the west are thousands of feet below surface in the east. The structural dip of the strata in the northern Trinity and Woodbine groups is regular and concentric to the East Texas Basin, which is an embayment (now filled with sediment) of the Gulf of Mexico Basin (Figure 4.1.7). Structural dip increases toward the center of the East Texas Basin (to the southeast). The lowest dips (15 feet per mile) occur in the southwest outcrop area. In the northwest outcrop area, dips are 25 to 30 feet per mile. Along the downdip margin of the study area, dips range from 250 to 350 feet per mile (Figure 4.1.7). Along with lithology and stratigraphy, structural dip is another key property of layered aquifers, because it enables downward groundwater flow.

Subsidence also impacts sedimentary thicknesses. Without subsidence of the land surface, sediments would not be able to accumulate to form sedimentary rocks. The opposite of subsidence is uplift. Sediments are eroded in uplifted areas (plateaus and mountains) and deposited in subsided areas (river valleys and ocean basins). Gulfward increasing subsidence has resulted in the formation of sedimentary wedges that thicken Gulfward (Figure 4.1.3). The stratigraphic intervals of the northern Trinity and Woodbine groups in the study area thicken southeastward in a regular pattern, which parallels the structural dip (compare Figures 4.1.7 and 4.1.8).

The same structural forces that tilt stratigraphic layers also break them along surfaces of discontinuity called faults or fractures. A fault displaces the broken layer so that the two sides are no longer fully in contact. Fault displacements range from a few feet to hundreds of feet. In the latter case, a faulted layer may be completely disconnected. Fractures are breaks in layers without displacement. Both faults and fractures are generally oriented vertically and provide opportunities for vertical groundwater flow. Fault locations and properties in the study area were compiled from the geologic literature in Ewing (1990, 1991). These documented faults represent the largest faults (most laterally extensive and largest vertical displacements) in the study area that disrupt Cretaceous-age strata (Figure 4.1.7). Small faults and fractures are common in most geologic formations, and have been mapped in outcrops of the Cretaceous-age strata and

excavated tunnels (Nance and others, 1994). These localized structures are typically less than 1 mile long, have displacements less than 10 feet, and are subvertically oriented (cross cutting horizontal bedding). Many small faults drip or even flow water into excavated tunnels, indicating that they form pathways for vertical groundwater flow.

Faults tend to occur in closely spaced groups (fault zones) in response to geographically focused structural forces. The study area includes three regions of large-scale faulting and structural deformation. The Balcones Fault Zone extends into the study area from the south through Travis, Bell, McLennan, and Hill counties (Figure 4.1.7). Displacements across faults in this fault zone range from 100 to 400 feet, which are sufficient to completely disconnect some layers (Klemt and others, 1975). Faults in the Balcones Fault Zone are mostly down to the east, with the disconnected layer deeper on the east side of the fault relative to its position on the west side. The Mexia-Talco Fault Zone is a complex zone of interweaving faults that extends along the entire length of the downdip boundary of the study area (Figure 4.1.7). Individual faults in this fault zone have as much as 700 feet of displacement (Ewing, 1990). Fresh groundwater in the aquifers in the study area does not extend beyond the Mexia-Talco Fault Zone (Klemt and others, 1975).

An area of faulted and folded strata occurs in Cooke and Grayson counties and extends northwest into Oklahoma (Figure 4.1.7). This structurally deformed area is commonly known as the Sherman Syncline and Preston Anticline. In some cases, strata that experience compressive forces will fold instead of break along faults. Near the city of Sherman in Grayson County, there are several faults that parallel the southeast-trending folds (Figure 4.1.7). Structural complexity in the Sherman area is mainly confined to underlying Paleozoic-age strata, but is manifested in overlying Cretaceous-age strata as gentle folds. The thickness patterns in the Cretaceous-age strata also reflect the folds (Figure 4.1.8), indicating that structural movement occurred during deposition in the Cretaceous Period. The structures in the area of Sherman, Texas lie at the hinge between north-oriented outcrops to the south and east-oriented outcrops through Oklahoma (Figure 4.1.7). These large-scale trends resulted from continental breakup that preceded formation of the Gulf of Mexico Basin.

4.1.5 Paleogeography and Depositional Environment

Paleogeography and depositional environment affect the properties of sedimentary rocks. Paleogeography is the configuration of landforms and water bodies that existed at the time of deposition. Depositional environment is the specific setting of sediment accumulation, such as a river or a marine shoreline. A depositional system, introduced later in this section, is a three-dimensional body of rock or sediments deposited in a specific depositional environment. Paleogeography is reconstructed from the rocks themselves (the rock record), which involves comparison of properties of rocks of the same age across broad regions. Missing rocks indicate that an area was uplifted (nondeposition or erosion). Fossils are important to paleogeographic reconstruction because the habitats of specific plant and animal species are generally understood. Fossils of marine shellfish are ubiquitous in Cretaceous-age limestones, for example. Paleogeography provides a context for interpreting depositional environments, which are more specific and localized. A marine shoreline (sandy) is different from a marine bay (muddy). Sandstones are deposited where currents are strong, such as river channels and shorelines; shales are deposited in quiet water, such as bays and lagoons. Understanding depositional environments allows prediction of rock properties where data are discontinuous (in between wells). Depositional environments for all formations in the northern Trinity and Woodbine groups were interpreted and used to infer rock properties and directionality of those properties as discussed in Section 4.2.

Paleogeographic reconstructions of North and Central America during the Cretaceous Period provide a starting point and context for the exploration of depositional history and environments for the northern Trinity and Woodbine groups. The Cretaceous Period was characterized by long-term rising sea level and flooding of the continents. At the beginning of the Cretaceous Period, most of North America was covered by terrestrial landforms, much like today (Figure 4.1.9a). The ancestral Gulf of Mexico was in a similar position as it is today, and rivers carried sediment from mountainous areas in the northwest across north-central Texas to depositional sites farther southeast. Figure 4.1.9a is a schematic representation of the eroded surface of the Paleozoic-age strata upon which basal sands in the Trinity Group were deposited (Boone, 1968).

Later in the early Cretaceous Period, rising sea level caused the Gulf of Mexico shoreline to move west and north, flooding east Texas and changing north-central Texas into a low-lying

coastal area (Figure 4.1.9b). Basal sands (Hosston Aquifer) of the northern Trinity Group, which were deposited in river channels, represent the first Cretaceous-age depositional system to develop along that coast. The shoreline coincided approximately with the downdip boundary of the study area (Figure 4.1.9b). Following deposition of the Hosston Aquifer, the coastal plain partly flooded, and the shales and limestones of the Pearsall Formation were deposited in the south and east. Pearsall Formation deposition was followed, in turn, by another sandy coastal plain system (Hensell Aquifer). Glen Rose Formation limestones and Paluxy Aquifer sandstones record yet another episode of rising sea level followed by shoreline progradation.

In the late Cretaceous Period, sea levels continued to rise, eventually flooding the northern Trinity Group coastal plain and creating marine conditions across most of Texas as well as the central portion of North America (Figure 4.1.9c). Limestones and shales of the Washita and Fredericksburg groups were deposited at this time in shallow marine waters similar to the modern Florida Keys. By late Cretaceous time, renewed input of sand-rich sediments from land areas to the north formed the depositional systems of the Woodbine Group in a variety of near-shore environments.

Rising sea levels in the Cretaceous Period were periodically offset by input of sand-rich sediment. Each episode of sand deposition built up the coastal plain and pushed the shoreline back toward the southeast. Sand was supplied discontinuously by episodic uplift in the north and west. During times when the supply of sand was low, the study area flooded and limestones and shales were deposited. Thus, fluctuating paleogeographic conditions resulted in vertical alternation of sandstone-rich and limestone-rich sedimentary formations. The western and northwestern portions of the study area, which were always farthest from the coast, are sand dominated, whereas the eastern and southern portions are limestone and shale dominated.

4.1.6 Methods and Data

Data compilation and quality control represent major tasks in creating the hydrostratigraphic framework. Previous geologic studies did not cover the entire study area and were not focused on data compilation. Furthermore, hydrostratigraphic frameworks used to construct previous groundwater models were not preserved. In addition to developing a well-documented hydrostratigraphic framework for the GCDs in GMA 8, another goal was to build an equally well-documented, publically available database, encompassing all raw data and interpretations

used to complete this study. This database will provide a firm foundation for further studies and future work in a large and complex aquifer system.

The stratigraphic and lithologic study presented here was based on geophysical logs. Geophysical logs are required for correlating stratigraphic boundaries. Lithologic descriptions from previous studies were used to calibrate geophysical logs, but standard logging principles provided the basis for interpreting lithology from spontaneous potential and resistivity log responses. Although there is some uncertainty where limestone and sandstone are interbedded in a freshwater environment, an attempt was made to reduce this uncertainty by referring to published descriptions.

Geophysical well logs were used to correlate boundaries, map lithologies, interpret depositional environments, and estimate water quality in each layer of the northern Trinity and Woodbine aquifers. Large amounts of time and effort were spent searching for, evaluating the quality of, and depth calibrating geophysical well logs. When that work was complete, a database comprising 1,498 geophysical well logs distributed across the study area was compiled. During the progress of the study, some of those logs were eliminated from the database owing to problems with log quality or incomplete vertical coverage. The final database includes 1,302 logs, which represent the best available coverage of Cretaceous-age formations across the study area (Figure 4.1.10). Almost all logs in the final database are electric logs, meaning they include spontaneous potential and resistivity curves. Some wells also have gamma-ray and other log types, but for consistency and comparability, only the spontaneous potential and resistivity curves were used. The final database includes 408 geophysical logs from water wells and 894 geophysical logs from oil and gas wells.

The well log database is primarily composed of electronic image files, such as TIFF or JPEG, which are typically referred to as rasters. Before the advent of desktop computing, well logs were printed on long, folded paper. Rasters are scanned versions of those paper logs. The commercially available Petra software (IHS, Inc.) was used to prepare and interpret logs and display results. Petra is a GIS-type program that specializes in spatial data from wells. Raster versions of well logs are just images with no attached quantitative information. Petra provides functions for visually examining the images and recording observations at specific depths.

Raster logs were used to correlate stratigraphic boundaries and interpret lithologies. Geologic formation boundaries were defined in outcrop and traced into the subsurface using standard well log correlation techniques. The work documented here established that formation definitions in various portions of the study area are essentially correct; no significant changes are necessary. This study focused on regional consistency and connecting layers across lithologic changes. For example, it was confirmed that the Paluxy and Glen Rose formations in the south are at the same stratigraphic level as the upper part of the Antlers Formation in the north (Figure 4.1.5). In other words, strata in the Paluxy and Glen Rose formations are physically connected to strata in the upper Antlers Formation even though lithologies differ. In contrast, strata in the Fredericksburg Group everywhere overlie strata in the Antlers or Paluxy formations. Actual stratigraphic details are complicated, however, and most formation boundaries are gradational to some extent. The layer definitions and well-to-well correlations establish a regionally consistent stratigraphic framework while preserving as much local detail as possible.

Lithology interpretations were based on geophysical well logging principles supported by limited well sample information and best professional judgment. Lithologic interpretation was conducted on 988 geophysical logs. Electrical properties, as measured in wells, provide information about both lithology and fluid saturation. If fluid saturation is relatively homogeneous (as is expected in an aquifer), then lithology has a pronounced effect on electric log responses. Shales are relatively conductive (low resistivity), whereas limestones generally have high resistivities. Sandstones display intermediate resistivities, which are partly controlled by pore fluid composition (salinity). Shales display distinctive responses on electric logs and can be interpreted with high confidence. Sandstones and limestones can be distinguished from each other with less confidence, especially in a freshwater environment. The spontaneous potential log, which under certain conditions provides a qualitative measure of hydraulic conductivity, is useful for distinguishing permeable sandstone from impermeable limestone. Knowledge of local lithologies from previous studies provides a context for lithologic interpretation. Using Petra functions, a foot-by-foot continuous vertical record of lithology for each electric log was constructed. Lithologies (sandstone, shale, limestone) were then summed by layer and mapped.

Electric logs in digital format were used to interpret water quality and for graphical display (Figure 4.1.11). Whereas raster images are just pictures, digital logs are computer files of measured log responses. Digital logs are tables of measured values, generally having one log

value for every half foot of depth. Information can be extracted wholesale from digital logs without painstaking log-by-log measurement. Digital log values can be analyzed statistically and used in equations to create derivative logs. Unfortunately, the availability of digital logs is limited, and the cost is high. For older wells, and most water wells, log curves must be manually traced using digitizing software. A distribution of 109 digital electric logs across the study area was compiled. The locations of the digital logs are shown in red on Figure 4.1.10.

4.1.7 Lithologic Character of Enclosing Formations

Prior to the onset of deposition during the Cretaceous Period, north-central Texas was covered by eroded landforms comprising three different geologic provinces. These underlying rocks possess differing hydraulic properties that may influence groundwater flow in the aquifers. Where log depths permitted, lithologies of underlying rocks extending 300 feet below the base of the Cretaceous-age strata were interpreted. Paleozoic-age strata underlie the western and northwestern portions of the study area (Figure 4.1.12). Paleozoic-age strata are composed of sandstone, shale, and limestone similar to the overlying Cretaceous-age strata (Brown and others, 1990). Paleozoic-age sandstones are potential aquifers and may be in hydraulic communication with Cretaceous-age sandstones where the two are superimposed.

Deformed rocks of the Ouachita fold belt underlie Cretaceous-age sandstones east of the Paleozoic-age terrain (Figure 4.1.12). Ouachita rocks are also Paleozoic in age, but have a different history. Ouachita rocks were squeezed between two continental plates (ancestral North and South America) during a collision that took place during the Paleozoic Era (Flawn and others, 1961). During that collision, Ouachita rocks experienced high pressures and temperatures, which destroyed whatever hydraulic conductivity they originally possessed. Ouachita rocks in the study area are aquitards.

Jurassic-age sandstones (Cotton Valley Group) underlie Cretaceous-age sandstones along the downdip margin of the study area (Figure 4.1.12). Sandstones of the Cotton Valley Group and overlying Hosston Aquifer are lithologically similar and in hydraulic communication.

Black shales of the Eagle Ford Group overlie the sandstones of the Woodbine Group, forming an effective aquitard and top seal across the eastern portion of the study area. Additional low hydraulic conductivity rocks of the Austin Chalk overlie Eagle Ford shales. Somewhat higher in the stratigraphic section, sandstones forming minor aquifers are present in uppermost

Cretaceous-age strata (Nacatoch and Blossom aquifers). These overlying formations are only present east of the Woodbine Aquifer outcrop. Through the TWDB, a GAM has been developed and is available for the Nacatoch Aquifer (Beach and others, 2009) and a GAM is currently under development for the Blossom Aquifer.

4.1.8 Regional Sandstone Distribution and Depositional Systems

Sandstones in the northern Trinity and Woodbine groups record a major pulse of sediment input in the face of rising sea levels during the Cretaceous Period (Figure 4.1.9). Within that overall sandy interval, smaller scale pulses of sand deposition alternated with marine flooding. This back and forth fluctuation formed the layered system of aquifers and aquitards in the northern Trinity and Woodbine groups in the study area, which is the focus of this report. This section describes regional lithologic properties and sandstone depositional systems of each layer in the Woodbine, Washita/ Fredericksburg, and northern Trinity groups (see Figure 4.1.6). Sandstone distribution, geometry, and orientation are illustrated using net and percent sandstone maps. Depositional systems interpretations are also illustrated on maps. Sandstone and depositional systems maps are shown on Figures 4.1.13 through 4.1.30 by layer from deepest to shallowest. Net sandstone maps show total sandstone thickness in the layer, which is sensitive to the gross layer thickness, whereas the percent sandstone maps show a measure of sandstone concentration without regard to absolute thickness. Where sandstone percentages are high, individual sandstone beds are thick and interbedded shales are thin. Together, the two types of sandstone maps delineate fairways where potential for groundwater flow is greatest.

Figures 4.1.31 through 4.1.37 are schematic, reduced-scale cross sections showing depths, lithologies, and water quality in profile. The cross sections were developed using high-resolution digital electric logs. Large-format versions of the cross sections, showing the digital logs, are included in Appendix C.

Depositional systems maps are based largely on sandstone patterns in paleogeographic context and further emphasize sandstone geometries and orientations. Sandstones in the northern Trinity and Woodbine groups were deposited in two contrasting environments settings: fluvial and shoreline. Fluvial environments include river channels and valleys, whereas shoreline environments include coastal barrier and near offshore areas. The term “fluvial” is also used here for rivers in coastal plains and delta plains. The term “deltaic shoreline” is used here for

coastal barrier and near offshore areas and on adjacent to river deltas. Both fluvial and shoreline environments produce sandstone bodies having elongated external geometries, but orientations vary. Both of these environments produce sandstone bodies having elongated external geometries, but orientations vary. Fluvial sandstones are elongated in the direction of river flow, mainly toward the coast, whereas shoreline sandstones are elongated parallel to the coast. In the northern Trinity and Woodbine depositional systems, fluvial sandstones are oriented mainly northwest-southeast, whereas shoreline sandstone are oriented mainly southwest-northeast. Sandstone geometry and orientation are important because they influence groundwater flow directions. The following discussion is presented by layer from deepest to shallowest.

The specific depositional environments and systems described here are based on previous studies. The depositional systems of the Hensell and Hosston aquifers and the Antlers Aquifer equivalent are documented by Boone (1968) and Hall (1976). The depositional systems of the Paluxy Aquifer are documented by Caughey (1977) and those of the Woodbine Aquifer are documented by Dodge (1968, 1969) and Oliver (1971). Along the downdip margin of the study area, the depositional systems of the Hosston Member of the Travis Peak Formation are documented by McGowen and Harris (1984). The work conducted for this study supports these earlier studies and adds detail relevant to groundwater modeling.

Hosston Aquifer

The Hosston Aquifer is sand-dominated across the entire study area. The aquifer is relatively thin (less than 100 feet) in western outcrops but thickens greatly (500 to 1,000 feet) in downdip areas to the east (see Figures 4.1.31 through 4.1.35). Net sandstone thickness ranges from less than 50 feet to greater than 800 feet along the downdip margin of the study area (Figure 4.1.13). The percent sandstone map displays the opposite pattern, with highest sandstone percentages occur in the west (Figure 4.1.14). High percentage sandstone lobes extend eastward from the outcrop. Net sandstone patterns show relatively thicker sandstones at and near the outcrop, which coincide with high sandstone percentages (compare Figures 4.1.13 and 4.1.14). Two broad high-sand trends dominate the study area: one in the north from Cooke to Parker counties and extending downdip to Dallas and Collin counties and another one in the south centered on Comanche and Erath counties and extending downdip to Bell, McLennan, and Hill counties. The Hosston Aquifer typically has a sharp lower contact with the underlying Paleozoic-age strata

and is sandiest in its lower part. Individual sandstones range from a few feet to about 100 feet thick and average 20-feet thick.

Based on the orientation of sand-rich trends (Figure 4.1.14) and paleogeographic context (Figure 4.1.9b), sandstones of the Hosston Aquifer were deposited in a fluvial environment. Major rivers (channel axes) entered the study area from the west and flowed east and southeast into the East Texas Basin (Figure 4.1.15). Based on the concentration of sand (percent sandstone), the coastal plain must have contained several broad sandy rivers. These rivers were not confined in steep-walled valleys but were free to migrate laterally, depositing sand in wide, coalescing belts. Thus, individual sandstones in the Hosston Aquifer display broad, sheet-like geometries, which are elongated toward the southeast (Figure 4.1.14). These rivers supplied abundant sand to deltaic shoreline systems located beyond the study area in the East Texas Basin (McGowen and Harris, 1984). Increased subsidence in the Mexia-Talco Fault Zone along the eastern boundary of the study area allowed sand to accumulate in thick sequences (Figure 4.1.13).

Pearsall Formation

The Pearsall Formation is composed of sandstone and shale in the north and limestone and shale in the south (see Figures 4.1.36 and 4.1.37). Sandstone is best developed in northwestern counties extending south into Collin and Dallas counties (Figure 4.1.16). Thickest sandstone is located mainly downdip in northeastern counties. Unlike the Hosston Aquifer, sandstones in the Pearsall Formation do not display strong west-east orientation, rather, they are oriented mainly north-south (Figure 4.1.16). The Pearsall Formation is not a sand-dominated sequence; percent sand is less than 50 percent in most wells (Figure 4.1.17). Limestone dominates in downdip counties in the southern half of the study area (see Figures 4.1.33 through 4.1.35).

The Pearsall Formation was deposited during a transgressive episode. The supply of abundant sand that fed fluvial systems in the Hosston Aquifer was shut off, and the marine waters flooded (transgressed) the south. Sand deposition persisted in the north where a deltaic shoreline system formed (Figure 4.1.18). Relatively small rivers supplied sand to the delta from source areas to the north and northeast. Sand-poor coastal plain environments flanked the small rivers. South of the sandstone area, limestone and shale were deposited in offshore marine environments. In summary, shallow marine environments encroached the area from the southeast in response to

rising sea level, while coastal plain and shoreline environments persisted in the north (Figure 4.1.18).

Hensell Aquifer

The Hensell Aquifer is another sand-dominated interval. This aquifer, which is generally relatively thin (less than 120 feet), is thickest in outcrop areas and thins downdip (Figures 4.1.31 through 4.1.35). Net sandstone thickness ranges from 0 to 100 feet, averaging 50 feet (Figure 4.1.19). Percent sandstone is greater than 50 percent across most of the study area (Figure 4.1.20). Several high sandstone trends extend directly away from the outcrop and are west-east oriented in the south but become more north-south oriented to the north (Figure 4.1.20). Most high sandstone trends terminate before reaching the downdip margin of the study area. In more downdip areas, sandstones display north to northeast orientations (Figure 4.1.20). Individual sandstones in the Hensell Aquifer are thickest (15 to 25 feet) within the high percent sandstone trends.

The Hensell Aquifer was deposited in fluvial and deltaic shoreline systems that migrated (prograded) into the study area mainly from the west and northwest. Broad sandy rivers flowed eastward and merged with an equally broad sandy shoreline system (Figure 4.1.21). The Hensell Aquifer coastal plain and shoreline never extended as far southeast as they did in the Hosston Aquifer. In effect, the Hosston Aquifer constructed a platform of sand that completely covered the study area, and Hensell Aquifer depositional systems never reached the edge of that stable platform. Thus, the Hensell Aquifer never experienced large-scale subsidence in downdip areas and, consequently, does not thicken downdip. Along the downdip margin of the area, the Hensell Aquifer was deposited in shale-dominated offshore marine systems. Uppermost sands in the Hensell Aquifer were partly reworked during the marine transgression that deposited the limestones of the overlying Glen Rose Formation.

Glen Rose Formation

The Glen Rose Formation is limestone dominated across most of the study area except in the northwest. Limestones in the Glen Rose Formation range from 0 to 400 feet thick in the outcrop and 300 to 1,300 feet thick in downdip areas (Figures 4.1.31 through 4.1.37). The Glen Rose Formation includes a northeast-oriented lobe of sandstone in the northwest, which reaches 200 feet in thickness (Figure 4.1.22) and consist of 40 to 60 percent sandstone (Figure 4.1.23).

Individual sandstones in the Glen Rose Formation are thinner than those in the Hensell and Hosston aquifers, averaging only 8-feet thick. Thus, the Glen Rose Formation is composed of thick limestones across most of the study area and thinly interbedded sandstone and shale in the northwest.

Limestones in the Glen Rose Formation record a marine transgressive episode, which was more extensive than the transgression during deposition of the Pearsall Formation. Shallow marine waters covered most of the study area, although sand deposition persisted in the northwestern corner (Figure 4.1.24). Based on sandstone geometries and bed thicknesses, sandstones in the Glen Rose Formation were deposited in marginal marine environments, including small fluvial systems, coastal lowlands, and shorelines. In summary, deposition of the Glen Rose Formation was coincident with another sea level rise and another flooded coastal plain. Shallow marine limestones covered much of the study area, but marginal marine and shoreline environments persisted in the northwest.

Paluxy Aquifer

The Paluxy Aquifer is a sandstone-dominated interval centered in the north. The aquifer is thickest (greater than 400 feet) in the northeast and thins to the south (Figure 4.1.37). Net sandstone is also thickest in the northeast (Figure 4.1.25). Net sandstone is closely related to interval thickness, so the percent sandstone map shows that the Paluxy Aquifer is commonly sand-dominated even where it is thin (Figure 4.1.26). The Paluxy Aquifer is shale dominated in a thin remnant in the southeast and in the far northeast. Sandstones in the Paluxy Aquifer display elongate trends that enter the study area from the north, northwest, and west (Figure 4.1.26). In the north, sandstone trends in the aquifer extend completely across the study area, exiting to the southeast. However, in the south, sandstones in the aquifer thin to zero thickness before reaching the eastern boundary of the study area (Figure 4.1.26). Within high percent sandstone trends (greater than 60 percent), individual sandstones in the Paluxy Aquifer average 20 feet in thickness. In areas with lower percent sandstone, individual sandstones average 10 to 15 feet in thickness.

During deposition of the Paluxy Aquifer, fluvial systems converged on the study area from the north, northwest, and west. Rivers flowed east to southeast across most of the study area but flowed directly south in the northeast portion of the area (Figure 4.1.27). In the north, the

shoreline was beyond the downdip boundary of the study area but, in the south, a broad sandy shoreline extended from Coryell County northeast to Dallas County (Figure 4.1.27). A shale-dominated marine shelf existed south and east of the shoreline system. Fluvial sandstones in the Paluxy Aquifer are elongated directly away from the outcrop (sandstone orientation perpendicular to outcrop orientation). In summary, deposition of the Paluxy Aquifer was coincident with major sediment input from the north, northwest, and west, which constructed broad sandy coastal plain and shoreline deposits. The offshore marine environments in the south resulted in shale-dominated deposits.

Washita/Fredericksburg Groups

The Washita/Fredericksburg groups are composed of limestone and shale across the entire study area (Figures 4.1.31 through 4.1.5.) The Washita/Fredericksburg groups are exposed at the surface in between the northern Trinity and Woodbine group outcrops. The Washita/Fredericksburg groups thicken downdip from about 400 feet near the outcrop to 800 feet along the downdip boundary of the study area. The thickness of the Washita/Fredericksburg groups is relatively constant from north to south (Figure 4.1.37). The deposition of the Washita/Fredericksburg groups records a major marine transgression similar to the Glen Rose Formation, but even more extensive. There were no significant sources of sand during the Washita/Fredericksburg depositional episode; shallow marine conditions prevailed across the area.

Woodbine Aquifer

The Woodbine Aquifer is sandstone dominated from Hill County in the south to Fannin County in the north, but is shale dominated in the far northeast and in the south (Figure 4.1.28). This aquifer is not present west or north of its outcrop. Net sandstone is thickest in the area where outcrop trends change from north to east oriented, forming a lobe of sandstone greater than 300-feet thick (Figure 4.1.28). Sandstone concentration (percent sandstone) is actually greater to the south of this net sandstone maximum (Figure 4.1.29). Sandstones in the Woodbine Aquifer are generally elongated to the northeast, paralleling outcrop trends. Thick sandstones are concentrated in the lower half of the interval. In the area where the Woodbine Aquifer includes greater than 200 feet of net sandstone (Figure 4.1.28), individual sandstones in the lower part of the interval average 20 feet in thickness. In Collin County, individual sandstones reach 80 feet in

thickness. South of Hill County, the Woodbine Aquifer is thin (less than 20 feet) and composed entirely of shale (Figure 4.1.37).

The Woodbine Aquifer records the final progradation of sandy depositional systems into the study area. Subsequent to deposition of the Woodbine Aquifer, the entire area was covered by an offshore marine, shale-dominated environment. Depositional systems in the Woodbine Aquifer were primarily deltaic marine shorelines and related coastal lowlands (Figure 4.1.30). Small fluvial systems may be present in Grayson County and in Oklahoma. Thick stacks of marine shoreline sandstones cover eastern Collin and western Hunt counties (Figure 4.1.28). Ellis and Dallas counties are covered by thinner but more concentrated shoreline sandstones (Figure 4.1.29). In summary, sandstones in the Woodbine Aquifer were deposited primarily in deltaic shoreline environments.

4.1.9 Water Quality from Resistivity Logs

Groundwater quality in sandstone aquifers can be estimated using electric log resistivities. Freshwater is more resistive to the flow of electrical current than is saline water. Therefore, in general, higher sandstone resistivity coincides with better quality groundwater. Empirical relationships have been established between groundwater salinity, as determined by chemical analysis, and resistivity of the corresponding saturated sandstone (Jones and Buford, 1951; Alger, 1966; Fogg and Blanchard, 1984; Hamlin and others, 1988; Collier, 1993). Lithology, bed thickness, porosity, water composition, and temperature among other variables also influence measured resistivities. Specific resistivity cutoffs for fresh or slightly saline groundwater are usually only valid in limited geographic areas where formation properties are relatively constant (Collier, 1993). Resistivity was mapped in selected sandstone-dominated layers without attempting to quantify corresponding groundwater salinities. Instead, resistivity maps and descriptions are presented in terms of relatively lower and higher groundwater salinities. Using digital electric logs, average (median) resistivity in the aquifers was calculated. To reduce bed thickness effects, only sandstones greater than 10-feet thick were included in the averaging process. The resistivity maps show trends that can be related, at least in part, to groundwater salinity changes. The approximate downdip limit of freshwater in each sandstone layer is marked on the cross sections in Figures 4.1.31 through 4.1.35. These downdip limits of freshwater, which is also general and qualitative, were based on resistivities, previous studies

(Klemt and others, 1975; Nordstrom, 1982), and the groundwater quality data in water wells presented in Section 4.4 of this report.

Low salinity groundwater extends deepest and farthest downdip in the Hosston Aquifer. Low salinity groundwater is present at depths of 3,500 to 5,000 feet below land surface in Collin, Dallas, and Ellis counties and at depths of 2,500 to 3,500 feet in Hill and McLennan counties (Figures 4.1.31 through 4.1.34). Farther south, low salinity groundwater in the Hosston Aquifer extends less than 2,000 feet below land surface (Figure 4.1.35). Resistivities in the Hosston Aquifer are relatively high in areas coincident with high percent sandstone trends (compare Figures 4.1.14 and 4.1.38), suggesting that recharging (low salinity/high resistivity) groundwater preferentially flows along these high conductivity pathways. Exceptionally high resistivities in the south are probably caused by high bicarbonate concentrations (Collier, 1993). Resistivities in the Hosston Aquifer are uniformly low in the far northeast, indicating generally high groundwater salinities in that region.

Groundwater in the Hensell Aquifer has relatively low salinity in and near the outcrop area, but the lower salinity groundwater does not extend as far downdip in the Hensell Aquifer as in the Hosston Aquifer. Higher salinity groundwater in the Hensell Aquifer commonly overlies lower salinity groundwater in the Hosston Aquifer, an example of decreasing salinity with depth (Figures 4.1.31 through 4.1.35). Resistivities in the Hensell Aquifer also show some geographic coincidence with high percent sandstone trends (compare Figures 4.1.19 and 4.1.39). As in the Hosston Aquifer, resistivities in the Hensell Aquifer are uniformly low in the northeast.

In the northern portion of the study area, relatively low salinity groundwater in the Paluxy Aquifer extends as far or farther downdip than it does in the Hosston Aquifer, although not as deep (Figures 4.1.31 and 4.1.32). Except in the far northeast, areas of high sandstone coincide with higher resistivities in the Paluxy Aquifer (compare Figures 4.1.26 and 4.1.40).

Resistivities in the sandstones of the Woodbine Aquifer are lower than in the sandstones of the Paluxy, Hensell, and Hosston aquifers. Formation-specific properties unrelated to water quality probably cause these resistivity differences within the Woodbine Aquifer, however, downdip decreasing resistivities reflect increasing groundwater salinity (Figure 4.1.41). High resistivities (low salinities) extend further downdip in two areas: in the south, where the Woodbine Aquifer is thin but the sandstone percentage is high (Figure 4.1.29), and, in the north, where the net

sandstone in the Woodbine Aquifer is high (Figure 4.1.28). In the Woodbine Aquifer, low salinity groundwater is best developed in Collin, Dallas, and Ellis counties, coinciding with greater concentrations of sandstone in those counties (compare Figures 4.1.29, 4.1.31, and 4.1.32). Even in this area, however, low salinity groundwater in the Woodbine Aquifer does not extend deeper than about 2,000 feet below land surface.

Resistivity maps were not constructed for other layers, owing to the effects of mixed lithologies, but approximate downdip limits of lower salinity groundwater are shown on cross sections. The Pearsall Formation generally contains higher salinity groundwater than do the other sandstone-bearing layers (Figures 4.1.31 through 4.1.35). The Glen Rose Formation contains low salinity groundwater in the northwest where it is sandstone-dominated (Figure 4.1.31).

4.1.10 Hydrostratigraphy for the GCDs Comprising the Inter-local Agreement

Hydrostratigraphy specific to each of the GCDs comprising the inter-local agreement (Prairielands, North Texas, Northern Trinity, and Upper Trinity GCDs) is provided in this subsection. Included are cross sections and discussions of aquifer characteristics in the GCDs. The following discussion is organized by GCD location from east to west and north to south.

4.1.10.1 Upper Trinity GCD

The Upper Trinity GCD is located almost entirely in the outcrop of the northern Trinity Aquifer (Figure 4.1.42). The northern Trinity Aquifer is missing where Paleozoic-age strata are exposed at the surface in the western portions of Montague, Wise, and Parker counties. The Woodbine Aquifer is not present in the Upper Trinity GCD. Two digital electric log cross sections were constructed to display the stratigraphy and sandstone development in the northern Trinity Aquifer in the Upper Trinity GCD (Figures 4.1.43 and 4.1.44). On these cross sections, both the layer terminology for the model (see Figure 4.1.6) and the local terminology of the Antlers Aquifer are given. In the west, the northern Trinity Aquifer extends from land surface down to 100 to 300 feet below land surface (Figure 4.1.43) and includes only the Hensell Aquifer, Pearsall Formation, and Hosston Aquifer. In the eastern portion of the Upper Trinity GCD, the northern Trinity Aquifer extends from land surface down to as much as 700-feet deep. The Paluxy Aquifer and Glen Rose Formation, as well as the Hensell Aquifer, Pearsall Formation, and Hosston Aquifer, are present in the southeast (Figure 4.1.44).

The northern Trinity Aquifer is sandstone-dominated across most of the Upper Trinity GCD. Shallow sandstones, 30- to 50-feet thick, are common in the west (Figure 4.1.43). Most of these thick sandstones correspond to the Hosston and Hensell aquifers. The Pearsall Formation is more shale dominated. The underlying Paleozoic-age sediments also include thick sandstones, which are in hydrologic communication with the Hosston Aquifer in some areas. In the eastern portion of the Upper Trinity GCD, sandstones are thickest in Montague County (Figure 4.1.44). In southern Parker and Hood counties, limestones of the Glen Rose Formation occupy a large part of the northern Trinity Aquifer, but sandstones of the Paluxy Aquifer are well developed above the Glen Rose Formation at depths less than 250 feet (Figure 4.1.44). Sandstones are thick locally below the Glen Rose Formation at depths ranging from 200 to 700 feet. Groundwater quality is generally good throughout the Upper Trinity GCD.

4.1.10.2 North Texas GCD

The North Texas GCD is located mostly east of the northern Trinity Aquifer outcrop, but the Woodbine Aquifer outcrop extends through the center of the District (Figure 4.1.45). Two digital electric log cross sections were constructed to display the stratigraphy and sandstone development in the northern Trinity and Woodbine aquifers in the North Texas GCD (Figures 4.1.46 and 4.1.47). In the western portion of Cooke and Denton counties, limestones of the Washita/Fredericksburg groups are exposed at the surface, overlying 500 to 800 feet of sandstones in the northern Trinity Aquifer. Limestones of the Glen Rose Formation are present in southern Denton County (Figure 4.1.46). In Collin County, sandstones in the northern Trinity Aquifer are present at much greater depths than in Denton County, owing to the eastward dipping stratigraphy (Figure 4.1.47). Sandstones in the Hosston Aquifer are found at depths greater than 5,000 feet in eastern Collin County. Sandstones in the Woodbine Aquifer range from 300- to 3,000-feet deep in Collin County. Sandstones in the Paleozoic-age sediments underlie the northern Trinity Aquifer locally in western Cooke County, but in most of the North Texas GCD, the northern Trinity Aquifer is underlain by shale and limestone. In southeastern Collin County, the Jurassic-age sandstones of the Cotton Valley Formation underlie and are in hydrologic communication with the Hosston Aquifer (Figure 4.1.47).

Sandstones in the Woodbine, Paluxy, Hensell, and Hosston aquifers are well developed in the North Texas GCD. Maximum sandstone thicknesses (summing all aquifers/formations across the study area) containing good quality groundwater are located in the North Texas GCD and in

adjacent Grayson and Dallas counties. Multiple, sandstone-dominated, fluvial and shoreline depositional systems are superimposed in the North Texas GCD. The western portion of the North Texas GCD includes thick sequences of northern Trinity Aquifer sandstones and relatively minor shales and limestones (Figure 4.1.46). In the eastern portion of the North Texas GCD in Collin County, sandstones in the northern Trinity Aquifer, although more deeply buried, are thicker than in the western portion of the North Texas GCD (Figure 4.1.47). In the Hosston Aquifer, the base of low salinity groundwater is 5,000-feet deep or deeper in parts of Collin County. The Woodbine Aquifer comprises 200 to 350 feet of sandstone having low to moderate salinity groundwater in Collin County.

4.1.10.3 Northern Trinity GCD

The Northern Trinity GCD is located east of the northern Trinity Aquifer outcrop, but the Woodbine Aquifer outcrop extends through the eastern portion of the District (Figure 4.1.48). Two digital electric log cross sections were constructed to display stratigraphy and sandstone development in the northern Trinity and Woodbine aquifers in the Northern Trinity GCD (Figures 4.1.49 and 4.1.50). On these cross sections, both the layer terminology used for the model and the local terminology of Twin Mountains Aquifer are given. The limestones of the Glen Rose Formation and the Washita/Fredericksburg groups are well developed confining layers throughout the Northern Trinity GCD. Sandstones of the Hensell and Hosston aquifers range in depth from about 500 feet in the west to 2,000 feet in the east (Figure 4.1.50). Sandstones in the Paluxy Aquifer range in depth from 100 to 1,000 feet. Sandstones in the Woodbine Aquifer are present at the surface to about 400 feet in the eastern portion of the District. The northern Trinity Aquifer is underlain by Paleozoic-age sandstone, shale, and limestone sediments throughout the Northern Trinity GCD, which are generally thin bedded and shale dominated (Figure 4.1.49).

The sandstones of the Paluxy, Hensell, and Hosston aquifers are well developed in the Northern Trinity GCD. The Paluxy Aquifer is composed of greater than 60 percent sandstone everywhere except in the northwest corner of Tarrant County. Major, east-oriented, fluvial channel axes in the Paluxy Aquifer are expressed as thick-bedded sandstone (Figure 4.1.49). The Hosston and Hensell aquifers also contain greater than 60 percent sandstone. The sandstones of the Paluxy and Hosston aquifers form the most hydraulically conductive and transmissive layers in the Northern Trinity GCD. In the channelized fluvial depositional systems of the Paluxy, Hensell,

and Hosston aquifers, however, well-to-well variability is high. Thick, river-channel sandstones are enclosed in shale-dominated interchannel areas. The abrupt sandstone-shale transitions are well displayed on the cross sections in Figures 4.1.49 and 4.1.50. Groundwater quality is good throughout the Northern Trinity GCD.

4.1.10.4 Prairielands GCD

The Prairielands GCD covers a broad region in the center of the study area. The western portion of the Prairielands GCD is located in the northern Trinity Aquifer outcrop, and the Woodbine Aquifer outcrop extends through the center (Figure 4.1.51). Both aquifers are deeply buried in the eastern portion of the Prairielands GCD. Three digital electric log cross sections were constructed to display the stratigraphy and sandstone development in the northern Trinity and Woodbine aquifers in the Prairielands GCD (Figures 4.1.52 through 4.1.54). In Somervell County, limestones of the Glen Rose Formation overlie sandstones in the Hensell and Hosston aquifers, which range in depth from about 250 to 700 feet. The Pearsall Formation is mostly shale in Somervell County. Sandstones in the Paluxy Aquifer are exposed at the surface in the southern and eastern portions of Somervell County (Figure 4.1.52). In portions of Johnson and western Hill counties, sandstones in the Woodbine Aquifer are exposed at the surface. Thick sequences of limestones in the Washita/Fredericksburg groups and Glen Rose Formation confine the Paluxy, Hensell, and Hosston aquifers (Figure 4.1.53). Sandstones of the Paluxy Aquifer are buried at depths ranging from 300 to 1,000 feet in Johnson and western Hill counties. Sandstones in the Hensell and Hosston aquifers range in depth from 1,000 to 2,000 feet (Figure 4.1.53). Ellis and eastern Hill counties include the full suite of sandstones in the northern Trinity and Woodbine aquifers (Figure 4.1.54). Sandstones in the Hosston Aquifer are underlain by shale- and limestone-dominated strata of Paleozoic age.

Sandstones in the northern Trinity and Woodbine aquifers are variably developed across the Prairielands GCD. Sandstones in the Woodbine and Paluxy aquifers are thick and concentrated (high sandstone percentages) in the northern portions of Ellis and Johnson counties, but thin southward, reaching essentially zero thickness in southern Hill County (Figures 4.1.53 and 4.1.54). Sandstones in the Hensell Aquifer are thick in Somervell and Johnson counties but are much thinner in Ellis and eastern Hill counties. Sandstones in the Hosston Aquifer, however, are well developed and contain low salinity groundwater throughout the Prairielands GCD. The Woodbine and Paluxy aquifers contain low salinity groundwater in Johnson and western Ellis

counties, whereas low salinity groundwater in the Hensell Aquifer is mainly restricted to Johnson and Somervell counties.

4.1.11 Summary of Northern Trinity and Woodbine Aquifers Hydrostratigraphy

Cretaceous-age sandstones in the northern Trinity and Woodbine groups in central and north-central Texas are important sources of groundwater and comprise the northern Trinity and Woodbine aquifers. The stratigraphy of the Cretaceous-age strata consists of interbedded sandstones, limestones, and shales. Cretaceous-age strata thicken and dip toward the East Texas Basin where they are overlain by thousands of feet of younger strata. Only along the western and northern margins of the East Texas Basin are Cretaceous-age sandstones saturated with fresh groundwater. The northern Trinity and Woodbine aquifers extend from the Edwards Plateau, through the Hill Country, and to the northeast into Oklahoma and Arkansas.

The Cretaceous Period (145 to 65 million years ago) was characterized by rising sea level and episodic input of sandy sediment. Limestones were deposited in shallow marine waters, whereas sandstones were deposited mainly in rivers on sandy coastal plains and along marine shorelines. Depositional environment controls sandstone geometry and orientation, which in turn, influence groundwater flow directions. Geographically fluctuating shorelines resulted in stratigraphic interlayering of sandstone and limestone (shale is interbedded with both). Sandstones form the aquifer units, and limestones form the confining units in the northern Trinity, Washita/Fredericksburg, and Woodbine groups. The hydrostratigraphy of the northern Trinity and Woodbine aquifers is based on this lithologic interlayering. The Woodbine, Paluxy, Hensell and Hosston aquifers are sandstone-dominated, the Glen Rose and Pearsall formations are mixed lithology, and the Washita/Fredericksburg groups are limestone-dominated.

At the regional level, geologic structure is relatively simple in the Cretaceous-age strata of north-central Texas. Stratigraphic dips range from eastward in the south to southward in the northeast. Gently folded strata are present in the northwest, and large, northeast-oriented fault zones are present in the south (Balcones Fault Zone) and along the eastern margin of the study area (Mexia-Talco Fault Zone). Faults in the Balcones Fault Zone displace aquifer sandstones by several hundred vertical feet and have the greatest potential to influence vertical groundwater flow within the freshwater interval. Faults in the Mexia-Talco Fault Zone are located downdip from the freshwater interval. Smaller, more localized faults and fractures are known to be

abundant in Cretaceous-age strata, but their effects on groundwater flow and quality have not been documented.

The northern Trinity Aquifer is sandstone-dominated in the northwest, where it is locally referred to as the Antlers Aquifer. In the rest of the study area, limestones of the Glen Rose Formation separate the lower portion of the northern Trinity Aquifer (i.e., sandstones of the Hosston and Hensell aquifers and the Pearsall Formation) from the sandstones in the upper portion of the northern Trinity Aquifer (i.e., Paluxy Aquifer). Sandstones in the Woodbine Aquifer are separated from the underlying northern Trinity Aquifer by limestones and shales in the Washita/and Fredericksburg groups. The Hosston Aquifer, which is the stratigraphically lowest sandstone layer, is the most widespread and best developed aquifer in the system. The Hosston Aquifer includes greater net sandstone and thicker individual sandstones than any other layer. The Hensell Aquifer is well developed in western portions of the study area, but thins and becomes increasingly shale dominated to the east. The Pearsall and Glen Rose formations include sandstones only in the north. The Paluxy Aquifer is dominated by thick sandstones across broad areas, where it rivals the Hosston Aquifer, but thins across the southern one-third of the study area. The Woodbine Aquifer includes thick sandstones in the east-central and northeastern portions of the study area.

With two exceptions, the distribution of low salinity groundwater in the northern Trinity and Woodbine aquifers coincides in a general way with sandstone development. Low salinity groundwater extends deepest and farthest southeast in widespread sandstones of the Hosston Aquifer. In the other aquifers/formations, low salinity groundwater is more limited geographically, coinciding with areas of maximum sandstone thickness. One exception is in the counties in northeastern Texas located east of Fannin County. Sandstones in the northern Trinity and Woodbine aquifers are present in this area, but contain poor quality groundwater. The second exception occurs along the eastern boundary of the study area at depths below the base of the low salinity groundwater.

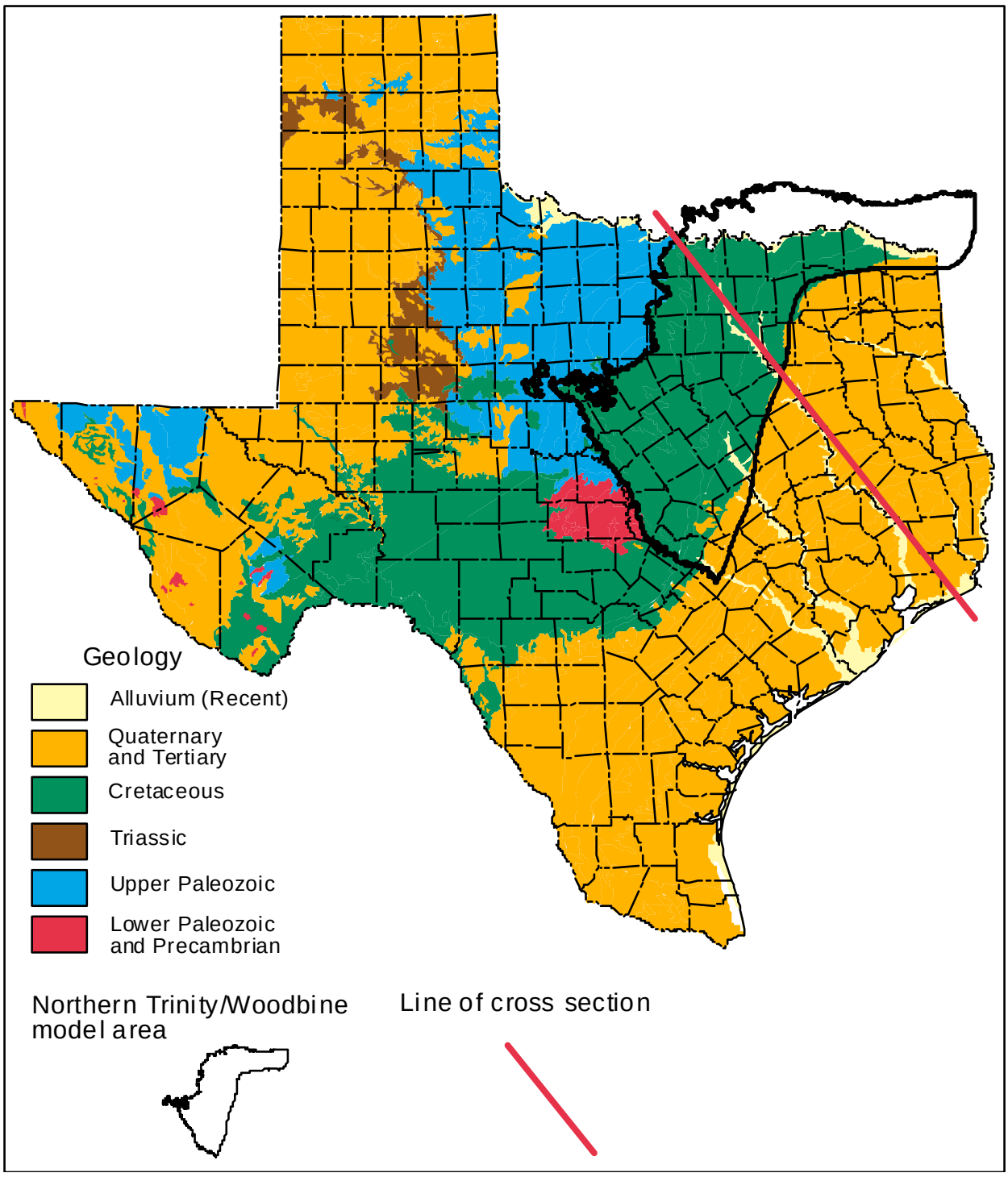


Figure 4.1.1 **Simplified surface geology of Texas showing the study area and the location of the cross section in Figure 4.1.3 (modified from Bureau of Economic Geology, 1992).**

Age m.y	Period	Group	Formations					
			North and West	Central		South		
65	Upper Cretaceous	Eagle Ford	not present	undifferentiated		undifferentiated		
		Woodbine	not present	undifferentiated		undifferentiated		
		Washita	Grayson Mainstreet Pawpaw Weno Denton Fort Worth Duck Creek	Buda Del Rio Georgetown		Buda Del Rio Georgetown		
100	Lower Cretaceous	Fredericksburg	Kiamichi Goodland Walnut	Kiamichi Edwards Comanche Peak Walnut		Kiamichi Edwards Comanche Peak Walnut		
		Trinity	Antlers	Paluxy Glen Rose		Paluxy Glen Rose		
				Twin Mountains	Hensell Pearsall Hosston	Travis Peak	Hensell Pearsall/Cow Creek/Hammett Hosston/Sligo	

Figure 4.1.2 Stratigraphic correlation showing Cretaceous-age stratigraphy in various portions of the study area (modified from Fisher and Rodda, 1966, 1967; Salvador and Muneton 1989; Walker and Geissman, 2009).

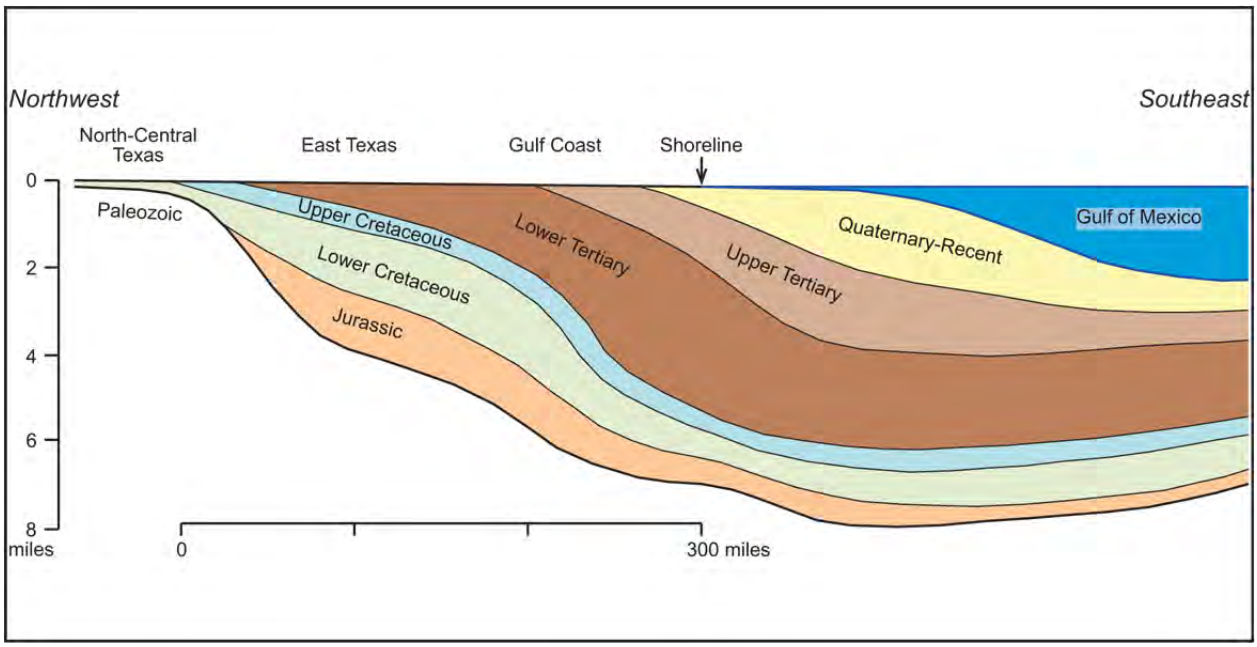


Figure 4.1.3 Schematic cross section showing sedimentary fill of the Gulf of Mexico Basin (modified from Salvador, 1991).

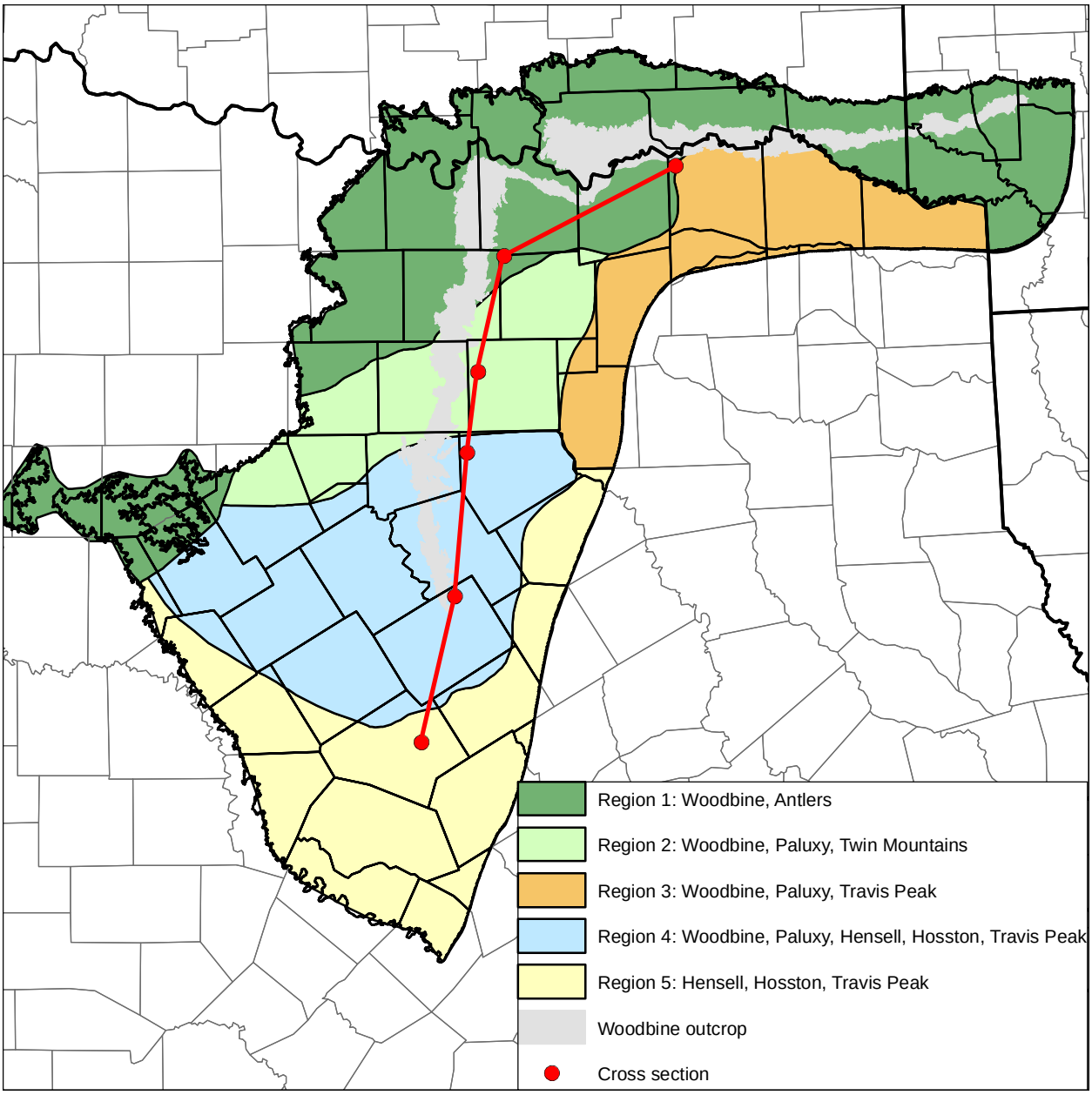
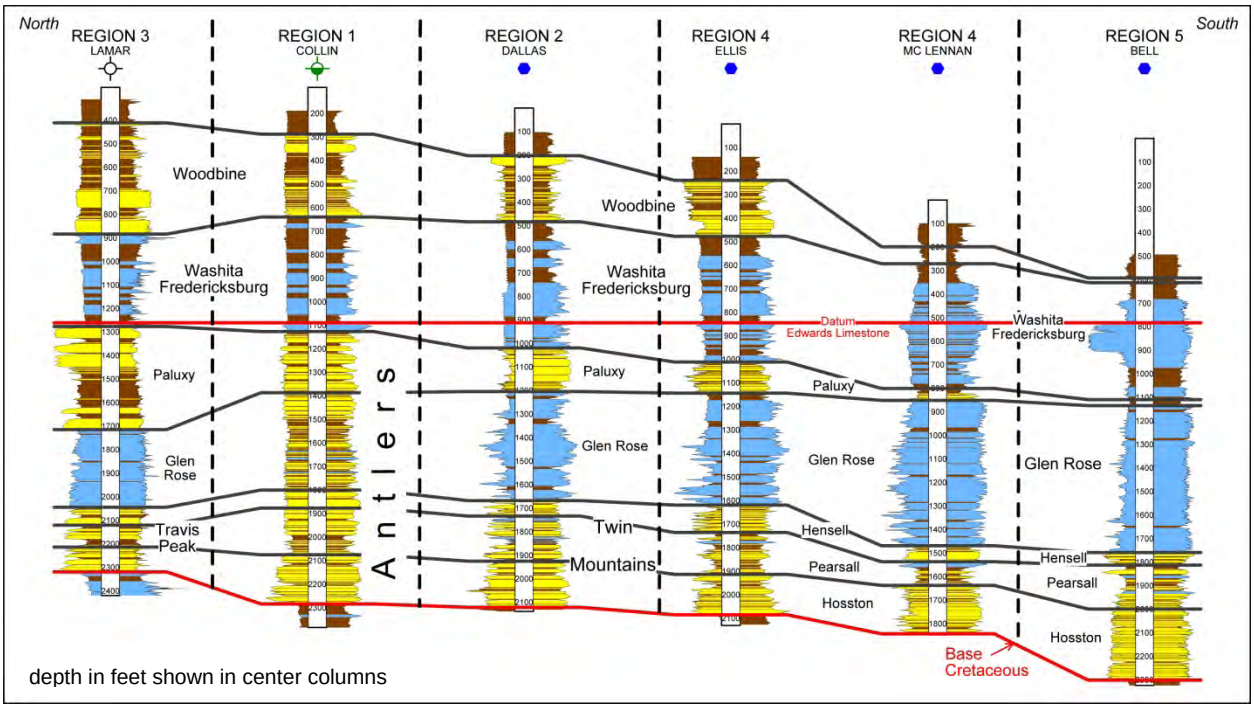


Figure 4.1.4 **Study area showing regions defined by stratigraphic and lithologic similarities and aquifer names common to each region, and the location of the cross section shown in Figures 4.1.5.**



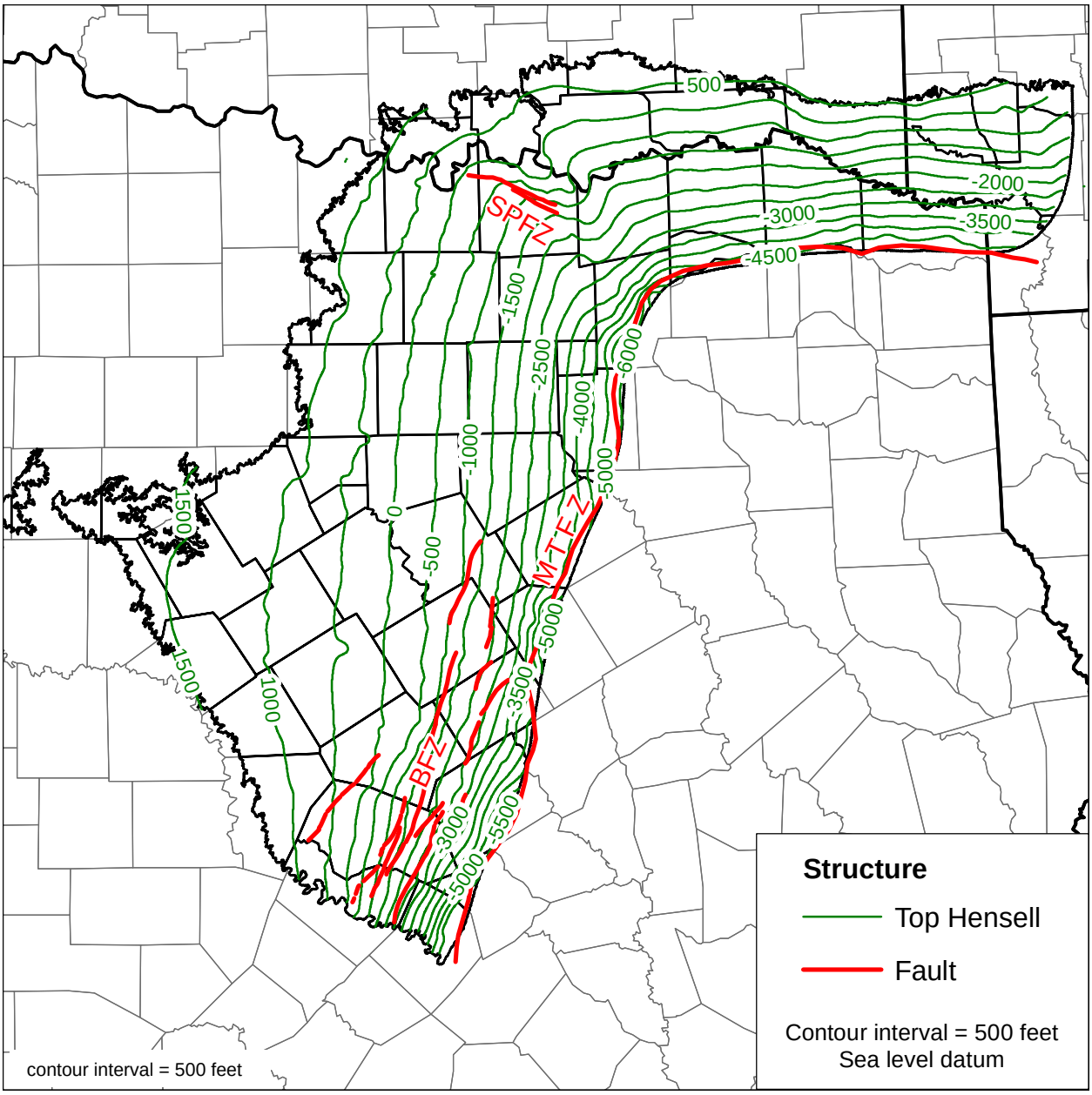
yellow = greater than 50 percent sandstone, blue = greater than 50 percent limestone, brown = greater than 50 percent shale

Figure 4.1.5 Cross section composed of typical electric logs in Regions 1 through 5 showing digital spontaneous potential curve on the left and a resistivity (short normal) curve on the right and aquifer names common to each region.

Model Terminology	Region 1	Region 2	Region 3	Region 4	Region 5
Woodbine Aquifer	Woodbine	Woodbine	Woodbine	Woodbine	Woodbine (no sand)
Washita/ Fredericksburg Groups	Washita/ Fredericksburg	Washita/ Fredericksburg	Washita/ Fredericksburg	Washita/ Fredericksburg	Washita/ Fredericksburg
Paluxy Aquifer	Antlers	Paluxy	Paluxy	Paluxy	Paluxy (no sand)
Glen Rose Formation	Antlers	Glen Rose	Glen Rose	Glen Rose	Glen Rose
Hensell Aquifer	Antlers	Twin Mountains	Travis Peak	Hensell/ Travis Peak	Hensell/ Travis Peak
Pearsall Formation	Antlers	Twin Mountains	Travis Peak	Pearsall/ Sligo	Pearsall/ Sligo
Hosston Aquifer	Antlers	Twin Mountains	Travis Peak	Hosston/ Travis Peak	Hosston/ Travis Peak

yellow = sandstone aquifers

Figure 4.1.6 Chart showing model terminology and corresponding formation names and aquifer names common to each region.



BFZ = Balcones Fault Zone
MTFZ = Mexia-Talco Fault Zone (numerous closely spaced faults are represented by a single line)
SPFZ = Sherman/Preston Fault Zone

Figure 4.1.7 Top of the Hensell Aquifer in feet above mean sea level and locations of faults that displace Cretaceous-age strata (from Ewing, 1990, 1991).

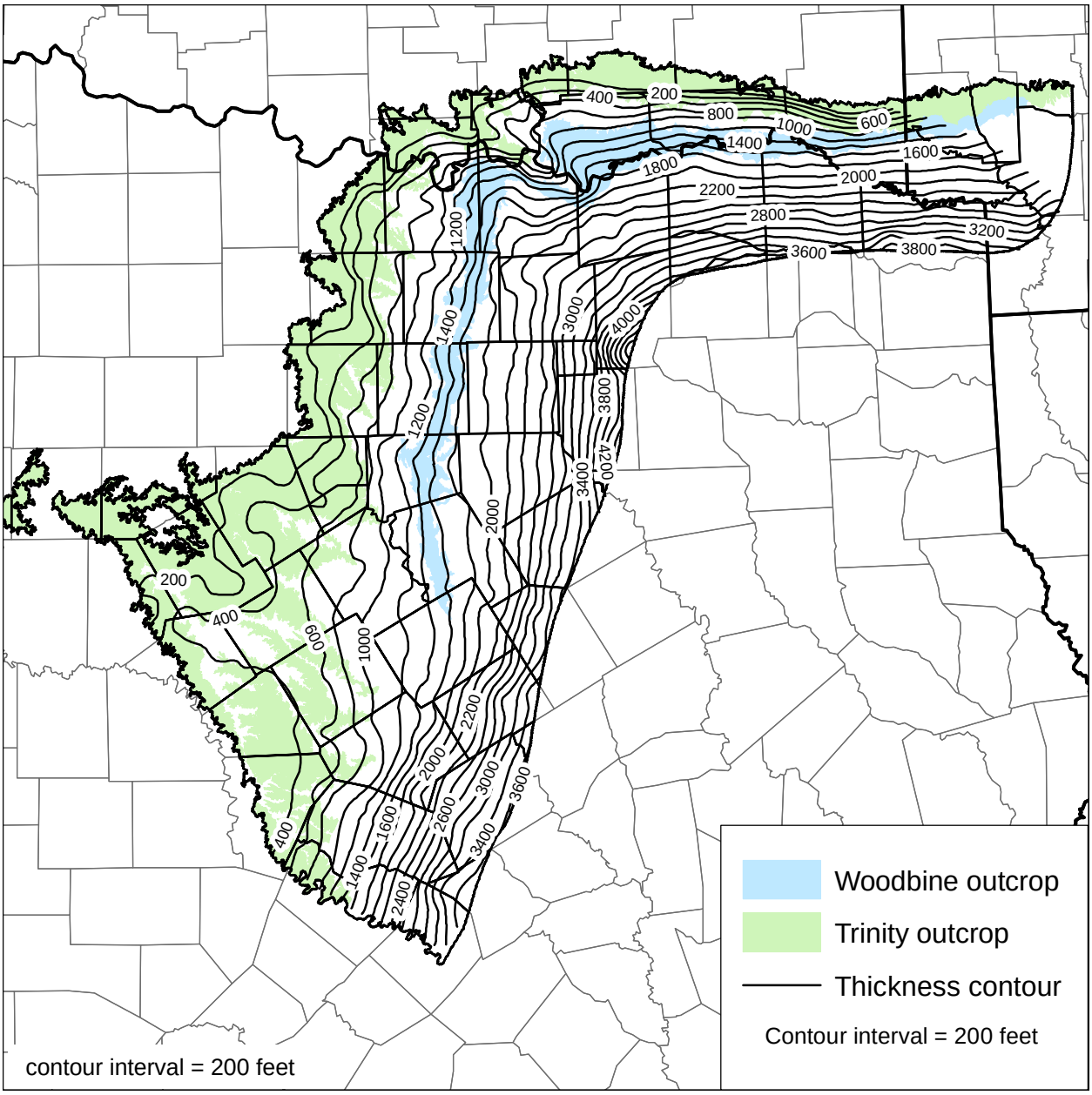


Figure 4.1.8 Isopach (thickness) map in feet from the base of the Cretaceous-age strata to the top of the Woodbine Aquifer.

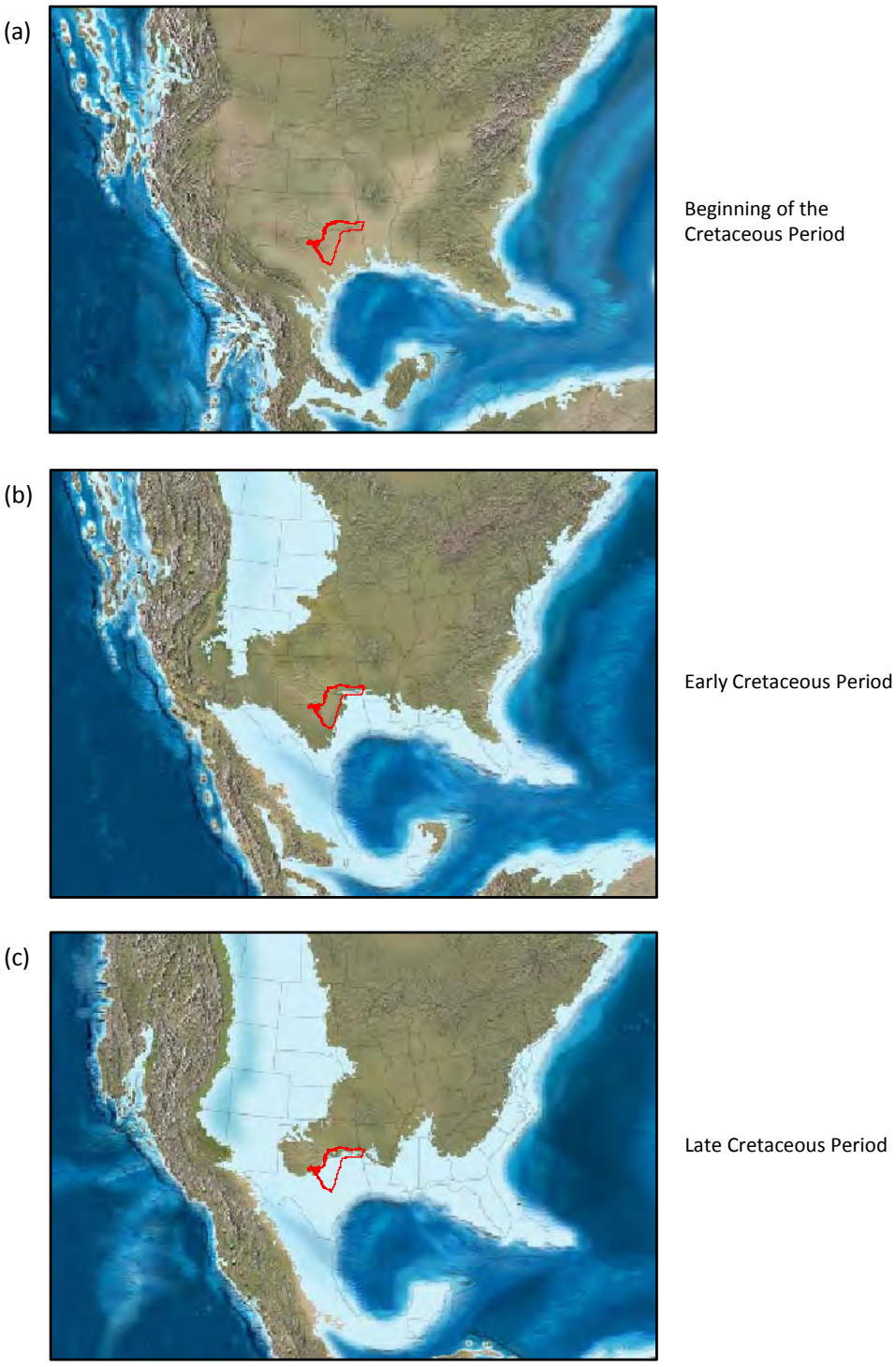


Figure 4.1.9 **Paleogeographic reconstructions showing (a) the beginning of the Cretaceous Period prior to deposition of the northern Trinity Group, (b) the early Cretaceous Period during deposition of the lower northern Trinity Group sandstones, and (c) the late Cretaceous Period during deposition of the Woodbine Group sandstones (modified from Blakey, 2011). (Brown areas represent land, light blue areas represent shallow marine water, and dark blue areas represent deep marine water.)**

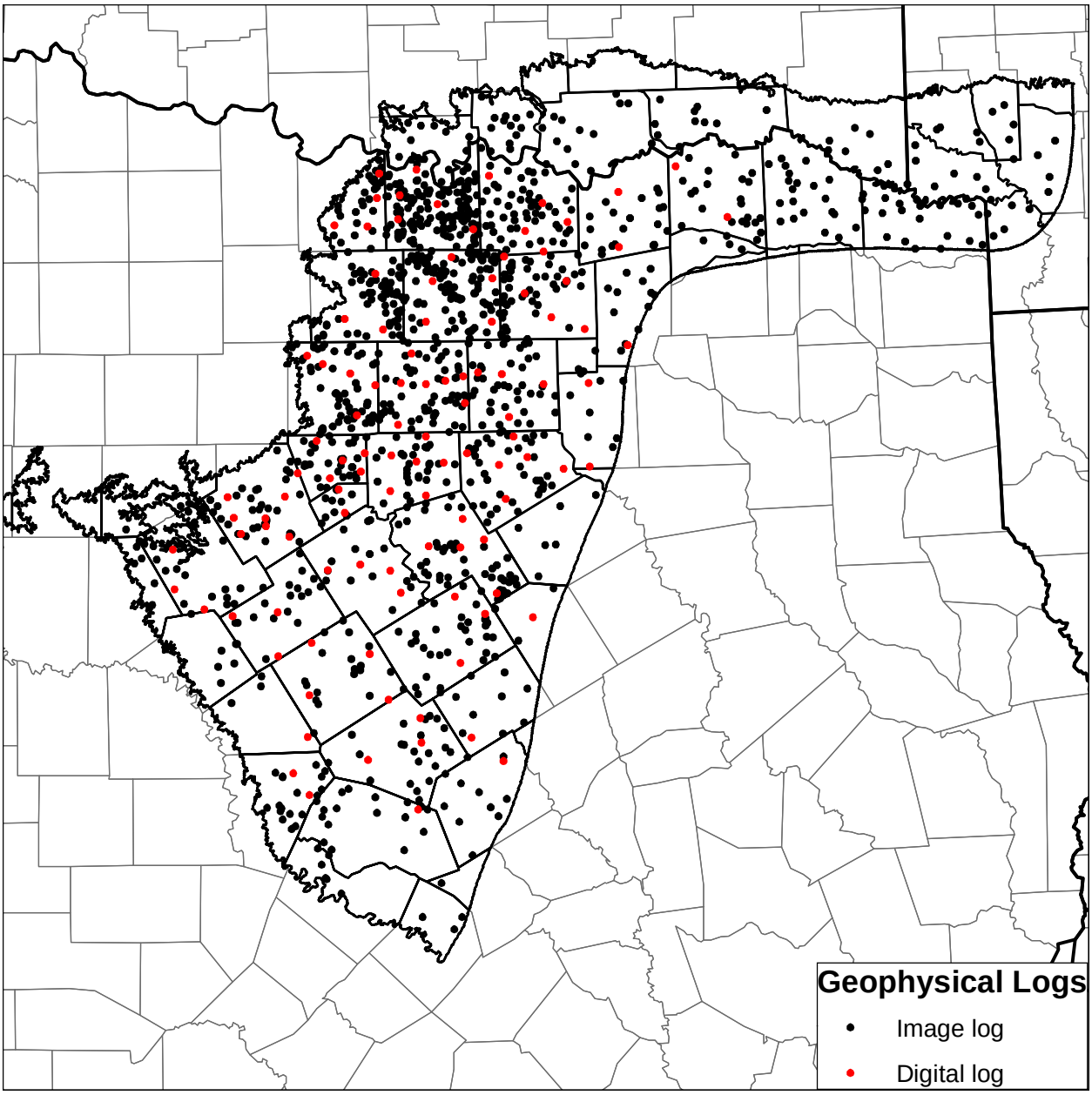
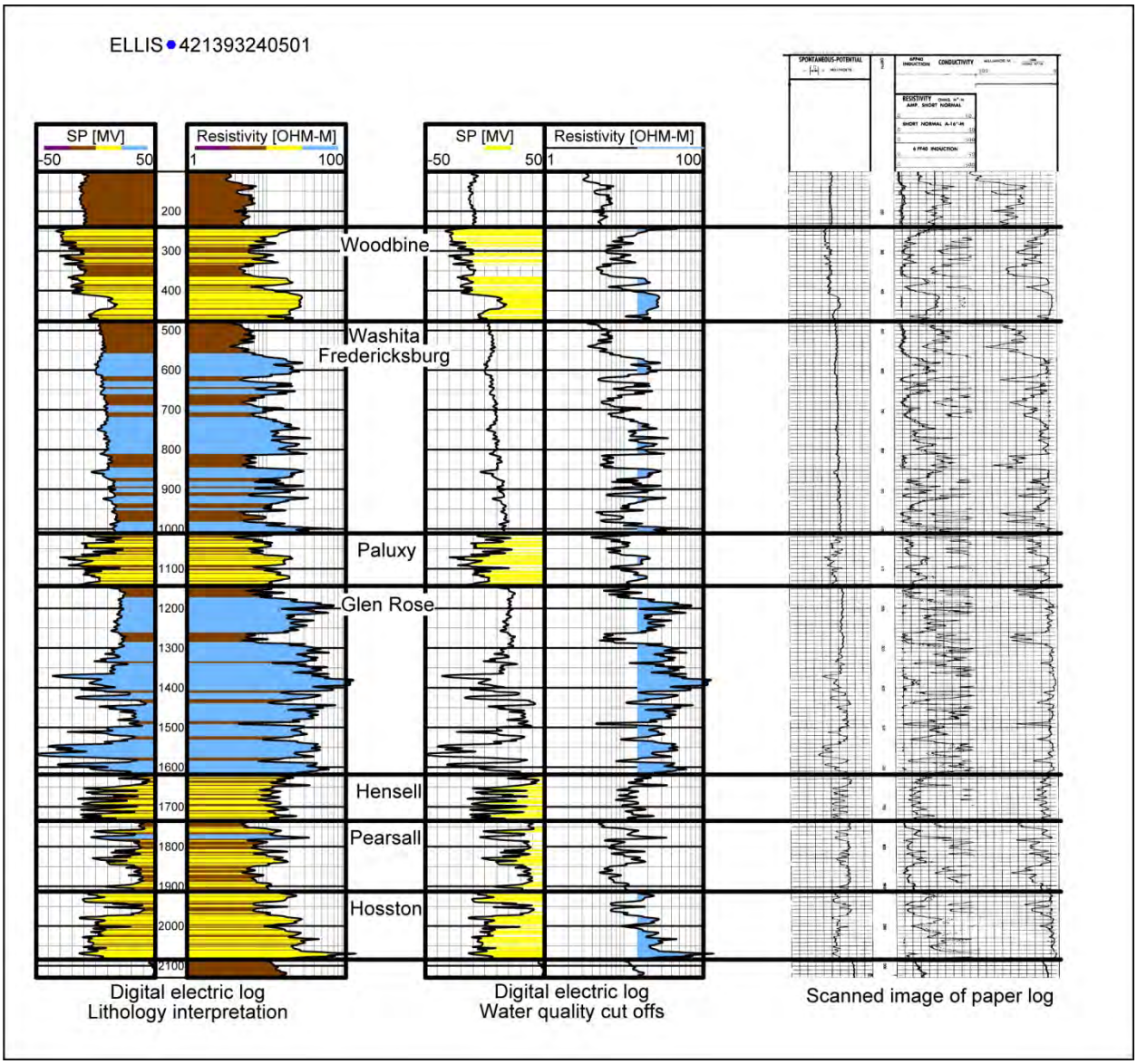


Figure 4.1.10 Location of geophysical well log data used for this study distinguishing between the 1,193 image logs and the 109 digital logs.



yellow = greater than 50 percent sandstone, blue = greater than 50 percent limestone, brown = greater than 50 percent shale

Figure 4.1.11 Example electric log from a well in Ellis County showing differences between digital logs and image (raster) logs from the same well.

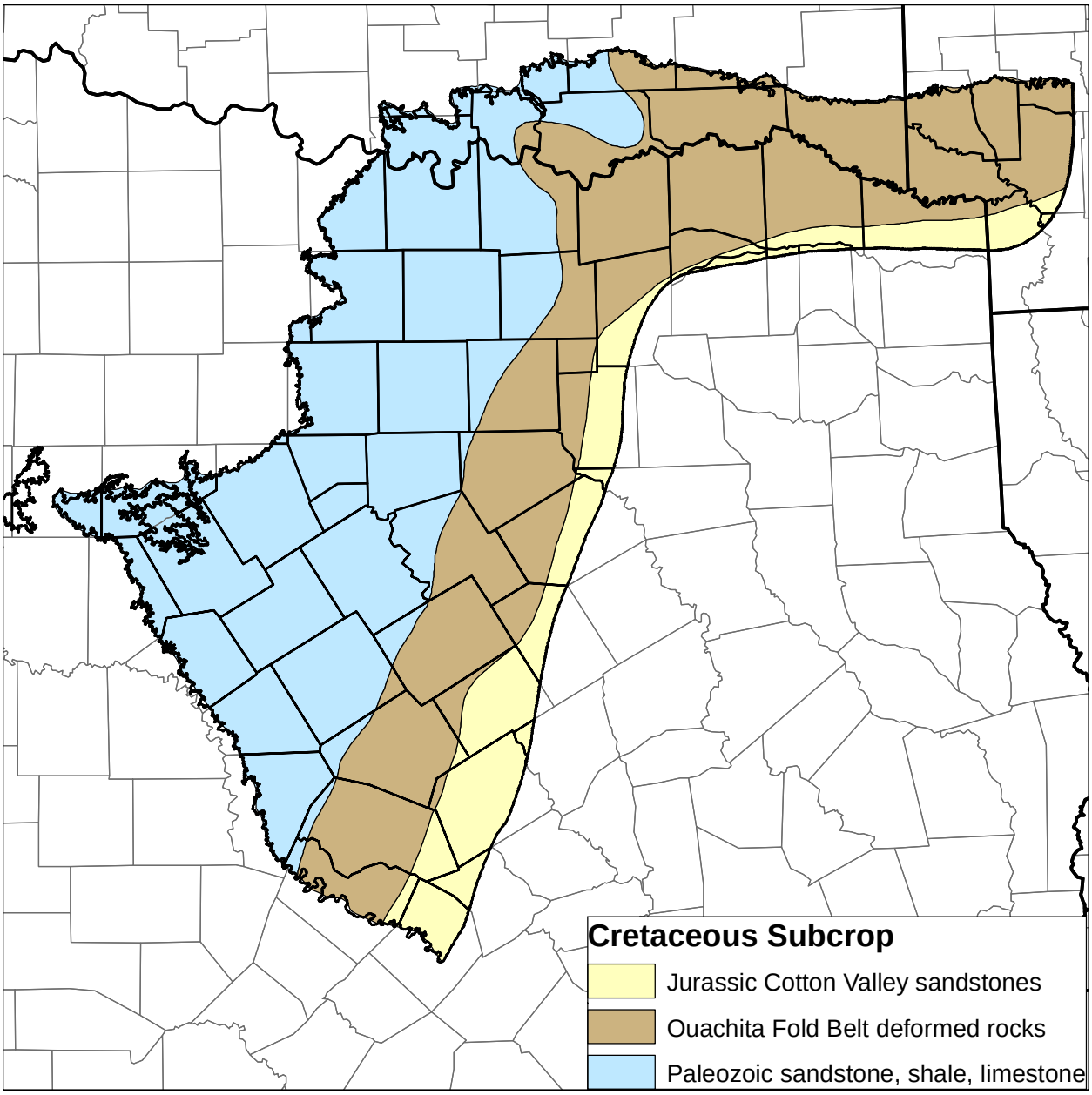


Figure 4.1.12 Geologic terrains underlying Cretaceous-age strata in the study area (modified from Ewing, 1990).

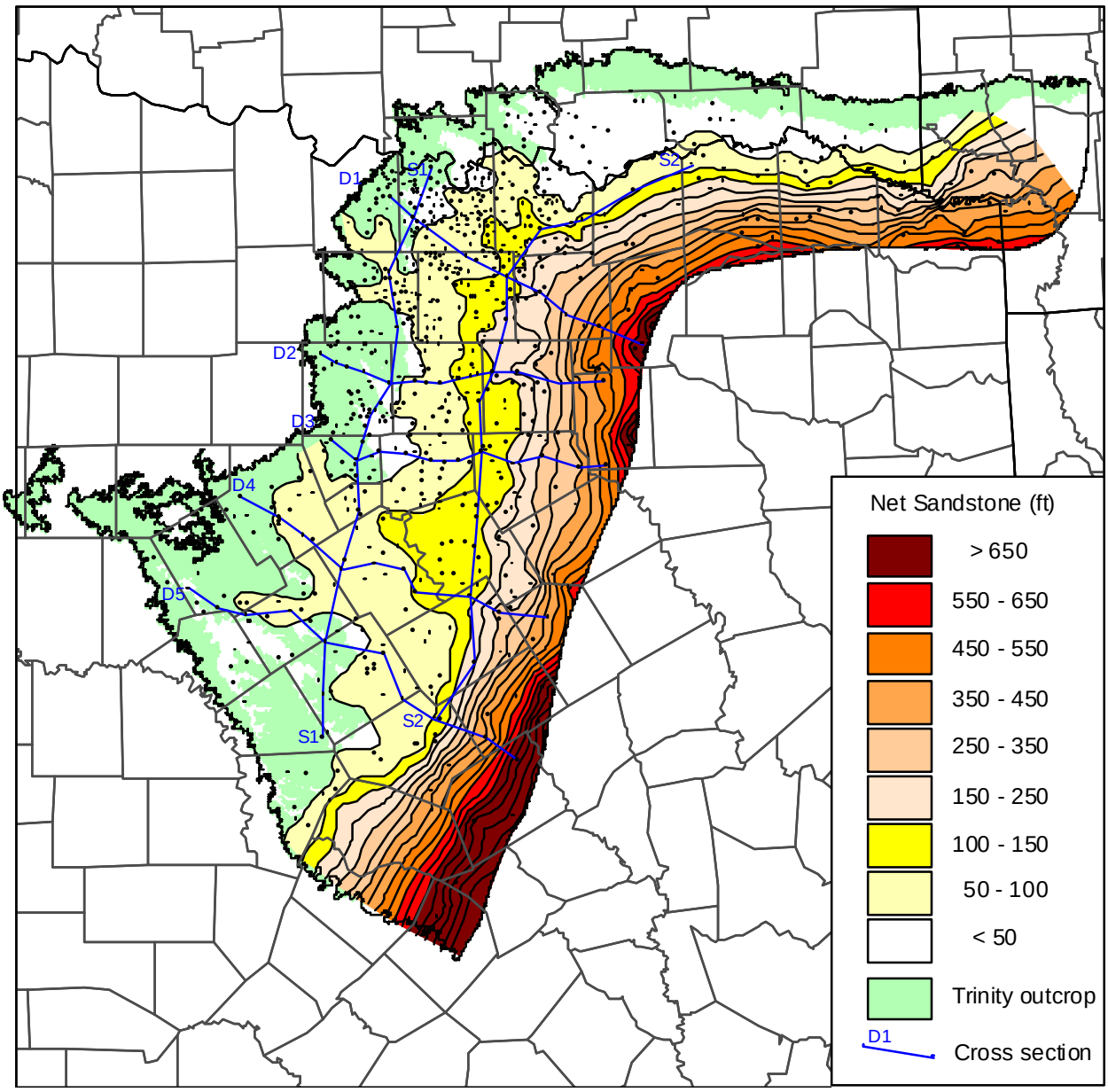


Figure 4.1.13 Net sandstone in the Hosston Aquifer in feet and location of cross sections shown in Figures 4.1.31 through 4.1.37.

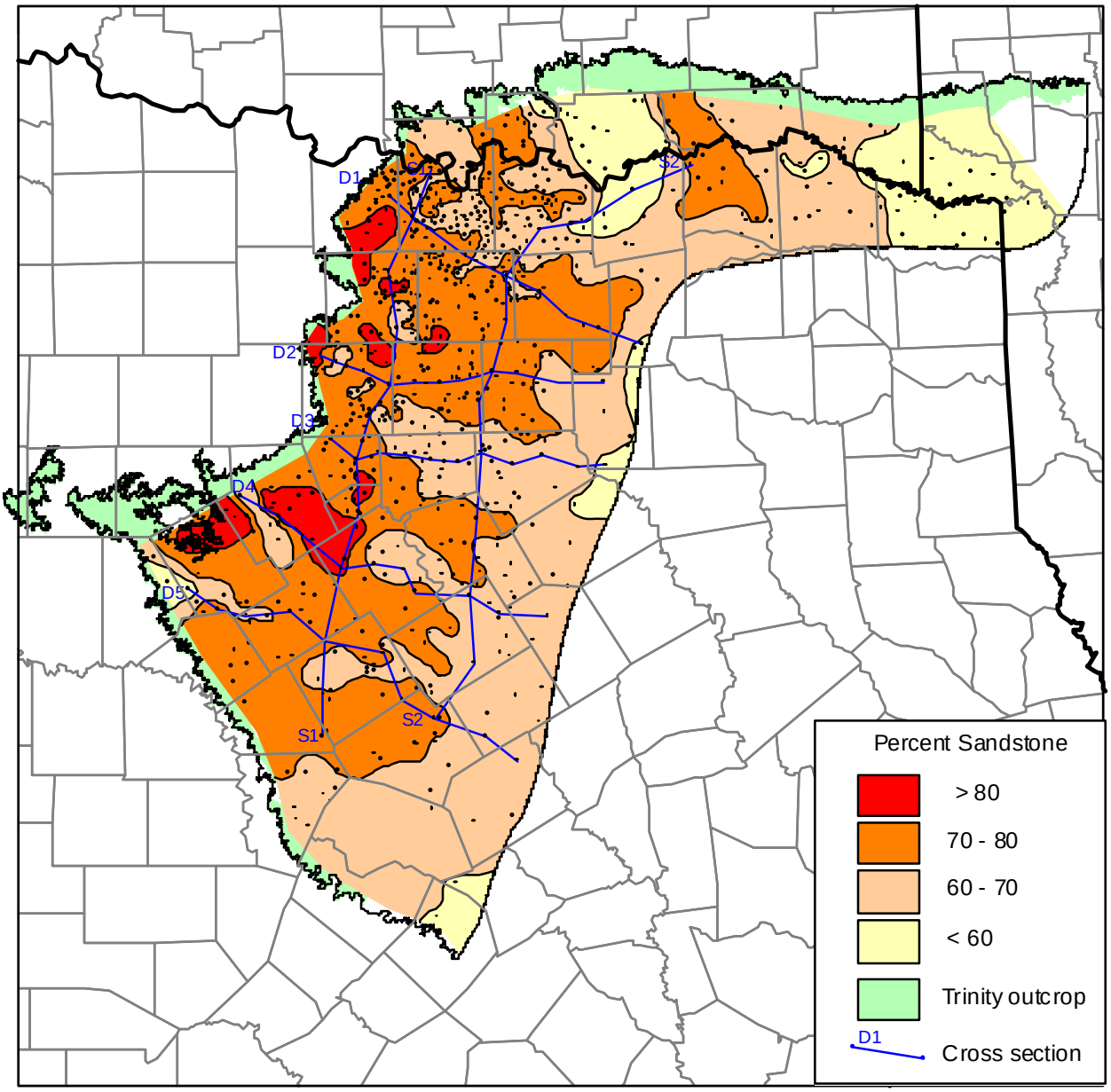


Figure 4.1.14 Percent sandstone in the Hosston Aquifer and location of cross sections shown in Figures 4.1.31 through 4.1.37.

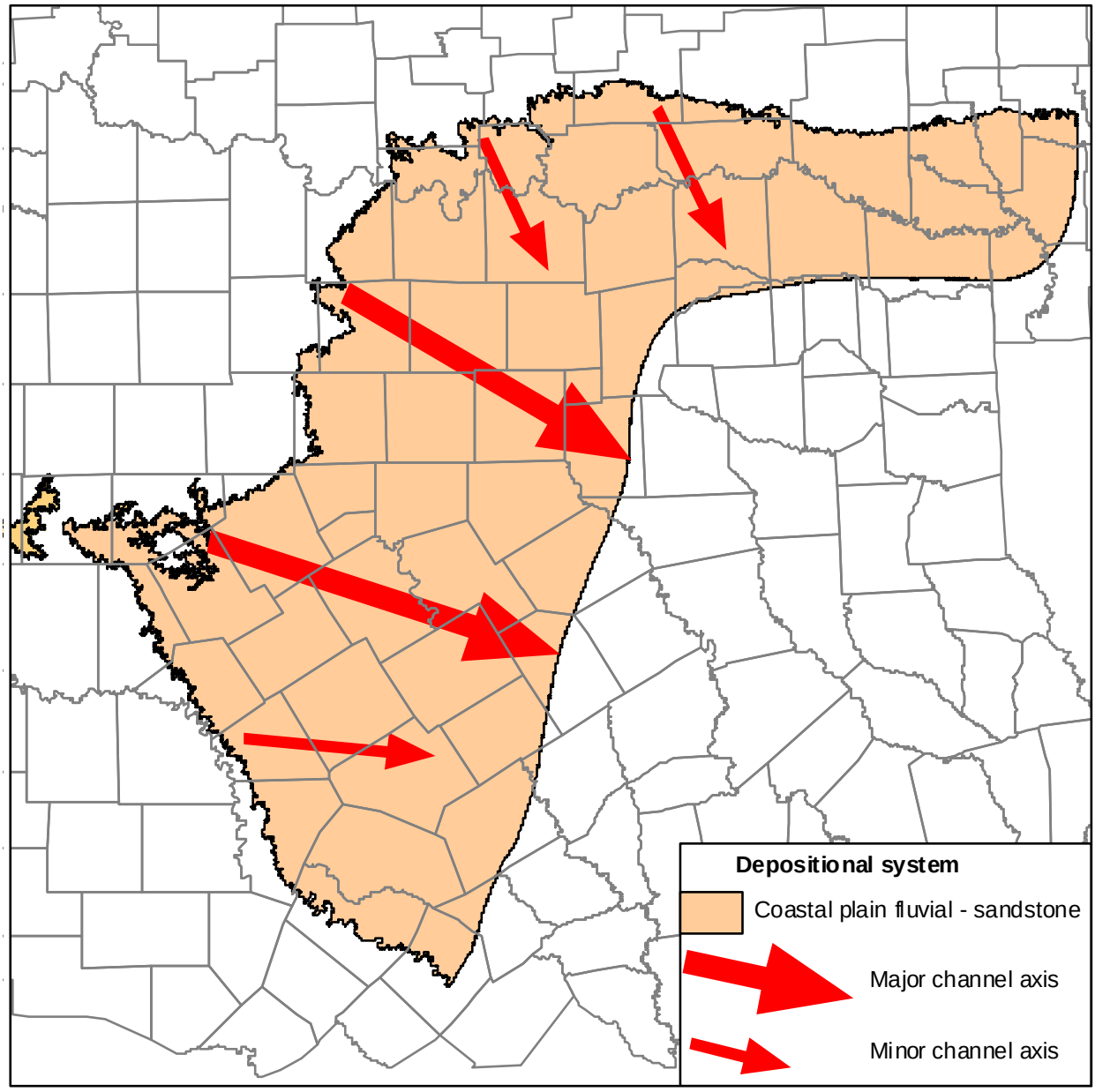


Figure 4.1.15 Depositional systems of the Hosston Aquifer showing locations where larger rivers persisted.

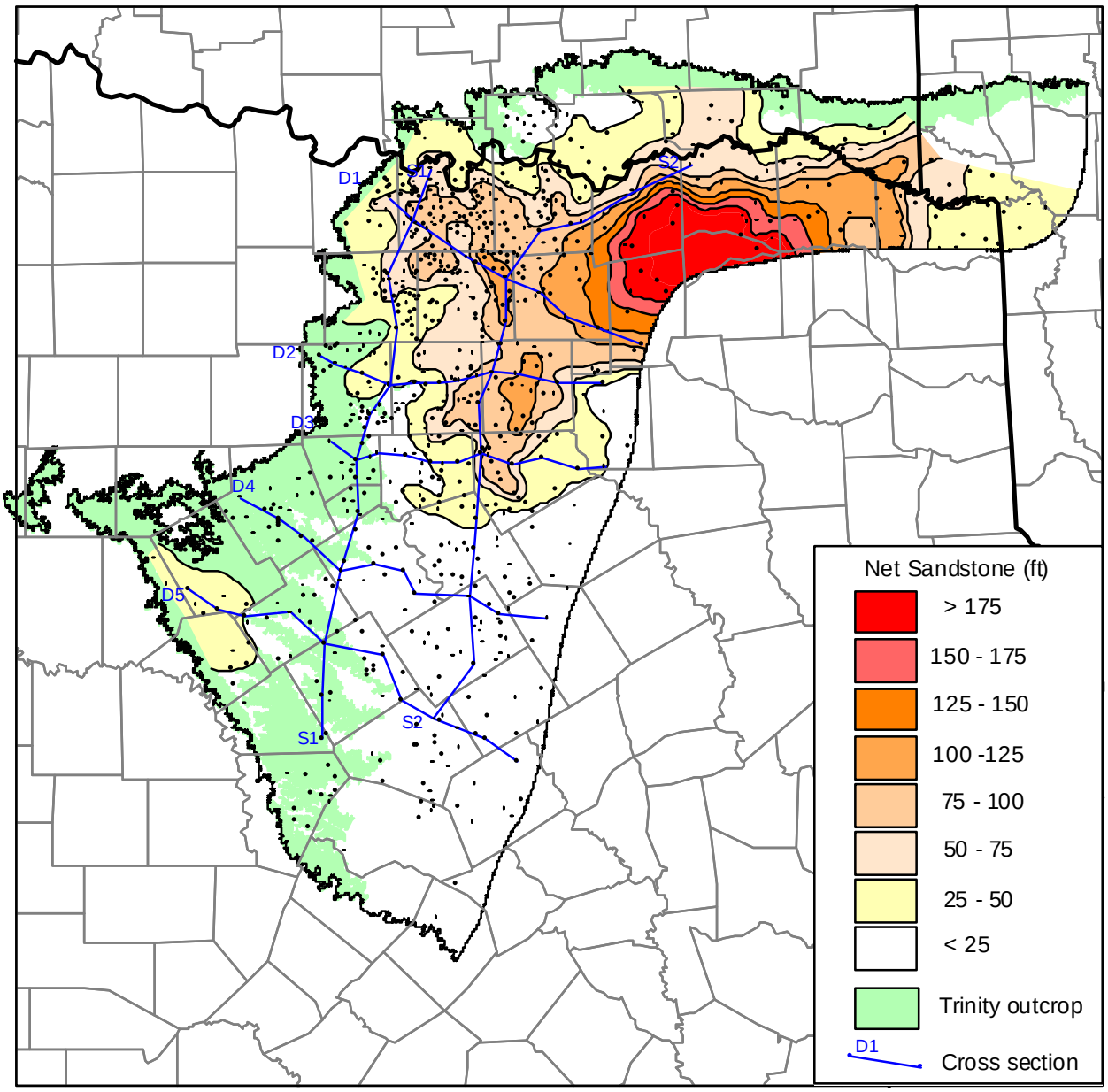


Figure 4.1.16 Net sandstone in the Pearsall Formation in feet and locations of cross sections shown in Figures 4.1.31 through 4.1.37.

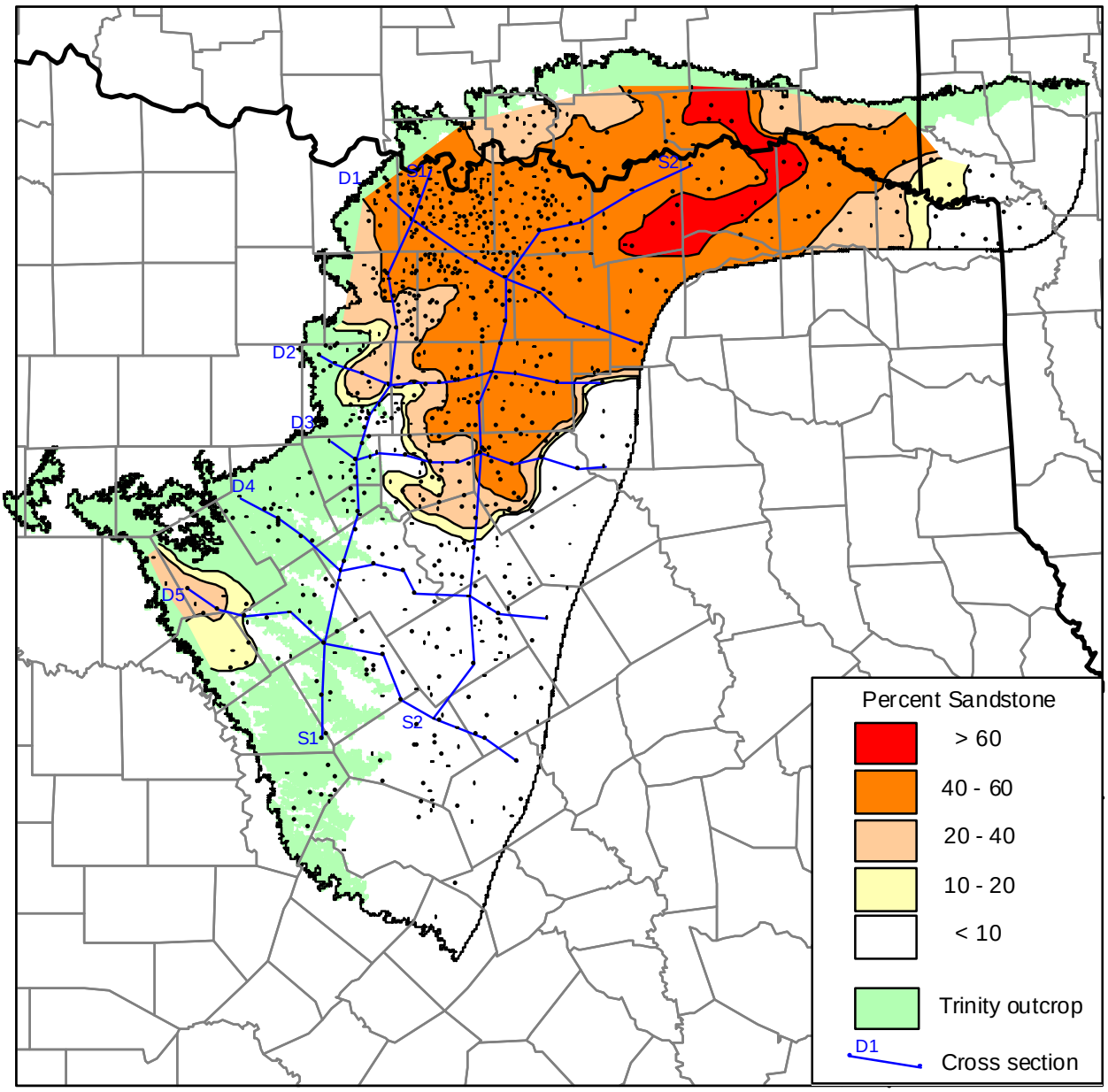


Figure 4.1.17 Percent sandstone in the Pearsall Formation and locations of cross sections shown in Figures 4.1.31 through 4.1.37.

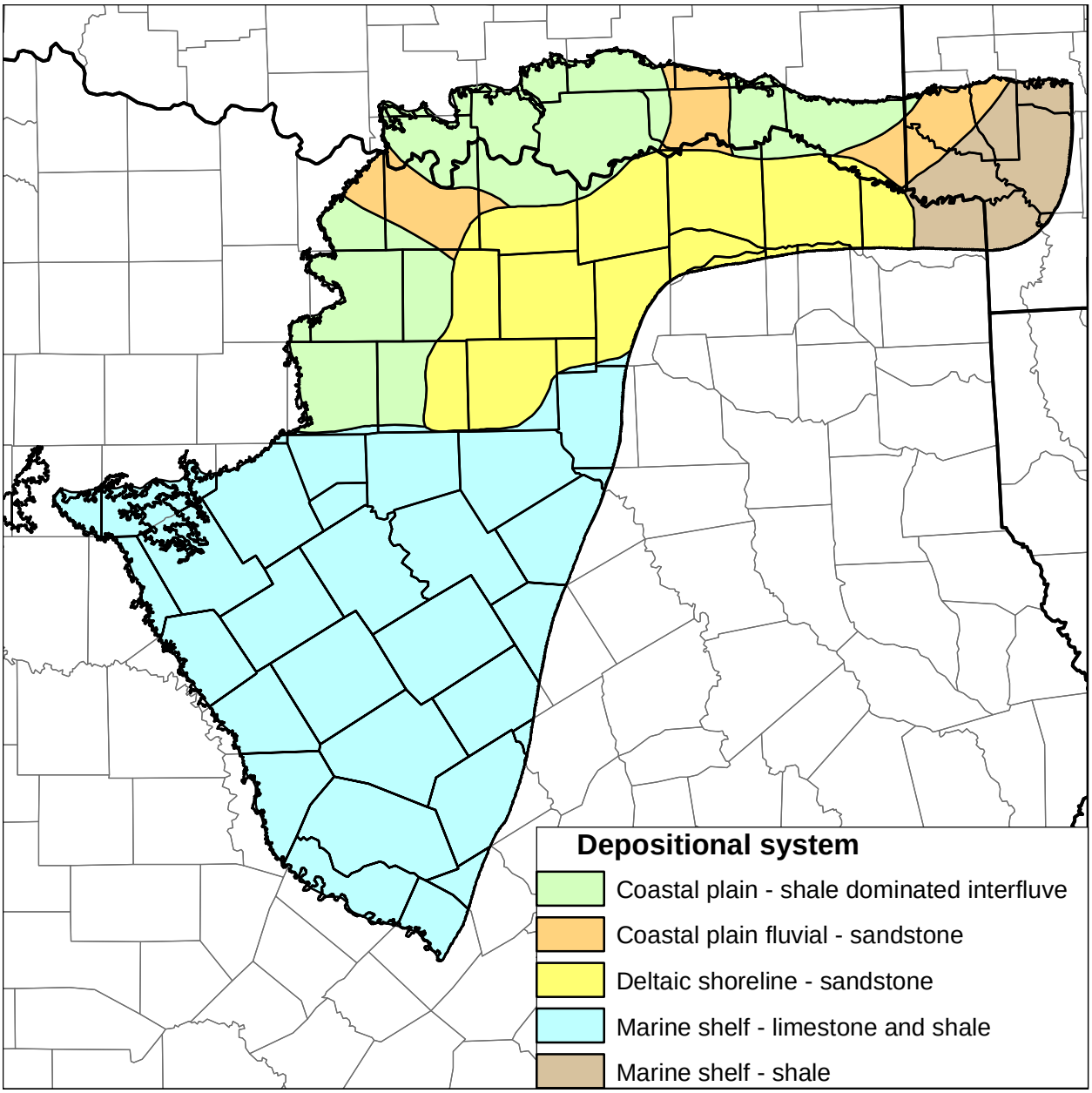


Figure 4.1.18 Depositional systems of the Pearsall Formation.

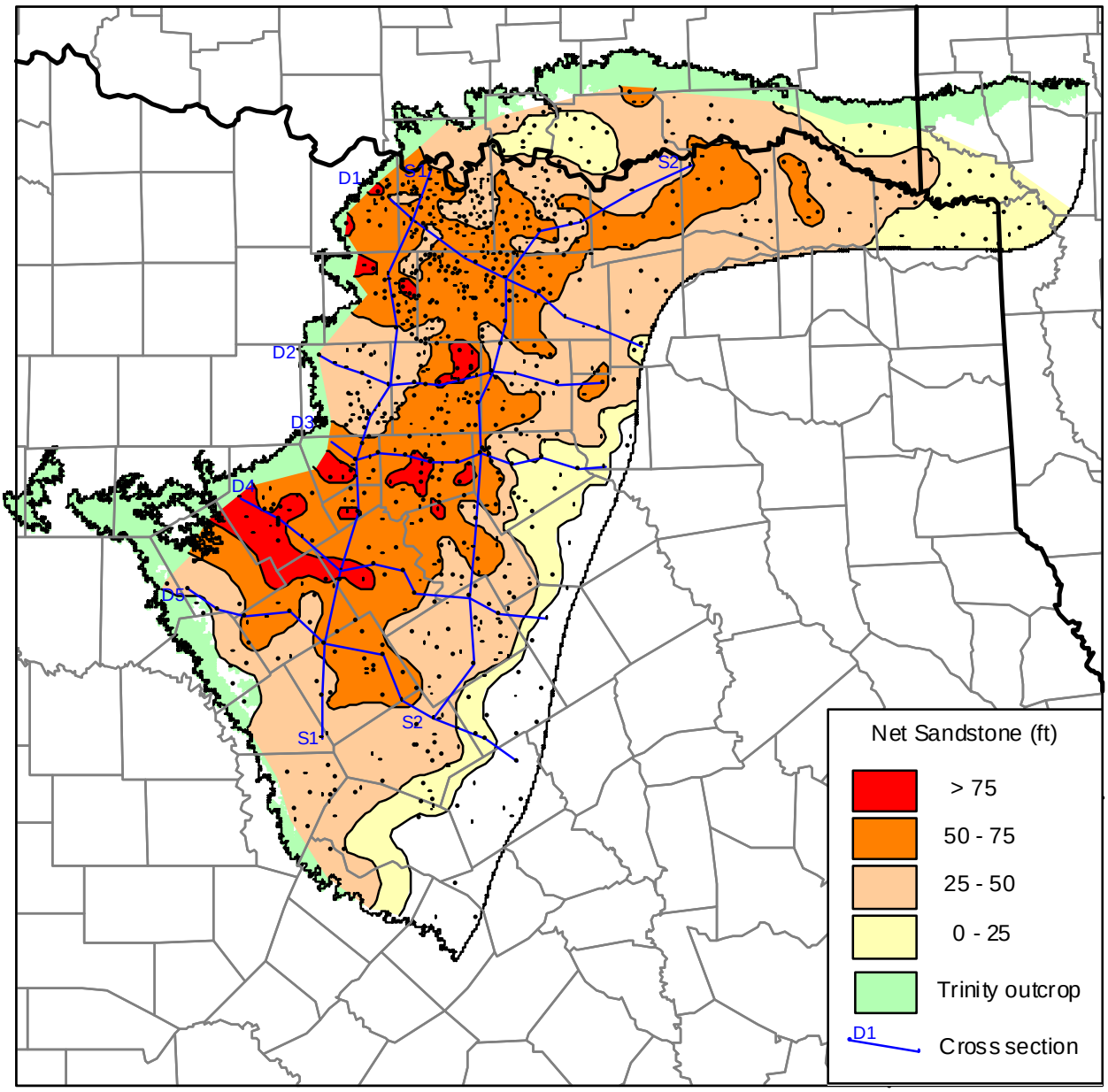


Figure 4.1.19 Net sandstone in the Hensell Aquifer in feet and locations of cross sections shown in Figures 4.1.31 through 4.1.37.

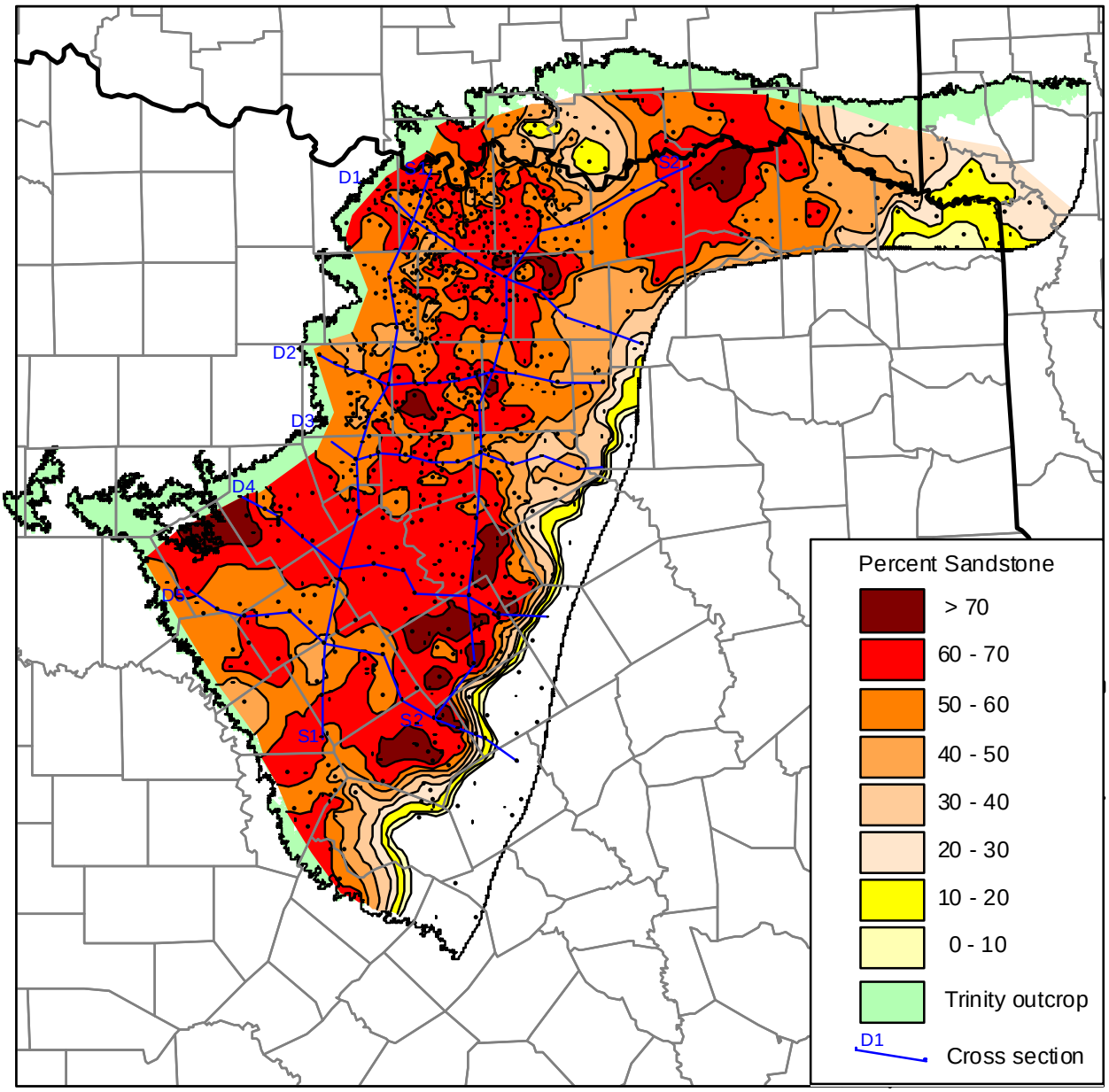


Figure 4.1.20 Percent sandstone in the Hensell Aquifer and locations of cross sections shown in Figures 4.1.31 through 4.1.37.

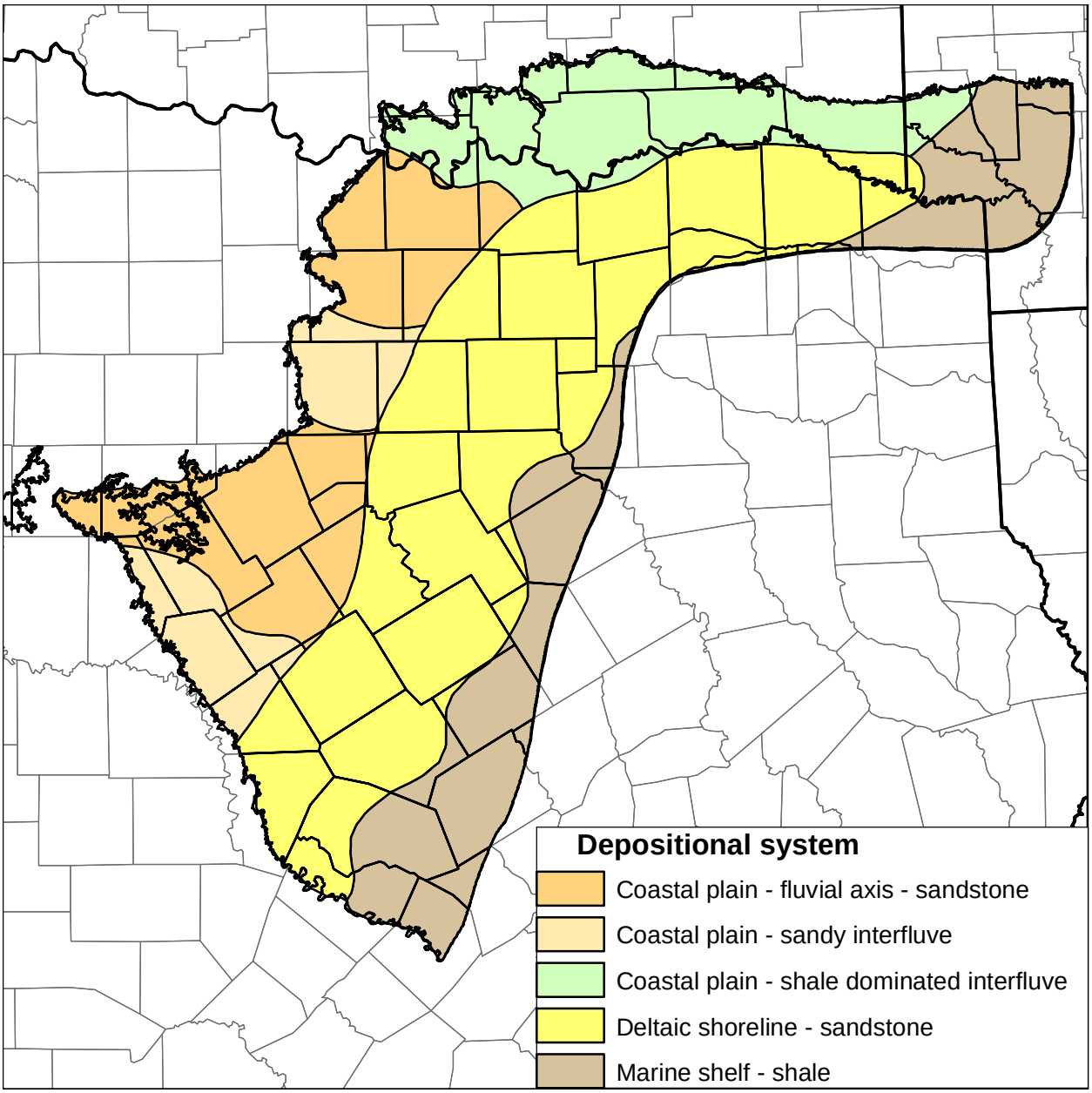


Figure 4.1.21 Depositional systems of the Hensell Aquifer.

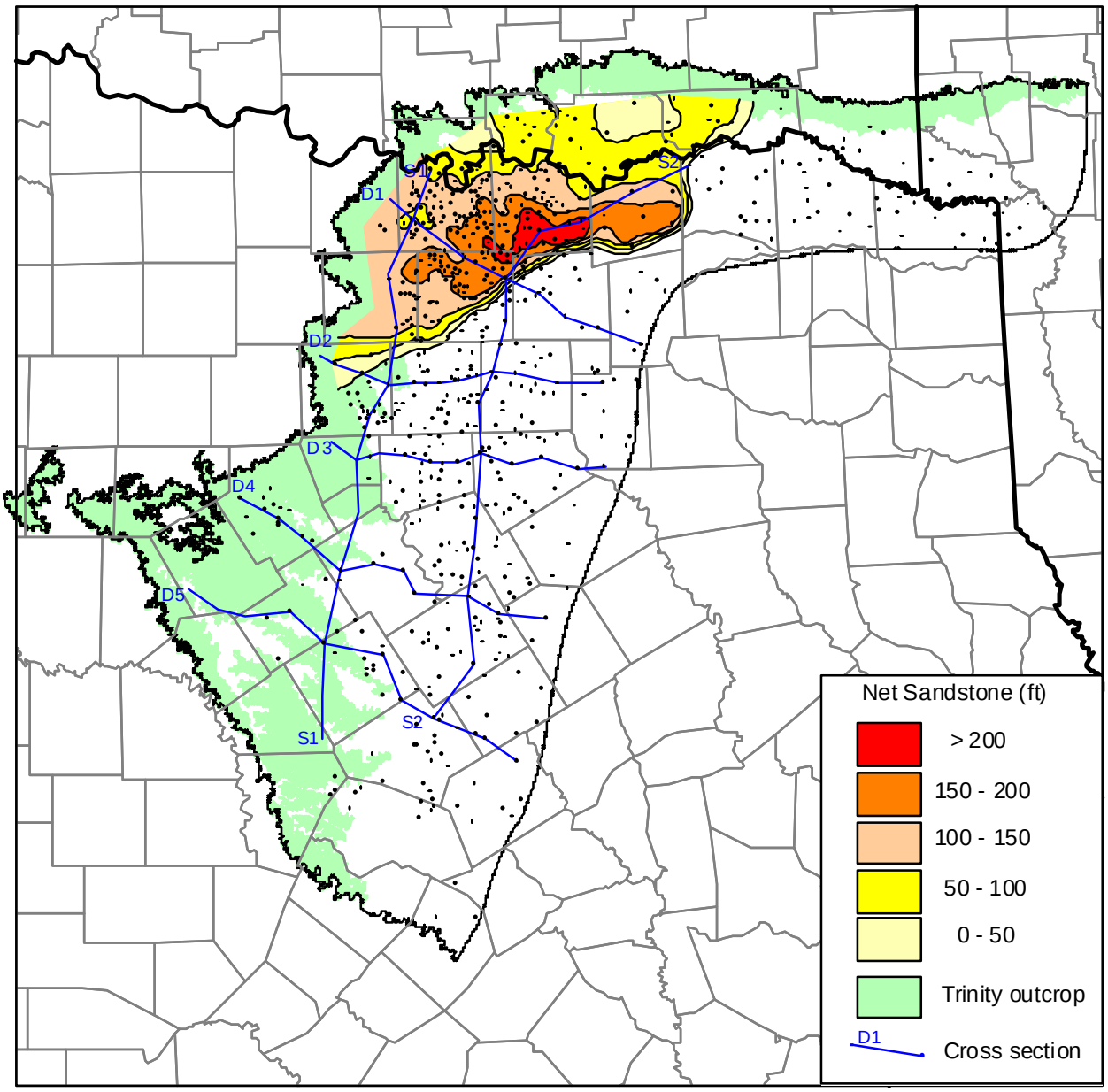


Figure 4.1.22 Net sandstone in the Glen Rose Formation and locations of cross sections shown in Figures 4.1.31 through 4.1.37.

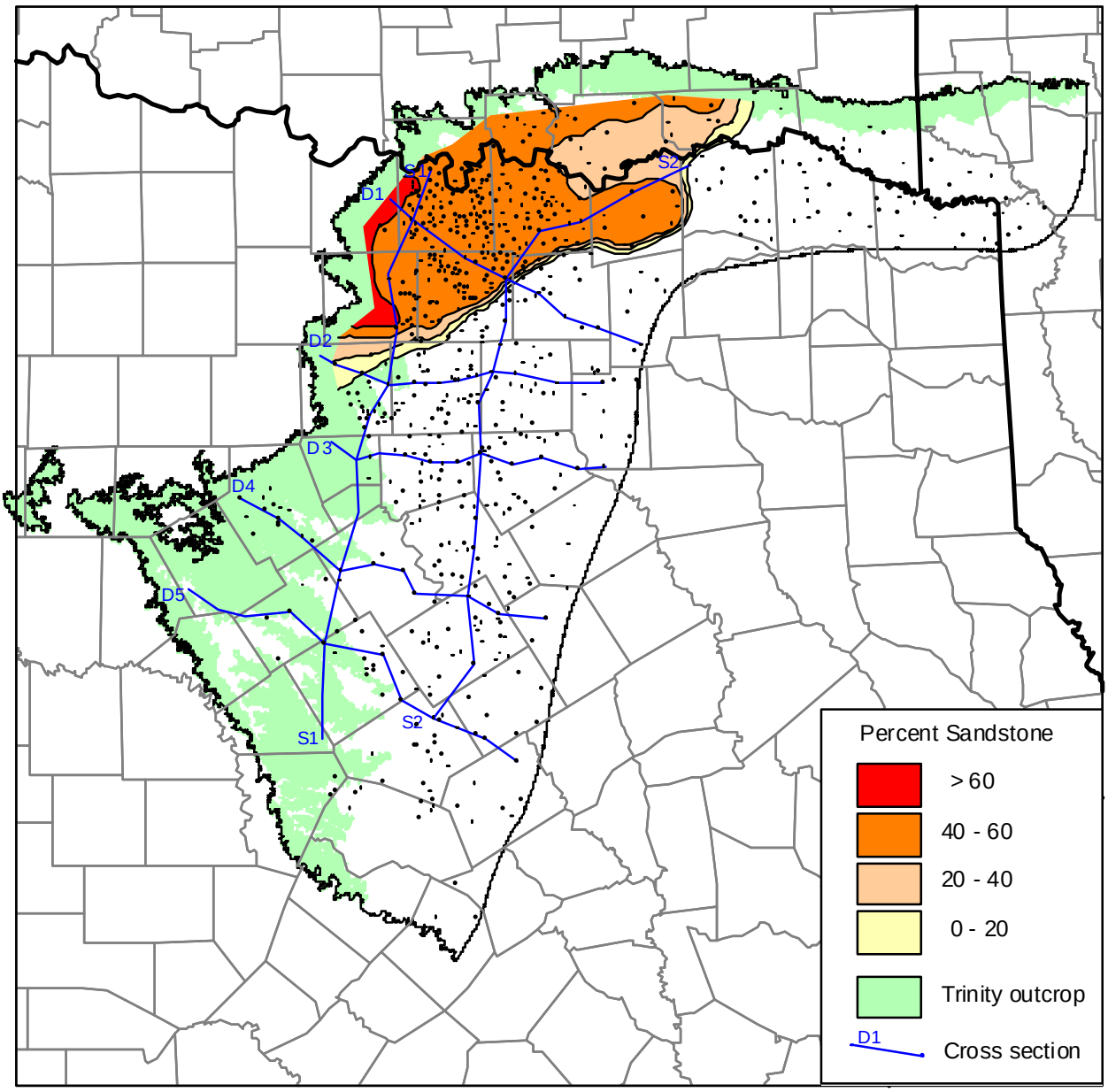


Figure 4.1.23 Percent sandstone in the Glen Rose Formation and locations of cross sections shown in Figure 4.1.31 through 4.1.37.

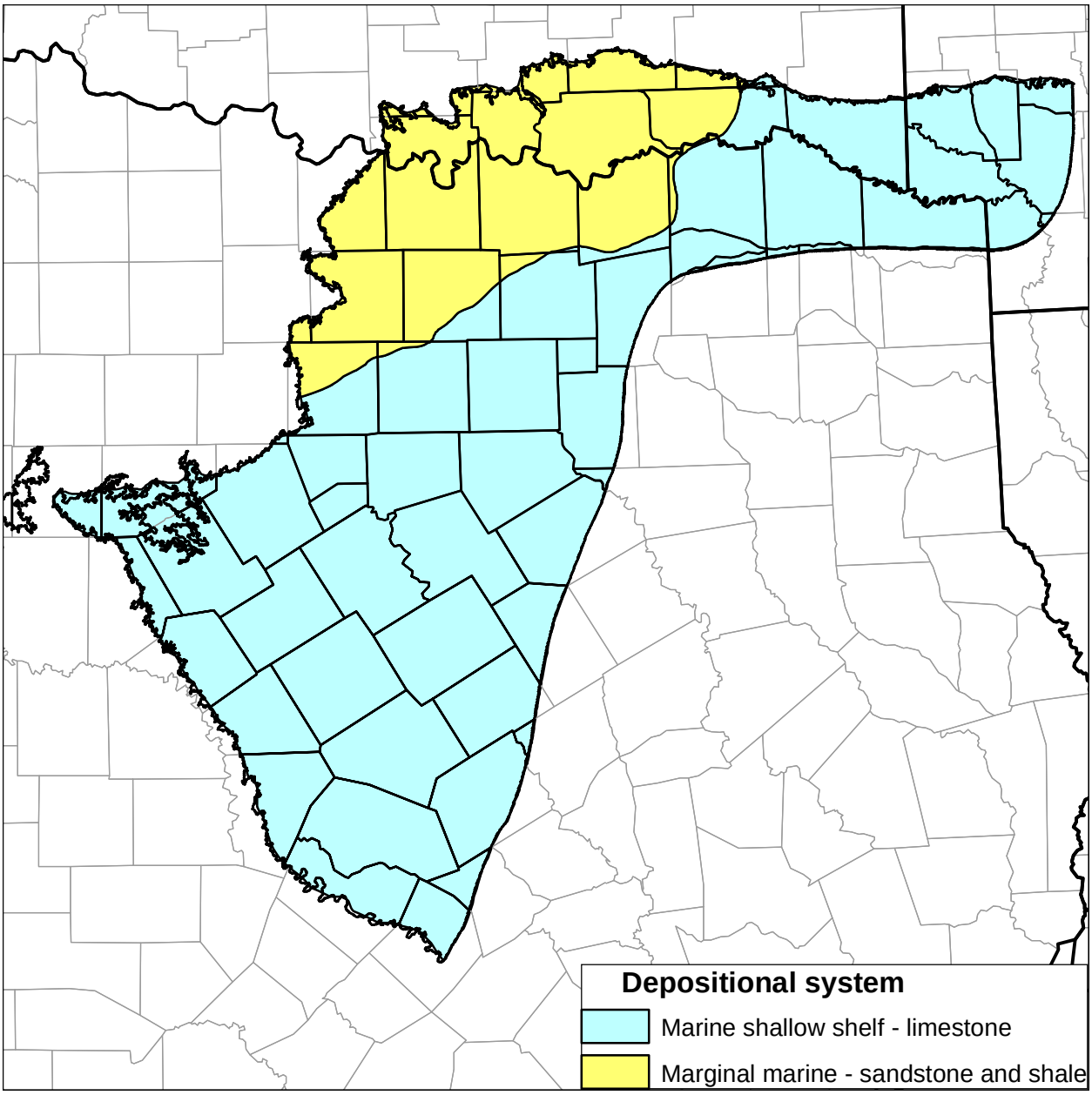


Figure 4.1.24 Depositional systems of the Glen Rose Formation.

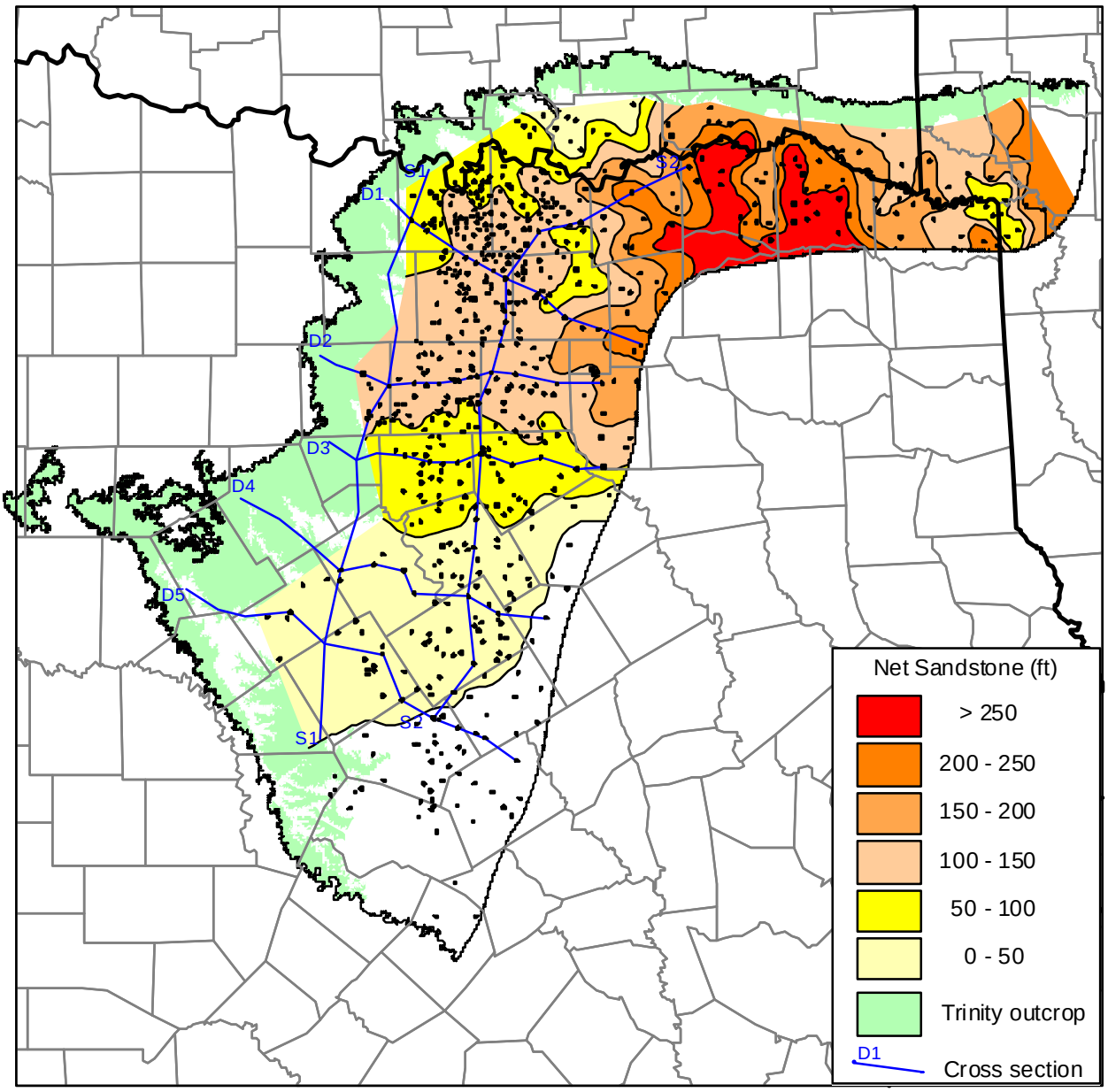


Figure 4.1.25 Net sandstone in the Paluxy Aquifer in feet and locations of cross sections shown in Figures 4.1.31 through 4.1.37.

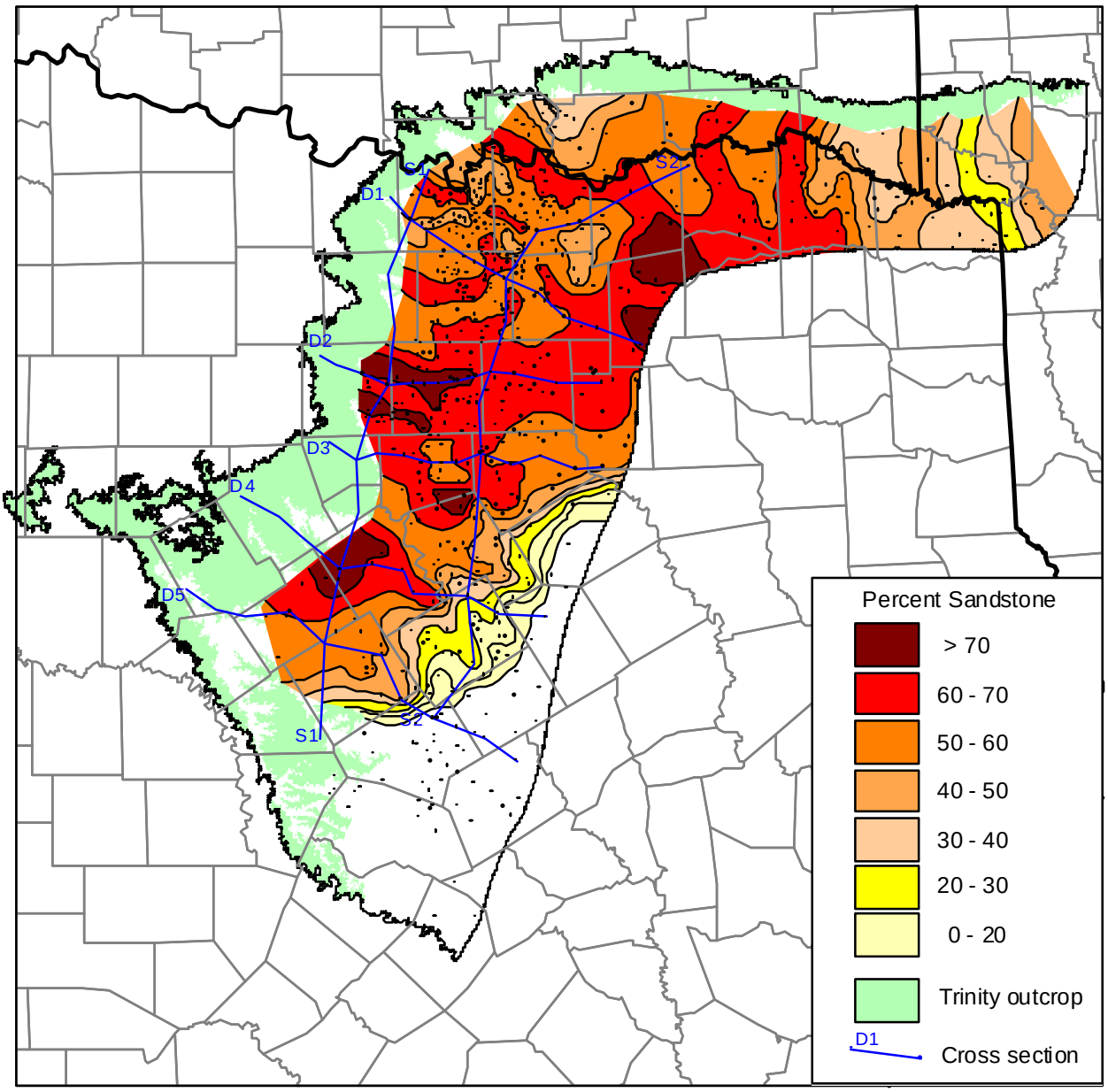


Figure 4.1.26 Percent sandstone in the Paluxy Aquifer and locations of cross sections shown in Figures 4.1.31 through 4.1.37.

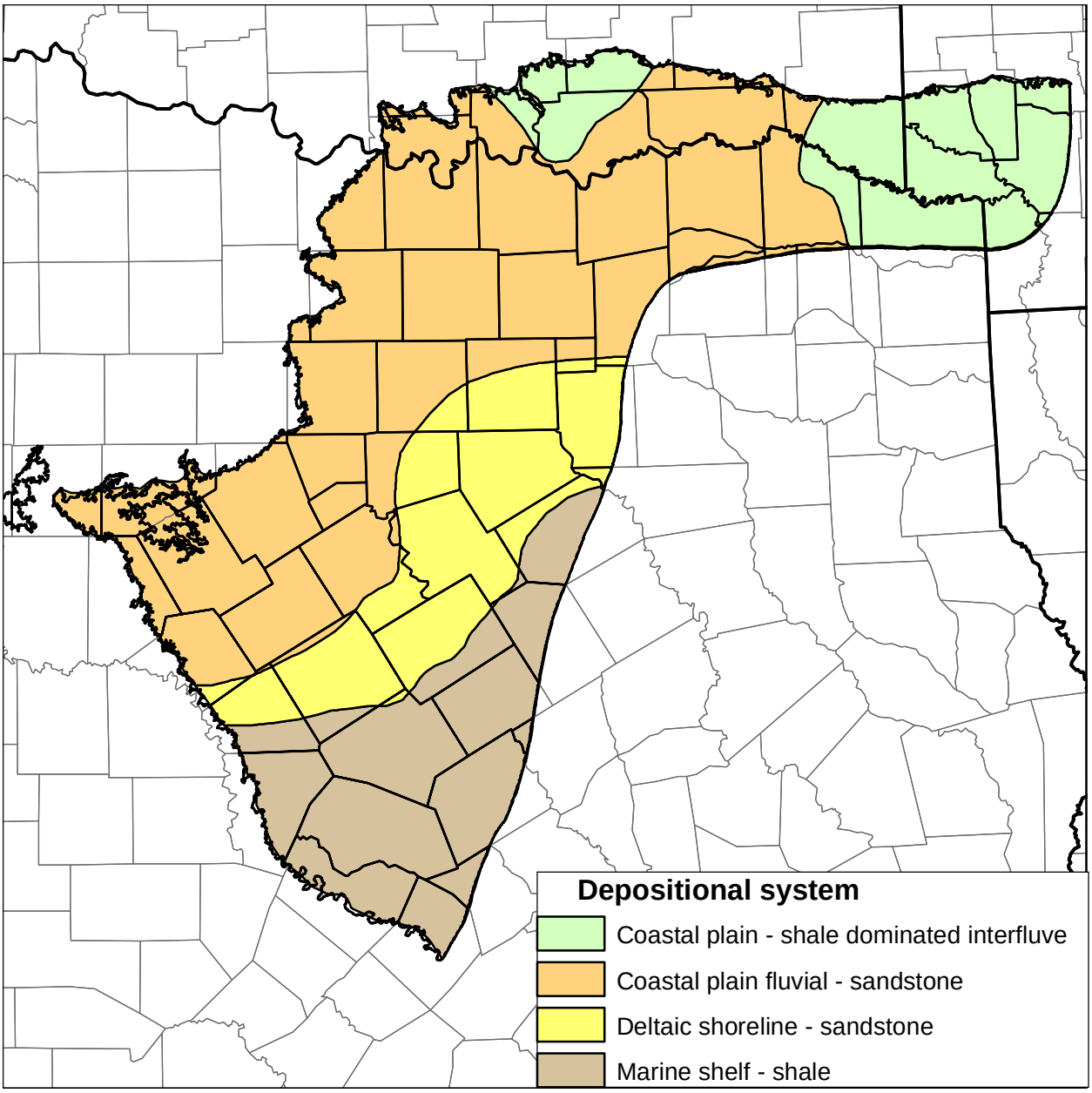


Figure 4.1.27 Depositional systems of the Paluxy Aquifer.

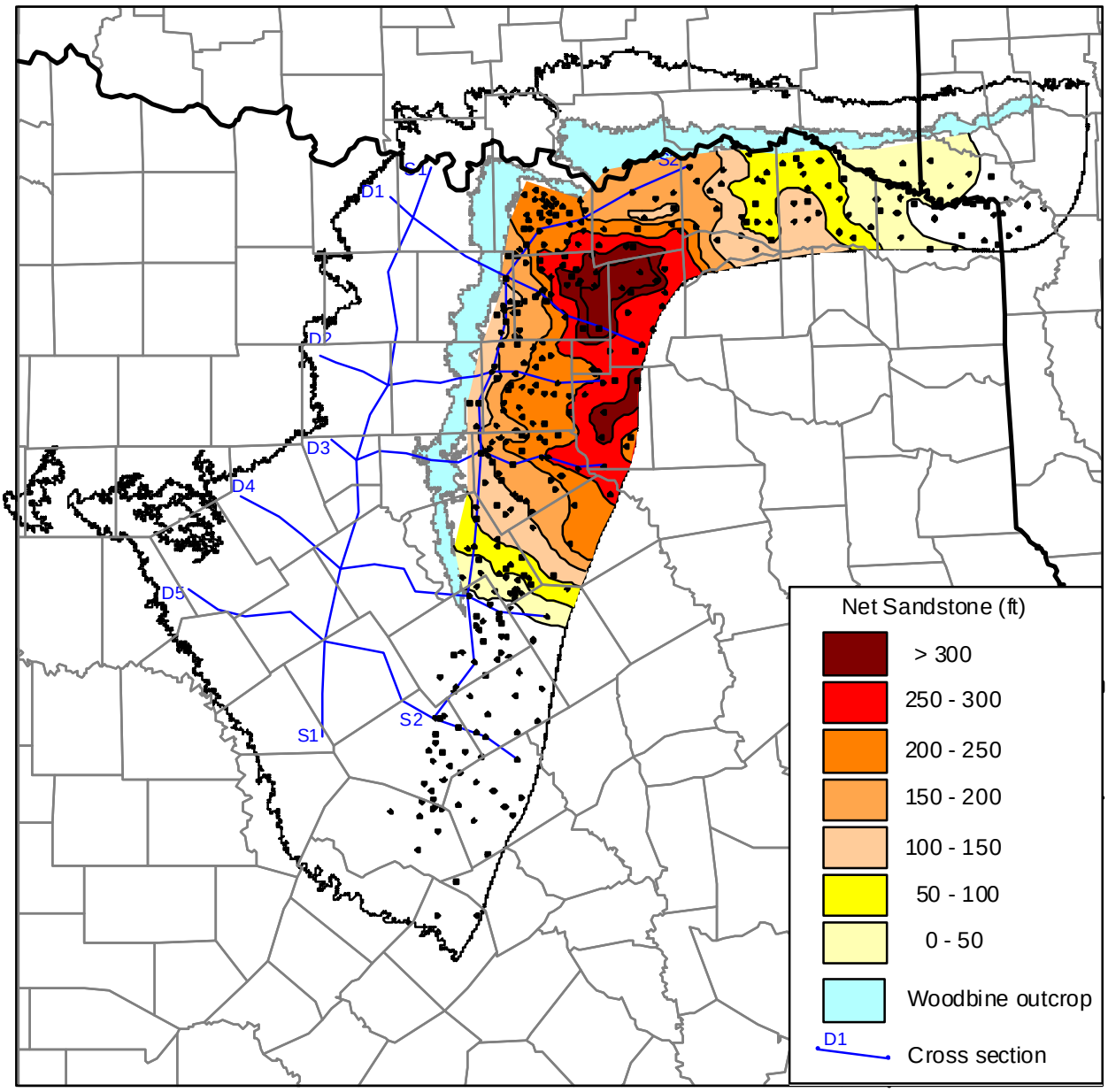


Figure 4.1.28 Net sandstone in the Woodbine Aquifer in feet and locations of cross sections shown in Figures 4.1.31 through 4.1.37.

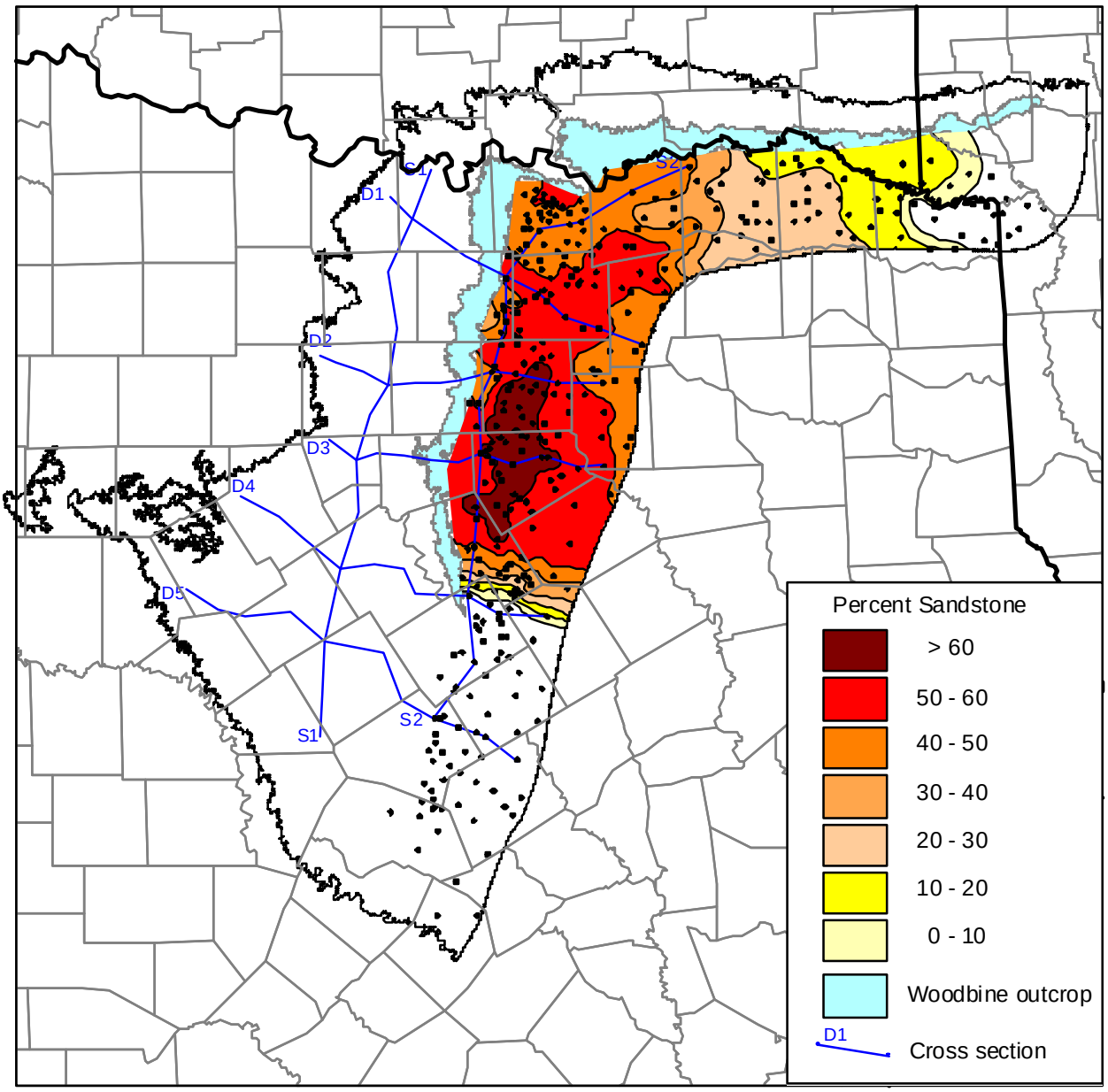


Figure 4.1.29 Percent sandstone in the Woodbine Aquifer and locations of cross sections shown in Figures 4.1.31 through 4.1.37.

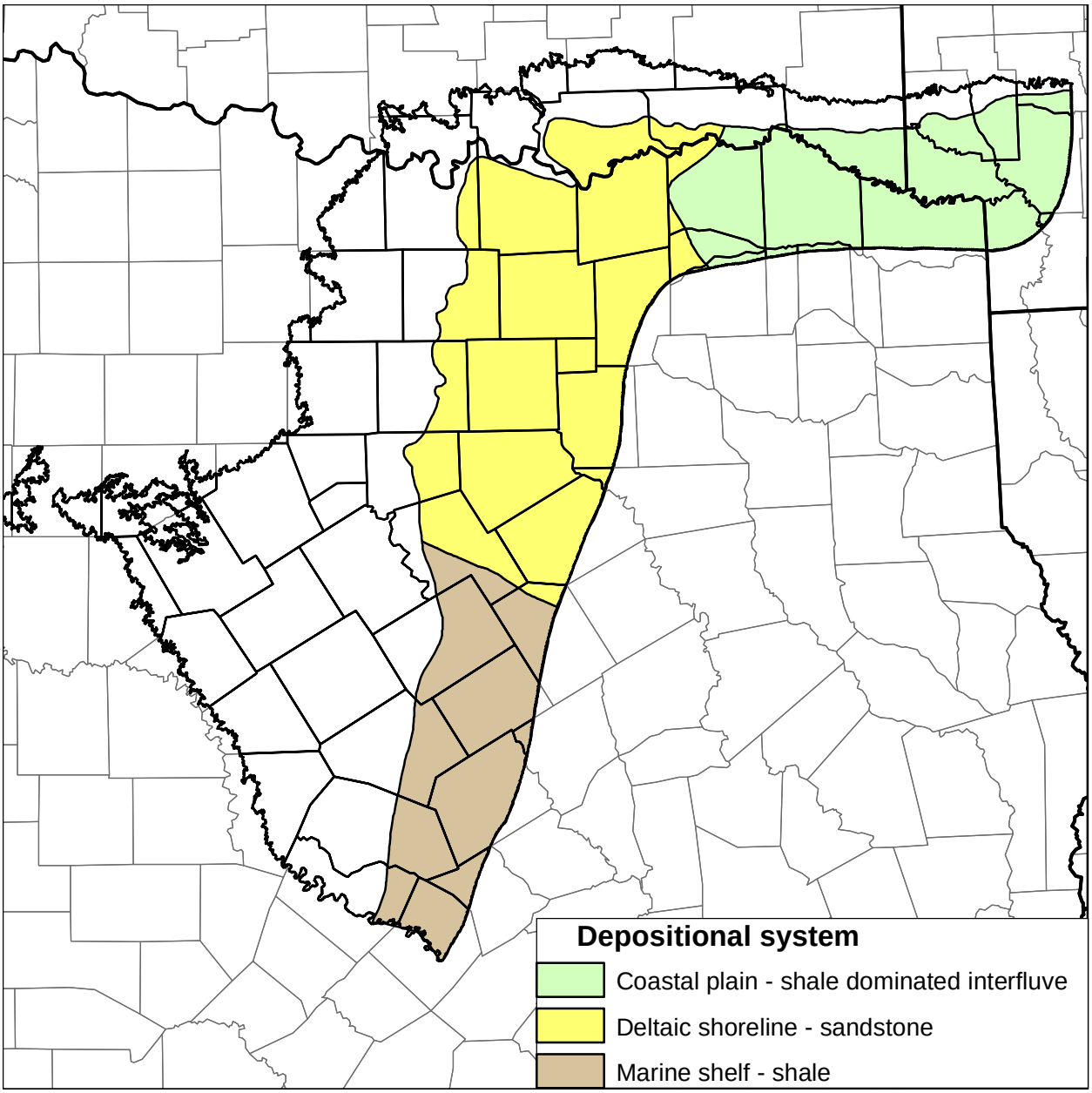


Figure 4.1.30 Depositional systems of the Woodbine Aquifer.

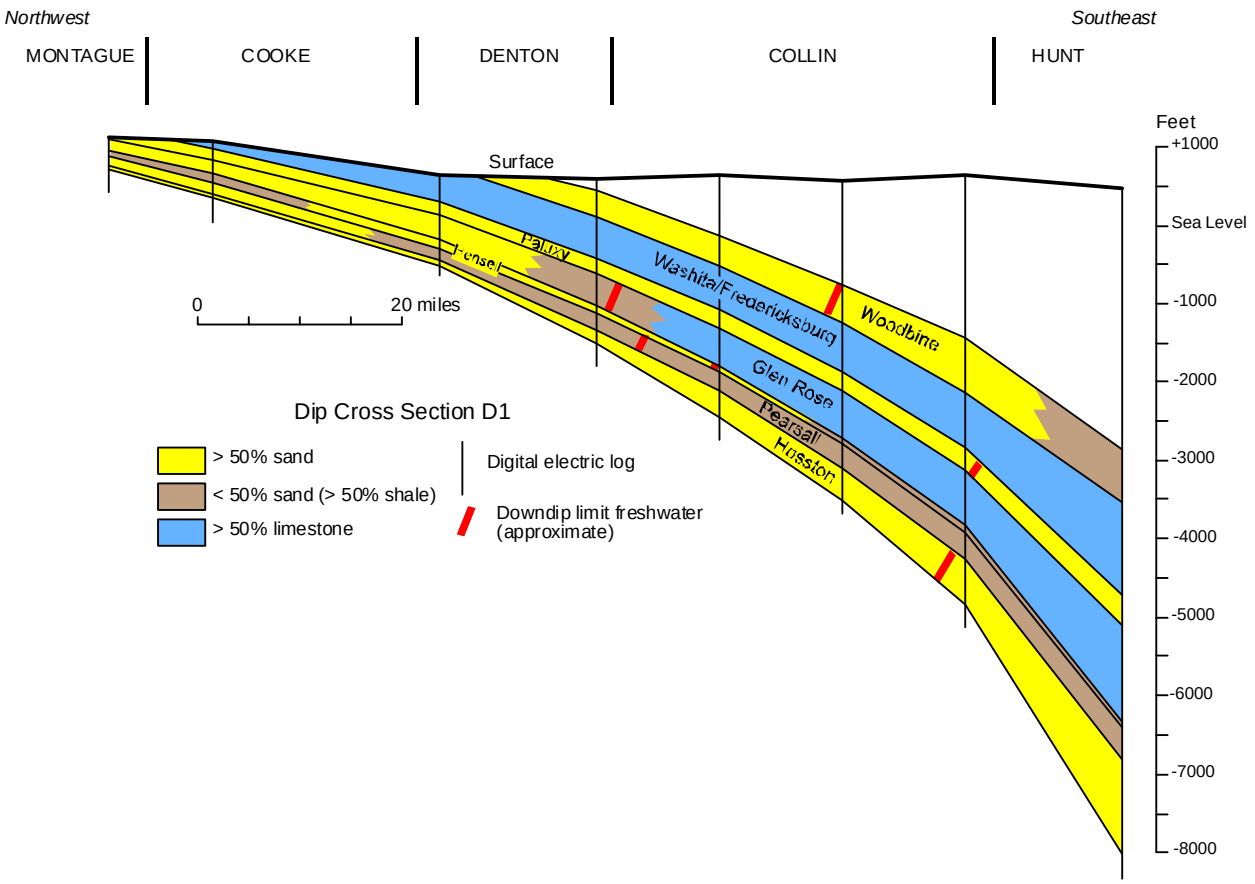


Figure 4.1.31 Dip-oriented cross section D1 showing stratigraphic boundaries, dominant lithologies, depths in feet, and downdip limits of freshwater in sandstone and shale layers.

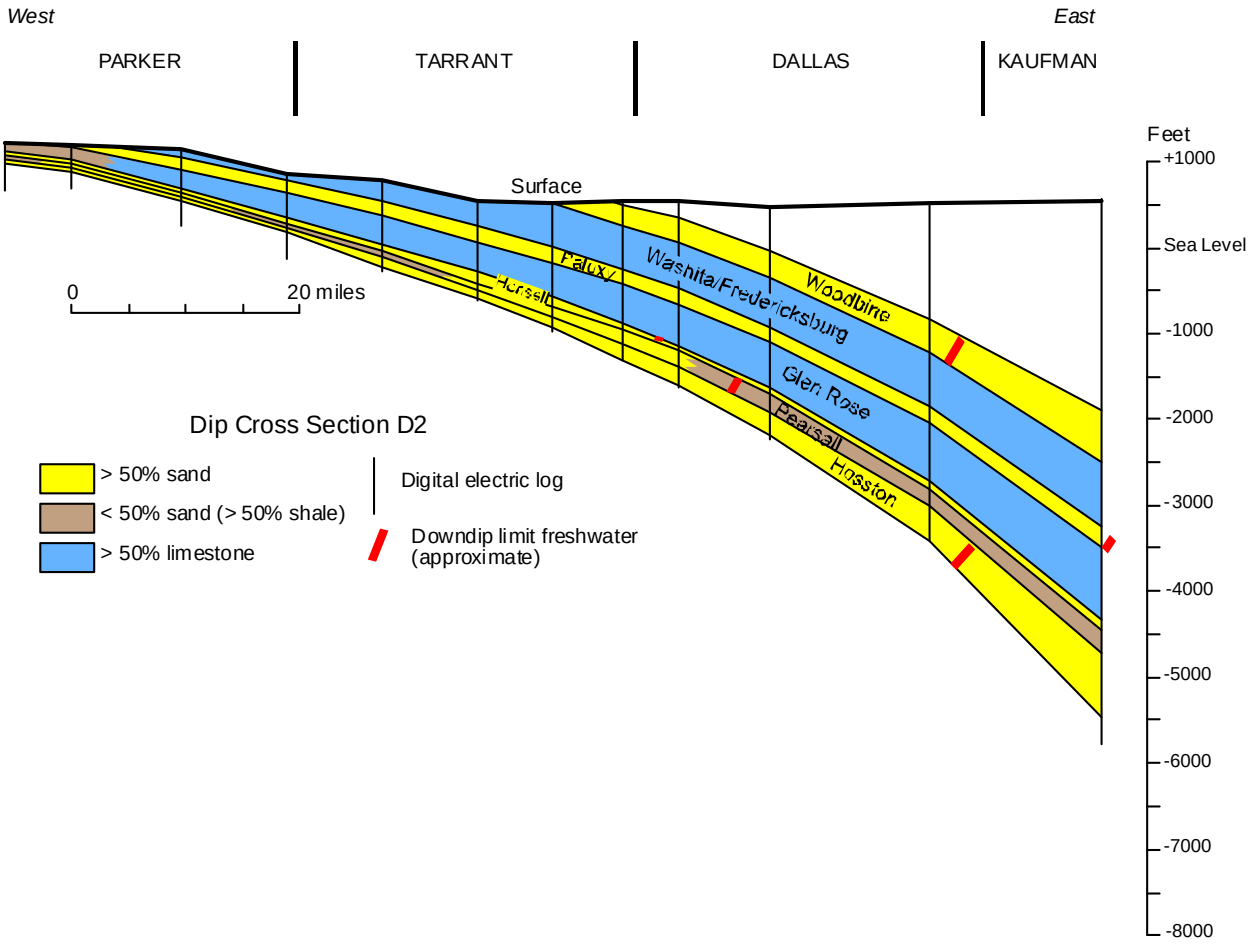


Figure 4.1.32 Dip-oriented cross section D2 showing stratigraphic boundaries, dominant lithologies, depths in feet, and downdip limits of freshwater in sandstone and shale layers.

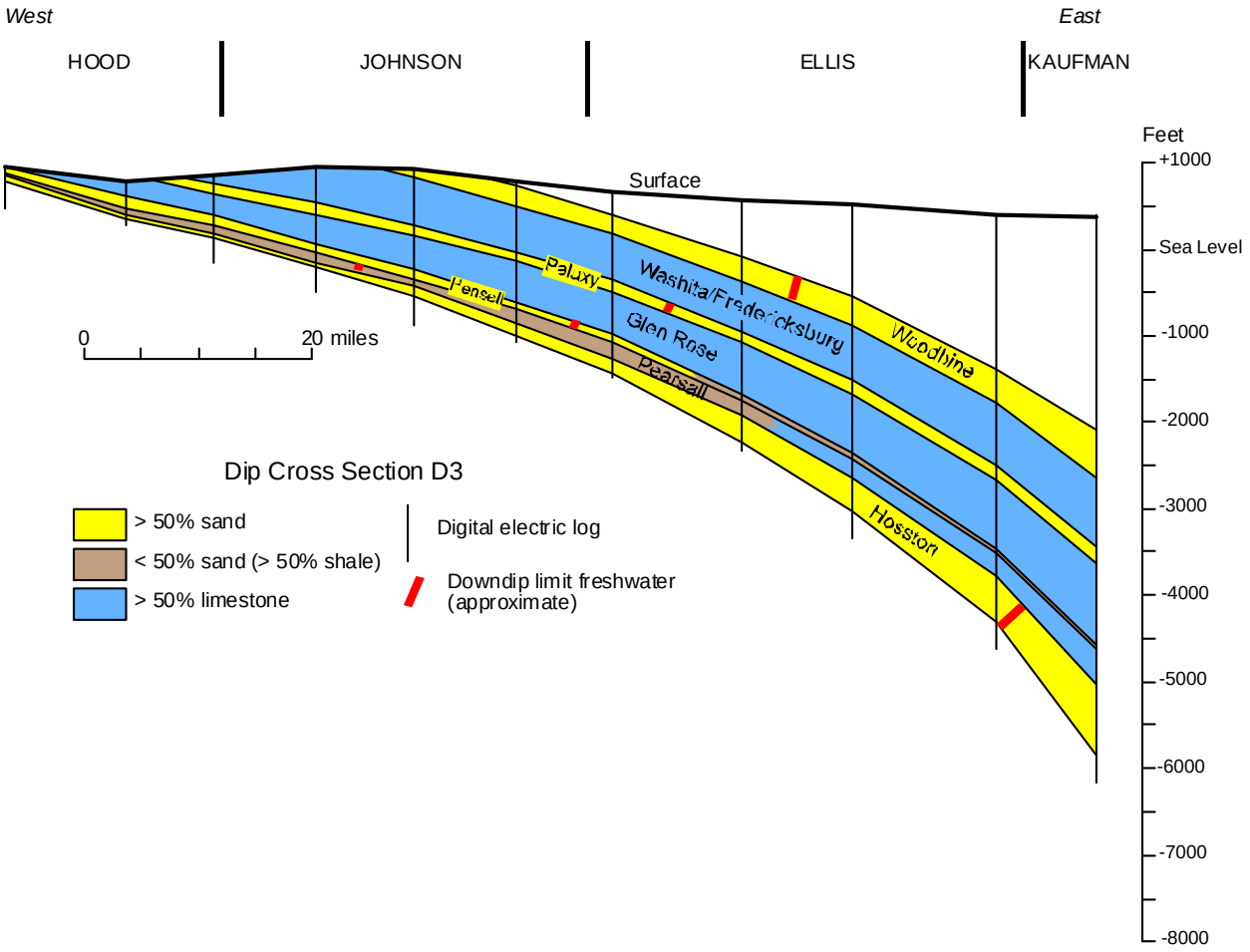


Figure 4.1.33 Dip-oriented cross section D3 showing stratigraphic boundaries, dominant lithologies, depths in feet, and downdip limits of freshwater in sandstone and shale layers.

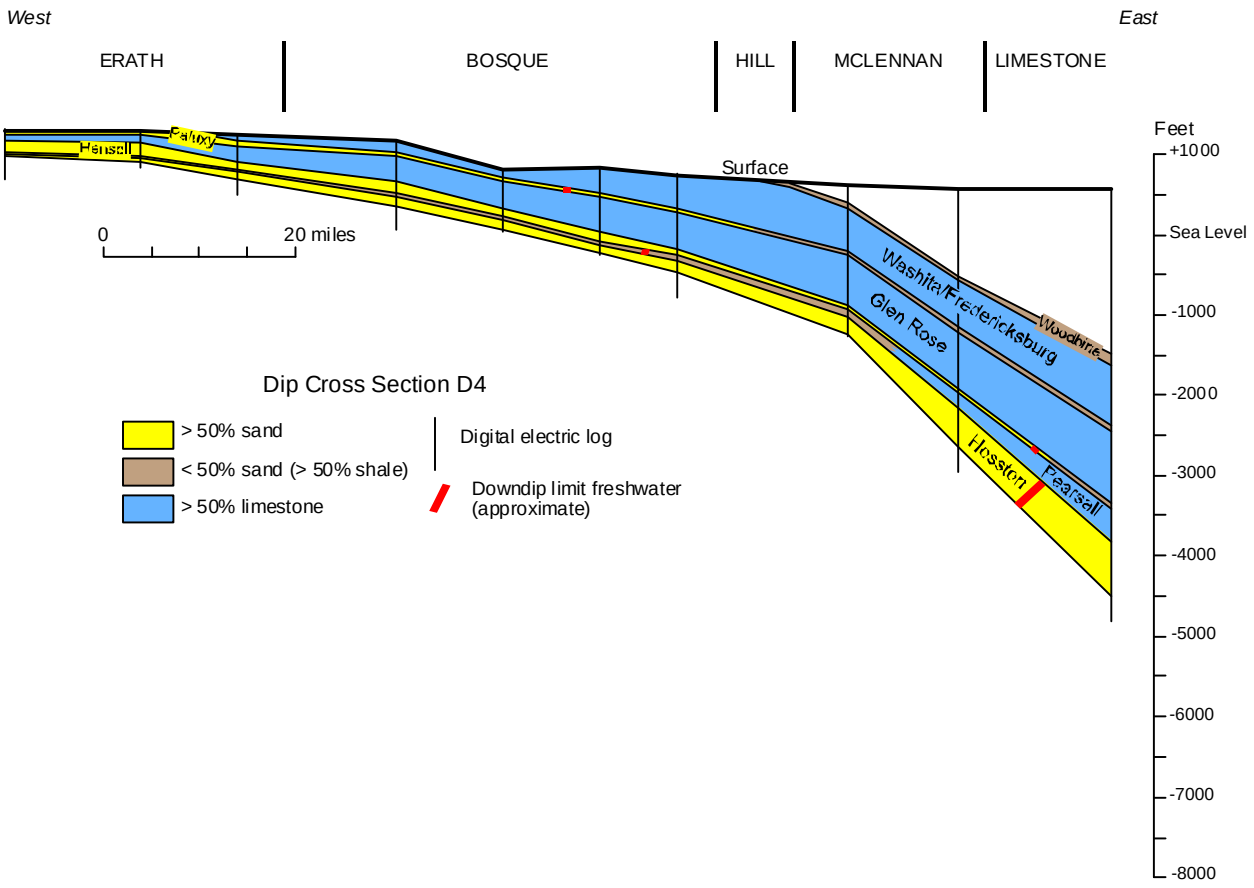


Figure 4.1.34 Dip-oriented cross section D4 showing stratigraphic boundaries, dominant lithologies, depths in feet, and downdip limits of freshwater in sandstone and shale layers.

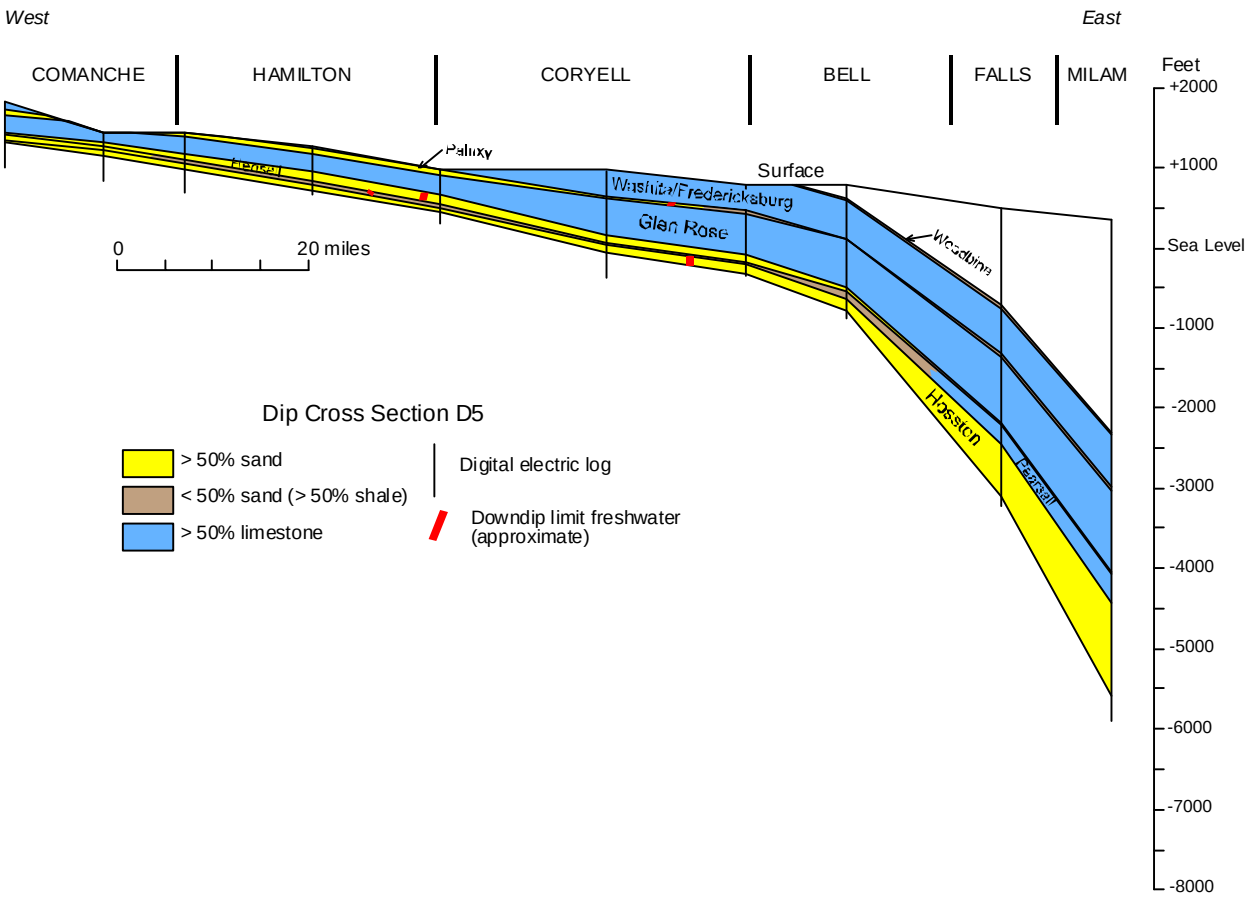


Figure 4.1.35 Dip-oriented cross section D5 showing stratigraphic boundaries, dominant lithologies, depths in feet, and downdip limits of freshwater in sandstone and shale layers.

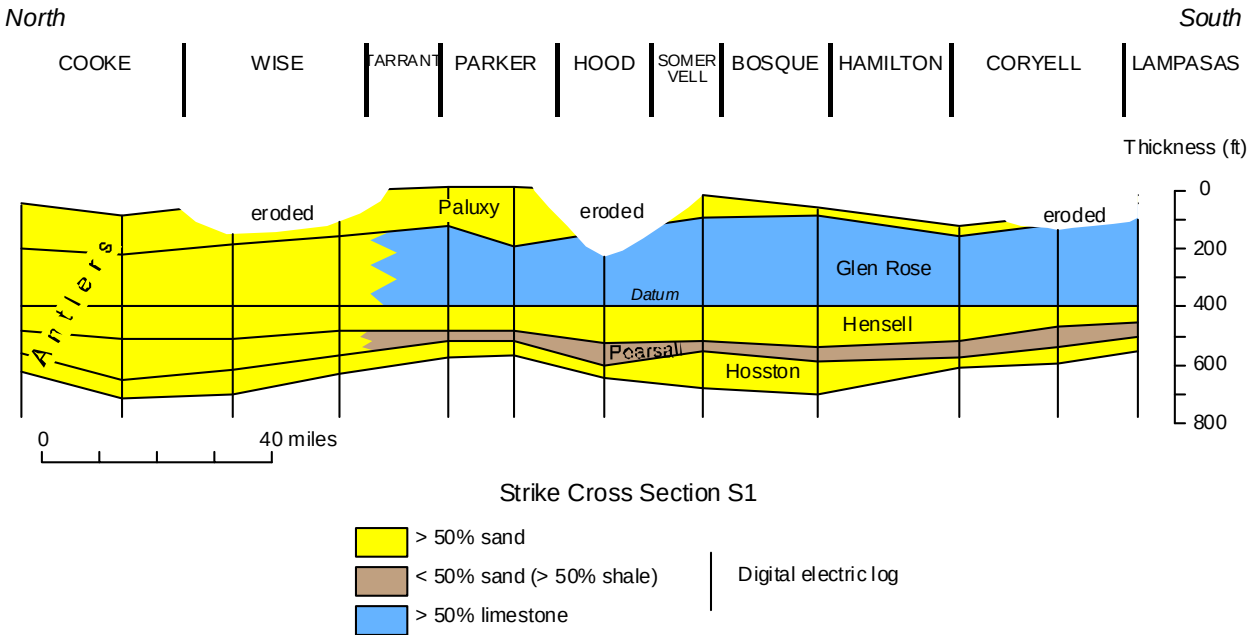


Figure 4.1.36 Strike-oriented cross section S1 showing stratigraphic boundaries, dominant lithologies, and thicknesses in feet.

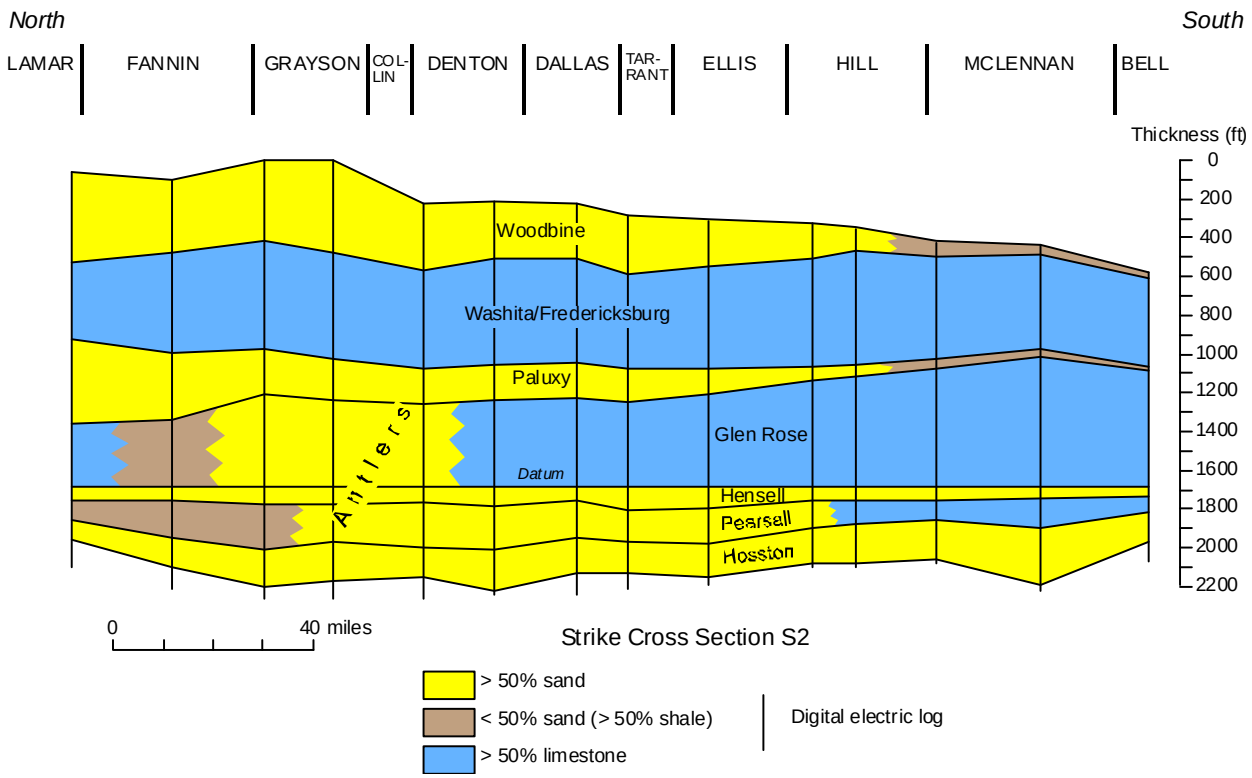


Figure 4.1.37 Strike-oriented cross section S2 showing stratigraphic boundaries, dominant lithologies, and thicknesses in feet.

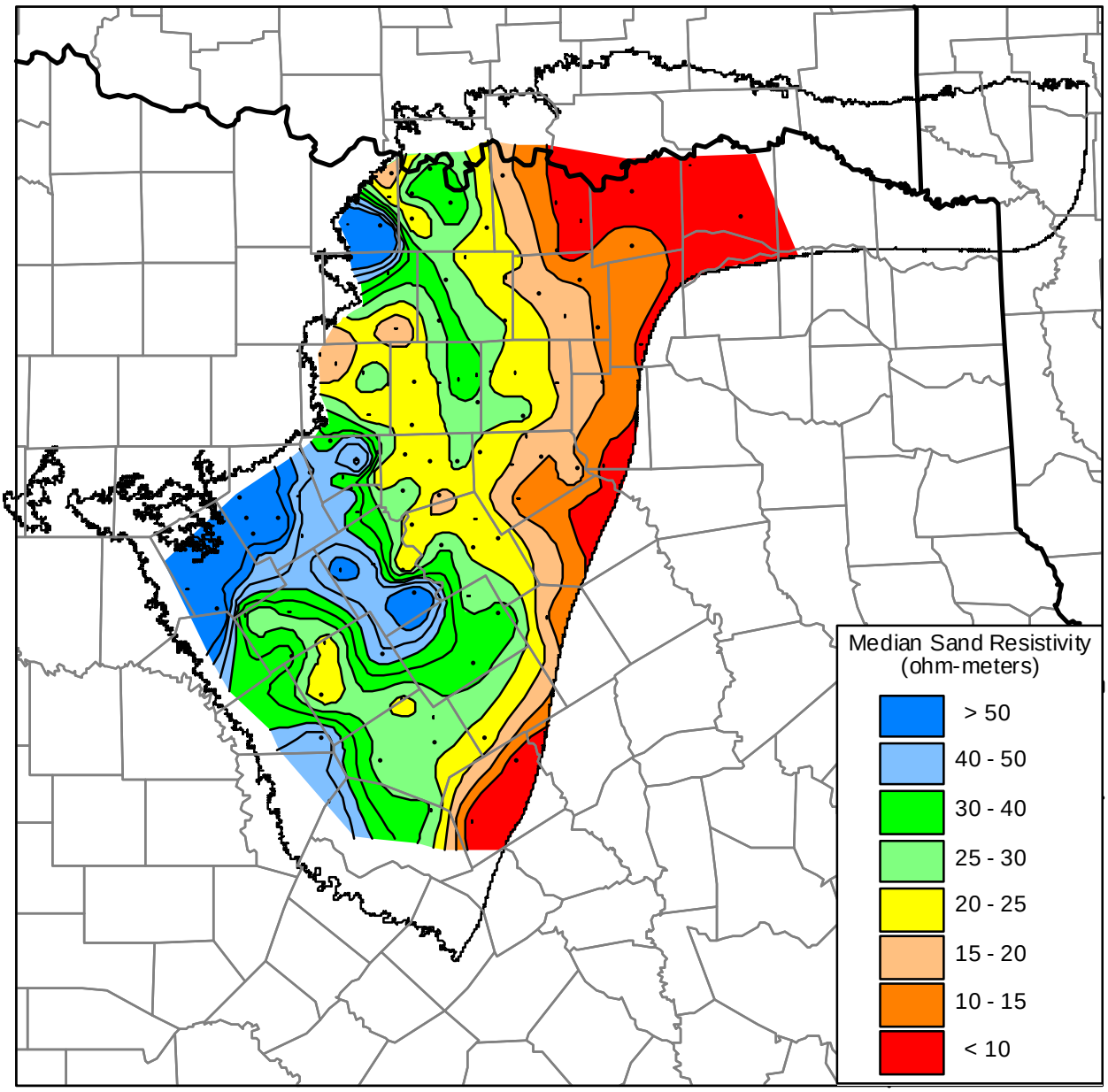


Figure 4.1.38 Median resistivity of sandstones greater than 10-feet thick in the Hosston Aquifer.

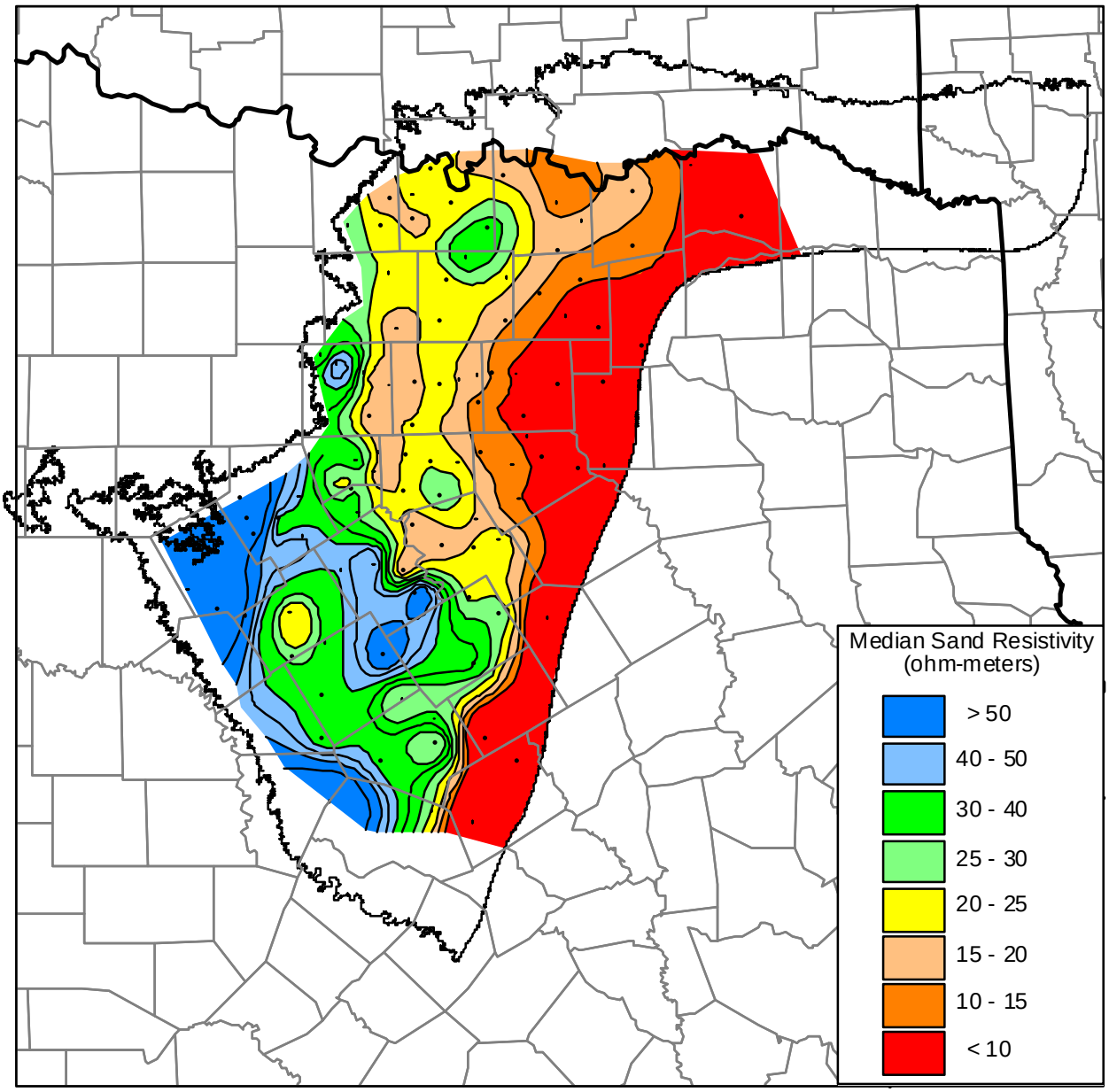


Figure 4.1.39 Median resistivity of sandstones greater than 10-feet thick in the Hensell Aquifer.

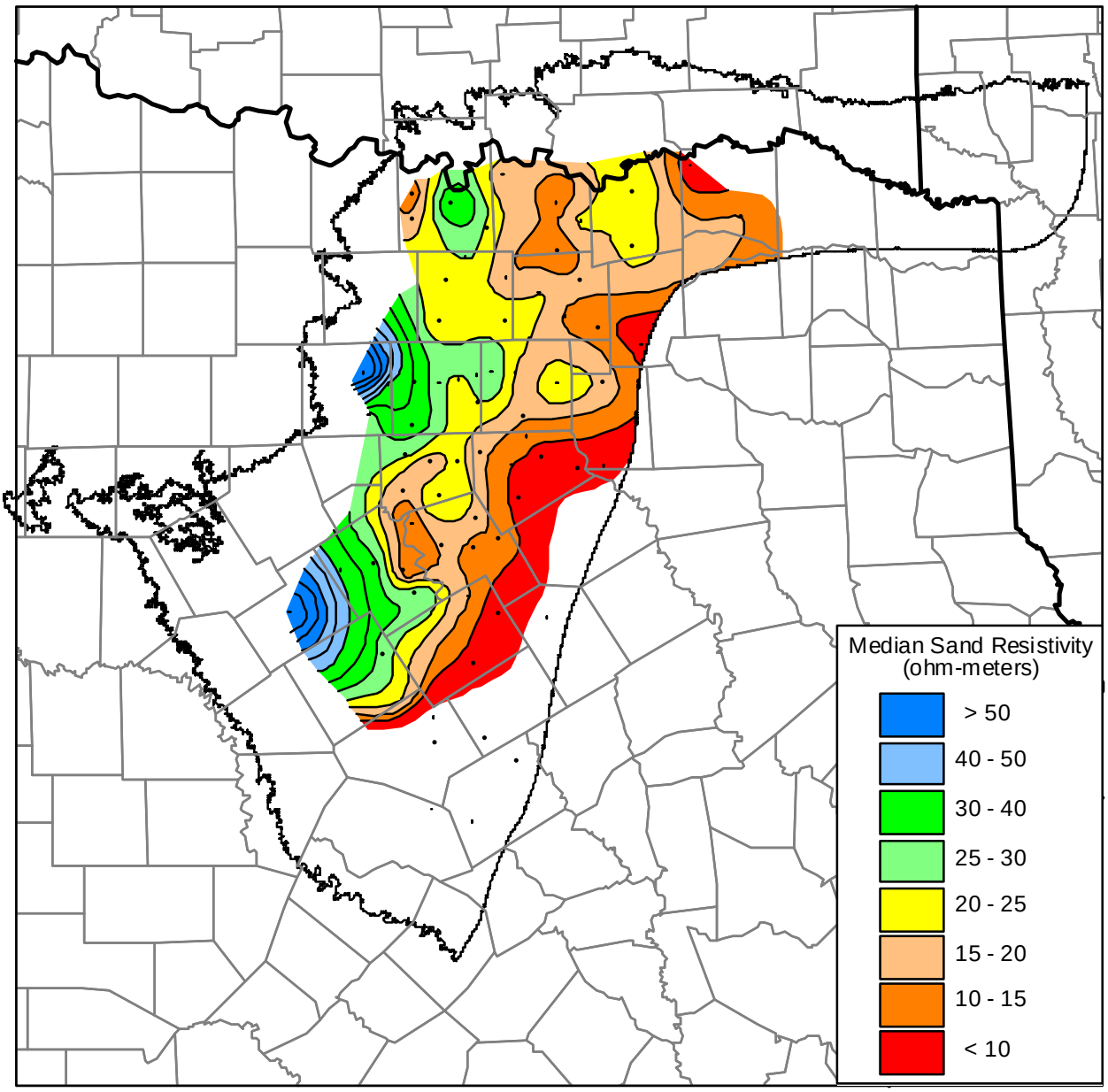


Figure 4.1.40 Median resistivity of sandstones greater than 10-feet thick in the Paluxy Aquifer.

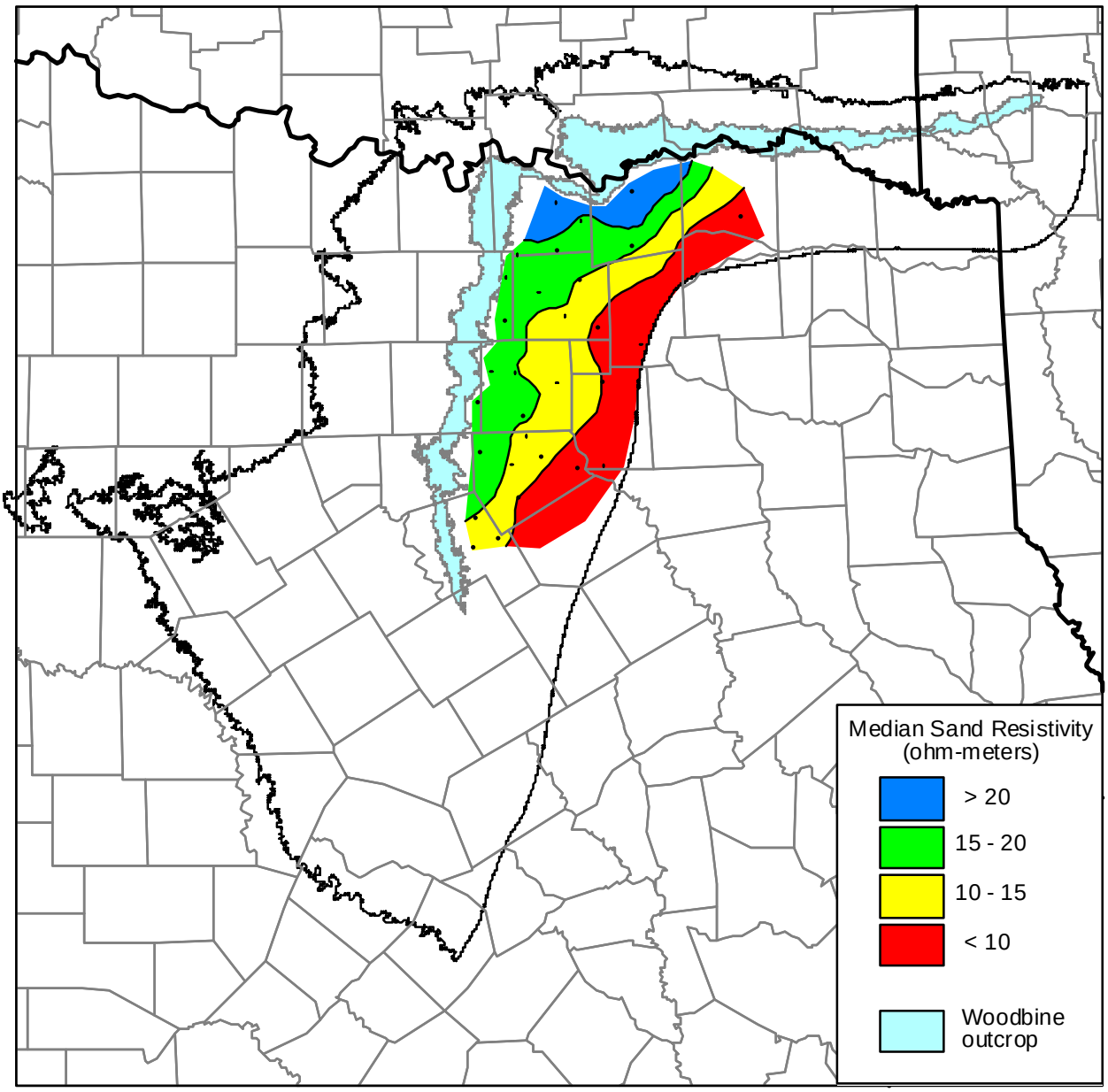


Figure 4.1.41 Median resistivity of sandstones greater than 10-feet thick in the Woodbine Aquifer.

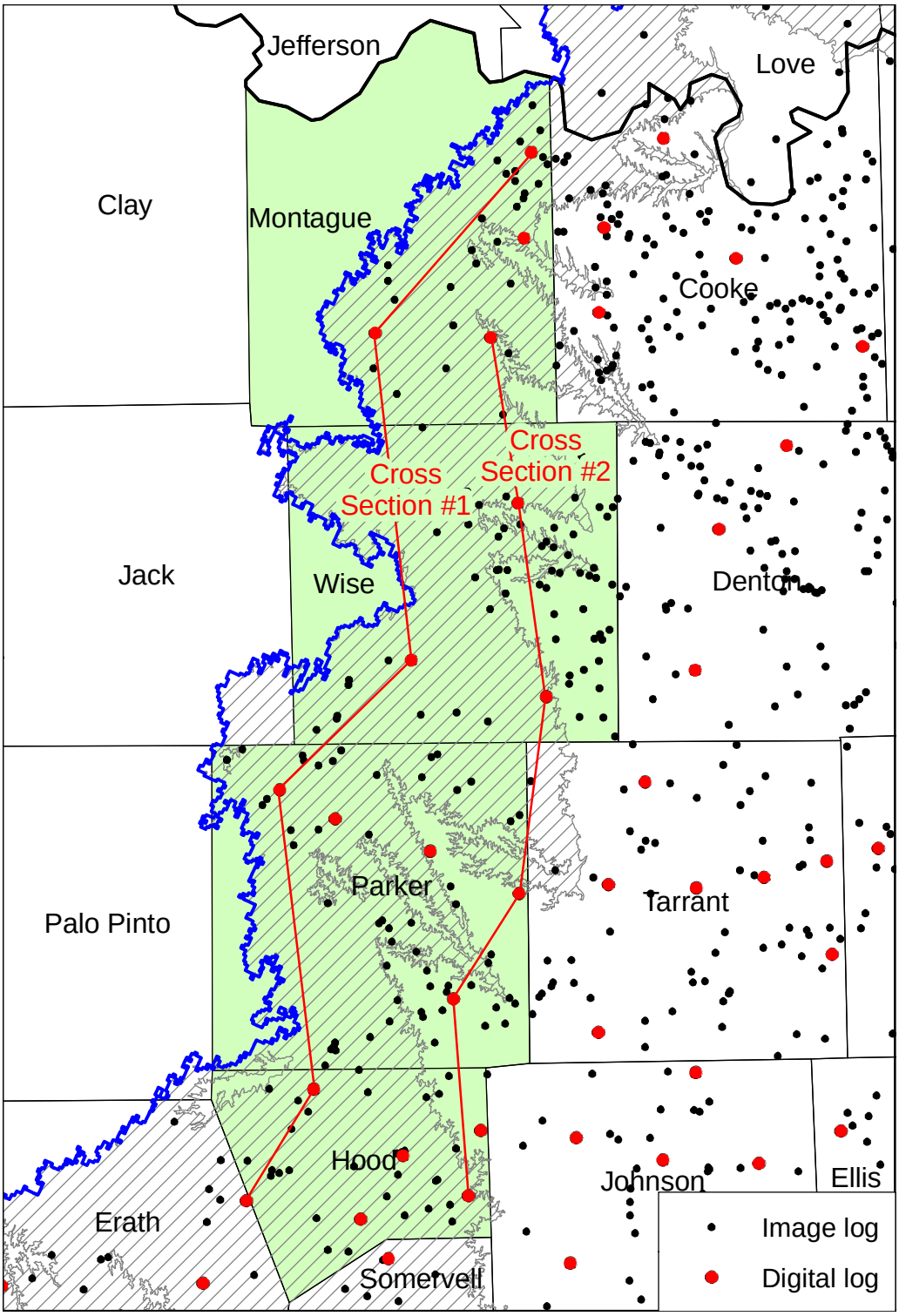
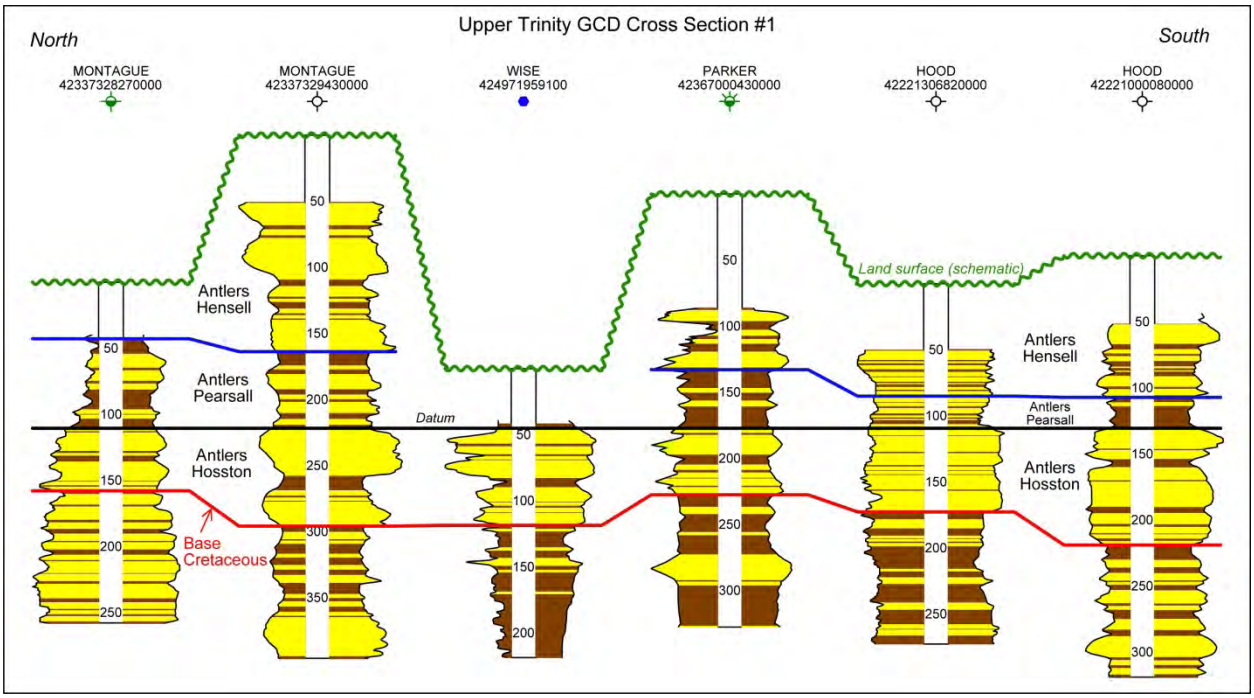
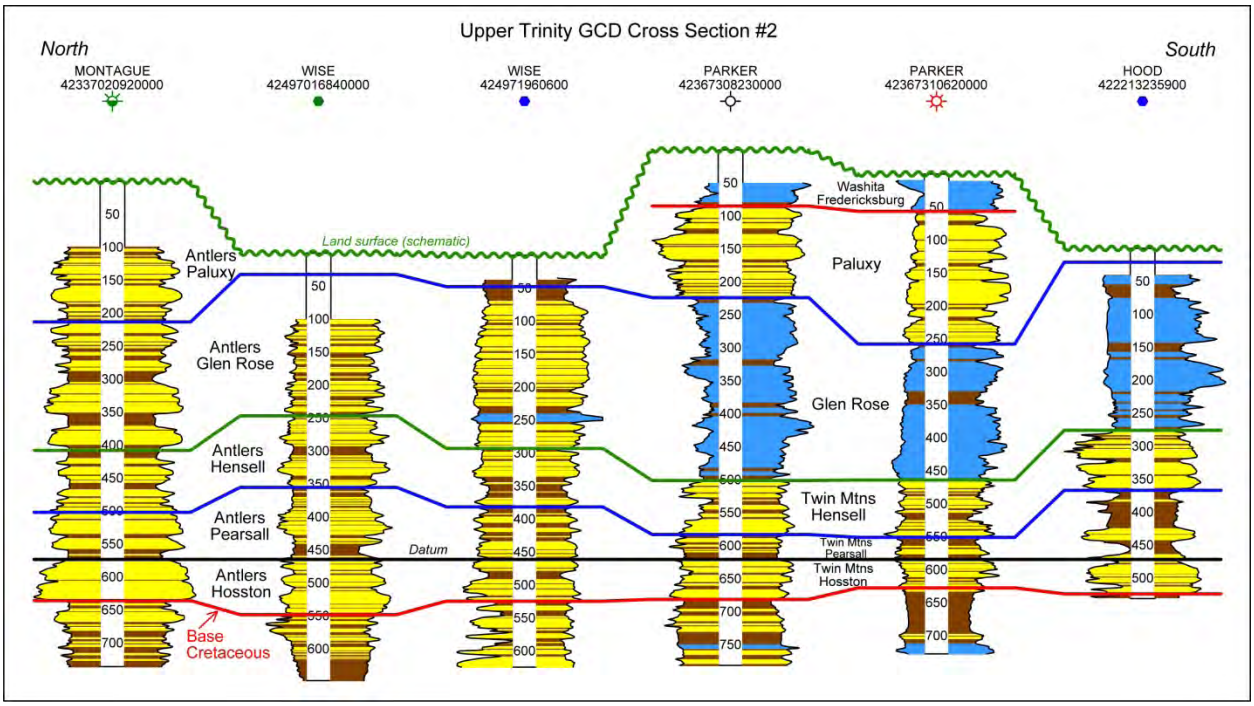


Figure 4.1.42 Upper Trinity GCD (green) showing the northern Trinity Aquifer outcrop (grey cross hatching), locations of geophysical well logs, and locations of cross sections shown in Figures 4.1.43 and 4.1.44.



yellow = greater than 50 percent sandstone, brown = greater than 50 percent shale

Figure 4.1.43 Upper Trinity GCD digital cross section # 1 with stratigraphic layers flattened on the top of the Hosston Aquifer (datum), so true elevations relative to sea level are not shown.



yellow = greater than 50 percent sandstone, blue = greater than 50 percent limestone, brown = greater than 50 percent shale

Figure 4.1.44 Upper Trinity GCD digital cross section # 2 with stratigraphic layers flattened on the top of the Hosston Aquifer (datum), so true elevations relative to sea level are not shown.

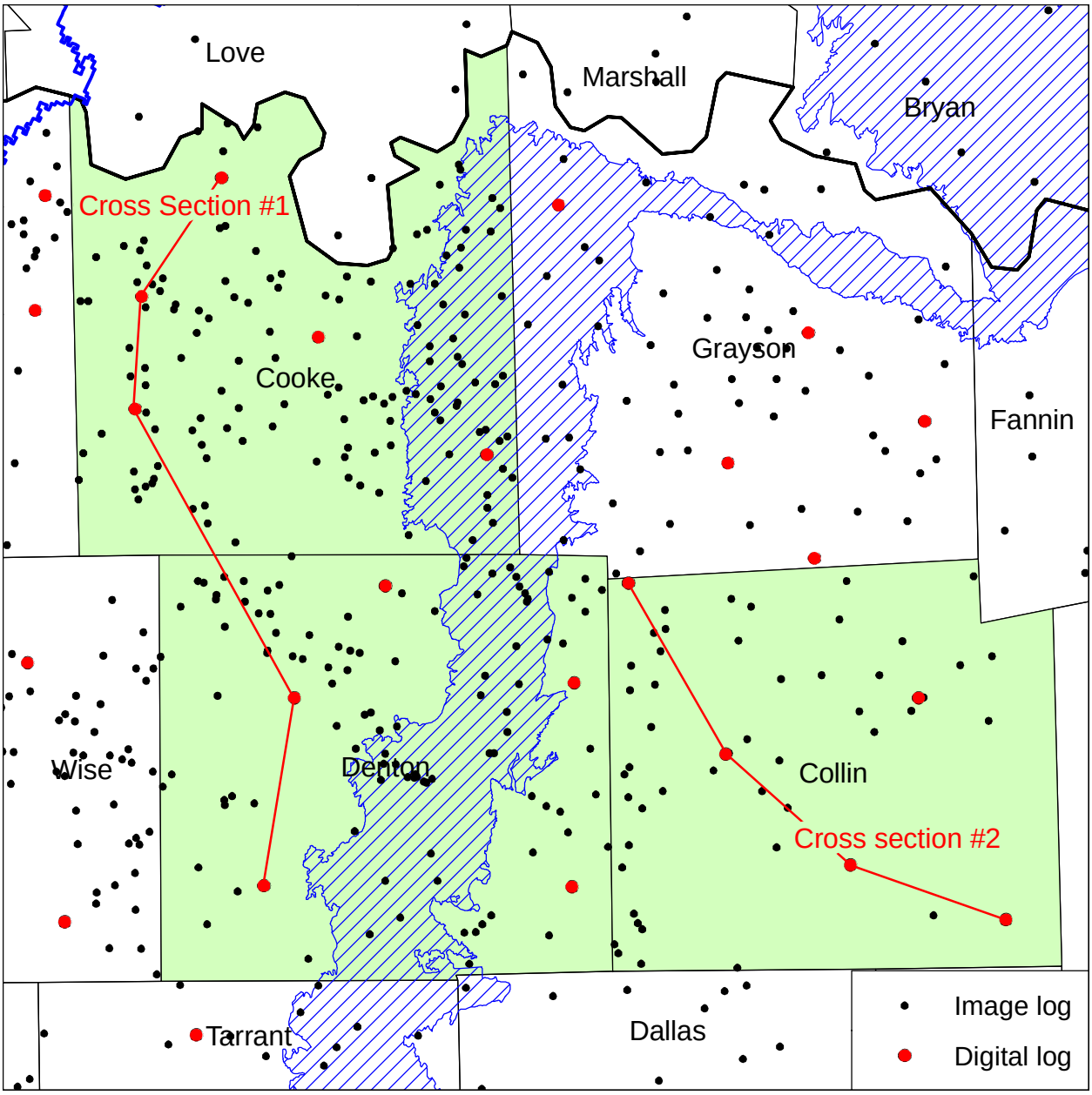
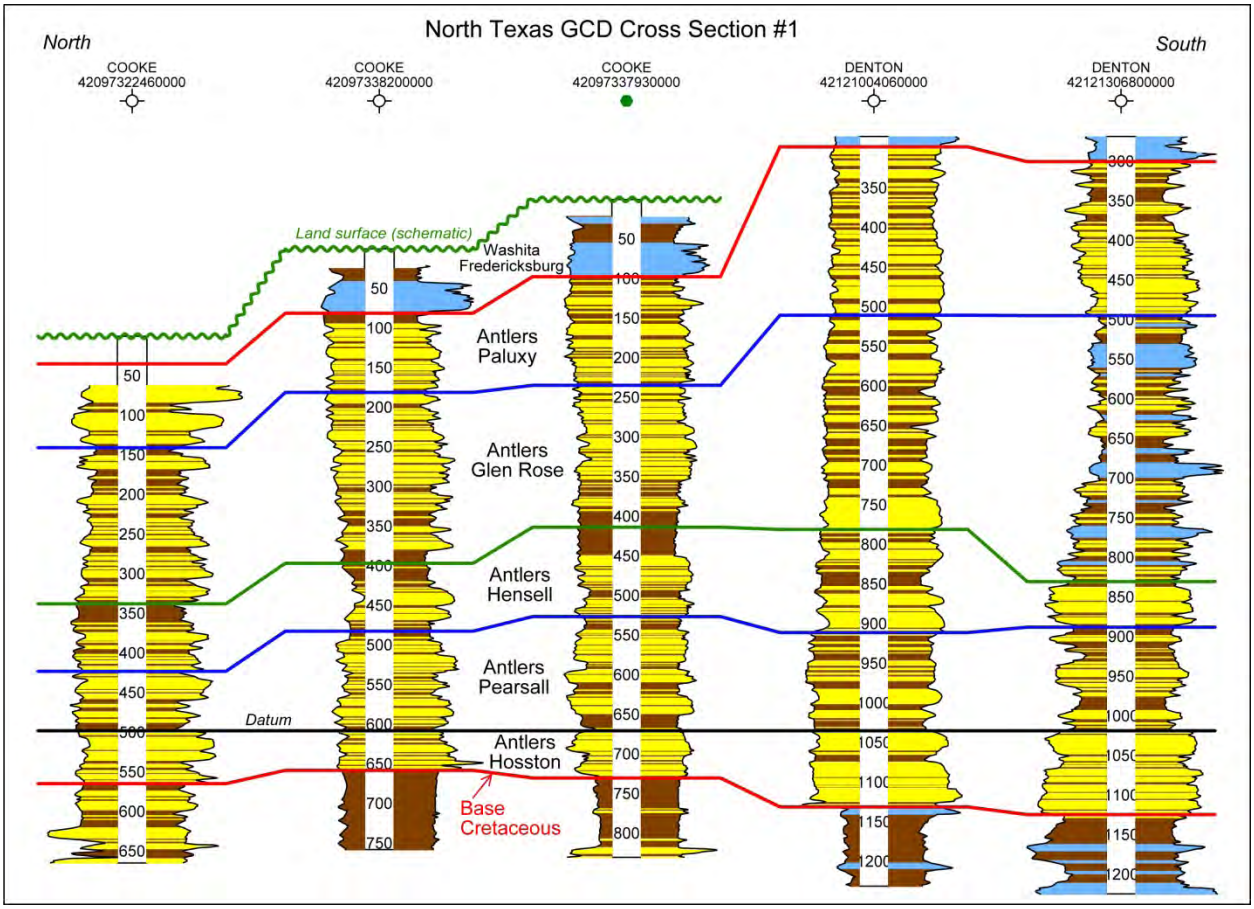
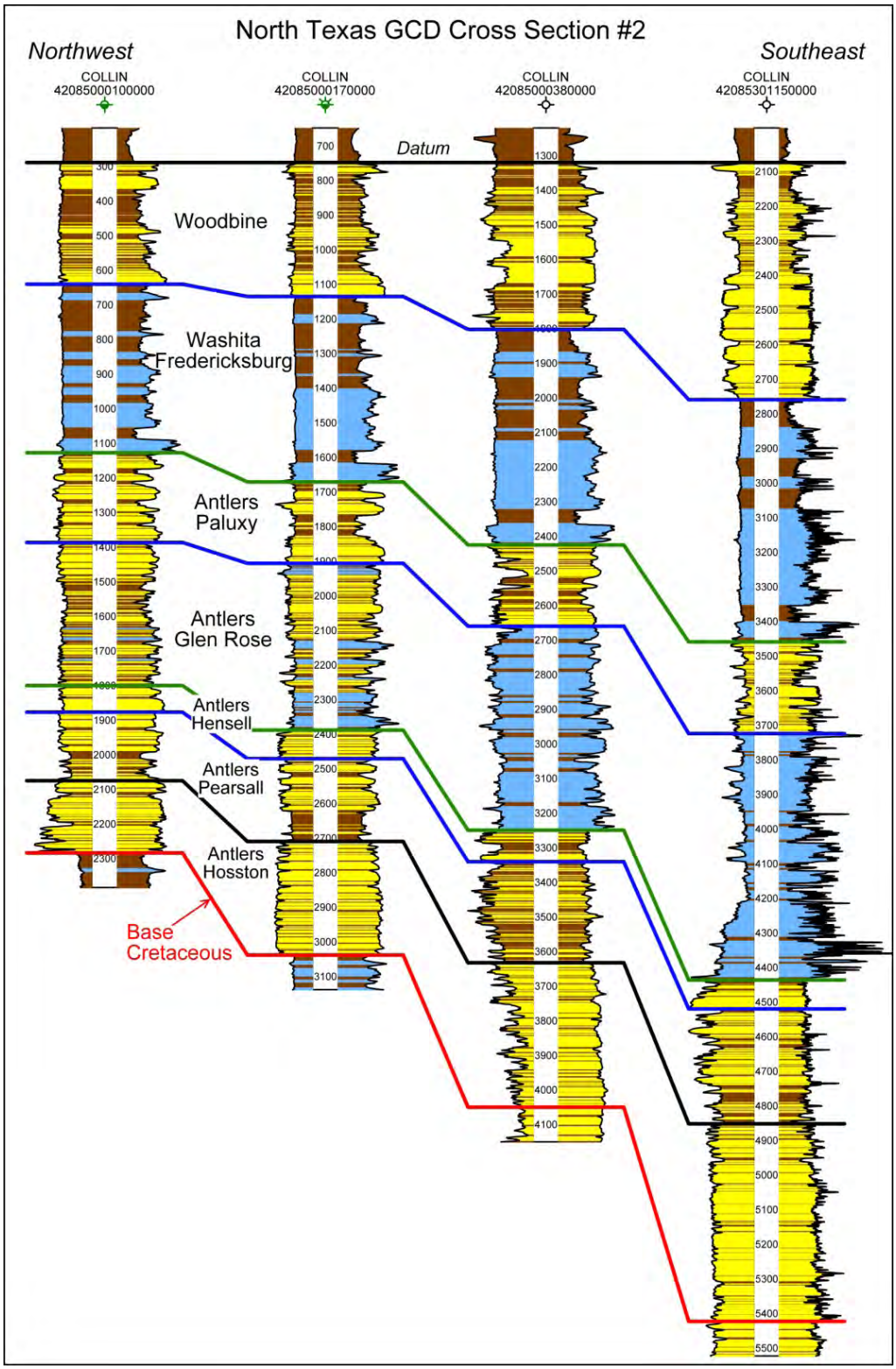


Figure 4.1.45 **North Texas GCD (green) showing the Woodbine Aquifer outcrop (blue cross hatching), locations of geophysical well logs, and locations of cross sections shown in Figures 4.1.46 and 4.1.47.**



yellow = greater than 50 percent sandstone, blue = greater than 50 percent limestone, brown = greater than 50 percent shale

Figure 4.1.46 North Texas GCD digital cross section # 1 with stratigraphic layers flattened on the top of the Hosston Aquifer (datum), so true elevations relative to sea level are not shown.



yellow = greater than 50 percent sandstone, blue = greater than 50 percent limestone,
brown = greater than 50 percent shale

Figure 4.1.47 North Texas GCD digital cross section # 2 with stratigraphic layers flattened on the top of the Woodbine Aquifer (datum), so true elevations relative to sea level are not shown.

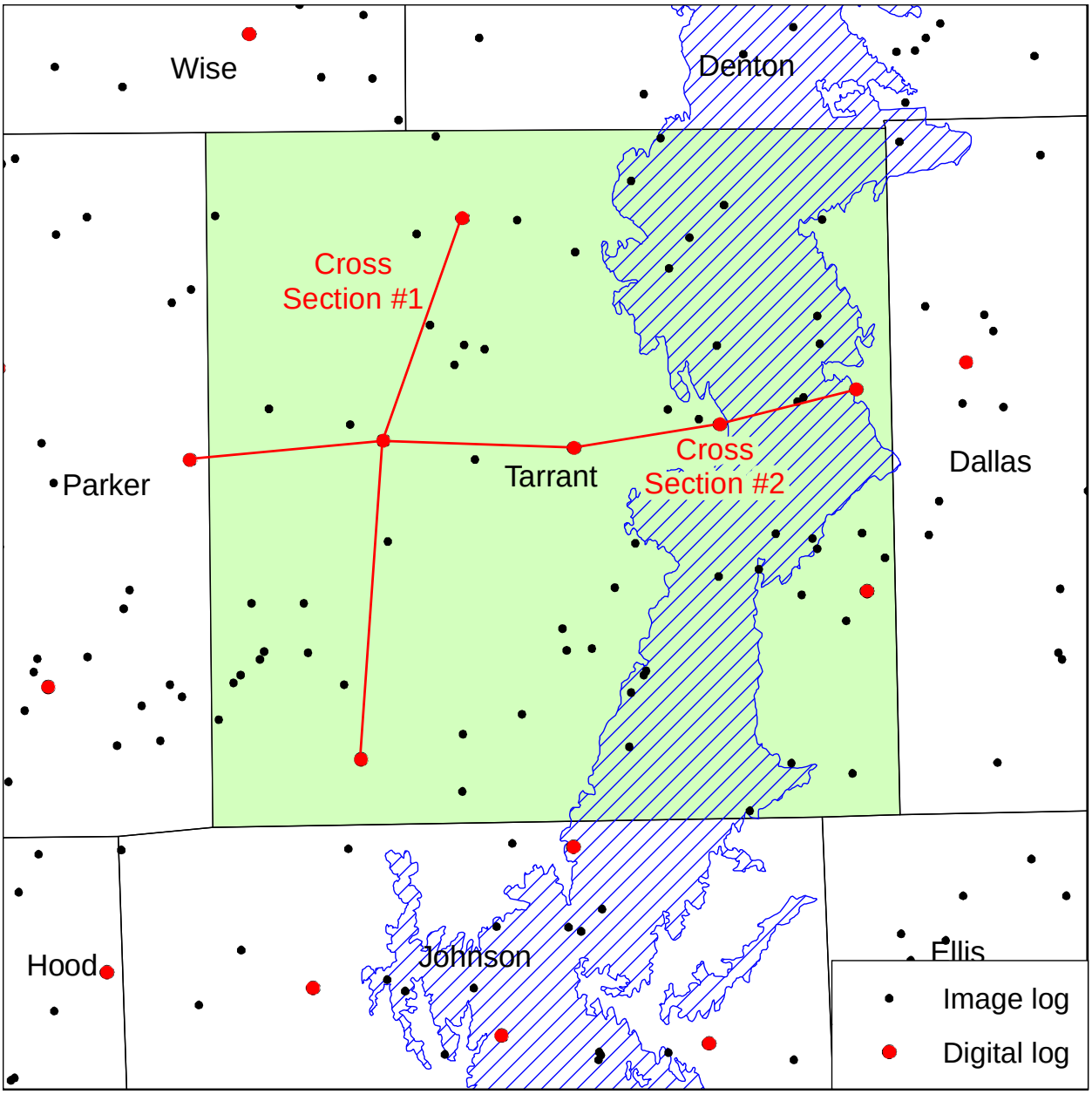
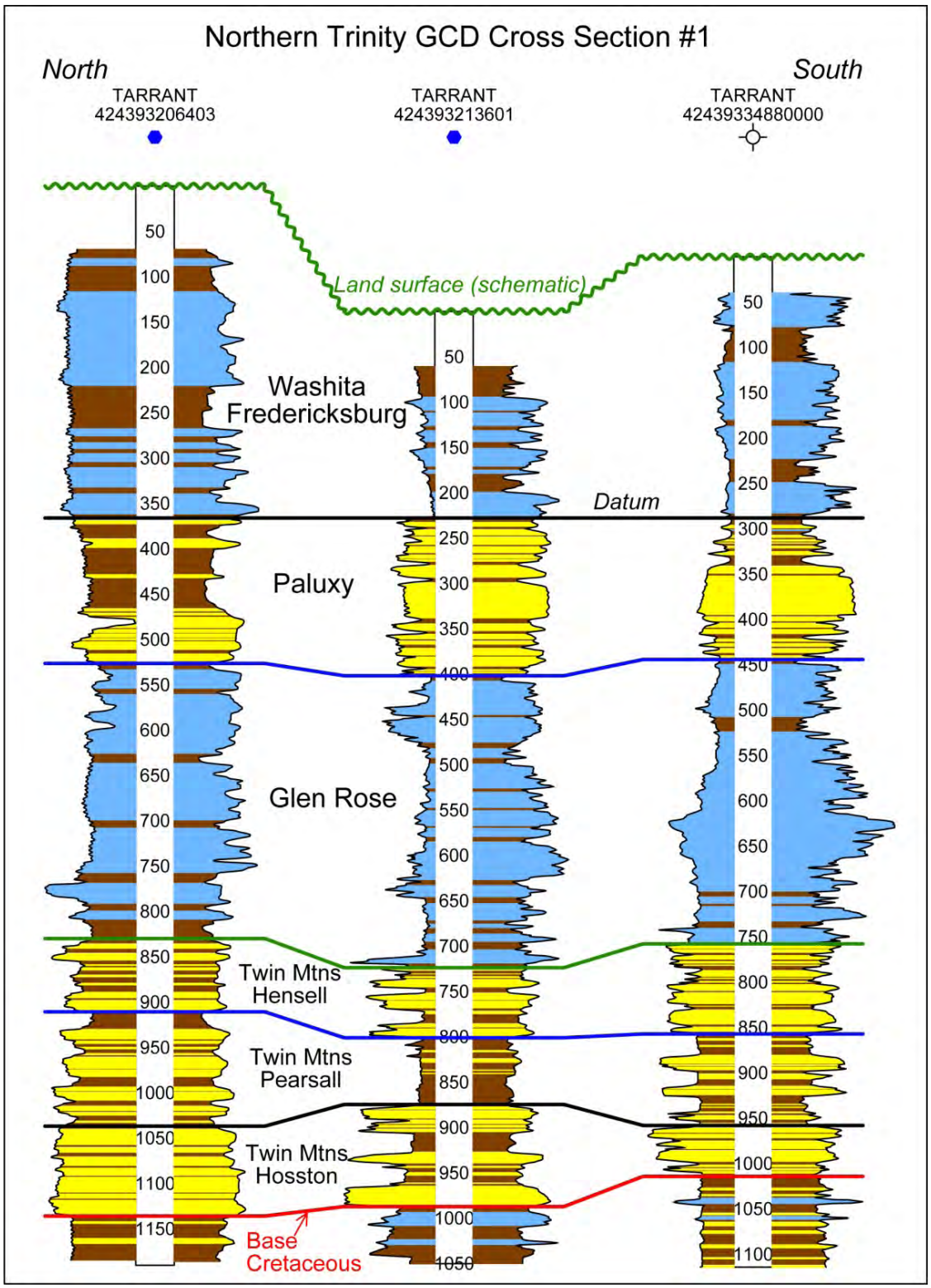


Figure 4.1.48 Northern Trinity GCD (green) showing the Woodbine Aquifer outcrop (blue cross hatching), locations of geophysical well logs, and locations of cross sections shown in Figures 4.1.49 and 4.1.50.



yellow = greater than 50 percent sandstone, blue = greater than 50 percent limestone,
brown = greater than 50 percent shale

Figure 4.1.49 Northern Trinity GCD digital cross section # 1 with stratigraphic layers flattened on the top of the Paluxy Aquifer (datum), so true elevations relative to sea level are not shown.

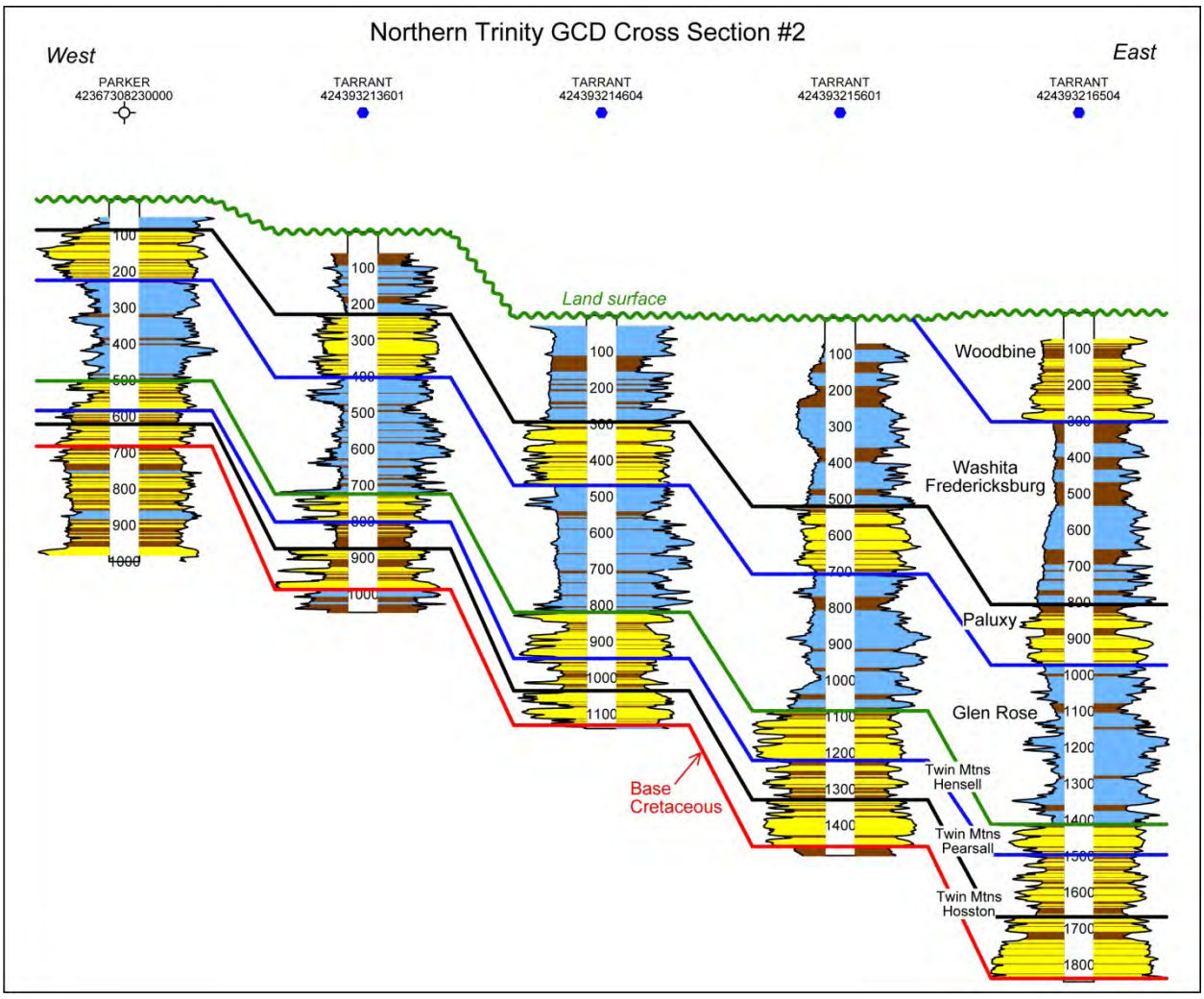


Figure 4.1.50 Northern Trinity GCD digital cross section # 2 with stratigraphic layers and land surface shown as true depths relative to sea level.

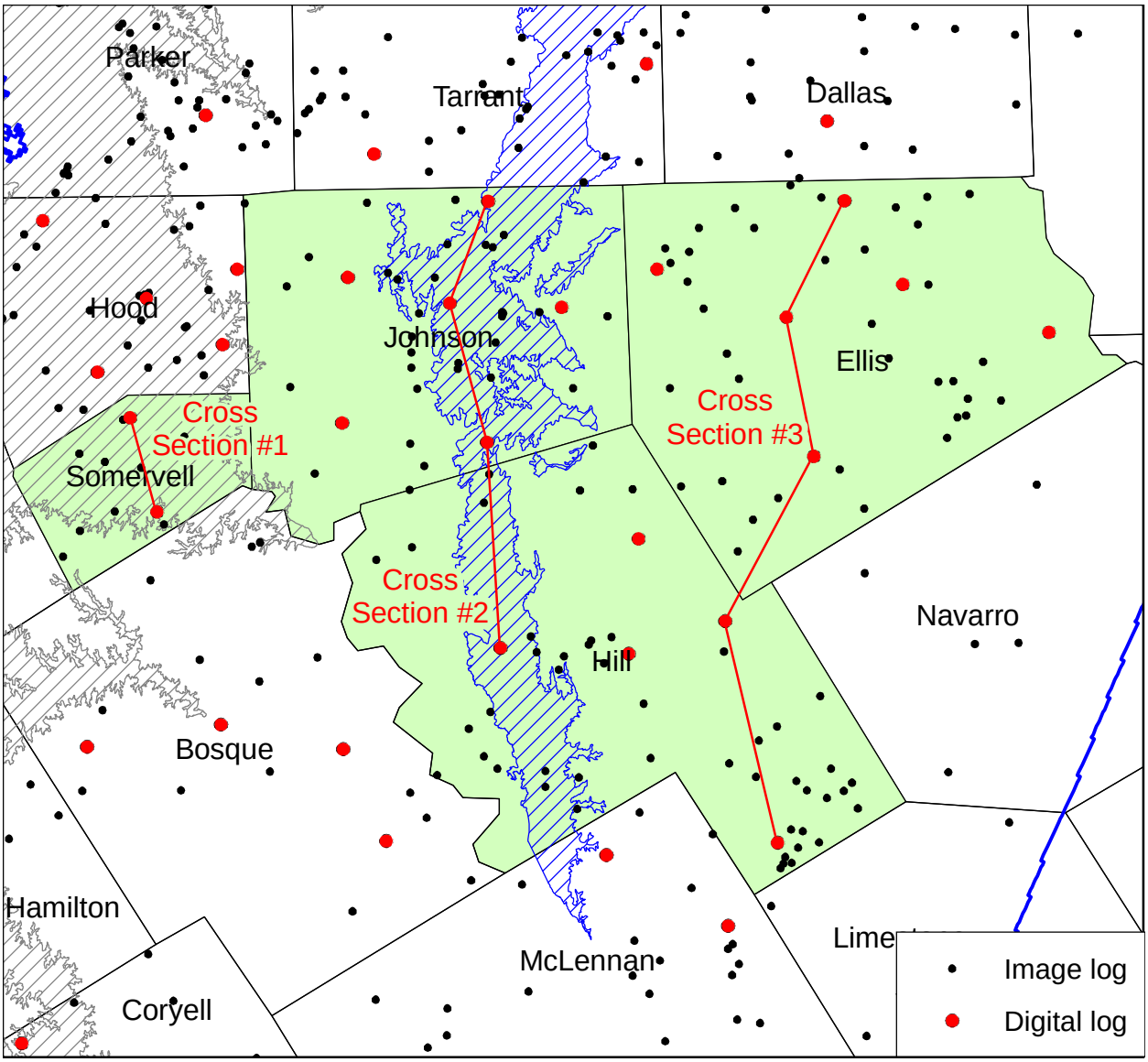
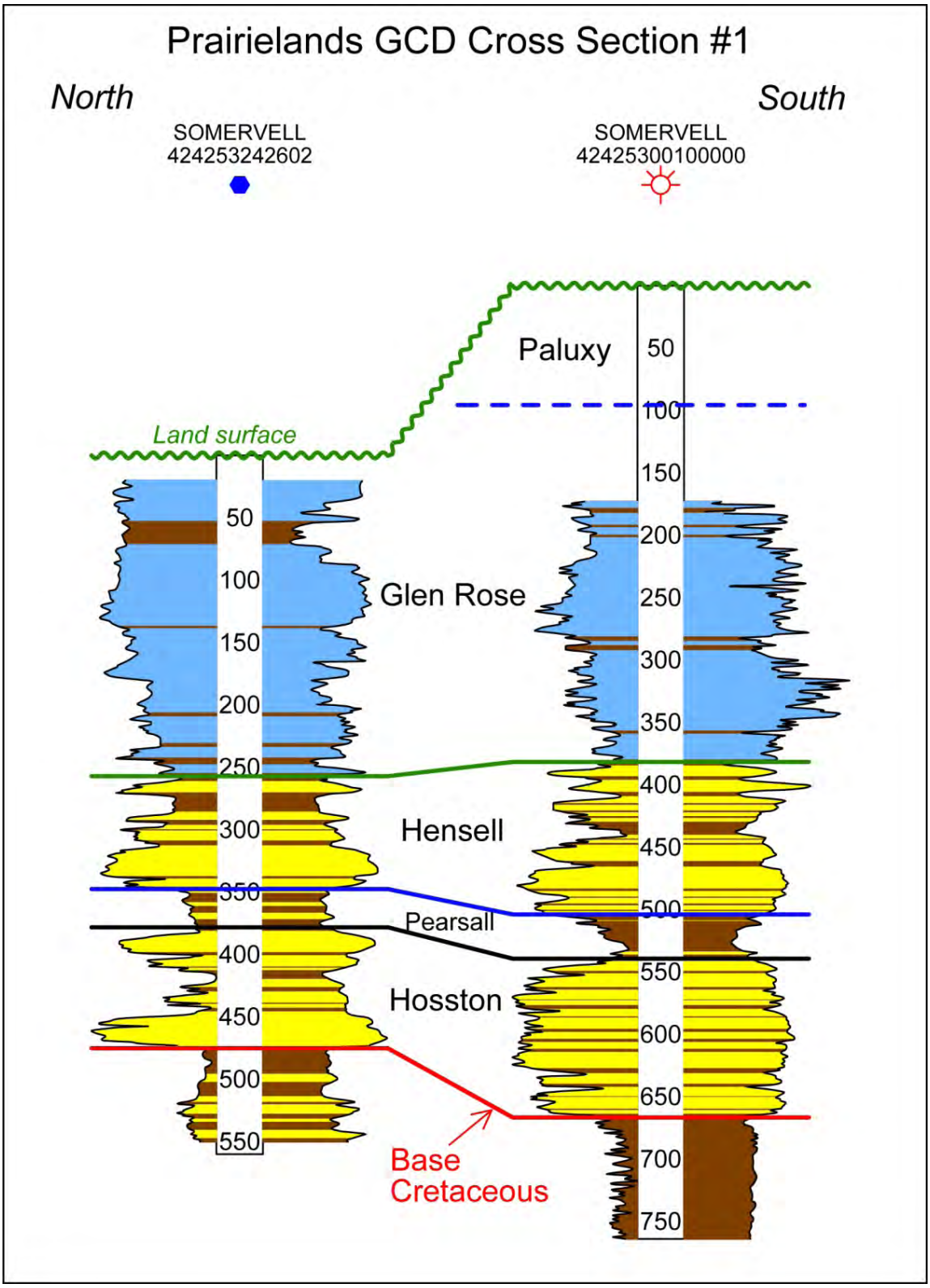


Figure 4.1.51 The Prairielands GCD (green) showing the northern Trinity and Woodbine aquifer outcrops (grey and cross hatching, respectively), locations of geophysical well logs, and locations of cross sections shown in Figures 4.1.52 and 4.1.54.



yellow = greater than 50 percent sandstone, blue = greater than 50 percent limestone,
brown = greater than 50 percent shale

Figure 4.1.52 Prairielands GCD digital cross section # 1 with stratigraphic layers and land surface shown as true depths relative to sea level.

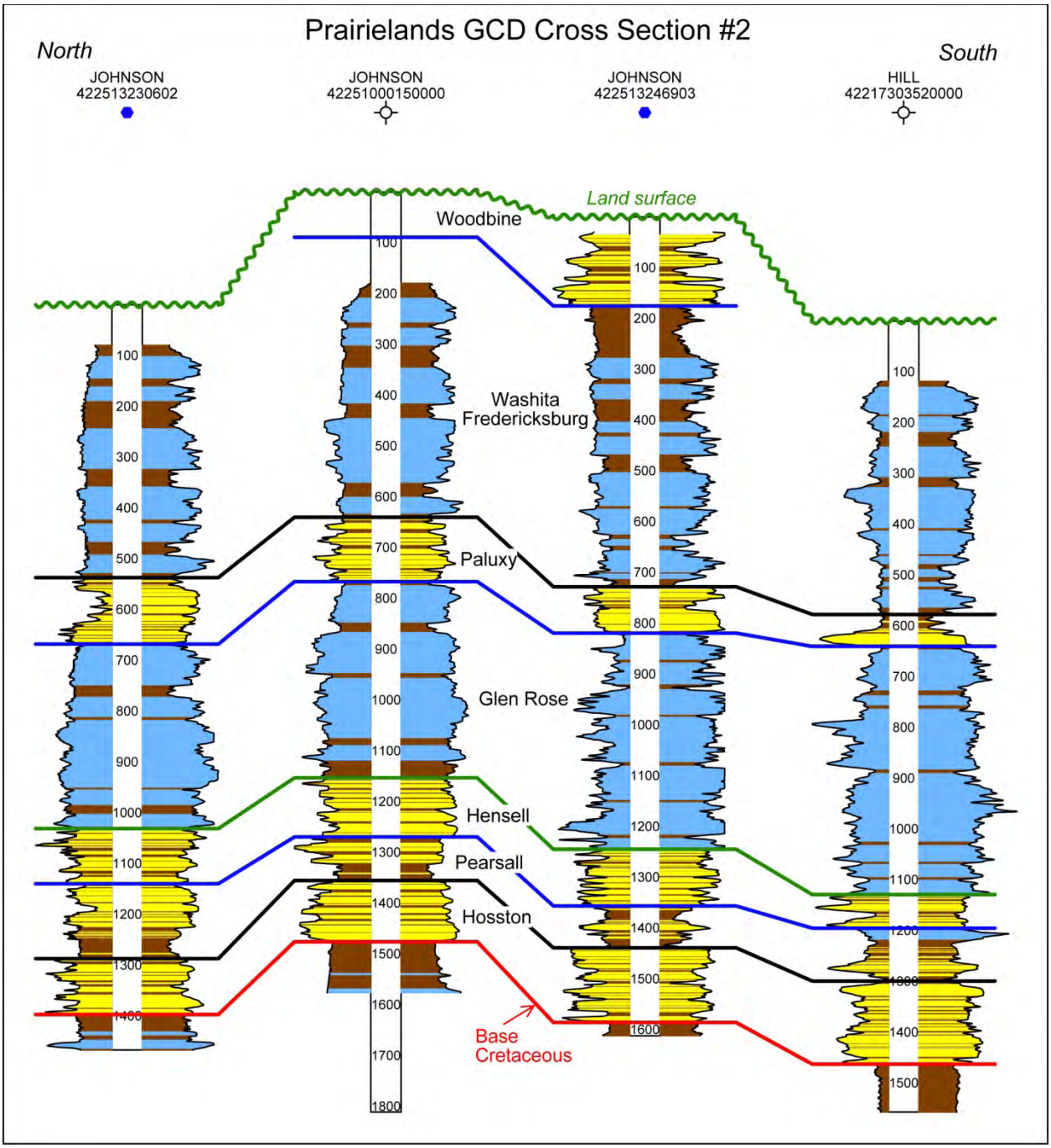


Figure 4.1.53 Prairielands GCD digital cross section # 2 with stratigraphic layers and land surface shown as true depths relative to sea level.

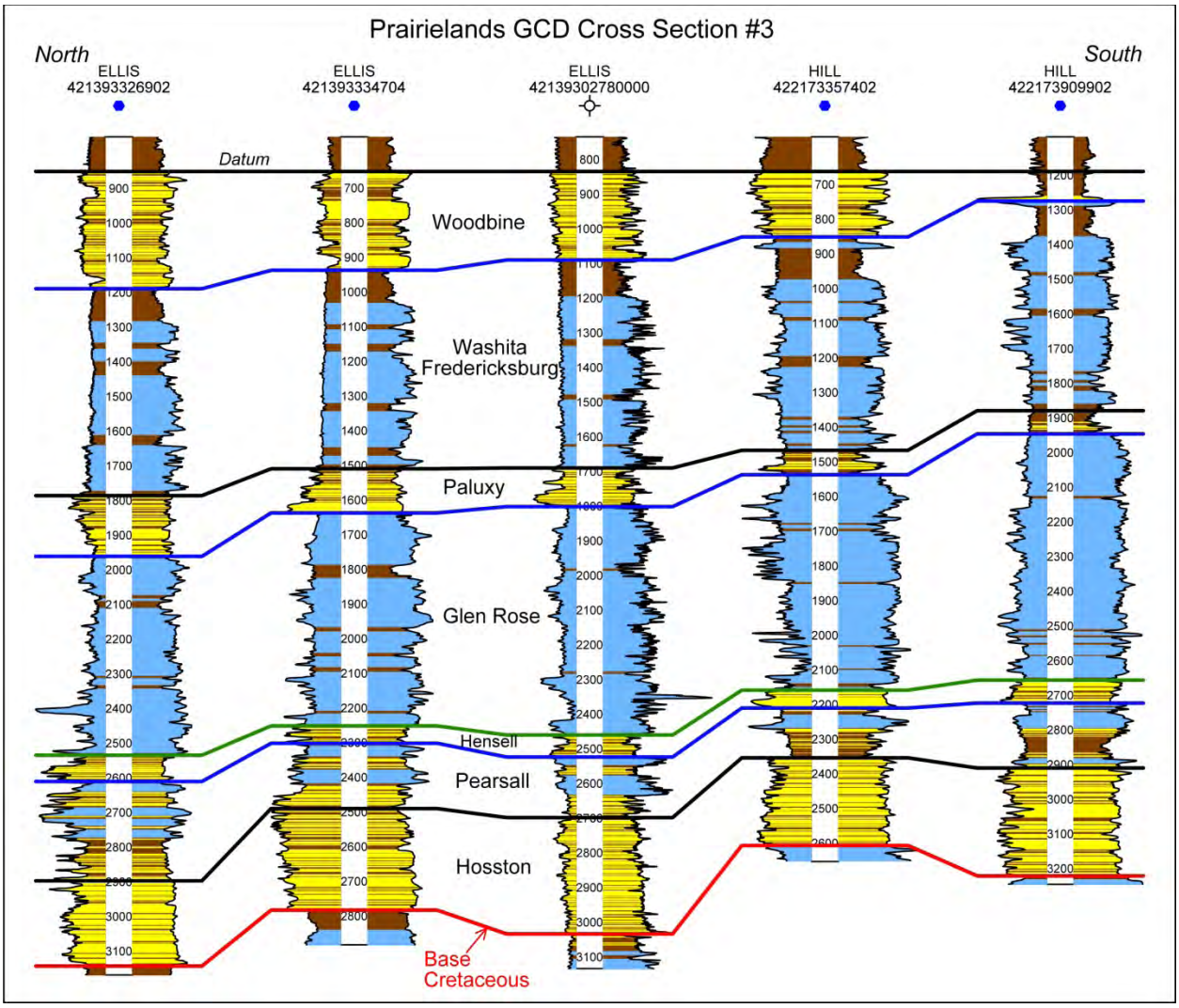


Figure 4.1.54 Prairielands GCD digital cross section # 3 with stratigraphic layers flattened on the top of the Woodbine Aquifer (datum), and so true elevations relative to sea level are not shown.

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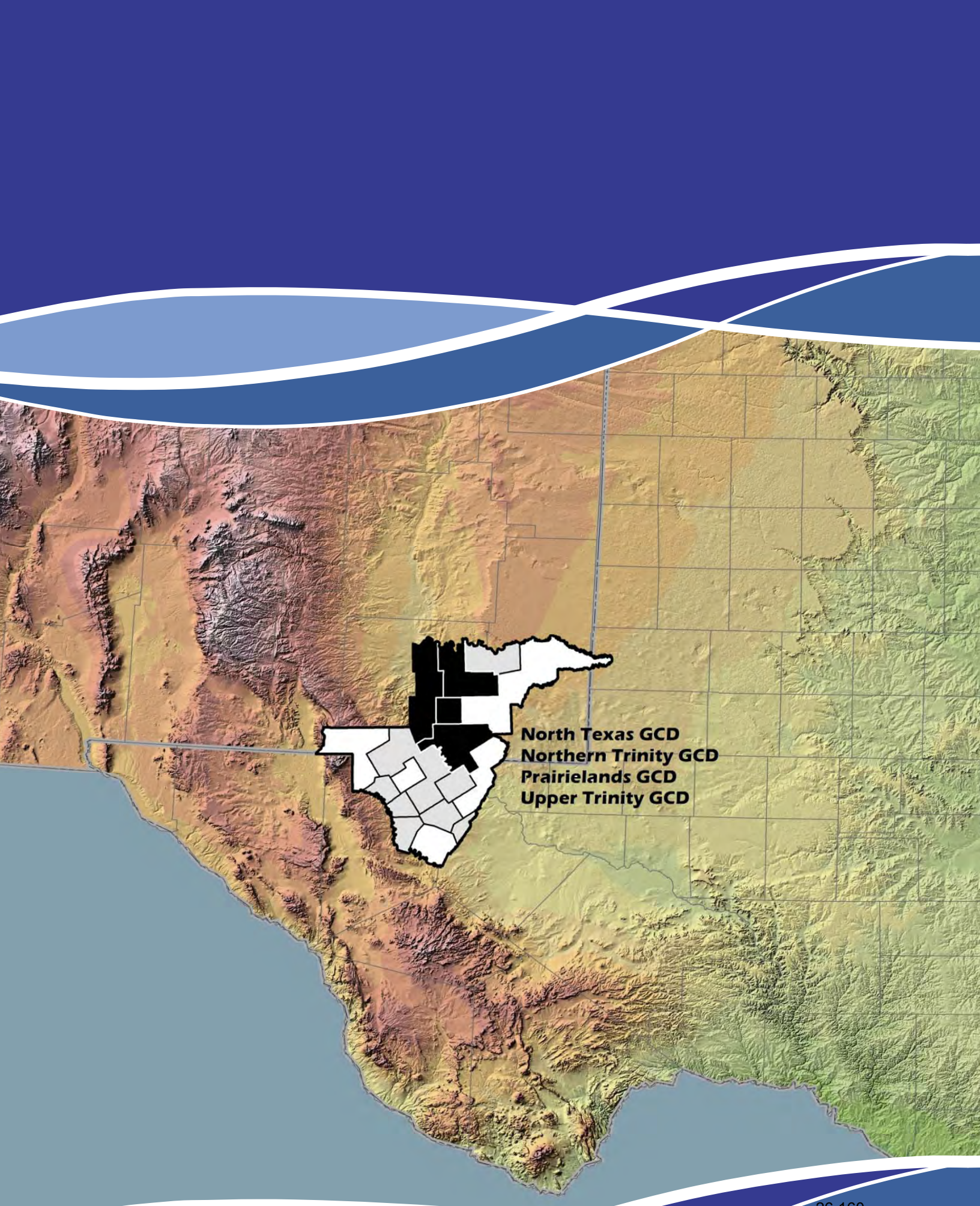

North Texas GCD
Northern Trinity GCD
Prairielands GCD
Upper Trinity GCD

Reference 27

U.S. climate data
Temperature - Precipitation - Sunshine - Snowfall

US Climate Data on

Home United States Texas Enter a location

Monthly Daily History Geo & Map Weather Forecast

You are here: United States > Texas > Dallas

Climate Dallas - Texas

°C | °F

	Jan	Feb	Mar	Apr	May	Jun
Average high in °F:	57	61	69	77	84	91
Average low in °F:	30	35	42	51	60	67
Av. precipitation in inch:	2.32	2.99	3.7	3.43	4.61	4.65
Days with precipitation:	-	-	-	-	-	-
Hours of sunshine:	-	-	-	-	-	-

	Jul	Aug	Sep	Oct	Nov	Dec
Average high in °F:	95	96	89	80	68	58
Average low in °F:	71	71	64	52	43	32
Av. precipitation in inch:	2.8	2.13	3.35	4.88	3.31	2.8
Days with precipitation:	-	-	-	-	-	-
Hours of sunshine:	-	-	-	-	-	-

Dallas weather averages

Annual high temperature:	77.1°F
Annual low temperature:	51.5°F
Average temperature:	64.3°F
Average annual precipitation - rainfall:	40.97 inch
Days per year with precipitation - rainfall:	-
Annual hours of sunshine:	-
Av. annual snowfall:	-

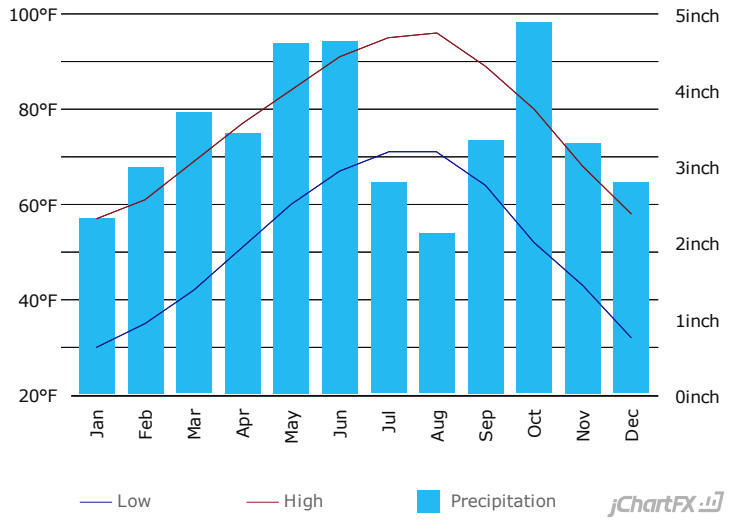
20

Dallas Climate Graph - Texas Climate Chart

Climate data for joe pool lake, Longitude: -96.974, Latitude: 32.6406
Average weather Dallas, TX - 75201 - 1981-2010 normals

Jan: January, Feb: February, Mar: March, Apr: April, May: May, Jun: June, Jul: July, Aug: August, Sep: September, Oct: October, Nov: November, Dec:

December



Climograph of Dallas on your website

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Reference 28

Aquifers of Texas

by Peter G. George, Ph.D., P.G. • Robert E. Mace, Ph.D., P.G. •
Rima Petrossian, P.G.

Report 380
July 2011

Texas Water Development Board
www.twdb.texas.gov

Aquifers of Texas

Report 380

by
Peter G. George, Ph.D., P.G.
Robert E. Mace, Ph.D., P.G.
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Texas Water Development Board

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The contents of this report (including figures and tables) document the work of the following licensed Texas geoscientists:

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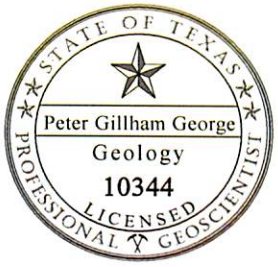

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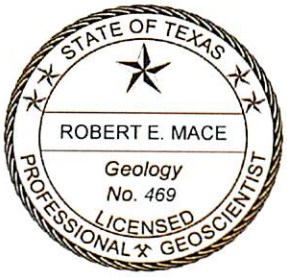

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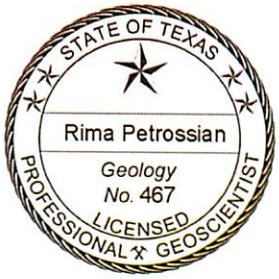

Cover photo: The Cow Creek Limestone of the Edwards-Trinity Plateau Aquifer at Hamilton Pool, Travis County, Texas
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1 Executive Summary

This report is an update to the Texas Water Development Board (TWDB) Report 345, *Major and Minor Aquifers of Texas*, published in 1995 and coauthored by John B. Ashworth and Janie Hopkins. Since the publication of that report more than 15 years ago, a great deal of information has become available through research at universities, state and federal agencies, and private environmental engineering firms as part of the TWDB's Groundwater Availability Modeling Program. The TWDB itself collects a large amount of data annually on water levels and water quality from wells around the state, which is incorporated into its groundwater availability models.

In addition to new research becoming available, the aerial extent of the aquifers has changed since 1995. In the 2007 Texas State Water Plan, the TWDB adjusted the boundaries of the Blaine, Bone Spring–Victorio Peak, Edwards (Balcones Fault Zone), Igneous, Lipan, Ogallala, Pecos Valley (formerly the Cenozoic Pecos Alluvium), Seymour, and Trinity aquifers. These changes are incorporated into the aquifer summaries presented in this report.

The aquifer summaries are short descriptions covering geology, hydrology, and water use, based largely on reports generated through the Groundwater Availability Modeling Program. The summaries are preceded by sections on groundwater in Texas, including the monitoring and modeling programs at the TWDB, a discussion of statewide groundwater issues, a summary of groundwater management in the state, and basic groundwater principles. The latter is included as a layman's guide to the state's groundwater resources.

As in any scientific report, the summary descriptions are based on current and past information. To keep the information current, aquifer descriptions will be updated and posted on the TWDB Web site as new research is completed.

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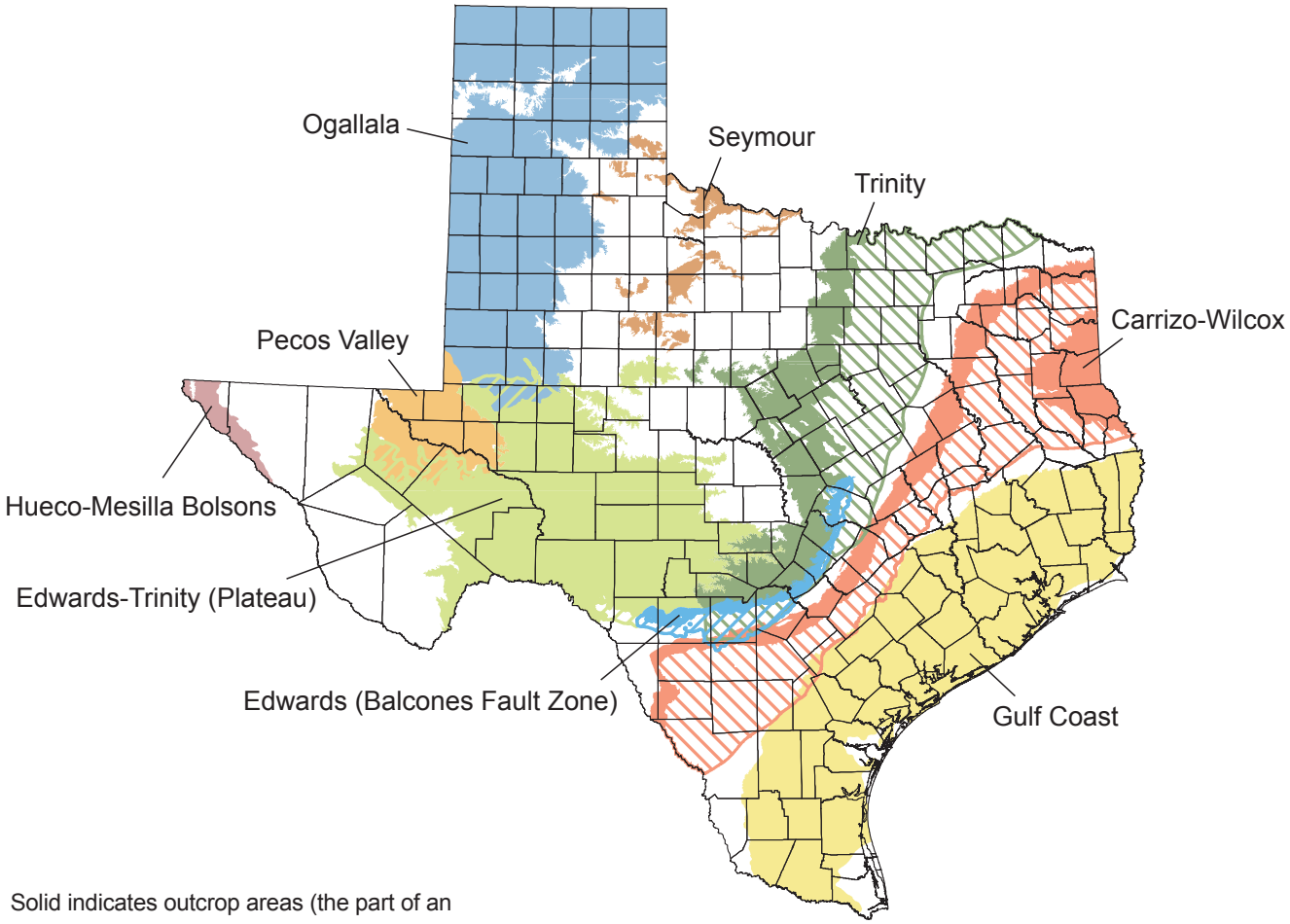
2 Introduction

Texas has numerous aquifers capable of producing groundwater for households, municipalities, industry, farms, and ranches. The Texas Water Development Board (TWDB) recognizes 9 major aquifers—aquifers that produce large amounts of water over large areas (Figure 2-1)—and 21 minor aquifers—aquifers that produce minor amounts of water over large areas or large amounts of water over small areas (Figure 2-2). These aquifers are a critical source of water for Texas, supplying 59 percent of the 15.6 million acre-feet of water used in the state in 2003. About 79 percent of this water is used for irrigation, with irrigators withdrawing most of this water from the Ogallala Aquifer alone (82 percent of all groundwater used for irrigation, or 6.0 million acre-feet per year). About 36 percent of water used to meet municipal demands is from groundwater. The number of aquifers appearing in reports and maps produced by the TWDB, and its predecessor agencies, has changed considerably over the years. In 1961, the



Solid indicates outcrop areas (the part of an aquifer that lies at the land surface).
Hatched indicates subsurface areas (the part of an aquifer that lies or dips below other formations).

Figure 2-1.
The major aquifers of Texas

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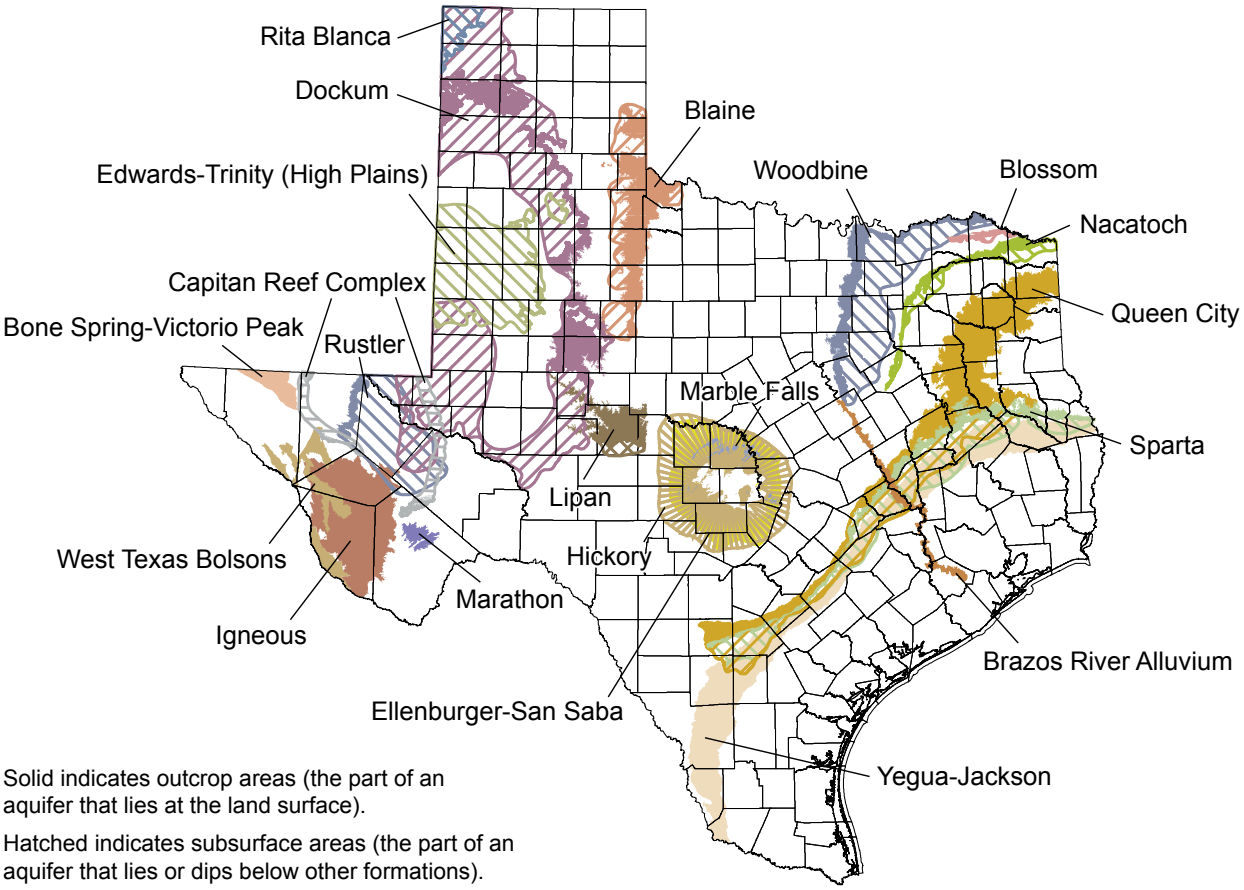
Texas Board of Water Engineers recognized only nine "principal" aquifers in the first state water plan. By 2002, the number of named aquifers increased to 30 with the addition of the Yegua-Jackson Aquifer. This increase was mainly due to the addition of minor aquifers.

The mapped extent of the aquifers has also changed over time. In the most recent water plan of 2007, the TWDB adjusted the boundaries of the Blaine, Bone Spring–Victorio Peak, Edwards (Balcones Fault Zone), Igneous, Lipan, Ogallala, Pecos Valley (formerly the Cenozoic Pecos Alluvium), Seymour, and Trinity aquifers. These changes were based on groundwater availability modeling and other scientific studies, and comments from the public supported by existing information. The TWDB also changed the name of the Hueco-Mesilla Bolson Aquifer to the Hueco-Mesilla Bolsons Aquifer to reflect that the aquifer is made up of sediments in two separate bolsons: the Hueco Bolson and the Mesilla Bolson.

It should be noted that this report is an update to TWDB reports of Ashworth and Flores (1991) and Ashworth and Hopkins (1995). Since their publication, a great deal of information has become available through research at universities, state and federal agencies, and private environmental



Solid indicates outcrop areas (the part of an aquifer that lies at the land surface).

Hatched indicates subsurface areas (the part of an aquifer that lies or dips below other formations).

The Edwards-Trinity (High Plains) and Rita Blanca aquifers are almost entirely subsurface.

Figure 2-2.
The minor aquifers of Texas

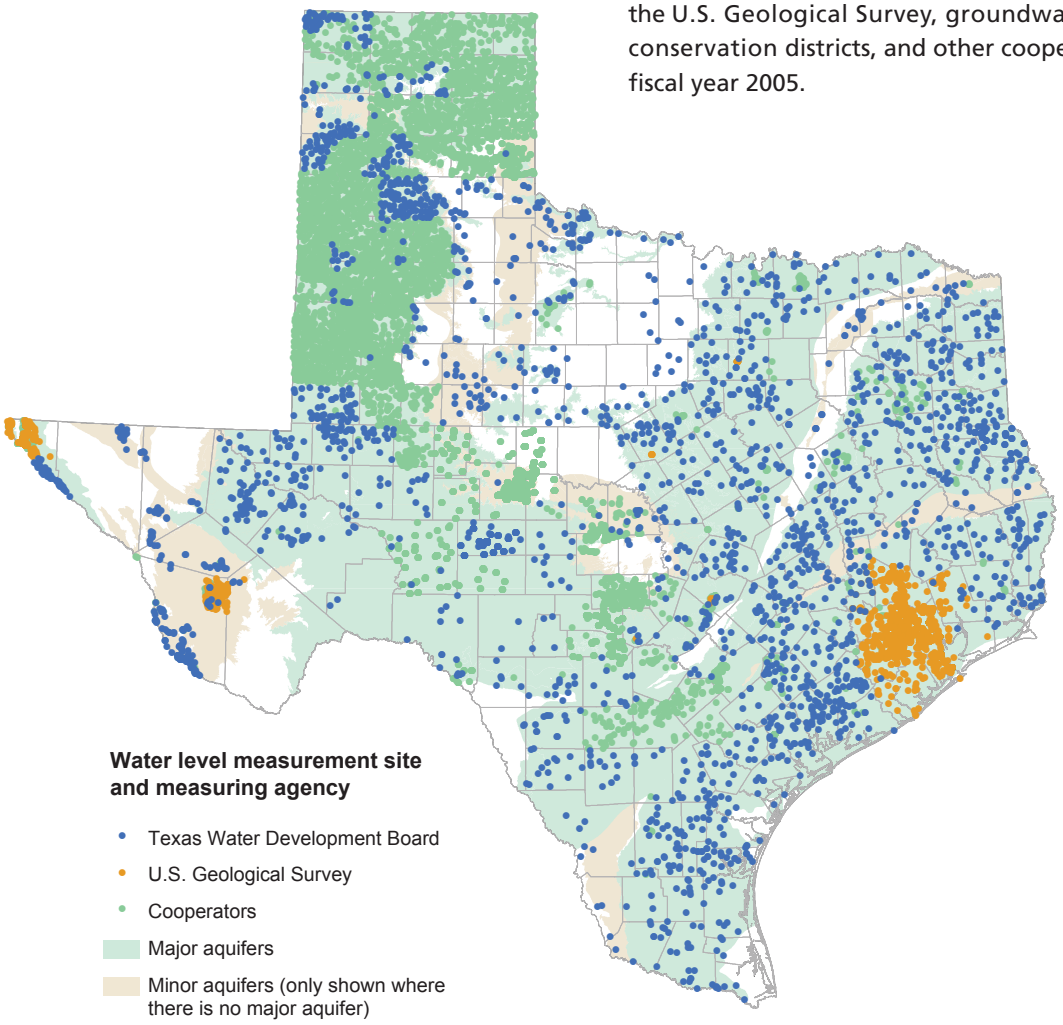


Figure 2-3. Location of wells measured by TWDB, the U.S. Geological Survey, groundwater conservation districts, and other cooperators in fiscal year 2005.

engineering firms as part of the Groundwater Availability Modeling (GAM) Program at the TWDB. The GAM reports have been particularly useful for this report in describing general aquifer characteristics. These characteristics are described at the end of individual reports for each aquifer.

2.1 TWDB Monitoring and Modeling Programs

To assess the quality and quantity of groundwater in Texas, the TWDB operates three monitoring programs that complement other local, state, and federal monitoring programs within the state. The first of the three is the annual groundwater level observation program. Its purpose is to detect trends in water levels over time on a regional basis, to provide support for groundwater management and state and regional water planning, and to collect information for groundwater modeling. In operation since 1957, the program relies on a network of approximately 8,000 observation wells (Figure 2-3). The majority of the wells—86 percent—are in major aquifers, with the remainder in minor or other undesignated aquifers, such as the Rio Grande Alluvium. The TWDB collects more than 2,000 water level measurements each year and receives at least another 11,000 measurements from other organizations, primarily groundwater conservation districts. Once collected, groundwater levels are stored in TWDB's groundwater database and are available on the agency's Web site at http://www.twdb.texas.gov.

The TWDB, along with other entities, operates

a second groundwater level program to detect trends in groundwater levels on a daily basis at more than 100 specific well sites. These water levels are from wells called "recorders" or "recorder wells" equipped to record water levels continuously (Figure 2-4). The information from these wells is transmitted daily to the TWDB, where it is posted on the agency's Web site.

The final program involves monitoring groundwater quality. Its purpose is to monitor natural, or ambient, water quality in each of the state's major and minor aquifers, to observe any trends in water quality over time, and to support state and regional water planning and groundwater management. Sample analyses include major ions, trace elements (primarily metals), and nutrients. The TWDB annually samples water from 600 to 700 sites, and cooperators collect samples from at least 200 more. Most of the samples are collected from wells, but, on occasion, springs are also sampled. Through these collection efforts, all aquifers are sampled once every four to five years, and five or six major and minor aquifers are sampled each year (Figure 2-5). The water quality data collected by the TWDB and other outside

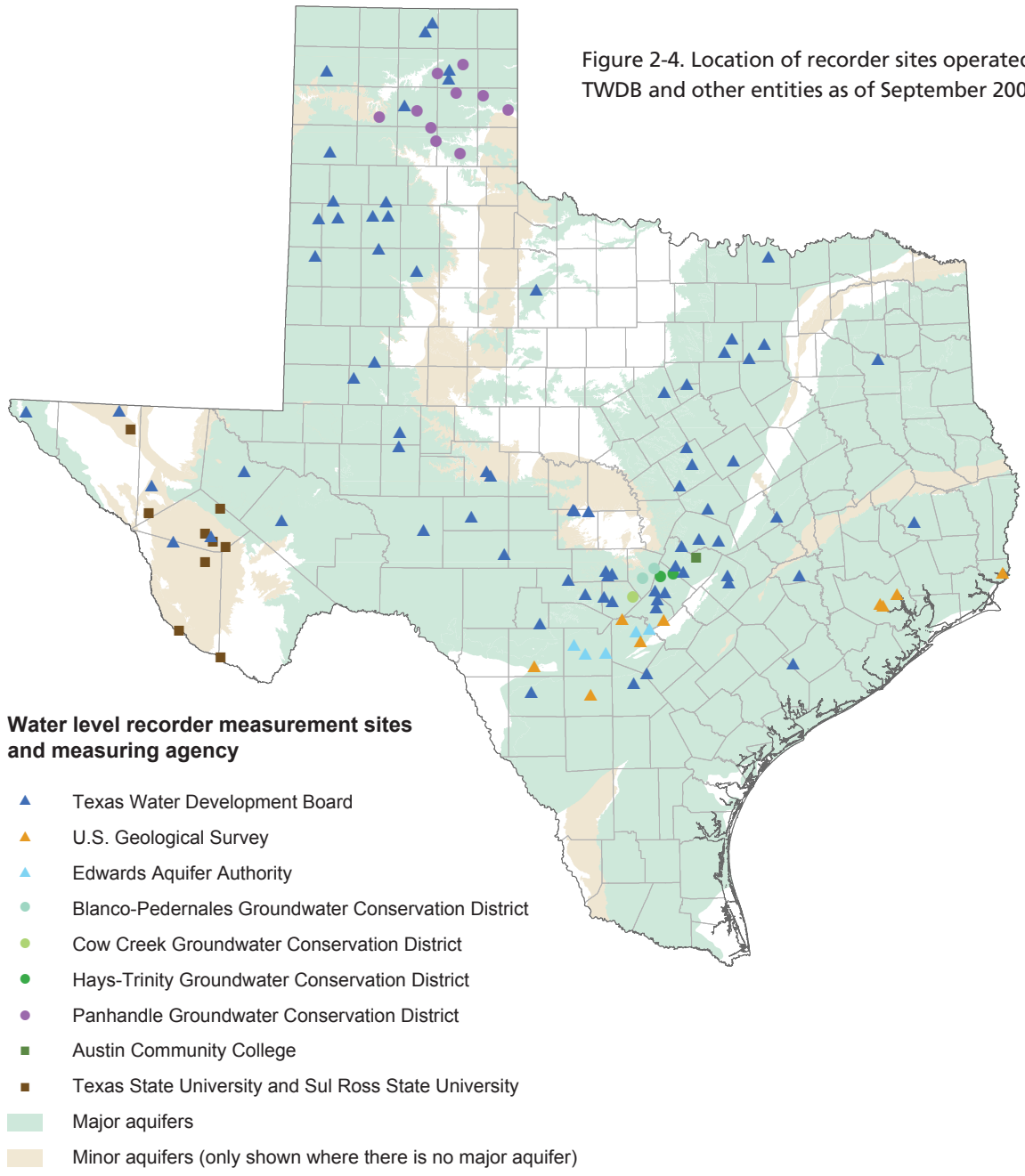


Figure 2-4. Location of recorder sites operated by TWDB and other entities as of September 2006.

groups are stored along with groundwater levels in the TWDB groundwater database. Other local, state, and federal organizations also monitor water quality. Groundwater conservation districts perform water quality analyses, usually at the request of well owners. Their analyses provide a general characterization of water quality based on concentrations of a few key constituents, such as bacteria, nitrate, total dissolved solids, and selected metals. Public water suppliers, as required by the Texas Commission on Environmental Quality, monitor groundwater quality, although generally after treatment. The U.S. Geological Survey collects water quality information in localized parts of the state to assess groundwater conditions and to determine how these conditions change over time and how natural features and human activities affect these conditions.

Groundwater availability models estimate current and future trends in the amount of water available for use from an aquifer. As part of its ongoing effort to provide vital, scientific information to the citizens and policy makers of Texas, the TWDB has obtained or developed models for all major aquifers and 8 of the 21 minor aquifers. In addition, the agency has begun to update some of the initial models and plans to review and update each model every five years.

TWDB groundwater availability models are computer-based, three-dimensional, numerical groundwater flow models that

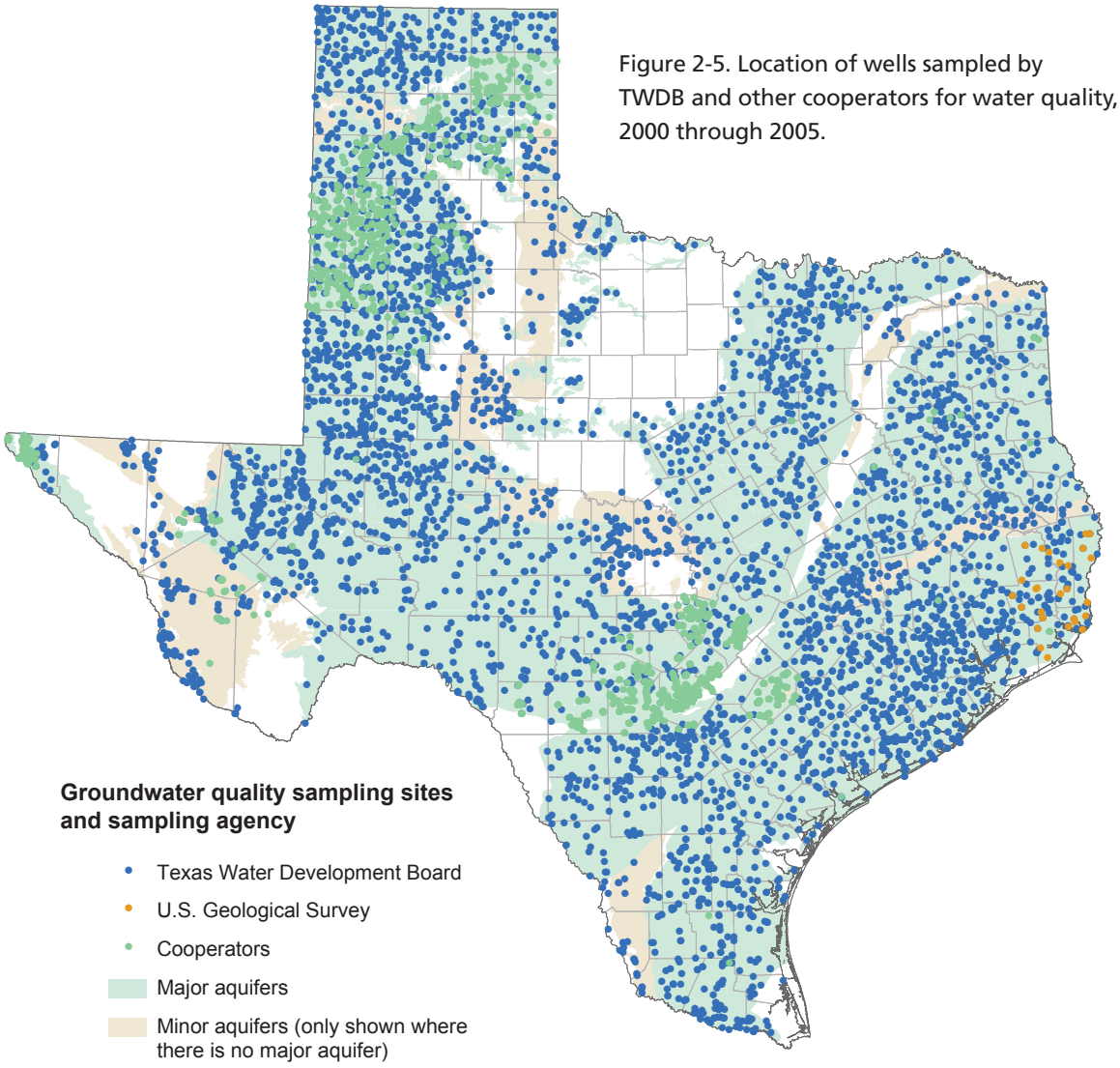


Figure 2-5. Location of wells sampled by TWDB and other cooperators for water quality, 2000 through 2005.

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simulate groundwater flow systems at a regional scale. The models estimate current and future trends in the amount of water available for use from an aquifer. They are meant to be "living tools" that can be updated as new information becomes available, adapted to reflect changing aquifer conditions, or refined to better address the needs and concerns of the groups using them. Because the groundwater availability models simulate large areas, these models allow users to see the big picture and understand groundwater flow through all or large parts of an aquifer. Complex physical parameters such as hydrogeologic properties, groundwater levels, pumpage, recharge, aquifer geometry, and groundwater–surface water interactions are simplified into mathematical equations that the model solves. The models are then calibrated using historically measured water levels, spring flows, and base flows to streams and rivers as targets.

Once an initial model has been created and calibrated, it becomes a tool that groundwater conservation districts, planning groups, and others can use to estimate groundwater availability and predict future water levels and regional groundwater flow in their aquifers on the basis of different scenarios. Ongoing refinement and improvement of the groundwater availability models are essential to addressing the needs and concerns of these various entities so that they can manage and plan the use of groundwater supplies. To view modeling reports, request a model, or check the status of the program, visit the TWDB Web site.

2.2 Statewide Groundwater Issues

2.2.1 Water Levels

TWDB monitoring of water wells throughout the state has identified areas of significant water level declines (Figure 2-6). Total water level declines in the state's aquifers range from less than 50 feet to more than 1,000 feet. The largest water level declines are in the Trinity Aquifer, focused in the Dallas–Fort Worth and Waco areas (Figure 2-6). One hundred years ago wells in much of the Trinity Aquifer flowed at the surface, releasing so much artesian pressure that most ceased to flow by the mid-1910s. Other areas of large water level declines are in the Carrizo-Wilcox Aquifer in the Winter Garden irrigation area north of Laredo; near Lufkin, Nacogdoches, and Tyler; and in the Gulf Coast Aquifer near Houston. Water levels in the Ogallala Aquifer have also declined more than 200 feet. All of these water level declines have been caused by groundwater withdrawals, primarily since the 1950s. Before the 1950s, it is estimated

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Figure 2-6. Estimated total water level declines in the major aquifers of Texas. Water level declines in the eastern part of the state tend to be declines in artesian pressure, whereas water level declines in the western part of the state tend to be declines in the water table. These estimates are from the groundwater availability models and are calculated by subtracting water levels from the most recently calibrated year (generally about 2000) from simulated predevelopment (prepumping) water levels.

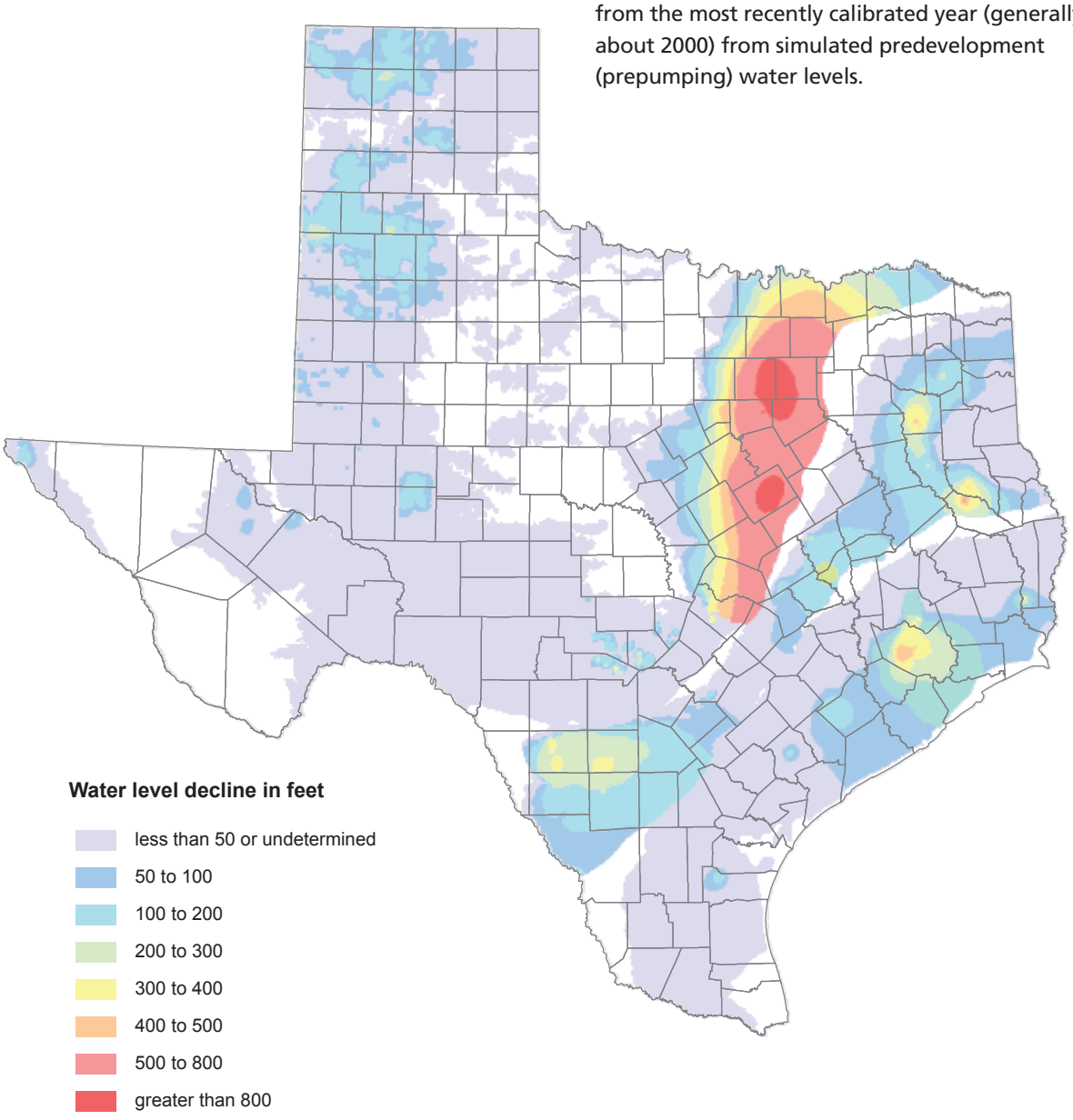

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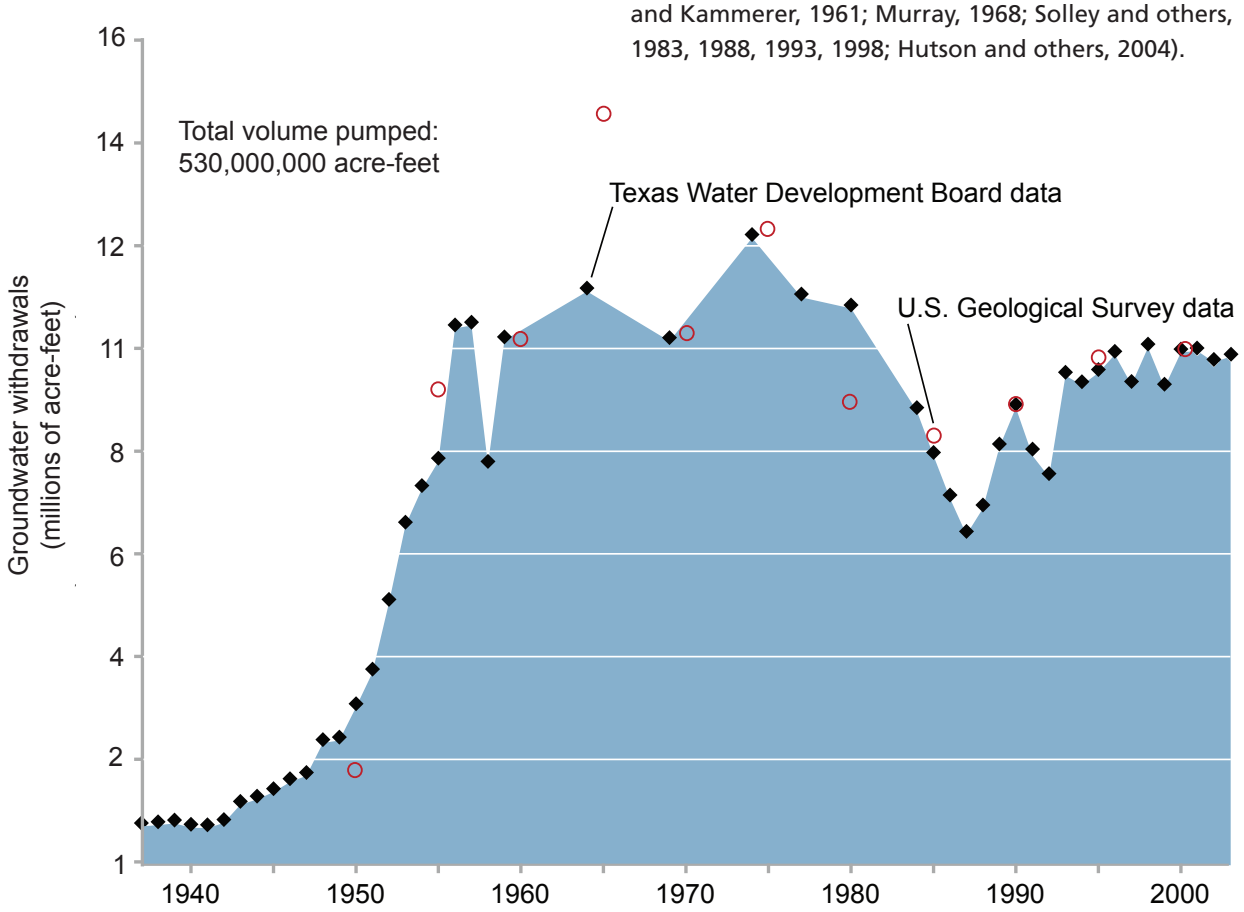
Figure 2-7. Historical estimates of groundwater withdrawals from the aquifers of Texas (data from the TWDB water use database; MacKichan, 1951, 1957; MacKichan and Kammerer, 1961; Murray, 1968; Solley and others, 1983, 1988, 1993, 1998; Hutson and others, 2004).



that Texans withdrew less than 2 million acre-feet of groundwater per year (Figure 2-7). After the 1950s, groundwater withdrawals have been estimated to be about 10 million acre-feet per year. (TWDB estimates withdrawals of about 9.2 million acre-feet in 2003). Between 1937 and 1993, about 530 million acre-feet of groundwater was withdrawn from the aquifers of Texas.

Between 1994 and 2004, water levels in the state's aquifers declined in some parts of the state and rose in others. Water levels continued to decline in much of the Ogallala Aquifer in West Texas, with declines greater than 40 feet in parts of the aquifer. However, other parts of the Ogallala Aquifer showed water level rises, presumably due to increased recharge resulting from fallow fields in areas of dry land farming. Water levels have risen more than 40 feet in 10 years in the Houston area because of reduced pumping to prevent land subsidence. Water levels have fallen more than 40 feet, however, in the suburbs north of Houston.

2.2.2 Groundwater Quality

Although the vast majority of groundwater used for drinking in Texas meets state and federal requirements for safety, in some parts of the state naturally occurring levels of total dissolved solids, arsenic, and radionuclides, as well as human-caused contamination, prevent the water from meeting those standards.

Total dissolved solids are a measure of the salinity of water and represent the amount of minerals dissolved in water, generally reported as milligrams per liter of water. If water is too saline, then it may not be drinkable without treatment, or it may not be suitable for

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irrigation. Water with total dissolved solids less than 1,000 milligrams per liter is considered fresh and is generally usable. Water with total dissolved solids of as much as 1,500 milligrams per liter may be used to irrigate crops, depending on the type of crop and the levels of salt, sodium, carbonate, bicarbonate, nitrogen, and boron. Water with total dissolved solids as high as 3,000 milligrams per liter may still be used for livestock. Water with total dissolved solids between 1,000 and 10,000 milligrams per liter, also called brackish groundwater, is a potential source of water for desalination. Much of the water in the state's aquifers is fresh; however, brackish groundwater is more common than fresh groundwater in the southern Gulf Coast area and in large parts of West Texas (Figure 2-8).

Although arsenic can occur both naturally and through human contamination, most of the arsenic in Texas groundwater is naturally occurring. Arsenic is a concern in drinking water because high levels of it can cause cancer and other health problems. Since January 2006, arsenic has become more of a concern because at that time the U.S. Environmental Protection Agency lowered the maximum acceptable level of arsenic in drinking water from 50 micrograms per liter to 10 micrograms per liter. Because this maximum acceptable level was lowered, many communities in Texas will now have to treat their

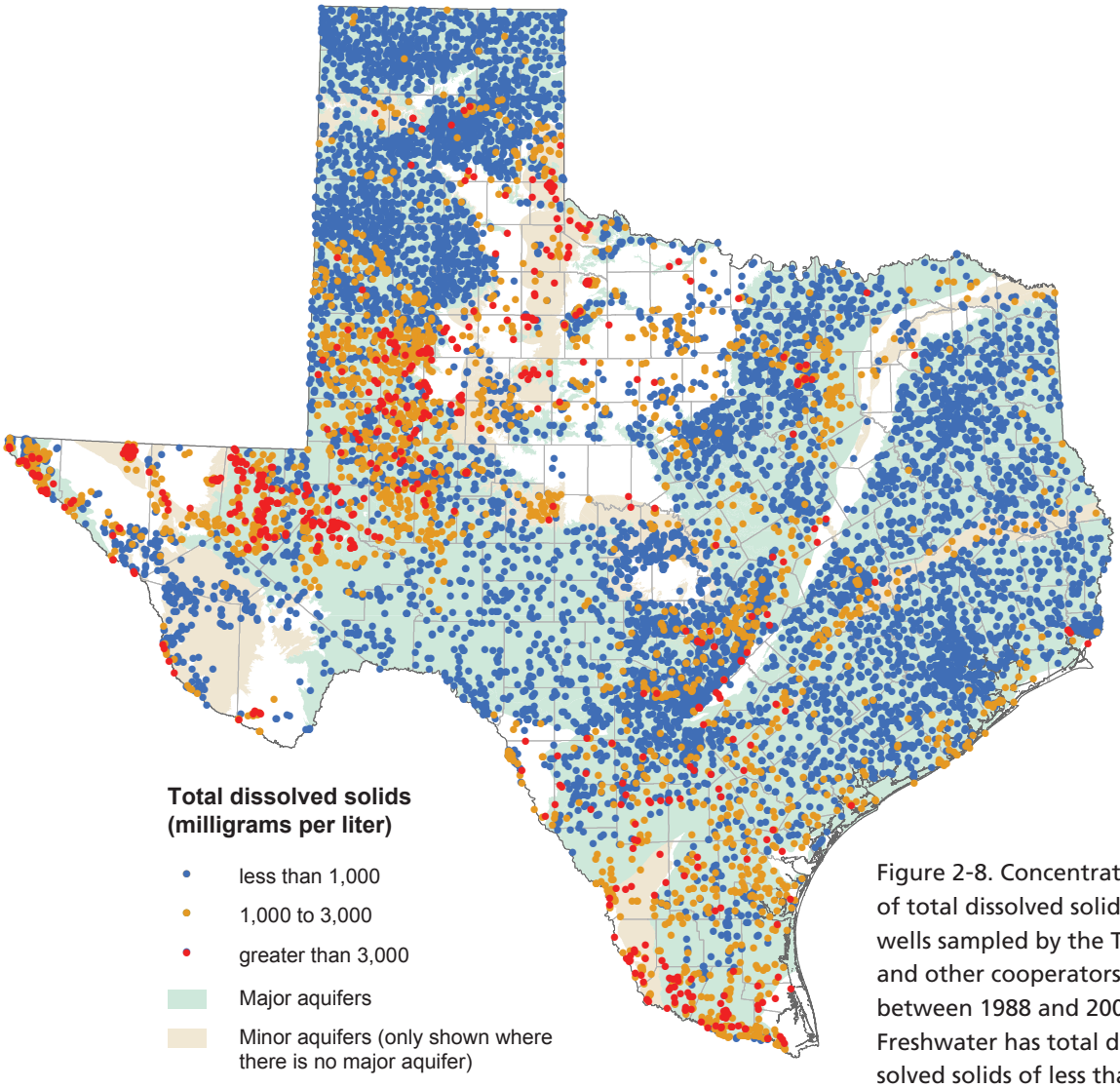

Figure 2-8. Concentration of total dissolved solids in wells sampled by the TWDB and other cooperators between 1988 and 2004. Freshwater has total dissolved solids of less than 1,000 milligrams per liter.

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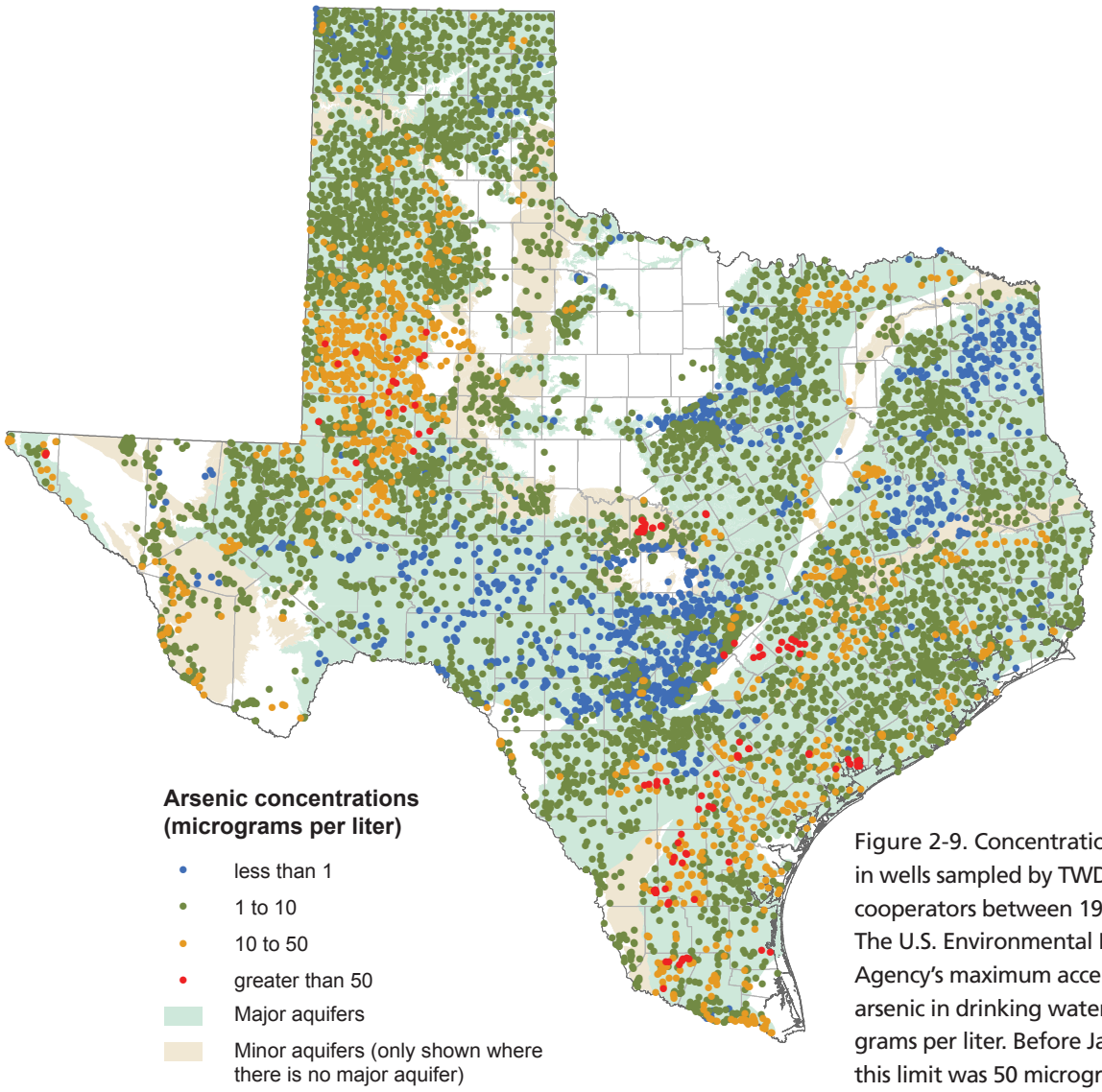

Figure 2-9. Concentration of arsenic in wells sampled by TWDB and other cooperators between 1988 and 2004. The U.S. Environmental Protection Agency's maximum acceptable limit for arsenic in drinking water is 10 micrograms per liter. Before January 2006, this limit was 50 micrograms per liter.

groundwater, blend it with another source, or find an alternative source of supply. Most of the groundwater in Texas with arsenic concentrations greater than 10 micrograms per liter is in southeast Texas in the Gulf Coast Aquifer, in West Texas in the southern half of the Ogallala Aquifer, and in parts of Far West Texas in the Hueco-Mesilla Bolsons and West Texas Bolsons aquifers (Figure 2-9).

A radionuclide is an atom having an unstable nucleus that emits radiation. One measure of radionuclides is gross alpha radiation, which represents the radiation emitted from uranium, radium, and radon. If groundwater contains enough radionuclides—most commonly radium, uranium, and radon gas—and if large enough quantities are consumed over time, there may be enough radiation to cause cancer and other health problems. The U.S. Environmental Protection Agency has set the maximum acceptable level of gross alpha radiation in drinking water at 15 picocuries per liter. Most groundwater in Texas with gross alpha radiation greater than the maximum acceptable level is found in the Hickory Aquifer in Central Texas and the Dockum Aquifer of West Texas (Figure 2-10). The Edwards-Trinity (Plateau), Gulf Coast, and Ogallala aquifers also have significant numbers of wells with high levels of gross alpha radiation. Although

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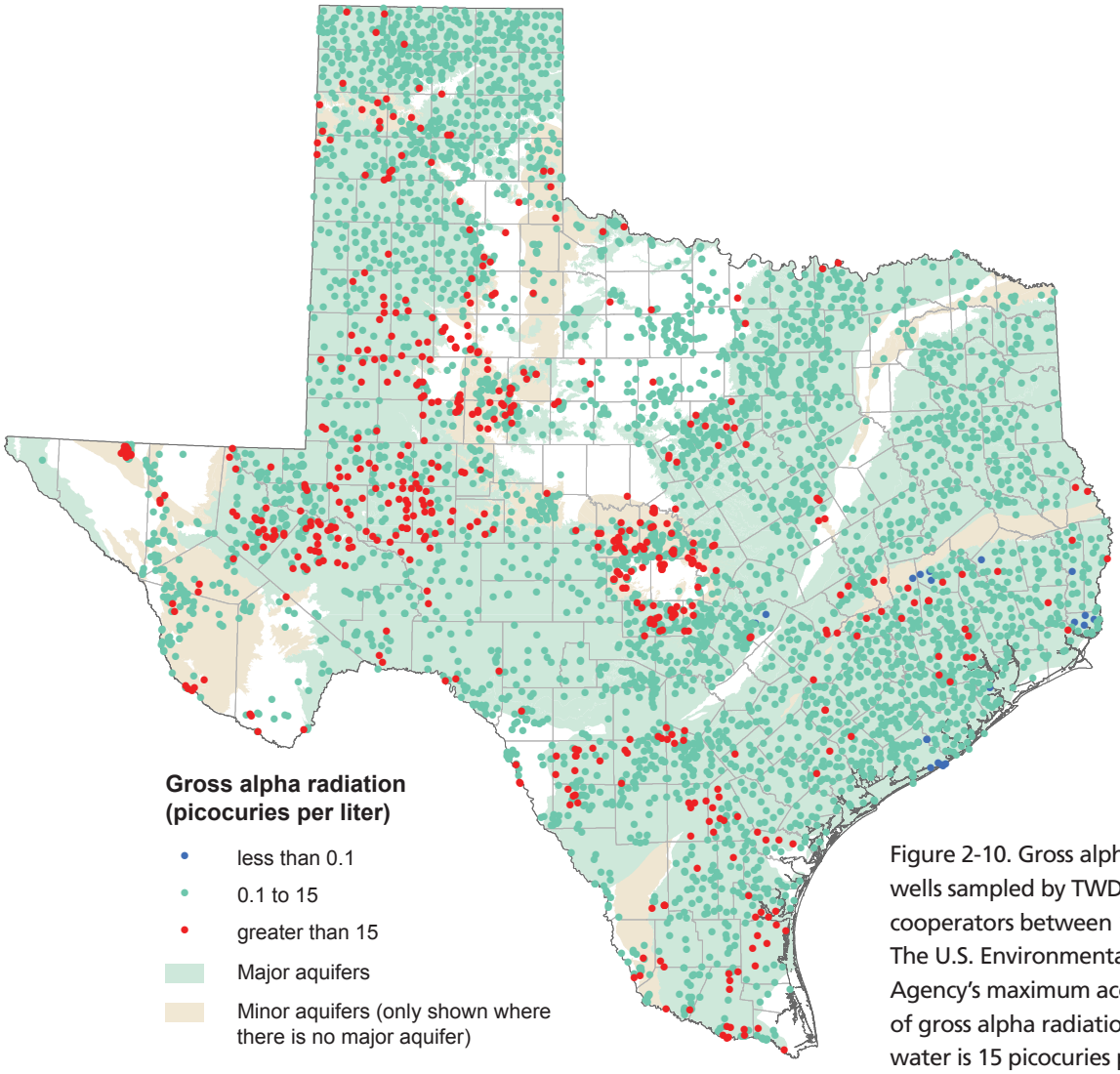

Figure 2-10. Gross alpha radiation in wells sampled by TWDB and other cooperators between 1988 and 2004. The U.S. Environmental Protection Agency's maximum acceptable limit of gross alpha radiation for drinking water is 15 picocuries per liter.

contamination from human activity can be a source of radionuclides, most of the radionuclides in Texas groundwater occur naturally. Where radionuclides are found in drinking water supplies, communities and water providers must treat the groundwater, blend it with another source, or find an alternative source of drinking water.

Although nitrate exists naturally in groundwater, elevated levels generally result from human activities, such as overuse of fertilizer and improper disposal of human and animal wastes. High levels of nitrate in groundwater often coexist with other contaminants: if the source is human and animal wastes, then bacteria, viruses, and protozoa are often present; if the source is fertilizer, then herbicides and pesticides are commonly found. The U.S. Environmental Protection Agency has established a maximum acceptable level of nitrate in drinking water of 10 milligrams of nitrogen per liter and 44.3 milligrams per liter of nitrogen oxide. Groundwater in Texas that exceeds this limit is located mostly in the Ogallala and Seymour aquifers, although parts of the Edwards-Trinity (High Plains), Dockum, and Trinity aquifers also have high levels of nitrate (Figure 2-11). High levels of nitrate in water can cause methemoglobinemia, referred to as "blue baby syndrome," in infants under six months of age.

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2.2.3
Supply and Availability

Existing groundwater supply is the amount of groundwater that can be produced with current permits and existing infrastructures on an annual basis. Because permits and existing infrastructure, such as wells and pipelines, limit how much groundwater can be produced, groundwater supply can be—and often is—less than the total amount of groundwater that can be produced from an aquifer.

Regional water planning groups in Texas estimated that existing groundwater supplies would be about 8.5 million acre-feet per year in 2010 and decline 32 percent to about 5.8 million acre-feet per year by 2060 (Figure 2-12). The decline is due primarily to reduced supply from the Ogallala Aquifer as a result of depletion (reduction of about 2.5 million acre-feet per year by 2060), as well as reduced supply from the Gulf Coast Aquifer due to mandatory reductions in pumping to prevent land surface subsidence (reduction of about 160,000 acre-feet per year by 2060). In most cases, groundwater supplies either remain at current amounts or decrease by 2060.

Groundwater availability is the amount of water from an aquifer that is available for use. One might think that the amount of groundwater available for use is all of the water in the aquifer; however, that may not be—and probably is not—the case. Whereas groundwater supplies are limited by permits and existing infrastructure, groundwater availability is limited by law, groundwater management goals and rules, and planning group policy.

Total groundwater availability in 2010, as assessed by the planning groups, is about 12.7 million acre-feet per year (Figure 2-13). Because of projected decreases in availability in the Dockum, Edwards-Trinity (High Plains), Gulf Coast, Ogallala, and Seymour aquifers, this availability decreases to 9.9 million acre-feet per year by 2060.

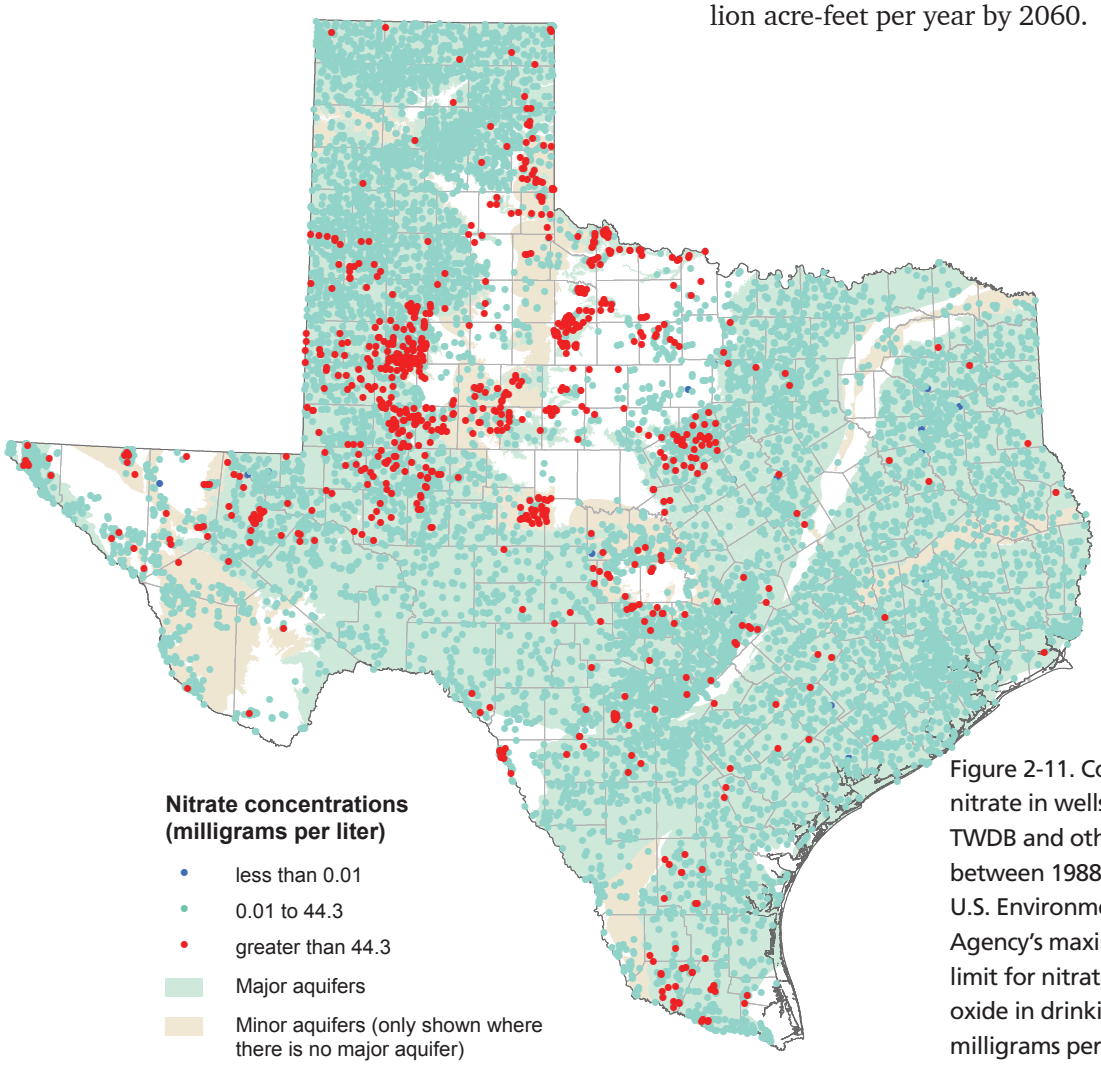


Figure 2-11. Concentration of nitrate in wells sampled by TWDB and other cooperators between 1988 and 2004. The U.S. Environmental Protection Agency's maximum acceptable limit for nitrate as nitrogen oxide in drinking water is 44.3 milligrams per liter.

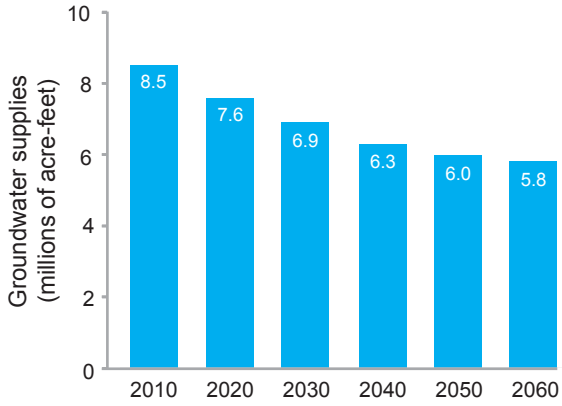
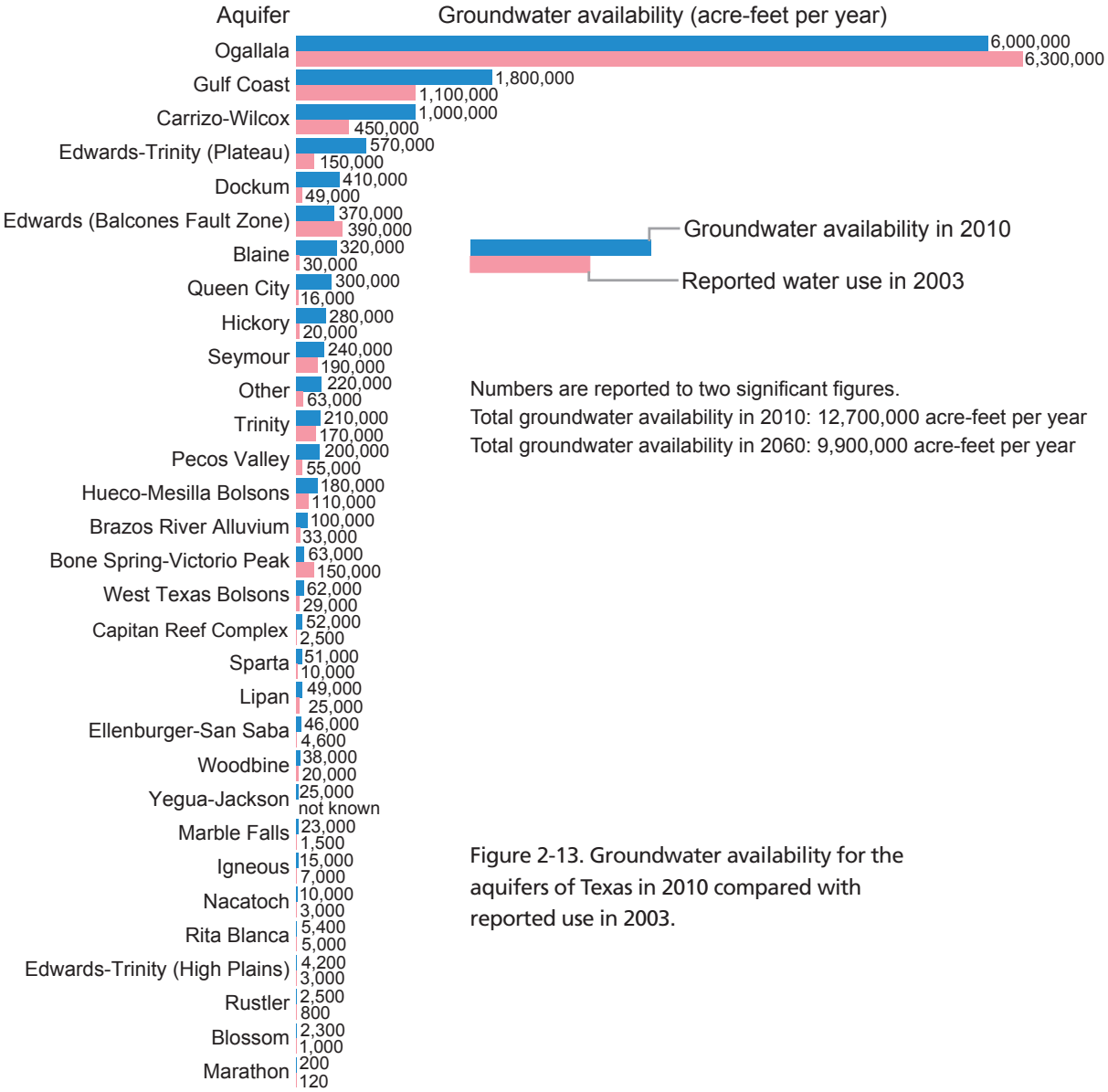


Figure 2-12. Projected existing groundwater supplies through 2060.



Numbers are reported to two significant figures.
Total groundwater availability in 2010: 12,700,000 acre-feet per year
Total groundwater availability in 2060: 9,900,000 acre-feet per year

Figure 2-13. Groundwater availability for the aquifers of Texas in 2010 compared with reported use in 2003.

2.3 Groundwater Management

In 1949, the legislature passed regulations establishing groundwater conservation districts as political subdivisions of the state (Figure 2-14). The districts originated as a way of establishing local control of groundwater resources, as opposed to state control. Over the past 60 years, a total of 120 districts have sprung up. As of September 2010, Texans have created 96 districts serving around 66 percent of the land area. In areas without groundwater conservation districts, the common law rule of capture prevails, with the exception of any applicable county subdivision or city rules, if they exist. More information on groundwater conservation districts is available on the TWDB Web site.

The common law rule of capture was the basis for groundwater ownership prior to the development of groundwater management by district. The Texas judicial system heard the first groundwater dispute case in 1904, explicitly establishing rule of capture as the basis for groundwater ownership. This rule meant that landowners retain the right to capture and beneficially use groundwater from their property. Furthermore, this decision allows landowners having superior pumping capability to ignore conservation

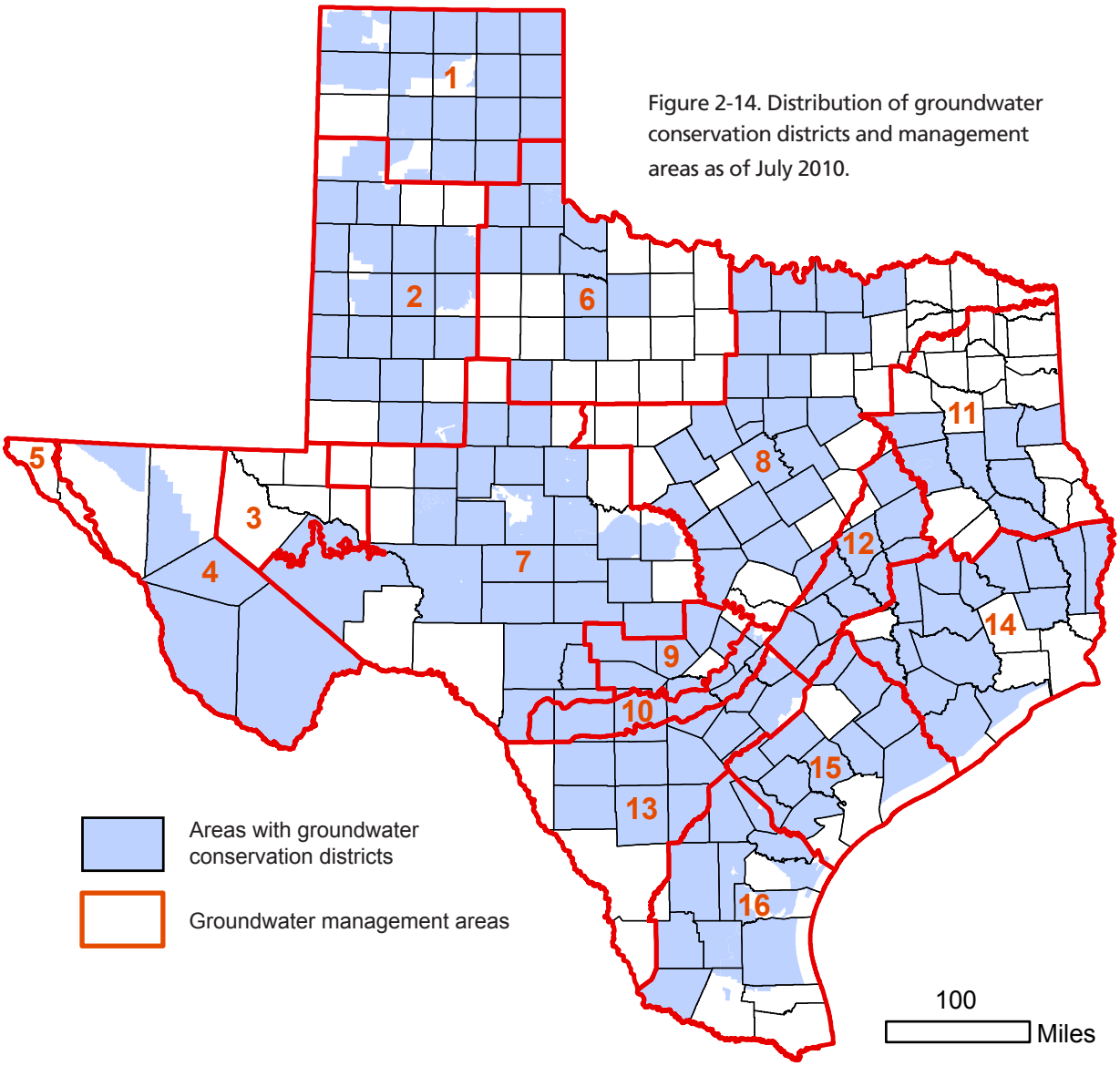


Figure 2-14. Distribution of groundwater conservation districts and management areas as of July 2010.

and to pump and pull groundwater into their well from surrounding properties and extract it without redress. Although the 1917 Texas Constitution addresses the state responsibility for conserving natural resources, it does not address groundwater specifically. Since then, the definition of water conservation has changed—conserving used to mean using water before it ran off property or traveled downstream in rivers to the Gulf of Mexico, quite the opposite of what it means today.

Texas Water Code Chapter 36 delineates the fundamental rules under which each district must operate. Through Chapter 36, groundwater conservation districts modify the rule of capture by respecting private ownership rights but reserve the option to register, permit, and establish production limitations or fees on the exploration and production of groundwater. According to Texas Water Code §36.117, all districts must exempt wells capable of producing up to or equal to 25,000 gallons per day, but they may choose to increase that amount. This exemption is restricted to domestic wells or wells serving as water supply for livestock or poultry on a 10-acre or larger piece of land. Wells permitted by the Railroad Commission of Texas for oil and gas operations are also exempt. Each district's enabling legislation or petition language indicates additional specific guidelines for that particular district to follow. Not all districts issued production permits, but in each district management plan, required by Senate Bill 1 in 1997, districts established the total usable amount of groundwater in the district, or groundwater availability.

In 2005, the legislature modified the process of establishing groundwater availability. Rather than allowing each district to develop an amount for its management plan, the legislature introduced a new collaborative process. Prior to that, in 2002, TWDB established 16 groundwater management areas, on the basis of aquifer and political boundaries, covering the entire state (Figure 2-14). These areas are composed of groundwater conservation districts within these areas, and each district has a vote on the future state of the aquifers in the region. The preferred state of an aquifer over the ensuing 50 years is called the desired future condition. Once a desired future condition is established, it is used to generate a quantity of groundwater that can be permitted—called managed available groundwater—to maintain or reach this adopted condition. Managed available groundwater is an annual rate used for issuing permits and is included in the regional water plans as the groundwater availability. Examples of desired future conditions include average drawdown rates and spring flow rates. At least every five years, or more often if the groundwater conservation districts choose, the districts consider and adopt desired future conditions for the relevant aquifers in their area.

2.4 Basic Groundwater Principles

Geologic *formations* are laterally continuous rock units having distinct lithologic characteristics that allow recognition and mapping from one outcrop or well to another. *Aquifers* are delineated by a formation or group of formations. Aquifers consist of subsurface rock or sediment that is porous and permeable. *Porosity* is the volume of pore space in rock or sediment, usually expressed as a percentage. This pore space can include openings between grains, fractures, and caverns. *Permeability* is a measure of how well a material can transmit water. Materials like gravel transmit water quickly and have high values of permeability. Materials such as shale transmit water poorly and have low permeability values. Permeability is primarily determined by the size of the pore spaces and their degree of interconnection.

Some of the largest aquifers in Texas, including the Ogallala, Gulf Coast, and Carrizo-Wilcox, consist of sedimentary rocks with intergranular porosity and relatively high permeability. Limestone aquifers, such as the Edwards (Balcones Fault Zone) Aquifer, contain water in crevices and caverns caused mainly by dissolution of the limestone by groundwater. The Igneous Aquifer in West Texas is an example of where groundwater flows through cracks, fractures, and joints developed in more competent igneous and volcanic rocks.

In addition to being porous and permeable, an aquifer must be able to store and transmit significant quantities of water. A measure of

the ability of an aquifer to transmit water is its *hydraulic conductivity*. Hydraulic conductivity is defined as the volume of water that will move in a porous medium in a unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow. In contrast to permeability, it is a function of the properties of the liquid as well as of the porous medium. A measure of an aquifer's ability to store water is its storativity value. *Storativity* is the volume of groundwater that an aquifer will release (or gain) per unit decline (or rise) in hydraulic head per unit area of aquifer (Figure 2-15). In an unconfined aquifer, the storativity value is equal to the specific yield. The *specific yield* represents the volume of groundwater released by pore-water drainage per unit drop in the water table per unit (horizontal) area of unconfined aquifer.

Unconfined aquifers are sometimes referred to as "water table aquifers." An unconfined aquifer is one in which the water table is at or near atmospheric pressure and is the upper boundary of the aquifer. Because the aquifer is not under pressure, the water level in a well is the same as the water table outside the well (Figure 2-15). Water levels in a well from an unconfined aquifer rise and fall in response to changes in recharge and discharge. When water levels decline, water physically drains from the aquifer from the higher water level to the lower water level. *Recharge* is the amount of water that infiltrates to the water table of an aquifer. This water may come from precipitation, streams, and lakes directly into a formation. Generally, only a small portion of the total precipitation seeps down through the soil to reach the water table. Among the factors that influence the amount of recharge to an aquifer are the amount and frequency of precipitation; the areal extent of the outcrop or recharge area; the topography, type and amount of vegetation, and condition of soil cover in the outcrop area; and the ability of the aquifer to accept recharge and transmit it to areas of discharge. *Discharge* is the loss of water from an aquifer by either artificial or natural means. Artificial discharge occurs from flowing and pumped water wells, from drainage ditches, gravel pits, or other excavations that intersect the water table. Natural discharge occurs as springs, evaporation, transpiration, and leakage between formations.

Confined aquifers are sometimes referred

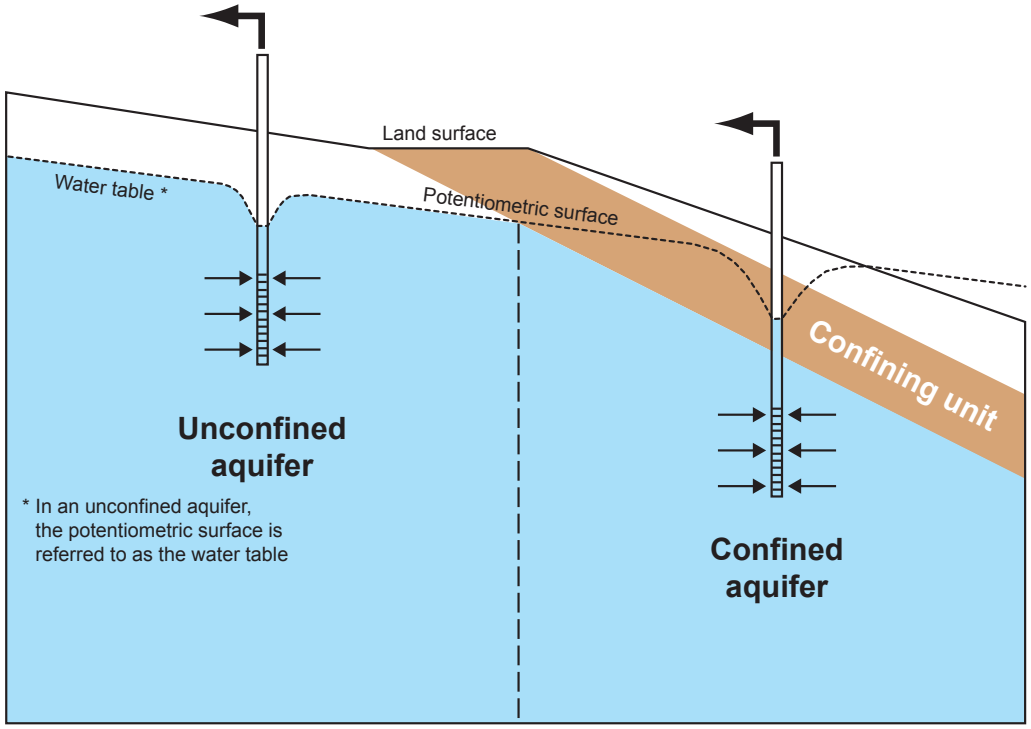


Figure 2-15. Schematic diagram showing unconfined and confined aquifers separated by a confining unit. Note that the dashed line represents the potentiometric surface for the confined aquifer.

28 028

to as “artesian aquifers.” These aquifers are overlain by confining units, such as clay and shale layers that do not readily transmit groundwater (Figure 2-15). These aquifers usually occur well below the land surface, are completely saturated with groundwater, and are under pressure. Because of this pressure, water in wells penetrating confined aquifers rises above the top of the aquifer. In some cases, water levels may rise above the land surface, resulting in a flowing well. The level to which water rises in a confined aquifer is the potentiometric surface of the confined aquifer. Pumping of wells reduces the water pressure in the aquifer, resulting in a lowering of the potentiometric surface even though the aquifer continues to be fully saturated.

Groundwater moves from areas of recharge to areas of discharge, or from points of higher water level to points of lower water level. Under normal artesian conditions, movement of groundwater is usually in the direction of the aquifer’s regional dip. Under water table conditions, the slope of the water table, and consequently the direction of groundwater movement, is usually closely related to the slope of the land surface. However, in the case of both artesian and water table conditions, local anomalies develop in which some water moves toward areas of groundwater pumping. When a water well is pumped, water levels in the vicinity are drawn down in the shape of an inverted cone with its apex at the pumped well (Figure 2-15). The development of these *cones of depression* depends on the aquifer’s ability to store and move water and on the rate of pumping. If the cone of one well overlaps the cone of another, additional lowering of water levels will occur as the wells compete for the same water.

The rate of groundwater movement in an aquifer is normally very slow, in the magnitude of a few feet to a few hundred feet per year. The rate of movement in a limestone aquifer, such as the Edwards (Balcones Fault Zone) Aquifer, is relatively greater than that in a sandstone aquifer, such as the Carrizo-Wilcox Aquifer, and can be miles per day.

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3 Aquifer Summaries

Aquifers summaries are listed in this section alphabetically in major and minor categories, along with additional references. The content for their description comes from TWDB reports and maps, TWDB groundwater availability modeling studies, scientific studies from outside institutions, and data from regional water planning groups in Texas. As TWDB groundwater availability modeling reports and other outside studies are completed or updated, this information will be incorporated into individual aquifer descriptions posted on the agency's Web site.

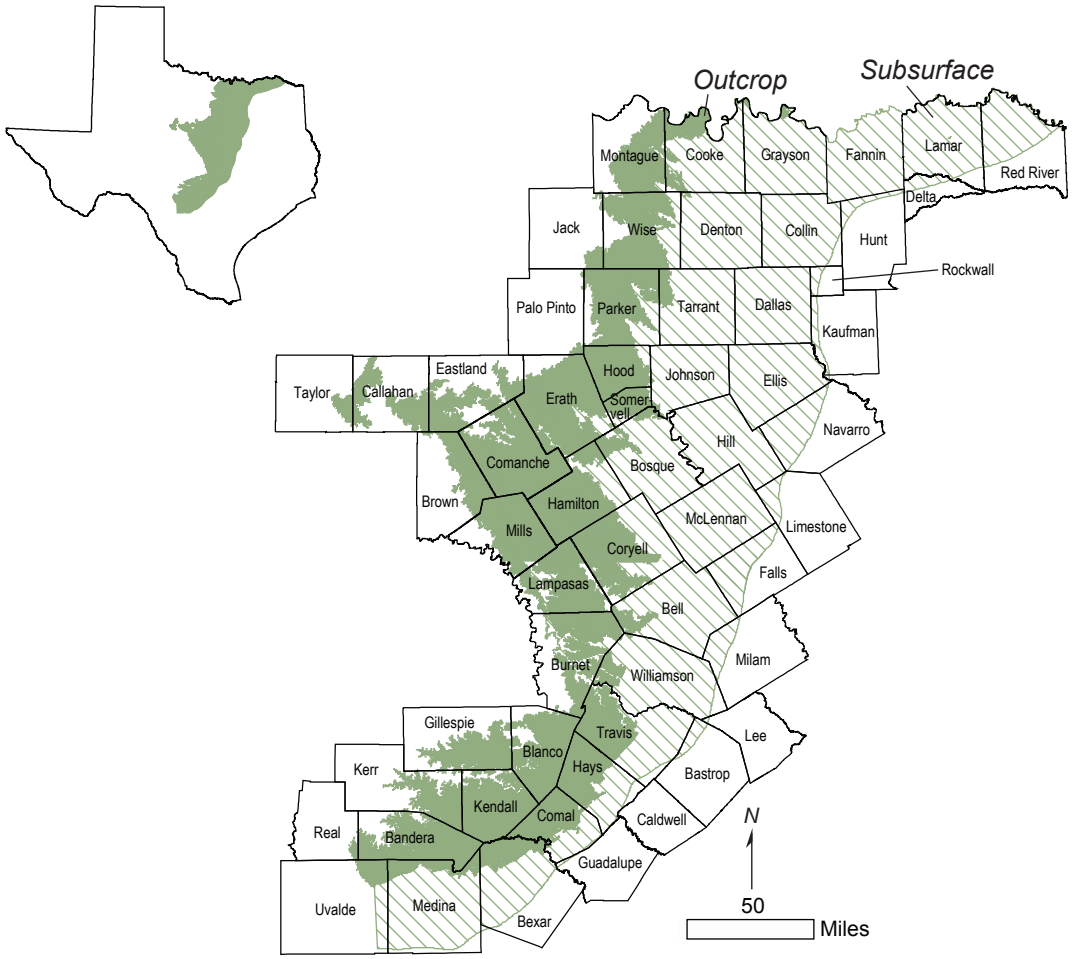
Photo (next page)

The Fort Terrett Formation of the Edwards-Trinity (Plateau) Aquifer west of Kerrville along Interstate 10. The Fort Terrett Formation is part of the Edwards Group and consists of carbonate rocks deposited in supratidal, intertidal, and subtidal depositional settings. It has a complex diagenetic history that affects groundwater flow.

28 031

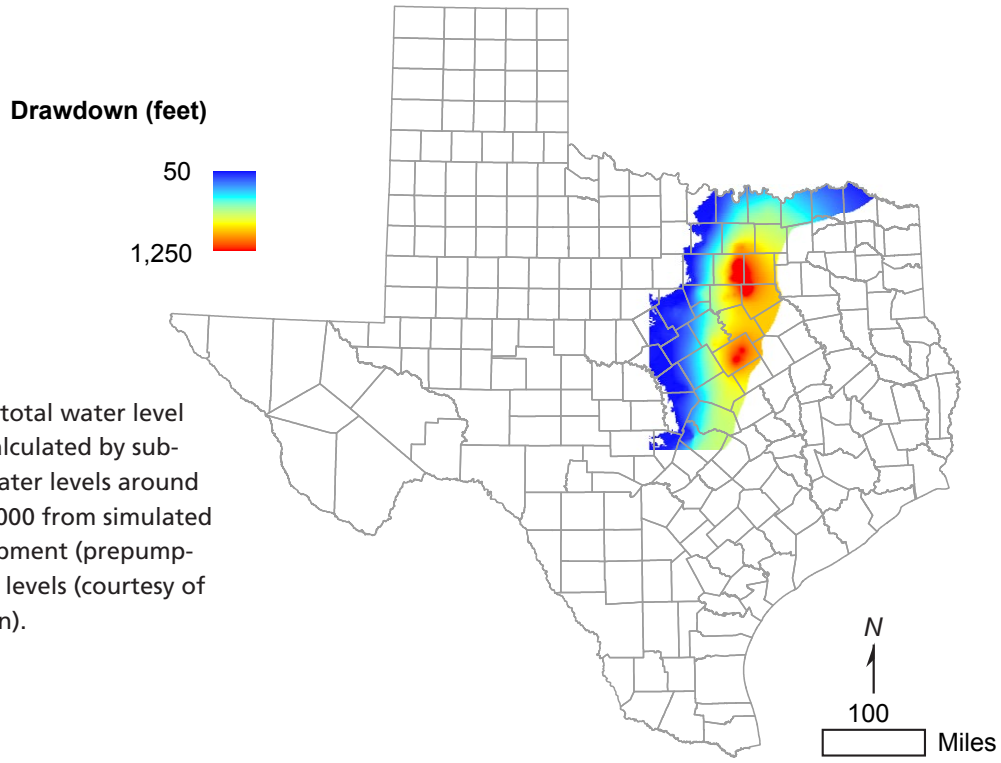
Major
Aquifers

Trinity
Aquifer



The Trinity Aquifer, a major aquifer, extends across much of the central and northeastern part of the state. It is composed of several smaller aquifers contained within the Trinity Group. Although referred to differently in different parts of the state, they include the Antlers, Glen Rose, Paluxy, Twin Mountains, Travis Peak, Hensell, and Hosston aquifers. These aquifers consist of limestones, sands, clays, gravels, and conglomerates. Their combined freshwater saturated thickness averages about 600 feet in North Texas and about 1,900 feet in Central Texas. In general, groundwater is fresh but very hard in the outcrop of the aquifer. Total dissolved solids increase from less than 1,000 milligrams per liter in the east and southeast to between 1,000 and 5,000 milligrams per liter, or slightly to moderately saline, as the depth to the aquifer increases. Sulfate and chloride concentrations also tend to increase with depth. The Trinity Aquifer discharges to a large number of springs, with most discharging less than 10 cubic feet per second. The aquifer is one of the most extensive and highly used groundwater resources in Texas. Although its primary use is for municipalities, it is also used for irrigation, livestock, and

other domestic purposes. Some of the state's largest water level declines, ranging from 350 to more than 1,000 feet, have occurred in counties along the IH-35 corridor from McLennan County to Grayson County. These declines are primarily attributed to municipal pumping, but they have slowed over the past decade as a result of increasing reliance on surface water. The regional water planning groups, in their 2006 Regional Water Plans, recommended numerous water management strategies for the Trinity Aquifer, including developing new wells and well fields, pumping more water from existing wells, overdrafting, reallocating supplies, and using surface water and groundwater conjunctively.



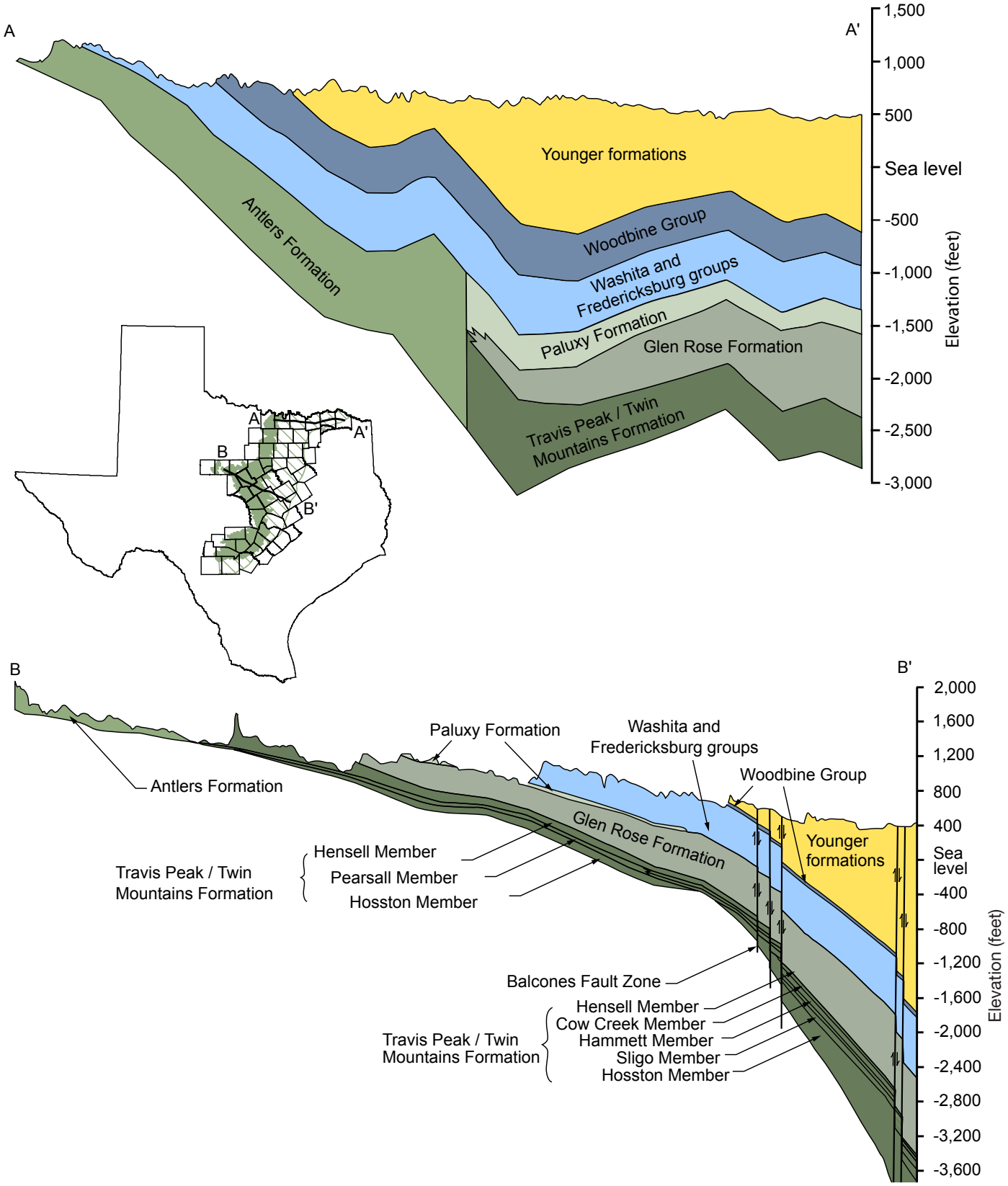
Estimated total water level declines calculated by subtracting water levels around the year 2000 from simulated predevelopment (prepumping) water levels (courtesy of H.S. Hamlin).

Upper Glen Rose Formation along Southwest Parkway southeast of Bee Cave, Texas.

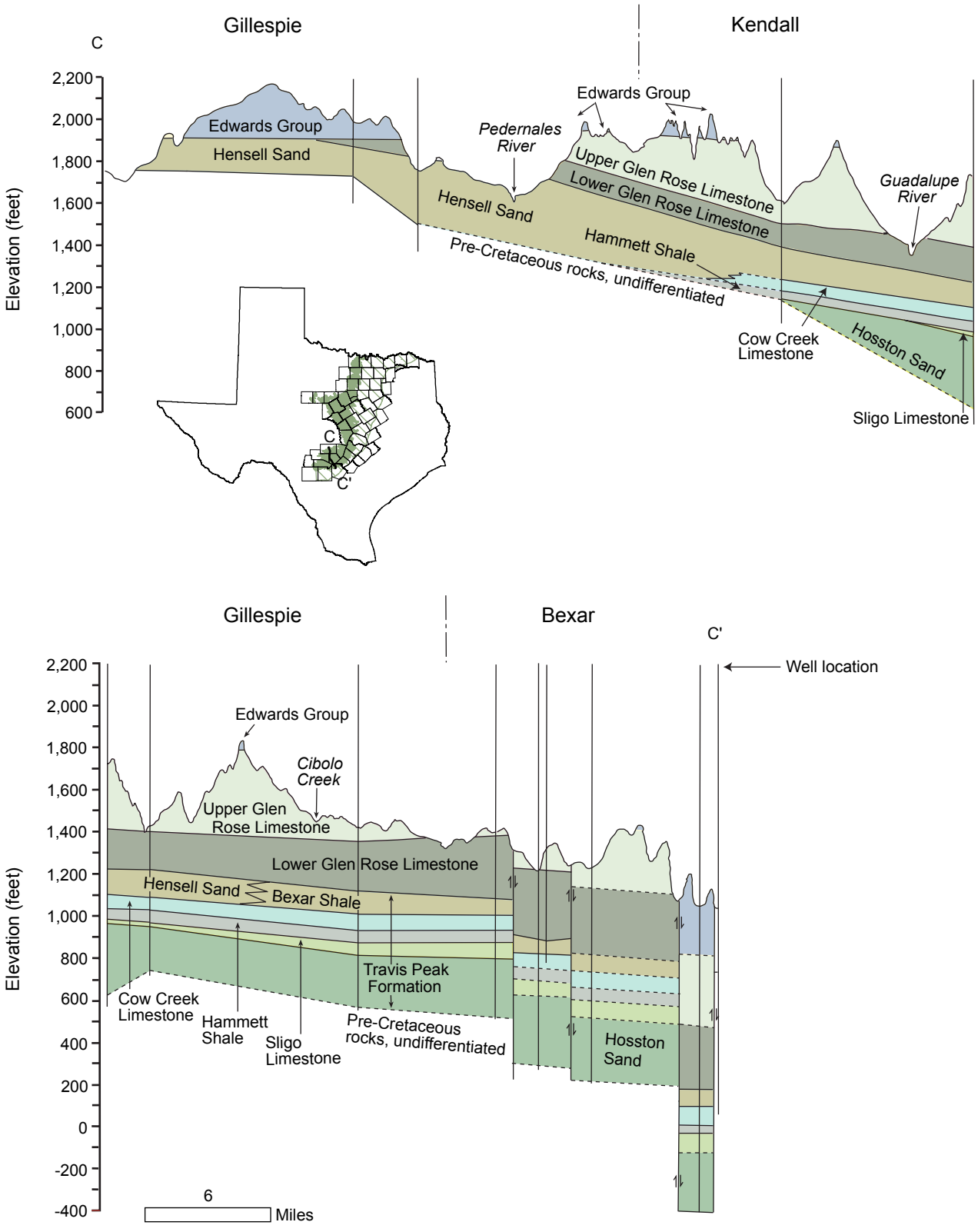
Lower Glen Rose Formation along State Highway 71 northwest of Bee Cave, Texas (note 6-inch ruler).

28 034

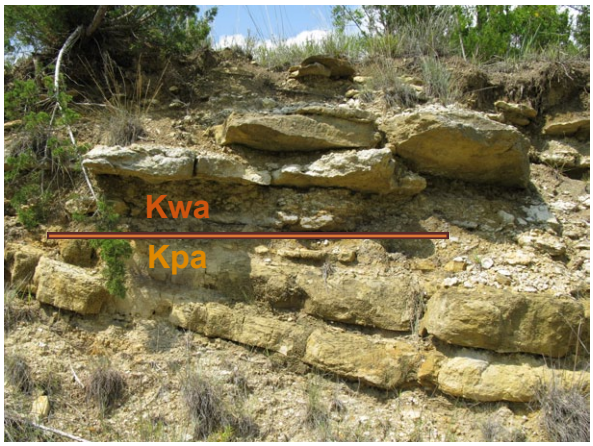
Structural cross sections across the northern Trinity Aquifer, shown in shades of green (modified from Klemt and others; 1975; Nordstrom, 1982).



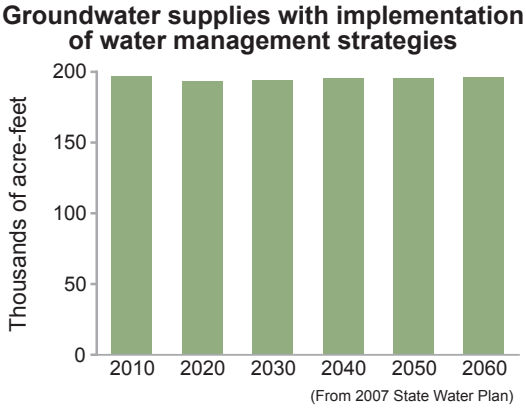
Structural cross section across the Trinity Aquifer in the Hill Country, including rocks from the Upper Glen Rose Formation to the Hosston Sand (modified from Ashworth, 1983; Mace and others, 2000b).



Theropod dinosaur track from the Glen Rose Formation at Dinosaur Valley State Park.



Paluxy Formation (Kpa) beneath the Walnut Formation (Kwa) along State Highway 67 southwest of Comanche, Texas.



Aquifer characteristics

- Area of outcrop: 10,652 square miles
- Area in subsurface: 21,308 square miles
- Proportion of aquifer with groundwater conservation districts: 32 percent
- Number of counties containing the aquifer: 61

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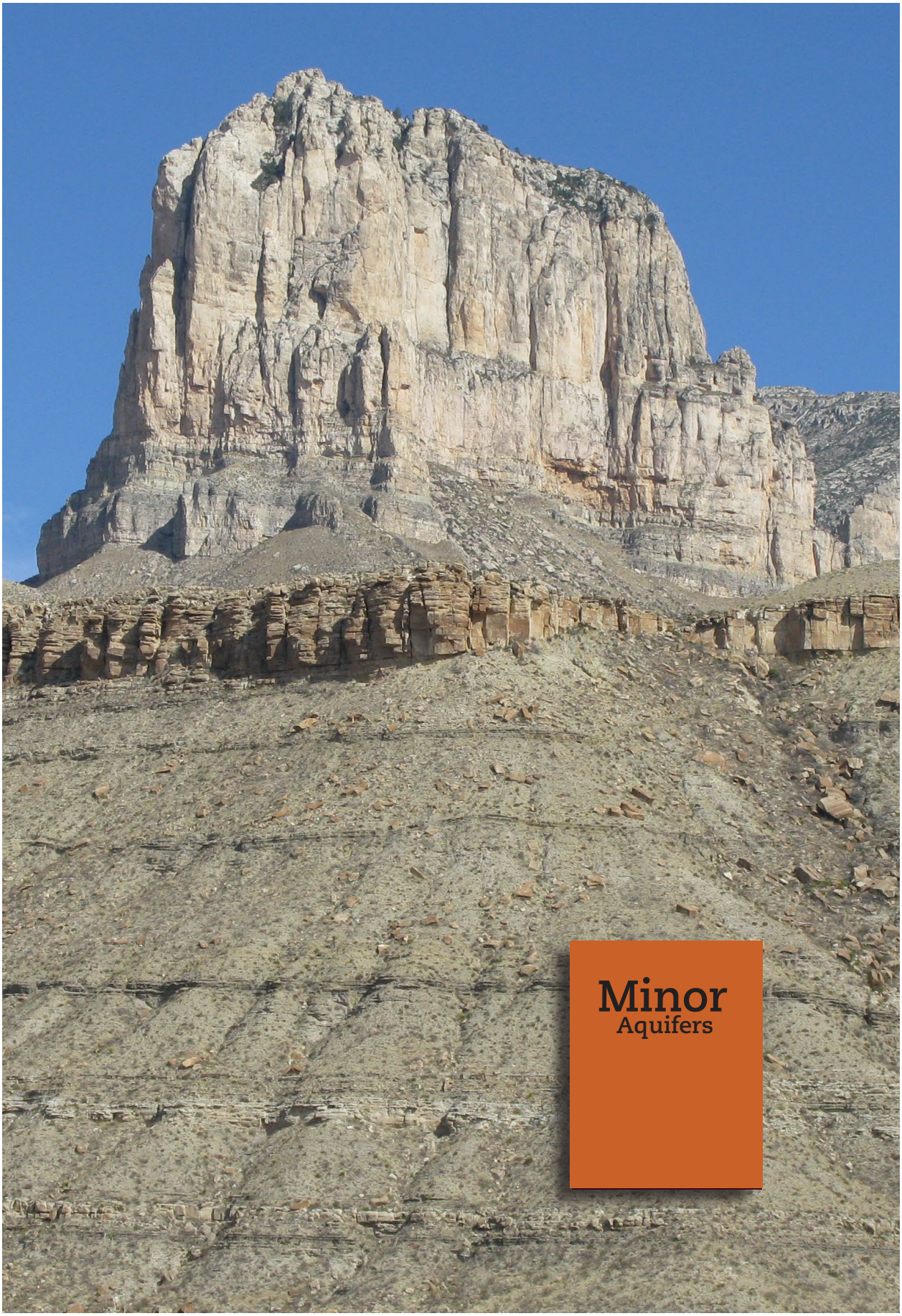
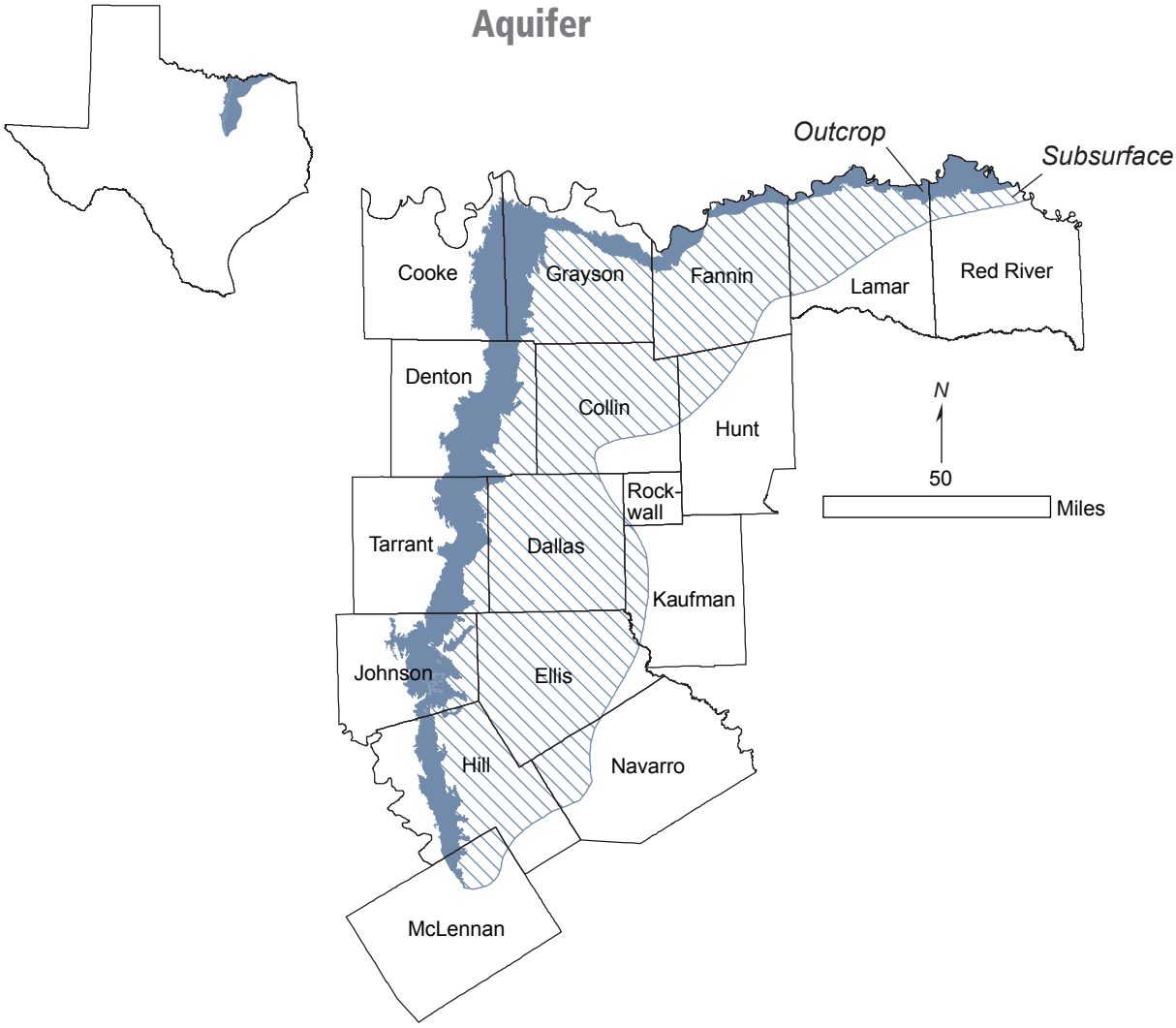

Minor
Aquifers

Photo (previous page)

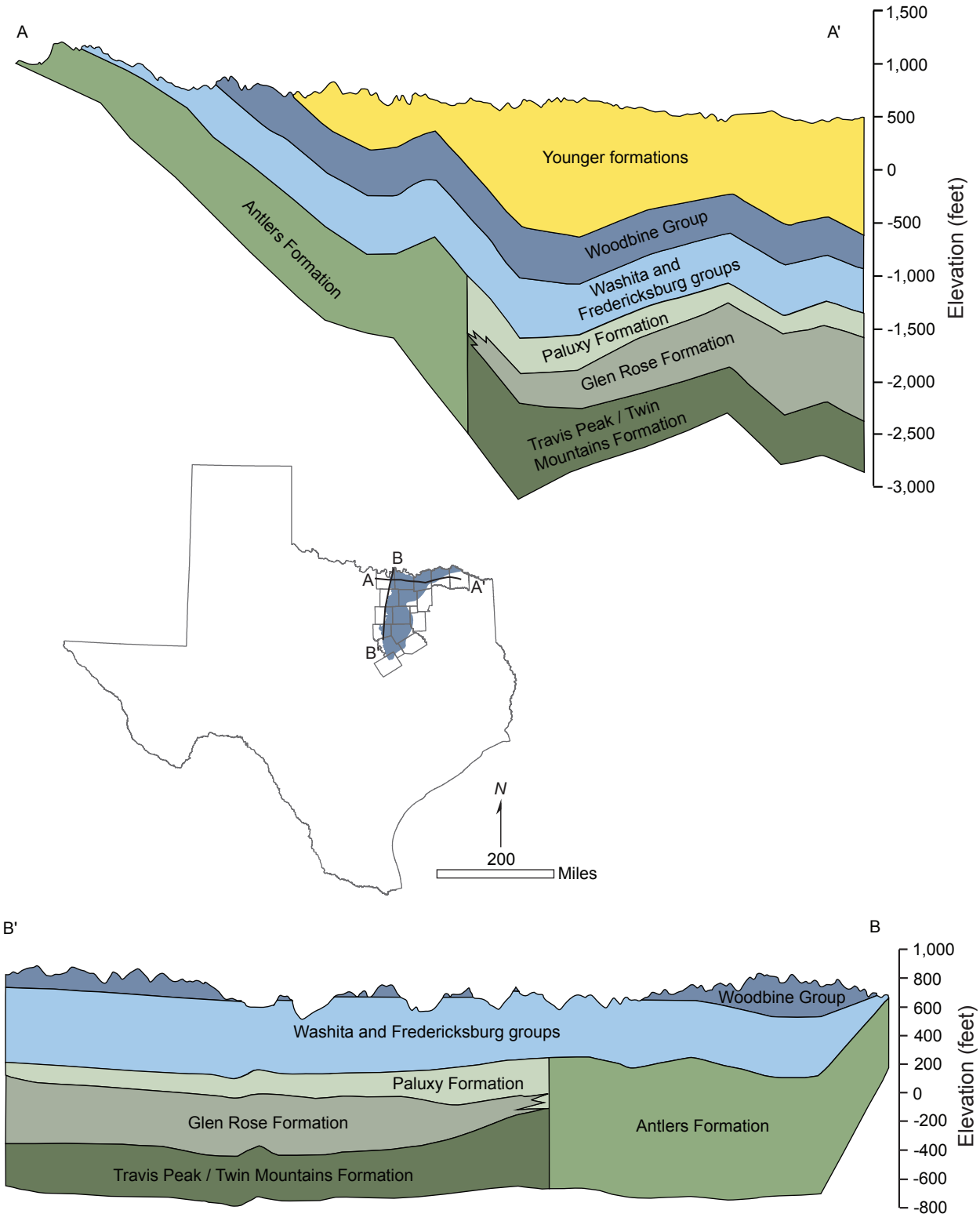
El Capitan at the southern end of the Guadalupe Mountains in northwest Culberson County, Texas. The upper part of the mountain is composed of forereef rubble facies of the Capitan Limestone, which is part of the Capitan Reef Complex Aquifer.

28 040

Woodbine
Aquifer



The Woodbine Aquifer is a minor aquifer located in northeast Texas. The aquifer overlies the Trinity Aquifer and consists of sandstone interbedded with shale and clay that form three distinct water-bearing zones. The Woodbine Aquifer reaches 600 feet in thickness in subsurface areas, and freshwater saturated thickness averages about 160 feet. Water quality and yield vary with the depth of the aquifer. The lower zones of the aquifer typically yield the most water, whereas the upper zone yields limited water that tends to be very high in iron. In general, water to a depth of 1,500 feet is fresh, containing less than 1,000 milligrams per liter of total dissolved solids. Water at depths below 1,500 feet is slightly to moderately saline, containing from 1,000 to 4,000 milligrams per liter of total dissolved solids. The aquifer provides water for municipal, industrial, domestic, livestock, and small irrigation supplies. Large water level declines, due to heavy municipal and industrial pumping in the Sherman-Denison area of Grayson County, have moderated in the past decade as suppliers have switched to surface water. The regional water planning groups, in their 2006 Regional Water Plans, recommended several water management strategies that use the Woodbine Aquifer, including constructing new wells, pumping more water from existing wells, developing supplemental wells to maintain current supplies, temporary overdrafting, and reallocating supplies.



Structural cross sections along and across Woodbine Group rocks (modified from Nordstrom, 1982).

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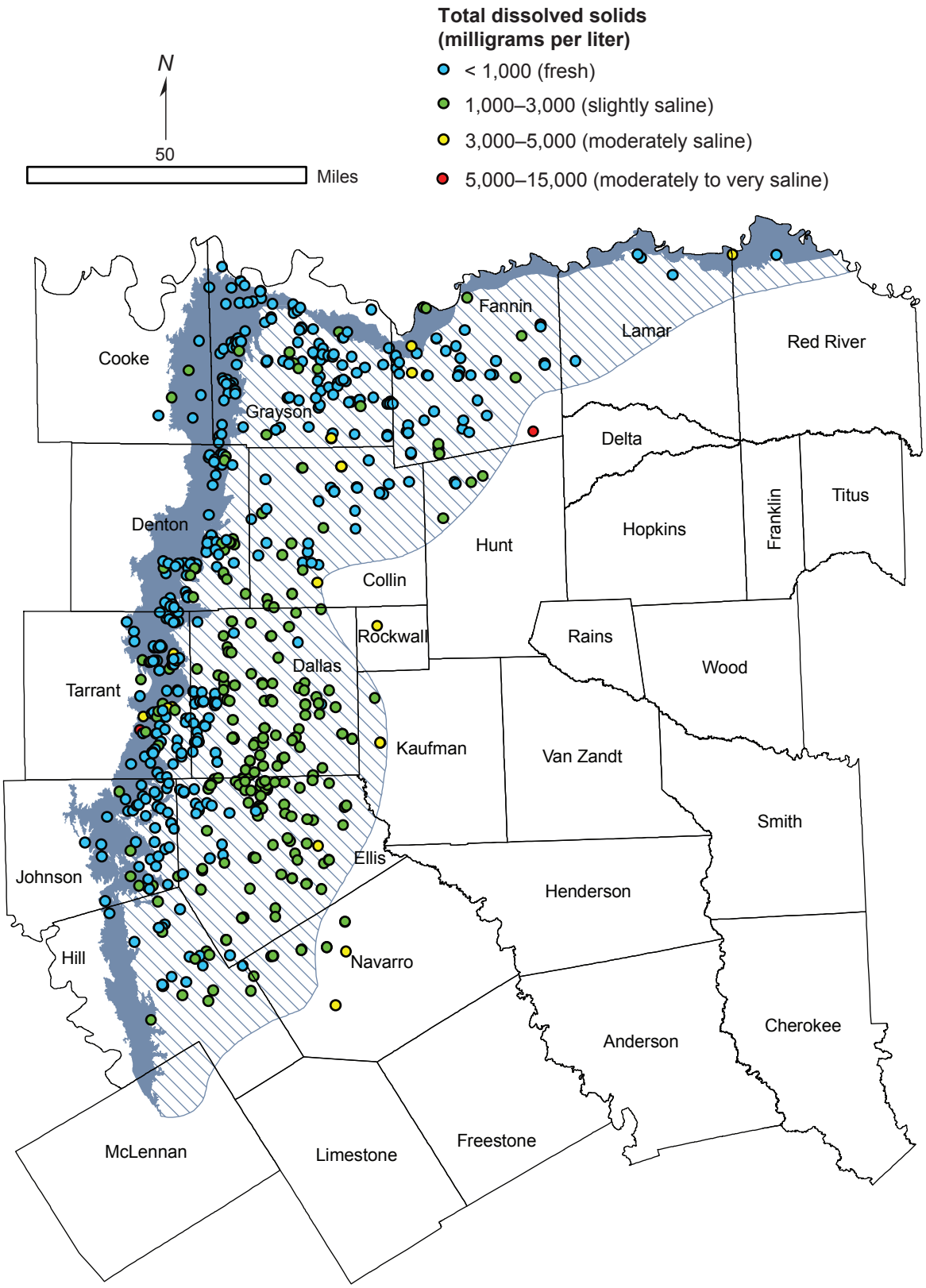
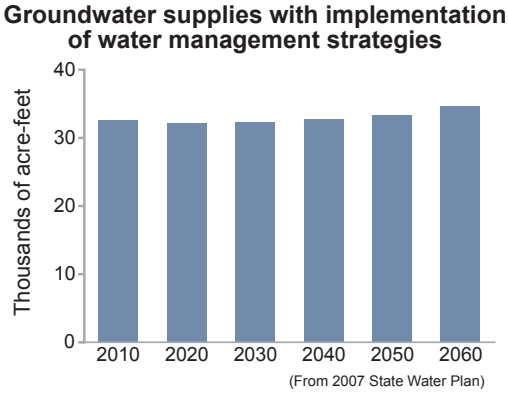


Total dissolved solids from Woodbine Aquifer wells (based on TWDB groundwater database).

Ferruginous sand of the Woodbine Formation 2 miles southwest of Denison, Grayson County, Texas (from Stephenson, 1919).

Lens of tuffaceous sand in laminated sandy clay of the Woodbine Formation along the Red River, Lamar County, Texas (from Ross and others, 1929).



Aquifer characteristics

- Area of outcrop: 1,557 square miles
- Area in subsurface: 5,766 square miles
- Proportion of aquifer with groundwater conservation districts: 0 percent
- Number of counties containing the aquifer: 17

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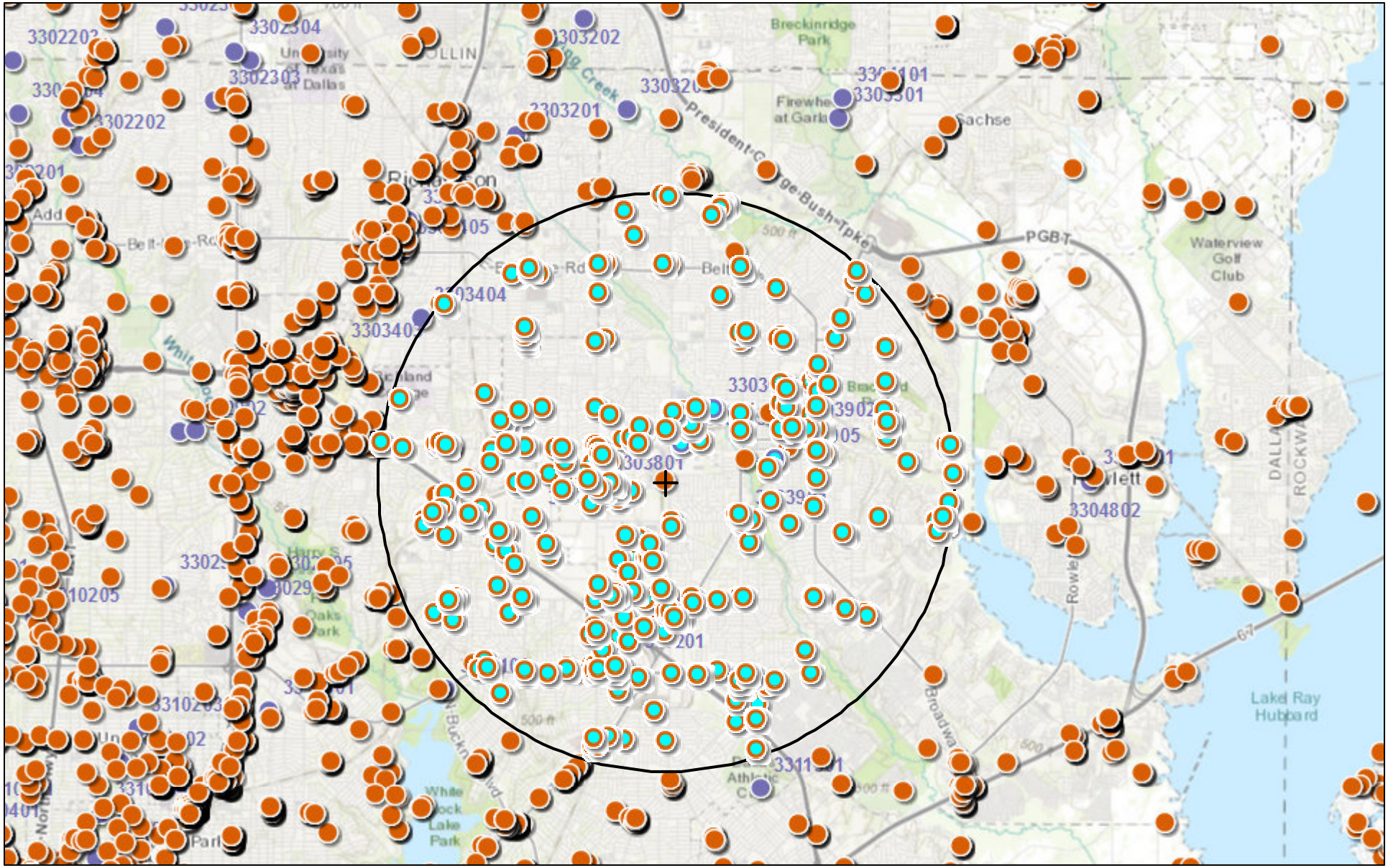
28 047

Reference 29

4-Mile TDL



Texas Water Development Board

June 5, 2019

Well Reports

TWDB Groundwater

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0 2 4 8 km

1:144,448

Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri

29 001

TEXAS WATER DEVELOPMENT BOARD

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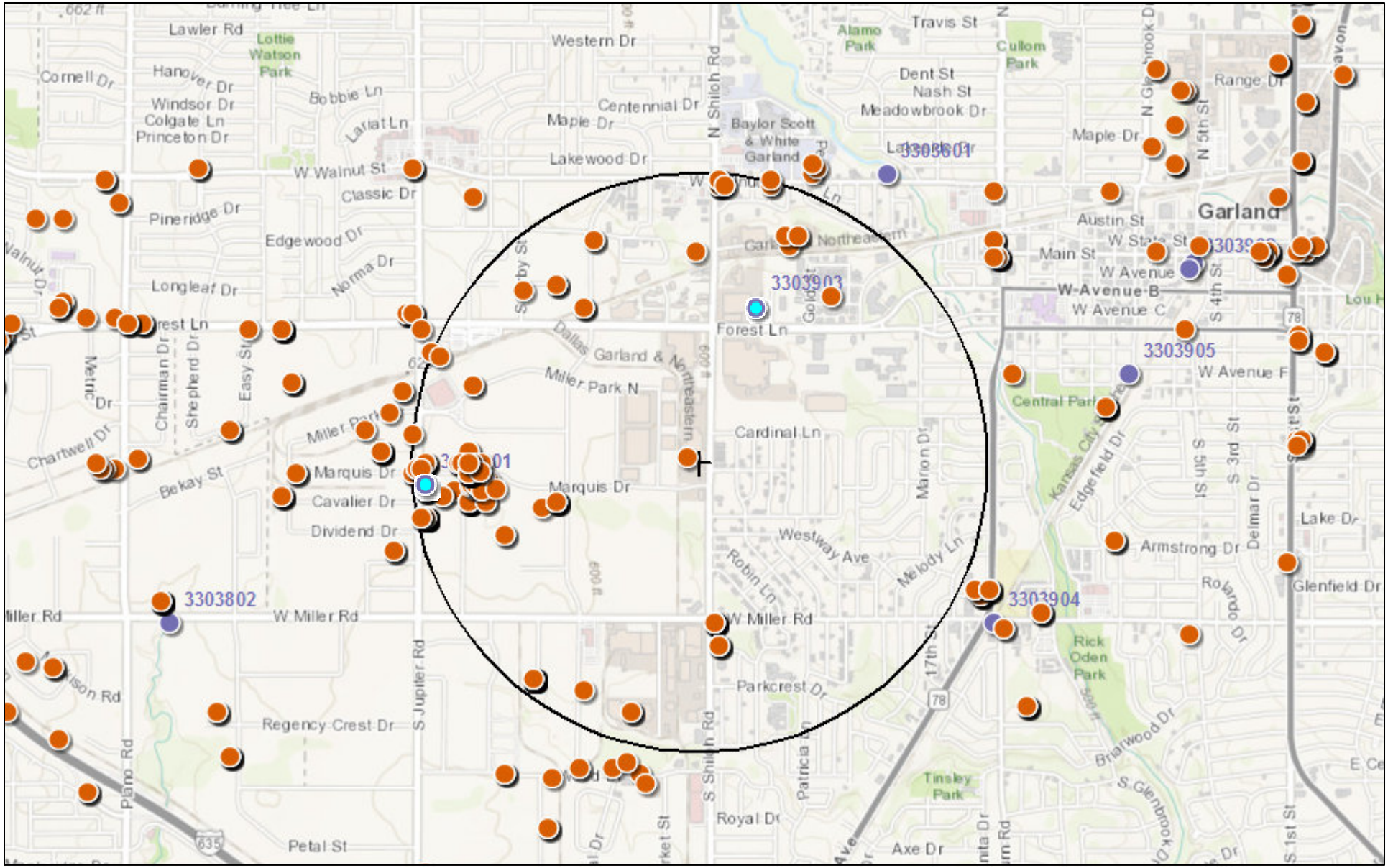
1-Mile TDL

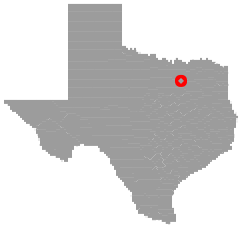


Texas Water Development Board

June 5, 2019

Well Reports

TWDB Groundwater



0 0.3 0.6 1.2 mi

0 0.5 1 2 km

1:36,112

Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri

29 002

TEXAS WATER DEVELOPMENT BOARD

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TWDB Groundwater Database

State Well Number	Owner	Water Use	Elevation (ft)	Well Depth (ft)	Aquifer Code Name	Distance
3303801 - 1	City of Garland	Plugged or Destroyed	614	3488	218TWMT - Twin Mountains Formation	0.5-1
3303903 - 1	City of Garland Well #3	Plugged or Destroyed	587	3454	218TWMT - Twin Mountains Formation	0.5-1
3303601 - 1	City of Garland	Plugged or Destroyed	545	3540	218TWMT - Twin Mountains Formation	1-2
3303802 - 1	Claude Smith	Unused	590	25	212WDBN - Woodbine Sand	1-2
3303901 - 1	City of Garland Well #5	Plugged or Destroyed	547	3689	218TWMT - Twin Mountains Formation	1-2
3303902 - 1	City of Garland Well #1	Plugged or Destroyed	547	2303	218PLXY - Paluxy Sand	1-2
3303904 - 1	City of Garland Well #4	Plugged or Destroyed	550	3626	218TWMT - Twin Mountains Formation	1-2
3303905 - 1	City of Garland Well #2	Plugged or Destroyed	572	2318	218PLXY - Paluxy Sand	1-2
3311201 - 1	Hudson Airport	Unused	595	2143	218PLXY - Paluxy Sand	2-3

TWDB Well Reports

Well Report Tracking Number	Proposed Use	Well Owner	Well Street	Date of Well Completion	Borehole Depth (ft)	Distance
281345	Environmental Soil Boring	Grand Six, LLC	1111 S. Shiloh Road	7-Feb-12	8	0-.25
285684	Environmental Soil Boring	Raytheon - Garland	1200 S. Jupiter Rd.	1-May-12	22.5	0.25-0.5
285685	Environmental Soil Boring	Raytheon - Garland	1200 S. Jupiter Rd.	1-May-12	27.5	0.25-0.5
285686	Environmental Soil Boring	Raytheon - Garland	1200 S. Jupiter Rd.	1-May-12	26	0.25-0.5
285688	Monitor	Raytheon - Garland	1200 S. Jupiter Rd.	1-May-12	20	0.25-0.5
285690	Monitor	Raytheon - Garland	1200 S. Jupiter Rd.	1-May-12	20	0.25-0.5
285693	Monitor	Raytheon - Garland	1200 S. Jupiter Rd.	1-May-12	33	0.25-0.5
285695	Monitor	Raytheon - Garland	1200 S. Jupiter Rd.	1-May-12	15	0.25-0.5
6461	Monitor	Flextronics	3233 W. Kingsley	8-Jul-01	10	0.5-1
6462	Monitor	Flextronics	3233 W. Kingsley	8-Jul-01	15	0.5-1
9728	Environmental Soil Boring	Washington Mutual	2430 W. Walnut	16-Jul-02	15	0.5-1
9729	Environmental Soil Boring	Washington Mutual	2430 W. Walnut	16-Jul-02	15	0.5-1
9730	Environmental Soil Boring	Washington Mutual	2430 W. Walnut	16-Jul-02	15	0.5-1
9731	Environmental Soil Boring	Washington Mutual	2430 W. Walnut	16-Jul-02	15	0.5-1
9732	Environmental Soil Boring	Washington Mutual	2430 W. Walnut	16-Jul-02	15	0.5-1
9733	Environmental Soil Boring	Washington Mutual	2430 W. Walnut	16-Jul-02	15	0.5-1
16012	Environmental Soil Boring	Betz Dearborn	222 Lonnecker	13-Jan-03	12	0.5-1
17140	Environmental Soil Boring	Reynolds Equipment Company	410 South Kirby Street	13-Feb-03	5	0.5-1
21862	Environmental Soil Boring	Citizens National Bank	3014 Benton Street	21-Apr-03	20	0.5-1
21863	Environmental Soil Boring	Citizens National Bank	3014 Benton Street	21-Apr-03	20	0.5-1
21864	Environmental Soil Boring	Citizens National Bank	3014 Benton Street	21-Apr-03	20	0.5-1
36754	Monitor	Tony Luong and Leon Hsu	115 South International	26-Apr-04	15	0.5-1
36755	Monitor	Tony Luong and Leon Hsu	115 South International	26-Apr-04	10	0.5-1
44718	Monitor	Sterling Bank c/o Guida Slavich	1100 S. Jupiter	27-Jul-04	20	0.5-1
44719	Monitor	Sterling Bank c/o Guida Slavich	1100 S. Jupiter	27-Jul-04	30	0.5-1
44721	Monitor	Sterling Bank c/o Guida Slavich	1100 S. Jupiter	27-Jul-04	22.5	0.5-1
44722	Monitor	Sterling Bank c/o Guida Slavich	1100 S. Jupiter	27-Jul-04	20	0.5-1
46810	Environmental Soil Boring	Masood Madery	1918 Platinum Street	20-Sep-04	4	0.5-1
61435	Monitor	Chevron 60304299	2301 Walnut St.	14-Jun-05	12	0.5-1
61436	Monitor	Chevron 60304299	2301 Walnut St.	14-Jun-05	12.5	0.5-1
61437	Monitor	Chevron 60304299	2301 Walnut St.	14-Jun-05	12	0.5-1
61438	Monitor	Chevron 60304299	2301 Walnut St.	14-Jun-05	12.5	0.5-1
61439	Monitor	Chevron 60304299	2301 Walnut St.	14-Jun-05	12.5	0.5-1
61440	Environmental Soil Boring	Chevron 60304299	2301 Walnut St.	14-Jun-05	8	0.5-1
61441	Environmental Soil Boring	Chevron 60304299	2301 Walnut St.	14-Jun-05	8	0.5-1
61442	Environmental Soil Boring	Chevron 60304299	2301 Walnut St.	14-Jun-05	8	0.5-1
75190	Environmental Soil Boring	Prior Remanufacturing	315 International	14-Jan-06	5	0.5-1
75192	Environmental Soil Boring	Prior Remanufacturing	315 International	14-Jan-06	10	0.5-1
75193	Environmental Soil Boring	Prior Remanufacturing	315 International	14-Jan-06	8	0.5-1
79624	Monitor	Raytheon Garland	1200 S. Jupiter	20-Mar-06	12	0.5-1
79625	Monitor	Raytheon Garland	1200 S. Jupiter	20-Mar-06	12	0.5-1
79626	Monitor	Raytheon Garland	1200 S. Jupiter	20-Mar-06	14	0.5-1
79630	Monitor	Raytheon Garland	1200 S. Jupiter	21-Mar-06	30	0.5-1
79633	Monitor	Raytheon Garland	1200 S. Jupiter	21-Mar-06	15	0.5-1
109532	Monitor	Raytheon Garland	1200 S. Jupiter	12-Apr-07	9	0.5-1
109535	Monitor	Raytheon Garland	1200 S. Jupiter	12-Apr-07	20	0.5-1
109537	Monitor	Raytheon Garland	200 S. Jupiter	12-Apr-07	20	0.5-1
109539	Monitor	Raytheon Garland	200 S. Jupiter	12-Apr-07	15	0.5-1
109540	Monitor	Raytheon Garland	200 S. Jupiter	12-Apr-07	18	0.5-1
121880	Monitor	Raytheon Garland	1100 Jupiter Rd.	5-Aug-07	20	0.5-1
135027	Environmental Soil Boring	QT #908	SEQ of Miller & Shiloh Road	19-Feb-08	30	0.5-1
135028	Environmental Soil Boring	QT #908	SEQ of Miller & Shiloh Road	19-Feb-08	15	0.5-1
135029	Environmental Soil Boring	QT #908	SEQ of Miller & Shiloh Road	19-Feb-08	15	0.5-1
135030	Environmental Soil Boring	QT #908	SEQ of Miller & Shiloh Road	19-Feb-08	15	0.5-1
135031	Environmental Soil Boring	QT #908	SEQ of Miller & Shiloh Road	19-Feb-08	15	0.5-1
135032	Environmental Soil Boring	QT #908	SEQ of Miller & Shiloh Road	19-Feb-08	15	0.5-1
135033	Environmental Soil Boring	QT #908	SEQ of Miller & Shiloh Road	19-Feb-08	15	0.5-1
135035	Environmental Soil Boring	QT #908	SEQ of Miller & Shiloh Road	19-Feb-08	10	0.5-1
135036	Environmental Soil Boring	QT #908	SEQ of Miller & Shiloh Road	19-Feb-08	10	0.5-1
145882	Monitor	GFRC Cladding	118 N. Shiloh	26-May-08	13	0.5-1

145884	Monitor	GFRC Cladding	118 N. Shiloh	26-May-08	15	0.5-1
145887	Monitor	GFRC Cladding	118 N. Shiloh	26-May-08	12	0.5-1
145890	Monitor	GFRC Cladding	118 N. Shiloh	26-May-08	15	0.5-1
198175	Environmental Soil Boring	Yellow Transport	3345 Miller Park N.	3-Nov-09	25	0.5-1
198176	Environmental Soil Boring	Yellow Transport	3345 Miller Park N.	3-Nov-09	20	0.5-1
199690	Monitor	Raytheon	Jupiter & Marquis	12-Nov-09	15	0.5-1
206257	Environmental Soil Boring	Sekar Inc.	2020 S. Shiloh Rd	25-Jan-10	25	0.5-1
206259	Environmental Soil Boring	Sekar Inc.	2020 S. Shiloh Rd	25-Jan-10	12.5	0.5-1
206260	Environmental Soil Boring	Sekar Inc.	2020 S. Shiloh Rd	25-Jan-10	6	0.5-1
206262	Environmental Soil Boring	Sekar Inc.	2020 S. Shiloh Rd	25-Jan-10	5	0.5-1
214659	Monitor	Raytheon	1200 S. Jupiter	27-Apr-10	23	0.5-1
214661	Monitor	Raytheon	1200 S. Jupiter	27-Apr-10	17.5	0.5-1
214662	Monitor	Raytheon	1200 S. Jupiter	27-Apr-10	25	0.5-1
214663	Monitor	Raytheon	1200 S. Jupiter	28-Apr-10	20	0.5-1
214664	Monitor	Raytheon	1200 S. Jupiter	28-Apr-10	20	0.5-1
214665	Monitor	Raytheon	1200 S. Jupiter	28-Apr-10	20	0.5-1
214683	Monitor	Raytheon	1200 S. Jupiter	29-Apr-10	19	0.5-1
214685	Monitor	Raytheon	1200 S. Jupiter	29-Apr-10	20	0.5-1
214686	Monitor	Raytheon	1200 S. Jupiter	30-Apr-10	20	0.5-1
214687	Monitor	Raytheon	1200 S. Jupiter	30-Apr-10	20	0.5-1
214689	Environmental Soil Boring	Raytheon	1200 S. Jupiter	30-Apr-10	20	0.5-1
214699	Monitor	Raytheon	1200 S. Jupiter	30-Apr-10	17.5	0.5-1
214706	Monitor	Raytheon	1200 S. Jupiter	30-Apr-10	25	0.5-1
214708	Monitor	Raytheon	1200 S. Jupiter	30-Apr-10	22.5	0.5-1
214711	Monitor	Raytheon	1200 S. Jupiter	11-Apr-10	20	0.5-1
214712	Monitor	Raytheon	1200 S. Jupiter	11-Apr-10	17.5	0.5-1
214715	Monitor	Raytheon	1200 S. Jupiter	11-Apr-10	20	0.5-1
214717	Monitor	Raytheon	1200 S. Jupiter	11-Apr-10	17.5	0.5-1
214719	Monitor	Raytheon	1200 S. Jupiter	11-Apr-10	20	0.5-1
214720	Monitor	Raytheon	1200 S. Jupiter	11-Apr-10	25	0.5-1
214721	Monitor	Raytheon	1200 S. Jupiter	11-Apr-10	20	0.5-1
214727	Monitor	Raytheon	1200 S. Jupiter	15-Apr-10	12.5	0.5-1
214729	Monitor	Raytheon	1200 S. Jupiter	15-Apr-10	15	0.5-1
214730	Monitor	Raytheon	1200 S. Jupiter	15-Apr-10	17.5	0.5-1
214731	Monitor	Raytheon	1200 S. Jupiter	15-Apr-10	15	0.5-1
214734	Monitor	Raytheon	1200 S. Jupiter	15-Apr-10	20	0.5-1
214736	Monitor	Raytheon	1200 S. Jupiter	15-Apr-10	15	0.5-1
214737	Monitor	Raytheon	1200 S. Jupiter	15-Apr-10	17.5	0.5-1
214740	Monitor	Raytheon	1200 S. Jupiter	15-Apr-10	20	0.5-1
214745	Environmental Soil Boring	Raytheon	1200 S. Jupiter	15-Apr-10	20	0.5-1
214746	Environmental Soil Boring	Raytheon	1200 S. Jupiter	15-Apr-10	10	0.5-1
214749	Environmental Soil Boring	Raytheon	1200 S. Jupiter	15-Apr-10	10	0.5-1
214754	Environmental Soil Boring	Raytheon	1200 S. Jupiter	15-Apr-10	12.5	0.5-1
236254	Monitor	Raytheon	1200 S. Jupiter	17-Nov-10	15	0.5-1
236255	Monitor	Raytheon	1200 S. Jupiter	18-Nov-10	20	0.5-1
236256	Monitor	Raytheon	1200 S. Jupiter	18-Nov-10	25	0.5-1
236257	Monitor	Raytheon	1200 S. Jupiter	14-Nov-10	20	0.5-1
236258	Monitor	Raytheon	1200 S. Jupiter	14-Nov-10	25	0.5-1
236259	Monitor	Raytheon	1200 S. Jupiter	15-Nov-10	20	0.5-1
236261	Monitor	Raytheon	1200 S. Jupiter	16-Nov-10	20	0.5-1
236262	Monitor	Raytheon	1200 S. Jupiter	16-Nov-10	25	0.5-1
236267	Environmental Soil Boring	Raytheon	1200 S. Jupiter	14-Nov-10	20	0.5-1
236268	Environmental Soil Boring	Raytheon	1200 S. Jupiter	15-Nov-10	20	0.5-1
236269	Environmental Soil Boring	Raytheon	1200 S. Jupiter	15-Nov-10	20	0.5-1
238547	Monitor	Raytheon	1200 S. Jupiter	9-Dec-10	25	0.5-1
238549	Monitor	Raytheon	1200 S. Jupiter	9-Dec-10	20	0.5-1
238552	Monitor	Raytheon	1200 S. Jupiter	9-Dec-10	25	0.5-1
238553	Monitor	Raytheon	1200 S. Jupiter	9-Dec-10	20	0.5-1
238564	Monitor	Raytheon	1200 S. Jupiter	9-Dec-10	20	0.5-1
238567	Monitor	Raytheon	1200 S. Jupiter	9-Dec-10	27.5	0.5-1
239359	Monitor	Raytheon	1200 S. Jupiter	28-Dec-10	25	0.5-1
241993	Environmental Soil Boring	Raytheon	1200 S. Jupiter	23-Jan-11	3	0.5-1
249187	Monitor	Raytheon	1200 South Jupiter Rd.	3-Apr-11	20	0.5-1
249188	Monitor	Raytheon	1200 South Jupiter Rd.	3-Apr-11	20	0.5-1

249190	Monitor	Raytheon	1200 South Jupiter Rd.	4-Apr-11	31.5	0.5-1
249191	Monitor	Raytheon	1200 South Jupiter Rd.	4-Apr-11	20	0.5-1
249192	Monitor	Raytheon	1200 South Jupiter Rd.	4-Apr-11	20	0.5-1
249193	Environmental Soil Boring	Raytheon	1200 South Jupiter Rd.	4-Apr-11	20	0.5-1
249194	Environmental Soil Boring	Raytheon	1200 South Jupiter Rd.	4-Apr-11	20	0.5-1
249372	Monitor	Alpeshkumar L. Vaghela	2430 W. Walnut St.	5-Apr-11	15	0.5-1
249374	Environmental Soil Boring	Alpeshkumar L. Vaghela	2430 W. Walnut St.	5-Apr-11	12	0.5-1
250105	Environmental Soil Boring	Raytheon	1200 South Jupiter Rd.	13-Apr-11	20	0.5-1
253431	Monitor	Raytheon	1200 South Jupiter Rd.	6-May-11	20	0.5-1
253436	Environmental Soil Boring	Raytheon	1200 South Jupiter Rd.	6-May-11	20	0.5-1
262756	Monitor	Raytheon Company	1200 S. Jupiter	3-Aug-11	10	0.5-1
262757	Monitor	Raytheon Company	1200 S. Jupiter	3-Aug-11	10	0.5-1
262759	Monitor	Raytheon Company	1200 S. Jupiter	3-Aug-11	10	0.5-1
265998	Monitor	Raytheon	Jupiter & Marquis	18-Aug-11	20	0.5-1
265999	Monitor	Raytheon	Jupiter & Marquis	18-Aug-11	15	0.5-1
266001	Monitor	Raytheon	Jupiter & Marquis	18-Aug-11	40	0.5-1
266002	Monitor	Raytheon	Jupiter & Marquis	18-Aug-11	20	0.5-1
266004	Environmental Soil Boring	Raytheon	Jupiter & Marquis	18-Aug-11	25	0.5-1
266005	Environmental Soil Boring	Raytheon	Jupiter & Marquis	18-Aug-11	15	0.5-1
266006	Environmental Soil Boring	Raytheon	Jupiter & Marquis	18-Aug-11	17.5	0.5-1
266007	Environmental Soil Boring	Raytheon	Jupiter & Marquis	18-Aug-11	20	0.5-1
269185	Environmental Soil Boring	Raytheon	Jupitr & Marquis	16-Oct-11	25	0.5-1
269187	Environmental Soil Boring	Raytheon	Jupitr & Marquis	16-Oct-11	22.5	0.5-1
269204	Environmental Soil Boring	Raytheon	Jupitr & Marquis	16-Oct-11	27.5	0.5-1
269205	Environmental Soil Boring	Raytheon	Jupitr & Marquis	16-Oct-11	10	0.5-1
269207	Monitor	Raytheon	Jupitr & Marquis	16-Oct-11	30	0.5-1
269208	Monitor	Raytheon	Jupitr & Marquis	16-Oct-11	25	0.5-1
269209	Monitor	Raytheon	Jupitr & Marquis	16-Oct-11	25	0.5-1
282353	Monitor	Raytheon	1200 South Jupiter Rd.	27-Mar-12	20	0.5-1
282354	Monitor	Raytheon	1200 South Jupiter Rd.	27-Mar-12	27.5	0.5-1
282355	Monitor	Raytheon	1200 South Jupiter Rd.	27-Mar-12	17.5	0.5-1
297228	Monitor	Raytheon	1200 S. Garland Rd.	27-Aug-12	25	0.5-1
297230	Monitor	Raytheon	1200 S. Garland Rd.	27-Aug-12	20	0.5-1
298330	Monitor	TIAA.CREF	1001 Jupiter Rd	22-Aug-12	7.5	0.5-1
309777	Monitor	ECOLAB	2305 Sherwin St	15-Jan-13	20	0.5-1
309779	Monitor	ECOLAB	2305 Sherwin St	15-Jan-13	15	0.5-1
309780	Monitor	ECOLAB	2305 Sherwin St	15-Jan-13	14	0.5-1
310420	Monitor	Raytheon	1200 S. Jupiter Rd	28-Jan-13	20	0.5-1
310422	Monitor	Raytheon	1200 S. Jupiter Rd	28-Jan-13	23	0.5-1
364988	Monitor	RAYTHEON INC.	1200 S. JUPITER	18-May-14	30	0.5-1
383733	Monitor	Raytheon	3350 Marquis Drive	5-Nov-14	25	0.5-1
383734	Monitor	Raytheon	3350 Marquis Drive	5-Nov-14	25	0.5-1
383772	Monitor	Raytheon	1200 S. Jupiter	3-Dec-14	45	0.5-1
383773	Monitor	Raytheon	1200 S. Jupiter	3-Dec-14	27.5	0.5-1
383774	Monitor	Raytheon	1200 S. Jupiter	3-Dec-14	25	0.5-1
384945	Monitor	RAYTHEON	1200 S. JUPITER	20-Oct-14	28	0.5-1
384946	Monitor	RAYTHEON	1200 S. JUPITER	21-Oct-14	27	0.5-1
384947	Monitor	RAYTHEON	1200 S. JUPITER	21-Oct-14	25	0.5-1
384948	Monitor	RAYTHEON	1200 S. JUPITER	22-Oct-14	30	0.5-1
389849	Environmental Soil Boring	RAYTHEON	1200 S. JUPITER	11-Feb-15	9	0.5-1
389851	Monitor	RAYTHEON	1200 S. JUPITER	11-Feb-15	22.5	0.5-1
394999	Monitor	RAYTHEON	1200 S. JUPITER	4-May-15	20	0.5-1
395000	Monitor	RAYTHEON	1200 S. JUPITER	4-May-15	20	0.5-1
395001	Monitor	RAYTHEON	1200 S. JUPITER	4-May-15	19	0.5-1
397615	Monitor	Raytheon	Marquis Drive	19-May-15	30	0.5-1
397614	Monitor	Raytheon	Marquis Drive	19-May-15	25	0.5-1
407936	Injection	Raytheon	Marquis Drive	27-Sep-15	45	0.5-1
407946	Injection	Raytheon	Marquis Drive	29-Sep-15	35	0.5-1
407949	Injection	Raytheon	Marquis Drive	29-Sep-15	35	0.5-1
407960	Injection	Raytheon	Marquis Drive	5-Oct-15	25	0.5-1
407962	Injection	Raytheon	Marquis Drive	5-Oct-15	35	0.5-1
407968	Injection	Raytheon	Marquis Drive	6-Oct-15	30	0.5-1
407976	Monitor	Raytheon	Marquis Drive	1-Oct-15	27.5	0.5-1
407987	Monitor	Raytheon	Marquis Drive	1-Oct-15	30	0.5-1

407953	Injection	Raytheon	Marquis Drive	30-Sep-15	30	0.5-1
407940	Injection	Raytheon	Marquis Drive	28-Sep-15	45	0.5-1
407950	Injection	Raytheon	Marquis Drive	30-Sep-15	30	0.5-1
407965	Injection	Raytheon	Marquis Drive	6-Oct-15	25	0.5-1
407930	Injection	Raytheon	Marquis Drive	27-Sep-15	35	0.5-1
410810	Monitor	Bank of the West	101 North Shiloh Road	3-Nov-15	18.5	0.5-1
433207	Monitor	Ratheon Company	3350 Marquis Drive	18-Jul-16	30	0.5-1
433206	Monitor	Raytheon Company	3350 Marquis Drive	18-Jul-16	25	0.5-1
433205	Monitor	Raytheon Company	3350 Marquis Drive	19-Jul-16	35	0.5-1
433203	Monitor	Raytheon Company	3350 Marquis Drive	19-Jul-16	30	0.5-1
433200	Monitor	Raytheon Company	3350 Marquis Dr.	20-Jul-16	25	0.5-1
433199	Monitor	Raytheon Company	3350 Marquis Drive	20-Jul-16	25	0.5-1
433198	Monitor	Raytheon Company	3350 Marquis Drive	20-Jul-16	25	0.5-1
433197	Other	Raytheon Company	3350 Marquis Drive	24-Jul-16	35	0.5-1
433196	Monitor	Raytheon Company	3350 Marquis Drive	25-Jul-16	30	0.5-1
433194	Other	Raytheon Company	3350 Marquis Drive	25-Jul-16	25	0.5-1
433192	Other	Raytheon Company	3350 Marquis Drive	26-Jul-16	30	0.5-1
433191	Other	Raytheon Company	3350 Marquis Drive	26-Jul-16	30	0.5-1
433190	Other	Raytheon Company	3350 Marquis Drive	27-Jul-16	25	0.5-1
436463	Monitor	JP Morgan Chase	630 S. Jupiter Rd.	10-Oct-16	9	0.5-1
436464	Monitor	JP Morgan Chase	630 S. Jupiter Rd.	10-Oct-16	15	0.5-1
440560	Monitor	Raytheon	1200 S. Jupiter rd	31-Oct-16	30	0.5-1
440562	Monitor	Raytheon	1200 S. Jupiter rd	31-Oct-16	28	0.5-1
440564	Monitor	Raytheon	1200 S. Jupiter rd	31-Oct-16	30	0.5-1
440568	Monitor	Raytheon	1200 S. Jupiter rd	31-Oct-16	33	0.5-1
440569	Monitor	Raytheon	1200 S. Jupiter rd	31-Oct-16	34	0.5-1
440571	Monitor	Raytheon	1200 S. Jupiter rd	31-Oct-16	28	0.5-1
440572	Monitor	Raytheon	1200 S. Jupiter rd	31-Oct-16	29.5	0.5-1
440573	Monitor	Raytheon	1200 S. Jupiter rd	31-Oct-16	29.5	0.5-1
461119	Other	Raytheon	3350 Marquis Dr.	31-Aug-17	40	0.5-1
461118	Other	Raytheon	3350 Marquis Dr.	31-Aug-17	35	0.5-1
465348	Injection	Raytheon	3350 Marquis Drive	8-Nov-17	32	0.5-1
465349	Injection	Raytheon	3350 Marquis Drive	8-Nov-17	31	0.5-1
465350	Injection	Raytheon	3350 Marquis Drive	8-Nov-17	32	0.5-1
465351	Injection	Raytheon	3350 Marquis Drive	8-Nov-17	31	0.5-1
465354	Injection	Raytheon	3350 Marquis Drive	17-Oct-17	33	0.5-1
465355	Injection	Raytheon	3350 Marquis Drive	17-Oct-17	31	0.5-1
465356	Injection	Raytheon	3350 Marquis Drive	17-Oct-17	31	0.5-1
465357	Injection	Raytheon	3350 Marquis Drive	17-Oct-17	30	0.5-1
465358	Injection	Raytheon	3350 Marquis Drive	17-Oct-17	30	0.5-1
465361	Injection	Raytheon	3350 Marquis Drive	17-Oct-17	31	0.5-1
465364	Injection	Raytheon	3350 Marquis Drive	17-Oct-17	31	0.5-1
465368	Injection	Raytheon	3350 Marquis Drive	17-Oct-17	30	0.5-1
465371	Injection	Raytheon	3350 Marquis Drive	17-Oct-17	9	0.5-1
465375	Injection	Raytheon	3350 Marquis Drive	17-Oct-17	31	0.5-1
465376	Injection	Raytheon	3350 Marquis Drive	17-Oct-17	31	0.5-1
465378	Injection	Raytheon	3350 Marquis Drive	17-Oct-17	32	0.5-1
465379	Injection	Raytheon	3350 Marquis Drive	17-Oct-17	32	0.5-1
467279	Monitor	Raytheon Company	3350 Marquis Drive	30-Nov-17	35	0.5-1
467277	Monitor	Raytheon Company	3350 Marquis Drive	30-Nov-17	35	0.5-1
467253	Monitor	Raytheon	Marquis Drive	28-Nov-17	25	0.5-1
467259	Monitor	Raytheon	Marquis Drive	28-Nov-17	25	0.5-1
468580	Monitor	Ratheon	3350 Marquis Drive	19-Nov-17	10	0.5-1
468582	Monitor	Ratheon	3350 Marquis Drive	19-Nov-17	9	0.5-1
468584	Monitor	Ratheon	3350 Marquis Drive	27-Nov-17	6	0.5-1
468586	Monitor	Ratheon	3350 Marquis Drive	27-Nov-17	6	0.5-1
468587	Monitor	Ratheon	3350 Marquis Drive	27-Nov-17	5.9	0.5-1
468579	Monitor	Ratheon	3350 Marquis Drive	19-Nov-17	10.5	0.5-1

STATE OF TEXAS WELL REPORT for Tracking #281345

Owner: **Grand Six, LLC**

Address: **1111 S. Shiloh Road Garland, TX 75042**

Well Location: **1111 S. Shiloh Road Garland, TX 75042**

Well County: **Dallas**

Owner Well #: **B-1, B-2 & B-3**

Grid #: **33-03-8**

Latitude: **32° 54' 09" N**

Longitude: **096° 40' 01" W**

Elevation: **No Data**

****Plugged Within 48 Hours****

****This well has been plugged****

Plugging Report Tracking #134941

Type of Work: **New Well**

Proposed Use: **Environmental Soil Boring**

Drilling Start Date: **2/8/2012** Drilling End Date: **2/8/2012**

	Diameter (in.)	*Top Depth (ft.)*	*Bottom Depth (ft.)*
Borehole:	**2**	**0**	**8**

Drilling Method: **Direct Push**

Borehole Completion: **Open Hole**

Annular Seal Data: **No Data**

Seal Method: **Not Applicable**

Sealed By: **Unknown**

Distance to Property Line (ft.): **No Data**

Distance to Septic Field or other concentrated contamination (ft.): **No Data**

Distance to Septic Tank (ft.): **No Data**

Method of Verification: **No Data**

Surface Completion: **Unknown**

Water Level: **No Data**

Packers: **No Data**

Water Quality:

Strata Depth (ft.)	Water Type
No Data	**No Data**

Chemical Analysis Made: **Unknown**

Did the driller knowingly penetrate any strata which contained injurious constituents?: **No**

Certification Data: The driller certified that the driller drilled this well (or the well was drilled under the driller's direct supervision) and that each and all of the statements herein are true and correct. The driller understood that failure to complete the required items will result in the report(s) being returned for completion and resubmittal.

Company Information: **MagnaCore Drilling & Environmental Services**

906 W. McDermott Dr., #116-313
Allen, TX 75013

Driller Name: **Cedric Cascio** License Number: **54735**

Apprentice Name: **Richard Regalado** Apprentice Number: **58476**

Comments: **No Data**

Lithology:
DESCRIPTION & COLOR OF FORMATION MATERIAL

Top (ft.)	Bottom (ft.)	Description
0	**7**	**Black to dark brown clay**
7	**8**	**Light brown to yellow weathered limestone**

Casing:
BLANK PIPE & WELL SCREEN DATA

Dia. (in.)	New/Used	Type	Setting From/To (ft.)
No Data			

IMPORTANT NOTICE FOR PERSONS HAVING WELLS DRILLED CONCERNING CONFIDENTIALITY

TEX. OCC. CODE Title 12, Chapter 1901.251, authorizes the owner (owner or the person for whom the well was drilled) to keep information in Well Reports confidential. The Department shall hold the contents of the well log confidential and not a matter of public record if it receives, by certified mail, a written request to do so from the owner.

Please include the report's Tracking Number on your written request.

Texas Department of Licensing and Regulation
P.O. Box 12157
Austin, TX 78711
(512) 334-5540

Reference 30

Texas Commission on Environmental Quality	Office of Water	Public Drinking Water Section
County Map of TX	Water System Search	Office of Compliance and Enforcement

Water System Detail			
Water System Facilities Source Water Assessment Results	Violations Enforcement Actions	TCR Sample Results	TTHM HAA5 Summaries
Sample Points	Assistance Actions	Recent Positive TCR Results	PBCU Summaries
Sample Schedules / FANLs / Plans	Compliance Schedules	Other Chemical Results	Chlorine Summaries
Site Visits Milestones	TOC/Alkalinity Results	Chemical Results: Sort by: Name Code	Turbidity Summaries
Operators All POC	LRAA (TTHM/HAA5)	Recent Non-TCR Sample Results	TCR Sample Summaries
Glossary		DWW Instructions	

Water System Detail Information

Water System No.:	TX0570010	System Type:	C
Water System Name:	CITY OF GARLAND	Primary Source Type:	SWP
Principal County Served:	DALLAS	System Status:	A
Principal City Served:		Activity Date:	01-01-1913
Population:	236786	System Recognition:	SUPERIOR

Water System Contacts

Type	Contact	Communication	
AC - Administrative Contact	DODSON, LORI, BARNETT 200 N 5TH ST GARLAND, TX 75040-6314	**Electronic Type**	**Value**
		Phone Type	**Value**
		BUS - Business	972-205-2400

30 001

Sources of Water			
Name	**Type**	**Activity**	**Availability**
SW FROM NORTH TEXAS MWD (LAVON PS)	CC	A	P
SW FROM NORTH TEXAS MWD (FIREWHEEL PS)	CC	A	P
SW FROM NORTH TEXAS MWD (WALLACE PS)	CC	A	P
SW FROM NORTH TEXAS MWD (APOLLO PS)	CC	A	P
SW FROM NORTH TEXAS MWD (BROADWAY PS)	CC	A	P
4	WL	I	P
1	WL	I	P

Source Water Percentages			
Surface Water	0	Surface Water Purchased	0
Ground Water	0	Ground Water Purchased	0
Ground Water UDI	0	Ground Water UDI Purchased	0

Water Purchases
Water System \ Treatment Status
TX0570010 buys from NORTH TEXAS MWD WYLIE WTP - TX0430044 / who is providing Treated and Filtered Water

Buyers of Water
Water System / Population / Availability (blank, (S)easonal, (E)mergency, (I)nterim, (P)ermanent, (O)ther
TX0570010sells to CITY OF MESQUITE - TX0570014 / 143350 / E
TX0570014 sells to KAUFMAN COUNTY MUD 12 - TX1290047 / 0 / P
TX1290047 sells to KAUFMAN COUNTY MUD 11 - TX1290046 / 3516 / P
TX1290047 sells to KAUFMAN COUNTY MUD 14 - TX1290053 / 2097 / P

Total Population Served = 385749

Total Population Served included ALL active connections, including emergency.

Annual Operating Period(s)					
Effective Begin Date	**Effective End Date**	**Start Month/Day**	**End Month/Day**	**Type**	**Population**

30 002

05-29-2018	No End Date	1/1	12/31	R	236786

Service Connections			
Type	**Count**	**Meter Type**	**Meter Size**
RS	88526	MU	0

Service Area	
Code	**Name**
R	RESIDENTIAL AREA

Regulating Agencies	
Name	**Alias/Inspector**
TX COMMISSION ON ENVIRONMENTAL QUALITY	TCEQ

Water System Historical Names
Historical Name(s)

System Certification Requirements		
Certification Name	**Code**	**Begin Date**

WS Flow Rates		
Type	**Quantity**	**UOM**
MDD - Maximum Daily Demand	38.86	MGD
PPRC - Provided Production Capacity	93.984	MGD
ADU - Average Daily Usage	25.22	MGD

30 003

WS Measures		
Type	**Quantity**	**UOM**
TESC - Total Elevated Storage Capacity	4.85	MG
TSTC - Total Storage Capacity	46.85	MG

WS Indicators		
Type	**Value**	**Date**
DBP2 - Stage2 DBPR Schedule Category	1 - 1	04-01-2012
MDDD - Maximum Daily Demand Date	MDDD - Maximum Daily Demand Date	08-25-2014
POWN - Previous Ownership Type Code. This is the WUD ownership code.	MUN - Municipality	
PRFT - Status as a For or Non Profit Entitiy	NON - Non Profit	
SSWP - State Source Water Program	YES - Yes	03-07-2019
UCM3 - UCMR3 EPA Monitoring Required	YES - Yes	01-01-2013
XCON - Cross Connection control Program Ranking	ADQTE - Adequate	07-25-2011

30 004

Reference 31

From:	Mason T. Miller
To:	Stephen Ellis
Cc:	Michele Risko; Sean Ables
Subject:	wellhead protection area
Date:	Friday, June 7, 2019 4:20:41 PM

Stephen,
Sean Ables is out this week.
The address you listed below is not within a PWS well capture zone or surface water area of primary influence. Let me know if I can assist with anything else. Take care.
Later,
Mason

From: Stephen Ellis
Sent: Wednesday, June 5, 2019 4:36 PM
To: Sean Ables <sean.ables@tceq.texas.gov>
Cc: Michele Risko <Michele.Risko@Tceq.Texas.Gov>
Subject: wellhead protection area

Hello Sean,

Can you please tell me if my site is located in a wellhead protection area? The address is 1111 S Shiloh Rd., Garland,
Dallas County, TX. GPS location is 32.922636° N, -96.665409° W.

Thanks, and please let me know if you need anything else,

Stephen Ellis
TCEQ PASI Program Manager
Superfund Section, Remediation Division
(512) 239-5337
Stephen.Ellis@tceq.texas.gov

Reference 32

QuickFacts

Dallas County, Texas; Garland city, Texas; United States

QuickFacts provides statistics for all states and counties, and for cities and towns with a ***population of 5,000 or more***.

Table

All Topics	Dallas County, Texas	Garland city, Texas	United States
Population estimates, July 1, 2018, (V2018)	**2,637,772**	**242,507**	**327,167,434**
PEOPLE			
Population			
Population estimates, July 1, 2018, (V2018)	**2,637,772**	**242,507**	**327,167,434**
Population estimates base, April 1, 2010, (V2018)	2,366,683	226,910	308,758,105
Population, percent change - April 1, 2010 (estimates base) to July 1, 2018, (V2018)	11.5%	6.9%	6.0%
Population, Census, April 1, 2010	2,368,139	226,876	308,745,538
Age and Sex			
Persons under 5 years, percent	△ 7.5%	△ 7.0%	△ 6.1%
Persons under 18 years, percent	△ 26.4%	△ 27.5%	△ 22.6%
Persons 65 years and over, percent	△ 10.5%	△ 11.1%	△ 15.6%
Female persons, percent	△ 50.7%	△ 51.0%	△ 50.8%
Race and Hispanic Origin			
White alone, percent	△ 66.9%	△ 59.8%	△ 76.6%
Black or African American alone, percent (a)	△ 23.4%	△ 13.7%	△ 13.4%
American Indian and Alaska Native alone, percent (a)	△ 1.1%	△ 0.5%	△ 1.3%
Asian alone, percent (a)	△ 6.5%	△ 11.0%	△ 5.8%
Native Hawaiian and Other Pacific Islander alone, percent (a)	△ 0.1%	△ 0.0%	△ 0.2%
Two or More Races, percent	△ 1.9%	△ 3.9%	△ 2.7%
Hispanic or Latino, percent (b)	△ 40.2%	△ 41.3%	△ 18.1%
White alone, not Hispanic or Latino, percent	△ 29.2%	△ 31.3%	△ 60.7%
Population Characteristics			
Veterans, 2013-2017	95,114	9,373	18,939,219
Foreign born persons, percent, 2013-2017	24.0%	28.2%	13.4%

Housing			
Housing units, July 1, 2018, (V2018)	1,027,837	X	138,537,078
Owner-occupied housing unit rate, 2013-2017	50.5%	61.9%	63.8%
Median value of owner-occupied housing units, 2013-2017	$148,300	$132,600	$193,500
Median selected monthly owner costs -with a mortgage, 2013-2017	$1,483	$1,351	$1,515
Median selected monthly owner costs -without a mortgage, 2013-2017	$549	$553	$474
Median gross rent, 2013-2017	$984	$1,013	$982
Building permits, 2017	19,428	X	1,281,977
Families & Living Arrangements			
Households, 2013-2017	906,179	75,837	118,825,921
Persons per household, 2013-2017	2.78	3.10	2.63
Living in same house 1 year ago, percent of persons age 1 year+, 2013-2017	83.5%	85.9%	85.4%
Language other than English spoken at home, percent of persons age 5 years+, 2013-2017	42.6%	48.3%	21.3%
Computer and Internet Use			
Households with a computer, percent, 2013-2017	87.2%	92.4%	87.2%
Households with a broadband Internet subscription, percent, 2013-2017	76.5%	84.2%	78.1%
Education			
High school graduate or higher, percent of persons age 25 years+, 2013-2017	78.3%	76.7%	87.3%
Bachelor's degree or higher, percent of persons age 25 years+, 2013-2017	30.1%	22.6%	30.9%
Health			
With a disability, under age 65 years, percent, 2013-2017	6.8%	6.9%	8.7%
Persons without health insurance, under age 65 years, percent	⚠ 23.0%	⚠ 26.1%	⚠ 10.2%
Economy			
In civilian labor force, total, percent of population age 16 years+, 2013-2017	68.6%	68.8%	63.0%
In civilian labor force, female, percent of population age 16 years+, 2013-2017	61.3%	61.1%	58.2%
Total accommodation and food services sales, 2012 ($1,000) (c)	6,753,112	286,787	708,138,598
Total health care and social assistance receipts/revenue, 2012 ($1,000) (c)	19,683,164	661,591	2,040,441,203
Total manufacturers shipments, 2012 ($1,000) (c)	37,035,625	5,396,642	5,696,729,632
Total merchant wholesaler sales, 2012 ($1,000) (c)	80,604,971	1,771,865	5,208,023,478
Total retail sales, 2012 ($1,000) (c)	35,957,895	2,725,356	4,219,821,871
Total retail sales per capita, 2012 (c)	$14,654	$11,669	$13,443
Transportation			
Mean travel time to work (minutes), workers age 16 years+, 2013-2017	27.2	28.6	26.4

Income & Poverty			
Median household income (in 2017 dollars), 2013-2017	$53,626	$55,637	$57,652
Per capita income in past 12 months (in 2017 dollars), 2013-2017	$29,810	$23,164	$31,177
Persons in poverty, percent	▲ 14.8%	▲ 15.7%	▲ 12.3%
BUSINESSES			
Businesses			
Total employer establishments, 2016	65,781	X	7,757,807
Total employment, 2016	1,456,092	X	126,752,238
Total annual payroll, 2016 ($1,000)	88,126,899	X	6,435,142,055
Total employment, percent change, 2015-2016	3.1%	X	2.1%
Total nonemployer establishments, 2016	233,530	X	24,813,048
All firms, 2012	259,298	21,545	27,626,360
Men-owned firms, 2012	139,455	11,895	14,844,597
Women-owned firms, 2012	96,076	7,871	9,878,397
Minority-owned firms, 2012	127,961	12,218	7,952,386
Nonminority-owned firms, 2012	122,666	8,691	18,987,918
Veteran-owned firms, 2012	22,942	1,822	2,521,682
Nonveteran-owned firms, 2012	225,505	19,035	24,070,685
GEOGRAPHY			
Geography			
Population per square mile, 2010	2,718.0	3,974.4	87.4
Land area in square miles, 2010	871.28	57.09	3,531,905.43
FIPS Code	48113	4829000	00

About datasets used in this table

Value Notes

⚠ Estimates are not comparable to other geographic levels due to methodology differences that may exist between different data sources.

Some estimates presented here come from sample data, and thus have sampling errors that may render some apparent differences between geographies statistically indistinguishable. Click the Quick Info ⓘ icon to the left of each row in TABLE view to learn about sampling error.

The vintage year (e.g., V2018) refers to the final year of the series (2010 thru 2018). *Different vintage years of estimates are not comparable.*

Fact Notes

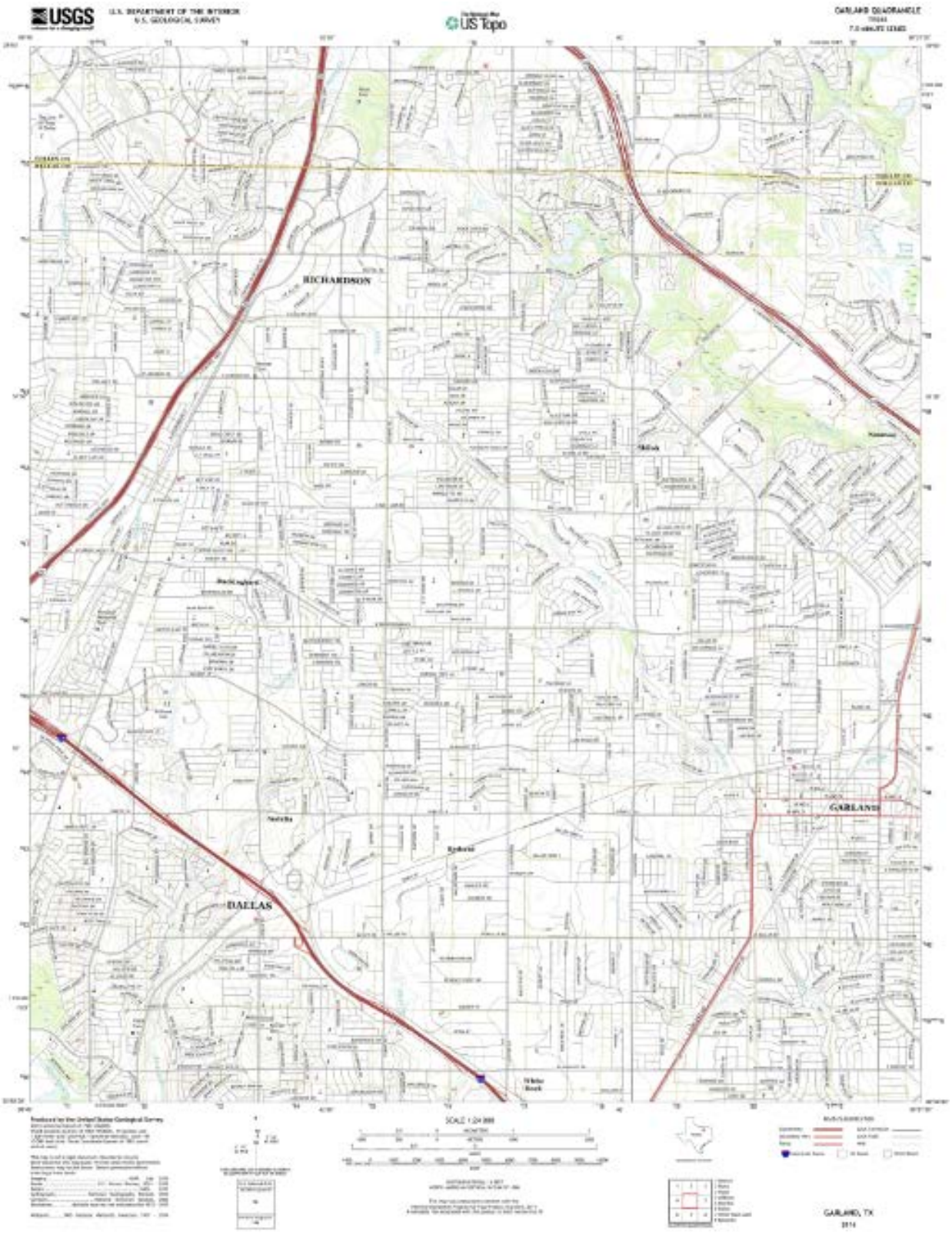
- **(a)** Includes persons reporting only one race
- **(b)** Hispanics may be of any race, so also are included in applicable race categories
- **(c)** Economic Census - Puerto Rico data are not comparable to U.S. Economic Census data

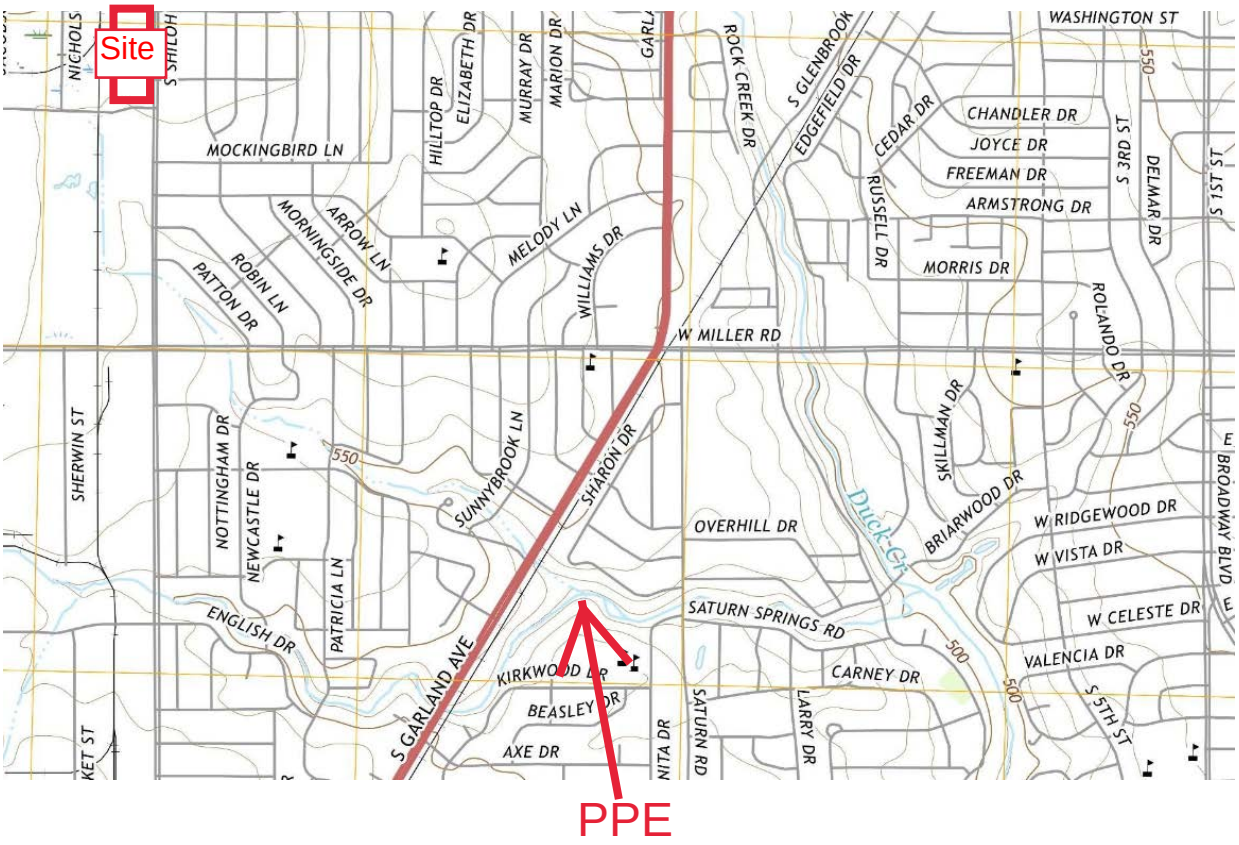
Value Flags

- **-** Either no or too few sample observations were available to compute an estimate, or a ratio of medians cannot be calculated because one or both of the median estimates falls in the lowest or upper interval of an open ended distribution.
- **D** Suppressed to avoid disclosure of confidential information
- **F** Fewer than 25 firms
- **FN** Footnote on this item in place of data
- **NA** Not available
- **S** Suppressed; does not meet publication standards
- **X** Not applicable
- **Z** Value greater than zero but less than half unit of measure shown

QuickFacts data are derived from: Population Estimates, American Community Survey, Census of Population and Housing, Current Population Survey, Small Area Health Insurance Estimates, Small Area Income and Poverty Estimates, State and County Housing Unit Estimates, County Business Patterns, Nonemployer Statistics, Economic Census, Survey of Business Owners, Building Permits.

Reference 33


USGS
U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY
US Topo
GARLAND QUADRANGLE
RICHARDSON
DALLAS
GARLAND
SCALE 1:24 000
GARLAND, TX
2014


Site
PPE
MOCKINGBIRD LN
W MILLER RD
WASHINGTON ST
S GARLAND AVE
SUNNYBROOK LN
SHARON DR
OVERHILL DR
SATURN SPRINGS RD
KIRKWOOD DR
BEASLEY DR
AXE DR
CARNEY DR
VALENCIA DR
W CELESTE DR
W VISTA DR
W RIDGEWOOD DR
BRIARWOOD DR
SKILLMAN DR
ROLANDO DR
MORRIS DR
ARMSTRONG DR
FREEMAN DR
JOYCE DR
CHANDLER DR
CEDAR DR
RUSSELL DR
EDGEFIELD DR
S GLENBROOK
ROCK CREEK DR
DELMAR DR
S 3RD ST
S 1ST ST
S 5TH ST
BROADWAY BLVD
HILLTOP DR
ELIZABETH DR
MURRAY DR
MARION DR
MELODY LN
WILLIAMS DR
ARROW LN
MORNINGSIDE DR
ROBIN LN
PATTON DR
NOTTINGHAM DR
NEWCASTLE DR
PATRICIA LN
ENGLISH DR
SHERWIN ST
NICHOLS
SATURN RD
LARRY DR
NITA DR
Duck Cr
550
500

Reference 34

U.S. DEPARTMENT OF COMMERCE
LUTHER H. HODGES, Secretary

WEATHER BUREAU
F. W. REICHELDERFER, Chief

TECHNICAL PAPER NO. 40

RAINFALL FREQUENCY ATLAS OF THE UNITED STATES

for Durations from 30 Minutes to 24 Hours and Return Periods from 1 to 100 Years

Prepared by
DAVID M. HERSHFIELD
Cooperative Studies Section, Hydrologic Services Division
for
Engineering Division, Soil Conservation Service
U.S. Department of Agriculture

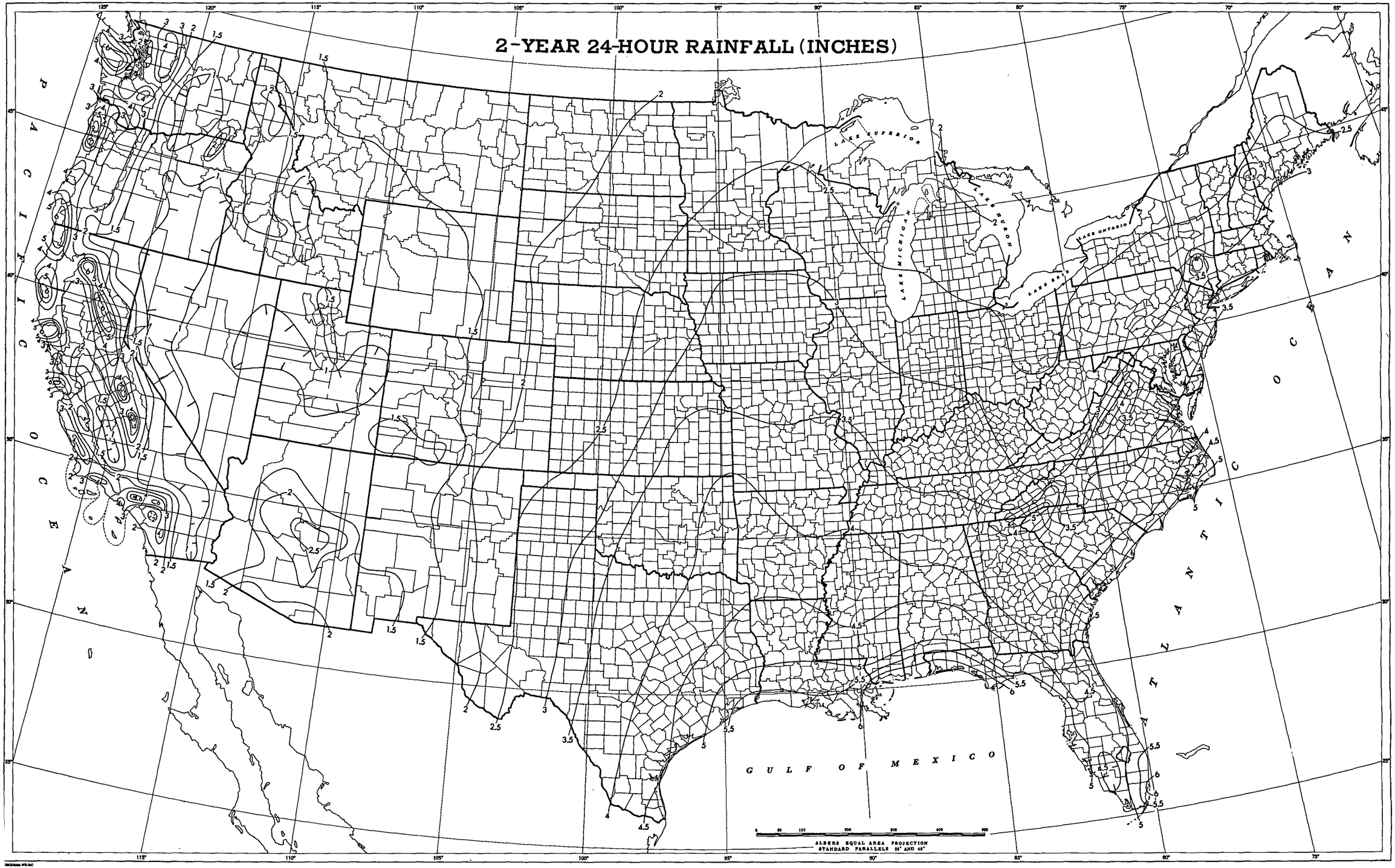
WASHINGTON, D.C.

May 1961

Repaginated and Reprinted January 1963

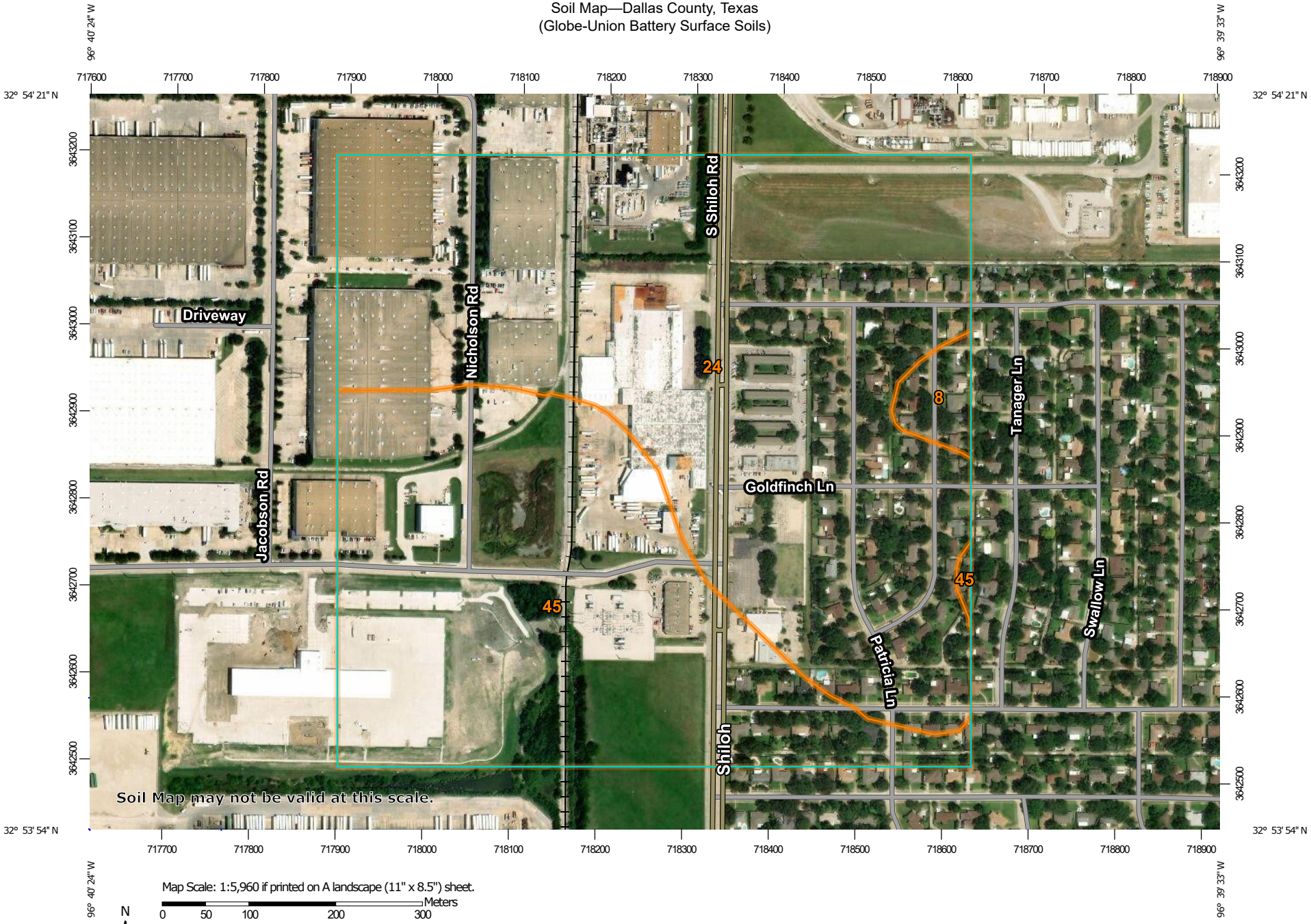
For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington 25, D.C. Price $1.25

2-YEAR 24-HOUR RAINFALL (INCHES)



Reference 35

Soil Map—Dallas County, Texas
(Globe-Union Battery Surface Soils)



Map Scale: 1:5,960 if printed on A landscape (11" x 8.5") sheet.

N

Meters
0 50 100 200 300

Feet
0 250 500 1000 1500

Map projection: Web Mercator Corner coordinates: WGS84 Edge tics: UTM Zone 14N WGS84

MAP LEGEND

Area of Interest (AOI)
- Area of Interest (AOI)

Soils
- Soil Map Unit Polygons
- Soil Map Unit Lines
- Soil Map Unit Points

Special Point Features
- Blowout
- Borrow Pit
- Clay Spot
- Closed Depression
- Gravel Pit
- Gravelly Spot
- Landfill
- Lava Flow
- Marsh or swamp
- Mine or Quarry
- Miscellaneous Water
- Perennial Water
- Rock Outcrop
- Saline Spot
- Sandy Spot
- Severely Eroded Spot
- Sinkhole
- Slide or Slip
- Sodic Spot
- Spoil Area
- Stony Spot
- Very Stony Spot
- Wet Spot
- Other
- Special Line Features

Water Features
- Streams and Canals

Transportation
- Rails
- Interstate Highways
- US Routes
- Major Roads
- Local Roads

Background
- Aerial Photography

MAP INFORMATION

The soil surveys that comprise your AOI were mapped at 1:20,000.

Warning: Soil Map may not be valid at this scale.

Enlargement of maps beyond the scale of mapping can cause misunderstanding of the detail of mapping and accuracy of soil line placement. The maps do not show the small areas of contrasting soils that could have been shown at a more detailed scale.

Please rely on the bar scale on each map sheet for map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL:
Coordinate System: Web Mercator (EPSG:3857)

Maps from the Web Soil Survey are based on the Web Mercator projection, which preserves direction and shape but distorts distance and area. A projection that preserves area, such as the Albers equal-area conic projection, should be used if more accurate calculations of distance or area are required.

This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: Dallas County, Texas
Survey Area Data: Version 16, Sep 14, 2018

Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Aug 20, 2016—Dec 13, 2017

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

Map Unit Legend

Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
8	Austin-Urban land complex, 0 to 2 percent slopes	2.2	1.7%
24	Dalco-Urban land complex, 0 to 3 percent slopes	75.4	59.1%
45	Houston Black-Urban land complex, 0 to 4 percent slopes	49.9	39.1%
Totals for Area of Interest		**127.5**	**100.0%**

Dallas County, Texas

24—Dalco-Urban land complex, 0 to 3 percent slopes

Map Unit Setting

National map unit symbol: d7lx
Elevation: 0 to 4,000 feet
Mean annual precipitation: 8 to 60 inches
Mean annual air temperature: 54 to 73 degrees F
Frost-free period: 180 to 310 days
Farmland classification: Not prime farmland

Map Unit Composition

Dalco and similar soils: 50 percent
Urban land: 30 percent
Minor components: 20 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Dalco

Setting

Landform: Ridges
Landform position (two-dimensional): Toeslope, footslope
Landform position (three-dimensional): Base slope
Down-slope shape: Linear
Across-slope shape: Convex
Parent material: Residuum weathered from austin chalk formation

Typical profile

H1 - 0 to 7 inches: clay
H2 - 7 to 26 inches: clay
H3 - 26 to 39 inches: clay
H4 - 39 to 80 inches: bedrock

Properties and qualities

Slope: 0 to 3 percent
Depth to restrictive feature: 24 to 40 inches to paralithic bedrock
Natural drainage class: Moderately well drained
Capacity of the most limiting layer to transmit water (Ksat): Very low to moderately low (0.00 to 0.06 in/hr)
Depth to water table: More than 80 inches
Frequency of flooding: None
Frequency of ponding: None
Calcium carbonate, maximum in profile: 25 percent
Salinity, maximum in profile: Nonsaline to very slightly saline (0.0 to 2.0 mmhos/cm)
Sodium adsorption ratio, maximum in profile: 4.0
Available water storage in profile: Low (about 5.8 inches)

Interpretive groups

Land capability classification (irrigated): None specified

Land capability classification (nonirrigated): 2e
Hydrologic Soil Group: D
Ecological site: Northern Blackland (R086AY010TX)
Hydric soil rating: No

Description of Urban Land

Typical profile

H1 - 0 to 40 inches: variable

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 8s
Hydrologic Soil Group: D
Hydric soil rating: No

Minor Components

Unnamed

Percent of map unit: 20 percent
Hydric soil rating: No

Data Source Information

Soil Survey Area: Dallas County, Texas
Survey Area Data: Version 16, Sep 14, 2018

Dallas County, Texas

45—Houston Black-Urban land complex, 0 to 4 percent slopes

Map Unit Setting

National map unit symbol: d7mn
Elevation: 0 to 4,000 feet
Mean annual precipitation: 8 to 60 inches
Mean annual air temperature: 54 to 73 degrees F
Frost-free period: 180 to 310 days
Farmland classification: Not prime farmland

Map Unit Composition

Houston black and similar soils: 55 percent
Urban land: 35 percent
Minor components: 10 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Houston Black

Setting

Landform: Ridges
Landform position (two-dimensional): Shoulder, summit
Landform position (three-dimensional): Interfluve
Microfeatures of landform position: Circular gilgai
Down-slope shape: Convex
Across-slope shape: Convex
Parent material: Residuum weathered from calcareous shale of taylor marl and eagleford shale

Typical profile

H1 - 0 to 6 inches: clay
H2 - 6 to 52 inches: clay
H3 - 52 to 78 inches: clay

Properties and qualities

Slope: 0 to 4 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Moderately well drained
Capacity of the most limiting layer to transmit water (Ksat): Very low to moderately low (0.00 to 0.06 in/hr)
Depth to water table: More than 80 inches
Frequency of flooding: None
Frequency of ponding: None
Calcium carbonate, maximum in profile: 40 percent
Salinity, maximum in profile: Nonsaline to slightly saline (0.0 to 4.0 mmhos/cm)
Sodium adsorption ratio, maximum in profile: 2.0
Available water storage in profile: Moderate (about 9.0 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 2e
Hydrologic Soil Group: D
Ecological site: Northern Blackland (R086AY010TX)
Hydric soil rating: No

Description of Urban Land

Typical profile

H1 - 0 to 40 inches: variable

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 8s
Hydrologic Soil Group: D
Hydric soil rating: No

Minor Components

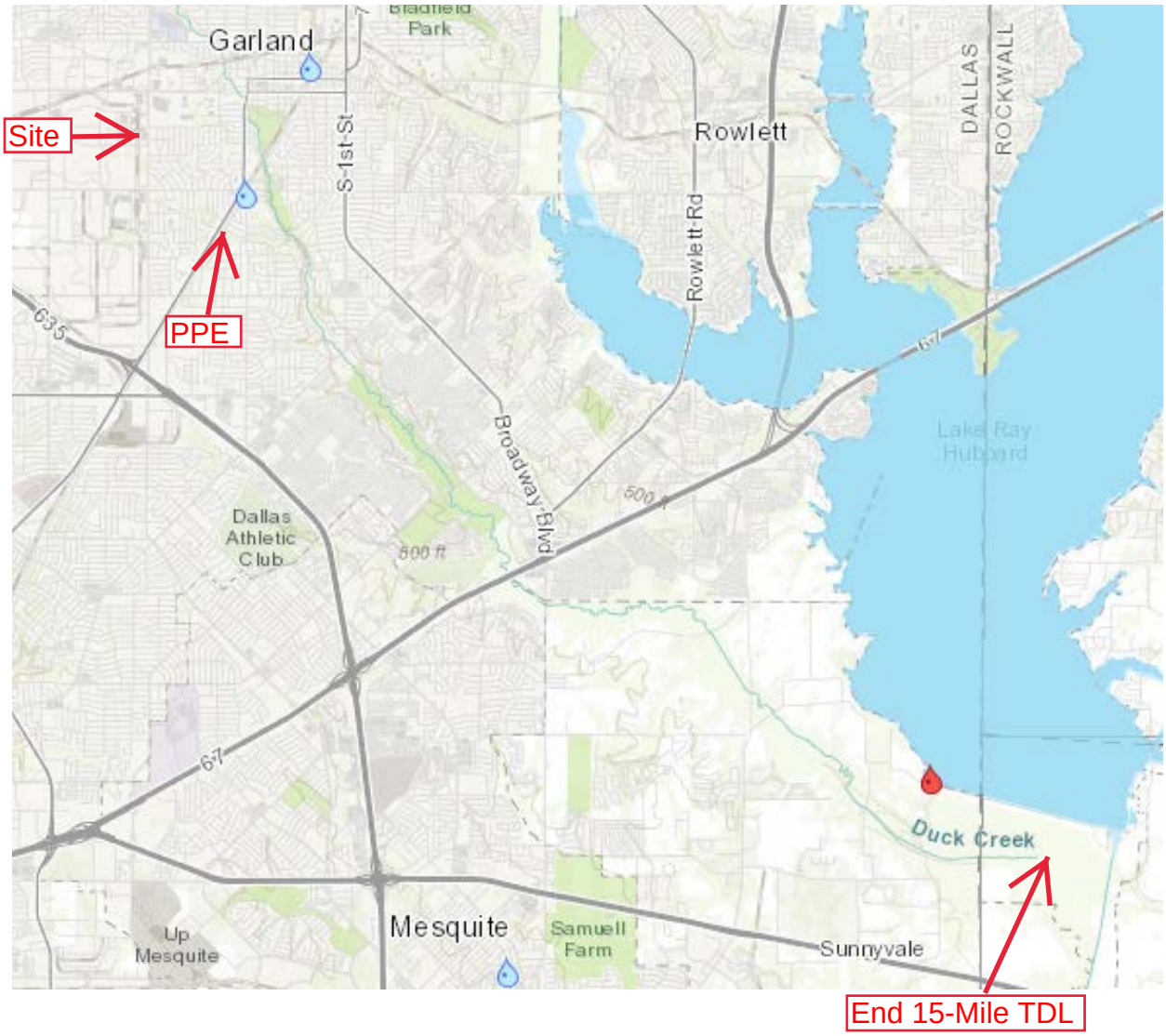
Unnamed

Percent of map unit: 10 percent
Hydric soil rating: No

Data Source Information

Soil Survey Area: Dallas County, Texas
Survey Area Data: Version 16, Sep 14, 2018

Reference 36


Site
PPE
End 15-Mile TDL
Garland
Bradfield Park
S-1st-St
Rowlett
Rowlett-Rd
DALLAS
ROCKWALL
635
67
Broadway-Blvd
Lake Ray Hubbard
Dallas Athletic Club
800 ft
500 ft
Duck Creek
Mesquite
Up Mesquite
Samuell Farm
Sunnyvale

Reference 37

Facilities

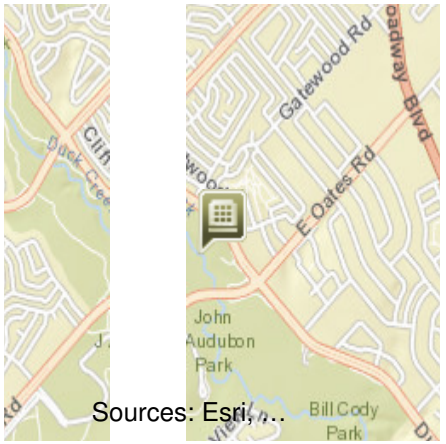
Duck Creek Greenbelt

Features

- Baseball
- Bike Trail
- Fishing
- Football
- Grill
- Parking
- Pavilion
- Picnic Areas
- Picnic Tables
- Restrooms
- Soccer
- Softball
- Trail

ADDITIONAL PARK FEATURES

- Backstop
- Benches



Duck Creek Greenbelt

4917 Duck Creek Drive
Garland, TX 75043

Contact

Email Administration Office
972-205-2750

Rating

This facility has not yet been rated.

37 001

- Cricket field with pitch
- Drinking fountains
- Fishing ponds - 2
- Pavilion - accommodates 48 people
- Multi-purpose field - Bill Cody
- Trail - 5.7 mile concrete

PARK FACILITIES

- Cody Park
- Gatewood Pavilion
- Troth Ablon Park

▲ Back to top

GOVERNMENT WEBSITES BY CIVICPLUS®

Facilities

Ablon Park

Features

- Baseball
- Fishing
- Parking
- Pavilion
- Picnic Areas
- Picnic Tables
- Playground
- Rental Facilities
- Restrooms
- Soccer
- Trail
- Water

ADDITIONAL PARK FEATURES

- Drinking fountain
- Practice Soccer goal and Baseball backstop

Ablon Park

3850 Ablon Trail Drive
Garland, TX 75043

Contact

Email Administration Office
972-205-2750

Rating

This facility has not yet been rated.

37 003

PARK FACILITIES

- Ablon Pavilion - accommodates 80 people, water and electricity available with reservation
- Ablon Park Trail - 0.9 mile concrete

▲ Back to top

GOVERNMENT WEBSITES BY CIVICPLUS®

Reference 37

Duck Creek Garland

Texas Fishing Forum

Duck Creek Garland - 02/27/12 02:06 AM Posted By: SteveStrasemeier

Finished all my chores at home so decided to hit the creek until Dark. Worked it down a bit with topwater popper and spinner. Caught a nice one and one more small LMB. Then on the way back played with the little ones. About 20-25 blue gill and sunfish and 5 good sized greenies - they were bunched up and could have caught a lot more but the sun was down and couldn't see.

Re: Duck Creek Garland - 02/27/12 03:01 AM Posted By: maconator

nice. i caught a couple little bass on duck creek as well today, was lots of fun

Re: Duck Creek Garland - 02/28/12 02:32 AM Posted By: ryand75

hey steve, i was the guy who was across the creek from. i threw u needle nose pliers . I only landing one that evening, a lmb ,no bigger then 1.5. Pm me if u plan on fishing there this week.

Re: Duck Creek Garland - 02/28/12 05:47 PM Posted By: feelafisherman

is that right off Ferguson?

Re: Duck Creek Garland - 02/28/12 08:26 PM Posted By: SteveStrasemeier

ryand75 - nice to meet you, and thanks for the bail out, I forgot my pliers. This LMB and the other one both ate that little popper all the way down inside. Usually with top water you may get 1 fish out of 3 strikes. This was two fish in a row and both just swallowed the whole thing. I scouted for the little ones on the way back because I beleive that if you find concentrated areas of little ones (bluegill/sunfish) the predators are not far away.

feelafisherman this is way upstream around Shiloh/Buchingham area but I imagine that there are fish all over the creek in holes. When the rains come a lot of them get washed down stream.

Re: Duck Creek Garland - 02/29/12 03:55 PM Posted By: RCSteve

Just wondering, the big pond in the park, would it be a good place to take the kids? They are not picky about what or how big, but how many. Maybe you can recommend some other kid friendly venues? We live in RC and are always scouting around for good spots.

Steve in RC.

38 001

Re: Duck Creek Garland - 02/29/12 04:56 PM Posted By: ryand75

RC, there are 3 maybe 4 ponds at huffins park. The Ponds are located between the tennis courts and Plano rd. Personally i never caught anything there. i have read on a previous post awhile back that it holds Blue gill and sunfish. U live in RC (royce city)?

If u need more details exactly where the park is located its on the NE corner Plano/belt line rd just behind the shopping center.

Re: Duck Creek Garland - 02/29/12 05:02 PM Posted By: ryand75

since no work today, ill be hitting up duck creek today working my from Jupiter/beltline corner to the Shiloh/Buckingham rd corner. Plus a few ponds, If i land any today ill post my results. Time to go!

Re: Duck Creek Garland - 02/29/12 08:19 PM Posted By: SteveStrasemeier

Very kid friendly area is Jupter and Beltline West all the way to Plano Road. Have caught a lot of bluegill and some good LMB.

Re: Duck Creek Garland - 02/29/12 09:56 PM Posted By: LTF2011

> **Originally Posted By: ryand75**
>
> since no work today, ill be hitting up duck creek today working my from Jupiter/beltline corner to the Shiloh/Buckingham rd corner. Plus a few ponds, If i land any today ill post my results. Time to go!

Can you fish that way looks like it runs right through a golf course on Google Earth?

Re: Duck Creek Garland - 03/01/12 06:48 AM Posted By: TxPacker4

> **Originally Posted By: LTF2011**
>
> > **Originally Posted By: ryand75**
> >
> > since no work today, ill be hitting up duck creek today working my from Jupiter/beltline corner to the Shiloh/Buckingham rd corner. Plus a few ponds, If i land any today ill post my results. Time to go!

38 002

> Can you fish that way looks like it runs right through a golf course on Google Earth?

Golf Course went bankrupt..

Re: Duck Creek Garland - 03/01/12 03:20 PM Posted By: LTF2011

> **Originally Posted By: TxPacker4**
>
> > **Originally Posted By: LTF2011**
> >
> > > **Originally Posted By: ryand75**
> > >
> > > since no work today, ill be hitting up duck creek today working my from Jupiter/beltline corner to the Shiloh/Buckingham rd corner. Plus a few ponds, If i land any today ill post my results. Time to go!
> >
> > Can you fish that way looks like it runs right through a golf course on Google Earth?
>
> Golf Course went bankrupt..

AHH... Explains why the greens are browns...

Re: Duck Creek Garland - 03/02/12 02:54 AM Posted By: Aquiles

Wow I did'nt know the golf course was closed I had just been fishing the ponds by Jupiter . I had a great time there caught four bass on four cast all between 15-19 inches really nice size for that creek .

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38 003

Duck Creek lately

Texas Fishing Forum

Duck Creek lately - 10/24/16 10:05 PM Posted By: SteveStrasemeier

I fish Duck Creek (Beltline/Jupiter) every once in a while because it is so close to my house. Until a week ago it has been very bad, got a lot of pressure this summer. Last week I managed two nice 2 lbers and couple smaller ones. This morning I caught several small ones then the one below on top water pop'r. He hit that pop'r just as soon as it touched the water. Was worried that my 6 lb. line would not hold up but it did. Not nearly as many in there as there used to be but still a few nice ones.

38 004

I wear a size 12 shoe

38 005

Re: Duck Creek lately - 10/25/16 03:03 PM Posted By: GigTheFish

Nice fish! I tried fishing there a few months ago and got no bites at all. I didn't think there were any fish in there let alone some nice ones. I'll have to go try it again.

Re: Duck Creek lately - 10/25/16 03:15 PM Posted By: TxPacker4

They're all super spooky. When I go waste time down there, I throw 4lb flouro and a craw imitation or after dark, ill throw a small popper. Always produces a couple out of each pocket. LIGHT line and tackle is the key.

Re: Duck Creek lately - 10/25/16 04:13 PM Posted By: musiclife_7

problem is since an unnamed person posted that on this forum, it's been over-fished. I live 2 blocks from the creek and every day driving home I see

38 006

4-5 people fishing it. There's maybe 20-30 bass in the whole creek since the last flood. If you can get into the golf course just south of there, it's loaded with fish. LOL

Re: Duck Creek lately - 11/10/16 06:11 PM Posted By: LakeForkGroupie

I live on this creek, I watch people fish it constantly. Over the summer I would say there would be 2 people there at lunch and 2 people or 2 groups every night. I think they bite, then get sore mouth and don't bite for a few weeks. There are differently more fisherman than fish. I rarely see anyone catch one. If the fish see you, it's game over.

Congrats to the OP. That section is the toughest section for me, I only get bit in the spawn there. (for the most part).

Also the bait fish population stays low thanks to a few people that show up with white 5 gallon buckets to take bluegill home.

The best part of the creek is that it has clear water at times, and it's great to practice casting, pitching, and seeing how my lures look in the water.

Re: Duck Creek lately - 11/11/16 09:18 PM Posted By: OleMiss11

Are there any bass closer to huffines park behind the rec center?

Re: Duck Creek lately - 11/17/16 08:27 PM Posted By: SteveStrasemeier

I have never caught or seen one there.

Re: Duck Creek lately - 11/24/16 05:55 AM Posted By: NocturneGaming

This is a creek that I used to fish very regularly. Never really got anything unless it was a small Texas rigged worm that had to be dragged along the bottom. Never went back since a homeless couple chased me out of the bottom of the Jupiter bridge for a solid 5 min.

Re: Duck Creek lately - 11/29/16 03:27 AM Posted By: HunterFJ

I agree!!! 6 years ago, I could catch 8-10 within an hour and was the only one fishing. Then someone posted, and it wasn't uncommon to see 10-15 others fishing on the weekend. Needless to say the catch rate plummeted to 1 maybe 2 fish per outing.

Re: Duck Creek lately - 11/29/16 01:52 PM Posted By: Indianation65

Good stuff, I've been there a couple times, saw bass, but didn't land any. I'll give it a go, hope to catch a few and then toss them back.

...------

Re: Duck Creek lately - 12/04/16 11:27 PM Posted By: SteveStrasemeier

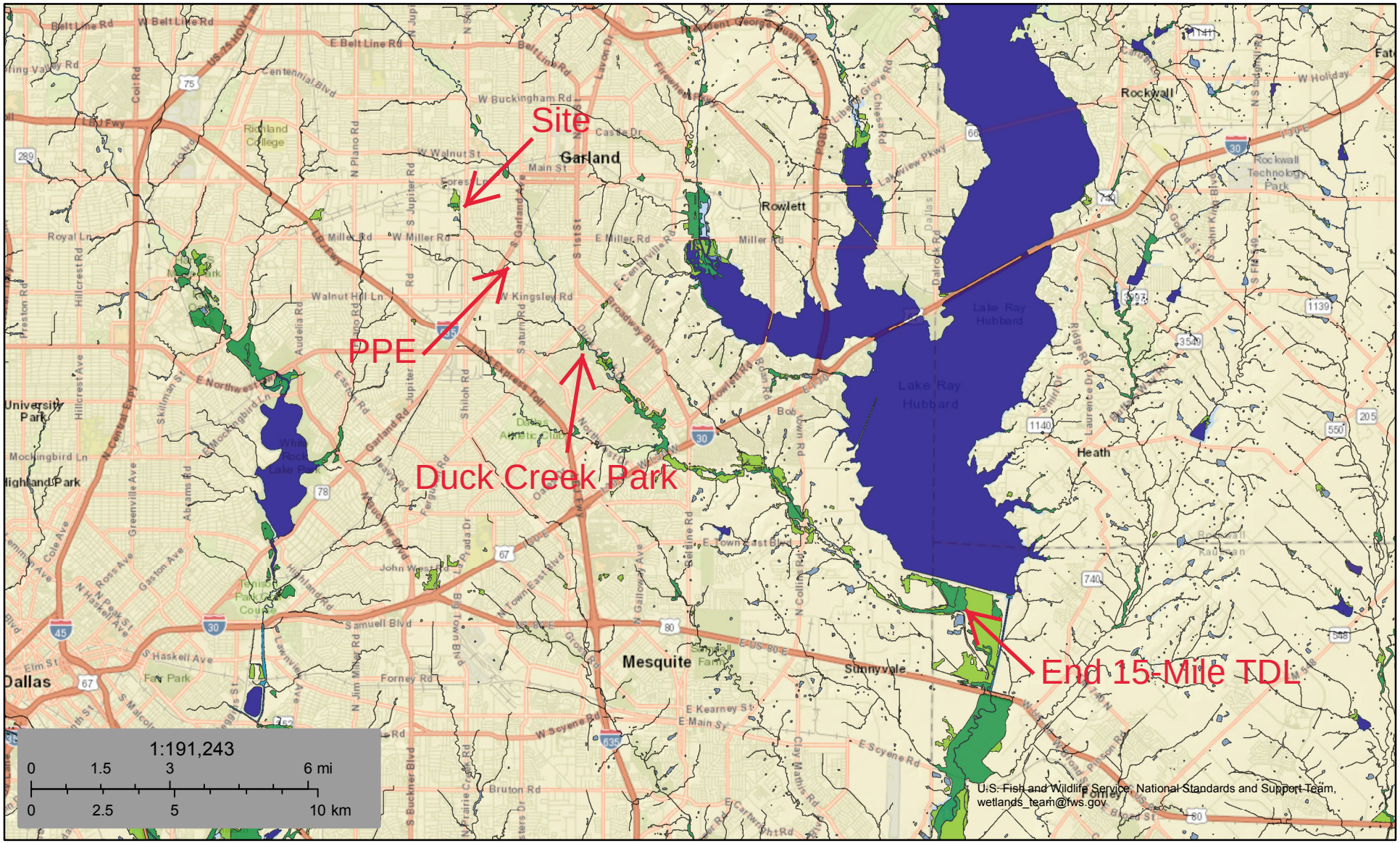
No problem will never post about duck creek again.

38 007

Reference 39

U.S. Fish and Wildlife Service
National Wetlands Inventory

Globe-Union: Sensitive Environments



June 12, 2019

Wetlands

- Estuarine and Marine Deepwater
- Estuarine and Marine Wetland
- Freshwater Emergent Wetland
- Freshwater Forested/Shrub Wetland
- Freshwater Pond
- Lake
- Other
- Riverine

This map is for general reference only. The US Fish and Wildlife Service is not responsible for the accuracy or currentness of the base data shown on this map. All wetlands related data should be used in accordance with the layer metadata found on the Wetlands Mapper web site.

39 001

National Wetlands Inventory (NWI)
This page was produced by the NWI mapper

Reference 40

Last Update: 4/18/2019

DALLAS COUNTY

AMPHIBIANS

southern dusky salamander *Desmognathus conanti*

Details unknown.

Federal Status:	State Status:	SGCN: N
Endemic:	Global Rank: G5	State Rank: S1

Strecker's chorus frog *Pseudacris streckeri*

Wooded floodplains and flats, prairies, cultivated fields and marshes. Likes sandy substrates.

Federal Status:	State Status:	SGCN: Y
Endemic: N	Global Rank: G5	State Rank: S3

Woodhouse's toad *Anaxyrus woodhousii*

Extremely catholic up to 5000 feet, does very well (except for traffic) in association with man.

Federal Status:	State Status:	SGCN: Y
Endemic: N	Global Rank: G5	State Rank: SU

BIRDS

bald eagle *Haliaeetus leucocephalus*

Found primarily near rivers and large lakes; nests in tall trees or on cliffs near water; communally roosts, especially in winter; hunts live prey, scavenges, and pirates food from other birds

Federal Status:	State Status: T	SGCN: Y
Endemic: N	Global Rank: G5	State Rank: S3B,S3N

black rail *Laterallus jamaicensis*

Salt, brackish, and freshwater marshes, pond borders, wet meadows, and grassy swamps; nests in or along edge of marsh, sometimes on damp ground, but usually on mat of previous years dead grasses; nest usually hidden in marsh grass or at base of Salicornia

Federal Status: PT	State Status:	SGCN: Y
Endemic: N	Global Rank: G3G4	State Rank: S2

black-capped vireo *Vireo atricapilla*

Oak-juniper woodlands with distinctive patchy, two-layered aspect; shrub and tree layer with open, grassy spaces; requires foliage reaching to ground level for nesting cover; return to same territory, or one nearby, year after year; deciduous and broad-leaved shrubs and trees provide insects for feeding; species composition less important than presence of adequate broad-leaved shrubs, foliage to ground level, and required structure; nesting season March-late summer

Federal Status:	State Status: E	SGCN: Y
Endemic: N	Global Rank: G3	State Rank: S2B

DISCLAIMER

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DALLAS COUNTY

BIRDS

Franklin's gull *Leucophaeus pipixcan*

Habitat description is not available at this time.

Federal Status:	State Status:	SGCN: Y
Endemic: N	Global Rank: G4G5	State Rank: S2N

golden-cheeked warbler *Setophaga chrysoparia*

Ashe juniper in mixed stands with various oaks (Quercus spp.). Edges of cedar brakes. Dependent on Ashe juniper (also known as cedar) for long fine bark strips, only available from mature trees, used in nest construction; nests are placed in various trees other than Ashe juniper; only a few mature junipers or nearby cedar brakes can provide the necessary nest material; forage for insects in broad-leaved trees and shrubs; nesting late March-early summer.

Federal Status: LE	State Status: E	SGCN: Y
Endemic: N	Global Rank: G2	State Rank: S2B

interior least tern *Sternula antillarum athalassos*

Sand beaches, flats, bays, inlets, lagoons, islands. Subspecies is listed only when inland (more than 50 miles from a coastline); nests along sand and gravel bars within braided streams, rivers; also know to nest on man-made structures (inland beaches, wastewater treatment plants, gravel mines, etc); eats small fish and crustaceans, when breeding forages within a few hundred feet of colony

Federal Status: LE	State Status: E	SGCN: Y
Endemic: N	Global Rank: G4T2Q	State Rank: S1B

piping plover *Charadrius melodus*

Beaches, sandflats, and dunes along Gulf Coast beaches and adjacent offshore islands. Also spoil islands in the Intracoastal Waterway. Based on the November 30, 1992 Section 6 Job No. 9.1, Piping Plover and Snowy Plover Winter Habitat Status Survey, algal flats appear to be the highest quality habitat. Some of the most important aspects of algal flats are their relative inaccessibility and their continuous availability throughout all tidal conditions. Sand flats often appear to be preferred over algal flats when both are available, but large portions of sand flats along the Texas coast are available only during low-very low tides and are often completely unavailable during extreme high tides or strong north winds. Beaches appear to serve as a secondary habitat to the flats associated with the primary bays, lagoons, and inter-island passes. Beaches are rarely used on the southern Texas coast, where bayside habitat is always available, and are abandoned as bayside habitats become available on the central and northern coast. However, beaches are probably a vital habitat along the central and northern coast (i.e. north of Padre Island) during periods of extreme high tides that cover the flats. Optimal site characteristics appear to be large in area, sparsely vegetated, continuously available or in close proximity to secondary habitat, and with limited human disturbance.

Federal Status: LT	State Status: T	SGCN: Y
Endemic: N	Global Rank: G3	State Rank: S2N

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DALLAS COUNTY

BIRDS

red knot *Calidris canutus rufa*

Red knots migrate long distances in flocks northward through the contiguous United States mainly April-June, southward July-October. A small plump-bodied, short-necked shorebird that in breeding plumage, typically held from May through August, is a distinctive and unique pottery orange color. Its bill is dark, straight and, relative to other shorebirds, short-to-medium in length. After molting in late summer, this species is in a drab gray-and-white non-breeding plumage, typically held from September through April. In the non-breeding plumage, the knot might be confused with the omnipresent Sanderling. During this plumage, look for the knot's prominent pale eyebrow and whitish flanks with dark barring. The Red Knot prefers the shoreline of coast and bays and also uses mudflats during rare inland encounters. Primary prey items include coquina clam (Donax spp.) on beaches and dwarf surf clam (Mulinia lateralis) in bays, at least in the Laguna Madre. Wintering Range includes- Aransas, Brazoria, Calhoun, Cameron, Chambers, Galveston, Jefferson, Kennedy, Kleberg, Matagorda, Nueces, San Patricio, and Willacy. Habitat: Primarily seacoasts on tidal flats and beaches, herbaceous wetland, and Tidal flat/shore.

Federal Status: LT	State Status:	SGCN: Y
Endemic: N	Global Rank: G4T2	State Rank: SNRN

western burrowing owl *Athene cunicularia hypugaea*

Open grasslands, especially prairie, plains, and savanna, sometimes in open areas such as vacant lots near human habitation or airports; nests and roosts in abandoned burrows

Federal Status:	State Status:	SGCN: Y
Endemic: N	Global Rank: G4T4	State Rank: S2

white-faced ibis *Plegadis chihi*

Prefers freshwater marshes, sloughs, and irrigated rice fields, but will attend brackish and saltwater habitats; currently confined to near-coastal rookeries in so-called hog-wallow prairies. Nests in marshes, in low trees, on the ground in bulrushes or reeds, or on floating mats.

Federal Status:	State Status: T	SGCN: Y
Endemic: N	Global Rank: G5	State Rank: S4B

whooping crane *Grus americana*

Small ponds, marshes, and flooded grain fields for both roosting and foraging. Potential migrant via plains throughout most of state to coast; winters in coastal marshes of Aransas, Calhoun, and Refugio counties.

Federal Status: LE	State Status: E	SGCN: Y
Endemic: N	Global Rank: G1	State Rank: S1N

wood stork *Mycteria americana*

Prefers to nest in large tracts of baldcypress (Taxodium distichum) or red mangrove (Rhizophora mangle); forages in prairie ponds, flooded pastures or fields, ditches, and other shallow standing water, including salt-water; usually roosts communally in tall snags, sometimes in association with other wading birds (i.e. active heronries); breeds in Mexico and birds move into Gulf States in search of mud flats and other wetlands, even those associated with forested areas; formerly nested in Texas, but no breeding records since 1960

Federal Status:	State Status: T	SGCN: Y
Endemic: N	Global Rank: G4	State Rank: SHB,S2N

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DALLAS COUNTY

CRUSTACEANS

a cave obligate isopod *Caecidotea bilineata*

Habitat description is not available at this time.

Federal Status:	State Status:	SGCN: N
Endemic: Y	Global Rank: G2G3	State Rank: S1

FISH

alligator gar *Atractosteus spatula*

Habitat description is not available at this time.

Federal Status:	State Status:	SGCN: Y
Endemic: N	Global Rank: G3G4	State Rank: S4

american eel *Anguilla rostrata*

Coastal waterways below reservoirs to gulf; spawns January to February in ocean, larva move to coastal waters, metamorphose, then females move into freshwater; most aquatic habitats with access to ocean, muddy bottoms, still waters, large streams, lakes; can travel overland in wet areas; males in brackish estuaries; diet varies widely, geographically, and seasonally

Federal Status:	State Status:	SGCN: Y
Endemic: N	Global Rank: G4	State Rank: S4

blue sucker *Cycleptus elongatus*

Usually inhabits channels and flowing pools with a moderate current, with bottoms of exposed bedrock sometimes in combination with hard clay, sand, and gravel; generally intolerant of highly turbid conditions.Larger portions of major rivers in Texas; adults winter in deep pools and move upstream in spring to spawn on riffles

Federal Status:	State Status: T	SGCN: Y
Endemic: N	Global Rank: G3G4	State Rank: S3

chub shiner *Notropis potteri*

Habitat description is not available at this time.

Federal Status:	State Status:	SGCN: Y
Endemic: N	Global Rank: G4	State Rank: S4

Guadalupe darter *Percina apristis*

Most common over gravel or gravel and sand raceways of large streams and rivers.

Federal Status:	State Status:	SGCN: Y
Endemic: Y	Global Rank: G4	State Rank: SNR

Red River pupfish *Cyprinodon rubrofluviatilis*

Habitat description is not available at this time.

Federal Status:	State Status:	SGCN: Y
Endemic: N	Global Rank: G5	State Rank: S4

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DALLAS COUNTY

FISH

sharpnose shiner *Notropis oxyrhynchus*

Endemic to Brazos River drainage; also, apparently introduced into adjacent Colorado River drainage; large turbid river, with bottom a combination of sand, gravel, and clay-mud

Federal Status: LE	State Status:	SGCN: Y
Endemic: Y	Global Rank: G3	State Rank: S3

silverband shiner *Notropis shumardi*

Habitat description is not available at this time.

Federal Status:	State Status:	SGCN: Y
Endemic: N	Global Rank: G5	State Rank: S4

western creek chubsucker *Erimyzon claviformis*

Habitat includes silt-, sand-, and gravel-bottomed pools of clear headwaters, creeks, and small rivers; often near vegetation; occasionally in lakes (Page and Burr 2011). Spawning occurs in river mouths or pools, riffles, lake outlets, or upstream creeks (Becker 1983, Goodyear et al. 1982). Prefers headwaters, but seldom occurs in springs.

Federal Status:	State Status: T	SGCN: Y
Endemic: N	Global Rank: G5	State Rank: S2S3

western sand darter *Ammocrypta clara*

To depths of 1.5 meters. Red and Sabine River basins; clear to slightly turbid water of medium to large rivers that have moderate to swift currents, primarily over extensive areas of sandy substrate.

Federal Status:	State Status:	SGCN: Y
Endemic: N	Global Rank: G3	State Rank: S3

INSECTS

American bumblebee *Bombus pensylvanicus*

Habitat description is not available at this time.

Federal Status:	State Status:	SGCN: Y
Endemic:	Global Rank: G3G4	State Rank: SNR

Comanche harvester ant *Pogonomyrmex comanche*

Habitat description is not available at this time.

Federal Status:	State Status:	SGCN: Y
Endemic: Y	Global Rank: G2G3	State Rank: S2

No accepted common name *Arethaea ambulator*

Habitat description is not available at this time.

Federal Status:	State Status:	SGCN: Y
Endemic:	Global Rank: GNR	State Rank: SNR

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DALLAS COUNTY

MAMMALS

American badger *Taxidea taxus*

Habitat description is not available at this time.

Federal Status: State Status: SGCN: Y
Endemic: N Global Rank: G5 State Rank: S5

big brown bat *Eptesicus fuscus*

Any wooded areas or woodlands except south Texas. Riparian areas in west Texas.

Federal Status: State Status: SGCN: Y
Endemic: N Global Rank: G5 State Rank: S5

cave myotis bat *Myotis velifer*

Colonial and cave-dwelling; also roosts in rock crevices, old buildings, carports, under bridges, and even in abandoned Cliff Swallow (Hirundo pyrrhonota) nests; roosts in clusters of up to thousands of individuals; hibernates in limestone caves of Edwards Plateau and gypsum cave of Panhandle during winter; opportunistic insectivore.

Federal Status: State Status: SGCN: Y
Endemic: N Global Rank: G4G5 State Rank: S4

eastern red bat *Lasiurus borealis*

Found in a variety of habitats in Texas. Usually associated with wooded areas. Found in towns especially during migration.

Federal Status: State Status: SGCN: Y
Endemic: N Global Rank: G3G4 State Rank: S4

eastern spotted skunk *Spilogale putorius*

Catholic; open fields prairies, croplands, fence rows, farmyards, forest edges & woodlands. Prefer wooded, brushy areas & tallgrass prairies. S.p. ssp. interrupta found in wooded areas and tallgrass prairies, preferring rocky canyons and outcrops when such sites are available.

Federal Status: State Status: SGCN: Y
Endemic: N Global Rank: G4 State Rank: S1S3

hoary bat *Lasiurus cinereus*

Known from montane and riparian woodland in Trans-Pecos, forests and woods in east and central Texas.

Federal Status: State Status: SGCN: Y
Endemic: N Global Rank: G3G4 State Rank: S4

long-tailed weasel *Mustela frenata*

Includes brushlands, fence rows, upland woods and bottomland hardwoods, forest edges & rocky desert scrub. Usually live close to water.

Federal Status: State Status: SGCN: Y
Endemic: N Global Rank: G5 State Rank: S5

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DALLAS COUNTY

MAMMALS

Mexican free-tailed bat *Tadarida brasiliensis*

Roosts in buildings in east Texas. Largest maternity roosts are in limestone caves on the Edwards Plateau. Found in all habitats, forest to desert.

Federal Status:	State Status:	SGCN: Y
Endemic: N	Global Rank: G5	State Rank: S5

mink *Neovison vison*

Intimately associated with water; coastal swamps & marshes, wooded riparian zones, edges of lakes. Prefer floodplains.

Federal Status:	State Status:	SGCN: Y
Endemic: N	Global Rank: G5	State Rank: S4

mountain lion *Puma concolor*

Rugged mountains & riparian zones.

Federal Status:	State Status:	SGCN: Y
Endemic: N	Global Rank: G5	State Rank: S2S3

plains spotted skunk *Spilogale putorius interrupta*

Catholic; open fields, prairies, croplands, fence rows, farmyards, forest edges, and woodlands; prefers wooded, brushy areas and tallgrass prairie

Federal Status:	State Status:	SGCN: N
Endemic: N	Global Rank: G4T4	State Rank: S1S3

southeastern myotis bat *Myotis austroriparius*

Caves are rare in Texas portion of range; buildings, hollow trees are probably important. Historically, lowland pine and hardwood forests with large hollow trees; associated with ecological communities near water. Roosts in cavity trees of bottomland hardwoods, concrete culverts, and abandoned man-made structures.

Federal Status:	State Status:	SGCN: Y
Endemic: N	Global Rank: G4	State Rank: S3

southern short-tailed shrew *Blarina carolinensis*

Habitat description is not available at this time.

Federal Status:	State Status:	SGCN: Y
Endemic: N	Global Rank: G5	State Rank: S4

swamp rabbit *Sylvilagus aquaticus*

Habitat description is not available at this time.

Federal Status:	State Status:	SGCN: Y
Endemic: N	Global Rank: G5	State Rank: S5

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DALLAS COUNTY

MAMMALS

thirteen-lined ground squirrel *Ictidomys tridecemlineatus*

Habitat description is not available at this time.

Federal Status:	State Status:	SGCN: Y
Endemic: N	Global Rank: G5	State Rank: S5

tricolored bat *Perimyotis subflavus*

Forest, woodland and riparian areas are important. Caves are very important to this species.

Federal Status:	State Status:	SGCN: Y
Endemic: N	Global Rank: G2G3	State Rank: S3S4

western hog-nosed skunk *Conepatus leuconotus*

Habitats include woodlands, grasslands & deserts, to 7200 feet, most common in rugged, rocky canyon country; little is known about the habitat of the ssp. telmalestes

Federal Status:	State Status:	SGCN: Y
Endemic: N	Global Rank: G4	State Rank: S4

woodland vole *Microtus pinetorum*

Include grassy marshes, swamp edges, old-field/pine woodland ecotones, tallgrass fields; generally sandy soils.

Federal Status:	State Status:	SGCN: Y
Endemic: N	Global Rank: G5	State Rank: S3

MOLLUSKS

Louisiana pigtoe *Pleurobema riddellii*

Streams and moderate-size rivers, usually flowing water on substrates of mud, sand, and gravel; not generally known from impoundments; Sabine, Neches, and Trinity (historic) River basins

Federal Status:	State Status: T	SGCN: Y
Endemic: N	Global Rank: G1G2	State Rank: S1

No accepted common name *Fusconaia chunii*

Habitat description is not available at this time.

Federal Status:	State Status:	SGCN: N
Endemic: Y	Global Rank: GNR	State Rank: SNR

sandbank pocketbook *Lampsilis satura*

Small to large rivers with moderate flows and swift current on gravel, gravel-sand, and sand bottoms; east Texas, Sulfur south through San Jacinto River basins; Neches River

Federal Status:	State Status: T	SGCN: Y
Endemic:	Global Rank: G2	State Rank: S1

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DALLAS COUNTY

MOLLUSKS

Texas heelsplitter *Potamilus amphichaenus*

Quiet waters in mud or sand and also in reservoirs. Sabine, Neches, and Trinity River basins

Federal Status:	State Status: T	SGCN: Y
Endemic: N	Global Rank: G1G2	State Rank: S1

REPTILES

alligator snapping turtle *Macrochelys temminckii*

Perennial water bodies; deep water of rivers, canals, lakes, and oxbows; also swamps, bayous, and ponds near deep running water; sometimes enters brackish coastal waters; usually in water with mud bottom and abundant aquatic vegetation; may migrate several miles along rivers; active March-October; breeds April-October

Federal Status:	State Status: T	SGCN: Y
Endemic: N	Global Rank: G3G4	State Rank: S2

American alligator *Alligator mississippiensis*

Coastal marshes; inland natural rivers, swamps and marshes; manmade impoundments.

Federal Status:	State Status:	SGCN: N
Endemic: N	Global Rank: G5	State Rank: S4

common garter snake *Thamnophis sirtalis*

Irrigation canals and riparian-corridor farmlands in west; marshy, flooded pastureland, grassy or brushy borders of permanent bodies of water; coastal salt marshes.

Federal Status:	State Status:	SGCN: N
Endemic:	Global Rank: G5	State Rank: S2

eastern box turtle *Terrapene carolina*

Eastern box turtles inhabit forests, fields, forest-brush, and forest-field ecotones. In some areas they move seasonally from fields in spring to forest in summer. They commonly enters pools of shallow water in summer. For shelter, they burrow into loose soil, debris, mud, old stump holes, or under leaf litter. They can successfully hibernate in sites that may experience subfreezing temperatures. In Maryland bottomland forest, some hibernated in pits or depressions in forest floor (usually about 30 cm deep) usually within summer range; individuals tended to hibernate in same area in different years (Stickel 1989). Also attracted to farms, old fields and cut-over woodlands, as well as creek bottoms and dense woodlands. Egg laying sites often are sandy or loamy soils in open areas; females may move from bottomlands to warmer and drier sites to nest. In Maryland, females used the same nesting area in different years (Stickel 1989).

Federal Status:	State Status:	SGCN: Y
Endemic: N	Global Rank: G5	State Rank: S3

massasauga *Sistrurus tergeminus*

Quite common in gently rolling prairie occasionally broken by creek valley or rocky hillside.

Federal Status:	State Status:	SGCN: Y
Endemic: N	Global Rank: G3G4	State Rank: S3S4

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DALLAS COUNTY

REPTILES

slender glass lizard *Ophisaurus attenuatus*

Prefers relatively dry microhabitats, usually associated with grassy areas. Habitats include open grassland, prairie, woodland edge, open woodland, oak savannas, longleaf pine flatwoods, scrubby areas, fallow fields, and areas near streams and ponds, often in habitats with sandy soil. This species often appears on roads in spring. During inactivity, it occurs in underground burrows. In Kansas, slender glass lizards were scarce in heavily grazed pastures, increased as grass increased with removal of grazing, and declined as brush and trees replaced grass (Fitch 1989). Eggs are laid underground, under cover, or under grass clumps (Ashton and Ashton 1985); in cavities beneath flat rocks or in abandoned tunnels of small mammals (Scalopus, Microtus) (Fitch 1989).

Federal Status:	State Status:	SGCN: Y
Endemic: N	Global Rank: G5	State Rank: S3

Texas garter snake *Thamnophis sirtalis annectens*

Irrigation canals and riparian-corridor farmlands in west; marshy, flooded pastureland, grassy or brushy borders of permanent bodies of water; coastal salt marshes. Wet or moist microhabitats are conducive to the species occurrence, but is not necessarily restricted to them; hibernates underground or in or under surface cover; breeds March-August.

Federal Status:	State Status:	SGCN: Y
Endemic: Y	Global Rank: G5T4	State Rank: S1

Texas horned lizard *Phrynosoma cornutum*

Occurs to 6000 feet, but largely limited below the pinyon-juniper zone on mountains in the Big Bend area. Open, arid and semi-arid regions with sparse vegetation, including grass, cactus, scattered brush or scrubby trees; soil may vary in texture from sandy to rocky; burrows into soil, enters rodent burrows, or hides under rock when inactive; breeds March-September.

Federal Status:	State Status: T	SGCN: Y
Endemic: N	Global Rank: G4G5	State Rank: S3

timber (canebrake) rattlesnake *Crotalus horridus*

Swamps, floodplains, upland pine and deciduous woodland, riparian zones, abandoned farmland. Limestone bluffs, sandy soil or black clay. Prefers dense ground cover, i.e. grapevines, palmetto.

Federal Status:	State Status: T	SGCN: Y
Endemic: N	Global Rank: G4	State Rank: S4

western box turtle *Terrapene ornata*

Ornate or western box trutles inhabit prairie grassland, pasture, fields, sandhills, and open woodland. They are essentially terrestrial but sometimes enter slow, shallow streams and creek pools. For shelter, they burrow into soil (e.g., under plants such as yucca) (Converse et al. 2002) or enter burrows made by other species; winter burrow depth was 0.5-1.8 meters in Wisconsin (Doroff and Keith 1990), 7-120 cm (average depth 54 cm) in Nebraska (Converse et al. 2002). Eggs are laid in nests dug in soft well-drained soil in open area (Legler 1960, Converse et al. 2002). Very partial to sandy soil.

Federal Status:	State Status:	SGCN: Y
Endemic: N	Global Rank: G5	State Rank: S3

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DALLAS COUNTY

REPTILES

western chicken turtle *Deirochelys reticularia miaria*

Habitat description is not available at this time.

Federal Status:	State Status:	SGCN: N
Endemic: N	Global Rank: G5T5	State Rank: S2S3

PLANTS

Engelmann's bladderpod *Physaria engelmannii*

Grasslands and calcareous rock outcrops in a band along the eastern edge of the Edwards Plateau, ranging as far north as the Red River (Carr 2015).

Federal Status:	State Status:	SGCN: Y
Endemic: N	Global Rank: G4	State Rank: S3

glandular gay-feather *Liatris glandulosa*

Occurs in herbaceous vegetation on limestone outcrops (Carr 2015)

Federal Status:	State Status:	SGCN: Y
Endemic: Y	Global Rank: G3	State Rank: S3

Glass Mountains coral-root *Hexalectris nitida*

Apparently rare in mixed woodlands in canyons in the mountains of the Brewster County, but encountered with regularity, albeit in small numbers, under Juniperus ashei in woodlands over limestone on the Edwards Plateau, Callahan Divide and Lampasas Cutplain; Perennial; Flowering June-Sept; Fruiting July-Sept

Federal Status:	State Status:	SGCN: Y
Endemic: N	Global Rank: G3	State Rank: S3

Glen Rose yucca *Yucca necopina*

Grasslands on sandy soils and limestone outcrops; flowering April-June

Federal Status:	State Status:	SGCN: Y
Endemic: Y	Global Rank: G1G2	State Rank: S1S2

Hall's prairie clover *Dalea hallii*

In grasslands on eroded limestone or chalk and in oak scrub on rocky hillsides; Perennial; Flowering May-Sept; Fruiting June-Sept

Federal Status:	State Status:	SGCN: Y
Endemic: Y	Global Rank: G3	State Rank: S3

Oklahoma phlox *Phlox oklahomensis*

Known from a 1958 collection from an oak woodland four miles east of Garland, Texas (Carr 2015).

Federal Status:	State Status:	SGCN: Y
Endemic: N	Global Rank: G3	State Rank: SH

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DALLAS COUNTY

PLANTS

Osage Plains false foxglove *Agalinis densiflora*

Most records are from grasslands on shallow, gravelly, well drained, calcareous soils; Prairies, dry limestone soils; Annual; Flowering Aug-Oct

Federal Status:	State Status:	SGCN: Y
Endemic: N	Global Rank: G3	State Rank: S2

plateau milkvine *Matelea edwardsensis*

Occurs in various types of juniper-oak and oak-juniper woodlands; Perennial; Flowering March-Oct; Fruiting May-June

Federal Status:	State Status:	SGCN: Y
Endemic: Y	Global Rank: G3	State Rank: S3

Texas milk vetch *Astragalus reflexus*

Grasslands, prairies, and roadsides on calcareous and clay substrates; Annual; Flowering Feb-June; Fruiting April-June

Federal Status:	State Status:	SGCN: Y
Endemic: Y	Global Rank: G3	State Rank: S3

tree dodder *Cuscuta exaltata*

Parasitic on various Quercus, Juglans, Rhus, Vitis, Ulmus, and Diospyros species as well as Acacia berlandieri and other woody plants; Annual; Flowering May-Oct; Fruiting July-Oct

Federal Status:	State Status:	SGCN: Y
Endemic: N	Global Rank: G3	State Rank: S3

Warnock's coral-root *Hexalectris warnockii*

In leaf litter and humus in oak-juniper woodlands on shaded slopes and intermittent, rocky creekbeds in canyons; in the Trans Pecos in oak-pinyon-juniper woodlands in higher mesic canyons (to 2000 m [6550 ft]), primarily on igneous substrates; in Terrell County under Quercus fusiformis mottes on terrraces of spring-fed perennial streams, draining an otherwise rather xeric limestone landscape; on the Callahan Divide (Taylor County), the White Rock Escarpment (Dallas County), and the Edwards Plateau in oak-juniper woodlands on limestone slopes; in Gillespie County on igneous substrates of the Llano Uplift; flowering June-September; individual plants do not usually bloom in successive years

Federal Status:	State Status:	SGCN: Y
Endemic: N	Global Rank: G2G3	State Rank: S2

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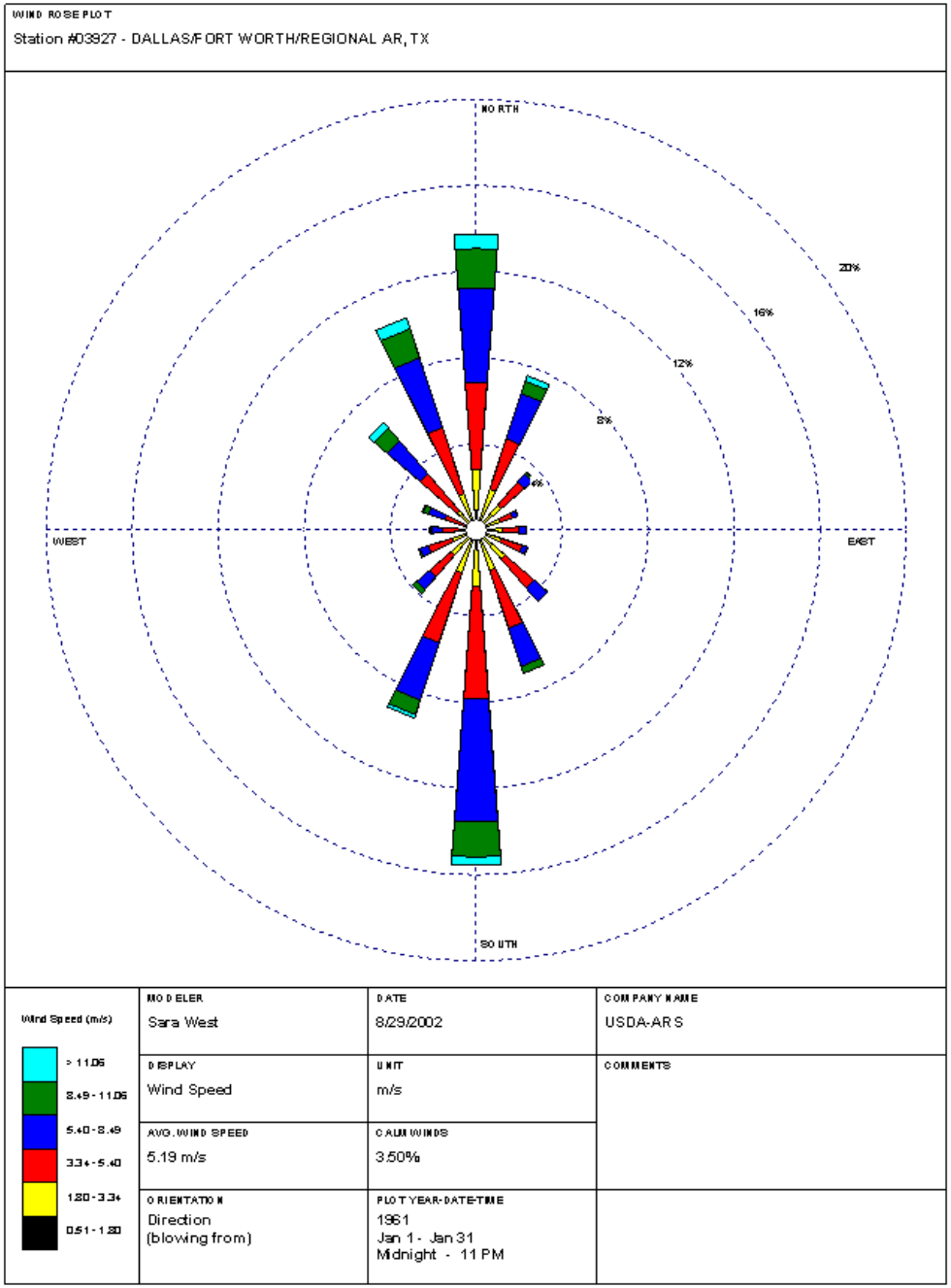
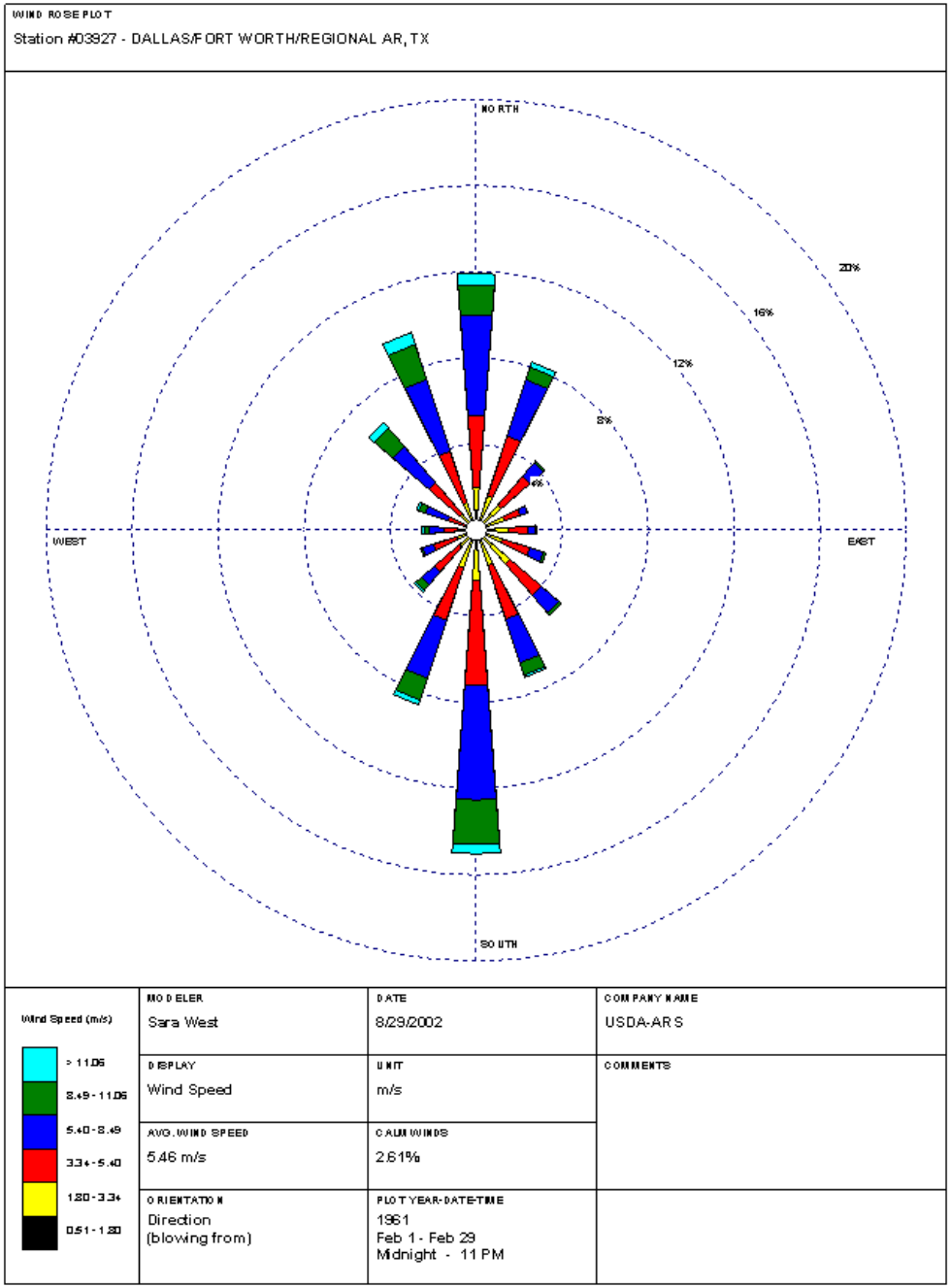
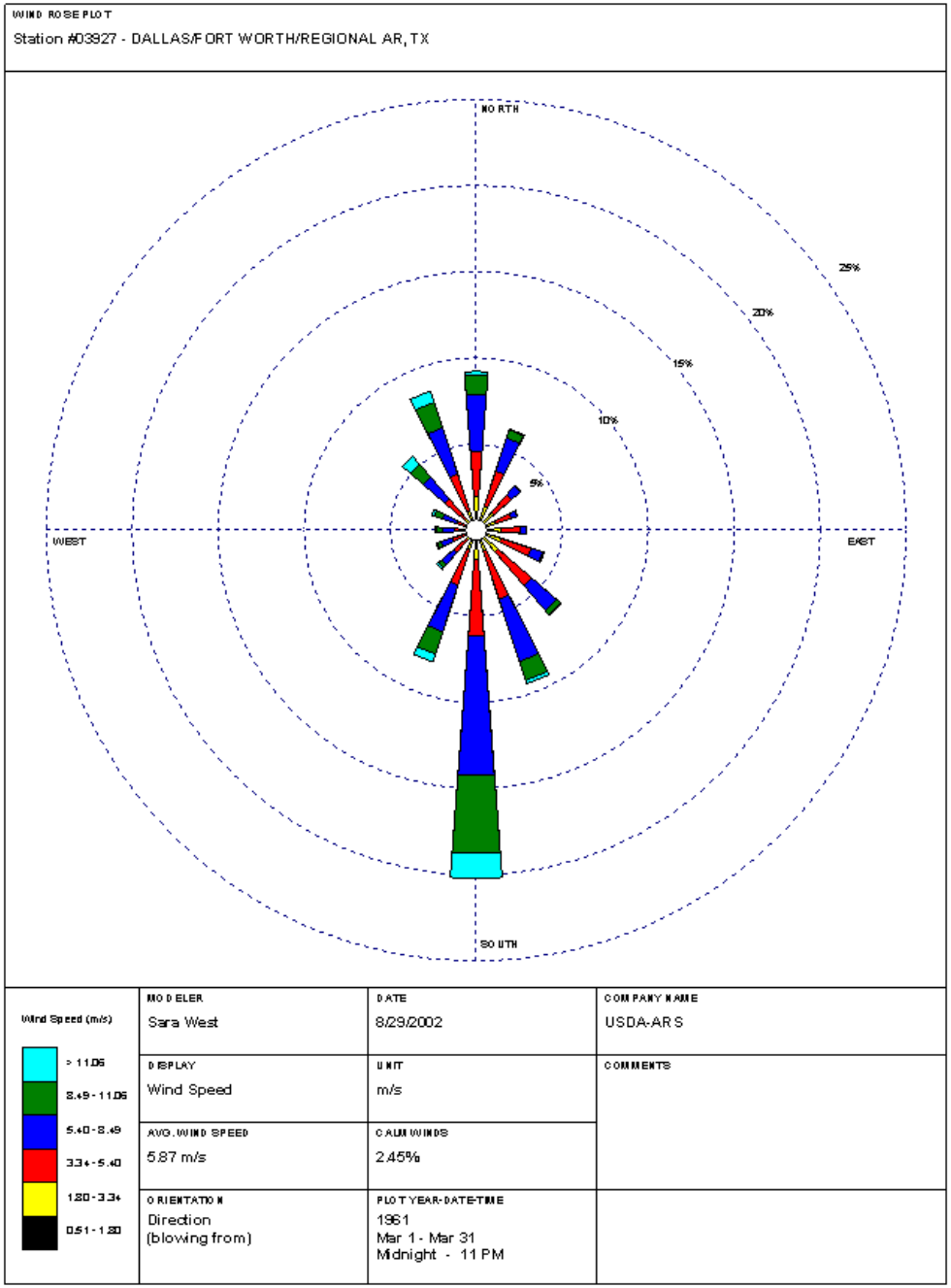
Reference 41


WIND ROSE PLOT
Station #03927 - DALLAS/FORT WORTH/REGIONAL AR, TX
NORTH
20%
16%
12%
8%
4%
WEST
EAST
SOUTH
Wind Speed (m/s)
> 11.06
8.49 - 11.06
5.40 - 8.49
3.34 - 5.40
1.80 - 3.34
0.51 - 1.80
MODELER
Sara West
DATE
8/29/2002
COMPANY NAME
USDA-ARS
DISPLAY
Wind Speed
UNIT
m/s
COMMENTS
AVG. WIND SPEED
5.19 m/s
CALM WINDS
3.50%
ORIENTATION
Direction
(blowing from)
PLOT YEAR-DATE-TIME
1961
Jan 1 - Jan 31
Midnight - 11 PM

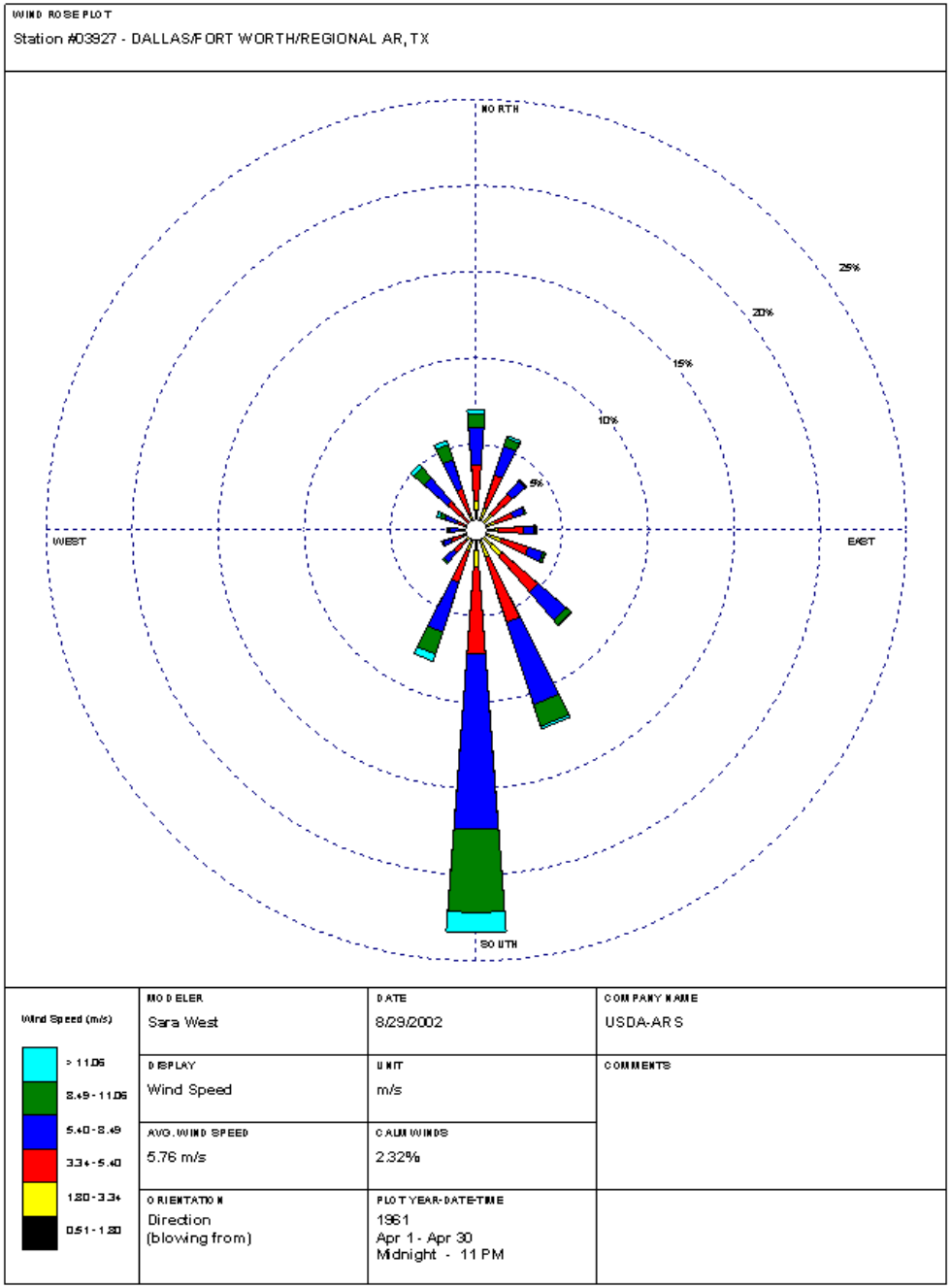
41 001


WIND ROSE PLOT
Station #03927 - DALLAS/FORT WORTH/REGIONAL AR, TX
NORTH
EAST
SOUTH
WEST
20%
16%
12%
8%
4%
Wind Speed (m/s)
> 11.06
8.49 - 11.06
5.40 - 8.49
3.34 - 5.40
1.80 - 3.34
0.51 - 1.80
MODELER
Sara West
DATE
8/29/2002
COMPANY NAME
USDA-ARS
DISPLAY
Wind Speed
UNIT
m/s
COMMENTS
AVG. WIND SPEED
5.46 m/s
CALM WINDS
2.61%
ORIENTATION
Direction
(blowing from)
PLOT YEAR-DATE-TIME
1961
Feb 1 - Feb 29
Midnight - 11 PM

41 002


WIND ROSE PLOT
Station #03927 - DALLAS/FORT WORTH/REGIONAL AR, TX
NORTH
25%
20%
15%
10%
5%
WEST
EAST
SOUTH
Wind Speed (m/s)
> 11.06
8.49 - 11.06
5.40 - 8.49
3.34 - 5.40
1.80 - 3.34
0.51 - 1.80
MODELER
Sara West
DATE
8/29/2002
COMPANY NAME
USDA-ARS
DISPLAY
Wind Speed
UNIT
m/s
COMMENTS
AVG. WIND SPEED
5.87 m/s
CALM WINDS
2.45%
ORIENTATION
Direction
(blowing from)
PLOT YEAR-DATE-TIME
1961
Mar 1 - Mar 31
Midnight - 11 PM

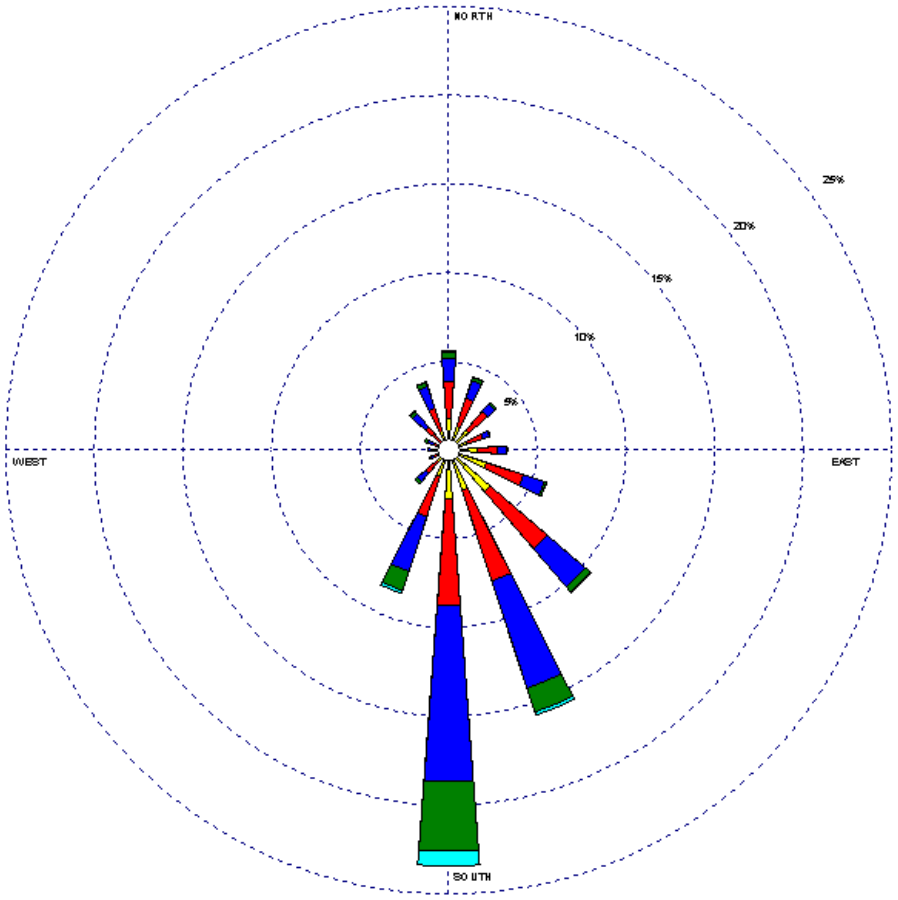
41 003


WIND ROSE PLOT
Station #03927 - DALLAS/FORT WORTH/REGIONAL AR, TX
NORTH
WEST
EAST
SOUTH
5%
10%
15%
20%
25%
Wind Speed (m/s)
> 11.06
8.49 - 11.06
5.40 - 8.49
3.34 - 5.40
1.80 - 3.34
0.51 - 1.80
MODELER
Sara West
DATE
8/29/2002
COMPANY NAME
USDA-ARS
DISPLAY
Wind Speed
UNIT
m/s
COMMENTS
AVG. WIND SPEED
5.76 m/s
CALM WINDS
2.32%
ORIENTATION
Direction
(blowing from)
PLOT YEAR-DATE-TIME
1961
Apr 1 - Apr 30
Midnight - 11 PM

41 004

WIND ROSE PLOT

Station #03927 - DALLAS/FORT WORTH/REGIONAL AR, TX



Wind Speed (m/s)

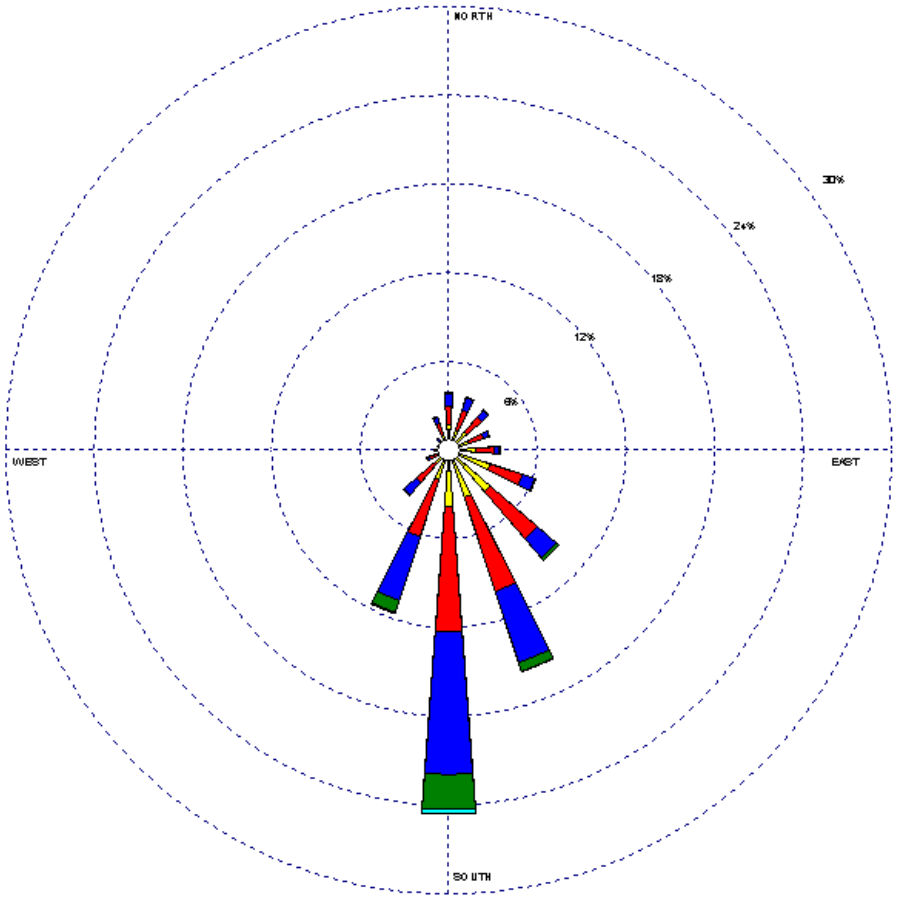
- > 11.06
- 8.49 - 11.06
- 5.40 - 8.49
- 3.34 - 5.40
- 1.80 - 3.34
- 0.51 - 1.80

MODELER	DATE	COMPANY NAME
Sara West	8/29/2002	USDA-ARS
DISPLAY: Wind Speed	UNIT: m/s	COMMENTS
AVG. WIND SPEED: 5.28 m/s	CALM WINDS: 3.23%	
ORIENTATION: Direction (blowing from)	PLOT YEAR-DATE-TIME: 1961 May 1 - May 31 Midnight - 11 PM	

41 005

WIND ROSE PLOT

Station #03927 - DALLAS/FORT WORTH/REGIONAL AR, TX



Wind Speed (m/s)

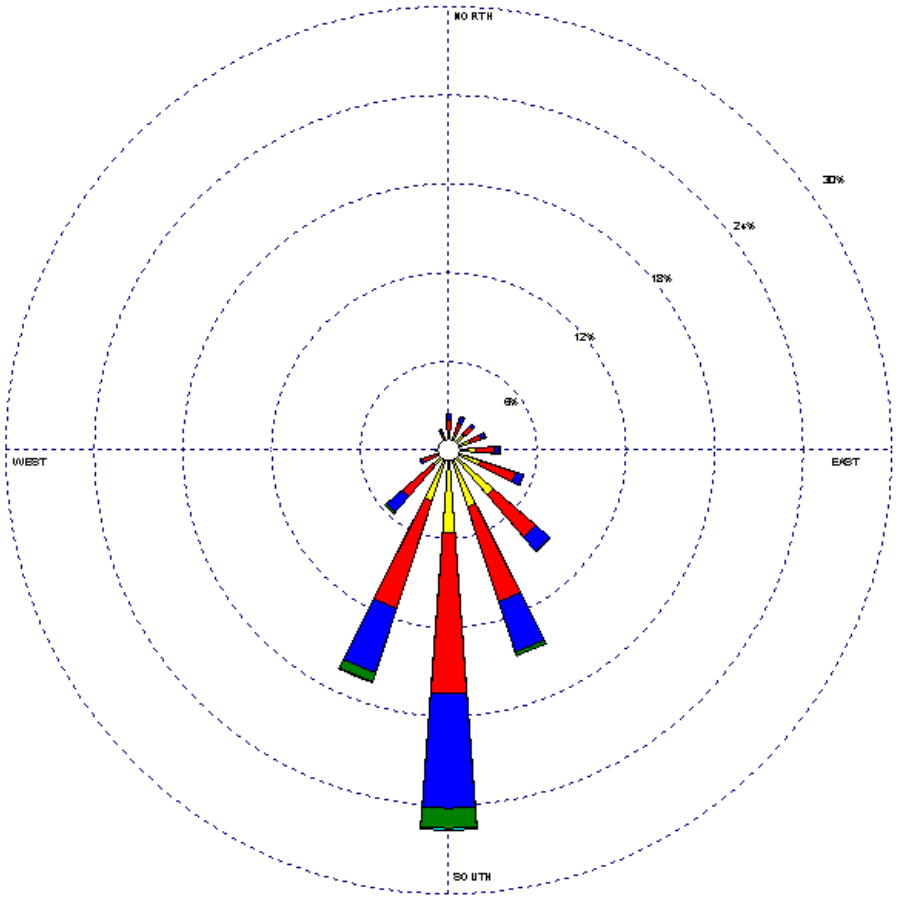
- > 11.06
- 8.49 - 11.06
- 5.40 - 8.49
- 3.34 - 5.40
- 1.80 - 3.34
- 0.51 - 1.80

MODELER	DATE	COMPANY NAME
Sara West	8/29/2002	USDA-ARS
DISPLAY: Wind Speed	UNIT: m/s	COMMENTS
AVG. WIND SPEED: 4.75 m/s	CALM WINDS: 3.20%	
ORIENTATION: Direction (blowing from)	PLOT YEAR-DATE-TIME: 1961 Jun 1 - Jun 30 Midnight - 11 PM	

41 006

WIND ROSE PLOT

Station #03927 - DALLAS/FORT WORTH/REGIONAL AR, TX

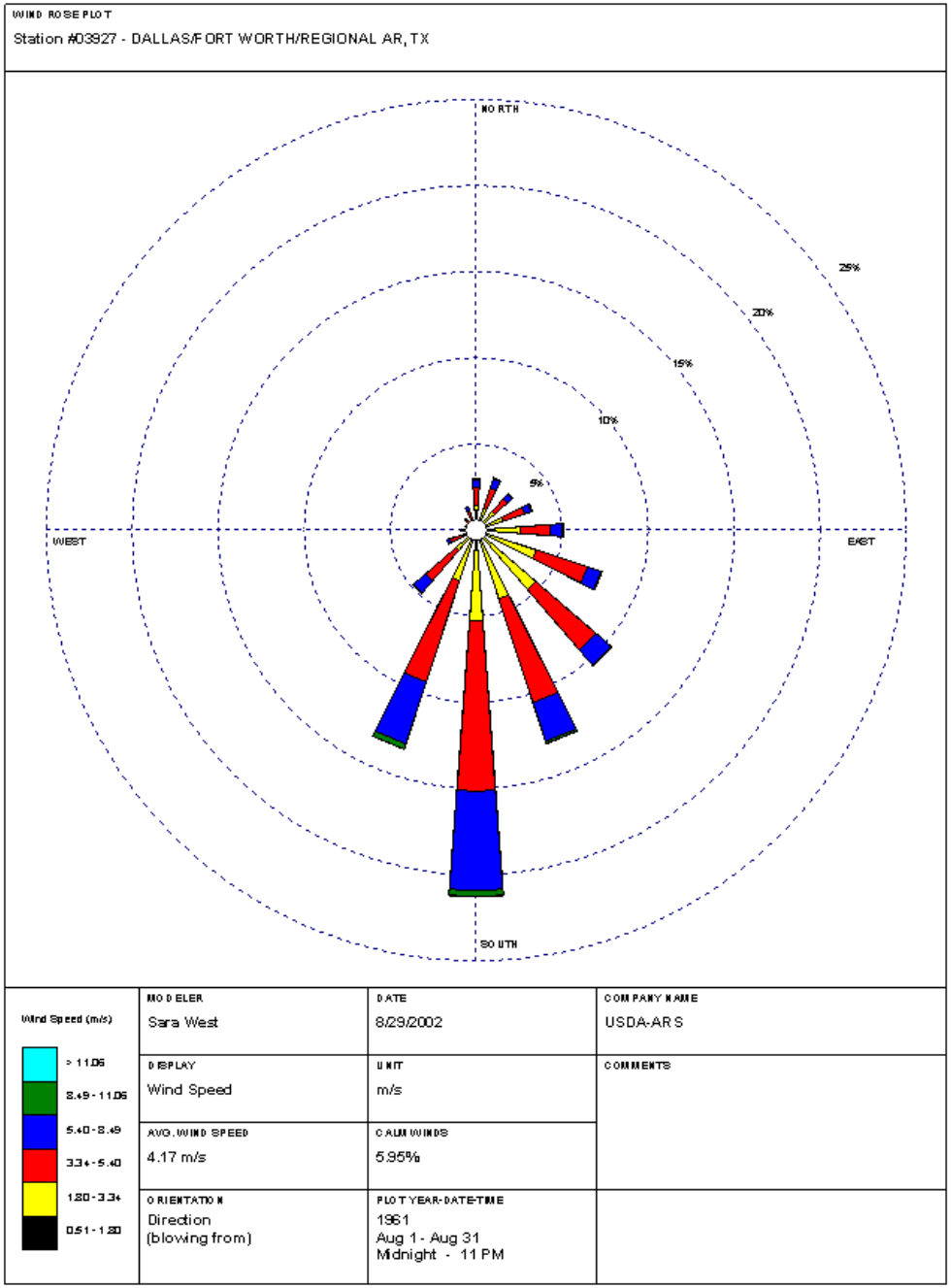


Wind Speed (m/s)

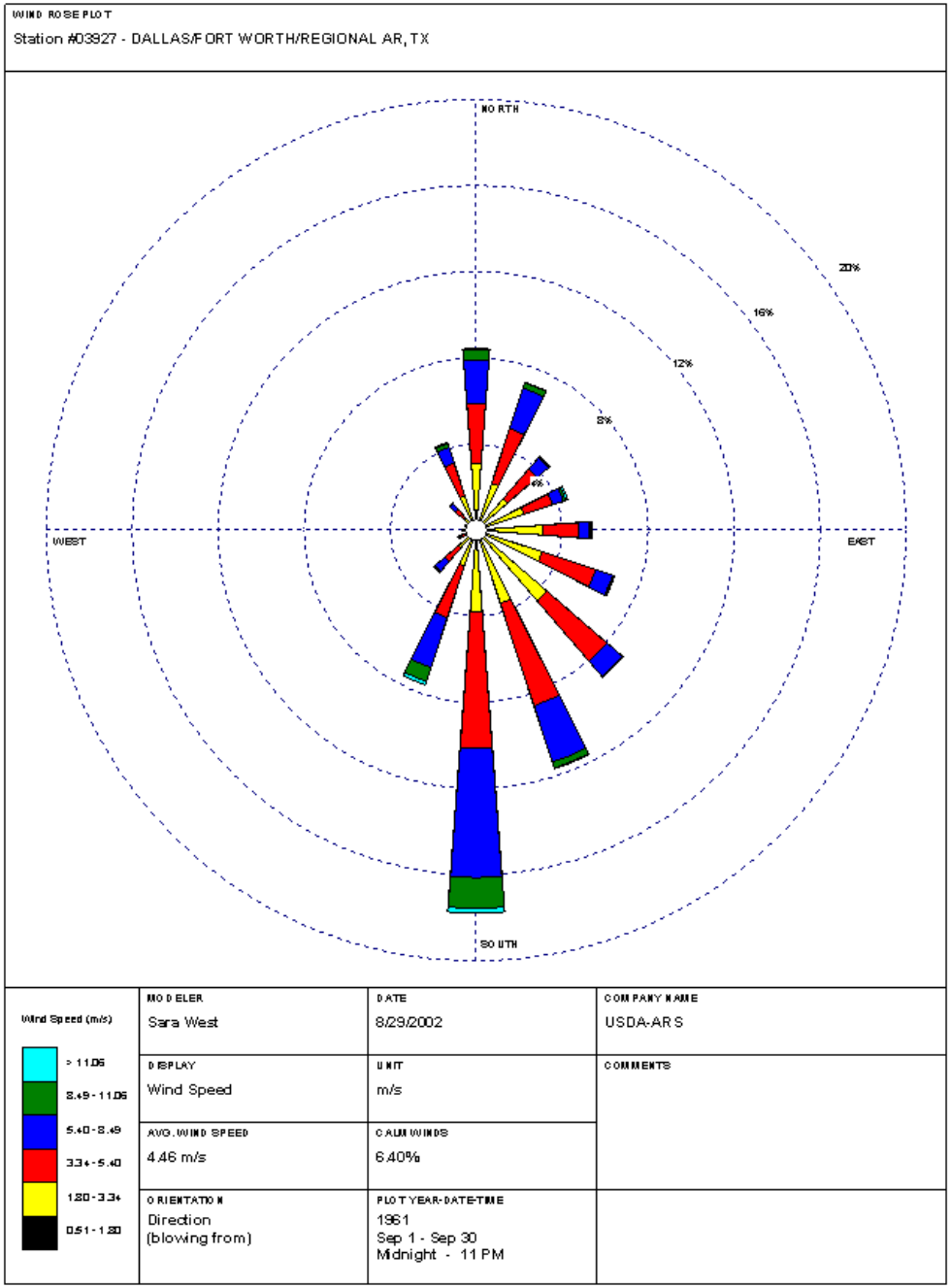
- > 11.06
- 8.49 - 11.06
- 5.40 - 8.49
- 3.34 - 5.40
- 1.80 - 3.34
- 0.51 - 1.80

MODELER	DATE	COMPANY NAME
Sara West	8/29/2002	USDA-ARS
DISPLAY: Wind Speed	UNIT: m/s	COMMENTS
AVG. WIND SPEED: 4.43 m/s	CALM WINDS: 3.92%	
ORIENTATION: Direction (blowing from)	PLOT YEAR-DATE-TIME: 1961 Jul 1 - Jul 31 Midnight - 11 PM	

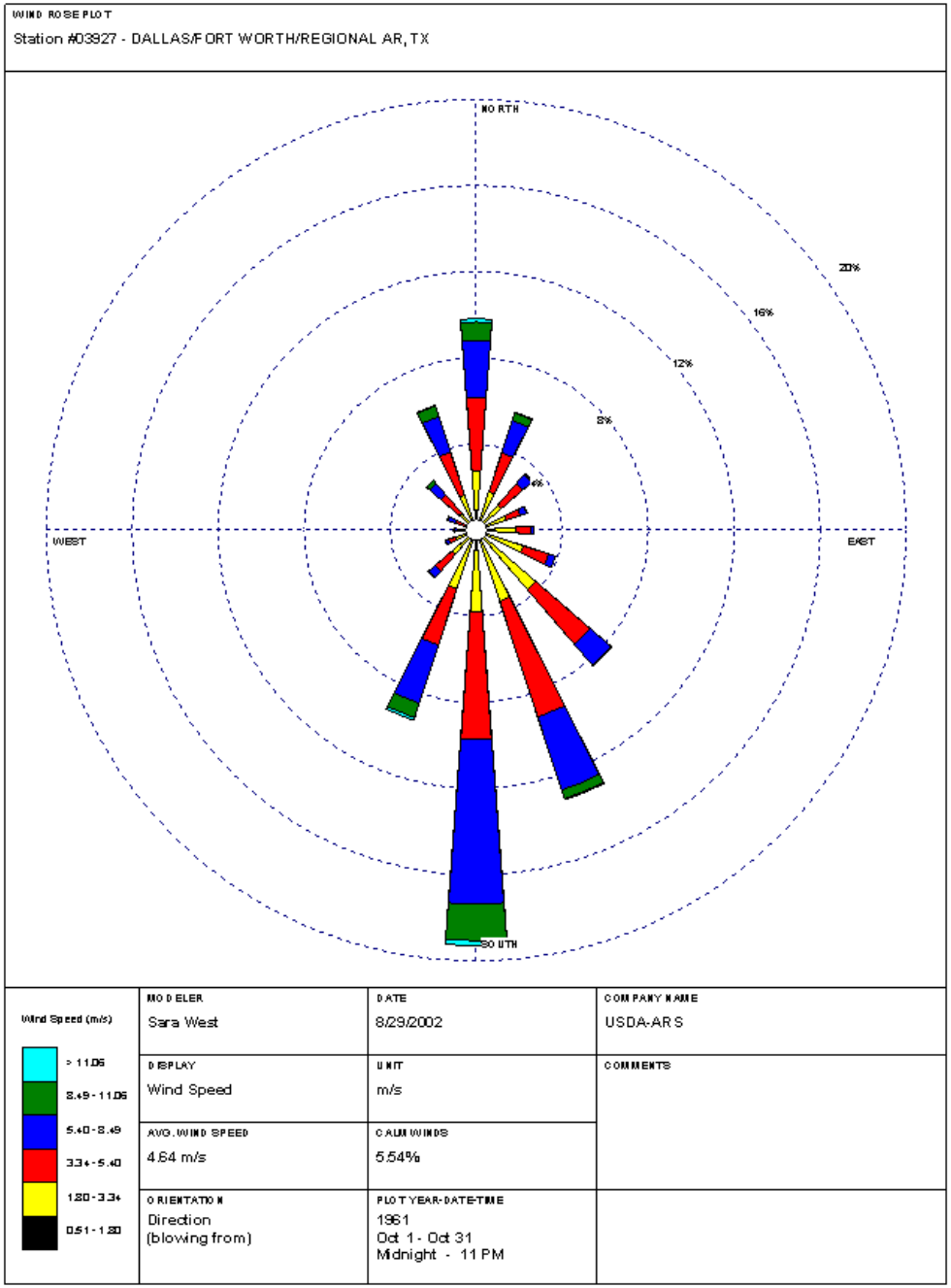
41 007


WIND ROSE PLOT
Station #03927 - DALLAS/FORT WORTH/REGIONAL AR, TX
NORTH
25%
20%
15%
10%
5%
WEST
EAST
SOUTH
Wind Speed (m/s)
> 11.06
8.49 - 11.06
5.40 - 8.49
3.34 - 5.40
1.80 - 3.34
0.51 - 1.80
MODELER
Sara West
DATE
8/29/2002
COMPANY NAME
USDA-ARS
DISPLAY
Wind Speed
UNIT
m/s
COMMENTS
AVG. WIND SPEED
4.17 m/s
CALM WINDS
5.95%
ORIENTATION
Direction
(blowing from)
PLOT YEAR-DATE-TIME
1961
Aug 1 - Aug 31
Midnight - 11 PM

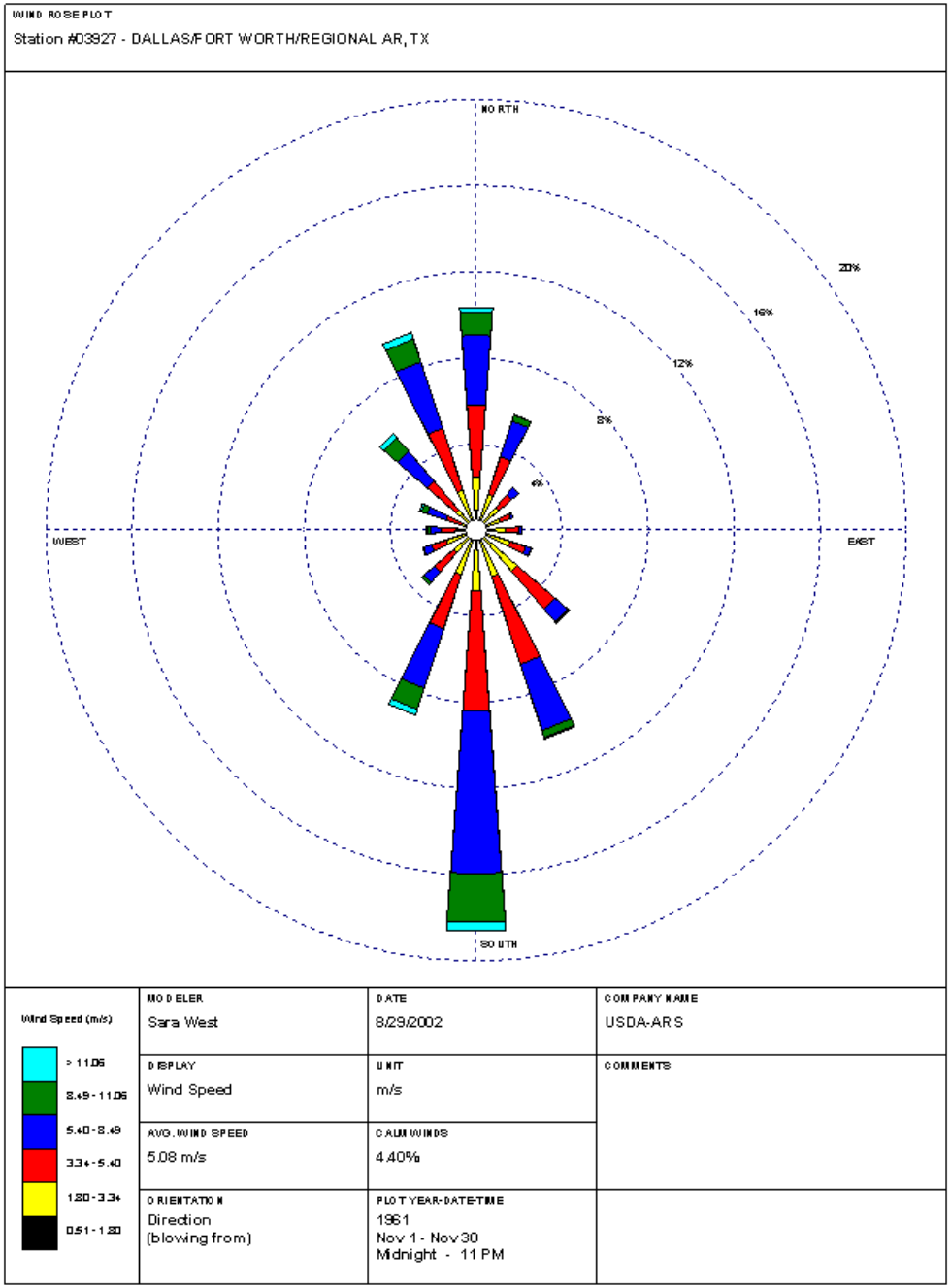
41 008


WIND ROSE PLOT
Station #03927 - DALLAS/FORT WORTH/REGIONAL AR, TX
NORTH
WEST
EAST
SOUTH
20%
16%
12%
8%
4%
Wind Speed (m/s)
> 11.06
8.49 - 11.06
5.40 - 8.49
3.34 - 5.40
1.80 - 3.34
0.51 - 1.80
MODELER
Sara West
DATE
8/29/2002
COMPANY NAME
USDA-ARS
DISPLAY
Wind Speed
UNIT
m/s
COMMENTS
AVG. WIND SPEED
4.46 m/s
CALM WINDS
6.40%
ORIENTATION
Direction
(blowing from)
PLOT YEAR-DATE-TIME
1961
Sep 1 - Sep 30
Midnight - 11 PM

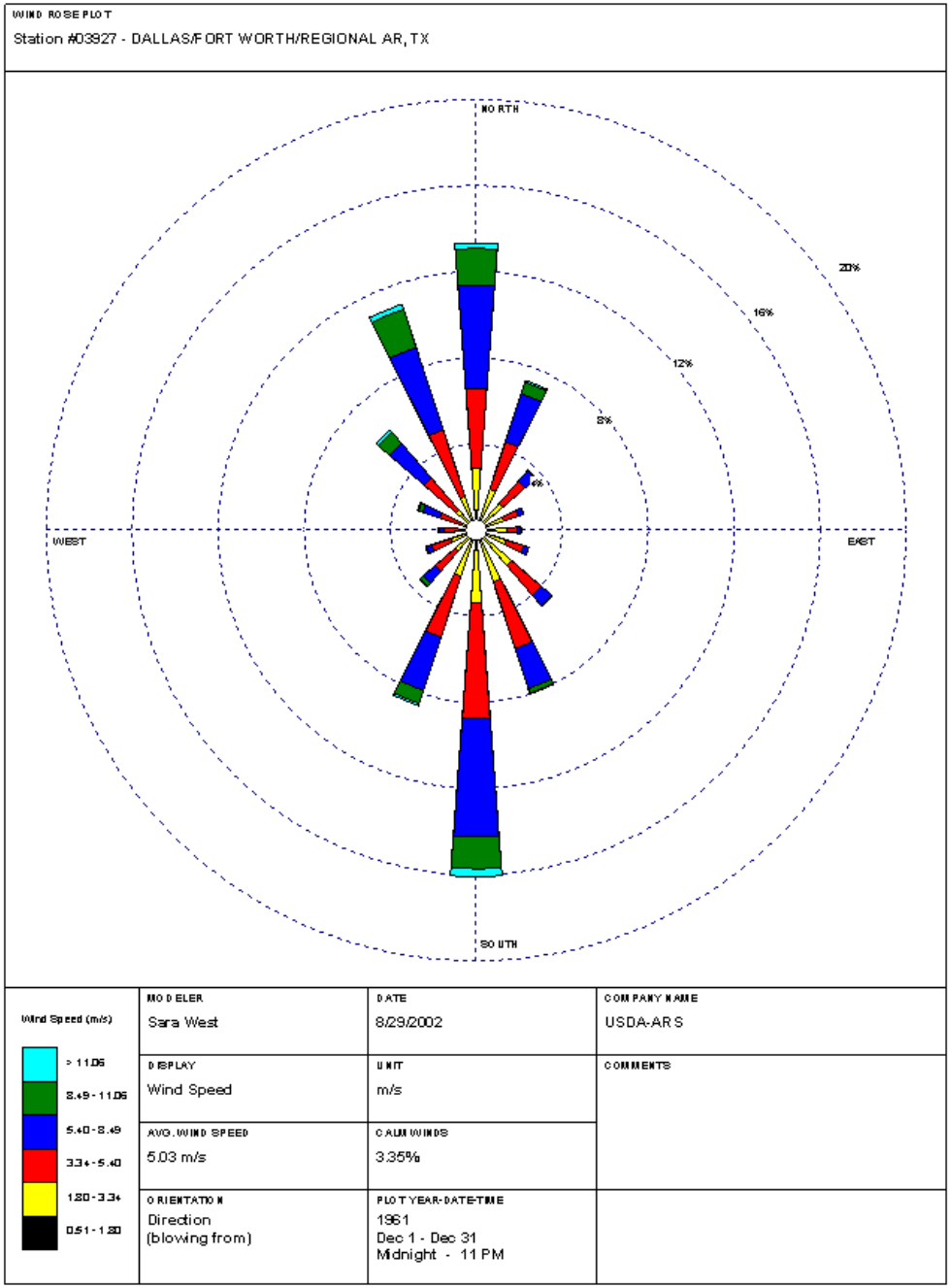
41 009


WIND ROSE PLOT
Station #03927 - DALLAS/FORT WORTH/REGIONAL AR, TX
NORTH
WEST
EAST
SOUTH
20%
16%
12%
8%
4%
Wind Speed (m/s)
> 11.06
8.49 - 11.06
5.40 - 8.49
3.34 - 5.40
1.80 - 3.34
0.51 - 1.80
MODELER
Sara West
DATE
8/29/2002
COMPANY NAME
USDA-ARS
DISPLAY
Wind Speed
UNIT
m/s
COMMENTS
AVG. WIND SPEED
4.64 m/s
CALM WINDS
5.54%
ORIENTATION
Direction
(blowing from)
PLOT YEAR-DATE-TIME
1961
Oct 1 - Oct 31
Midnight - 11 PM

41 010


WIND ROSE PLOT
Station #03927 - DALLAS/FORT WORTH/REGIONAL AR, TX
NORTH
WEST
EAST
SOUTH
20%
16%
12%
8%
4%
Wind Speed (m/s)
> 11.06
8.49 - 11.06
5.40 - 8.49
3.34 - 5.40
1.80 - 3.34
0.51 - 1.80
MODELER
Sara West
DATE
8/29/2002
COMPANY NAME
USDA-ARS
DISPLAY
Wind Speed
UNIT
m/s
COMMENTS
AVG. WIND SPEED
5.08 m/s
CALM WINDS
4.40%
ORIENTATION
Direction
(blowing from)
PLOT YEAR-DATE-TIME
1961
Nov 1 - Nov 30
Midnight - 11 PM

41 011


WIND ROSE PLOT
Station #03927 - DALLAS/FORT WORTH/REGIONAL AR, TX
NORTH
EAST
SOUTH
WEST
20%
16%
12%
8%
4%
Wind Speed (m/s)
> 11.06
8.49 - 11.06
5.40 - 8.49
3.34 - 5.40
1.80 - 3.34
0.51 - 1.80
MODELER
Sara West
DATE
8/29/2002
COMPANY NAME
USDA-ARS
DISPLAY
Wind Speed
UNIT
m/s
COMMENTS
AVG. WIND SPEED
5.03 m/s
CALM WINDS
3.35%
ORIENTATION
Direction
(blowing from)
PLOT YEAR-DATE-TIME
1961
Dec 1 - Dec 31
Midnight - 11 PM

41 012