Remedial Investigation

Lindsay, Nebraska

prepared for

Lindsay Manufacturing

Site Lindsay Manufacturing
ID # NED068645696
Break 3.5
Other Vol 1 of 3
6.20.90

prepared by

DAMES & MOORE

Seattle, Washington

June 20, 1990

VOLUME I
Report

40104500
SUPERFUND RECORDS

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Site LINDSAY
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Break 3 5
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June 20 1990

VIA EXPRESS COURIER

Nebraska Department of Environmental Control
301 Centennial Mall South
Lincoln Nebraska 68509-8922

Attention Richard Schlenker

RE Stipulation & Agreement
Case No 692
Lindsay Manufacturing

Dear Mr Schlenker

On behalf of Lindsay Manufacturing Co enclosed please find the Remedial Investigation (RI) Report for the Lindsay Manufacturing Co site in Lindsay Nebraska submitted in accordance with Paragraph V 4 of the above-referenced Stipulation and Agreement

We have learned since submittal of the Draft RI Report that the Village of Lindsay is installing an alternate public supply well by the water tower on the west end of the Village it is intended to be used only as a backup to the existing operating public supply well constructed in 1983 with Lindsay Manufacturing s assistance In our review of the test well logs test well performance and geologic conditions indicate that this site will provide a low yield Based on the well s distance from the site the low yield and influence area this well should not impact or be impacted by the site Assuming the accuracy of the preliminary data we have received from the State and the Village this well would have no impact on the results of our baseline risk assessment We have increased the frequency of monitoring of the Old Public Supply Well which is situated directly between the site and the new alternate well as additional assurance until the well is pump tested for the State and the preliminary testing is confirmed

DAMES & MOORE A PROFESSIONAL LIMITED PARTNERSHIP

Lindsay welcomes the opportunity to discuss any comments you may have concerning this RI Report

Yours truly

DAMES & MOORE

Roy W Elliott
Project Manager

RWE met

Enclosures

cc Cecilia Tapia
Annette Kovar Esq
Cliff Loseke
Douglas A Fisher Esq
Constance A Sadler Esq

004 16657 005/RI COV LET

REMEDIAL

INVESTIGATION

Lindsay Nebraska

Prepared for
LINDSAY MANUFACTURING
June 20 1990

Prepared by
DAMES & MOORE

Roy W Elliott
Professional Geologist 6684

EXECUTIVE SUMMARY

This report presents the results of a Remedial Investigation (RI) conducted by Lindsay Manufacturing Co pursuant to the Stipulation and Agreement Case No 692 Nebraska Department of Environmental Control dated January 5 1989 The RI has been performed in accordance with a Work Plan approved November 17 1989 The study area of this investigation includes the property owned by Lindsay Manufacturing and the adjacent lands

From the early 1970s to 1982 spent acid produced by irrigation pipe cleaning operations at the Lindsay Manufacturing facility was piped to an earthen disposal pit at the site In 1982 Lindsay Manufacturing Co replaced this pit with a new wastewater treatment facility designed to neutralize the spent acid

Four wells were constructed in December 1982 to be used as ground-water monitoring wells for the new treatment facility When sampled in January 1983 three of the wells were found to contain water with low pH and two of the wells had elevated water temperatures Lindsay reported those findings to the Nebraska Department of Environmental Control

Lindsay Manufacturing has subsequently performed remedial investigations of the underlying aquifer investigated site soils and performed extensive aquifer remediation The remedial system includes two high capacity interceptor wells and a wastewater treatment facility which are operated under an NPDES permit As of the date of this report over 800 million gallons of ground water have been pumped treated and discharged

This report summarizes the data collection and analysis from 1980 to January 1990 The current evaluation of the nature extent and transport of organic and inorganic compounds is based primarily on data collected between 1988 and 1990 and includes evaluation of the remedial effort to date The site risk assessment is based on current conditions as determined by data collected from February 1989 to January 1990

All tasks described in the RI Work Plan have been completed and the purposes of the RI have been met The definition of chemical occurrence has been refined by the monitoring and analysis program The magnitude vertical and horizontal extent of chemical occurrence in site soils and ground water have been evaluated during an annual cycle of aquifer recharge and discharge The rates directions and influences on ground-water have been monitored evaluated and modeled The potential and actual receptors of ground-water-transported compounds have been identified and a risk assessment performed

The organic and inorganic chemicals remaining in the site aquifer after approximately six years of remediation are contained within a ground-water monitoring network The primary occurrence is deep stratified and generally in the lower ten feet of the aquifer and is characterized by low pH and the presence of dissolved zinc iron sulfates and certain organic compounds

A zone of dispersed organic and inorganic compounds occurs between the Lindsay interceptor well (AOIW) and registered irrigation well #54278 During the irrigation season the efficiency of AOIW recovery of these compounds is reduced however during the non-irrigation period from September to May the AOIW s efficiency is recovered and its zone of capture includes the residuum and beyond to the irrigation well

Certain metals and organics also occur in site soils above the aquifer Both occurrences are on-site and within the capture zone of the Lindsay Manufacturing interceptor wells The occurrence is in low permeability sediments and a perched water table Both areas are ringed by on-site monitoring wells

A baseline risk assessment was performed using highly conservative worst-case assumptions to evaluate potential risk associated with the occurrences of chemical compounds at the site under a hypothetical scenario in which no further remediation would occur The Reasonable Maximum Exposure (RME) scenario Hazard Index (HI) a conservative measure of potential risk from hypothetical exposure to non-carcinogens indicated that the greatest potential non-carcinogenic exposures could be generated from the occurrence of zinc in off-site groundwater Using the highly conservative RME scenario assumptions the worst-case HI exceeded the guideline value of 1 0 suggesting that if hypothetically no further remediation were performed the possibility exists that long-term continued exposure to these compounds through ingestion could potentially have some non-carcinogenic health effects were each of the RME scenario conditions to occur However occurrence of this hypothetical worst-case scenario is not deemed probable because the likelihood of exposure is remote and also because continued ground-water remediation is reducing concentrations both on-site and off-site with attendant decreasing exposure potential Actual field results in fact indicate that zinc levels are close to background levels and well below the drinking water standards at the domestic water well that the occurrence of zinc is typically at the bottom of the aquifer and near the interceptor wells where it is being recovered Based on actual field sample results at the downgradient irrigation well #54278 the zinc levels do not pose a risk to human contact during irrigation or to crops soil livestock or wildlife

The anticipated baseline cancer risk was also evaluated using the hypothetical RME scenario Results indicated a cumulative RME potential cancer risk for all age groups including all evaluated compounds of approximately $1\ 6 \times 10^{2}$ were each of the stated RME scenario conditions to occur Sufficiently conservative assumptions have been incorporated into the risk

assessment model to protect individuals exposed even at the most conservative levels This estimated RME value is largely based on the unlikely occurrence and persistence of 1 1-DCE at the domestic well Actual field sample results demonstrate that this compound has never been detected at this well where water quality has consistently met applicable drinking water standards Therefore the RME is considered overly conservative in comparison to actual observed conditions As noted above the combined occurrence of each of the worst case RME assumptions is improbable and ongoing remediation acts to reduce exposure potential

The set of worst-case assumptions upon which the RME scenario risk assessment was based assumed an unlikely and even extraordinary site condition namely that remediation would cease and that the highest chemical concentrations identified on-site during 1989 which have in fact diminished would occur in the ground water off-site In addition the risk assessment hypothetically assumed that the conservative long-term (i e 75 years) future maximum exposure potential would be attained and sustained throughout that period at those maximum 1989 site concentrations for each compound This hypothetical scenario is contrary to ongoing and proposed remediation efforts which will continue to reduce ground-water concentrations both on-site and off-site The hypothetical RME scenario also does not take into account the fact that two monitoring wells placed between the site and upgradient of the domestic well safeguard the continued drinking water quality of that well Therefore due to the conservativeness of the assumed exposure scenarios and the limited occurrence and duration of any remaining chemicals in the aquifer the likelihood of actual exposure to site-associated chemicals as hypothetically assumed under the RME scenario is highly improbable

The ground-water pump and treat system installed at the site using high capacity recovery wells has demonstrated its capability to recover the organic and inorganics which occur in the aquifer This has been demonstrated by the operation of the remedial system The treatment system is appropriate for the ground-water conditions and is capable of maintaining NPDES permit criteria

Remedial action objectives are provided for use in the Feasibility study to evaluate the effectiveness and appropriateness of the ongoing remediation and monitoring operation and potential alternative remedial actions

REMEDIAL INVESTIGATION
TABLE OF CONTENTS

Section		Page
1 0 INTRODUCTION		1-1
1 1	PURPOSE OF LINDSAY REMEDIAL INVESTIGATION	1-2
1 2	SITE BACKGROUND	1-2
1 2 1	Site Description	1-2
1 2 2	Site History	1-3
1 2 2 1	Disposal Practice History	1-3
1 2 3	Previous Investigations	1-4
1 2 4	Interim Remediation	1-5
1 3	REPORT ORGANIZATION	1-6
2 0 STUDY AREA INVESTIGATIONS		2-1
2 1	SURFACE FEATURES	2-1
2 2	CONTAMINANT SOURCE INVESTIGATIONS	2-1
2 3	METEOROLOGICAL INVESTIGATIONS	2-2
2 4	SURFACE WATERS AND SEDIMENT INVESTIGATIONS	2-2
2 4 1	Drainage Channel Sediments	2-2
2 4 2	Surface Water	2-3
2 5	GEOLOGICAL INVESTIGATIONS	2-3
2 5 1	Data Collection	2-3
2 5 2	Deep Geologic Investigations	2-3
2 5 2 1	1980-1987 Borehole Logging	2-4
2 5 2 2	1988 Borehole Logging and Sampling	2-4
2 5 2 3	1989 Borehole Logging Sampling and Analyses	2-4

TABLE OF CONTENTS (continued)

Section		Page
2 6	SOIL AND VADOSE ZONE INVESTIGATIONS	2-5
2 6 1	Scope	2-5
2 6 2	Soil and Vadose Investigations	2-5
2 6 2 1	1983 Investigations	2-5
2 6 2 2	1987 Investigations	2-6
2 6 2 3	1988 Investigations	2-6
2 7	GROUND-WATER INVESTIGATIONS	2-7
2 7 1	Site History	2-7
2 7 2	Well Installation and Monitoring	2-7
2 7 2 1	1982 Investigations	2-8
2 7 2 2	1983-1986 Investigations	2-8
2 7 2 3	1987 Investigations	2-9
2 7 2 4	1988 Investigations	2-10
2 7 2 5	1989 Investigations	2-11
2 8	HUMAN POPULATION SURVEYS AND LAND USE	2-12
2 9	ECOLOGICAL INVESTIGATIONS	2-12
3 0	PHYSICAL CHARACTERISTICS OF THE STUDY AREA	3-1
3 1	SURFACE FEATURES	3-1
3 2	METEOROLOGY	3-2
3 2 1	Wind	3-3
3 2 2	Temperature	3-3
3 2 3	Precipitation	3-4
3 2 4	Evapotranspiration	3-4
3 2 5	Other Data	3-4
3 3	SURFACE WATER	3-4

TABLE OF CONTENTS (continued)

Section		Page
3 4	GEOLOGY	3-5
3 4 1	Regional Geology	3-5
3 4 2	Site Geology	3-6
3 5	SOILS	3-9
3 5 1	Introduction	3-9
3 5 2	Associations	3-9
3 5 3	Site Soils	3-13
3 6	HYDROGEOLOGY	3-13
3 6 1	Site Hydrogeology	3-14
3 6 1 1	Aquifer Characteristics	3-14
3 6 1 2	Aquitard Characteristics	3-18
3 6 2	Water Levels	3-21
3 6 2 1	Aquifer Water Levels	3-21
3 6 2 2	Aquitard Water Levels	3-23
3 6 2 3	Water Levels Summary	3-23
3 6 3	Ground-Water Flow	3-24
3 6 4	Ground-Water Models	3-26
3 7	DEMOGRAPHY AND LAND USE	3-28
3 8	ECOLOGY	3-30
3 8 1	Site History	3-30
3 8 2	Habitats	3-30
3 8 3	Aquatic Life	3-31
3 8 4	Wildlife	3-32

TABLE OF CONTENTS (continued)

Section				Page
4 0	NATURE AND EXTENT OF CONTAMINATION			4-1
	4 1	CONTAMINANT SOURCE INVESTIGATIONS		4-1
		4 1 1	Spent Acid Disposal Pit and Burn Pit	4-1
		4 1 2	Organic Source Areas	4-2
	4 2	SOILS		4-2
		4 2 1	Inorganics	4-2
		4 2 2	Organics	4-3
	4 3	GROUND WATER		4-7
		4 3 1	Introduction	4-7
		4 3 2	Inorganics	4-9
			4 3 2 1 May 1983 to November 18 1987	4-10
			4 3 2 2 November 1987 to September 1988	4-16
			4 3 2 3 February 15 1989 to January 1990	4-23
		4 3 3	Organics	4-30
			4 3 3 1 June 16 1987 to September 21 1988	4-31
			4 3 3 2 February 15 1989 to January 17 1990	4-35
	4 4	SEDIMENT SAMPLE RESULTS		4-41
	4 5	SURFACE WATER		4-42
	4 6	OFF-SITE SURFACE SOIL AND GRASS SAMPLES		4-43
5 0	CONTAMINANT TRANSPORT AND FATE			5-1
	5 1	ENVIRONMENTAL TRANSPORT AND FATE PROCESSES		5-1
	5 2	CHARACTERISTICS OF SITE CONTAMINANTS		5-7
		5 2 1	Characteristics of Metals	5-7
			5 2 1 1 Characteristics of Zinc and Cadmium	5-7
			5 2 1 2 Characteristics of Chromium	5-8
			5 2 1 3 Characteristics of Lead	5-9

TABLE OF CONTENTS (continued)

Section		Page
5 2 2	Characteristics of Organic Compounds	5-9
5 2 3	Transport and Fate of Other Inorganic Compounds	5-11
5 2 3 1	Acidity	5-11
5 2 3 2	Sulfate	5-12
5 3	TRANSPORT AND FATE OF CONTAMINANTS AT THE LINDSAY SITE	5-12
6 0	BASELINE RISK ASSESSMENT	6-1
6 1	EVALUATION OF DATA BASE	6-2
6 2	ASSESSMENT OF POTENTIAL HUMAN EXPOSURE	6-6
6 2 1	Potentially Exposed Populations	6-6
6 2 2	Exposure Pathways	6-7
6 2 3	Exposure Factors	6-8
6 2 3 1	General Considerations	6-8
6 2 3 2	Pathway I Potential Exposure via Incidental Soil Ingestion	6-9
6 2 3 3	Pathway II Potential Exposure via Dermal Contact	6-11
6 2 3 4	Pathway III Potential Exposure via Drinking Water Consumption	6-13
6 2 3 5	Pathway IV Potential Exposure via Inhalation of Vapors from Drinking Water	6-16
6 2 3 6	Pathway V Potential Exposure via Consumption of Homegrown Fruits and Vegetables	6-17
6 2 3 7	Pathway VI Potential Exposure via Inhalation of Particulates	6-19
6 2 3 8	Airborne Emissions and Dispersion of Soil Contaminants	6-20
6 2 3 9	Consumption of Game	6-21
6 3	TOXICITY ASSESSMENT	6-21

TABLE OF CONTENTS (continued)

Section		Page
6 4	RISK CHARACTERIZATION	6-23
6 4 1	Results of Exposure Assessment	6-25
6 4 2	Potential Non-carcinogenic Hazards	6-25
6 4 3	Potential Cancer Risks	6-26
6 4 4	Additivity of Risks in Different Areas	6-27
6 5	UNCERTAINTY ANALYSIS	6-28
6 5 1	Assessment of Uncertainty - Toxicity	6-28
6 5 2	Assessment of Uncertainty - Exposure	6-29
6 6	ASSESSMENT OF POTENTIAL ECOLOGICAL RISK	6-30
7 0	SUMMARY AND CONCLUSIONS	7-1
7 1	SUMMARY	7-1
7 1 1	Nature and Extent of Contamination	7-1
7 1 2	Fate and Transport	7-3
7 1 3	Risk Characterization	7-3
7 2	CONCLUSIONS	7-5
7 3	REMEDIAL OBJECTIVES	7-5

LIST OF FIGURES

1 2-1	Vicinity Map
1 2-2	Location of Registered Wells Lindsay Mfg Co
1 2-3	Location of Acid Disposal Pit and 1982-Series Wells
1 2-4	Site Plan Map
2 1-1	Site Specific Topographic Map
2 4-1	Stream Channel Sediment Sample Locations
2 8-1	Location of Public and Private Domestic and Stock Water Supply Wells
3 2-1	Wind Diagram Offut AFB
3 4-1	Lindsay Site Regional Stratigraphic Column
3 4-2	Lindsay Site Stratigraphic Column
3 4-3	Cross-Sections Legend
3 4-4 A	Location of Deep Geologic Cross-Sections A-A through C-C
3 4-4 B	Location of Deep Geologic Cross-Sections D-D through F-F
3 4-5 A - F	Deep Geologic Cross Sections
3 4-6 A	Location of Geologic Cross-Sections A-A through D-D
3 4-6 B	Location of Geologic Cross-Sections E-E and F-F
3 4-7 A - F	Geologic Cross-Sections

LIST OF FIGURES (continued)

3 4-8	Sand Channel Isopach
3 5-1	Surface Soil Types In and Around Lindsay Nebraska
3 6-1	Isopach of Aquifer
3 6-2	Base of the Aquifer Map
3 6-3	Radial Separation of Distance vs Transmissivity
3 6-4A-D	Site Hydrographs
3 6-5A	Location of Selected Observation Wells
3 6-5B	Recorder Well Hydrographs
3 6-6	Potentiometric Surface Map Interceptor Well Idle February 1988
3 7-1	General Land Use Map
4 2-1	Soil Boring Containing PCE
4 2-2	Soil Boring Containing TCA
4 2-3	Soil Boring Containing DCE
4 2-4	Soil Boring Containing PCE TCA & DCE
4 3-1a	Time vs pH On-Site Monitoring Wells Screened in Upper Portion of Aquifer May 1983 through November 13 1987
4 3-1b	Distribution of Field and Lab pH in Aquifer May-June 1983
4 3-1c	Time vs Zinc On-Site Monitoring Wells Screened in Upper Portion of Aquifer May 1983 through November 13 1987

LIST OF FIGURES (continued)

4 3-1d Distribution of Zinc in Aquifer May-June 1983

4 3-1e Time vs Iron On-Site Monitoring Wells Screened in Upper Portion of Aquifer May 1983 through November 13 1987

4 3-1f Distribution of Iron in Aquifer May-June 1983

4 3-1g Time vs Sulfate On-Site Monitoring Wells Screened in Upper Portion of the Aquifer May 1983 through November 13 1987

4 3-1h Distribution of Sulfate in Aquifer May-June 1983

4 3-1i Time vs Cadmium On-Site Monitoring Wells Screened in Upper Portion of Aquifer May 1983 through November 13 1987

4 3-1j Time vs Chromium On-Site Monitoring Wells Screened in Upper Portion of Aquifer May 1983 through November 13 1987

4 3-1k Time vs Lead On-Site Monitoring Wells Screened in Upper Portion of Aquifer May 1983 through November 13 1987

4 3-2a Time vs pH On-Site Monitoring Wells Screened in Lower Portion of Aquifer May 1983 through November 13 1987

4 3-2b Time vs Zinc On-Site Monitoring Wells Screened in Lower Portion of Aquifer May 1983 through November 13 1987

4 3-2c Time vs Iron On-Site Monitoring Wells Screened in Lower Portion of Aquifer May 1983 through November 13 1987

4 3-2d Time vs Sulfates On-Site Monitoring Wells Screened in Lower Portion of Aquifer May 1983 through November 13 1987

4 3-3a Time vs pH On-Site Monitoring Wells Screened in Aquifer May 1983 through November 13 1987

LIST OF FIGURES (continued)

4 3-3b Time vs Zinc On-Site Monitoring Wells Screened in Aquifer May 1983 through November 13 1987

4 3-3c Time vs Iron On-Site Monitoring Wells Screened in Aquifer May 1983 through November 13 1987

4 3-3d Time vs Sulfate On-Site Monitoring Wells Screened in Aquifer May 1983 through November 13 1987

4 3-4a Time vs pH Off-Site Monitoring Well (Old Lindsay Public Supply Well) Screened in Aquifer May 1983 through November 13 1987

4 3-4b Time vs Zinc Iron Sulfate Off-Site Monitoring Well (Old Lindsay Public Supply Well) Screened in Aquifer May 1983 through November 13 1987

4 3-5a Time vs pH On-Site Monitoring Well (82-2m) Screened in Upper Portion of Aquifer November 23 1987 through January 17 1990

4 3-5b Distribution of Field pH in Aquifer December 1987

4 3-5c Time vs Zinc Iron Sulfate On-Site Monitoring Well (82-2m) Screened in Upper Portion of Aquifer November 23 1987 through January 17 1990

4 3-5d Distribution of Zinc in Aquifer December 1987

4 3-5e Distribution of Iron in Aquifer December 1987

4 3-5f Distribution of Sulfate in Aquifer December 1987

4 3-6a Time vs pH On-Site Monitoring Wells Screened in Lower Portion of Aquifer November 23 1987 through January 17 1990

4 3-6b Time vs Zinc On-Site Monitoring Wells Screened in Lower Portion of Aquifer November 23 1987 through January 17 1990

4 3-6c Time vs Iron On-Site Monitoring Wells Screened in Lower Portion of Aquifer November 23 1987 through January 17 1990

LIST OF FIGURES (continued)

4 3-6d Time vs Sulfate On-Site Monitoring Wells Screened in Lower Portion of Aquifer November 23 1987 through January 17 1990

4 3-7a Time vs pH On-Site Monitoring Wells Screened in Aquifer November 23 1987 through January 17 1990

4 3-7b Time vs Zinc On-Site Monitoring Wells Screened in Aquifer November 23 1987 through January 17 1990

4 3-7c Time vs Iron On-Site Monitoring Wells Screened in Aquifer November 23 1987 through January 17 1990

4 3-7d Time vs Sulfate On-Site Monitoring Wells Screened in Aquifer November 23 1987 through January 17 1990

4 3-8a Time vs pH Off-Site Monitoring Wells Screened in Aquifer November 23 1987 through January 17 1990

4 3-8b Time vs Zinc Off-Site Monitoring Wells Screened in Aquifer November 23 1987 through January 17 1990

4 3-8c Time vs Iron Off-Site Monitoring Wells Screened in Aquifer November 23 1987 through January 17 1990

4 3-8d Time vs Sulfate Off-Site Monitoring Wells Screened in Aquifer November 23 1987 through January 17 1990

4 3-9a Time vs pH Off-Site Monitoring Wells Screened in Lower Portion of Aquifer November 23 1987 through January 17 1990

4 3-9b Time vs Zinc Off-Site Monitoring Wells Screened in Lower Portion of Aquifer November 23 1987 through January 17 1990

4 3-9c Time vs Iron Off-Site Monitoring Wells Screened in Lower Portion of Aquifer November 23 1987 through January 17 1990

LIST OF FIGURES (continued)

4 3-9d Time vs Sulfate Off-Site Monitoring Wells Screened in Lower Portion of Aquifer November 23 1987 through January 17 1990

4 3-10a Distribution of Field pH in Aquifer February 15 1989

4 3-10b Distribution of Field pH in Aquifer May 16-28 1989

4 3-10c Distribution of Field pH in Aquifer August 14-16 1989

4 3-10d Distribution of Field pH in Aquifer November 13-17 1989

4 3-11a Distribution of Zinc in Aquifer February 15 1989

4 3-11b Distribution of Zinc in Aquifer May 16-21 1989

4 3-11c Distribution of Zinc in Aquifer August 14-17 1989

4 3-11d Distribution of Zinc in Aquifer November 17 1989

4 3-12a Distribution of Iron in Aquifer May 1989

4 3-12b Distribution of Iron in Aquifer August 14-17 1989

4 3-12c Distribution of Iron in Aquifer November 17 1989

4 3-13a Distribution of Sulfates in Aquifer February 15 1989

4 3-13b Distribution of Sulfates in Aquifer May 1989

4 3-13c Distribution of Sulfates in Aquifer August 14-17 1989

4 3-13d Distribution of Sulfates in Aquifer November 17 1989

4 3-14a Distribution of Field pH in Sand Channel Based on MW89-13 and MW89-14 November 17 1989

LIST OF FIGURES (continued)

4 3-14b Distribution of Zinc in Sand Channel Based on MW89-13 and MW89-14 November 17 1989

4 3-14c Distribution of Iron in Sand Channel Based on MW89-13 and MW89-14 November 17 1989

4 3-14d Distribution of Sulfate in Sand Channel Based on MW89-13 and MW89-14 November 17 1989

4 3-15 Distribution of Total Organics in Aquifer March-August 1988

4 3-16a Time vs 1 1-DCE On-Site Monitoring Wells Screened in Lower Portion of Aquifer November 18 1987 through January 1 1990

4 3-16b Time vs 1 1-TCA On-Site Monitoring Wells Screened in Lower Portion of Aquifer November 18 1987 through January 1 1990

4 3-16c Time vs 1 1-PCE On-Site Monitoring Wells Screened in Lower Portion of Aquifer November 18 1987 through January 1 1990

4 3-17 Time vs 1 1-DCE 1 11-TCA PCE On-Site Monitoring Well (MW87-3) Screened in Aquifer

4 3-18a Time vs 1 1-DCE 1 11-TCA PCE Off-Site Monitoring Well (MW88-6) Screened in Lower Portion of Aquifer

4 3-18b Time vs 1 1-DCE 1 11-TCA PCE Off-Site Monitoring Well (54278) Screened in Lower Portion of Aquifer

4 3-19a Distribution of Total Organics in Aquifer February 15 1989

4 3-19b Distribution of Total Organics in Aquifer May 16-21 1989

4 3-19c Distribution of Total Organics in Aquifer August 14-17 1989

4 3-19d Distribution of Total Organics in Aquifer November 17 1989

LIST OF FIGURES (continued)

4 3-19e Distribution of Total Organics in Aquifer in Sand Channel Based on MW89-14 and MW89-13 November 17 1989

6 2-1 In-Situ Demal Adherence of Soil

LIST OF TABLES

3 5-1	Engineering Index and Soil Properties of the Soils
3 6-1	Summary of Aquifer Transmissivity and Conductivity Calculations
3 6-2	Summary of Aquifer Parameter Calculations Original Interceptor Well
3 6-3	Constant Rate Pump Test Results by Well February 21 1989
3 6-4	Summary of Step-Drawdown and Constant Rate Pump Test Results Add On Interceptor Well
4 2-1	Summary of Laboratory Soil Sample Results - Total Metal and EP Toxicity Metal
4 2-2	Summary of Laboratory Soil Sample Results - Organic Compounds
4 3-1	Summary of On-Site Ground-Water Monitoring Wells
4 3-2	Inorganic Ground-Water Monitoring
4 3-3	Summary of Selected Inorganic Analysis Collected between 1977 and January 1 1983
4 3-4	Summary of Select Inorganic Results in On-Site Aquifer
4 3-5	Summary of Inorganic Laboratory Results Beller Wells
4 3-6	Organic Ground-Water Monitoring 1987-1990
4 3-7	Summary of Organic Results Water Samples Collected from Initial Facility Wells
4 3-8	Summary of Organic Laboratory Results 1987 through 1989 Beller Wells
4 6-1	Approximate Location of Off-Site Soil and Grass Samples

LIST OF TABLES (continued)

5 3-1 Estimated Distribution of Selected organics Compounds in Site Soils

6 1 Selection of Potential Exposure Pathways for Quantitative Exposure Assessment

6 2 Summary of Exposure Factors Off-Site Receptors

6 2-1 Selection of Potential Exposure Pathways for Quantitative Exposure Assessment

6 2-2 Summary of 1989 Ground Water Data Used for Baseline Assessment

6 2-3 Summary of Off-Site Soil and Grass Metals Concentrations

6 2-4 Summary of Factors Used For Quantitative Exposure Assessment Lindsay Site

6 2-5 Off-Site Ambient Air Concentrations Based on Mean Soil Contaminant Concentrations

6 2-6 Off-Site Ambient Air Concentrations Based on 95% Percentile Soil Contaminant Concentrations

6 3 Summary of Ground-Water Concentrations Used for Baseline Risk Assessment

6 3-1 Summary of Non-carcinogenic Chronic RfD Values for Lindsay Site Compounds

6 3-2 Summary of Carcinogenic Toxity Criteria for Lindsay Site Compounds

6 4 Summary of Soil Concentrations Used for Baseline Risk Assessment

6 4-1 Summary of Potential Total Exposure (i e dose) to Off-Site Receptors By Age Class

6 4-2 Summary of Risk Characterization for Non-Carcinogenic Compounds Reasonable Maximum Scenario Off-Site Receptors

LIST OF TABLES (continued)

6 4-3 Summary of Potential Cancer Risk Characterization Reasonable Maximum Exposure Scenario Cancer Risk Off-Site Receptors

6 4-4 Exposure to Individual Contaminants by Age Class and Pathway Off-Site Receptors

6 5 Summary of Non-Carcinogenic Toxicity Criteria for Lindsay Site Compounds

6 6 Summary of Carcinogenic Toxicity Criteria for Lindsay Site Compounds

6 7 Summary of Potential Total Exposure (i e Dose) to Off-Site Receptors by Age Class

6 8 Summary of Risk Characterization for Non-Carcinogenic Risk-Reasonable Maximum Scenario Off-Site Receptors

6 9 Summary of Cancer Risk Characterization - Reasonable Maximum Exposure Scenario Cancer Risk Off-Site Receptors

6 10 Total Potential Exposure to Individual Compounds by Age Class and Pathway Off-Site Receptors

1 0 INTRODUCTION

Lindsay Manufacturing Co located in Lindsay Nebraska is a producer of center pivot irrigation equipment Two operations pivot painting and galvanizing are involved in the production process Prior to galvanizing the pivot pipes are cleaned with a sulfuric acid solution This solution once its effectiveness has been reduced through use is replaced

From the early 1970 s to 1982 the spent acid stream was piped to an earthen disposal pit (the pit) located north of the company s galvanizing building In 1982 Lindsay Manufacturing Co replaced this pit with a new wastewater treatment facility (the facility) designed to neutralize the spent acid

Four monitoring wells were constructed to be used as ground-water monitoring wells for the new treatment facility The wells were installed in December 1982 and sampled in January 1983 Three of the wells were found to contain water with low pH and two of the wells had elevated water temperatures Lindsay reported those findings to the Nebraska Department of Environmental Control (NDEC) As a result of this discovery Hoskins-Western-Sonderegger Inc (HWS) was retained by Lindsay Manufacturing Co to conduct a remedial investigation of the soils and ground water

A Stipulation (Case No 692) by NDEC and Lindsay dated April 19 1983 and amended on August 10 1983 and March 7 1984 directed the subsequent site investigation and remediation

An on-site interceptor well was installed by Lindsay in March 1983 to intercept and recover acidic contamination from the aquifer beneath the site These waters were neutralized and treated in the wastewater treatment facility Treated wastewater and sludge from the treatment facility were handled according to NPDES Permit No NEO113905 Under the NPDES Permit the sludge is dewatered onsite with the resulting effluent returned to the waste-water treatment facility The sludge is disposed of at a local landfill located approximately 4 miles from the site

On August 22 1988 NDEC notified Lindsay Manufacturing Co that it was the potentially responsible party for the site as proposed (October 1984) and reproposed (June 1988) for the Superfund National Priorities List (NPL) Lindsay Manufacturing Co was invited to participate in formal negotiations to conduct a Remedial Investigation/Feasibility Study (RI/FS) for the site

The State of Nebraska through a cooperative agreement with the United States Environmental Protection Agency (EPA) was authorized to enter into a Stipulation and Agreement with Lindsay Manufacturing Co whereby Lindsay Manufacturing Co agreed to conduct a Remedial Investigation/Feasibility Study (RI/FS) for the site The Stipulation and Agreement became effective on January 5 1989 Pursuant to the terms of the Stipulation and Agreement Lindsay Manufacturing Co submitted a proposed RI Work Plan on February 21 1989 The Work Plan was

reviewed by NDEC supplemental information was provided by Lindsay Manufacturing and technical discussions were held on April 13 1989 and again on November 2 1989 A revised RI Work Plan was approved on November 17 1989

The interceptor well remedial system expanded in February 1989 to include a second interceptor well designed to enhance the recovery of contaminants has continued to be operated by Lindsay Manufacturing throughout the period of remedial investigation

This report was prepared to describe and document the results of the Remedial Investigation including the results of the interim remedial action undertaken by Lindsay Manufacturing and to provide the site information needed to perform the Feasibility Study

1 1 PURPOSE OF LINDSAY REMEDIAL INVESTIGATION

The purpose of the Lindsay Remedial Investigation is to

- Define the presence magnitude extent vertical and horizontal direction and rate of movement of any hazardous substance pollutant or contaminant within and beyond the facility boundaries

- Conduct investigations necessary to characterize potential pathways of contaminant migration characterize the sources of the contamination define the degree and extent of vertical and horizontal contamination and identify actual and potential receptors of the contamination

1 2 SITE BACKGROUND

1 2 1 Site Description

The Lindsay Manufacturing Co site (the site) is located in the Village of Lindsay Nebraska in Platte County The site is in the southeast 1/4 of the southwest 1/4 of section 17 T20N R3W (Figure 1 2-1) The site is situated in the drainage basin of Shell Creek surrounded on the north and east by farmland and on the south and west by the Village of Lindsay Nebraska

The site occupies approximately 42 acres and is situated above a regional aquifer This aquifer is developed at certain locations by high capacity irrigation and public supply wells (Figure 1 2-2) The aquifer is capped by low permeability soils over 30 feet in thickness Depth to ground water at the site is greater than 20 feet The occurrence of ground water is confined by the capping soils

The climate is typical of the mid-continent A broad range of temperature change occurs from winter to summer with frequent winds and an average annual precipitation of 26 inches Humidity averages 60 percent and tornadoes and severe thunder storms occur occasionally

Although situated in the uplands of the Shell Creek drainage the site is in a topographic low between a tableland to the east and north and rolling hills to the west Plant expansion has cut eastward into the hill slope and regraded local soils

1 2 2 Site History

The site was originally owned by Paul Zimmerer and was operated as a gasoline service station until the late 1950 s In 1958 Paul Zimmerer began a sprinkler manufacturing line In 1961 a manufacturing plant was constructed on the site and in 1965 a partnership was formed under the name of Lindsay Manufacturing Co The Zimmatic center pivot system was marketed in 1969 and the plant was expanded In 1970 the operation was incorporated followed by additional expansions in plant and office space in 1971 and 1972 The present galvanizing building was constructed in 1972 and in 1973 a warehouse and gear box manufacturing facility were added to the site DeKalb Agresearch Inc acquired Lindsay Manufacturing Co in January 1974 a business relationship that lasted until September 1988 at which time Lindsay became a publicly-owned corporation

1 2 2 1 Disposal Practice History

Disposal of materials from plant operations historically included discharge of spent acid from the galvanizing building to an earthen pit

The disposal pit (pit) was located north of the galvanizing building (Figure 1 2-3) where the spent acid was generated The pit was generally tear-shaped dimensionally 50 feet in width 100 feet in length and approximately 8 to 10 feet deep The bottom and steep side slopes (1 1 or less) were apparently unlined The pit was used between 1971 and 1982 It had a capacity of 270 000 gallons and typically received slugs of 10 000 to 15 000 gallons approximately monthly The last slug of spent acid was received in December 1982 Since that time only two discharges to the pit have occurred A one-time discharge of neutralized spent acid occurred on January 28 to 31 1983 As Lindsay informed NDEC at the time the discharge was necessary due to a leak detected in the acid storage tanks The liquid was later pumped from the facility and shipped to an off-site disposal facility

On March 29 1983 approximately 107 000 gallons of ground water were pumped to the pit during a well test conducted for remedial action data collection This liquid was also reclaimed by pumping from the pit and shipped to an off-site disposal facility

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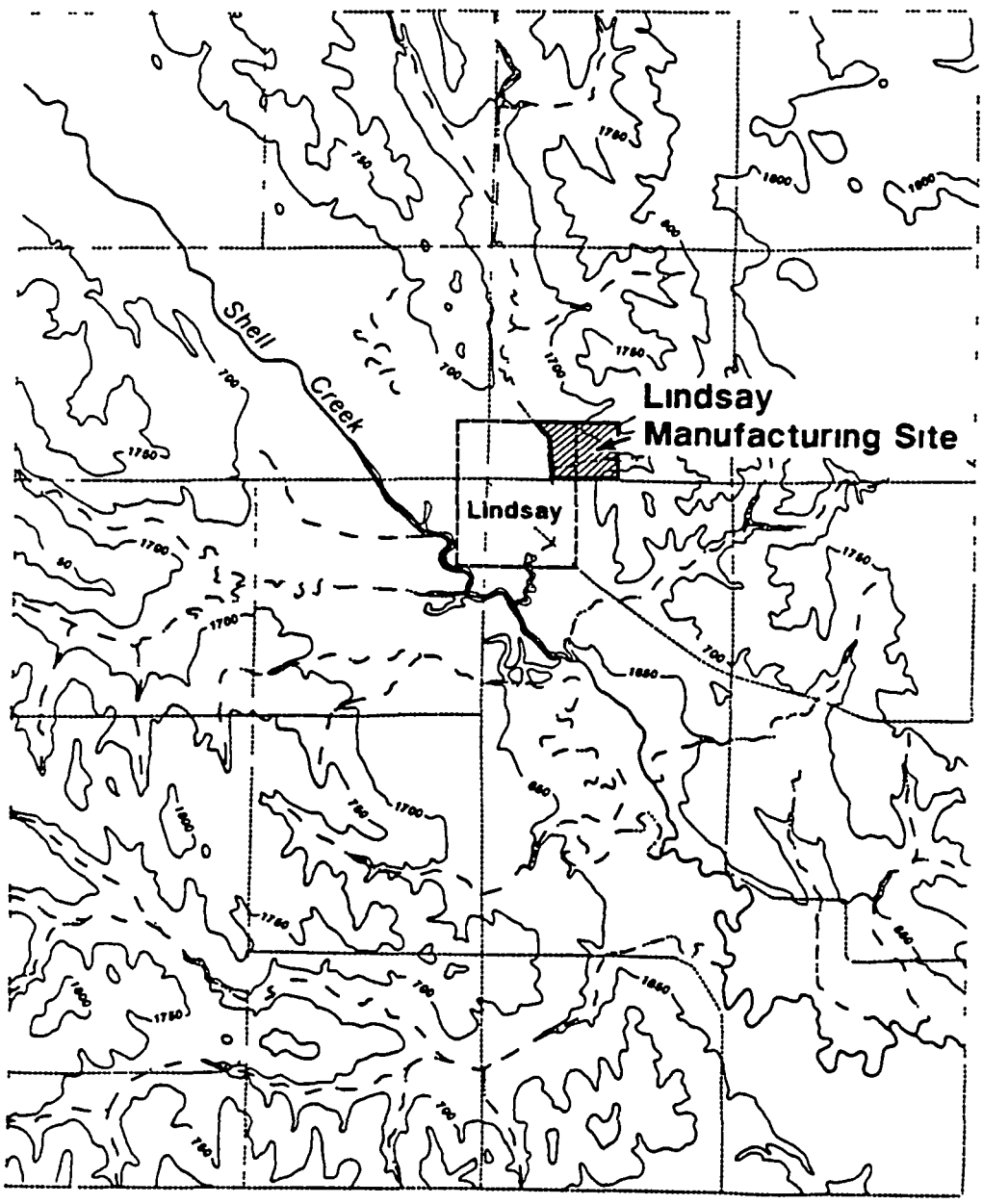

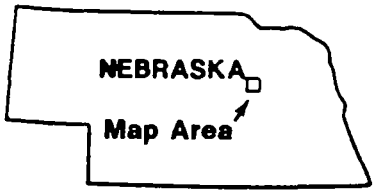

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Scale in Feet

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Reference Lindsay Quadrangle Nebraska
7 5 Minute USGS Topographic Map 1966

Figure 1.2 1
Vicinity Map
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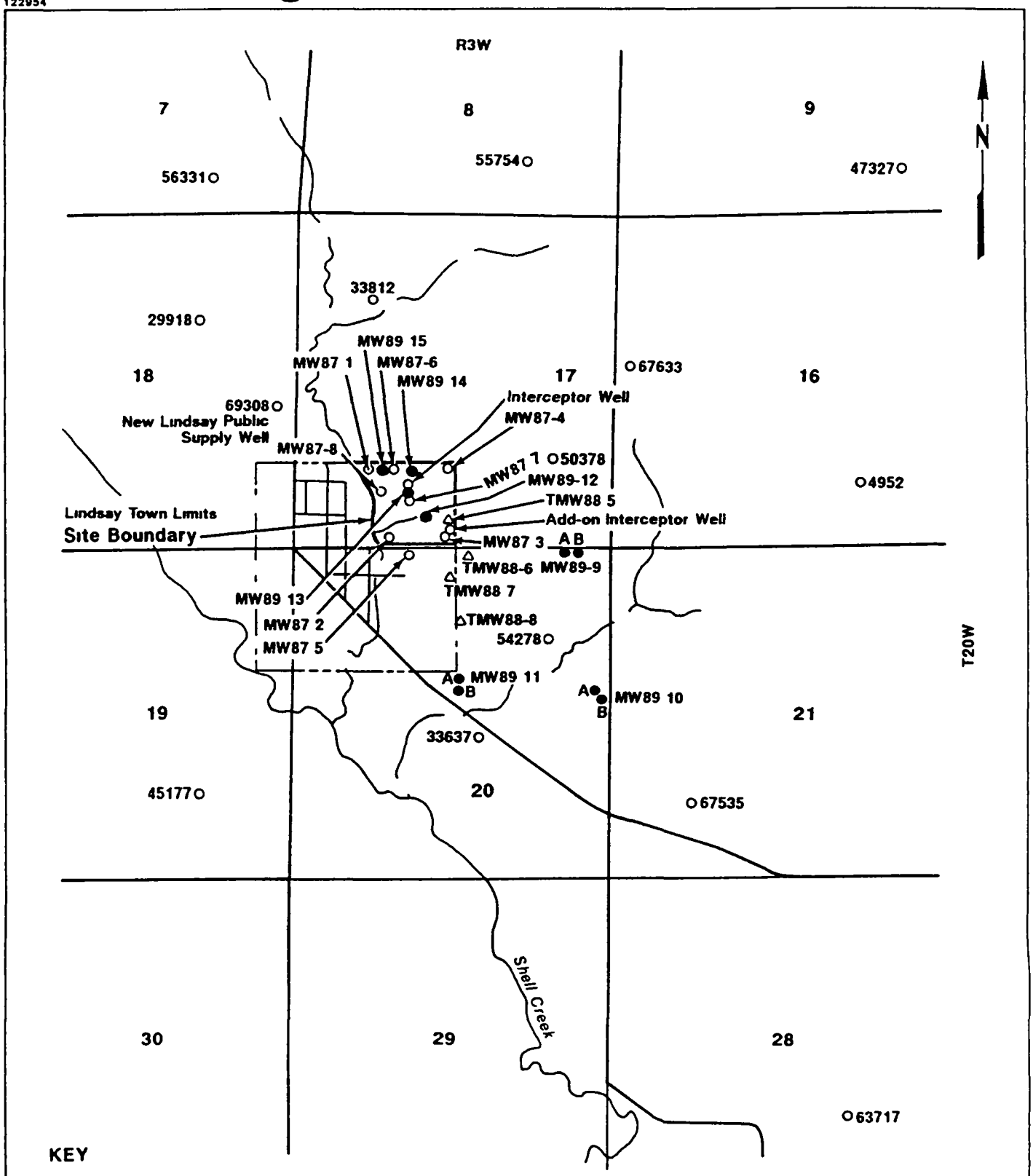

KEY

- ○ Registered Well
- ○ Monitoring Well, 1987
- △ Temporary Monitoring Well 1988
- ● Monitoring Well 1989
  A Shallow B Deep

0 2000 4000
Scale in Feet

Figure 1 2 2
Location of Registered Wells and Monitoring Wells Lindsay Manufacturing Site
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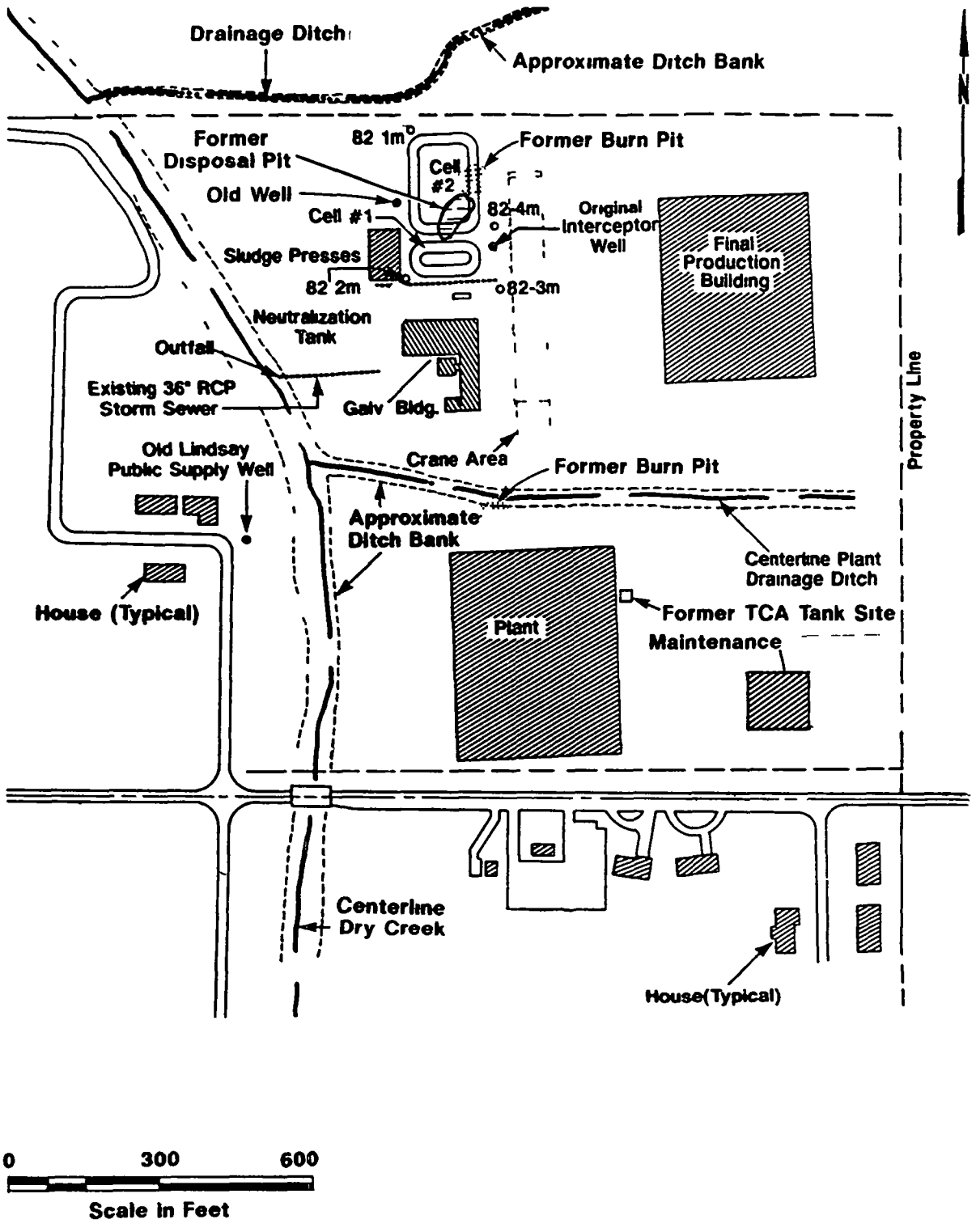

Figure 1 2 3

Location of Former Acid Disposal Pit, Approximate Location of Former Burn Pits and 1982-Series Monitoring Wells Lindsay Manufacturing Site

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Cells 1 and 2 of the existing wastewater treatment facility were installed over the area of the former disposal pit in 1983 These cells are plastic lined From 1983 on pursuant to the facility NPDES permit the ground water was pumped to the wastewater treatment facility where it was neutralized and the solids dewatered and disposed off site

The burning of discarded wood and cardboard was performed north of the main plant before 1971 and adjacent to the pit on the northern side after 1971

Discussions with company personnel have indicated the possibility that historically small quantities of solvents degreasers and aerosol cans of degreasing compounds may on occasion have been disposed of by discarding at the back door of the main plant Small quantities of solvents and degreasers may also historically have been burned in both of the burn pits and disposed of in the pit along with the spent acid

The burn area and ground surface where historic disposal is reported behind the main plant was paved in 1971 The former pit and adjacent burn area were covered by the lined Cells 1 and 2 in 1983

1 2 3 Previous Investigations

Data collection on soils and ground water began in 1980 with the installation of a deep (98 ft) ground-water monitoring well west of the pit The well was installed by Staska Drilling & Supply Co Inc and is subsequently called Old Well in this report (Appendix I) Additional data were collected by Bruce Gilmore & Associates and Layne-Western Co Inc in December 1982 when four wells and a deep test hole were drilled for the proposed waste water treatment facility (Appendix I)

Sampling of these wells in January 1983 revealed acidic water conditions and above normal ground-water temperatures in three of the four facility wells and the Old Well Previous sampling of the Old Well had reported only normal pH conditions Hoskins-Western-Sonderegger Inc (HWS later to become HWS Technologies Inc or HWST) was retained to investigate this new occurrence This resulted in a series of site investigations prepared by HWS which include the following

1983 Hydrogeologic Investigation, Lindsay Manufacturing Company, Acid Waste Pond

1983 Closure Plan for Lindsay Manufacturing Co., Waste Acid Disposal Pit, EPA-I D No NED068645696

1983 Remedial Action Plan for Lindsay Waste Acid Disposal Pit

1984 Supplemental Remedial Action Plan for Lindsay Waste Acid Disposal Pit

1986 Status Report

1987 Interim Status Report

In 1988 Lindsay Manufacturing Co contracted with Dames & Moore for additional study of the site which resulted in the following studies

1987 Annual Status Report

1988 Extended Remedial Subsurface Investigation Report

1989 Monthly and Quarterly Monitoring Reports

1 2 4 Interim Remediation

The Old Lindsay Public Supply Well (Figure 1 2-4) was identified in January 1983 to be a potential receptor of acidic ground water detected in the new facility monitoring wells and the Old Well on site Lindsay Manufacturing Co notified the Nebraska Department of Health and the Village of Lindsay The Lindsay Public Supply Well water was sampled and found to remain at background quality Nevertheless as a precautionary measure Lindsay Manufacturing Co initiated siting of a new public well to replace the well in question

HWS recommended that Lindsay Manufacturing Co install a fully penetrating high capacity test well into the aquifer and perform an aquifer pump test to determine if the acidic waters could be intercepted and recovered and the aquifer restored

The Original Interceptor Well (OIW) was installed on March 22 to 24 1983 and tested The successful performance of the OIW and its broad radius of influence made it an appropriate choice for ground-water cleanup (HWST 1987 Interim Status Report D&M 1988 Extended Subsurface Investigation) The new wastewater facility was determined to be capable of treating this intercepted ground water

Treatment of the pumped ground water has involved injection of neutralizing caustic sodium hydroxide and a flocculating agent into the pumped ground water produced by the interceptor well Appendix VI includes summaries of the Original Interceptor Well pumping data caustic consumption on an annual basis annual solids production and the relationship of the acidity (measured pH) of intercepted ground water to time during interim remediation

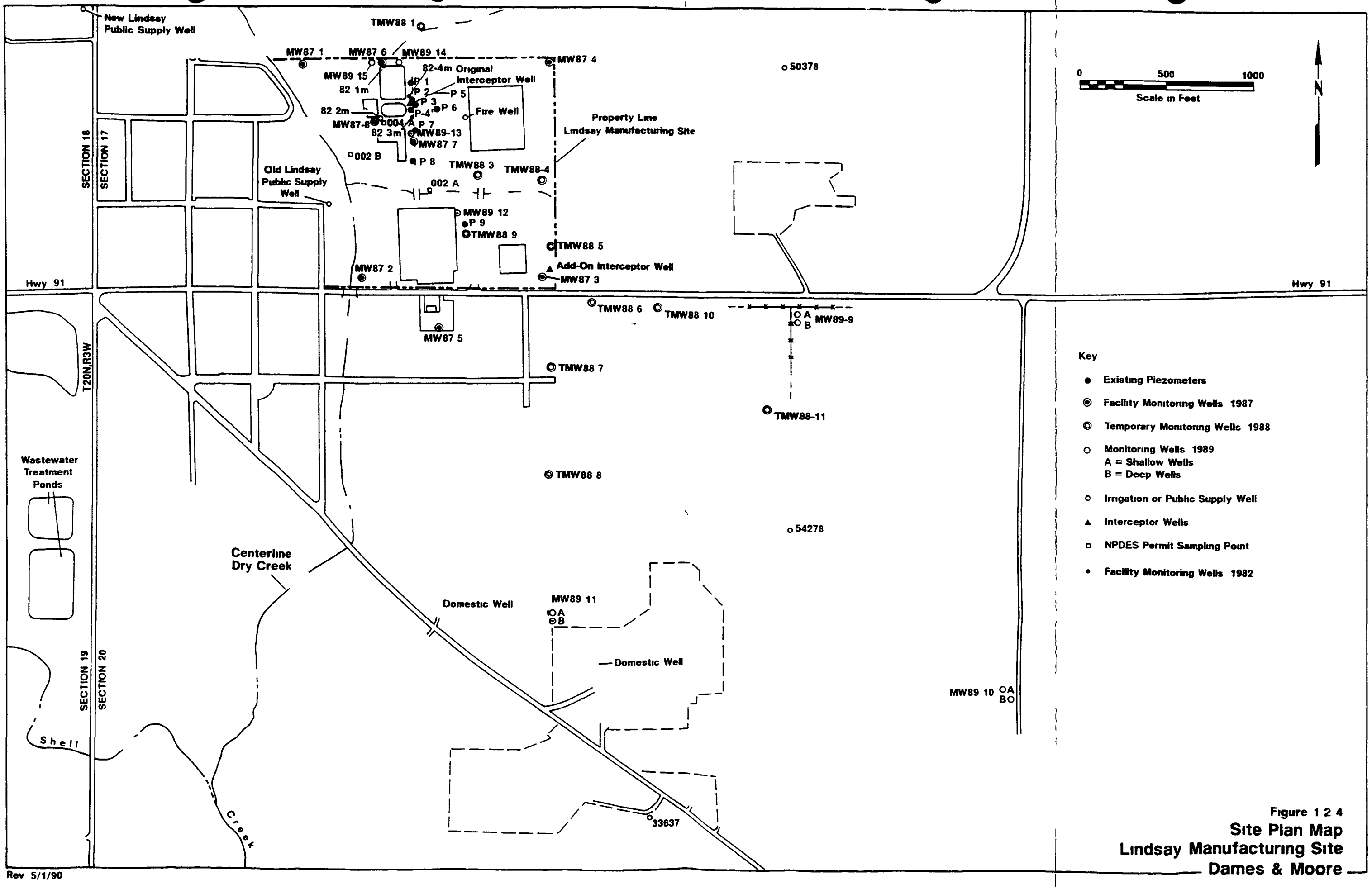

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Figure 1 2 4
Site Plan Map
Lindsay Manufacturing Site
Dames & Moore

The interim pumping system began operating in spring 1984 By the end of 1984 approximately 10 000 000 gallons (30 acre ft) were intercepted and approximately 1 200 tons of dewatered sludge (treated solids) were produced (Figure D Appendix VI) The pump and treat operation in 1985 brought the total pumpage to over 60 million gallons (185 acre ft) and the sludge production to a total of 2 500 tons By the end of 1986 pump and treat operations advanced to totals of 100 million gallons (310 acre ft) and 3,000 tons of sludge

By the end of 1987 the accumulated gallons pumped were approximately 320 million gallons (980 acre ft) and the total sludge production exceeded 5 000 tons Sludge production levels were reduced in response to the success of the aquifer restoration efforts

The pump and treat interim action by the end of 1988 brought the total gallons pumped from the aquifer to 550 million gallons (1680 acre ft) and the tons of dewatered sludge to approximately 7 500 In early 1989 as the result of the recommendation in the 1988 Extended Subsurface Remedial Investigation the Add-On Interceptor Well (AOIW) was installed and connected by above-ground pipe line to the wastewater treatment facility This AOIW was designed to intercept and recover acidic contamination at the bottom of the aquifer which had been identified in the 1988 study Additional provisions were included in the NPDES permit for the alternate operation of the AOIW and the OIW with the AOIW operated approximately 156 hours per week and the OIW operated about 12 hours per week during the maximum operating periods

The total gallons pumped by the AOIW in 1989 was 144 169 000 (442 acre ft) The total gallons pumped by the OIW through January 16 1990 was 616 052 000 (1 890 acre ft) The total gallons of intercepted ground water by both wells through January 16 1990 was 760 million (2330 acre ft) The total amount of sludge produced by the treatment operation since 1984 was 8 770 tons Sludge production in 1989 was increased due to the operation of the AOIW to recover contaminants

1 3 REPORT ORGANIZATION

The scope of work included in this report was specified in the Remedial Investigation Work Plan The RI Work Plan was submitted pursuant to the January 5 1989 Stipulation and Agreement Case Number 692 between Lindsay Manufacturing Co and the NDEC A proposed RI Work Plan was submitted February 21 1989 and following review by NDEC submittal of additional information by Lindsay Manufacturing and discussions between NDEC and Lindsay Manufacturing NDEC granted partial approvals for the RI Work Plan on April 13 1989 July 19 1989 and August 7 1989 A revised RI Work Plan was submitted November 15 1989 and approved November 17 1989 The work performed for the RI is supplemented by previous investigations (Section 1 2 3) This investigation reported and therefore includes work performed during this RI and supplemental information extracted from previous remedial investigations

The format of the work presented in this Remedial Investigation Report as outlined below follows the format set out in Attachment 2 to the January 5 1989 Stipulation and Agreement and is consistent with Table 3-13 Suggested RI Report Format in the EPA Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA Interim Final August 1988 The report is divided into seven Sections and Appendices as follows

Volume I

Section

1 Introduction
2 Study Area Investigations
3 Physical Characteristics of the Study Area
4 Nature and Extent of Contamination
5 Contaminant Fate and Transport
6 Baseline Risk Assessment
7 Summary and Conclusions

Volumes II & III

Appendices I through XI

Each section of the RI Report is summarized below

Section 2 reviews the data collection and field procedures used to investigate the site The methods of characterizing the hydrogeologic and geologic conditions are presented in detail These descriptions are augmented with pertinent physiographic ecologic meteorologic and demographic data collection procedures Section 3 reports the results of the investigations described in Section 2 The pertinent physical characteristics of the site and vicinity are comprehensively detailed A description of and results of computer models used in this investigation are provided

The nature and extent of the contamination as determined from the site characterization are presented in Section 4 The types of contaminants and extent of occurrence in soils ground water surface water and sediments are discussed

Section 5 discusses Contaminant Fate and Transport This section relates the analyses of the site s characteristics and identifies factors affecting contaminant migration and persistence The results of computer modeling are also presented and discussed

A Baseline Risk Assessment Section 6 was performed to evaluate the potential risk to human health and the environment based on site conditions In this case extensive interim remediation has already been performed and current site conditions are assessed Included are exposure and toxicity assessments, a risk characterization of the site, and an environmental assessment

The RI summary and conclusions are presented in Section 7 The nature and extent of the site contamination the fate and transport of the contamination and the site risk assessment are summarized Recommended remedial action objectives the investigation s data limitations and further recommendations are presented

A comprehensive compendium of appendices is also presented The appendices include technical data used to support the RI results from previous investigations supporting tables and figures and relevant data from the public geologic hydrologic hydrogeologic and meteorologic data bases

2 0 STUDY AREA INVESTIGATIONS

2 1 SURFACE FEATURES

The surface features of the site and vicinity have been studied using historic aerial photographs and topographic maps These documents were reviewed and interpreted for indications of original land forms and associated land-use modifications Pertinent photographs of the site vicinity include privately commissioned areal coverage on October 17 1986 and May 6 1989 In addition 1966 and 1985 versions of the U S Geological Survey 7-1/2 minute Lindsay topographic quadrangle map were reviewed and interpreted for indications of ground surface conditions cultural and land-use impact on the site and its surroundings Interviews with plant operators and civic personnel were performed during this investigation to evaluate on-site and local off-site alterations in land use and drainage A site specific topographic map is included as Figure 2 1-1

2 2 CONTAMINANT SOURCE INVESTIGATIONS

The direction of the initial site investigations (1983 and 1984) became focused after the early detection of an acidic water in the site monitoring wells These wells were located in the immediate vicinity of the spent acid disposal pit (pit) and the adjacent former burn pit (burn pit) (Figure 1 2-3) Acidic water ranging in pH from 2 0 to 2 9 was found to be draining from a sandy strata perched above the aquifer Three of the four wells installed in December 1982 penetrated the sandy strata and the underlying clay which perched acidic waters above the aquifer and acted as an aquitard to prevent these waters from entering the aquifer The annuli of these three wells were backfilled with a gravel rather than a grout which created a direct hydraulic connection between the sandy strata and the aquifer Subsurface studies in 1983 and 1984 had three main purposes to evaluate the quantity of acid contaminants to assess the response of the aquifer to proposed high capacity well interception and to determine the aquifer s response to flushing of the acid contaminants from the overlying clayey soils and perched sandy strata With closure of the disposal pit the studies concentrated on the perched strata immediately below the source of contamination

In 1987 the Nebraska Department of Environmental Control requested additional analyses for organic compounds of water samples from the monitoring wells and the treatment facility wastewater inflow and outflow Lindsay Manufacturing Co extended its sampling program in 1987 and 1988 to include organics and to perform shallow subsurface investigations The 1987 study reported in the 1987 Annual Status Report reviewed the effectiveness of draining the perched sandy strata during the interim remediation The 1988 study reported in the 1988 Extended Subsurface Remedial Investigation described the nature and occurrence of organics as well as metals in soils and the aquifer

In 1988 additional areas were sampled for organic chemicals These areas reported to have been used historically to discard degreasers and solvents or used as burn pits included the area northward of the plant expansion the reported burn pits one adjacent to the disposal pit and a historic burn site located between the galvanizing building and the Main Plant building (Section 1 2 2)

2 3 METEOROLOGICAL INVESTIGATIONS

Information on site and regional meteorology represents data collected by the Center for Agricultural Meteorology and Climatology at the University of Nebraska the National Weather Service and the United States Air Force In addition compiled meteorologic data was obtained from the National Climatic Data Center and Climates of the States 3rd Edition a National Oceanic and Atmospheric Administration publication U S Geological Survey topographic maps were consulted to evaluate the representativeness of meteorological data collected elsewhere to conditions at the site The meteorological data selected for presentation in this document represent the data set geographically nearest to the site (Section 3 2)

2 4 SURFACE WATERS AND SEDIMENT INVESTIGATIONS

2 4 1 Drainage Channel Sediments

In November 1989 a Dames & Moore hydrogeologist conducted a field reconnaissance of two drainage channels located central to and directly north of the Lindsay site The two channels drain to the west and are small runoff tributaries of the Dry Creek drainage system (Figure 2 4-1) The field reconnaissance was intended to assess whether organic compounds or metals were present within the channel sediments An organic vapor analyzer (OVA) was used to monitor the presence of organic compounds

Six sediment samples were collected from the central on-site drainage channel and three sediment samples were collected from the northern off-site channel (Figure 2 4-1) Sediment sample locations were based on the OVA measurements site observations and proximity to outfall pipes or other potential sources of wastewater discharge The samples were collected by pushing a 6-inch stainless steel tube six inches into the soil The tube was then extracted and sealed with a teflon cap and tape The samples were sent to Cenref Laboratories of Brighton Colorado for organic analyses All samples were preserved and shipped on ice accompanied by a chain of custody form in accordance with Dames & Moore s sampling plan Appendix A of the RI Work Plan

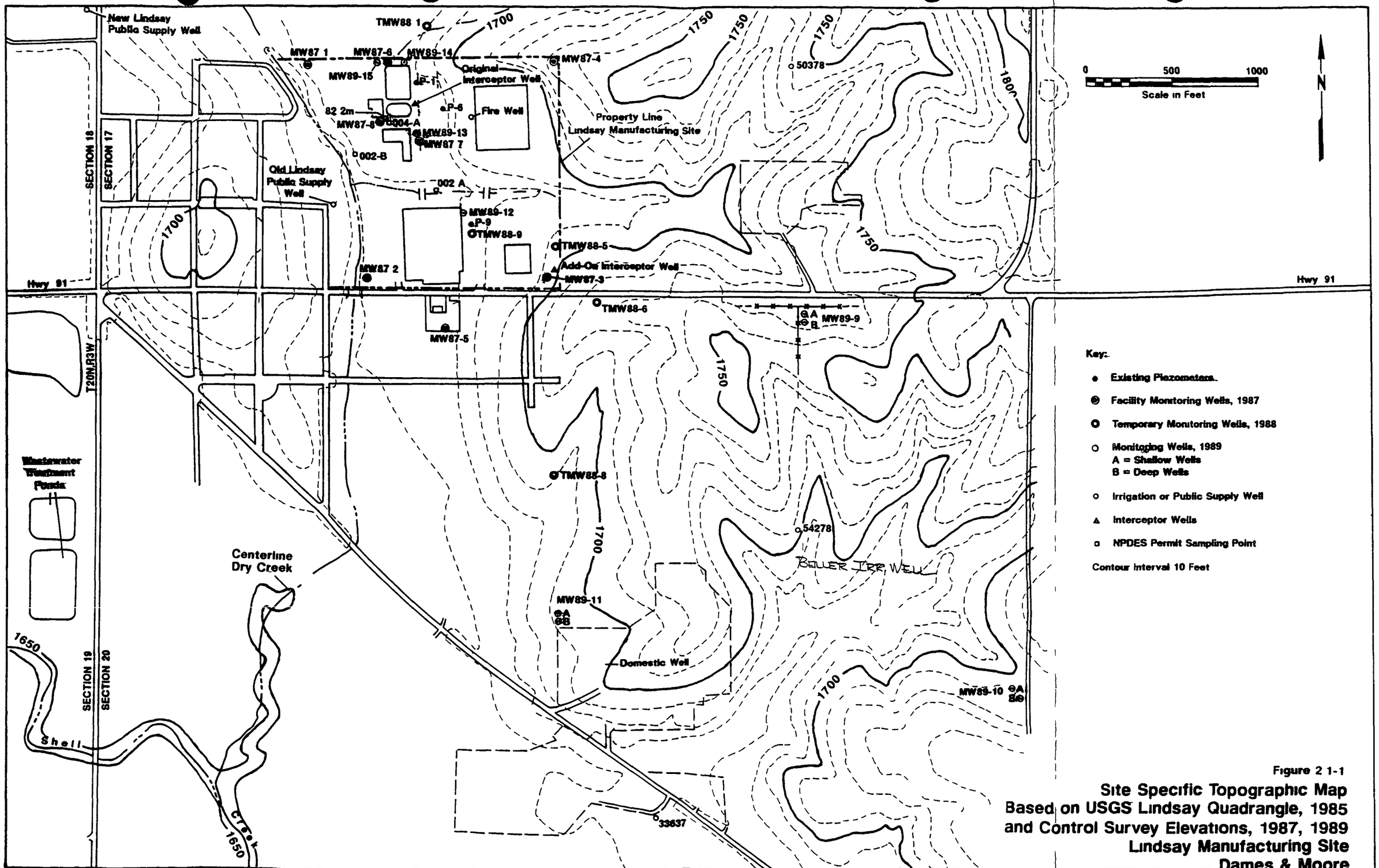

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Figure 2 1-1

Site Specific Topographic Map Based on USGS Lindsay Quadrangle, 1985 and Control Survey Elevations, 1987, 1989 Lindsay Manufacturing Site

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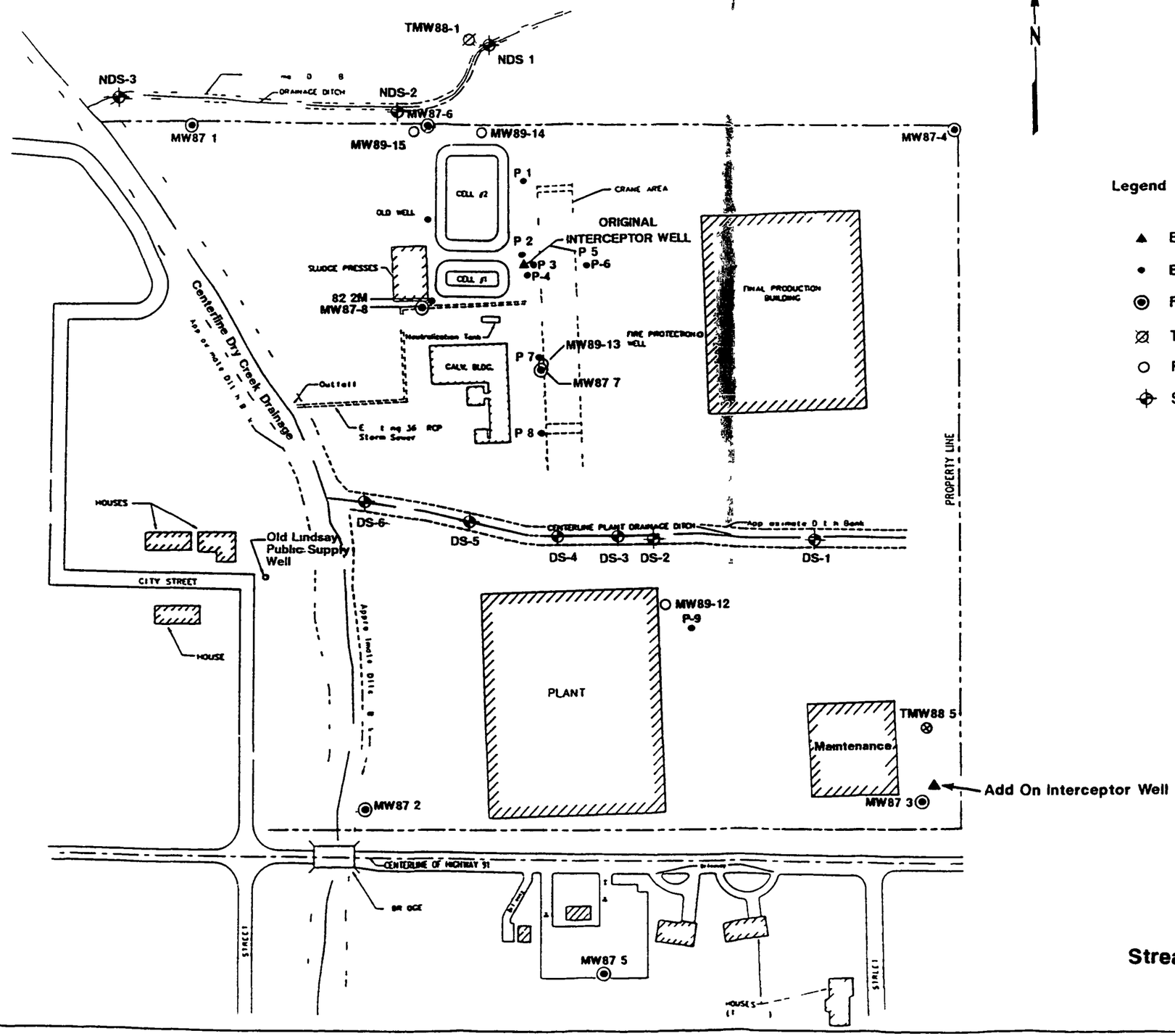

Figure 2.4-1
Stream Channel Sediment Sample Locations
November 14, 1989
Lindsay Manufacturing Site
Dames & Moore

Job No 16657 002

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2 4 2 Surface Water

Surface water investigations at the site consisted of a review of the NPDES permit (NE0113905) records for Lindsay Manufacturing Co manufacturing operations and the interim remediation pump and treatment system These records are maintained both by the Nebraska Department of Environmental Control and Lindsay Manufacturing Co

2 5 GEOLOGICAL INVESTIGATIONS

Since 1983 a number of different geological investigations of the study area have been undertaken by Lindsay Manufacturing Co These investigations were performed in conjunction with the on-going ground-water monitoring programs (see Sections 2 6 and 2 7) HWS began the investigations in 1983 and continued their work until 1987 Dames & Moore has managed the studies since then The geological investigations have included reviews and analyses of existing geologic documents borehole logging and sampling and laboratory analyses of subsurface samples for physical and chemical properties (Section 3 5) A list of these investigations was presented earlier in Section 1 2 3

2 5 1 Data Collection

A literature search and a compilation of local and regional geologic reports and maps was performed to characterize the site geology The data sources included

- United States Geological Survey topographical hydrological and geological maps
- Nebraska Geological Survey Bulletins
- United States Department of Agriculture Soil Conservation Service Platte County Soil Survey Maps
- aerial photographs published articles and previous reports and
- registered well logs

2 5 2 Deep Geologic Investigations

Much of the geologic data was acquired during the drilling of 42 on- and off-site wells designed for ground-water monitoring testing and sampling The details of the drilling for these ground water-related boreholes is found in Section 2 7 The following chronology details the information relevant to the geologic investigations Drilling logs for all boreholes during geological investigations are presented in Appendix I

2 5 2 1 1980-1987 Borehole Logging

In June 1980 Lindsay Manufacturing Co contracted with Staska Drilling Co to install a monitoring well fully penetrating the aquifer In 1982 Bruce Gilmore & Associates through their contractor Christianson Construction Co hired Layne-Western Co Inc to install four monitoring wells (82M series) for the proposed wastewater treatment facility (facility) (Figure 1 2-3) Preceding installation of the wells a test hole 100 feet deep was drilled (December 15 1982) at the proposed location of 82-1M (Section 2 7) to provide geological and geophysical logs for use in evaluating soil permeability In March of 1983 deep drill hole logs were obtained during installation of the Original Interceptor Well (OIW) and eight piezometers All drilling into or through the aquifer was performed by direct rotary methods and circulation The OIW was installed by reverse rotary method

In May of 1987 HWS Technologies (HWST) drilled eight deep test holes (TH-1 through TH-8) to further characterize the subsurface lithology and stratigraphy (Figure 1 2-4) The test holes were sited at proposed locations of ground-water monitoring wells The test holes were drilled using a 5-inch rotary rig and sample cuttings were obtained at 5-foot intervals The test holes ranged in depth from 84 to 169 feet

2 5 2 2 1988 Borehole Logging and Sampling

In August of 1988 ten deep test borings (DB-1 through DB-11) were performed by Grosch Irrigation Drilling Co under the supervision of Dames & Moore personnel (Figure 1 2-4) DB-1 was drilled north of the site four borings (DB-3 4 5 and 9) were drilled in the southeast quarter of the site and five borings (DB-6 7 8 10 and 11) were drilled in pasture southeast of the site DB-2 was abandoned while drilling due to rig failure and subsequent borehole collapse The deep borings were intended to supplement the existing knowledge of the subsurface lithology and stratigraphy and for installation of temporary monitoring wells The borings penetrated to bedrock which ranged from 75 to 162 feet deep and were drilled using a 5-inch diameter conventional rotary rig The cuttings were logged at 5-foot intervals The deep borings were abandoned and filled with cuttings to one foot below the top of the aquifer The remainder of the hole was grouted to the surface with bentonite

2 5 2 3 1989 Borehole Logging Sampling and Analyses

In June of 1989 three off-site test holes DB-9 10 and 11 which correspond to couplet locations MW89-9A & B MW89-10A & B and MW89-11A & B were drilled in the NE 1/4 of section 20 southeast of the Site (Figure 1 2-4) The off-site test holes were drilled under Dames & Moore supervision by Christensen Enterprises using a direct mud rotary rig to depths ranging from 120 to 190 feet Standard split spoon samples were collected at five foot intervals The

samples were logged using the Unified Soil Classification System Samples collected by penetration tests were analyzed for grain size distribution

Additional geologic data (June 1989) was acquired prior to the installation of four proposed on-site monitoring wells MW89-12 through MW89-15 (Section 2 7) MW89-13 through MW89-15 were logged and sampled at 5-foot intervals using standard penetration tests MW89-12 was logged and sampled from continuous examination of cuttings Disturbed samples were taken from all boreholes for grain size distribution analyses moisture density tests liquid limits and plasticity indexing

2 6 SOIL AND VADOSE ZONE INVESTIGATIONS

2 6 1 Scope

Extensive shallow soil borings and test hole drilling have been conducted at the site for the soil and vadose zone investigations These investigations were intended to

- assess the nature and extent of organic and inorganic compounds in the perched sand channel and the reduction of such compounds through interim remediation
- determine the composition and properties of the soils underlying the manufacturing plant
- identify the physical characteristics and occurrence of organic compounds in the vadose zone and
- assess the potential for migration and attenuation of chemical compounds in the soils

2 6 2 Soil and Vadose Investigations

2 6 2 1 1983 Investigations

In 1983 HWS conducted two preliminary investigations to characterize the shallow soils and the vadose zone (HWS 1983) In January Western Laboratories drilled five soil borings (P-1 and 2 and B-1 2 and 3) using a 6-inch continuous flight auger to depths ranging from 15 to over 30 feet In March Western Laboratories drilled fifteen additional soil borings (C-1 through C-15) using a 6-inch continuous flight auger to depths ranging from 30 to 70 feet All samples were obtained with standard penetration tests using a 2-inch split barrel sampler The soil borings were logged by a HWS geologist Water level depths depth to cave-in and soil pH were measured in the field Standard laboratory chemical analyses for inorganic constituents were also conducted

Liquid and plastic limit determinations moisture density tests and mechanical soil analyses were performed on selected samples

2 6 2 2 1987 Investigations

In May of 1987 a shallow boring program was conducted by HWST to reassess the quantity and disposition of acidic contaminants perched in site soils (HWST 1987 D & M 1988) This investigation consisted of fifteen continuous flight auger borings (87-1 through 87-15) that ranged in depth from 40 to 52 feet Disturbed and undisturbed samples were collected at five foot intervals by standard penetration and shelby tube methods and were logged by an on-site HWST geologist Water level depths depths to cave-in soil pH eH and temperature were measured in the field Laboratory analyses of soils samples were similar to those performed in 1983 In addition saturated soils extracts were analyzed for metals and acidity

2 6 2 3 1988 Investigations

Between June and August 1988 an extensive soils investigation was performed by HWST under the direction of Dames & Moore (D & M 1988) Investigation was directed to further characterize the nature and extent of acidic contaminants in both the perched sand channel and the silty clayey soils In addition the study evaluated organic compound occurrence

This extended investigation included 38 borings and five test holes The borings were advanced by hollow stem auger and continuous flight solid core auger The test holes were drilled with straight flight auger only and were exploratory in nature they were not intended as soil sampling sites The borings ranged in depth from 38 to 53 feet deep and the test holes ranged in depth from 44 to 48 feet All the holes were sampled and logged by a HWST geologist The soil samples were obtained using standard penetration tests and thin-walled shelby tubes All samples were field screened for organic compounds and pH followed by portable on-site gas chromatographic analyses Water levels and depth to cave-in were also measured in the borings prior to grout closure Laboratory analyses of soil properties included Atterburg limits permeability tests grain size distribution and moisture/density analyses The analytic chemical laboratory analyses of soils included organic and inorganic constituents

At the completion of the 1988 field program the borings and test holes were grouted with bentonite and bentonite/native clay mixtures In borings that penetrated the aquifer a pure bentonite grout was used to seal the aquifer-aquitard contact to prevent the potential migration of contaminants

The boring logs and materials physical parameters are presented in Appendix I Analytical soil sample results are discussed in Section 4 2 and laboratory data are presented in Appendix II

2 7 GROUND-WATER INVESTIGATIONS

2 7 1 Site History

In 1980 Lindsay Manufacturing Co began conducting ground-water investigations designed to monitor ground-water quality around the spent acid disposal pit (pit) and proposed wastewater treatment facility (facility) Lindsay Manufacturing retained Staska Well Drilling Co to install a deep monitoring well adjacent to the proposed facility This well is labeled Old Well in this report

In 1983 Lindsay Manufacturing Co identified contaminated ground water in the 1982 monitoring wells and the Old Well installed by Staska (Section 2 5 2) and contracted with HWS to identify and characterize the contamination and remediate the ground water In the geologic/hydrogeologic (Feb 11 1983) reconnaissance it was recognized that the ground water could be subject to dispersal by high capacity wells such as the surrounding irrigation wells and public supply well The investigations were subsequently designed to determine the local and regional ground-water levels flow rates flow directions aquifer characteristics and water chemistry

Since 1983 installation and pumping of first one and later two interceptor wells pursuant to an existing NPDES permit have recovered over 757 million gallons (2 330 acre-ft) of purged ground water The interim remediation of the site has been based on extensive investigation of the local dynamic hydrogeologic and geochemical conditions The investigation has developed from an expanding network of monitoring wells and piezometers and an increasing data base Monitoring well piezometer and interceptor well placement is based upon a continual process of re-evaluation of aquifer conditions and of the status of interim remediation Computer simulation provides additional information of the hydrologic regime (Section 3 6)

2 7 2 Well Installation and Monitoring

This subsection describes the chronology of field procedures for the ground-water investigations Installation development and testing methods are outlined for each year beginning in 1982 and extending to the present Ground-water monitoring and sampling have been performed at the site by Lindsay Manufacturing Co HWST and Dames & Moore periodically since 1981 Monitoring has been performed according to plans which include the March 1981 and revised January 1983 Ground-water Monitoring Plans (Lindsay Manufacturing Co) the 1986 Remediation Monitoring Plan (HWS) the 1988 Quality Assurance/Quality Control Project Plan and the 1989 RI Work Plan All the monitoring well construction diagrams are presented in Appendix III

2 7 2 1 1982 Investigations

In 1982 Bruce Gilmore & Associate s main contractor Christianson Construction Co subcontracted with Layne-Western Co Inc to install four wells (82-1M through 82-4M) to monitor local ground-water conditions at the location of the proposed wastewater treatment facility (Figure 1 2-3) Between December 15-21 1982 three wells were installed downgradient (82-2M 3M and 4M) and one well (82-1M) was installed upgradient of the existing disposal pit Preceding well installation a 100 feet deep test hole was drilled (December 15 1982) at the proposed location of MW82-1M to provide geologic and geophysical logs for use in evaluating soil permeability

The deep test hole was drilled with 4-inch direct rotary method and apparently overreamed with 10-inch bit for completion of the monitoring well 82-1M The other 82-M series wells were drilled with 10-inch bit to depths ranging from 57 to 58 feet (Appendix III-A)

The wells were constructed of 4-inch PVC casing and PVC screen in the 10-inch diameter holes All the screen lengths were 12 feet and were placed in the upper portion of the aquifer The filter packs ranged from 30 to 33 feet thick and consisted of road gravel The remaining hole annuli were filled to the surface with native silty clay material or a mixture of native material and bentonite

2 7 2 2 1983-1986 Investigations

The Original Interceptor Well (OIW) designed to remediate the ground water was installed between March 22 and March 24 1983 (Figure 1 2-4 & Appendix III) Also in March 1983 Grosch Irrigation Drilling Co was contracted to install nine piezometers (P-1 through P-9) in the study area (Figure 1 2-4) The piezometers were designed to measure and record changes in ground-water levels during interceptor well test pumping All the wells were drilled to approximately 88 feet using a rotary rig and constructed of 2-inch PVC with 10 feet screens placed near the bottom of the aquifer More details of the well installations can be found in HWST documents previously submitted to NDEC (HWS 1983 1986 and HWST 1987)

Two types of aquifer pump tests a step-drawdown test and a five hour constant drawdown rate recovery test (Appendix VIII) were performed on this well to provide data to estimate aquifer characteristics The constant rate recovery test was limited to 5 hours due to a limited wastewater storage capacity Measurements from the OIW and the piezometers have been used to calculate the aquifer s transmissivity storativity and hydraulic conductivity Lindsay Manufacturing Co personnel have monitored the OIW operation for water levels pH temperature flow rates and well efficiency (Appendix VI)

A comprehensive ground-water monitoring program began in 1983 Quarterly water sampling for chemical analyses was conducted in three sets of wells

- monitoring wells 82-1M through 82-4M which partially penetrated the aquifer
- three deeply screened piezometers (P-1 P-6 and the Old Well) and
- the Old Lindsay Public Supply Well (sampled although closed for supply purposes and replaced with a new public supply well) the Fire Well and P-9

A 72-hour pump test of the OIW was performed in June 1984 (Appendix VIII-C) to more accurately determine the aquifer s transmissivity and storage coefficient and to evaluate the influence area of the OIW

In 1985 HWS recommended increasing the monitoring frequency to monthly sampling of select wells The Old Lindsay Public Supply Well and the Fire Well were added to the monthly sampling program in 1986 Monthly field measurements included water levels pH specific conductance water and air temperature

2 7 2 3 1987 Investigations

Eight additional monitoring wells (MW87-1 through MW87-8) were sited and designed by HWST and installed during October and November of 1987 (Appendix III-C) The 1987 monitoring wells were intended to reassess the extent of contamination in the aquifer Three of the 1982-series wells penetrated the perching aquitard but were connected to the sand channel by the hydraulically conductive filter pack The water quality data from these 1982-series wells were regarded as more representative of acidic contamination in the perched sand channel than of the aquifer conditions

In 1987 these three 1982-series monitoring wells were removed and their boreholes plugged (Appendix III-A) ending this pathway for continued transmission of acidic contaminants into the aquifer Monitoring well 82-2M was retained and continues to serve as a ground-water monitoring well Since 82-2M did not penetrate the sand channel it does not transmit contaminants into the underlying aquifer it is regarded as a representative partially penetrating monitoring point

The 1987 monitoring wells were installed by Grosch Irrigation Drilling Co HWST well designs were based on data compiled from five test holes drilled earlier in 1987 and one test hole (82-1M) drilled by Layne-Western Co Inc in 1983 Three of the wells (MW87-1 4 and 6) were drilled upgradient and five (MW87-2 3 5 7 and 8) were drilled downgradient of the location of

the closed pit Eight 12-3/8 inch boreholes were drilled using a conventional rotary rig to depths ranging from 95 to 180 feet All the wells were constructed of 4-inch PVC casing with stainless steel screens ranging from 11 to 45 feet in length Each filter pack consisted of clean well-graded siliceous sand which was capped by a bentonite grout A concrete seal was placed above the bentonite grout to the ground surface

In December of 1987 HWST performed a third pump test (Appendix VIII-B) of the OIW to measure the water yield response in the recently installed 1987-series monitoring wells Personnel from the Nebraska Department of Environmental Control attended the operation of this test

Water level measurements and the hydrographs of this data have supplemented the pump test analyses on an annual basis from 1983 to 1987 In June of 1987 with the advent of continuous pumping of the OIW water level measurements from the piezometers and monitoring wells could be evaluated over longer stress periods Analysis of this data and registered irrigation/public supply boring logs allowed construction of a hydraulic model of the site aquifer This model created at HWST was presented in 1988 (D & M 1988)

The analysis of water from MW87-3M revealed that acidic contaminants with organic components occurred deep in the aquifer The hydraulic model suggested that this contamination although well within the influence area of the OIW could possibly be intercepted and captured by the irrigation wells south and southeast of the site The 1987-series wells were added to the quarterly monitoring plan and later fitted with dedicated pumps An extended deep aquifer investigation was undertaken and the irrigation wells were added to the sampling plan

2 7 2 4 1988 Investigations

In 1988 ten temporary monitoring wells (TMW88-1 and TMW88-3 through TMW88-11) were installed by Grosch Irrigation Drilling Co under the supervision of Dames & Moore personnel (Appendix II-D) TMW88-2 was not installed because of drill rig failure and bore hole collapse Four of the wells (TMW88-3 4 5 and 9) were located on-site and six wells (TMW88-1 6 7 8 10 and 11) were located off-site The boreholes were drilled to depths ranging from 102 to 162 feet and the temporary wells were constructed of 2-inch PVC casing and a three feet section of 2-inch slotted PVC screen A filter pack of clean well-graded silicious sand was placed from the bottom of the bore hole to two feet above the top of the screen Bore hole cuttings consisting of sand and gravel were placed above the filter pack to within one foot of the top of the aquifer The sand and gravel cuttings were capped by a 3-foot bentonite seal and the remainder of the borehole was left open to facilitate later well dismantling and abandonment

The 1988-series temporary wells were developed by purging with compressed air Eight of the wells provided water samples from the base of the aquifer and wells TMW88-8 and 11

provided water samples from slightly above the base of the aquifer (Dames & Moore 1988) In 1988 quarterly sampling was performed on the 1987 wells (MW87-1 through MW87-8) 82-2M the Fire Well the Old Lindsay Public Supply Well and irrigation wells 50378 54278 and 33637 The temporary wells were sampled twice in 1988

2 7 2 5 1989 Investigations

As part of the continuing remediation program in February of 1989 an Add-On Interceptor Well (AOIW) was installed in the southeast corner of the site (Figure 1 2-4) (Appendix III-B) A step-drawdown pump test and a constant rate pump/recovery test (Appendix VIII-C) were performed to determine aquifer transmissivity storativity hydraulic conductivity well specific capacity and well efficiency During the pump tests water level changes were recorded in selected monitoring wells and piezometers The step-drawdown test consisted of three stages during which pumping rates were increased over approximately one and one-half hours Water level recovery was monitored for two hours following pump shutdown The constant rate pump/recovery test was conducted during the last four hours of the pumping period followed by an additional water level recovery monitoring lasting approximately 5 5 hours

From September 18 through November 8 1989 seven additional monitoring wells were installed to further characterize the aquifer and delineate the extent of the contamination (Appendix E) Three off-site couplet wells were drilled and installed by Grosch Irrigation Drilling Co using a direct mud rotary rig under the supervision of Dames & Moore personnel The off-site wells were installed at the geologic test hole locations TH-9 TH-10 and TH-11 (see Section 2 1 5) and were labeled MW89-9A 9B 10A 10B 11A and 11B where A are shallow and B are deep All the wells ranged in depth from 40 to 190 feet

Four additional shallow wells (MW89-12 13 14 and 15) were installed on-site The on-site wells were drilled and installed by Christensen Enterprises using a direct mud rotary drilling method also under Dames & Moore supervision

All of the 1989 monitoring wells were constructed in 10-inch boreholes with 4-inch PVC casing and 4-inch stainless steel screens The screens ranged from 10 to 15 feet in length The screens in on-site wells MW89-12 and 15 were placed at the top of the aquifer while in wells MW89-13 and 14 the screens were placed above the aquifer in a perched sand channel The screens in the shallow off-site wells (MW89-9A 10A and 11A) were installed at the top of the aquifer and in the deep off-site wells (MW89-9B 10B and 11B) the screens were installed at the bottom of the aquifer

At each well a filter pack consisting of clean well-graded siliceous sand was placed to 2-3 feet above the top of the screen Each filter pack was sealed by a minimum of 5 feet of bentonite

grout and then filled to the ground surface with cement grout The wells were developed by purging the well with a submersible pump until the water was clear and the field water quality parameters were constant (Dames & Moore, 1989)

The 1989 quarterly sampling schedule included the 1987 wells (MW87-1 through MW87-8) 82-2M Old Lindsay Public Supply Well the Beller domestic well and the seven 1989-series wells after installation Also in 1989 irrigation wells 50378 54278 and 33637 were tested twice once prior to the irrigation season and once after the irrigation season

2 8 HUMAN POPULATION SURVEYS AND LAND USE

Information on local human populations and their water use was collected from the Omaha Office of the U S Department of Housing and Urban Development U S Geological Survey topographic maps and the Nebraska well registration board Land use was determined by field reconnaissance and by a review of 1986 and 1988 aerial photographs of the site and vicinity Personal interviews were conducted with the State Commission on Economic Development and private residences in an arc two miles south of the site not known to use the Village of Lindsay public water supply (Figure 2 8-1) This information base was evaluated to identify the areas and human populations potentially exposed to soils and ground water at the site (Section 3 7)

2 9 ECOLOGICAL INVESTIGATIONS

The purpose of the ecological investigations was to assess the potential risks to the natural environment A worst-case conservative scenario was applied wherein it was assumed that the largest possible area might be impacted and that higher levels of exposure to the environment might result if no further action was undertaken These assumptions are based heavily on a contaminant transport ground-water model which is described in Section 3 6

The primary objectives of the ecological risk assessment were to

- describe the wildlife and habitats in the area downgradient of the Lindsay site
- identify areas where contaminants could potentially enter the surface water or terrestrial environments and
- estimate the nature and extent of any potential hazards to the biological community

As described in the RI Work Plan information on wildlife and habitats in the Lindsay area was based on aerial photography state agency records consultations with local resource personnel and available literature There is very little site-specific data Much of the information was

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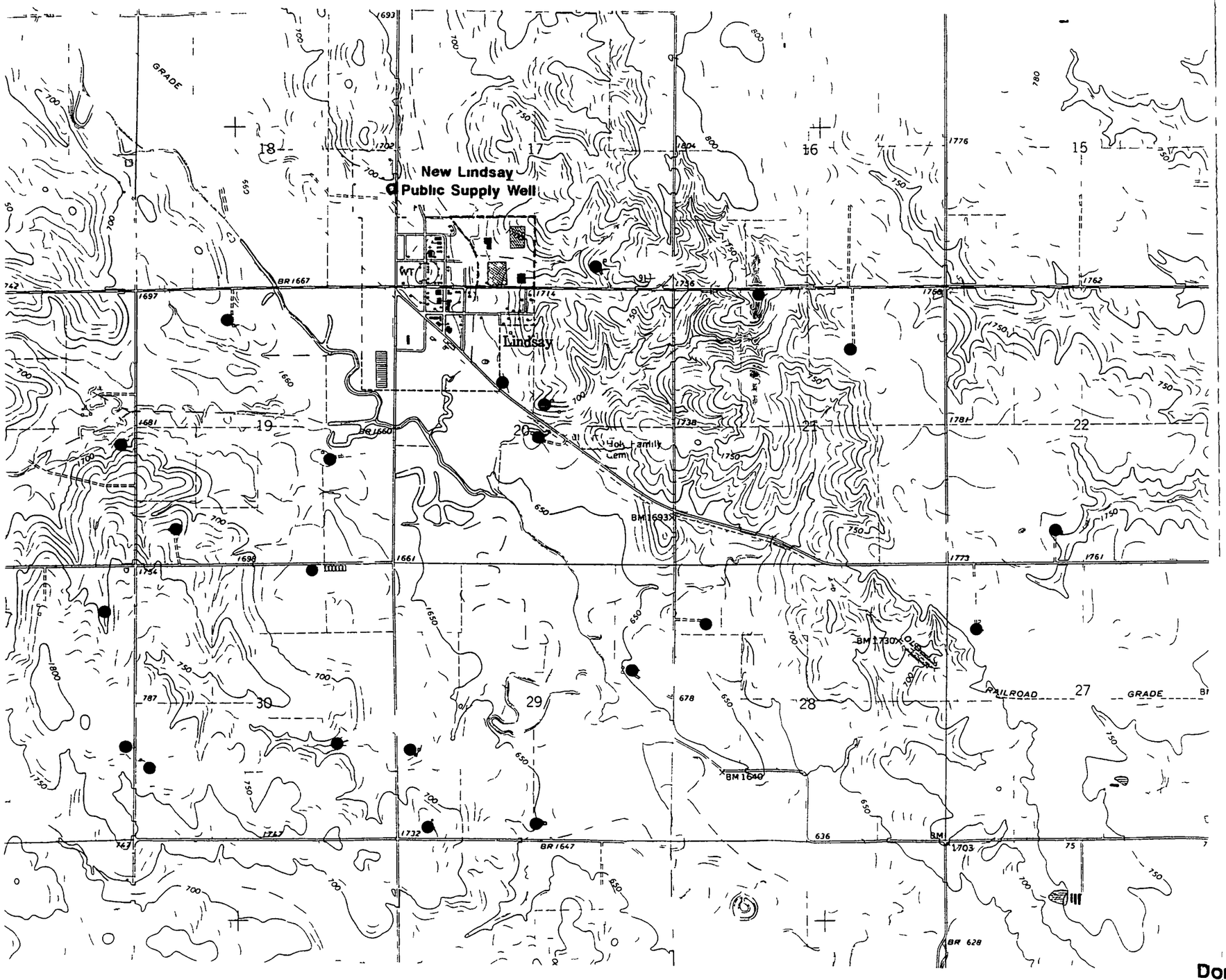

Key

● Residential Well

O Public Supply Well

0 2000 4000

Approximate Scale in Feet

Figure 2 8-1

Location of Public and Private Domestic and Stock Water Supply Wells

Lindsay Manufacturing Site

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extracted from data sets for larger geographic areas For example a wildlife species list was compiled which represents species that are likely to occur in the area Since there have been no field studies in the Lindsay area there is no data on active species occurrence or populations for this specific locale However the lists and population lists are believed to be representative based on discussions with resource personnel The site ecology is discussed in Section 3 8

3 0 PHYSICAL CHARACTERISTICS OF THE STUDY AREA

3 1 SURFACE FEATURES

The Lindsay Manufacturing Co site is located in the southeast quarter of the southwest quarter of Section 17 Township 20 North Range 3 West Platte County Nebraska (Figure 1 2-1) The Village of Lindsay lies on the east boundary of the Nebraska sandhills and the local region is characterized by rolling and dissected loess plains The site is situated in a relative topographic low created by Shell Creek and its tributary drainages The average elevation of the site is approximately 1 670 feet above mean sea level while local relief ranges from 1 650 to 1 800 feet above mean sea level (Figure 1 2-1)

The site is bounded on the north by farmland on the east by Lindsay town limits and farmland on the south by State Highway 91 and a residential area of Lindsay and on the west by a tributary to Shell Creek its greenbelt and a residential area of Lindsay The drainage channel is dry except during storm runoff and when receiving plant waste- water discharge Plant discharge is according to NPDES permit

The site has been selectively leveled and stabilized Drainage swales have been filled and some surfaces paved for transportation and equipment storage A loessal slope on the east half of the site has been locally incised for construction of the maintenance and final production buildings (Figure 1 2-3) During the 1980s the drainage west of the site (Dry Creek) was straightened and improved as part of a flood control and land stabilization project

The site is approximately 1 300 feet long (north to south) and the width ranges from approximately 1 570 feet at the north end of the property to 1 100 feet at the south end The surface gradient across the property drains to the west and ranges from 023 ft/ft in the central drainage channel to 053 ft/ft across the south property boundary Currently the site contains five buildings including the main manufacturing plant and offices the maintenance building the galvanizing building the final production building and sludge presses Two settling ponds located on the north end of the property are part of a waste-water treatment system originally designed to receive and treat spent acid from the galvanizing building The system also includes a neutralization tank piping and appurtenances This system no longer receives spent acid and has been converted to an interim wastewater treatment facility to assist in the aquifer restoration program This program includes two high capacity interceptor wells (OIW and AOIW) and above-ground pipe lines connecting them to the wastewater treatment facility The plant is supplied by the Lindsay public water supply system and serviced by the Lindsay public sanitary sewer Storm drains at the plant discharge to the intermittent tributary to Shell Creek along the west property boundary pursuant to NPDES permit No NEO113905

3 2 METEOROLOGY

Nebraska s climate is characterized by hot summers and cool winters with large seasonal and annual variations in temperature and precipitation Alternating and interacting air masses from the Rocky Mountains and the Gulf of Mexico greatly influence the climate and are the cause of frequent and dramatic weather changes The air masses from the Rocky Mountains are usually dry whereas the air masses from the Gulf are wet The distance to the Gulf and the variability in regional winds are the principal reasons for the large annual variations in precipitation

The meteorological conditions present at the Lindsay site are expected to be similar to regional meteorologic conditions and therefore meteorological data recorded in neighboring communities can be taken as representative Detailed meteorological data has been recorded at stations located in Albion (16 miles west of the site) Genoa (17 miles south) Tarnov (12 miles southeast) and Norfolk (24 miles northeast) as well as in Lincoln (85 miles southeast) Omaha (95 miles east) Central City (45 miles southeast) and Grand Island (65 miles southwest) The following summary of site meteorologic conditions except wind is based primarily on data recorded in Albion during the period 1951-80 by the National Weather Service A comparison is made to data recorded in Genoa and Norfolk during the period 1951-80 Some data is presented from the Tarnov station obtained during 1988 and 1989 by the University of Nebraska Wind data from the Norfolk station and Offutt Air Force Base in Omaha are presented

The site is situated at an elevation of 1680 ft in the shallow river valley formed by Shell Creek which flows southeast The valley walls rise 80 to 100 ft within one-quarter mile of the site In general the topography within several tens of miles of the site is characterized by shallow rolling hills and shallow drainage basins

Albion is located in a very slightly depressed river channel formed by Beaver Creek which flows southeast the meteorological station elevation is 1760 ft Genoa is located at the northern corner of the intersection of the shallow river valleys formed by Beaver Creek which flows southeast and the Loup and Platte Rivers which flow east the meteorological station elevation is 1590 ft Tarnov is located on a very slight rise in an area with generally little relief the exact meteorological station elevation is unknown but it is approximately 1850 ft Norfolk is located in a shallow river channel formed by the Elkhorn River which flows east and south east the meteorological station elevation is 1544 ft

Temperature and precipitation data from the Albion station is very similar to the data from the Genoa station The Genoa station was generally about 2 °F warmer The number of days with a temperature of 90 °F at the Genoa station was 42 rather than 36 for Albion Precipitation data was very comparable

Temperature and precipitation data from the Albion station is also very similar to the data from the Norfolk station The Norfolk station was generally about 0 1 °F warmer and averaged 34 days per year with a temperature greater than 90 °F Annual mean precipitation at Norfolk was 3 1 inches less than at Albion

3 2 1 Wind

From May to September the prevailing wind directions were from the south to southwest across the state and from the northwest during the remainder of the year The average annual wind speed was approximately 10 mph

An annual wind rose for Offutt Air Force Base in Omaha during the period 1960-64 is shown in Figure 3 2-1 The average wind speed was 7 7 mph and winds occurred most frequently from the north-northwest Calm conditions occurred 15 6% of the time

At the Norfolk station mean annual wind speed was 11 5 mph Monthly data from the Norfolk station shows that winds were strongest from November through March and were generally from the northwest with an average speed of 12 8 mph The winds were weakest during April through October and generally were from the south with an average speed of 10 5 mph

Thunderstorms occurred an average of 45 to 50 days per year mainly in the spring and summer Peak winds associated with the storms commonly reached 60 mph with a maximum recorded wind speed of 78 mph However these winds were generally brief lasting less than one minute The fastest wind speeds of greater than one minute duration were generally less than 50 mph

3 2 2 Temperature

The average annual temperature at the Albion station was 48 1 F The average annual daily maximum and minimum temperatures were 60 9 and 35 2 °F respectively The temperature data shows a pronounced seasonal variation The average daily maximum and minimum temperatures in July were 87 6 and 62 0 F The average daily maximum and minimum temperatures in January were 30 6 and 6 5 °F

The extreme maximum temperature recorded 111 °F occurred in July On average 36 days per year had a high temperature of 90 °F or above with 24 of the days occurring in July and August

The extreme minimum temperature recorded -28 °F occurred in January On average 166 days per year had a low temperature of 32 °F or below and 22 days per year had a low temperature of 0 °F or below

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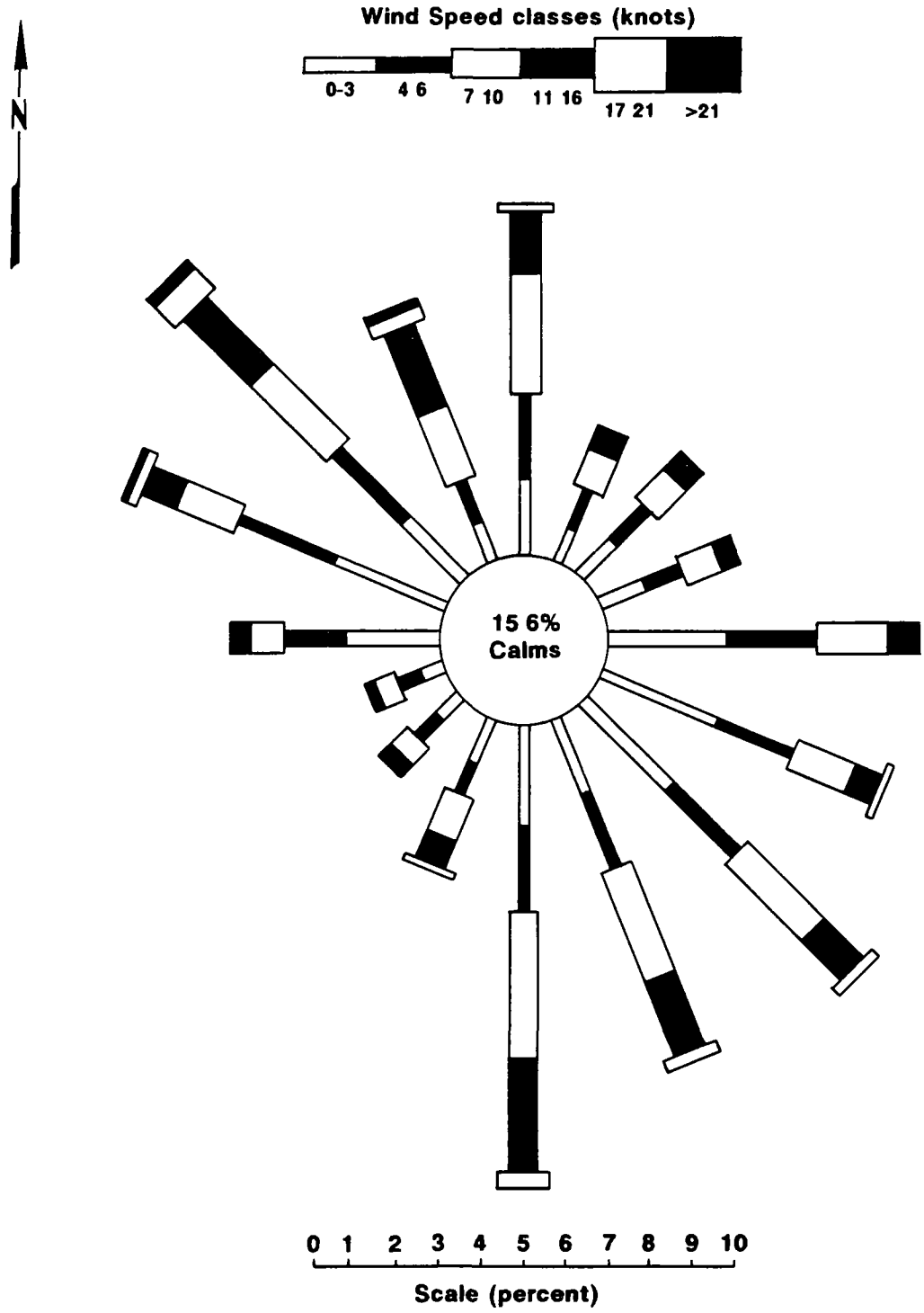

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Figure 3 2 1

Offut Air Force Base, Omaha Nebraska, 10m Level 5 Year Wind Rose 1960-1964 (Calms Included in 0-3 kt Speed Category)

Dames & Moore

3 2 3 Precipitation

The average annual precipitation at the Albion station was 27 inches The wettest months were May June July and August with 3 4 to 4 3 inches per month The driest months were November December January and February with 0 4 to 0 9 inches per month The greatest precipitation in one month 12 6 inches occurred in August as did the greatest daily precipitation 10 3 inches On average there was one storm per month during the period April through September which produced more than 1 inch of rain

The average annual snowfall was 30 1 inches (as snow not water) Approximately 7 inches per month occurred in December February and March with 5 5 inches in January The greatest monthly snowfall 21 5 inches occurred in December

3 2 4 Evapotranspiration

At the Tarnov station evapotranspiration was typically less than 0 1 inch per day in the winter and was often 0 25-0 35 inches per day in the summer Total annual evapotranspiration was 56 inches in 1988 and 58 inches in 1989 for the period through December 13

3 2 5 Other Data

Statewide data on relative humidity and frequency of sunny conditions is available Relative humidity varied from 55 to 73 percent in January to 35 to 55 percent in July Sunny conditions occurred 65 percent of the time annually varying from 55 percent in December to nearly 80 percent in July

At the Norfolk station skycover during daylight hours averaged 57% annually Sky cover was slightly greater than average during the winter and spring and less than average during the summer and fall Annually relative humidity averaged 80% in the morning and 57% in evening Morning relative humidity was fairly constant throughout the year although the evening relative humidity varied from 65% during November through March to 50% from April through October

Annual atmospheric stability class frequency distributions for Offutt Air Force Base in Omaha are shown in Appendix V Classes D (neutral) and F (most stable) occurred most frequently averaging 43 and 28% of the time respectively

3 3 SURFACE WATER

The site is in the upland drainage area of Shell Creek The western boundary of the site is a tributary drainage to Shell Creek which is intermittent flowing only during runoff events Since June 1987 this tributary has received practically continuous discharge from the interim ground-

water remediation operation The treated waters are monitored by the facility s NPDES permit (Section 1 0) Additionally plant cooling water is discharged through a permitted outfall in an east to west drainage ditch central to the site

3 4 GEOLOGY

3 4 1 Regional Geology

The site is situated in the Great Plains physiographic province on wind-deposited (loessal) sediments mantling sands and gravels of the Pleistocene geologic epoch (Condra and Reed 1959) The discussion below summarizes the geologic structure and bedrock conditions beneath the sands and gravels and is then followed by a general discussion of the age and origin of the sands and gravels Figure 3 4-1 is a generalized stratigraphic column for the region

The site is located near the eastern limit of the Central Nebraskan Basin which is a large depression in the pre-Cambrian basement The axis of the basin extends in a general northwest/southeast direction and is located to the west of Platte and Boone Counties (Figure 1 2-1) The pre-Cambrian basement is composed of granites quartzites and schists which have been encountered in oil and gas boreholes (Condra 1959) The depth to the pre-Cambrian rocks is over 4 500 feet at the center of the basin but probably less than 3 000 feet at the site Sedimentary deposits overlie the pre-Cambrian basement at the site and are represented by rocks of the Cambrian Ordovician Devonian Mississippian and Pennsylvanian geological systems (Figure 3 4-1)

The uppermost of the sedimentary rocks are the Cretaceous deposits which unconformably overlie Pennsylvanian deposits and form the bedrock surface for Quaternary deposits in most of Eastern Nebraska At the site Cretaceous deposits may be over 1 000 feet thick and are represented by the Dakota Sandstone Greenhorn Limestone Graneros Shale Carlile Shale and the Niobrara Formation (Burchett 1975) The Lower Cretaceous Dakota Sandstone Formation is up to 650 feet thick and comprised of sandstone and shale The Greenhorn Limestone and the Graneros Shale Formation total less than 85 feet thick and overlie the Dakota Sandstone Formation The Carlile Shale Formation is comprised mainly of shale with minor amounts of fine-grained sandstone siltstone and thin layers of limestone (Figure 3 4-1)

The Cretaceous Niobrara Formation is the shallowest bedrock unit in the vicinity of Lindsay Nebraska This formation is comprised of argillaceous chalk and limestone with interbedded chalky shale and ranges up to 300 feet thick however its surface was once exposed and subject to weathering and erosion The Niobrara is less than 300 feet thick at Lindsay Nebraska and has been totally eroded east of Platte County To the west of Platte County the Niobrara is overlain by the Ogallala Formation of the Tertiary System but the Ogallala is not reported present at the site The upper bedrock contact of the Niobrara is a paleo-erosional surface which generally

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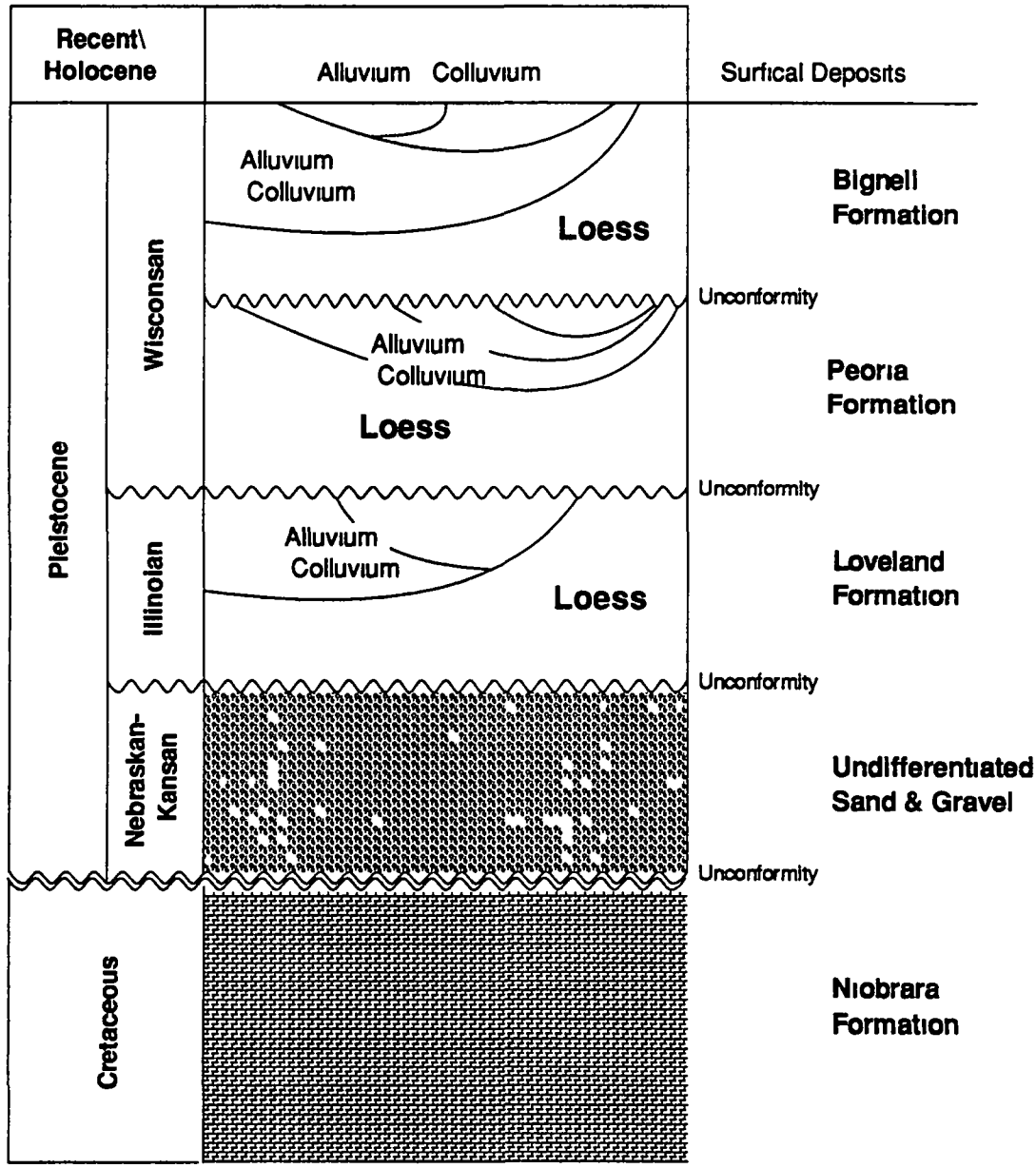

Figure 3 4-1
Lindsay Site Regional Stratigraphic Column
Lindsay Manufacturing Site
Dames & Moore

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slopes to the east at an average of 10 to 15 degrees (Weeks 1981) The bedrock surface in the vicinity of Lindsay Nebraska occurs at approximately 1580 feet above sea level and is covered by about 100 to 200 feet of Quaternary deposits (Figure 3 4-1)

Although not reported in the literature or on maps several test holes encountered materials characteristic of the Pliocene Ogallala Formation (Section 3 4 2) including inter-bedded silty claystone siltstones and fine sandstone These occurrences are limited in extent and no effort was made to age date these materials

The region s Quaternary deposits result from glacial alluvial (river) and loessal (wind) processes The furthest extent of glaciation in Nebraska did not reach the Lindsay Nebraska area terminating approximately 15 miles to the east The Nebraskan and Kansan age glaciers however reached eastern Nebraska and formed great dams across the pre-existing eastward-trending river valleys of Nebraska The dammed rivers deposited large accumulations of sand and gravel in their valleys over a wide belt in Central Nebraska These sand and gravel deposits (the Holdredge and Grand Island Formations) have been penetrated in numerous borings at the site and will be described below in the site geology section

During the more recent Illinoisan and Wisconsin glacial stages ice did not advance as far west as the two previous stages As a consequence the depositional environment was favorable for lower energy alluvial erosion and deposition The less energetic alluvial cuts and deposits are found along the trend of Shell Creek The thick sands and gravels have been partially incised and replaced by finer sands and silts which originated from the sand hills to the west (HWST 1987)

During interglacial periods the environment was suited for the accumulation of fine wind blown silt and clays known as loess Two loess units the Loveland and Peorian occur in the area west of the glacial drift deposits including the area of Lindsay Nebraska These fine-grained wind-deposited sediments have a total thickness of approximately 140 feet in the upland areas The bottom land and terrace areas may have loess deposits present but are less thick than that of the upland areas due to post glacial erosion

3 4 2 Site Geology

The site-specific geologic conditions are typical of the regional stratigraphy as evidenced in numerous testholes registered well logs and borings For convenience Figure 3 4-2 is included as a site-specific stratigraphic column Since it was beyond the scope of this study the geologic ages of most units are omitted

The bedrock is the Niobrara Formation which is characteristically weathered in its upper section The Niobrara is unconformably mantled by a sands and gravels unit (lower) and a fine-grained silty deposit (upper unit) which has been locally reworked by water and wind

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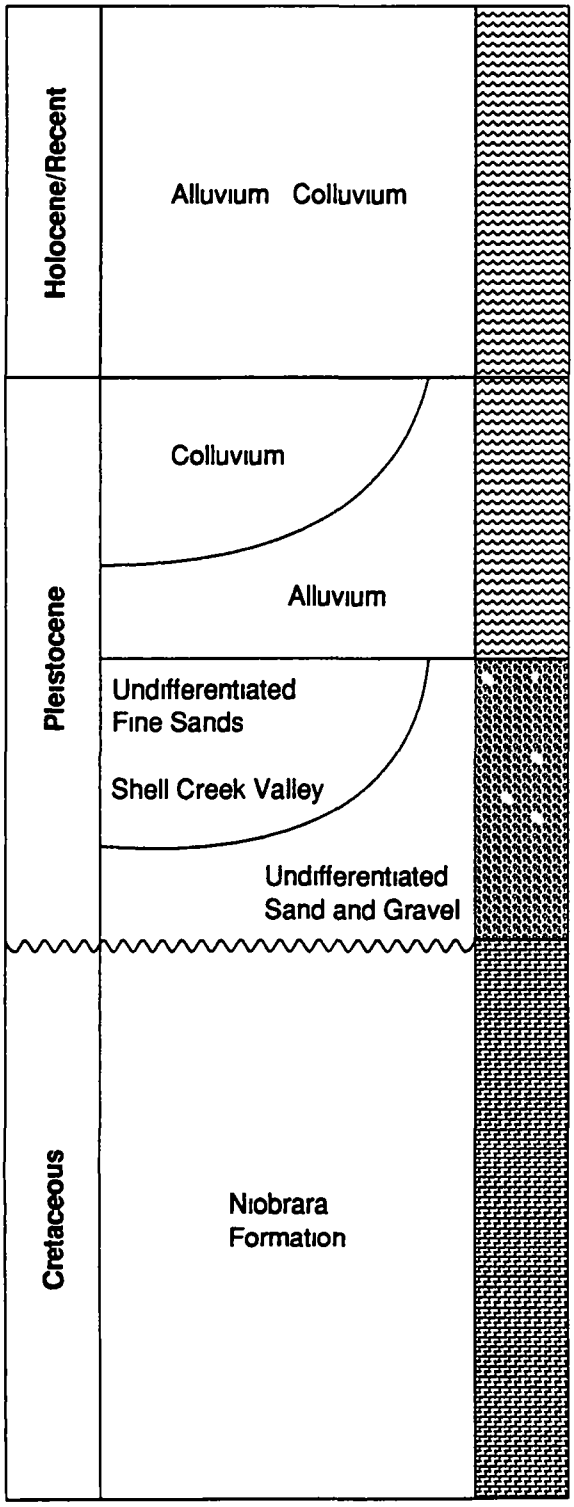

Predominantly Silt Loam
Dark grayish brown to light brown friable to firm well drained increasing clay content with depth minor calcerous areas Scattered minor thin fine sand lenses and channels

Undifferentiated Alluvial Colluvial Silts Clays, and Fine Sands
Silts and Clays light to dark brown gray olive low to moderate plasticity soft to firm scattered Mg and Fe staining scattered calcerous concretions scattered sand grains quartz and feldspar rounded

Sand very fine to fine grain subangular to subrounded well to moderately well sorted medium dense to hard contains scattered interbedded silty and sandy clay lenses composition predominately quartz minor feldspar and mafic minerals

Undifferentiated Fine Sands **Shell Creek Valley**

Undifferentiated Sands and Gravels
Sand fine to coarse subrounded to rounded poorly to well sorted dense Gravel fine to cobbles rounded composition quartz 80-90% feldspar 5-15% other 2 5 % granitic origin Unit grain size decreases upwards and contains scattered thin silty clay lenses 1 2 ft. thck

Chalk and Limestone, Argillaceous
Chalk is medium gray to white weathers dark yellowish orange very pale orange or white contains interbedded chalky shale many fossil clams oysters and Foraminifera and shell fragments Limestone is light gray to medium gray and yellowish gray argillaceous contains interbedded medium-gray chalky shale and Foraminifera Inoceramus and shell fragments

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Figure 3 4 2
Lindsay Site Stratigraphic Column
Lindsay Manufacturing Site
Dames & Moore

The composition of the two main geologic units the Cretaceous Niobrara Formation and the Quaternary deposits are important for describing the geology at the site (Figure 3 4-2) A weathered bedrock surface of the Niobrara has been encountered in numerous boreholes drilled during geologic and ground-water investigations however none of the boreholes penetrated through the entire thickness of the Niobrara Formation The uppermost weathered portions of the Niobrara consist of clays weathered shale and a carbonate cemented silty claystone

HWST (1987) reported the surface of the Niobrara bedrock to be saddle-shaped with paleo-drainages cut in the surface which trended away from Lindsay to the north and south The saddle rises to elevations of 1600 and 1620 feet respectively to the west and east Generally the bedrock surface elevation ranges from 1565 feet at the northeast corner of the site to 1585 feet at the northwest corner The gradient of the bedrock surface can be approximated from Figure 3 6-2 (Hydro-geology Section) In general the surface gradient ranges from 0 03 ft/ft to 0 008 ft/ft In the area of the Pit the paleo-drainage is to the east-northeast at a gradient of 0 011 ft/ft

The depiction of the top of the bedrock surface (as the base of the aquifer) in Figure 3 6-1 makes no distinction between the Niobrara Formation and other local remnant fine-grained bedrock units Sediments interpreted to be primarily lacustrine and fluvial in origin (Dr W Wayne personnel communciation 1990) were encountered in the lower 170-188 feet of boring MW89-10B located approxiamately one-half mile southeast of the Lindsay Manufacturing facility This strata is composed of sandy clays interbedded with lenses of sand mantling typical Niobrara weathered clay The bedrock surface is depicted on six geologic cross sections (A-A through F-F') drawn based on borehole data (Figures 3 4-5A through 3 4-5F) The location of these cross sections is shown on Figure 3 4-4A and 3 4-4B November 1989 water levels are based on field measurements by Lindsay Manufacturing Projections laterally are based on hydrogeologic assumptions believed to be representative of the site

Two distinct Quaternary deposits which unconformably overlie the weathered surface of the Niobrara Formation range in thickness from less than 100 feet to 200 feet (Figure 3 4-5) A lower unit is composed of alluvial sand and gravel which have mineral components indicative of a granitic source-predominately quartz with 5 to 15% feldspar grains The sand and gravel layer is relatively uniform laterally extensive and ranges from 35 to 50 feet thick at the site The sands and gravel unit thins to the west of the site and generally thickens to the east and south To the southwest of the site approximately 1 mile an upper portion of this unit is reduced in thickness by erosion and replaced by fine-grained sands and silts from the Shell Creek drainage The lower and upper limits of this unit at the site are relatively flat at elevations of 1575 feet and 1625 feet respectively

The upper unit is composed predominantly of silty clays and clayey silts and is less uniform than the lower sands and gravels unit The thickness of these deposits ranges from 30 feet in the

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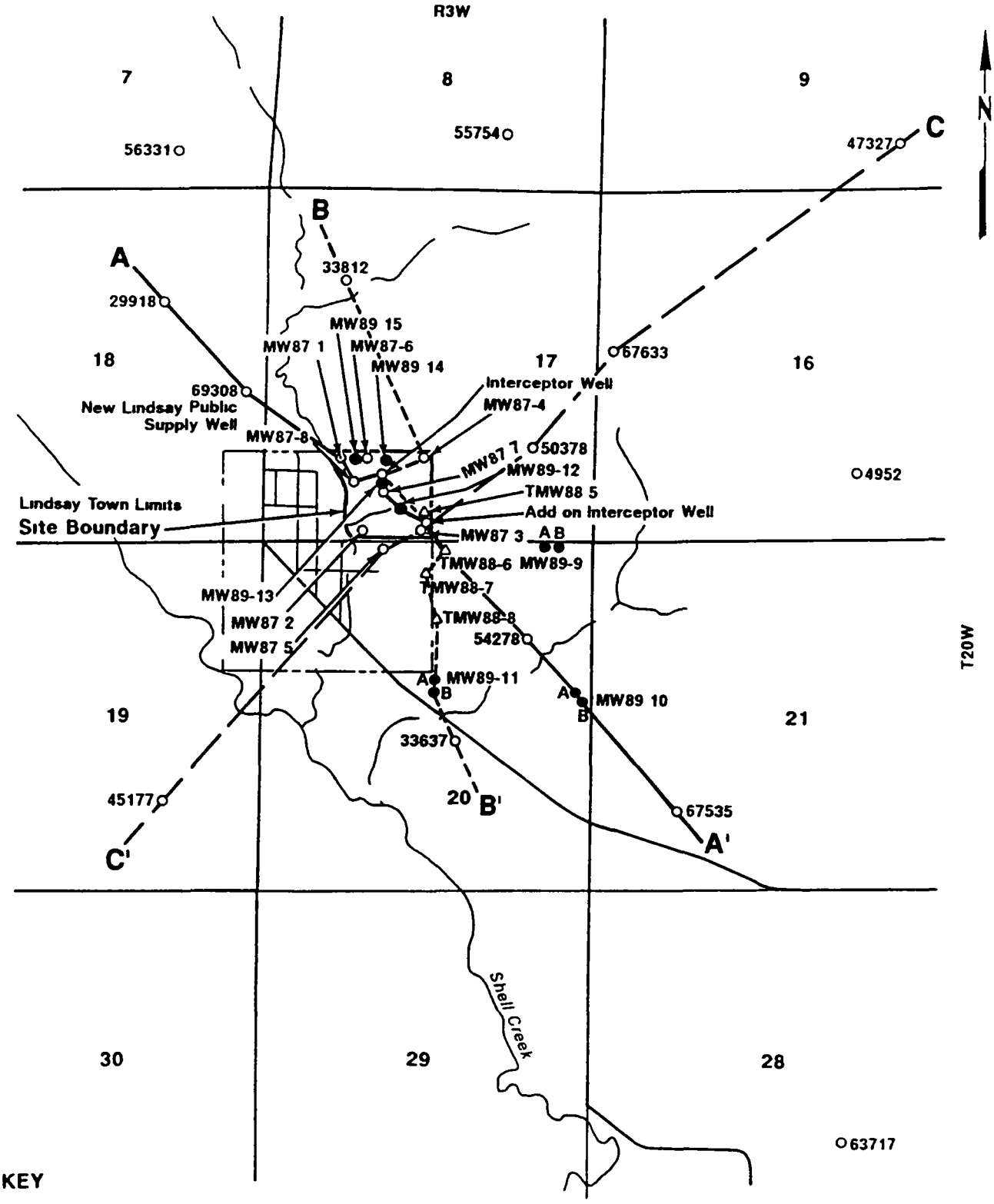

KEY

- ○ Irrigation or Public Supply Well
- ○ Monitoring Well 1987
- △ Temporary Monitoring Well 1988
- ● Monitoring Well 1989
  A Shallow B Deep

0 2000 4000
Scale in Feet

Figure 3 4 4a
Location of Deep Geologic Cross-Sections A-A' Through C-C'
Lindsay Manufacturing Site
Dames & Moore

Job No 16657 002

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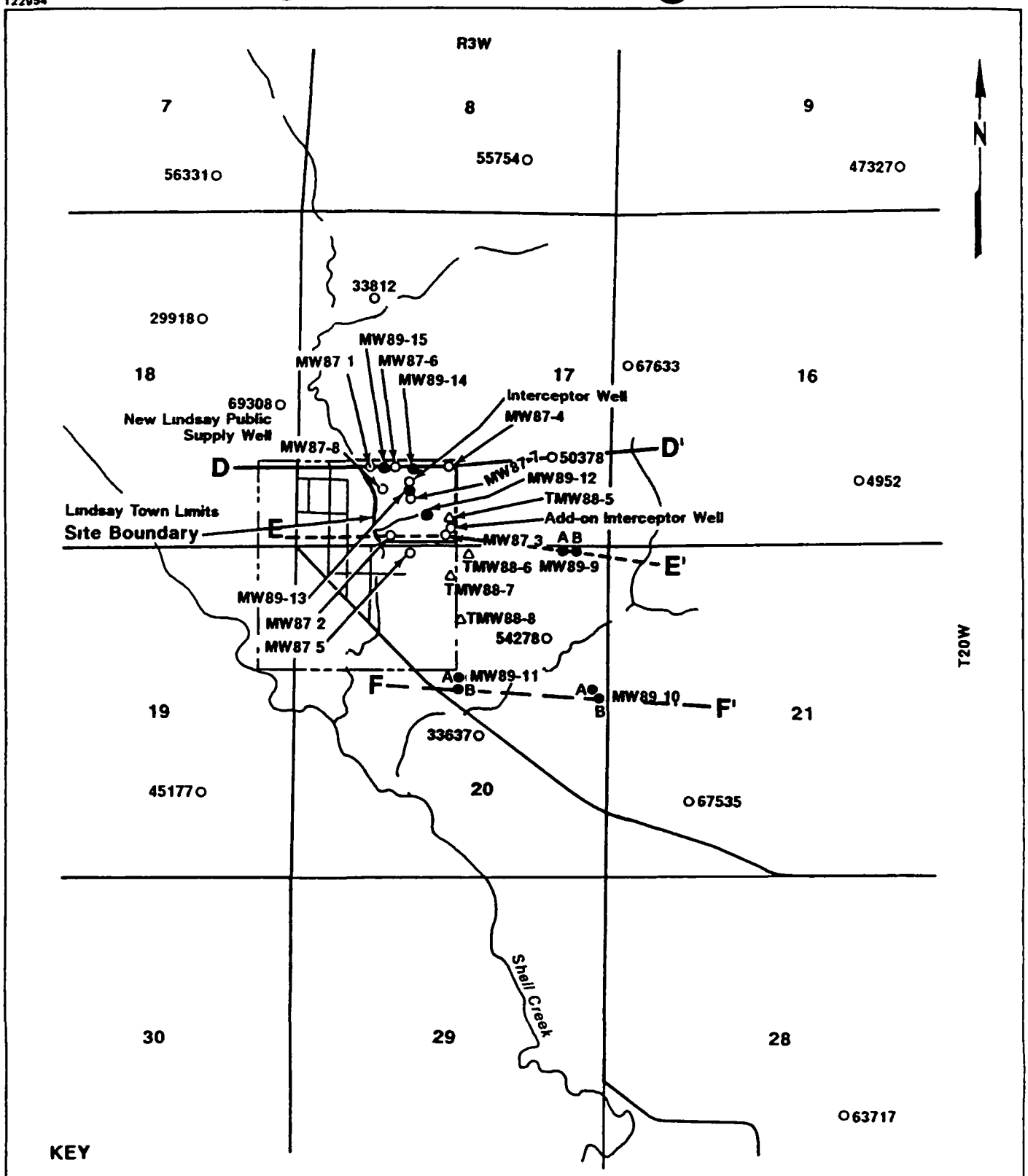

Figure 3 4 4b
Location of Deep Geologic Cross-Sections D-D' Through F-F'
Lindsay Manufacturing Site
Dames & Moore

Job No 16657 002

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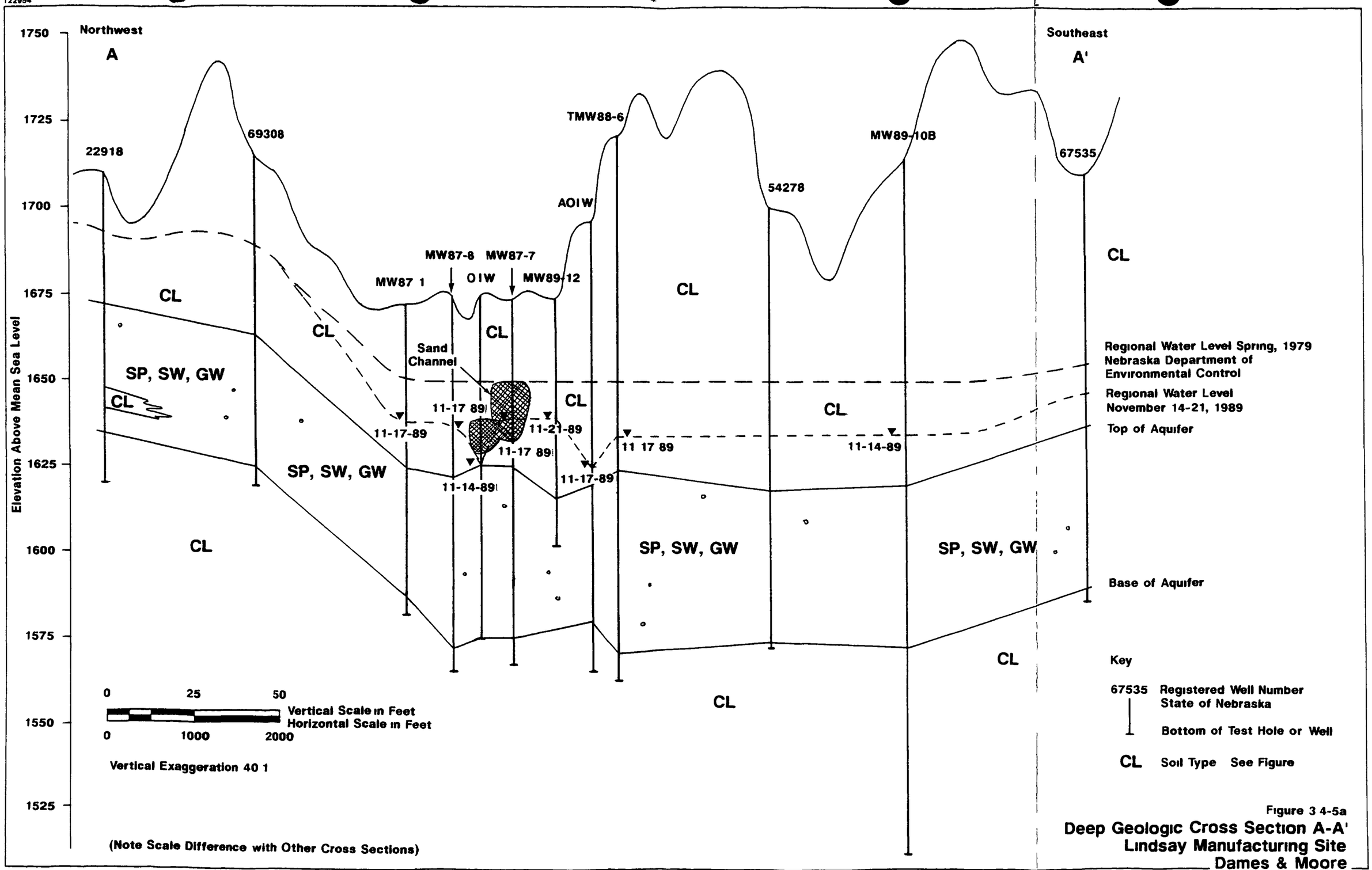

Figure 3 4-5a
Deep Geologic Cross Section A-A'
Lindsay Manufacturing Site
Dames & Moore

Job No 16657 002 005

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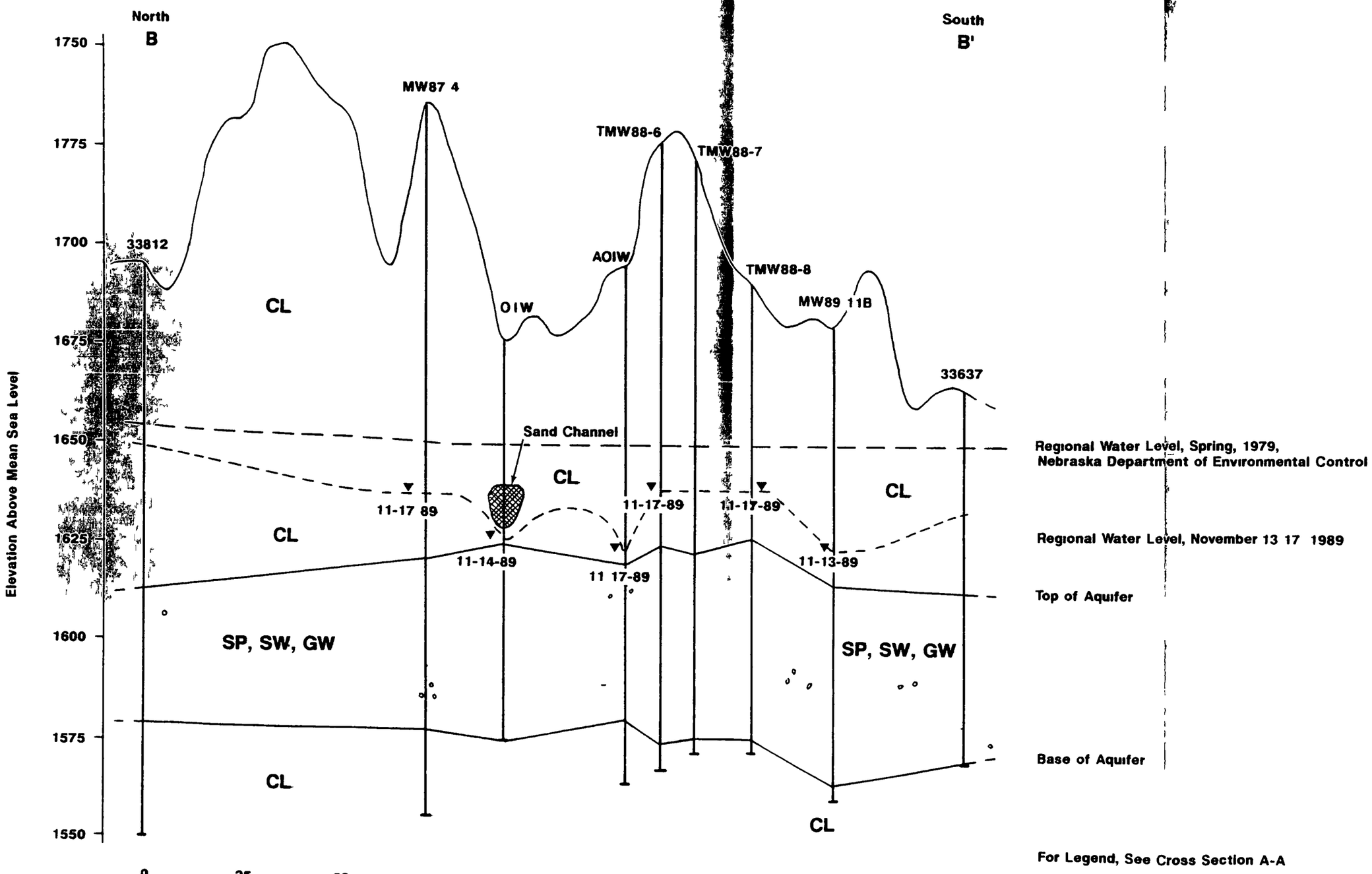

0 25 50 Vertical Scale in Feet
0 1000 2000 Horizontal Scale in Feet

Vertical Exaggeration 40 1
(Note Scale Difference with Other Cross Sections)

Figure 3 4-5b
Deep Geologic Cross Section B-B'
Lindsay Manufacturing Site
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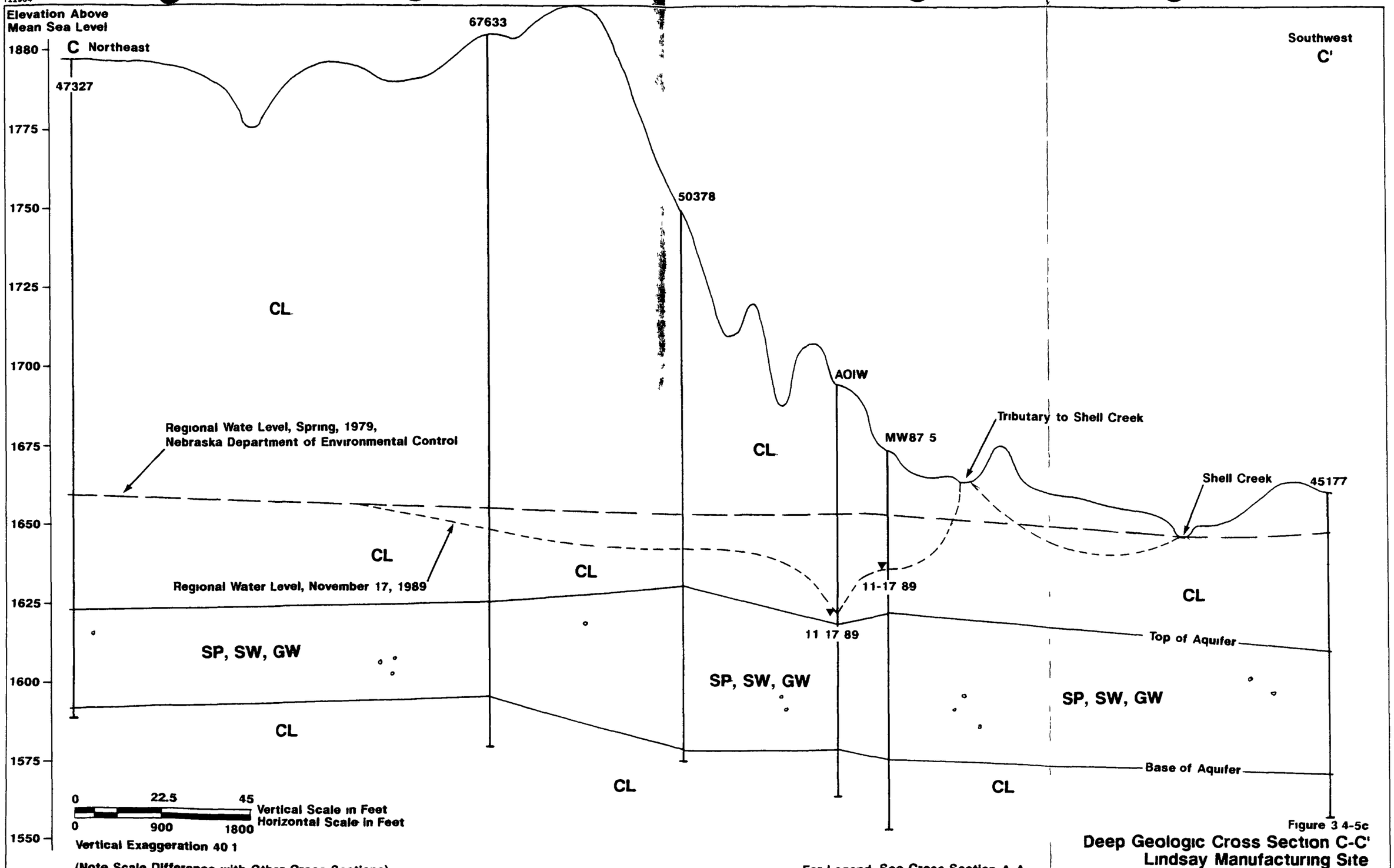

Figure 3 4-5c

Deep Geologic Cross Section C-C'
Lindsay Manufacturing Site
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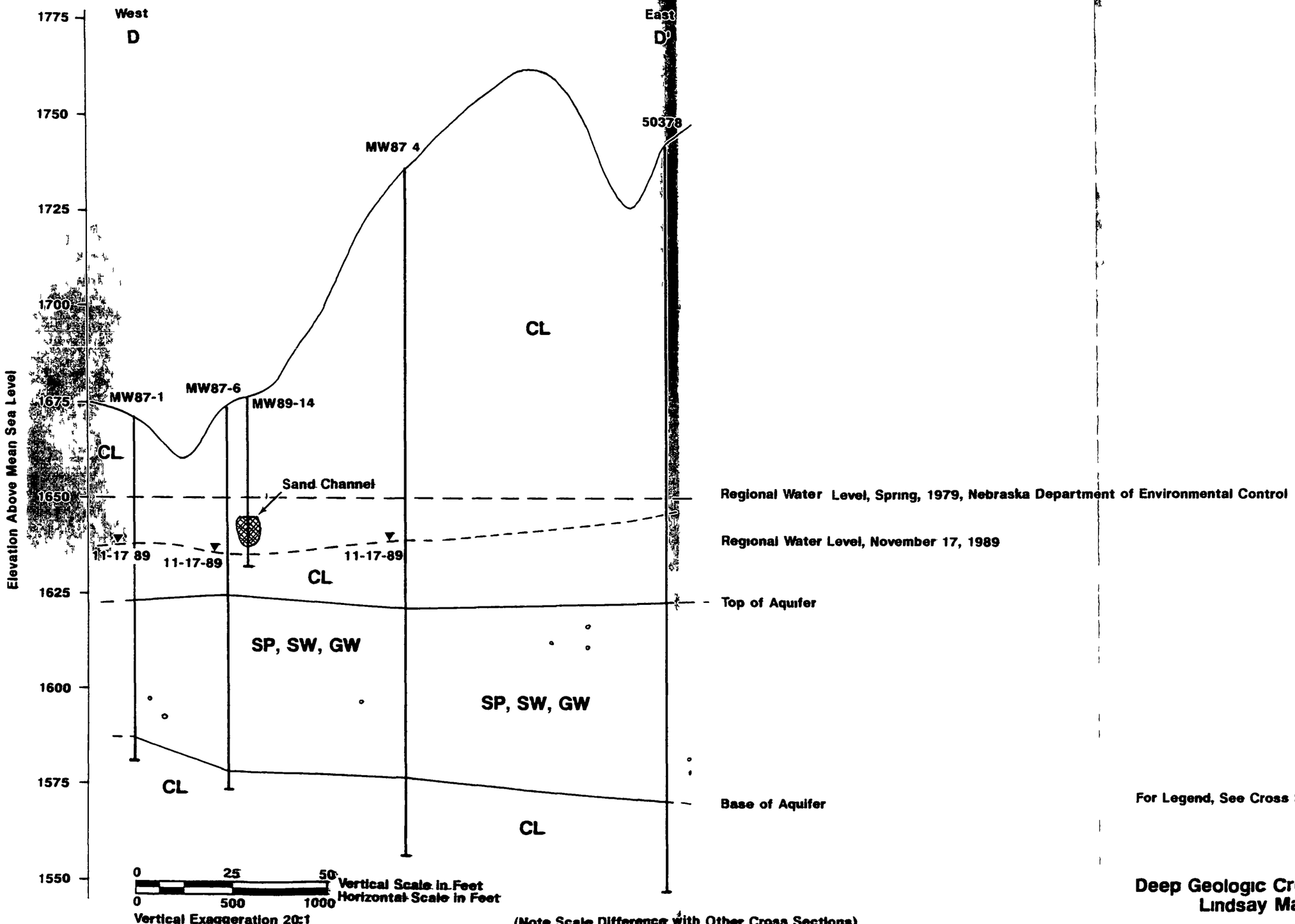

Figure 3.4-5d
Deep Geologic Cross Section D-D'
Lindsay Manufacturing Site
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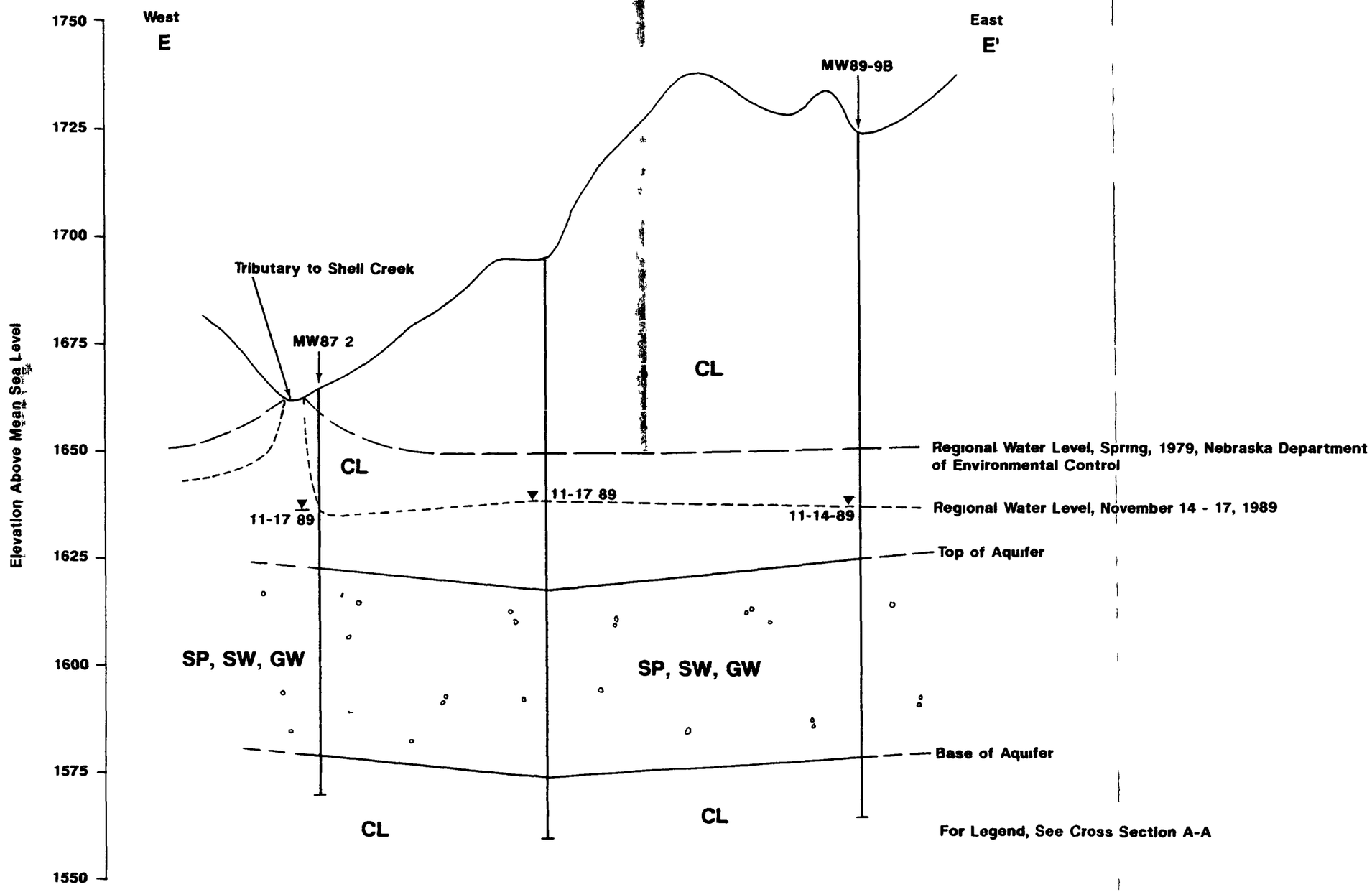

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0 500 1000 Horizontal Scale in Feet

Vertical Exaggeration 20 1

(Note Scale Difference with Other Cross Sections)

Figure 3 4-5e

Deep Geologic Cross Section E-E'
Lindsay Manufacturing Site
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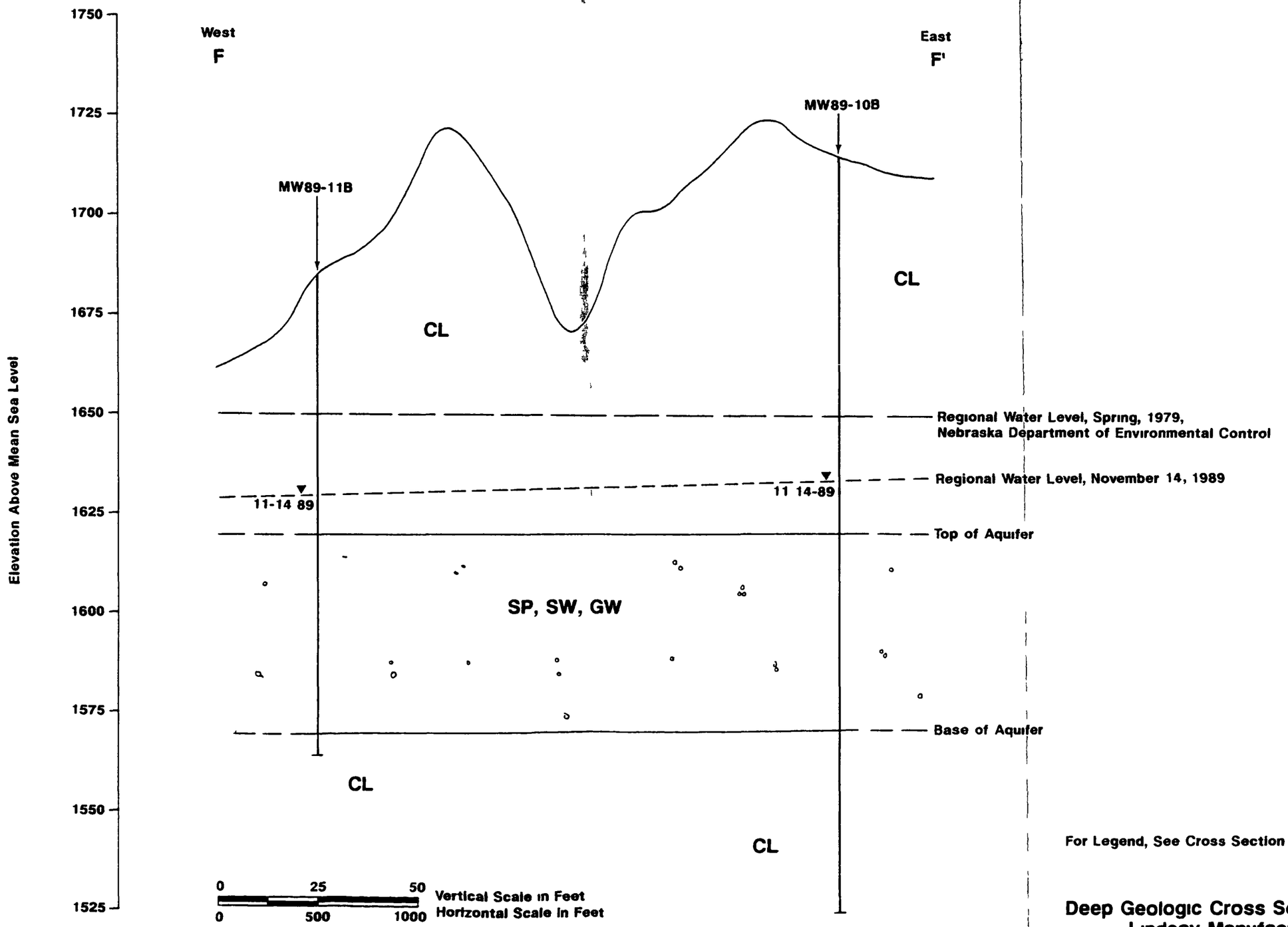

For Legend, See Cross Section A-A

Figure 3 4-5f

Deep Geologic Cross Section F-F'
Lindsay Manufacturing Site
Dames & Moore

Job No 16657 002 005

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creek bottoms and terrace areas to 150 feet at the upland areas These deposits are interpreted to have a wind blown origin Since deposition these fine-grained deposits have been partially incised and reworked by weathering and wind

Alluvial incision has also occurred in the upper unit The upper silty clay unit has been incised and infilled with fine sands and silts in meandering channels These incisions are local and probably associated with episodic storm events occurring in the same valley Such a channel is evident in the borings and test hole logs in the northern half of the site It is composed of quartz-rich well sorted fine-grained sands with a feldspar fraction The sand channel is approximately 800 feet long and up to 150 feet wide at its maximum extent It is up to 25 feet thick and overlain by 10 to 30 feet of lean clay The sand channel is located in the north central part of the site and trends northwest-southeast (Figure 3 4-8)

The upper unit is represented on geologic cross sections which were developed from the boring logs The cross sections can be referenced to a legend (Figure 3 4-3) are located on Figures 3 4-6A & B and are depicted in Figures 3 4-7A to F

The site-specific geology of the upper unit can be characterized as a matrix of lean clay with a meandering buried channel deposit The lack of coarse sand in the channel is evidence that the erosional incision which created the feature probably did not cut to the lower sand and gravel unit This has hydraulic significance to the ground water occurrence in the buried channel (Section 3 6)

The fine grain sediments of the upper unit ranges from soft to stiff and slight to high plasticity In general the density of these materials reflects the depositional environment The wind-deposited sediments on the eastern site boundary are less dense than the central water-deposited sediments beneath the west half of the site Zones of clay enrichment and remnant rootlets and caliche fragments are evidence of paleosols which developed during the depositional history of the upper unit The plasticity of the sediments is a function of the clay fraction which contributes both to unit water retention and cohesion The resulting plasticity contributes to the low permeability of sediments that range from sandy clays to clayey silts in grain size distribution The permeability of these materials under saturated ground-water flow conditions ranges from 10^{6} to 10^{7} cm/sec

The sands of the channel deposit are loose to dense and non-cohesive The depositional event that eroded and incised the cohesive sediments and deposited the coarser sands was a high energy flood event Sediments accumulated in the valley by subsequent lesser flood events wind and water accretion

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MAJOR DIVISIONS			GRAPH SYMBOL	LETTER SYMBOL	TYPICAL DESCRIPTIONS
Coarse Grained Soils More than 50% of material is LARGER than No 200 sieve	Gravel & Gravelly Soils More than 50% of coarse fraction RETAINED on No. 4 sieve	Clean Gravels (Little or no fines)		GW	Well-graded gravels, gravel-sand mixtures, little or no fines
				GP	Poorly-graded gravels gravel-sand mixtures, little or no fines
		Gravels with Fines (Appreciable amount of fines)		GM	Silty gravels, gravel-sand-clay mixtures
				GC	Clayey gravels, gravel-sand-clay mixtures
	Sand and Sandy Soils More than 50% of coarse fraction PASSING No. 4 sieve	Clean Sand (Little or no fines)		SW	Well-graded sands gravelly sands little or no fines
				SP	Poorly-graded sands, gravelly sands, little or no fines
		Sands with Fines (Appreciable amount of fines)		SM	Silty sands, sand-silt mixtures
				SC	Clayey sands, sands-clay mixtures
Fine Grained Soils More than 50% of material is SMALLER than No 200 sieve	Silts and Clays Liquid Limit LESS than 50			ML	Inorganic silts and very fine sands, rock flour silty or clayey fine sands or clayey silts with slight plasticity
				CL	Inorganic clays of low to medium plasticity gravelly clays, sandy clays, silty clays, lean clays
				OL	Organic silt and organic silty clays of low plasticity
	Silts and Clays Liquid Limit GREATER than 50			MH	Inorganic silts micaceous or diatomaceous fine sand or silty soils
				CH	Inorganic clays of high plasticity fat clays
				OH	Organic clays of medium to high plasticity organic silts
Highly Organic Soils				PT	Peat humus swamp soils with high organic contents

Note Dual symbols are used to indicate borderline soil classifications

Unified Soil Classification System

Legend

SB 3	Feature Location and Number (See Below for Feature Type)
CL	Soil Type Unified Soil Classification System
	Contact
7/15/87	Water Level and Date
IAD 12/15/82	Water Level and Date (Immediately After Drilling)
DCI 7/18/88	Dry Cave-In Level and Date
827	Undisturbed Sample and Number
	Bottom of Hole
	Hole Continues
	End of Log

Explanation of Feature Types

87-6	Shallow Auger Borings (1987)
SB 3	Shallow Auger Borings (1988)
82-1, P-2	Piezometers
TH 36	Test Holes 1988 and Number
C 7	Auger Borings 1983, and Number

Figure 3 4-3
Cross -Sections Legend
Lindsay Manufacturing Site
Dames & Moore

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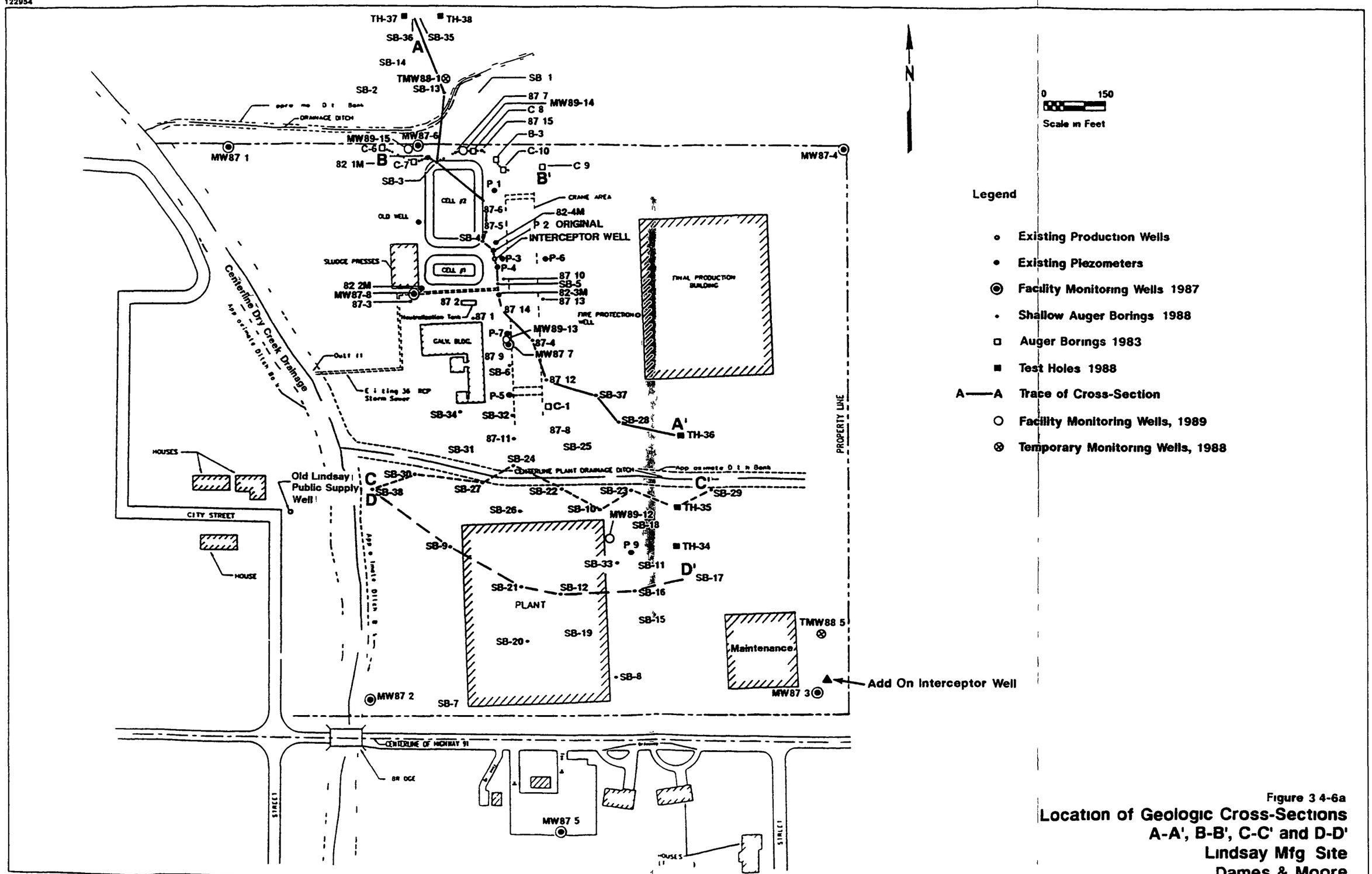

Figure 3 4-6a
Location of Geologic Cross-Sections
A-A', B-B', C-C' and D-D'
Lindsay Mfg Site
Dames & Moore

Job No 16657 002

Rev 01/15/90

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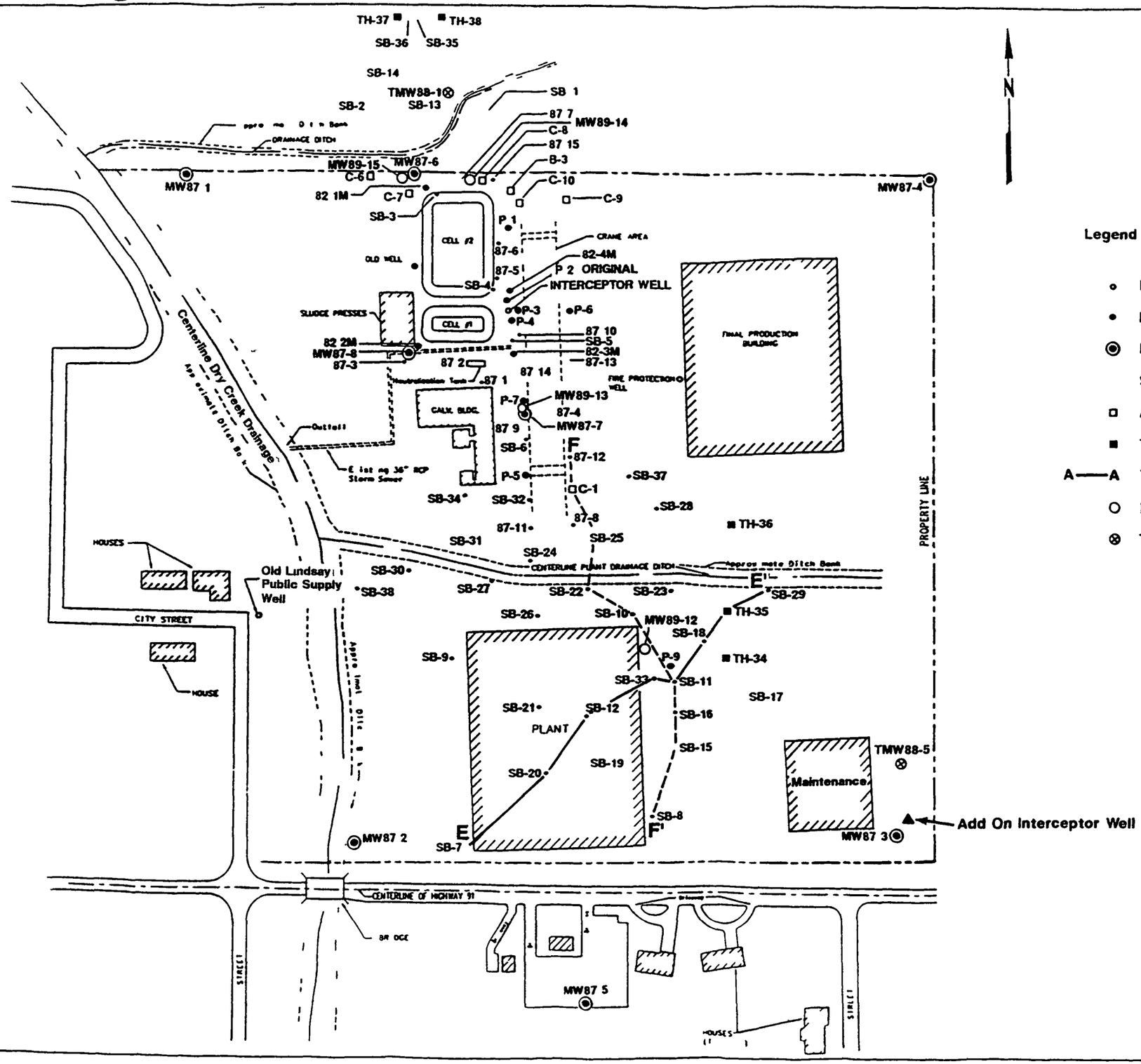

Legend

- ○ Existing Production Wells
- ● Existing Piezometers
- ◉ Facility Monitoring Wells 1987
- Shallow Auger Borings 1988
- □ Auger Borings 1983
- ■ Test Holes 1988
- A——A Trace of Cross-Section
- ○ Facility Monitoring Wells, 1989
- ⊗ Temporary Monitoring Wells, 1988

Figure 3 4-6b

Location of Geologic Cross-Sections E-E', F-F'

Lindsay Mfg Site

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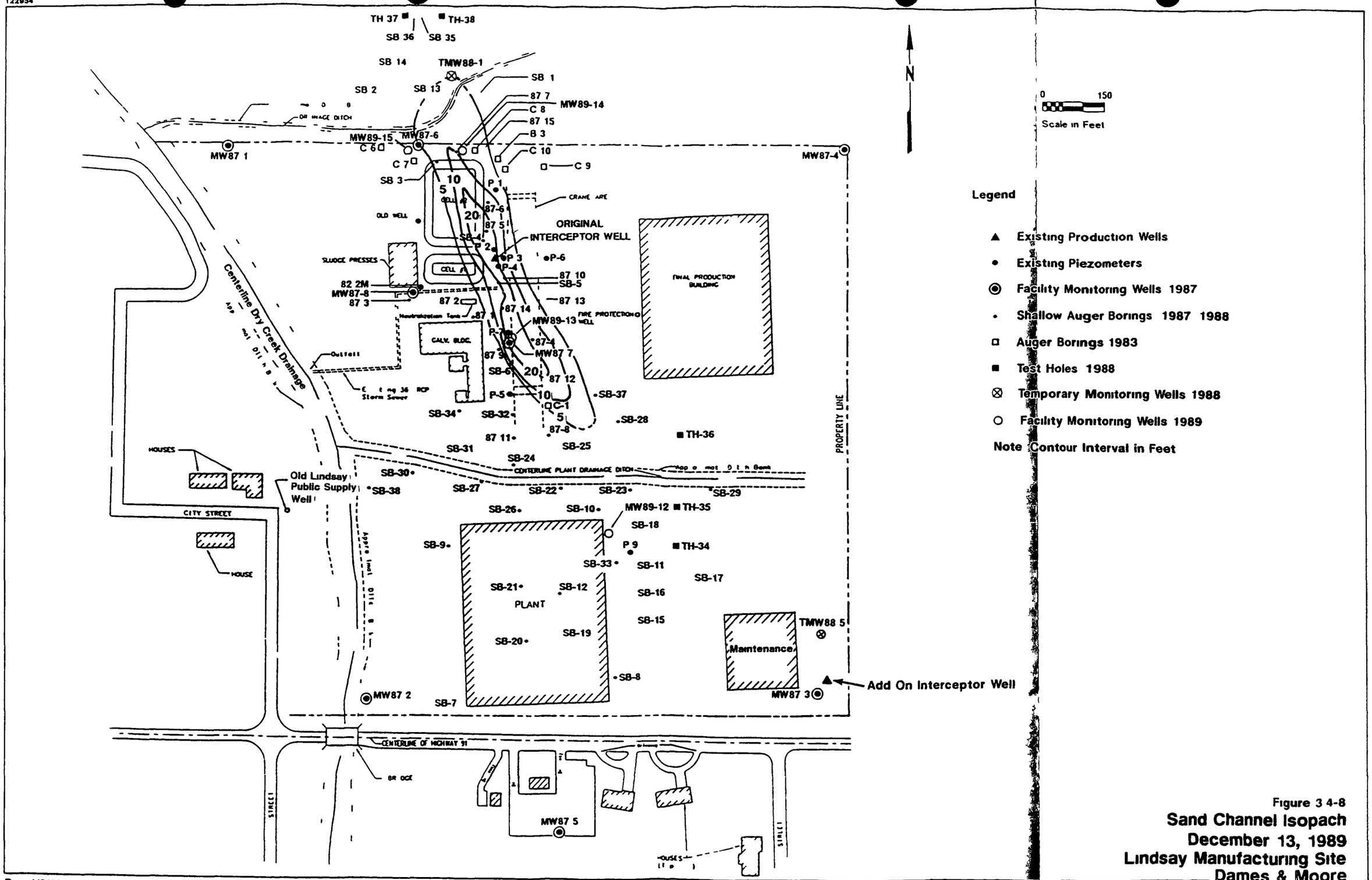

Figure 3 4-8
Sand Channel Isopach
December 13, 1989
Lindsay Manufacturing Site
Dames & Moore

Job No 16657 002

Rev 1/9/90

3 5 SOILS

3 5 1 Introduction

Soils development at the site and in the vicinity of Lindsay Nebraska occurs in fine grained cohesive silty clays and clayey silts of the upper geologic unit (Section 3 4 2) Soil types are presented on Figure 3 5-1

3 5 2 Associations

Soil associations are general groupings of related soil types Three distinct soil associations are located in the Lindsay area Each association has a distinctive pattern of soils relief and drainage The associations consist of one or more major soils with some minor soils and are named for the major soil The three soil associations described below are taken directly from by the Platte County Soil Survey (USDA 1988) and include the Nora-Crofton-Moody the Belfore-Moody and the Shell-Hobbs-Muir Associations

Nora-Crofton-Moody Association

Deep very gently sloping to steep well drained and somewhat excessively drained silty soil formed in loess on uplands

This association consists of soils on broad and narrow ridgetops side slopes and foot slopes of dissected uplands Slopes range from 1 to 30 percent

This association takes in 277 413 acres or about 51 percent of the county It is about 37 percent Nora soils 25 percent Crofton soils 17 percent Moody soils and 21 percent minor soils

The Nora soils are gently sloping to moderately steep and well drained They are on convex ridgetops and side slopes Typically the surface layer is very dark grayish brown friable silty clay loam about 7 inches thick The subsurface layer is dark grayish brown friable silty clay loam about 5 inches thick The subsoil is friable silty clay loam about 17 inches thick It is pale brown in the upper part and light yellowish brown in the lower part The underlying material is very pale brown silt loam in the lower part to a depth of more than 60 inches

The Crofton soils are on narrow convex ridgetops and on the steeper parts of side slopes They are gently sloping on ridgetops and strongly sloping to steep on side slopes They are well drained and somewhat excessively drained and calcareous Typically the surface layer is grayish brown very friable silt loam about 4 inches thick The transition

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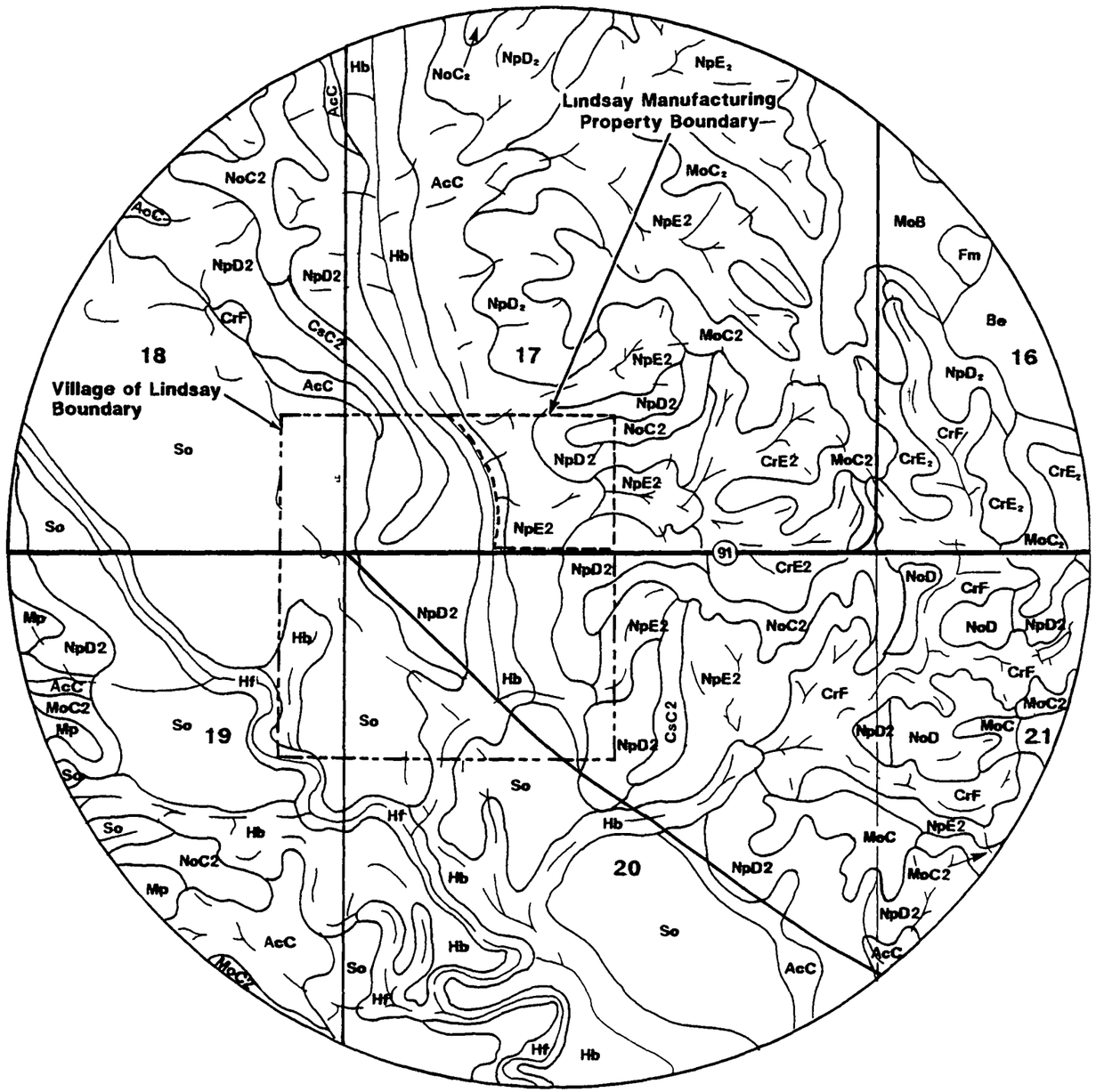

Key

AcC	Alcester Silt Loam, 2 to 6 Percent Slopes
Be	Belfore Silty Clay Loam, 0 to 1 Percent Slopes
CrE2	Crofton Silt Loam, 11 to 15 Percent Slopes
CrF	Crofton Silt Loam 15 to 30 Percent Slopes
CsC2	Crofton Nora Complex 2 to 6 Percent Slopes, Eroded
Fm	Fillmore Silt Loam, 0 to 1 Percent Slopes
Hb	Hobbs Silt Loam, 0 to 2 Percent Slopes
Hf	Hobbs Silt Loam, Channeled
MoB	Moody Silty Clay Loam, 1 to 3 Percent Slopes
MoC	Moody Silty Clay Loam, 3 to 6 Percent Slopes
MoC2	Moody Silty Clay Loam, 1 to 3 Percent Slopes
MoD2	Moody Silty Clay Loam 3 to 6 Percent Slopes
Mp	Moody Silty Clay Loam, Terrace, 0 to 2 Percent Slopes
NoC2	Nora Silty Clay Loam 2 to 6 Percent Slopes, Eroded
NoD	Nora Silty Clay Loam, 6 to 11 Percent Slopes
NpD2	Nora-Crofton Complex 6 to 11 Percent Slopes Eroded
NpE2	Nora-Crofton Complex 11 to 15 Percent Slopes Eroded
So	Shell Silt Loam, 0 to 2 Percent Slopes
	Soil Type Contact
91	State Highway
	Lindsay Manufacturing Property Boundary
	Drainage, Intermittent
	Drainage, Perennial
	Village of Lindsay Boundary
	Section Line
16	Section Number

0 0.5 1

Scale in Feet

Figure 3.5-1

Surface Soil Types in and Around Lindsay, Nebraska
Lindsay Manufacturing Site
Dames & Moore

Job No. 7 002 005

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layer is pale brown friable silt loam about 5 inches thick The underlying material is silt loam It is light yellowish brown in the upper part and light gray in the lower part to a depth of more than 60 inches

The Moody soils are on broad and narrow convex ridgetops shoulders and side slopes They are very gently sloping and gently sloping on ridgetops and shoulders and strongly sloping on side slopes They are well drained Typically the surface layer is dark grayish brown friable silty clay loam about 8 inches thick The subsoil is friable silty clay loam about 29 inches thick It is dark grayish brown in the upper part brown in the middle part and pale brown in the lower part The underlying material is light yellowish brown silty clay loam in the upper part and light yellowish brown silt loam in the lower part to a depth of 60 inches or more

The minor soils in this association are the Alcester Belfore Fillmore and Hobbs soils Alcester soils are on concave foot slopes They have dark upper layers more than 20 inches thick Belfore soils are on broad nearly level ridgetops and contain more clay than the major soils Fillmore soils are poorly drained and in upland depressions Hobbs soils are stratified and are in narrow upland drainage-ways that are subject to occasional flooding

Farms in this association are diversified They are mainly a combination of cash-grain and livestock enterprises The very gently sloping to moderately steep areas of soils on ridge tops and side slopes are generally used for cultivated crops A few areas of steep soils on side slopes and areas around farmsteads support native or introduced grasses and are used for grazing Most of the acreage in the association is used for dryland cultivated crops The main crops are corn soybeans grain sorghum oats and alfalfa A few areas where high yielding wells are available are irrigated by sprinkler systems

Soil erosion is the main hazard Maintaining soil fertility controlling runoff and conserving moisture are the main management concerns In the narrow drainageways flooding is a hazard

Belfore-Moody Association

Deep nearly level to gently sloping well drained silty soils formed in loess on uplands

This association consists of soils on nearly level broad divides on loess uplands Slopes range from 0 to 6 percent

This association takes in about 51 000 acres or about 12 percent of the county It is about 68 percent Belfore soils 24 percent Moody soils, and 8 percent minor soils

The Belfore soils are nearly level and on broad divides Typically the surface layer is dark grayish brown firm silty clay loam about 14 inches thick The subsoil is very firm and firm silty clay loam about 31 inches thick It is grayish brown in the upper part brown and pale brown in the middle part and light yellowish brown in the lowerpart The underlying material is light yellowish brown silty clay loam in the upper part and very pale brown silt loam in the lower part to a depth of more than 60 inches

The Moody soils are on broad and narrow convex ridgetops shoulders and side slopes They are very gently sloping and gently sloping on ridgetops and shoulders and strongly sloping on side slopes They are well drained Typically the surface layer is dark grayish brown friable silty clay loam about 29 inches thick It is dark grayish brown in the upper part brown in the middle part and pale brown in the lower part The underlying material is light yellowish brown silty clay loam in the upper part and light yellowish brown silt loam in the lower part to a depth of more than 60 inches

The minor soils in this association are the Alcester Butler and Fillmore soils Alcester soils are on concave foot slopes along the intermittent drainageways They have dark upper layers more than 20 inches thick Butler soils are somewhat poorly drained and in slightly concave basins Fillmore soils are poorly drained and in depressions

Farms in this association are diversified They are mainly a combination of cash-grain and livestock enterprises Most of the acreage is used for dryland cultivated crops The crops are small areas of oats winter wheat and grain sorghum but mainly corn soybeans and alfalfa A few depressional areas are in introduced or native grasses and are used for grazing In areas where high yielding wells are available gravity and sprinkler systems are common The principal irrigated crops are corn soybean and alfalfa The potential for irrigation in the association is high

Erosion on the gently sloping Moody soils and ponding in the depressional areas of Fillmore soils are the main hazards Maintaining fertility is the main management concern Another management concern is drainage in depressional areas but suitable outlets are commonly not available In places large pits are dug to hold the excess water

Shell-Hobbs-Muir Association

Deep nearly level well drained silty soils formed in silty alluvium on bottom lands and stream terraces

This association consists of nearly level soils on bottom lands and stream terraces of Beaver Creek Shell Creek Looking Glass Creek Loseke Creek Tracy Creek South Fork Union Creek and other creeks Slopes range from 0 to 2 percent

This association takes in 33 500 acres or about 8 percent of the county It is about 33 percent Shell soils 29 percent Hobbs soils 18 percent Muir soils and 20 percent minor soils

The Shell soils are well drained and on nearly level bottom lands that are subject to occasional flooding Typically the surface layer is dark grayish brown very friable silt loam about 8 inches thick The subsurface layer is dark grayish brown very friable silt loam about 17 inches thick The underlaying material is silt loam It is grayish brown in the upper part and brown in the lower part to a depth of more than 60 inches

The Hobbs soils are on nearly level flood plains adjacent to the creeks and their tributary drainage-ways below the Shell soils in the landscape They are subject to occasional flooding and some areas are channeled The are well drained Typically the surface layer is grayish brown thinly stratified friable silt loam about 8 inches thick The underlying material is silt loam It is dark grayish brown and pale brown and thinly stratified in the upper part and dark grayish brown in the lower part to a depth of more than 60 inches

The Muir soils are on high stream terraces above the Shell soils and are subject to rare flooding They are well drained and nearly level Typically the surface layer is dark grayish brown friable silt loam about 6 inches thick The subsurface layer is very dark grayish brown friable silt loam about 12 inches thick The subsoil is friable and about 19 inches thick It is dark grayish brown in the upper part and brown in the lower part The underlying material is pale brown silt loam to a depth of more than 60 inches

The minor soils in this association are the Colo Kezan Lamo and Zook soils which have a seasonal high water table and are on bottom lands

The farms in this association are diversified mainly combination cash-grain and livestock enterprises Most of the acreage is used for cultivated crops The main crops are corn soybeans grain sorghum, and alfalfa Most of the acreage is irrigated from high producing deep wells Gravity systems are well suited to these soils but a few areas have sprinkler systems Small pastures of introduced grass or native grass are near the stream channels

The hazard of flooding in spring on bottom lands maintaining fertility and efficient use of irrigation water are the main management concerns

3 5 3 Site Soils

The soils at the site consist mostly of NpE2 (Nora-Crofton complex 11 to 15 percent slopes eroded) with minor NpD2 (Nora-Crofton complex 6 to 11 percent slopes, eroded) NoC2 (Nora silty clay loam 2 to 6 percent slopes eroded) and Hb (Hobbs silt loam 0 to 2 percent slopes) The NpE2 NpD2 and NoC2 soils consist of deep well drained moderately permeable silt loams and silty clay loams on uplands The Hb soils consist of deep moderately permeable silt loam located in bottom lands of narrow drainageways in the uplands The soil s physical properties are presented in Table 3 5-1 Major soil properties permeability alkalinity and shrink-swell potential do not show significant variance across the site The permeability of all three soil types in all soil horizons range from 0 6 to 2 0 inches per hour The soil reaction (pH) of the soil ranges from slightly acidic to alkaline the pH varies from 6 1 to 8 4 The shrink-swell potential varies from low to moderate

The manufacturing operations conducted at the site have significantly altered the surface of the local soils Expansion of the plant facilities has required the relocation of natural drainage and the creation of new drainage pathways (Section 2 1) The installation of pavement over portions of site has increased and concentrated surface water runoff Paving has also capped large portions of the site vicinity Localized cut and fill operations since the 1960 s have altered and reworked previously existing soil structures and horizons These operations have included localized cuts and fills for foundations and buried utilities

3 6 HYDROGEOLOGY

The site is situated above a regional aquifer composed of Quaternary sands and gravels Weeks and Guttentog (1981) include this aquifer with other Tertiary aquifer units to the west and label the entire hydraulic unit the High Plains Aquifer

In northwest Platte County (the site vicinity) this aquifer is reported by the Conservation and Survey Division of Nebraska (CSDN) Institute of Agriculture and Natural Resources (1986) to have a range in transmissivity between 20 000 to 100 000 gallons per day per foot (gpd/ft) Transmissivity is a measure of the volume of water that will flow through a unit width of an aquifer under a unit hydraulic gradient (Lohman 1973) Transmissivity is a practical measurement which indicates the potential for well yield at a specific location These reported values are sufficiently high to provide an irrigation resource which can be developed by wells

Ellis and Wigley (1987) report 1390 irrigation wells in Platte Co as of December 31 1987 This equates to approximately two wells per square mile (Figure 1 2-4) Thirteen registered irrigation wells and one public supply well currently exist within a two mile radius of the site (HWS 1983 and HWST 1987) Seventeen domestic wells have been identified in a two mile radius south of the site (Figure 2 8-1) Nebraska has not required registration of private and

Table 3.5-1: Engineering Index and Soil Properties of the Soils*

Soil Name and Map Symbol	Depth (Inches)	USDA Texture	Classification Unified	Percent Passing Sieve Number 4	10	40	200	Liquid Limit (%)	Plasticity Index	Clay (%)	Moist Bulk Density (g/cc)	Permability (in/hr)	Available Water Capacity (in/in)	Soil Reaction (pH)
AcC	0-8	Silt Loam	CL, CL ML, ML	100	100	95-100	85-100	25-40	6-20	20-26	1 20-1 35	0 6-2 0	0 19-0 22	5 6-7 8
Alcester	8-45	Silty clay loam silt loam	CL, ML	100	100	95-100	90-100	35-50	10-25	20-32	1 20-1 35	0 6-2 0	0 19-0 22	6 1 7 8
	45-60	Silty clay loam silt loam	ML, CL	100	95-100	95-100	85-100	30-50	10-20	20-32	13 0-1 45	0 6-2 0	0 17 0 20	6 6-8 4
Be	0-14	Silty clay loam	CL, CH	100	100	100	95-100	35-55	15-30	27 39	1 30-1 50	0 2 0 6	0 21 0 24	5 6-6 5
Belfore	14-45	Silty clay loam silt loam	CL, CH	100	100	100	95-100	45-60	20-30	35-43	1 20-1 40	0 2-0 6	0 11 0 18	5 6-7 8
	45-60	Silty clay loam silt loam	CL, CH	100	100	100	95-100	35-55	15-30	25-35	1 30-1 50	0 2 0 6	0 18-0 22	6 1-8 4
CrE2	0-6	Silt loam	ML, CL	100	95-100	95-100	95-100	35-50	10-25	20-27	1 20-1 30	0 6-2 0	0 21-0 24	7 4 8 4
Crofton	6-60	Silt loam	CL	100	95-100	95-100	95-100	32 50	10-25	15-27	1 10-1 20	0 6-2 0	0 18-0 22	7 4 8 4
CrF	0-4	Silt loam	ML, CL	100	95-100	95-100	95-100	35-50	10-25	20-27	1 20-1 30	0 6-2 0	0 21-0 24	7 4 8 4
Crofton	4-60	Silt loam	CL	100	95-100	95-100	95-100	32 50	10-25	15-27	1 10-1 20	0 6-2 0	0 18-0 22	7 4 8 4
CsC2														
Crofton	0-5	Silt loam	ML, CL	100	95-100	95-100	95-100	35-50	10-25	20-27	1 20-1 30	0 6-2 0	0 21 0 24	7 4-8 4
	5-60	Silt loam	CL	100	95-100	95-100	95-100	32 50	10-25	15-27	1 10-1 20	0 6-2 0	0 18-0 22	7 4 8 4
Fm	0-12	Silt Loam	ML, CL, CL ML	100	100	100	95-100	20-40	2 20	18-27	1 30-1 40	0 6-2 0	0 21 2 0	5 6-6 5
Fillmore	12 41	Sily clay clay	CH CL	100	100	100	95-100	40-75	20-45	40-55	1 30-1 50	<0 06	0 11 0 14	5 6-7 8
	41 52	Sily clay loam	CL, CH	100	100	100	95-100	35-60	20-40	32 40	1 20-1 40	0 2 0 6	0 18-0 20	6 6-8 4
	52 60	Sily clay loam silty clay	CL, CH	100	100	100	95-100	25-75	Oct 45	18-45	1 30-1 50	0 6-2 0	0 10-0 22	6 6-8 4
Hb Hf	0-8	Silt loams	CL, CL ML	100	100	95-100	85-100	25-40	5-20	15-30	1 20-1 40	0 6-2 0	0 21-0 24	6 1 7 8
Hobbs	8-60	Silt loam silty clay loam very fine sand	CL, CL ML, MH	100	100	95-100	80-100	25-55	5-25	15-30	1 20-1 40	0 6-2 0	0 18-0 22	6 1 8 4
Mo MoB MoC	0-8	Silty clay loam	CL	100	100	95-100	95-100	35-50	13-25	27 35	1 20-1 30	0 2 0 6	0 21-0 23	5 6-7 3
Moody	8-37	Silty clay loam	CL, CH	100	100	95-100	95-100	32 55	11 33	27 35	1 20-1 30	0 2 0 6	0 18-0 20	6 1 7 3
	37 60	Silty loam Silty clay loam	CL, CL ML, ML	100	100	95-100	85-100	25-46	5-25	20-32	1 20-1 30	0 6-0 2	0 19-0 21	6 6-8 4
MoC2 MoD2	0-6	Silty clay loam	CL	100	100	95-100	95-100	35-50	13 25	27 35	1 20-1 30	0 2 0 6	0 21-0 23	5 6-7 3
Moody	6-34	Silty clay loam	CL, CH	100	100	95-100	95-100	32 55	11 33	27 35	1 20-1 30	0 2 0 6	0 18-0 20	6 1 7 3
	34 60	Silty loam Silty clay loam	CL, CL ML, ML	100	100	95-100	85-100	25-46	5-25	20-32	1 20-1 30	0 6-0 2	0 19-0 21	6 6-8 4

Table 3 5-1: Engineering Index and Soil Properties of the Soils* (cont.)

Soil Name and Map Symbol	Depth (inches)	USDA Texture	Classification Unified	Percent Passing Sieve Number 4	10	40	200	Liquid Limit (%)	Plasticity Index	Clay (%)	Moist Bulk Density (g/cc)	Permability (in/hr)	Available Water Capacity (in/in)	Soil Reaction (pH)
Mp	0-12	Silty clay loam	CL	100	100	95-100	95-100	35-50	13-25	27 35	1 20-1 30	0 2 0 6	0 21 0 23	5 6-7 3
Moody	12 24	Silty clay loam	CL, CH	100	100	95-100	95-100	32 55	11 33	27 35	1 20-1 30	0 2-0 6	0 18-0 20	6 1 7 3
	24-60	Silty loam Silty clay loam	CL, CL ML, ML	100	100	95-100	85-100	25-46	5-25	20-32	1 20-1 30	0 6-0 2	0 19-0 21	6 6-8 4
NoC2	0-6	Silty clay loam	CL	100	100	95-100	95-100	35-50	12 25	27 25	12 0-1 25	0 6-2 0	0 19-0 22	6 1 7 3
Nora	6-15	Silty loam silty clay loam	CL, Ml	95-100	95-100	95-100	85-100	35-50	11 20	20-35	1 25-1 35	0 6-2 0	0 17 0 20	6 1 7 8
	15-60	Silty loam silty clay loam	CL, CL ML, ML	95-100	95-100	95-100	85-100	27 50	6-20	18-30	1 30-1 45	0 6-2 0	0 17-0 20	6 6-8 4
NoD	0-12	Silty clay loam	CL	100	100	95-100	95-100	35-50	12 25	27 25	12 0-1 25	0 6-2 0	0 19-0 22	6 1 7 3
Nora	12 25	Silty loam silty clay loam	CL, Ml	95-100	95-100	95-100	85-100	35-50	11 20	20-35	1 25-1 35	0 6-2 0	0 17-0 20	6 1 7 8
	25-60	Silty loam silty clay loam	CL, CL ML, ML	95-100	95-100	95-100	85-100	27 50	6-20	18-30	1 30-1 45	0 6-2 0	0 17-0 20	6 6-8 4
NpD2* NpE2*	0-5	Silty clay loam	CL	100	100	95-100	95-100	35-50	12 25	27 25	12 0-1 25	0 6-2 0	0 19-0 22	6 1 7 3
Nora	5-25	Silty loam silty clay loam	CL, Ml	95-100	95-100	95-100	85-100	35-50	11 20	20-35	1 25-1 35	0 6-2 0	0 17-0 20	6 1 7 8
	25-60	Silty loam silty clay loam	CL, CL ML, ML	95-100	95-100	95-100	85-100	27 50	6-20	18-30	1 30-1 45	0 6-2 0	0 17-0 20	6 6-8 4
So	0-25	Silt loam	CL, CL ML	100	100	95-100	90-100	25-40	6-18	15-27	1 20-1 30	0 6-2 0	0 22-0 24	5 6-7 3
Shell	25-35	Silt loam silty clay loam	CL	100	100	95-100	90-100	25-46	10-25	20-30	1 20-1 30	0 6-2 0	0 20-0 22	5 6-7 3
	35-60	Silt loam loam silty clay loam	CL	100	100	95-100	90-100	25-40	35-60	20-30	1 20-1 30	0 6-2 0	0 20-0 22	6 1 7 8

From The Soil Survey Of Platte County Nebraska 9/88

domestic/stock wells These wells have been located through area canvass of the owners/tenants and operators of properties (Section 2 8)

This aquifer is known to mantle the Niobrara Formation in this area of Platte County (Weeks and Guttentog 1981) and it is locally known that the Niobrara does not yield sufficient water to be developed This is evident from many test holes which have been advanced into the Niobrara (HWST 1987) Although in localized areas the Niobrara has developed secondary porosity as the result of fractures and solution channels and may produce large volumes of water (Enberg 1989)

Failure by the private well drilling industry to find zones of ground-water contribution from the Niobrara in the vicinity of the site is indicated by the well logs (Appendix I) None of the vicinity wells are completed in the Niobrara HWST and Dames & Moore test holes into the Niobrara (Appendix I) confirm the registered irrigation well logs in the definition of Niobrara subcrop to be a weathered plastic dense silty clay The plasticity of this material inhibits the development and persistence of fracture or solution porosity which develops in brittle material

3 6 1 Site Hydrogeology

The following hydrogeologic concepts of the site are based on the results of extensive test drilling aquifer testing and water level monitoring performed from 1980 to the present

Ground water at the site can be generally characterized as occurring in a sand and gravel aquifer bounded on the top and bottom by aquitards which include the upper loessal soils and the lower Niobrara Formation Some ground water also occurs in the upper and lower units but water movement in them is significantly retarded by the fine-grained and plastic nature of the strata

Ground water occurrence in the aquifer is confined having a storage coefficient of approximately 10^{2} to 10^{5} averaging 10^{3} to 10^{4} Storage coefficient is an indicator of the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head (Lohman 1979) The range of values found on site indicates that the release of water from the aquifer occurs primarily by hydrostatic pressure rather than by gravity drainage This local pressure is insufficient to produce artesian conditions or discharge by wells without pumps

3 6 1 1 Aquifer Characteristics

The aquifer at the site is laterally extensive and hydraulically connected between all penetrating wells within a two mile radial distance of this site It is likely that the sand and gravel aquifer extends at least 10 miles in every direction based on its stratigraphic occurrence in the area (Burchett et al 1975 Weeks and Guttentog 1981) The thickness of the aquifer ranges from

20 to over 80 ft within two miles of the site (HWST 1987) however at the site the range is 35 to 50 ft (Figure 3 6-1) Figure 3 6-2 is a contour map of the basal surface of the aquifer This map is constructed from the logs of 26 test holes across and around the site

The aquifer is primarily composed of fine sand to medium gravel The average grain size (D-50) determined from sieve analyses ranged from 0 6 to 2 0 mm (HWST 1987) The upper five feet of the aquifer is generally less uniform ranging from silt to gravel The bottom five feet is generally poorly sorted and slightly coarser than the materials above

Aquifer Parameters

Transmissivity values for the aquifer were determined primarily from aquifer tests performed with pumping wells (Section 2 7) and additionally from the record of pumping responses of the registered irrigation and public supply wells (HWST 1987) Transmissivity values for the aquifer range from 34 000 gpd/ft to over 340 000 gpd/ft These values are generally in the range reported by CSDN (Section 3 6) but exceed the maximum value In general the CSDN values are based on registered well log reports and are not quality controlled in the field

Tables 3 6-1 to 3 6-4 are summaries of aquifer pump test data and transmissivity (T) storativity (S) and hydraulic conductivity (K) values They represent data collected in 1983 1984 1987 1988 and 1989 The summaries are based on data presented in the 1984 Remedial Action Plan the 1987 Interim Status Report the 1988 Extended Subsurface Investigation and data collected in 1989 from the AOIW Additional aquifer pump test data can be found in Appendix VIII

The primary descriptive parameter of an aquifer transmissivity (T) is a function of hydraulic conductivity saturated thickness (M) and geologic properties (Lohman 1972) Therefore spatial changes in either K or M within the influence area of the aquifer test well will affect the values of T determined For example if K averages 300 ft/day and the saturated thickness 50 ft a change in M = 5 ft will change T by 10 percent Because the potential range in M of + 15 ft at the site T could change by as much as 30 percent based on thickness only

Transmissivity as determined by aquifer pump tests is evaluated from data collected over a testing period sufficient to determine the hydraulic anomaly of the area Its value is based on the degree and the rate of change at a measuring point and can be different directionally and with distance from the pumped well Because of site-specific geologic conditions including changes in aquifer thickness and grain-size sorting transmissivity is expected to vary over the duration of the pump testing period and with the direction in which the measurements are made from the pumped test well

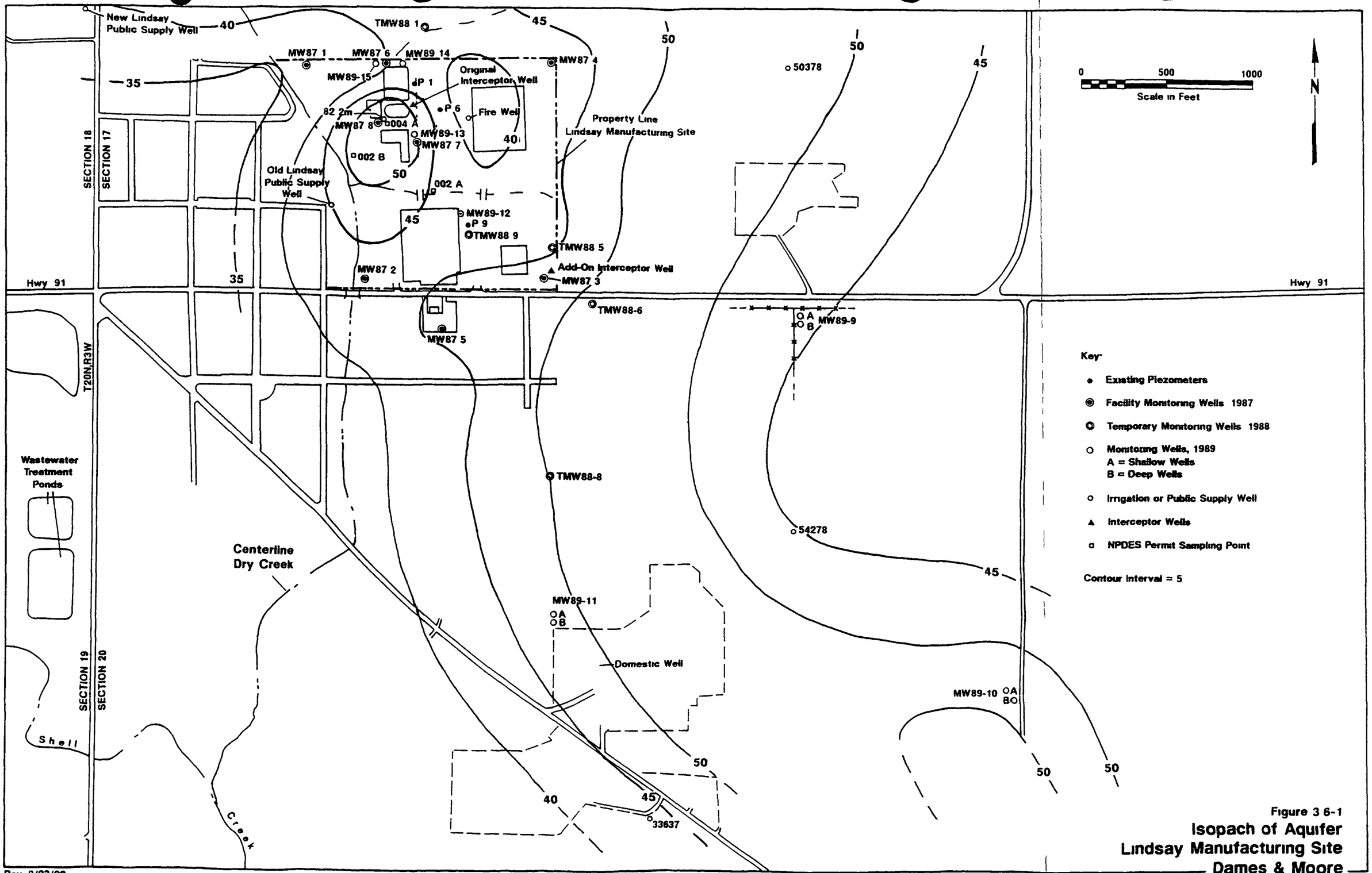

Figure 3 6-1
Isopach of Aquifer
Lindsay Manufacturing Site
Dames & Moore

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Rev 2/23/90

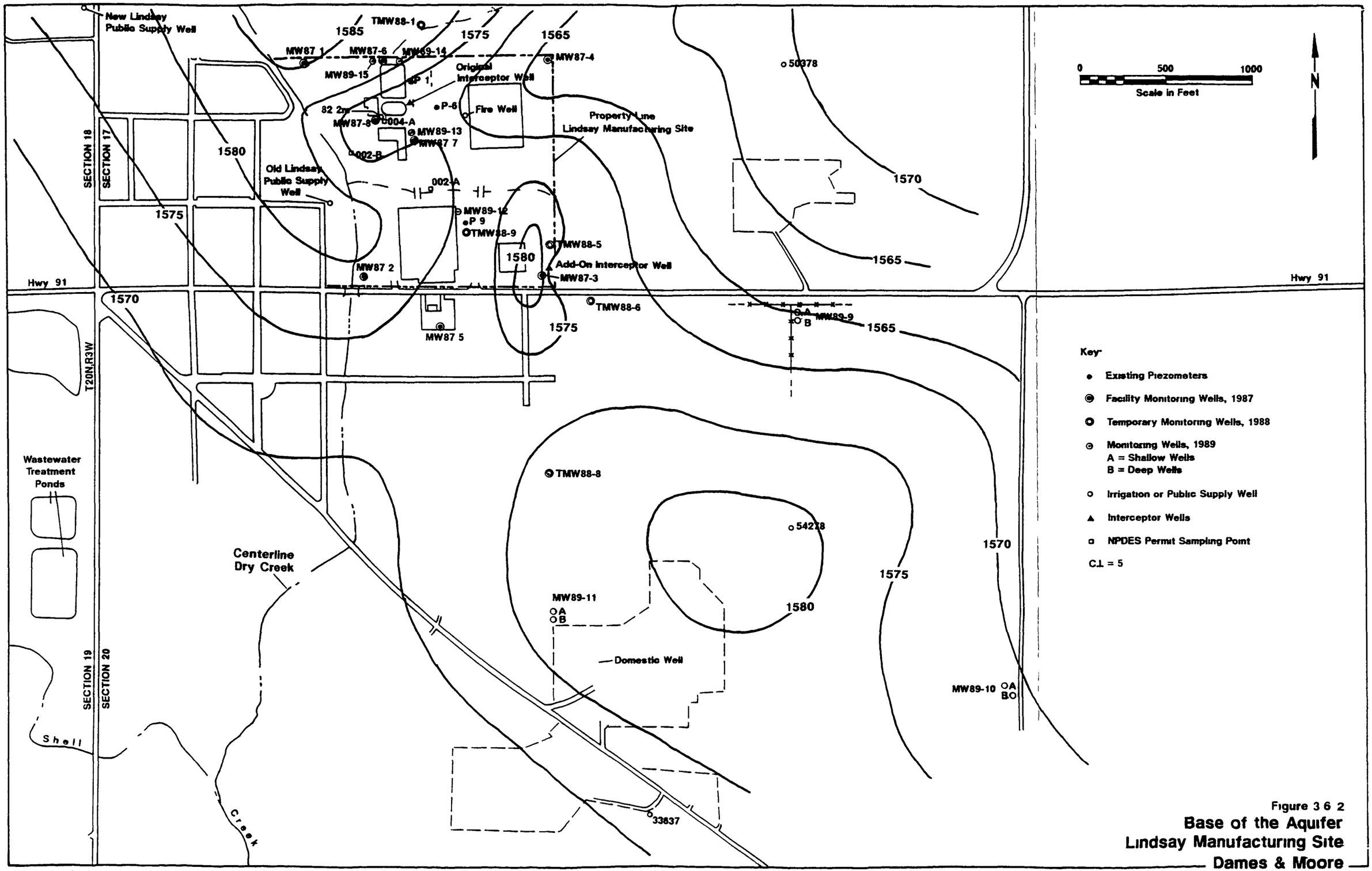

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Figure 3 6 2
Base of the Aquifer
Lindsay Manufacturing Site
Dames & Moore

Table 3.6-1

Aquifer Transmissivity and Conductivity Calculations, Irrigation and Registered Wells and 1987-series Monitoring Wells

Well Number	Transmissivity (gallons/day/foot)	Hydraulic Conductivity (feet/day)
55754	37 000	150
45177	200 000	500
33812	50 000	200
50378	100 000	270
67633	40 000	170
4952	33 000	150
56331	125 000	200
29918	34 000	150
45471	82 000	150
54278	100 000	290
33637	130 000	400
67535	83 000	200
63717	96 000	160
Fire Well	110 000	310
69308	65 000	280
29918	34 000	150
MW87 1	74 000	270
MW87 2	97 000	290
MW87 3	100 000	290
MW87-4	95 000	290
MW87 5	101 000	290
MW87 6	72 000	240
MW87 7	100 000	270
MW87 8	120 000	290

Notes

Well data and calculations based upon registered well logs HWST 1987

** Estimated from grain size distribution curves HWST 1987 Tests conducted 11/3/87 11/11/87

Table 3.6-2

Summary of Aquifer Parameter Calculations, Original Interceptor Well*

Analysis	Aquifer Test							
	Step-Drawdown 3/31/83		4 Hour Constant Discharge 6/3/83		72 Hour Constant Discharge 6/25-27/84		4 Hour Pump Test 12/21/87	
	Transmissivity	Storativity	Transmissivity	Storativity	Transmissivity	Storativity	Transmissivity	Storativity
Distance Drawdown Method	33 000 gpd/ft	6 5E-04	65 000 gpd/ft	4 1E-03	115 000 gpd/ft	8 1E-02	NA	NA
Specific Capacity Method	69 000 gpd/ft	NA	119 000 gpd/ft	NA	NA	NA	NA	NA
Time vs Drawdown Straight Line Approx imation Method								
Well Name								
P 1	NA	NA	127 000 gpd/ft	2 4E-04	189 000 gpd/ft	4 5E-03	NA	NA
P 2	NA	NA	116 000 gpd/ft	3 4E-05	NA	NA	NA	NA
P 3	NA	NA	120 000 gpd/ft	1 8E-05	137 000 gpd/ft	9 9E-04	NA	NA
P-4	NA	NA	110 000 gpd/ft	8 8E-05	143 000 gpd/ft	1 2E-03	NA	NA
P-6	NA	NA	NA	NA	165 000 gpd/ft	4 5E-02	NA	NA
P 7	NA	NA	NA	NA	162 000 gpd/ft	2.1E-03	NA	NA
P-8	NA	NA	NA	NA	153 000 gpd/ft	1 5E-02	NA	NA
P 9	NA	NA	NA	NA	176 000 gpd/ft	1 6E-03	NA	NA
MW87 1							139 000	4 30E-04
MW87 2							343 000	6 00E-04
MW87 3							380 000	3 50E-04
MW87-4							207 000	2.70E-04
MW87 5							520 000	3 90E-04
MW87-6							143 000	3 80E-04
MW87 7							180 000	NA
MW87-8							150 000	NA
Old Well							140 000	NA

HWST 1987

Table 3.6-3

Constant Rate Pump Test Results by Well - February 21, 1989

Add-On Interceptor Well

Lindsay Mfg Co

Location	Radius [a] (feet)	Approximate Saturated Thickness (feet)	Time Drawdown Analysis			Recovery Analysis		Average Values	
			Storativity	Transmissivity (gpd/ft) [c]	Hydraulic [b] Conductivity (feet/day)	Transmissivity (gpd/ft) [c]	Hydraulic [b] Conductivity (feet/day)	Transmissivity (gpd/ft) [c]	Hydraulic [b] Conductivity (feet/day)
Add-On	0 7	50		1 29E+05	345	1 06E+05	283	1 18E+05	314
MW87-3	22 4	50	1 10E-05	1 52E+05	406	9 97E+04	267	1 26E+05	337
TMW88-5	114 7	47	2 37E-05	1 70E+05	483	9 36E+04	266	1 32E+05	375
TMW88-6	375	52	3 49E-05	1 97E+05	506	2 34E+05	602	2 16E+05	554
TMW88-9	510	44 5	1 47E-04	1 94E+05	583	2 41E+05	724	2 18E+05	654
TMW88-4	517 4	59	1 44E-03	1 16E+05	263	1 45E+05	329	1 31E+05	296
P 9	543 8	46	1 59E-04	2 45E+05	712	2 69E+05	782	2 57E+05	747
TMW88-7	637 5	47	5 36E-05	2 67E+05	759	3 01E+05	856	2 84E+05	808
MW87 5	697 5	46	7 27E-05	2 84E+05	825	3 01E+05	875	2 93E+05	850
MW87 2	1076 3	44	2 32E-04	3 42E+05	1 039	4 99E+05	1 516	4 21E+05	1 278
Mean	**NA**	**NA**	**2.42E-04**	**2.10E+05**	**592**	**2.29E+05**	**650**	**2.19E+05**	**621**

Notes

[a] Radius from pumped Add-On Interceptor Well

[b] Hydraulic Conductivity = Transmissivity/Saturated Thickness

[c] Gallons per day per foot.

Table 3.6-4

Summary of Step-Drawdown and Constant Rate Pump Test Results
Add-On Interceptor Well
Pump Tests Conducted February 20 and 21, 1989
Lindsay Mfg Co

Pump Test	Analysis	Transmissivity (gpd/ft) [a]	Storativity	Hydraulic Conductivity (feet/day)	Well Efficiency	Specific Capacity (gpm/ft) [b]
Step-Drawdown	Qi/Si [c]		–			38 9
Constant Rate (pumping)	Time/ Drawdown	2 10E+05	2 42E 04	592		
	Distance/ Drawdown	6 61E+04	1 73E 03	162	0 73	
Constant Rate (recovery)	Time/Residual Drawdown	2 19E+05	---	650		
Average		**1 65E+05**	**9 86E-04**	**468**	—	—

Notes

[a] Gallons per day per foot
[b] Gallons per minute per foot
[c] Discharge (gallons per minute) per drawdown (feet) at pump rate i

In general the following qualitative conditions should be considered in the evaluation of the aquifer pump test data

- T and S values are best determined from the longer (72-hour) pump test and the data collected from actual remedial pumping of the interceptor well s long term continuous pumping measurements (HWS 1984 1987)

- Aquifer pump test data are effected by other pumping operations within its influence area For example results from the 1989 AOIW pump test are somewhat affected by the aquifer s response to the OIW which had been pumping continuously during the previous 20 months

The storativity (S) of the aquifer can be derived from the same methods used to calculate transmissivity and is subject to similar effects The range in S values (10^{2} to 10^{5}) is consistent with typical ranges for semi-confined to confined aquifers as previously reported (HWS 1987)

Hydraulic conductivity (K) depends on the intrinsic properties of the aquifer and can be estimated from grain size distributions laboratory tests and pump test data in which T and M are known In this case K values range from 160 to 1 000 ft/day

Four significant trends have been identified concerning T values and their supporting data These trends are as follows

- Transmissivity at the OIW as determined by the specific capacity method (Table 3 6-2) increased significantly from March 1983 to June 1983

- Transmissivity values are significantly greater southeast of the site than in the area of the OIW

- Transmissivity values plotted against distance (x) from the AOIW are linear (Figure 3 6-3) This suggests a direct relationship between T and x This linear correlation is most evident in off-site wells to the south southeast and southwest

- A break in the response of the aquifer to pumping during the 72-hour constant rate pump test occurred after approximately 2 000 minutes (Appendix VIII) After the break there was no obvious relationship between water level and pumping time A similar break and in some cases a recovery occurred in the 1983 4-hour constant rate pump test (Appendix VIII)

The first trend indicates a change in hydraulic conductivity at the OIW since the saturated thickness (M) was relatively constant This change in K value is also indicated by relative

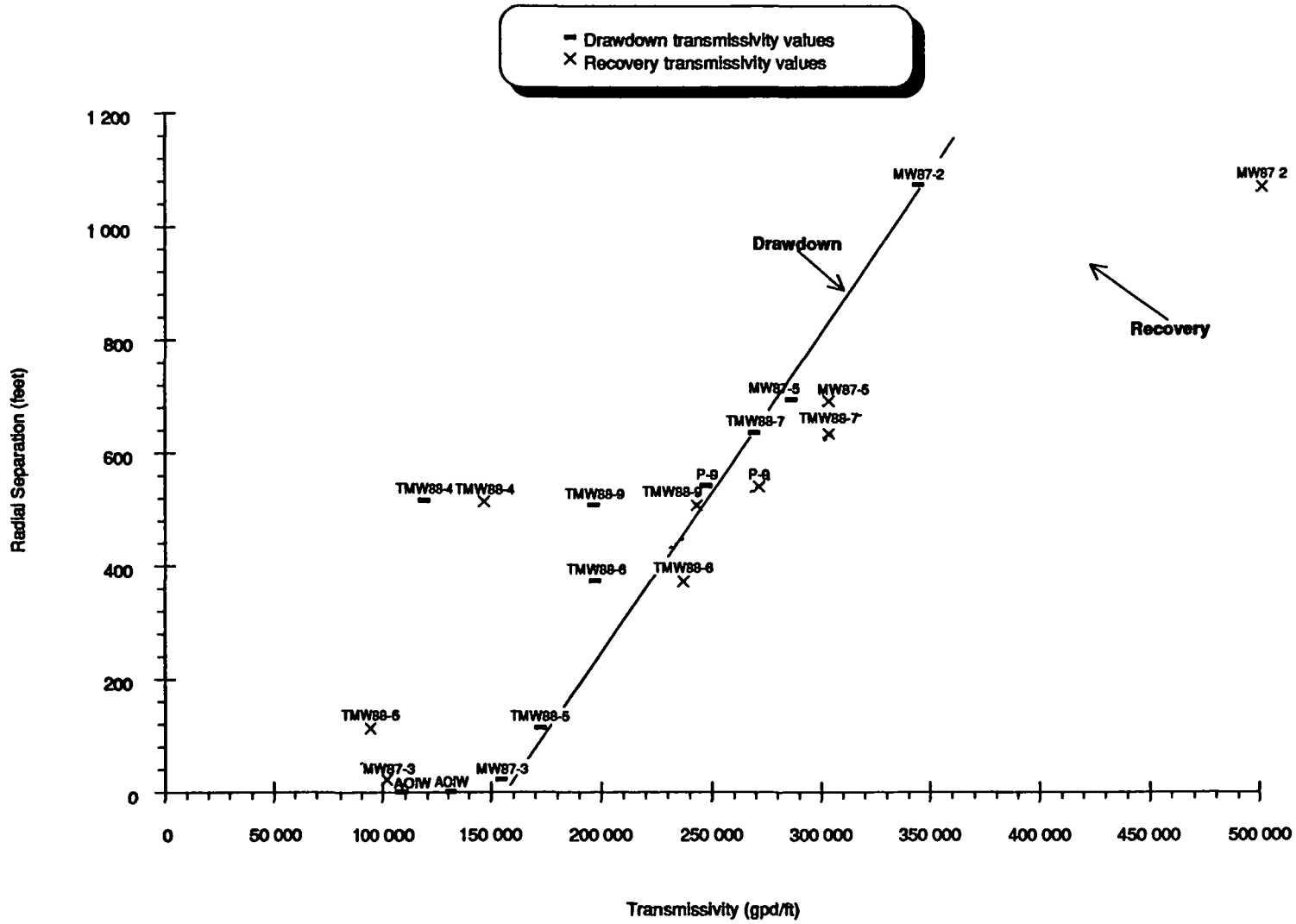

Figure 3 6-3

Radial Separation of Distance vs Transmissivity
Add-On Interceptor Well Pump Test, February 21, 1989
Lindsay Mfg Site
Dames & Moore

Job Number 16657-002-005

increases in T values from the 1983 test to the 1984 aquifer pump test in the same wells Although the cause is not evaluated in this study the change in K suggests increased porosity possibly resulting from the sudden inflow of acidic waters in 1983 The second of these trends indicate that the aquifer is more transmissive with greater saturated thicknesses off site to the south southeast and southwest and is less transmissive with thinner saturated thicknesses to the west northwest and northeast (Figure 3 4-5A-F) This trends are consistent with the geologic conditions (Section 3 4) The sand and gravel unit (aquifer) increases in thickness to the south southeast and east T values also increase with longer pump tests in which the radius of influence progresses to these areas of greater aquifer thickness

The aquifer tests are subject to interference by nearby wells as is evident in the fluctuations in measurement trends that occurred across the site at approximately the same time during the 1983 aquifer test where it is believed a nearby well was shut off during the test

The phenomenon of well interference is important to understanding the aquifer parameters and the field measurements The rate of progression of a well s influence area across the site can be calculated based on the aquifer characteristics T and S and using the equation presented by Lohman (1972) based on Cooper & Jacob (1946)

$$r^2 = \frac{2\ 25\ Tt}{S \log^{-1}\left[\frac{4\pi\ TS}{2\ 30\ Q}\right]}$$

where r = radial separation from the pumped well (ft) t = time since pumping started (mins) and Q = well discharge (ft /min) Solving for t for any given drawdown yields

$$t = \frac{r^2\ S \log^{-1}\left[\frac{4\pi\ TS}{2\ 30\ Q}\right]}{2\ 25\ T}$$

If one uses a typical T value of 120 000 gpd/ft and a range of S from 10^{-3} to 10^{-4} the time to achieve a drawdown at a selected radial distance can be calculated The nearest well to the site is the Old Lindsay Public Supply Well If this well were pumped at 750 gal/min (100 ft^3/min) the time it would take for a drawdown of 0 1 ft at a 1 000 ft distance would range from 4 6 to 46 mins For the drawdown to progress to 0 5 ft at a distance of 1 000 ft the range in time would vary from 8 to 80 mins Similarly a drawdown of 1 0 ft at 1 000 ft distance would require 16 to 160 mins A well such as this could cause the trend reported in the 1983 aquifer pump test

This rapid response of the aquifer hydraulic head to a well s operation is consistent with the data reported by HWST from the December 21 1987 aquifer pump test (Appendix VIII) For example wells MW87-2 and MW87-5 both responded significantly (greater than 0 1 ft head change) in less than 27 minutes at radial distances of greater than 1 000 ft

The rapid response is also consistent with the February 21 1989 D & M aquifer pump test of the AOIW MW87-2 exhibited 1 ft of drawdown at 47 minutes at a radial separation of greater than 1 000 ft

In summary the values of T and S characteristic of the site aquifer indicate a highly transmissive semi-confined to confined aquifer condition The influence of a pumped well spreads outward in a radial direction and the rate of progression of the hydraulic head drop is rapid As a consequence the aquifer s horizontal flow direction can be shifted toward a well simply by pumping that well Some wells have the capacity to influence each other by reducing available yield and thereby causing fluctuations in the hydraulic gradient

The calculated hydraulic conductivities across the site range from 240 to 1500 ft/day (Tables 3 6-1 3 & 4) The high range values are based on recovery data of short duration only and have not been verified on-site by test hole logs sieve analysis or previous pump tests In general the site has an average K value of 350 ft/day

3 6 1 2 Aquitard Characteristics

As previously discussed in the vicinity of the site the aquifer is bounded on top by an aquitard Freeze and Cherry (p 47 1979) define an aquitard as a

> less-permeable bed in a stratigraphic sequence These beds may be permeable enough to transmit water in quantities that are significant in the study of regional ground-water flow but their permeability is not sufficient to allow the completion of production wells within them

The definition is met at the site aquitard by the low permeability of the silt clay units which cannot sustain yield to a well at hydraulic conductivities of 10^{6} to 10^{7} cm/sec

To illustrate the limitations on transmission of deeply infiltrating rainwater snowmelts or wastewater through the aquitard the area of recharge to a well can be calculated If we assume the Old Lindsay Public Supply Well supplied 10 million cubic feet of water per year to the village and Lindsay Manufacturing and the recharge rate is 0 075 feet per year then the area of recharge contribution would be 133 million square feet (4 8 square miles) If no recharge occurred an unlikely event the stored water in the aquitard would drain to supply this well If we assume an average porosity of 0 35 for the aquitard 10 million cubic feet of water over 4 8 square miles represents an average drop of 0 2 feet in water level At this rate it would take approximately 100 years to drain the ground water from the aquitard Only long-term pumping proximity to a high capacity well or induced recharge will accelerate the transmission of water through the aquitard

The aquitard contains a sand channel (Section 3 4) which is bounded on the bottom sides and from above by silty clays and clayey silts Ground water is perched in the sand channel above the aquifer The sand channel is not completely saturated its drainage is by gravity as opposed to flow in the underlying aquifer which is by release of hydraulic pressure The channel is locally recharged by deep infiltration of rainfall and snow melt except in some areas where the overlying soils are capped by facilities including the concrete pad of the crane (central north 1/2 of site between the OIW and P-6 west to east and C-10 and 87-11 north to south) the lined cells 1 & 2 and the concrete pad between the crane and the galvanizing building Infiltration does not occur through the capped areas

Prior to closure of the pit (1983) and completion of construction of the wastewater treatment facility cells #1 and #2 (1984) the sand channel also received recharge in those areas The pit is estimated to have contributed 500 to 5 000 ft^3/yr of acidic leachate (4 000 to 40 000 gal/yr) to the sand channel

This estimate is based upon the disposal practice history outlined in Section 1 2 2 1 Approximately 3% to 22% of the acidic contamination from the disposal pit is estimated to have entered the sand channel while the remainder has evaporated or settled to the bottom of the disposal pit as sludge solids These solids and residual fluids in the pit were removed during the pit closure

Annual recharge to the sand channel during the existence of the pit can be assumed to be over approximately 50 percent of the area of the sand channel not capped by concrete (68 000 ft) or approximately 5 100 ft^3/yr (38 000 gal/yr) at 0 075 ft of recharge per year Total annual recharge to the sand channel during the period of the pit s use is estimated to be 42 000 to 78 000 gal/yr

Assuming this recharge equilibrates annually with the potentiometric surface and recharges the aquifer what is the ratio of the sand channel recharge to the flow beneath it in the aquifer? It is estimated that 5 8 to 58 million gallons of water would flow through the aquifer annually This volume is based on the following equation

$$Q = KAi$$

where Q equals the volume of water transported through a cross sectional area (A) with a given hydraulic conductivity (K) and a steady-state hydraulic gradient (i)

$$Q = K(50\ ft)(150\ ft)(365\ days/yr)(0\ 0019\ ft/ft)$$

$$Q_{min} = (150\ ft/day)(5201\ ft^2/day/yr)$$

$$= 780\ 000\ ft^3/yr$$

or

= 5 8 million gals/yr

Q_{max} = (5201 ft^2/day/yr)(1500 ft/day)

= 7 8 million ft^3/yr

or

= 58 million gals/yr

The ratio of annual sand channel recharge (SCR) to the volume (AV) of flow beneath the sand channel in the aquifer is estimated as follows

$$\frac{SCR}{AV} = \frac{42{,}000 \text{ gal/yr}}{5\ 835\ 000 \text{ gal/yr}}$$

$$= 0\ 0072$$

$$\frac{SCR}{AV} = \frac{78{,}000 \text{ gal/yr}}{58\ 000\ 000 \text{ gal/yr}}$$

$$= 0\ 0013$$

The water displaced in the aquitard by this annual recharge (42 000 to 78 000 gal/yr) represents an average progression of these waters through the aquitard from 0 07 ft to 0 14 ft

The restriction to transmission by the aquitard in the area of the perched sand channel was significantly affected by well drilling and construction operations in December 1982

The ratio of sand channel recharge to aquifer flow allows a comparison of the ground water originating on site to the volume of ground water moving past the site in the aquifer This information is useful in evaluating the feasibility of remedial options (Section 5 0)

The aquitard was punctured in 1982 by three of the four new wastewater treatment facility monitoring wells (1982-M series) These three wells also penetrated the sand channel and the silty clay which separated the channel from the aquifer In addition the well annuli were backfilled with a coarse sand and gravel which provided relatively high permeability connections between the sand channel and the aquifer HWST (1987) reported that the drainage rates for the perched sand channel waters from these wells into the underlying aquifer ranged from 1 250 to 2 500 gallons/day (gpd) They also reported that the drainage could increase to 6 200 to 12 000 gpd during pumping of the OIW as the pressure head in the aquifer is reduced by well draw down and the perched sand channel waters drain by gravity The drainage rate of these wells was also subject to the influence from the pumping of the Old Lindsay Public Supply Well because they were within its radius of influence until it was shut off in mid 1983 The drainage rate of these

three wells over one month is estimated to have been 110 000 to 230 000 gal prior to installation and pumping of the OIW in March 1983

An intentional conduit through the sand channel and aquitard has been made by the OIW This was intended to provide gravity drainage from the recently punctured sand channel through the well annulus to the well screen where interception could occur unimpeded by the aquitard The drainage of the 1982-M series monitoring wells was within the capture zone of the OIW the continuous drainage to the aquifer from those wells could be captured recovered and treated more effectively in this manner The OIW drainage rate is estimated at an initial transient rate of 3 000 gal/day (HWST 1987) which would decline with the loss of storage in this sand channel reservoir

The sand channel is estimated to be approximately 800 ft in length averaging 150 ft in width and containing at least 5 ft of saturation If a conservative value of 0 20 is used for the sand channel porosity an estimate of the sand channel ground-water reservoir can be calculated

Volume = (800 ft)(5 ft)(150 ft)(0 20)

= 120 000 ft^3 (900 000 gallons)

In summary the aquitard contains a sand channel reservoir of perched ground water which received annually recharge contributions from rainfall snowmelt and the pit of 42 000 to 78 000 gal/yr In December 1982 three monitoring wells installed penetrated the sand channel and aquitard creating a direct hydraulic connection to the aquifer These connections provided initial drainage in the order of 110 000 to 230 000 gal/month which exceeded the estimated annual recharge of the sand channel In March 1983 the OIW was installed with the annulus of the well designed to perform as a conduit to enhance this drainage with the intent to more effectively capture the acid leachate

3 6 2 Water Levels

3 6 2 1 Aquifer Water Levels

Ground-water levels in the aquifer are higher in elevation than the contact of the top of the aquifer and the overlying silty clay aquitard Maps of water levels (potentiometric surface maps) in this report are based on measurements of the hydraulic head of ground water in wells which penetrate the aquitard into the aquifer and are hydraulically connected to the aquifer

Ground-water elevations at the site ranged from 1651 5 to 1647 1 ft in January 1983 (HWS 1983) which is similar to the published potentiometric surface at Lindsay Nebraska of 1650 ft MSL for spring 1979 (NDEC 1980)

Water levels and elevations are tabulated and attached (Appendix IV) Figures 3 6-4A to 4D are hydrographs of selected monitoring wells and piezometers which have been measured during this and previous studies Figures 3 6-5A & 5B are a set of hydrographs and their locations from continuous monitoring wells in this area of Nebraska which are maintained through a cooperative program between the Conservation and Survey Division (Nebraska) and the United States Geological Survey

In general the hydrographs of the site water levels are typical of a confined aquifer responding to seasonal irrigation well stress Significant drops in elevation occur in early summer and are followed by relatively rapid initial recovery in August or September followed by a gradual recovery during fall winter and spring The impact of interceptor well discharges became significant in the summer of 1987 when the OIW was pumping continuously Later in 1987 additional aquifer water level downward impacts resulted when both the AOIW and the OIW were operating The hydrographs show a downward trend on the overall annual cycle

The hydrograph of well 82-2M is the only extant measurement point from 1983 to the present (Figure 3 6-4A) This well's water level response is subject to significant influence of the OIW which is approximately 190 feet away This has been demonstrated repeatedly in pump test data (HWS 1984 and HWST 1987) The 82-2M hydrograph exhibits trends of a summer decline followed by a winter recovery In addition a gradual decline occurred in the potentiometric surface from approximately 1650 ft in 1983 to approximately 1640 to 1643 ft in 1990

The second longest record of water level measurement occurs in piezometers P-1 4 6 and 9 (Figure 3 4-4B) These measurements began on a regular basis in the summer of 1985 and continue to the present Their hydrographs exhibit both the seasonal summer lows in addition to the long term decline beginning in 1987 It is evident that prior to continuous pumping the aquifer could recover to its 1983 elevation of 1650 ft however by spring 1989 the recovery was only to 1645 ft

The hydrographs of the 1987-series wells (Figures 3 6-4C & 4D) also depict annual cycles including summer lows and winter recoveries The annual winter/spring recoveries exhibit the impact of extensive local irrigation stress on the aquifer responding to a widespread drought that began in late 1988 and has extended through 1989

The Recorder Well hydrographs of east central Nebraska which include hydrographs from Albion Archer Elgin and Oceola (Figures 3 6-5) exhibit similar trends including summer lows and winter recoveries These hydrographs also exhibit a general upward trend in the recovery of annual water levels from 1981 to 1987 This trend was probably due to generally wetter than average conditions in central Nebraska (Johnson & Pederson 1984 Ellis & Dreeszen 1987 Ellis & Wigley 1987) which resulted in increased ground-water recharge and decreased irrigation well withdrawals The trend was reversed in 1988 consistent with the deficit soil moisture during the

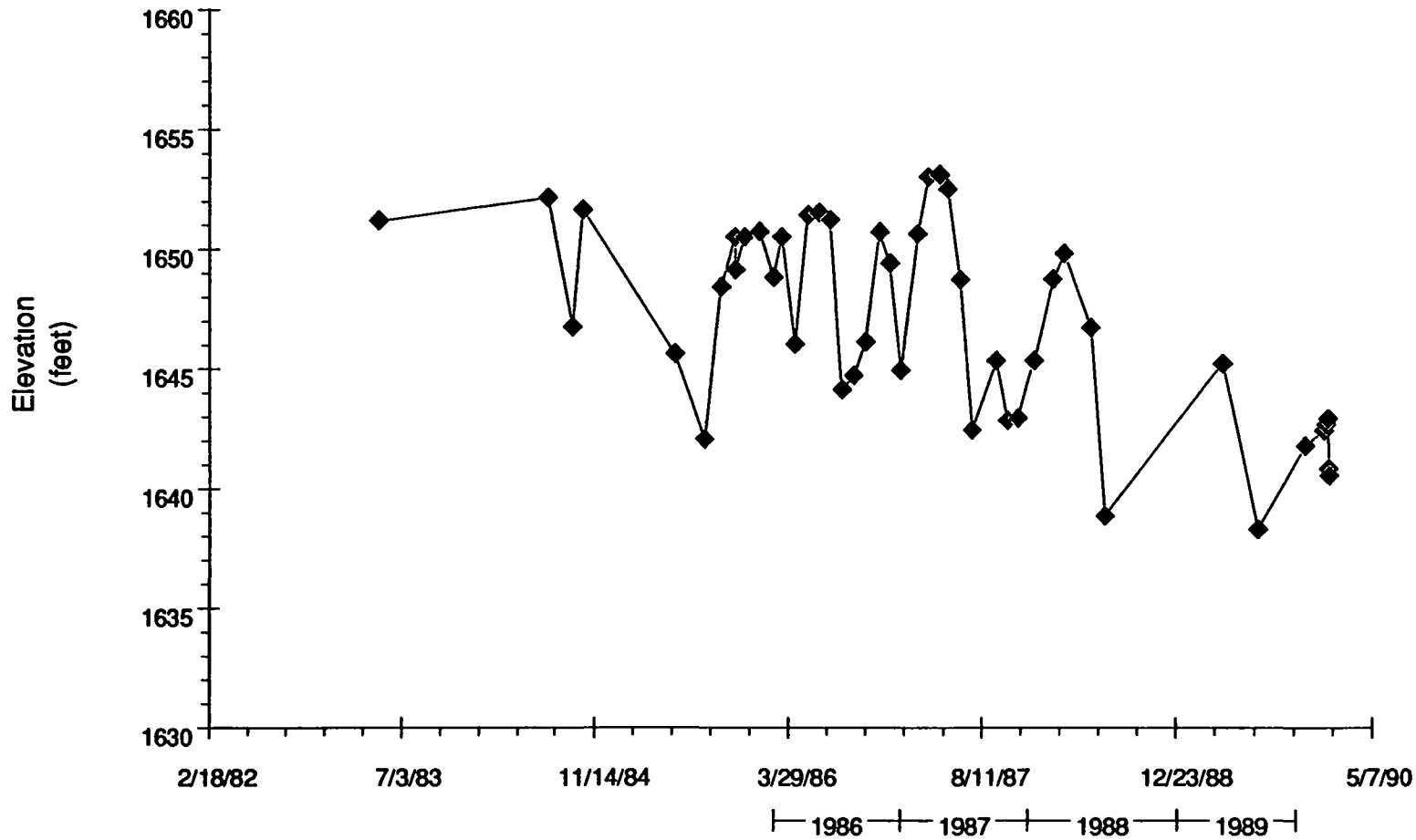

Figure 3 6-4a

Hydrograph

All Available Data - 82-2M

Lindsay Mfg Co

Dames & Moore

Job Number 16657-002-005

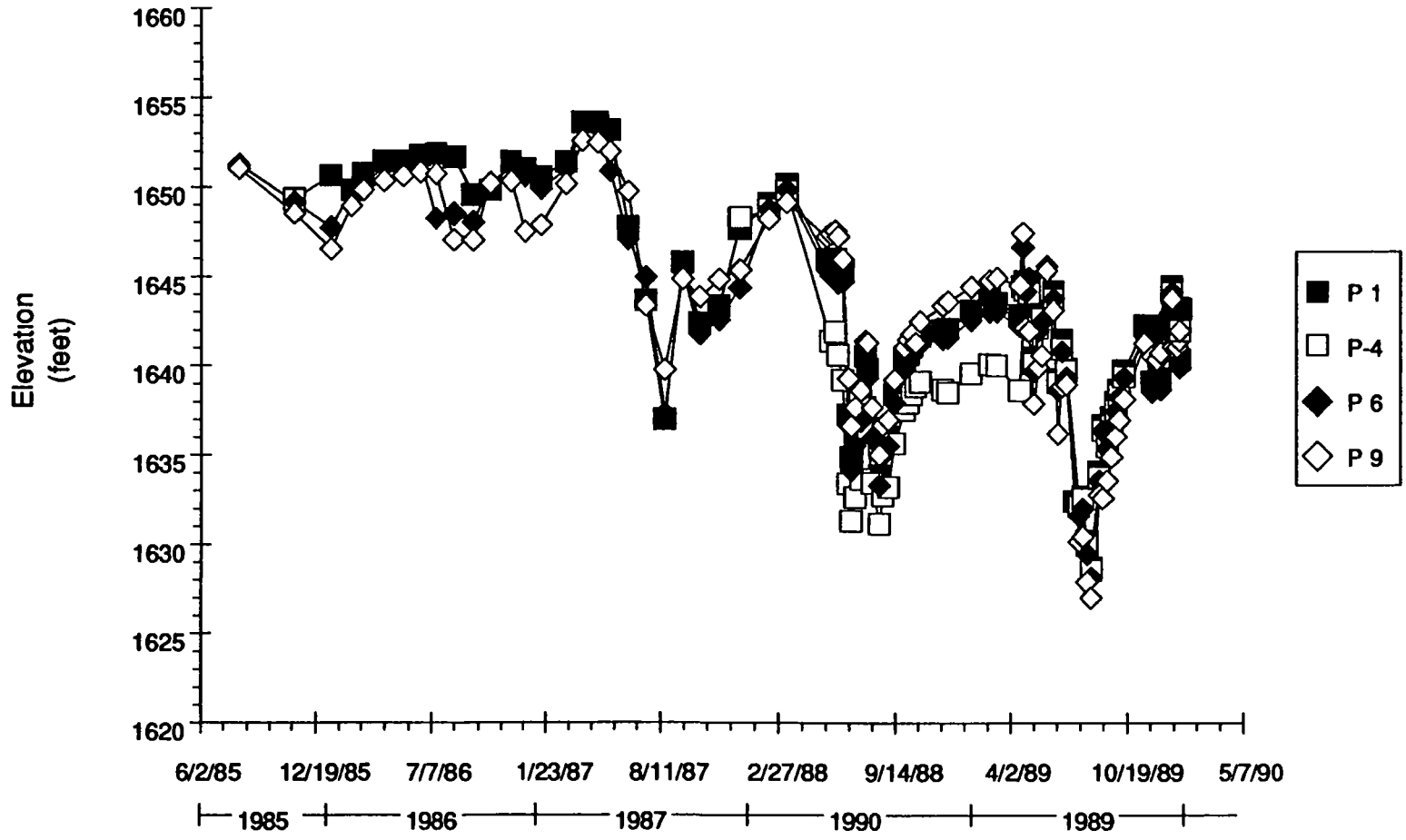

Figure 3 6-4b

Hydrograph

All Available Data - P-1, - 4, -6, -9

Lindsay Mfg Co

Dames & Moore

Job Number 16657-002-005

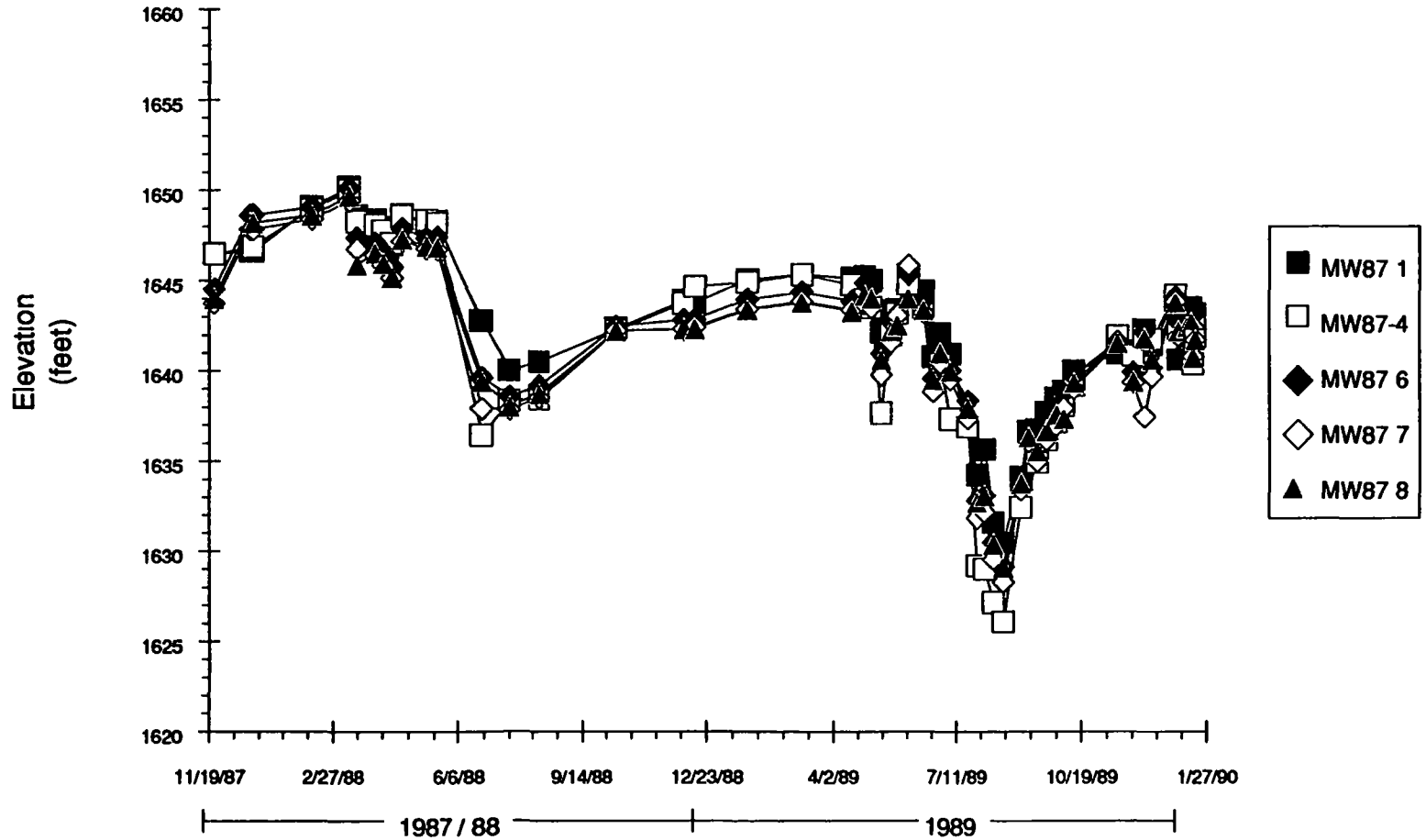

Figure 3 6-4c

Hydrograph

All Available Data - MW87-1, -4, -6, -7, -8

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Job Number 16657-002-005

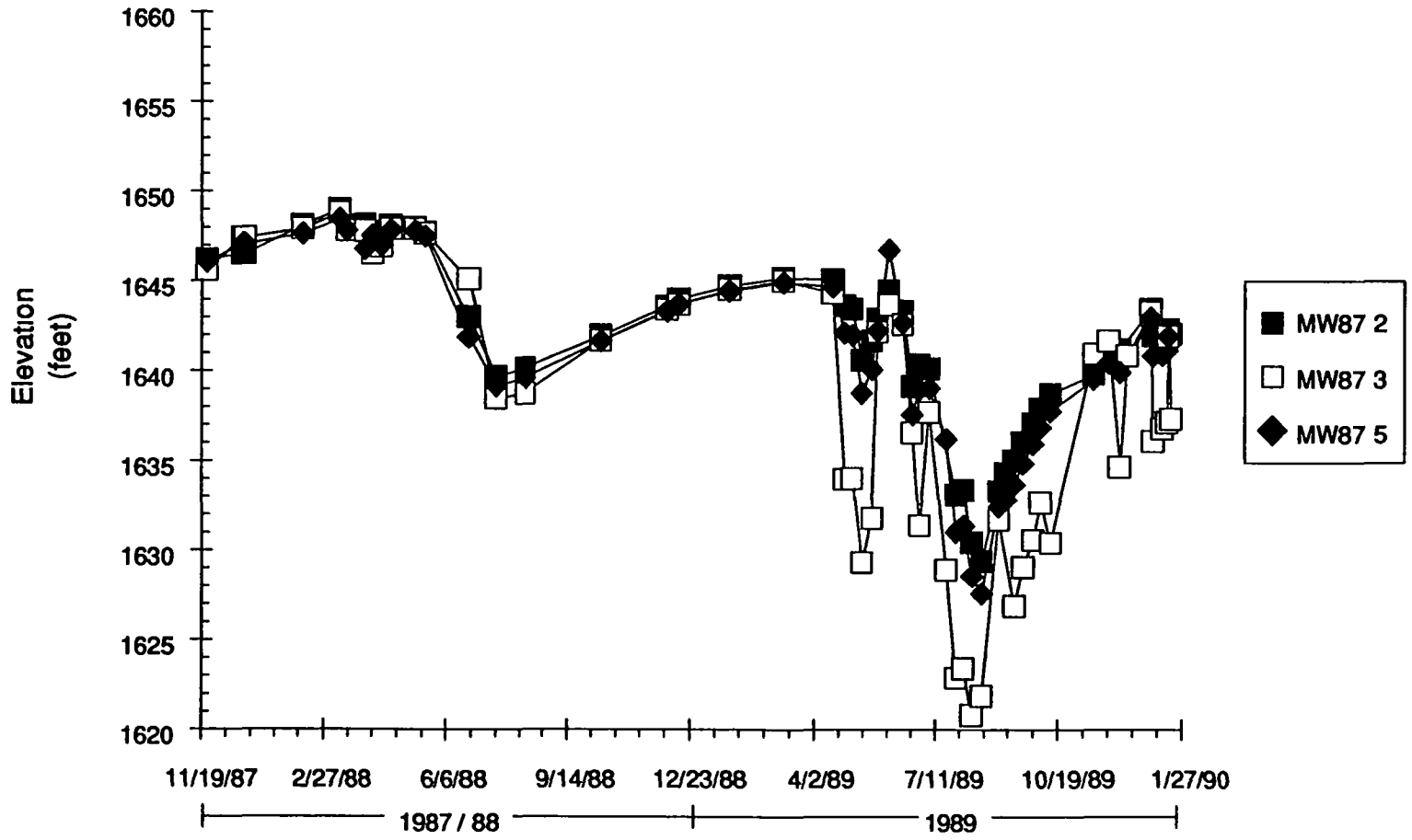

Figure 3 6-4d

Hydrograph

All Available Data - MW87-2, -3, -5

Lindsay Mfg Co

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Job Number 16657-002-005

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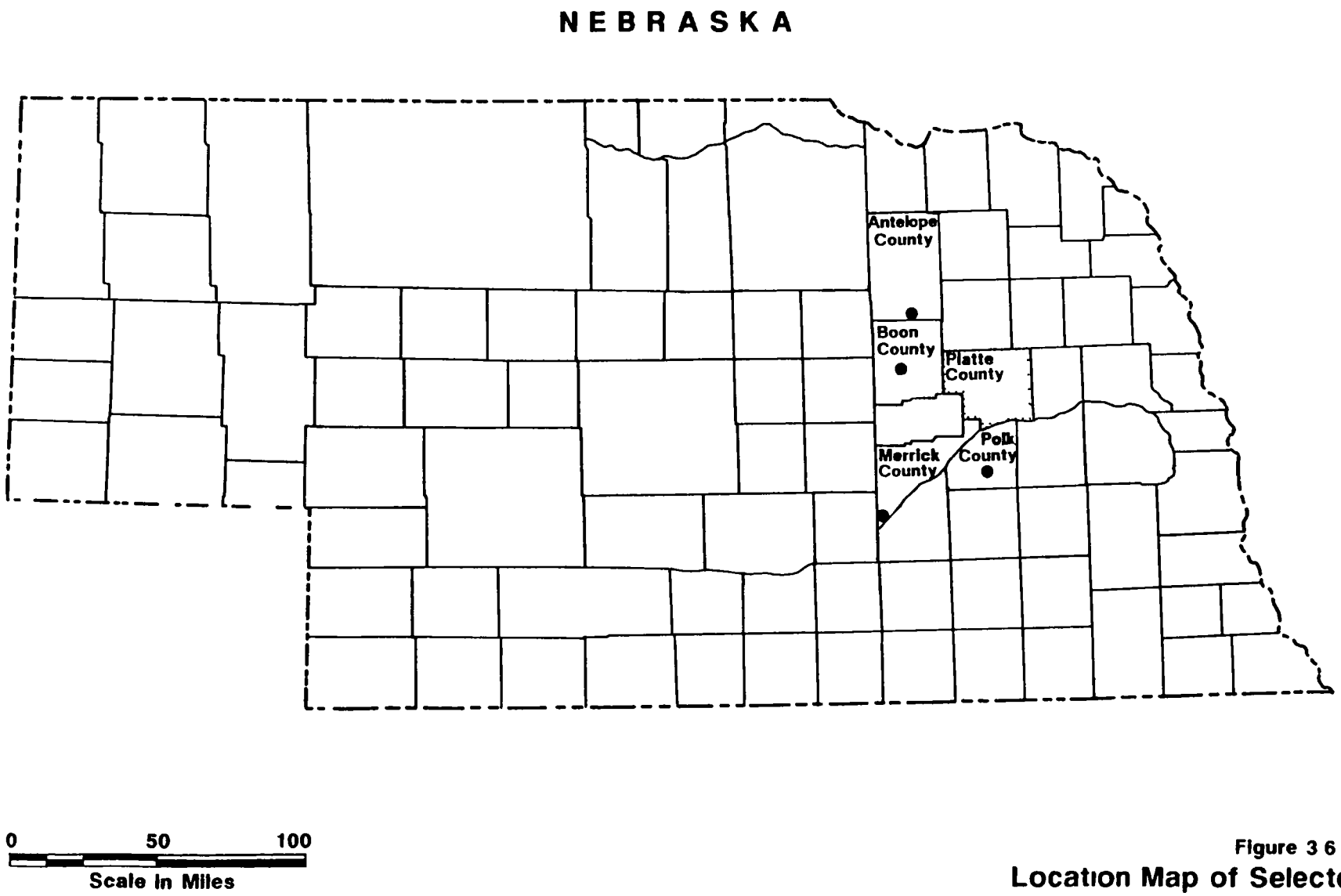

Figure 3 6 5a
Location Map of Selected Observation Wells
Lindsay Manufacturing Area
Dames & Moore

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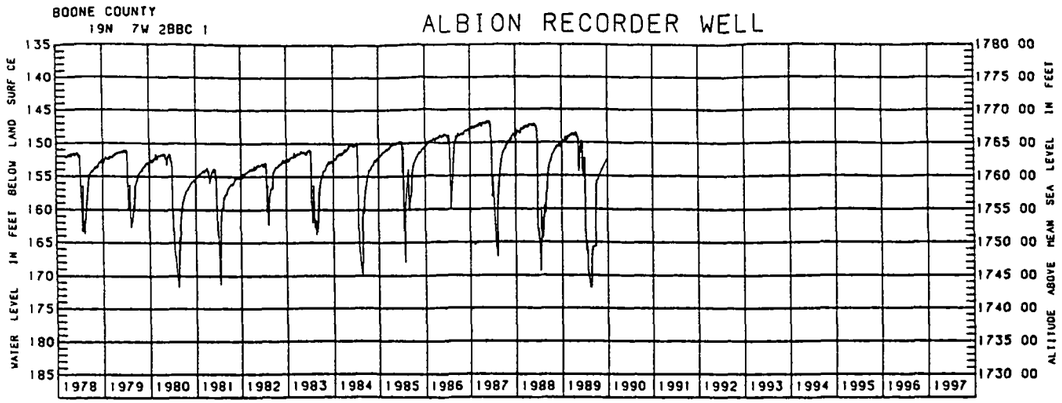

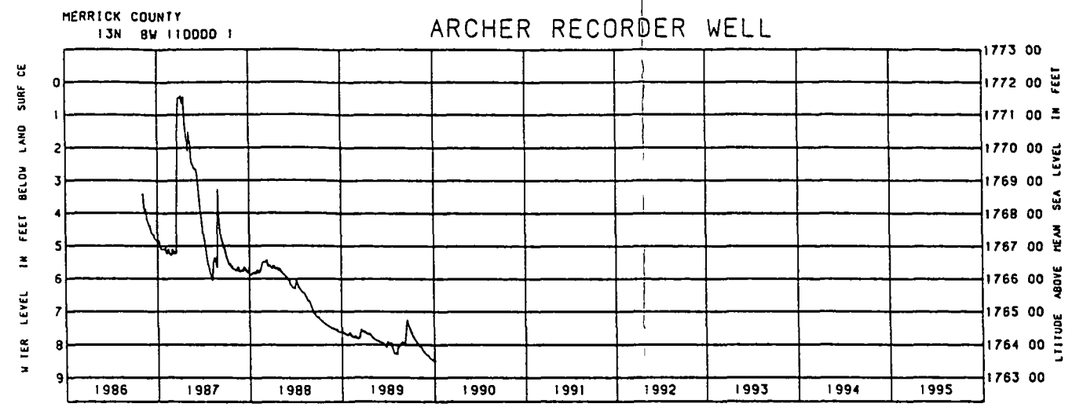

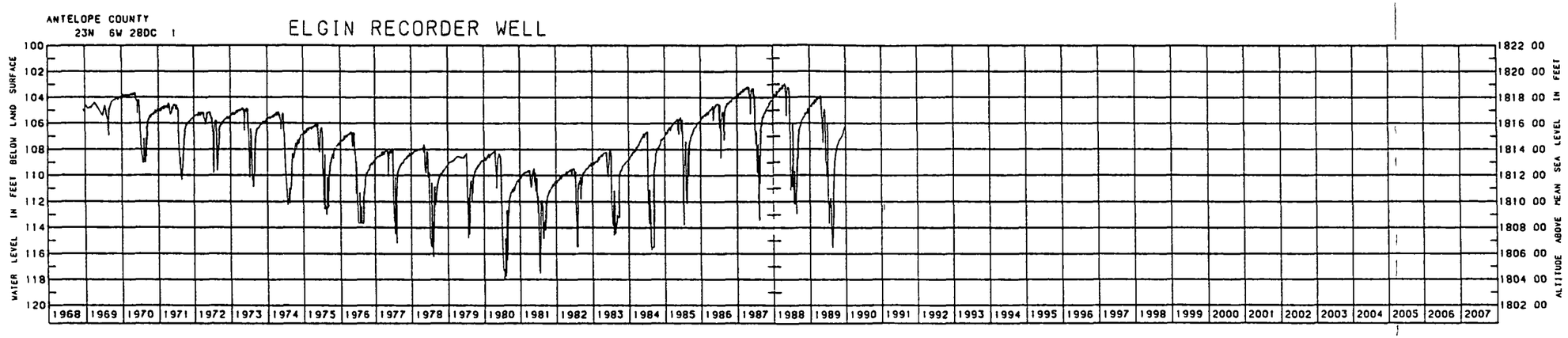

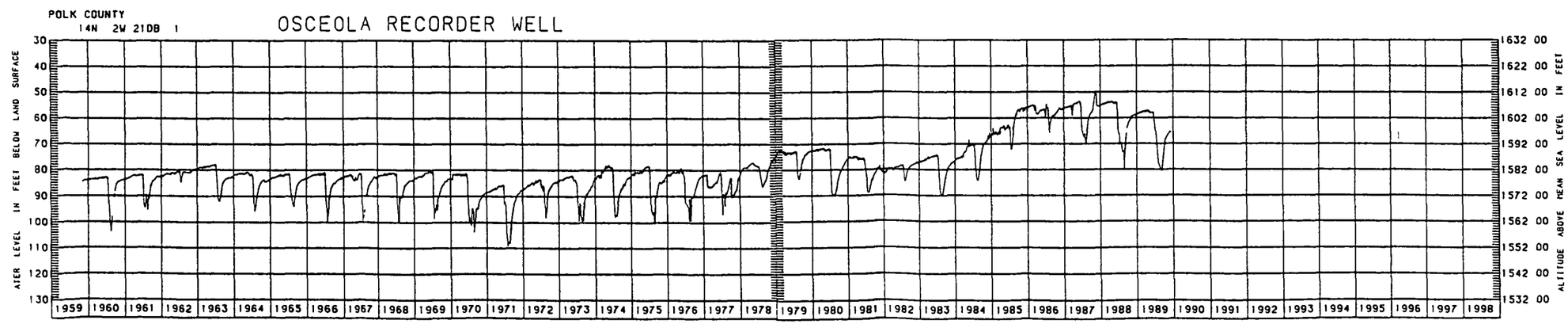

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Figure 3 6-5b

Recorder Well Hydrographs
East Central Nebraska
Dames & Moore

These values can be influenced increased and decreased locally by the operation of wells which affect the hydraulic gradient

3 6 4 Ground-Water Models

In 1987 HWST produced a hydraulic model of the vicinity of Lindsay Nebraska (D&M 1988) The computer model is a USGS public domain model abbreviated Modflow (A Modular Three-Dimensional Finite-Difference Groundwater Flow Model by Michael McDonald and Arlen Harbaugh)

The model is run under transient conditions and uses the Simply Implicit Procedure (SIP) The SIP is a method for iteratively solving a large system of simultaneous linear equations The input parameters used for this site are as follows

1 One layer
2 Confined conditions
3 Variable flow at all nodes
4 Input array of static heads (feet above mean sea level)
5 Input array of transmissivity
6 Boundary conditions - constant head
7 Annual recharge rate as a percent of annual rainfall

Methodology used to set up model

1 Boundaries were chosen to encompass the cone of influence from continuous pumping at the OIW This boundary was also chosen to include surrounding irrigation wells

2 A variable spacing grid was superimposed on the site map Tightly spaced cells were placed in the center for more detailed results whereas the larger cells were located around the periphery where site influence is not as great The OIW is located at the center of the grid

3 Node points are located at the center of the cells this is a block-centered flow model

4 The grid was overlain on a static water level map and a transmissivity map The nodes were assigned values in accordance with the maps The arrays of node values were input into the model

The model was calibrated against the 72-hour pump test performed in 1984 The modeled scenarios included hypothetical pumping over a typical annual cycle of the OIW only pumping

of all wells (OIW Old Lindsay Public Supply Well and local irrigation wells) and pumping of both the Old and New Lindsay Public Supply Wells The significant findings were

- The New Lindsay Public Supply Well is sufficiently upgradient to prevent capture of ground water beneath the site

- The Old Lindsay Public Supply Well if pumped once again could capture water from beneath the site

- The OIW has a limited capture zone to the south which fluctuates laterally with irrigation well use to the south and southeast

In 1988 and 1989 additional monitoring wells were installed on-and off-site including the 1988-temporary series and the 1989-series Additional short duration pump tests incorporating some of these wells and water level monitoring through time have aided in the development of a new site-specific hydraulic model

Two additional ground-water models have been developed for the site (Appendix IX) The first is a numerical model of the sand and gravel aquifer The purpose of this model is to study the mechanisms that affect the transport of contaminants in the vicinity of the site It is a two dimensional horizontal ground-water flow and mass-transport numerical model The model was calibrated to the January 1989 site conditions and the modeled compound (zinc) concentrations exhibit a close match to observed conditions The model begins in January 1983 and produces hydrographs with a high degree of correlation to the observed temporal water-level measurements The model simulates conditions from January 1983 to the present

The second model is a two dimensional cross-section model The purpose of this model was to study the mechanisms that affect transport of contaminants in the vicinity of the site just after the installation of monitoring well 82-1M

Conclusions derived from the sand and gravel model are

1 The model accurately simulates site conditions

2 The interceptor wells capture water from the site and areas next to the site

3 Ground-water flow is northwest to southeast to north-northwest to south-southeast except when wells are in operation then the well influence controls ground water flow

4 A hydraulically static zone develops for a short period during the irrigation season between the AOIW and Irrigation Well #54278 (Figure IX-30) During this period little or no flow

occurs in this zone After the irrigation season this condition is eliminated by the influence of the AOIW (Figure IX-37)

Conclusions derived from the cross-sectional model are

1 Contaminants could move down a high permeability conduit to the lower regions of the sand and gravel aquifer This conduit connecting the contaminated sand channel to the sand and gravel aquifer was created by the installation of monitoring well 82-1M

2 After installation of 82-1M contaminants migrate laterally towards the original deep groundwater monitoring well on site (Old Well) reaching the Old Well within 20 days

3 A precipitation-induced low-permeability plug in the sand and gravel aquifer beneath the sand channel may have been important in controlling the distribution of contaminants in the aquifer particularly just after the sand channel was punctured by the 82-series monitoring wells

4 The effects of density on the flow may have been small to negligible just after the sand channel was punctured

This model was intended to simulate the effects of leakage from only one puncture of the sand channel Multiple punctures such as the 82-M series wells created are addressed in the two-dimensional horizontal model (Part A of the Appendix IX)

3 7 DEMOGRAPHY AND LAND USE

Total population of Lindsay Nebraska in 1980 was 383 people Results from the Natural Resources Commission in conjunction with the Census board state an average population for 1980 through 1986 of 392 Land use in the vicinity of Lindsay Nebraska is summarized on Figure 3 7-1 The population center is located within 0 3 miles west and south of the Lindsay Manufacturing west property boundary Three schools serve the Lindsay area A public elementary school has an average enrollment of 35 students A second public elementary school has an average enrollment of 151 students The high school is private and has an average enrollment of 109 students The high school and elementary schools are located approximately 0 25 miles west of the site boundary No hospitals clinics or retirement centers are known to exist within a two mile radius of the site

Platte County population in 1977 was 28 000 Previous census results indicate an 8 to 10 percent growth rate in the county Therefore the current population (in 1990) is estimated to be approximately 31 600 people Census results indicate 58 percent of the county is under the age

drought like years of 1988/89 In addition the summertime phenomenon of low ground-water elevations due to irrigation well stress is indicated by this data

3 6 2 2 Aquitard Water Levels

The decline in the elevation of the aquifer s potentiometric surface has resulted in a decline in the water surface in the aquitard Although this can only be approximated localized drops between 10 to 20 ft are projected to have occurred from spring 1979 to November 1989 Although these declines which are measured in monitoring wells represent only drops in the aquifer/pressure head some declines in water levels can be expected in the overlying aquitard These declines represent equilibration to the release in upward pressure from the aquifer

On-site declines in water levels in the aquitard are approximated on Figures 3 4-7A to 7F The water levels in the sand channel are subject to the gravity drainage influence of the OIW annulus and until these conduits were plugged the puncturing wells 82-1M 3M and 4M The estimated and measured water levels in the silty clays are presented based on auger boring measurements These measurements may have errors of + 5 ft due to cave-in slow infill from low permeability soils and constriction of plastic clays in the phreatic zone In general declines of the free-water surface in the silty clay aquitard of 1 to 10 ft are possible from the summer of 1987 to the summer of 1988 Such declines are consistent with the low hydraulic conductivity values for the aquitard

There may be an additional reason for the declines of the free-water surface in the aquitard at the site Paving and other hard surfacing over the last decade has caused an overall reduction in the local recharge (Section 1 2 2)

A limited set of water level measurements in couplet wells (that is paired well sites with shallow and deep screened intervals) during the fourth quarter of 1989 and early first quarter of 1990 (Appendix IV-A) suggest that there is little or no difference in hydraulic head vertically in the aquifer However there is limited data that supports previous comparisons of the water level in the sand channel with the pressure head in the aquifer In this case the sand channel and aquifer exhibit an apparently independent response of water levels

The significance of these trends is that the movement of water in the aquifer is generally horizontal with little or no vertical flow and the movement is independent of the perched sand channel

3 6 2 3 Water Levels Summary

In summary water levels at the site are somewhat lower than the pre-1983 elevations This decline began before drought conditions started in 1988 and preceded general ground-water level

declines in central Nebraska by at least a year The cause of this decline is due to continuous pumping of the site interceptor wells

The declines reported in ground-water levels on-site and in the general area maybe explained more simply as over-withdrawals on the ground-water budget The rate of recharge has been exceeded The occurrence of ground water in the aquifer is commonly understood to result from deep infiltration of rainfall and snowmelt however it has been demonstrated repeatedly by pump test and stratigraphic logging that the aquifer is confined by a low permeability aquitard Hence it is unlikely that on-site recharge to the aquifer originates from rainfall of the same year Annual well discharges from an area experiencing water level declines will reflect a combination of the rate of inflow of deeply infiltrating waters and withdrawals from storage in the finer grained aquitards

3 6 3 Ground-Water Flow

Ground-water flow in the vicinity of Lindsay Nebraska is generally to the south (NDEC 1979) In addition the shape of the water table indicates that the ground water contributes to flow in Shell Creek in the vicinity of Lindsay Nebraska Nevertheless ground-water flow direction at the site is complex because of the influence of several high capacity wells In general when within the radius of well influence a molecule of water flows toward the well when it is being pumped This is particularly true in confined aquifers in which the radius of well influence advances radially from the well as the pressure head decreases However the radius of influence is not always equivalent to the zone of well capture The zone of capture can be affected by a regional gradient which can overcome the downgradient reach of the well cone of depression or influence

The regional gradient in the spring of 1979 (NDEC) was approximately 10 ft/mile (0 0019 ft/ft) The radius of influence of the Old Lindsay Public Supply Well when operated for six hours was approximately 1 500 ft with one foot of drawdown At about 1 500 ft the effect from the regional gradient exceeded the well influence Because of the pumping influence and the broad radius of influence the Old Lindsay Public Supply Well was shut down as a precautionary measure in 1983

After shutdown of the Old Lindsay Public Supply Well the OIW became the most influential control on ground-water flow on site By June 1987 (HWST 1987) this well was actively influencing flow across the site as demonstrated by the cone of depression created and sustained across the site (HWST 1987) The radius of influence is time dependent expanding with ongoing well operation In 1984 the influence of the OIW was found to exceed 1200 feet during continuous well operation In December 1988 the influence of the OIW was demonstrated during a shutdown and recovery test observed by NDEC

The New Lindsay Public Supply Well is sufficiently hydraulically upgradient of the site to prevent capture of groundwater at the site It probably does contribute to the general downward trend in water levels in the vicinity during the drought by intercepting a portion of the lateral inflow from the region upgradient of the site

The effect of long-term pumping on ground-water flow is evident during February 1988 when the OIW was idle for repair (Figure 3 6-6) At this time the potentiometric surface had recovered to approximately 1 to 2 ft below pre-pumping conditions and the gradient was approximately 50 percent of the regional gradient In general the drawdown created by a pumping cycle requires approximately as much time to recover as it took to develop The residual drawdown is indicative of this phenomena

Horizontal ground-water flow at the site can be interpreted from potentiometric maps (Appendix VII) Three periods are selected to represent the range in annual conditions at the site In March (pre-irrigation) August (during irrigation stress) and November (after irrigation stress) 1989 ground-water flow at the site was predominantly influenced by one or both of the interceptor wells During the irrigation season the irrigation wells became the significant influence on flow off-site and outside the influence and capture zone of the AOIW off-site

As a result of sustained pumping the AOIW radius of influence exceeds that observed from the OIW and Old Lindsay Public Supply Well The radius of influence of the AOIW when operated for 24 hours is approximately 3000 feet with one foot of drawdown

Ground-water velocities are a function of aquifer porosity hydraulic conductivity and hydraulic gradient The relationship can be expressed by the following equation

$$V = Ki/n$$

where V = velocity (length/time L/t) K = hydraulic conductivity of the aquifer (L/t) n = effective porosity a percentage and i = the hydraulic gradient (L/L)

The steady-state hydraulic gradient (i) of the aquifer is approximately 10 ft/mile (0 0019 ft/ft) as determined from regional data (NDEC 1979) The effective porosity (n) of 0 15 is applied based on values reported for this area of Nebraska (Pettijohn & Chen 1983) Using these values for K i and n the range in velocity can be calculated as follows

$$V_{min} = (150 \text{ ft/day})(0\ 0019)(0\ 15)^{1}$$

$$= 1\ 9 \text{ ft/day}$$

$$V_{max} = (1500 \text{ ft/day})(0\ 0019)(0\ 15)^{1}$$

$$= 19\ 0 \text{ ft/day}$$

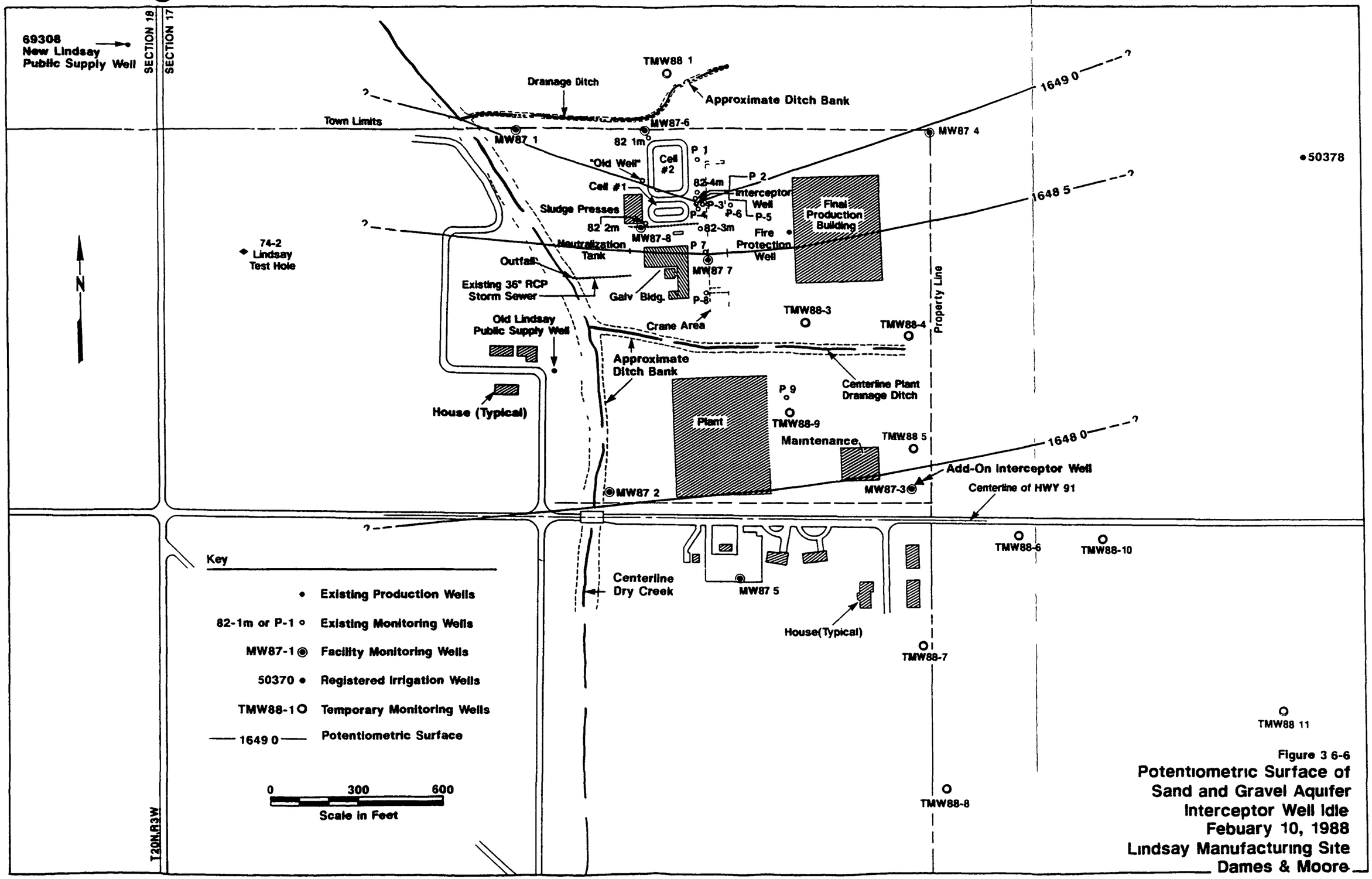

Figure 3 6-6
Potentiometric Surface of Sand and Gravel Aquifer
Interceptor Well Idle
Febuary 10, 1988
Lindsay Manufacturing Site
Dames & Moore

Job No 16657 002 005

Rev 2/23/90

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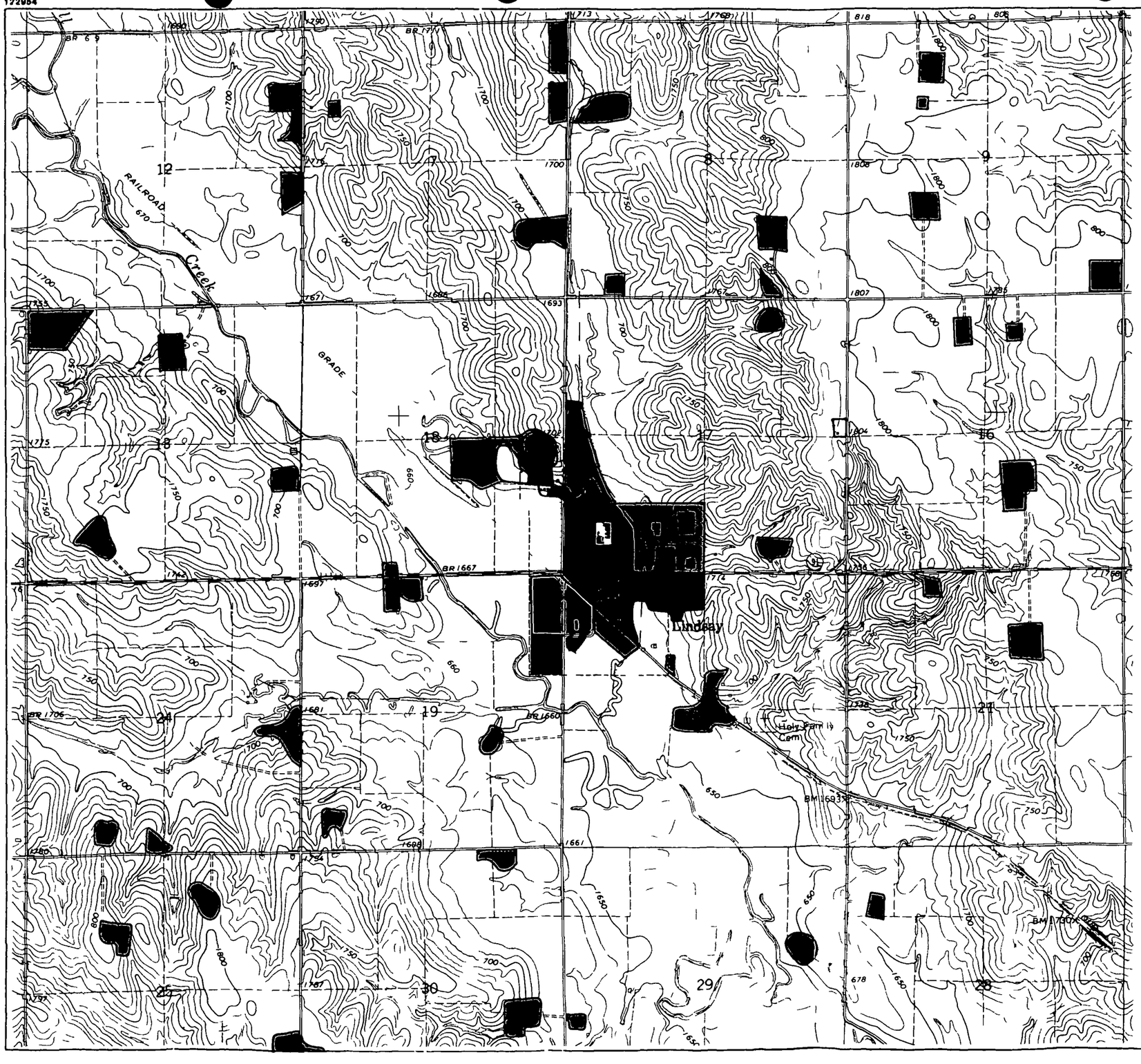

Key

- Agriculture
- Farmstead
- Residential
- School
- Commercial
- Manufacturing
- Utilities
- Recreational

0 0.5 1.0
Scale in Miles

Figure 3 7 1
General Land Use Map
Lindsay, Nebraska
Dames & Moore

Job No 7 002 005

of 18 or over the age of 54 Vital statistics from the Nebraska Department of Health indicates there are an average of 500 births per year in Platte County

Land use within the city limits is primarily residential with the exception of the Lindsay Manufacturing site and a community business and general commerce area located southwest of the site A public recreational and utilities area is located approximately 0 2 miles southwest of the site The utilities area consists of the town public sewage treatment plant and ponds Use of the area located within a two mile radius of the Lindsay town limits is primarily agricultural with an average of three farmsteads per square mile

Water service for the town has historically included four municipal supply wells owned and operated by the Village of Lindsay a well installed in 1923 (23-1) another installed in 1943 (43-1) a third installed in 1975 (75-1) and the most recent in 1983 (83-1) Two of the wells (23-1 and 43-1) have been out of use since 1975 when a replacement well (75-1) was installed directly west of Lindsay Manufacturing This well (75-1) was taken off line in 1983 as a precautionary measure when the site ground-water investigation began It has been replaced by the new well (83-1) Well 75-1 labeled Old Lindsay Public Supply Well in this report has been used since 1983 as a monitoring site for ground water The two other historic water supply wells are located approximately 0 2 miles southwest of the site The fourth well (83-1) is currently in operation and is located approximately 0 25 miles northwest of the site This well is the primary source of potable water to Lindsay Nebraska Its current pumping capacity is 500 gpm The average water consumption from the well is approximately 100 000 gallons per day and its estimated annual pumping is 78 million gallons per year (Bruce Hanson personal communication February 1990 Lower Platte Natural Resources District) There are approximately 40 private domestic and irrigation wells within a two mile radius of the site (Figures 1 2-5 and 2 8-1)

Public supply industrial and irrigation wells require registration in Nebraska but domestic and stock wells do not A survey of domestic and stock wells was performed by HWS Technologies in accordance with the RI Work Plan in a 180 arc south of Lindsay Manufacturing Co Private unregistered well locations are provided on Figure 2 8-1

Twenty private residences were identified in the survey Seventeen domestic/stock wells on these properties were identified Others may exist but could not be found due to non-response by property owner The information provided by operator/owners of these wells is generally insufficient to characterize well screen settings and volume of daily uses Because of the low permeability of the sediments mantling the aquifer this report assumes all domestic/stock wells are screened in the aquifer

Information obtained from the U S Department of Housing and Urban development indicates there are no swimming pools or fishing areas within a two-mile radius of the site The Lindsay

Manufacturing site is fenced with a chain link fence on all property boundaries and access to the site is limited to employees and escorted vendors and visitors

3 8 ECOLOGY

3 8 1 Site History

The village of Lindsay is located in eastern Nebraska north of the Platte River Shell Creek runs along the southern edge of Lindsay and is a tributary to the Platte River Dry Creek runs through the center of town and is an ephemeral tributary to Shell Creek Lindsay is located in a region that historically was a transition zone among three major grassland-dominated communities which included the bluestem or tallgrass prairie the wheatgrass-bluestem-needlegrass or medium grass prairie and the Nebraska sandhills prairie (Johnsgard 1979) There would also have been fingers of the floodplain forest communities associated with perennial streamcourses such as Shell Creek

Today the area is intensively farmed by clean farming practices which use all available land for growing crops leaving virtually no natural vegetation along field borders road verges and stream corridors The vegetation therefore consists primarily of row crops of corn milo and sorghum As a result of farming practices habitat quality and species diversity have declined

3 8 2 Habitats

Habitats in the vicinity of the Village of Lindsay include cropped lands a number of small treed areas riparian and wetland areas and aquatic habitats in Shell and Dry Creeks There are a number of isolated trees around village residences and between fields There are also several small patches of trees south and east of the town by the sewage treatment plant and around farm buildings outside of the town There are a few patches along Shell Creek which appear to support small stands of trees Trees in the upland areas are most likely to be russian olive (Elaeagnus angustifolia) hawthorn (Crataegus douglasii) elm (Ulmus spp) box elder (Acer negundo) maple (Acer spp) and oak (Quercus spp) species and possibly other exotic species that have been planted by humans (Hyman 1990) Riparian areas that support trees may also include cottonwood (Populus spp) and willow (Salix spp) species (Hyman 1990) However stream banks appear to be vegetated primarily with grasses perennials annuals and some shrubs It is not possible to identify the species present from aerial photography However the few species that have been reported include giant ragweed (Ambrosia trifida) and hemp (Swotek 1990) sunflowers and brome grasses (Hyman 1990) There are no threatened or endangered plant species known to occur in the area of Lindsay (Clausen 1990 Troendle 1990)

Both Shell Creek and Dry Creek are considered to be wetlands by the USDA Soil Conservation Service (1990) The well- vegetated meanders south and west of Shell Creek are also classified

as wetlands This wetland classification is made on the basis of hydric soils and the size of the drainage areas Swotok (1990) reports that giant ragweed occurs on the stream banks and serves as a further indicator of wetland conditions

The quality of the aquatic habitats of Shell Creek appear to have been significantly degraded since the early 1950 s Shell Creek flows year round with a reported average flow of 1 6 cfs (Bazata 1990) The banks appear to be fairly steep The riparian corridor is narrow with an abrupt transition to cropland on either side (Holloway 1990) Plant cover is reported to be sufficient for aquatic life and pools that could provide adequate cover for fish are present (Walker 1990 Lund 1990a) However the water quality is poor and the species that would normally be expected to be present are no longer found (Lund 1990b Bliss & Schainost 1973) There are a number of deleterious sources that may be impacting Shell Creek They include cattle and hog feedlots along the stream sewage treatment plants for the villages in the area a cheese processing plant upstream of Lindsay and agricultural runoff (Lund 1990a 1990b)

In summary natural habitats are limited by the intensive clean farming practices employed by local farmers and the aquatic habitats have been degraded The conditions described above existed prior to and are unrelated to the ground-water contamination at the Lindsay site

3 8 3 Aquatic Life

The diversity of fish species in Shell Creek is much lower than similar streams in eastern Nebraska (Bliss & Schainost 1973) Limited stream sampling was done in the early 1970 s for fish distributions (Bliss & Schainost 1973) and again in 1985 for fish and macroinvertebrates (Bazata 1990) However these sampling locations were generally downstream near Columbus NE or upstream near Newman Grove NE Fish kill reports from recent years also supply information on species that might be present in Shell Creek

Three species of fish were found by Bliss and Schainost (1973) at a sample location just downstream of Newman Grove and included fathead minnows green sunfish, and sand shiners Only fathead minnows were found at a second site located roughly 10 to 12 miles downstream of Lindsay Three species were found at a third site located another 7 to 10 miles downstream of the second site and included fathead minnows sand shiners and red shiners (Bliss & Schainost 1973) Fish kill reports indicated that fathead minnows were killed in Dry Creek in 1989 red shiners sand shiners and fathead minnows were killed near Columbus NE in 1988 and fathead minnows and black bullheads were reported killed near Platte Center (Lund 1990b)

All five species (fathead minnows green sunfish sand shiners red shiners and black bullheads) are commonly found in intermittent streams with high turbidity They all are tolerant of drought are reproductively active throughout the summer months and are generalized in their food preferences and in choice of spawning sites Fathead minnows are probably the most

tolerant of pollutants low oxygen levels high salinity and turbidity Fathead minnows also appear to be the most common species in Shell Creek occurring at all sample sites including the one fish kill report at Lindsay Nebraska None of the five species are considered as sport fish for human consumption

The aquatic invertebrate populations appear to be as depauperate as the fish population The only sample from Shell Creek in Platte County taken in 1985 found only two annelids one gastropod and about ten insect species in the macroinvertebrate community (Bazata 1990) The 1989 Dry Creek fish kill report also noted the presence of several dead crayfish (Lund 1990b) Shell Creek was originally named for the beds of mollusks in the stream bottom (Clausen 1990) however these mollusk beds are apparently no longer present

3 8 4 Wildlife

Residents of Lindsay were known to have trapped beaver mink and muskrat on Shell Creek as recently as the late 1940 s (Lindsay CBC 1987) However recent aerial photographs show no indications of the continued presence of beaver In addition it is unlikely that mink or muskrats continue to be present since they are semi aquatic and aquatic species which have also declined There is still a fair diversity of vertebrate species expected to be present although it is lower than might be expected for similar areas of eastern Nebraska The abundance of any particular species is probably also low due to the restricted size of available habitat areas A list of vertebrate species that might be expected to occur in the general area around Lindsay is presented in Appendix V There are no known threatened or endangered animal species present in the Lindsay area (Clausen 1990 Troendle 1990)

4 0 NATURE AND EXTENT OF CONTAMINATION

The discussion of the nature and extent of contamination at the site is based on extensive field and laboratory data collected from 1983 to 1990 The following sections summarize the analyses and associated quality assurance/quality control issues The limitations of the data are described where necessary

4 1 CONTAMINANT SOURCE INVESTIGATIONS

Contaminant source investigations have centered around the presence of select inorganic and organic compounds found in site ground water and soil Lindsay s site investigations have found that the former spent acid disposal pit (pit) is the primary contributing source of inorganic and organic contamination at the site Additional contaminant source areas may have contributed to organic contamination on site based on Lindsay personnel reports of historic practices These areas have been investigated in the 1988 Extended Subsurface Investigation and in the 1989 RI Contaminant source areas and associated types of contamination are discussed below

4 1 1 Spent Acid Disposal Pit and Burn Pit

The spent acid disposal pit has been identified as the primary contaminant source area associated with both inorganic and organic contamination at the site Spent acid was piped into the earthen pit from the early 1970s to 1982 (Section 1 2 2 1) Small quantities of grease oil and 1 1 1-trichloroethane (TCA) were also disposed of and burned in the burn pit located adjacent to the spent acid disposal pit as well as in the pit itself Inorganic and organic contaminants slowly began to infiltrate through the bottom of the pit into the underlying perched sand channel The sand channel is limited in extent (Sections 3 4 & 3 6) and separated from the aquifer by a silty clay layer This clay layer confines water in the aquifer and perches water in the sand channel Inorganic ground-water data collected from an onsite well in 1980 and 1981 indicated that ground-water quality in the aquifer on site was at background conditions (see Section 4 3) The introduction of three of the four 82M series wells designed to monitor ground water around the pit in late 1982 resulted in the puncture of the sand channel and the confining clay layer at three points Lindsay s site investigations have found that these punctures provided a direct conduit through the confining clay layer below for the subsequent release of metal acid and organic contaminants into the underlying aquifer from the spent acid and burn pit The types of contaminants found in ground water due to this event have included

- heavy metals primarily iron and zinc and other trace metals
- sulfate and

- certain organic compounds tetrachloroethene (PCE) 1 1 1-trichloroethane (1 1 1-TCA) 1 1-dichloroethane (1 1-DCA) 1 1-dichloroethene (1 1-DCE)

4 1 2 Organic Source Areas

In addition to disposal of small quantities of solvents and degreasers reported at the spent acid disposal pit and the burn pit small quantities of solvents and degreasers are also reported (Section 1 2 2 1) to have been historically disposed of at the rear of the main plant prior to paving

4 2 SOILS

The nature and extent of site soil contamination is based on analytical results of subsurface soil samples collected between June and August 1988 The results were presented in a Dames & Moore report entitled Extended Remedial Subsurface Investigation dated November 1988

The inorganic and organic soil laboratory data reports generated during this time included sample data summary sheets and limited summaries of analytical quality assurance/quality control (QA/QC) results Although QA/QC data validation reviews of the raw data were not performed the data is considered to be generally acceptable based on laboratory compliance with the QA/QC criteria specified for the EPA methodology utilized Standard EPA approved procedures were used which are considered to be Level III quality (EPA/540/6-87/003) Level III protocols have built-in QA/QC procedures including calibration runs surrogate standards etc which provide laboratory analysis similar to CLP analysis The analyses performed using Level III techniques provided confirmed identification and quantification of organic and inorganic compounds and the results obtained during the soils investigation are therefore acceptable

4 2 1 Inorganics

Sixteen subsurface soil samples were collected from the source area in the perched sand channel and analyzed for total arsenic cadmium barium chromium lead mercury selenium silver iron and zinc by EPA Methods (EPA 1987 1988) Metal concentrations reported above the detection limit are summarized in Table 4 2-1 A complete listing of laboratory results is summarized in Appendix XI-A A concentration range for elemental naturally occurring concentrations in soils is also provided in Table 4 2-1 for comparative purposes Metal results listed in Table 4 2-1 are all within the elemental concentration ranges

Five subsurface soil samples were analyzed for EP toxicity metal analysis Table 4 2-1 lists EP toxicity results and EP toxicity limits All results were well below EP toxicity limits

Table 4.2-1

Summary of Laboratory Soil Sample Results
Total Metal and EP Toxicity Metal

Total Metal (mg/kg)

Boring	Depth (feet)	Total Arsenic	Total Barium	Total Chromium	Total Iron	Total Zinc
SB 3	37	1 83	216	9 26	10 146	596
	41	0 96	159	14 6	13 073	832
SB 5	27	0 15U	131	9 54	10 047	168
	32	0 44	116	11 9	10 766	274
	43	0 29	173	20 4	15 005	1 633
SB-6	37	6 09	220	15 3	16 394	51 5
	44	0 69	74 5	9 19	10 838	190
SB 13	33	0 79	233	20 3	21 534	1 071
	38	0 31	218	15 9	19 779	1 059
SB 14	38	11 10	294	16 6	19 995	68 1
SB 32	33	12 30	258	17 9	21 215	63 6
	43	9 92	236	18 0	19 148	48 7
SB 35	43	2 70	220	14 9	16 450	45 8
SB 36	33	0 90	259	20 1	21 591	52 3
SB 37	33	0 30	193	18 1	15 709	26 7
	38	0 19	58 8	4 19	4,118	2 79
Average Elemental Soil Concentration Range (1)		<0 1 97	10 50,000	1 2,000	100 >100,000	< 5 29,000

Notes
(1)

U

EP Toxicity Metal (mg/l)

Boring	Depth (feet)	Arsenic	Barium	Chromium	Lead	Mercury	Selenium
SB 2	38 5	0 002	0 1	0 05U	0 1U	0 2	0 002U
SB-4	40	0 002U	0 1U	0 05U	0 1U	0 02U	0 002U
SB 5	43	0 002U	0 1U	0 05U	0 1U	0 02U	0 002U
SB 6	44 5	0 002U	0 1U	0 05U	0 1U	0 02U	0 002U
EP Toxicity Limits		5 0	100	5 0	5 0	0 2	1 0

The deposition of spent acid in the acid disposal pit was discontinued in 1983 thus ending the source of metal contamination to site soils Interim remediation (Section 1 2 4) has drained substantial metal laden shallow ground water from the perched sand channel and removed dissolved metals from the source area Based on the removal of the source and total metal and EP toxicity metal results which are below the range of elemental concentrations in soil and EP toxicity limits respectively the presence of residual heavy metals in soil is not considered to be significant

4 2 2 Organics

Subsurface soil samples collected in 1988 were analyzed for organic components using a combination of field screening and laboratory analysis Soil samples were analyzed by field screening methodologies by HWS using the headspace technique followed by on-site gas chromatograph (GC-PID) analyses (Photovac 10S50) Nineteen percent of the soil samples collected during this time were sent to A&L Laboratories and Wilson Laboratory for organic analysis by EPA Method 8240

The purpose of submitting 19 percent of the soil samples for laboratory analysis was to confirm field screening results and to provide additional information on organic occurrence The laboratory sample detection limit for all compounds in soil was 0 3 mg/kg as specified in the EPA method at that time This detection limit was well above the average volatile field screening concentrations reported by HWS

The use of field screening data is not intended to be a one-to-one correlation with laboratory data Field screening analysis was used to perform target organic screening analysis of all subsurface soil samples collected during drilling of soil borings The purpose of field screening was to provide immediate results to qualitatively determine if select organic components were present or absent and to evaluate data trends

In discussing the nature and extent of organics in on-site subsurface soils only target field screening results > 0 05 mg/kg are considered valid due to limitations of accuracy of field screening methodology Those compounds with valid field screening levels and confirmatory laboratory analysis are included as representative of site conditions Compounds not meeting these criteria are discussed at the end of this section This set of organics is characterized by few occurrences concentrations close to field detection levels and for two of the three compounds nondetection by the laboratory They have been determined not to be representative of site conditions and are therefore not considered further in the RI report The following discussion is based primarily on laboratory results however field screening results > 0 05 mg/kg (i e the field detection limit) have also been used to identify occurrence and trends in site soils

Three organic compounds PCE TCA and 1 1-DCE were predominant in extent and concentration in subsurface soil samples collected from the site Soil sample field screening and laboratory results are listed in Appendix XI-B

Tetrachloroethene

Tetrachloroethene (PCE) is the most frequent of the organic compounds found in subsurface soils Laboratory PCE results reported above sample detection limits are summarized in Table 4 2-2 The approximate horizontal extent of PCE is presented in Figure 4 2-1 The broadest area of PCE occurrence is centered around the central drainage ditch and the northeast corner of the main plant building Select soil samples collected from six borings contained PCE concentrations greater than 1 mg/kg and are located in three areas on site the central drainage ditch SB-23 SB-22 SB-24 the northeast corner of the main plant building SB-11 and SB-33 and near the southeast corner of Cell 2 SB-4 PCE was found in silty clay between 32 feet and 42 feet below surface grade in these borings with the exception of SB-23 (18 feet) The highest PCE concentrations were detected in SB-24 at 33 feet 3 1 mg/kg and 38 feet 6 8 mg/kg Geologic cross-sections of these areas and associated soil PCE concentrations and depths are provided in Appendix X

PCE occurs in silty clay material in the central drainage ditch throughout the soil column (from approximately 3 feet to 48 feet below surface grade) and generally is found at higher levels between 33 feet and 48 feet PCE levels appear to increase in concentration in a westwardly direction as indicated by PCE levels detected in SB-23 SB-22 and SB-24 (Table 4 2-2) with the highest PCE concentration found in SB-24 In relation to SB-24 PCE decreases in concentration further west 0 13 mg/kg SB-30 south 0 42 mg/kg SB-10 and SB-26 and north 0 08 mg/kg SB-6

PCE was also found near the northeast corner of the main plant building throughout the soil column (silty clay) from approximately 3 feet to 43 feet below surface grade The highest PCE concentrations were found in SB-11 and SB-33 (Table 4 2-2) at similar concentrations at 32 feet and 33 feet respectively PCE decreases in concentration from SB-11 and SB-33 in all directions PCE concentrations detected during field screening (> 0 05 mg/kg) were present at SB-12 and SB-20 between 21 feet and 33 feet

PCE was found in the vicinity of the wastewater treatment facility Cell #2 and extending north to SB-14 above within and below the perched sand channel The highest concentration of PCE in this area was found in SB-4 (1 2 mg/kg) at 42 feet which is below the sand channel PCE decreased in concentration to the north as indicated by 0 4 mg/kg PCE found at SB-13 at 45 feet and SB-14 at 43 feet and to the south SB-6 0 08 mg/kg In relation to SB-4 similar PCE

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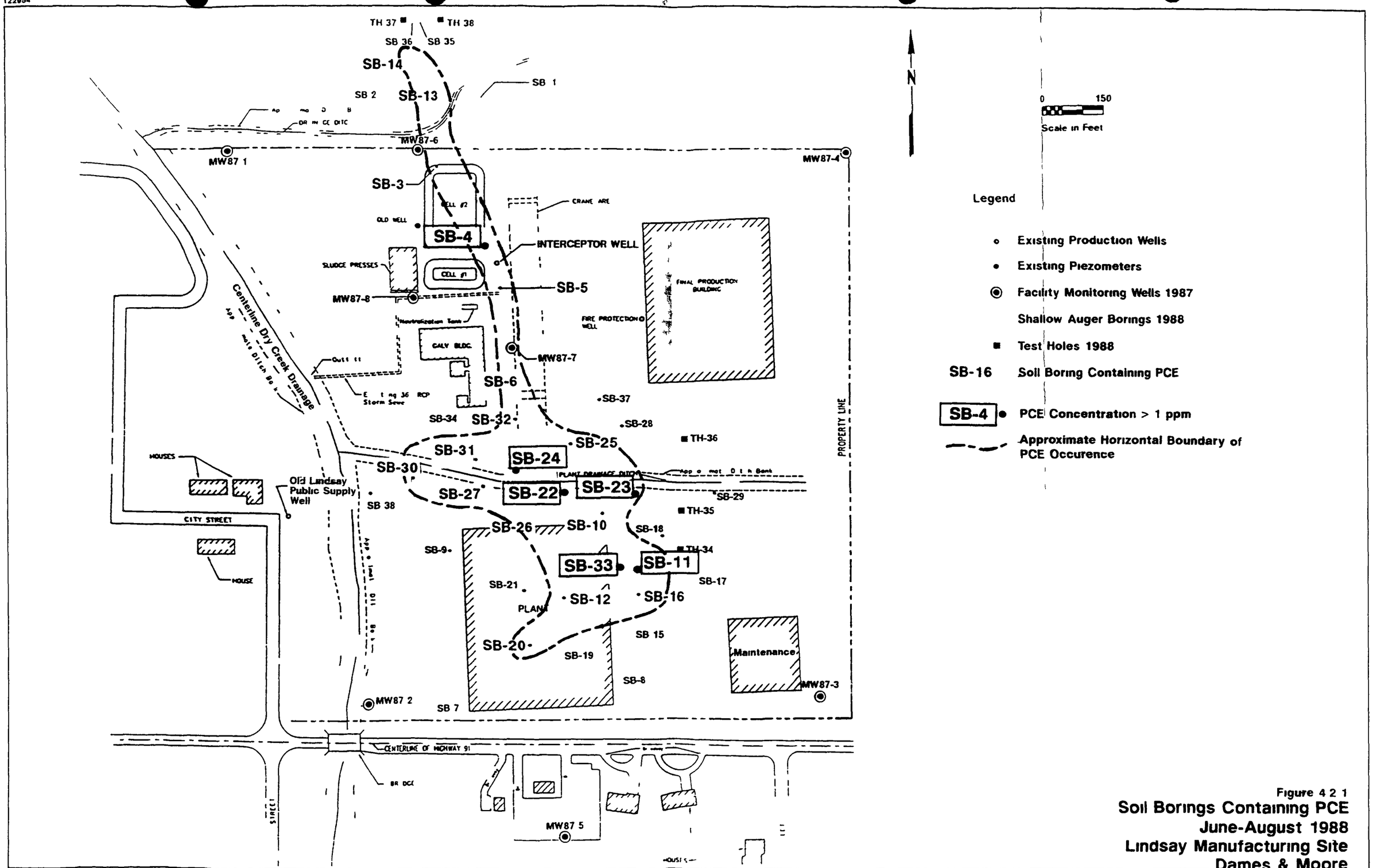

Figure 4 2 1
Soil Borings Containing PCE
June-August 1988
Lindsay Manufacturing Site
Dames & Moore

Job No 7 002 005

Rev 2/28/90

Table 4.2-2

Summary of Laboratory Soil Sample Results
Organic Compounds (mg/kg)

Area of Site	Boring	Depth (feet)	PCE	TCA	DCE
Central Drainage Ditch	SB 23	18	1 2	1 0	0 3
		38	0 3U	0 3	0 3U
	SB 22	28	2 7	2 1	0 3U
		43	2 4	1 2	0 3U
	SB 24	33	3 1	1 3	0 3U
		38	6 8	1 1	0 3U
	SB 27	38	0 3	0 3U	0 3U
	SB 25	38	0 4	0 7	0 3U
		48	0 4	0 6	0 3U
	SB 32	38	0 3U	1 1	0 4
		48	0 3U	0 7	0 3U
Northeast Corner of Main Plant	SB 11	8	0 3U	0 5	0 3U
		22	0 3U	6 4	0 7
		32	1 7	14 1	1 9
		40	0 4	2 7	0 6
		44	0 3U	0 4	0 3U
	SB 33	23	0 3U	0 5	0 3U
		33	1 6	7 4	1 5
	SB 12	28	0 3U	3 4	0 8
	SB 16	3	0 3U	0 73	0 3U
Cell #2	SB 3	42	0 6	1 2	0 5
		45	0 3U	0 7	0 3U
	SB-4	42	1 2	0 3U	0 3U
	SB 14	43	0 4	1 5	0 3
		46	0 3U	1 0	0 3U

Notes

U Undetected

* 0 4 mg/kg 1 1 DCA also detected at this location

concentration trends observed below the sand channel were also observed above and within the sand channel

1,1,1,-Trichloroethane

The approximate horizontal extent of 1 1 1 -trichloroethane (TCA) is presented in Figure 4 2-2 Although TCA was not found as broadly on site as PCE TCA contained the highest individual level of the organic compound found on site Laboratory TCA results reported above sample detection limits are summarized in Table 4 2-2 Similar to PCE TCA was found in the following areas on site the central drainage ditch the northeast corner of the main plant building and north of the wastewater treatment facility Cell #2 Three soil borings SB-11 SB-12 and SB-33 contained TCA concentrations >3 4 mg/kg with the highest TCA concentration 14 1 mg/kg at SB-11 at 32 feet All soil borings within the residual soil occurrences contained TCA levels >0 7 mg/kg Geologic cross-sections of these areas and associated soil TCA concentrations and depths are provided in Appendix X

TCA occurrence and trends in subsurface soils are similar to PCE trends TCA was found in silty clays in the central drainage area primarily between 18 feet and 43 feet below surface grade ranging in concentration from 0 3 mg/kg to 2 1 mg/kg TCA levels increase in concentration in a westwardly direction from SB-23 1 0 mg/kg to SB-22 2 1 mg/kg and then decrease further west as indicated by SB-24 1 3 mg/kg (Table 4 2-2) In relation to SB-22 TCA levels decrease to the west east and north

TCA was found in highest concentration near the northeast corner of the main plant building throughout the soil column (silty clay) from approximately 8 feet to 42 feet below surface grade and ranged in concentration from 0 4 mg/kg to 14 1 mg/kg The highest TCA concentrations were found at SB-11 at 32 feet 14 1 mg/kg and SB-33 at 3 feet 7 4 mg/kg These levels appear to be limited in extent and TCA concentrations (in relation to these borings) decrease in concentration to the north south east and west

TCA occurrence is limited in the area north of the wastewater treatment facility Cell #2 which extends to SB-14 TCA was found below the sand channel in SB-3 SB-13 and SB-14 between 32 and 46 feet ranging in concentration between 1 mg/kg to 1 5 mg/kg (Table 4 2-2)

1,1-Dichloroethene

The approximate horizontal extent of 1 1-dichloroethene (DCE) is presented in Figure 4 2-3 DCE occurs over a broad area and like PCE and TCA is centered around the central drainage ditch and the northeast corner of the main plant building DCE is also found north of the central drainage area near the wastewater treatment facility Cell #2 where PCE and TCA were found

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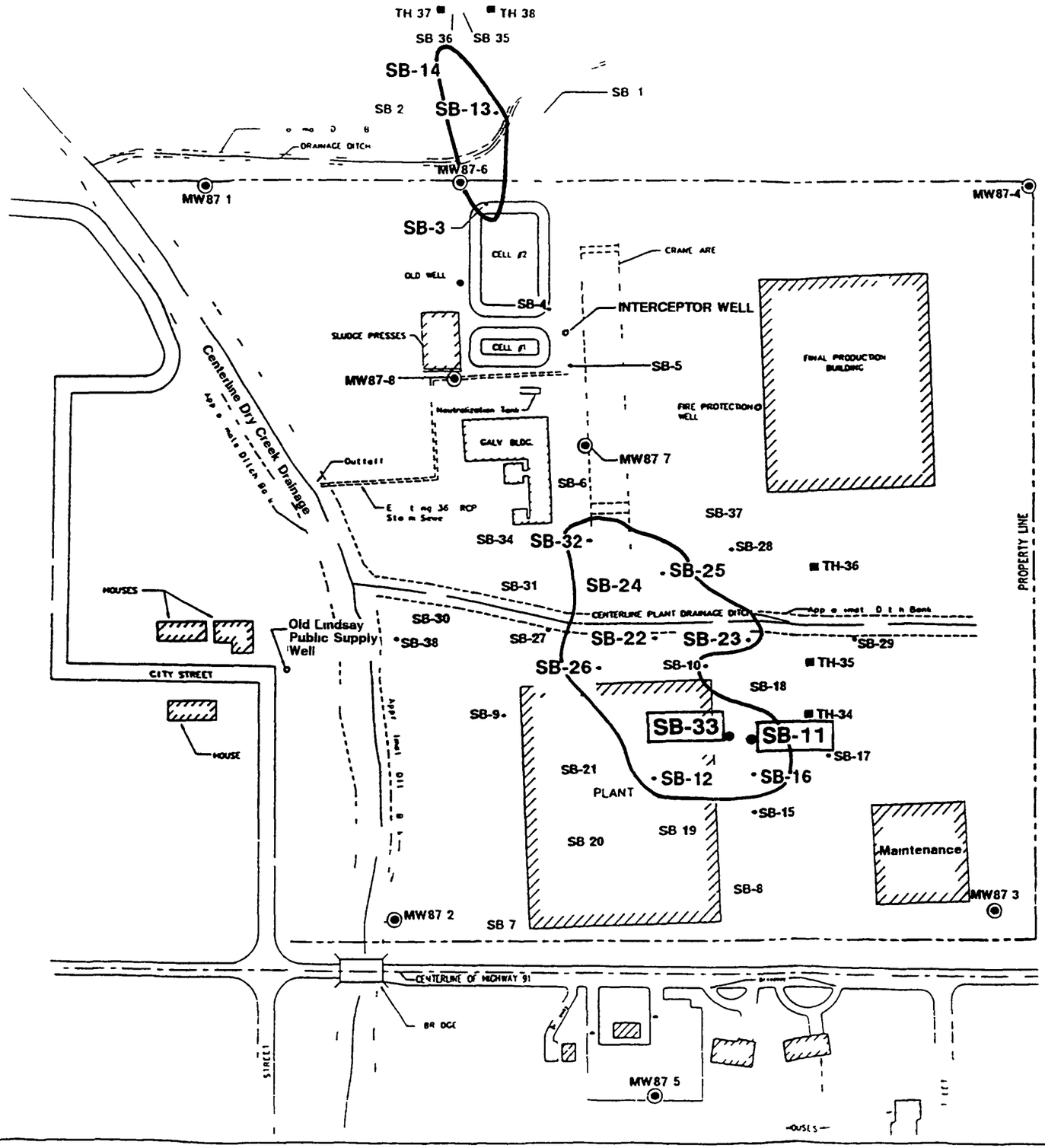

Legend

- Existing Production Wells
- Existing Piezometers
- Facility Monitoring Wells 1987
- Shallow Auger Borings 1988
- Test Holes 1988
- SB-16 Soil Boring Containing DCA & TCA (Determined by Field Analysis)
- SB-11 TCA Concentration > 5 ppm
- Approximate Horizontal Boundary of TCA Occurence

Figure 4 2 2
Soil Borings Containing TCA
June-August 1988
Lindsay Manufacturing Site
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Job No 002 005

Rev 2/28/90

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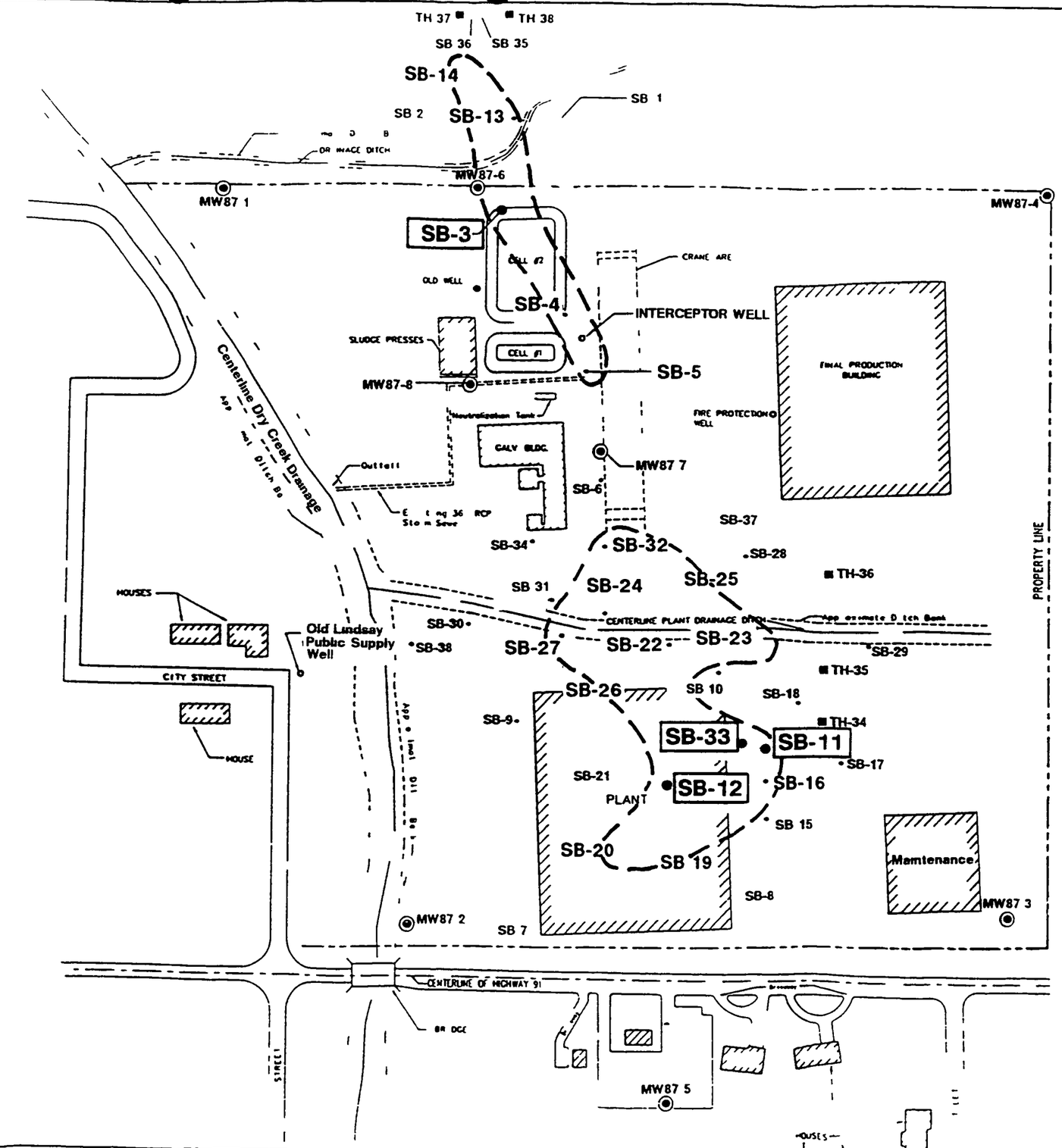

N

0 150
Scale in Feet

Legend

- Existing Production Wells
- Existing Piezometers
- Facility Monitoring Wells 1987
- Shallow Auger Borings 1988
- Test Holes 1988
- SB-16 Soil Boring Containing DCE
- SB-11 DCE Concentration > 0 5 ppm
- Approximate Horizontal Boundary of DCE Occurence

Figure 4 2 3
Soil Borings Containing DCE
June-August 1988
Lindsay Manufacturing Site
Dames & Moore

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Laboratory DCE results reported above sample detection limits are summarized in Table 4 2-2 Three soil borings SB-11 SB-33 and SB-12 contained DCE concentrations > 0 6 mg/kg Geologic cross-sections of these areas and associated soil DCE concentrations and depths are provided in Appendix X

DCE was found in silty clays in the central drainage area primarily between 13 feet and 43 feet below surface grade DCE levels were highest in SB-23 0 3 mg/kg and decreased in concentration in a westwardly direction as indicated by field screening concentrations of 0 53 mg/kg in SB-22 SB-24 and SB-27 The northern extent of DCE in this area was found at SB-32 at 38 feet at a level of 0 51 mg/kg

DCE was found in highest concentration near the northeast corner of the main plant building throughout the soil column (silty clay) from approximately 13 feet to 38 feet below surface grade and ranged in concentration from 0 6 mg/kg to 1 9 mg/kg The highest DCE concentrations were found in SB-11 and SB-33 (Table 4 2-2) which is similar to the highest concentration occurrences of PCE and TCA Field screening DCE concentrations of <0 1 mg/kg were detected in SB-19 SB-20 and SB-16

DCE was found north of the central drainage area which includes wastewater treatment facility Cell #2 The highest DCE concentrations were found beneath the sand channel at SB-3 at 42 feet 0 5 mg/kg and SB-14 at 43 feet 0 3 mg/kg In relation to SB-3 DCE decreased in concentration to the south as indicated by the field screening results of SB-5 0 05 mg/kg

Other Organic Compounds

Three additional organic compounds 1 1-DCA toluene and TCE were reported as preliminary findings in field screening and/or laboratory results (Appendix XI-B) 1 1-DCA 0 4 mg/kg was detected in one sample SB-23 at 18 feet by laboratory analysis only PCE TCA and DCE were also present at the same location

Toluene field screening results were reported in two soil samples SB-13 at 45 feet 0 046 mg/kg and SB-16 at 13 feet 0 052 mg/kg Toluene was not reported in any soil samples analyzed by the laboratory Due to the lack of laboratory confirmatory results lack of laboratory detection above the 0 3 mg/kg sample detection limit and the low field screening toluene concentrations reported it is unlikely that toluene actually occurs in subsurface soils at these locations

TCE field screening results of 0 07 mg/kg were found in three soil borings SB-16 at 13 and 18 feet SB-23 at 13 and 18 feet and SB-24 at 38 feet TCE was not reported in any soil samples analyzed by the laboratory Due to the lack of laboratory confirmatory results lack of laboratory detection above the 0 3 mg/kg sample detection limit and the reportedly low field screening TCE

concentrations it is unlikely that TCE actually occurs in subsurface soils at these locations This is consistent with the ground-water monitoring results TCE has not been detected in ground-water samples in the RI

Organics Summary

Approximate PCE TCA and DCE occurrence boundaries are overlain as shown in Figure 4 2-4 These compounds occur in similar locations on the site and at similar depths The significant trends in organic occurrence in soils include

- Limited organics occur in shallow soils at the location of the former pit All other occurrences are deep associated with perched ground-water flow paths in the sand channel Organics in the perched sand channel are spread out both to the north and south of the pit

- Organics in site soils not associated with the pit or the perched sand channel are not concentrated or are dispersed at relatively low concentrations throughout the soil column

- The highest concentrations of total organics are present in the vicinity of SB-11 and SB-33 followed by the central drainage ditch and in the vicinity of wastewater treatment facility Cell #2

- As shown in Figure 4 2-4 PCE and DCE are the broadest occurring organics TCA is limited in extent but appears at the highest individual organic concentration

4 3 GROUND WATER

4 3 1 Introduction

Ground-water quality at the site is not static historically The hydrogeologic investigations and the water quality analyses trace a dynamic geochemical and hydraulic episode that began in 1982 and continues to the present Lindsay s site investigations have found that the episode began when dense acidic metal-laden water drained via the gravel packs of three of the 1982-series monitoring wells down into the top of the aquifer Subsequent commingling of this water with the aquifer waters occurred This was followed by the interception and recovery of these mixed waters Remediation of the ground-water monitoring data from 1983 to the present provides a record of these events and the effectiveness of the interim pump and treat remediation

The following discussion includes classification of the background water quality a description of monitoring well sites and their depth in or above the aquifer and the monitored occurrence of

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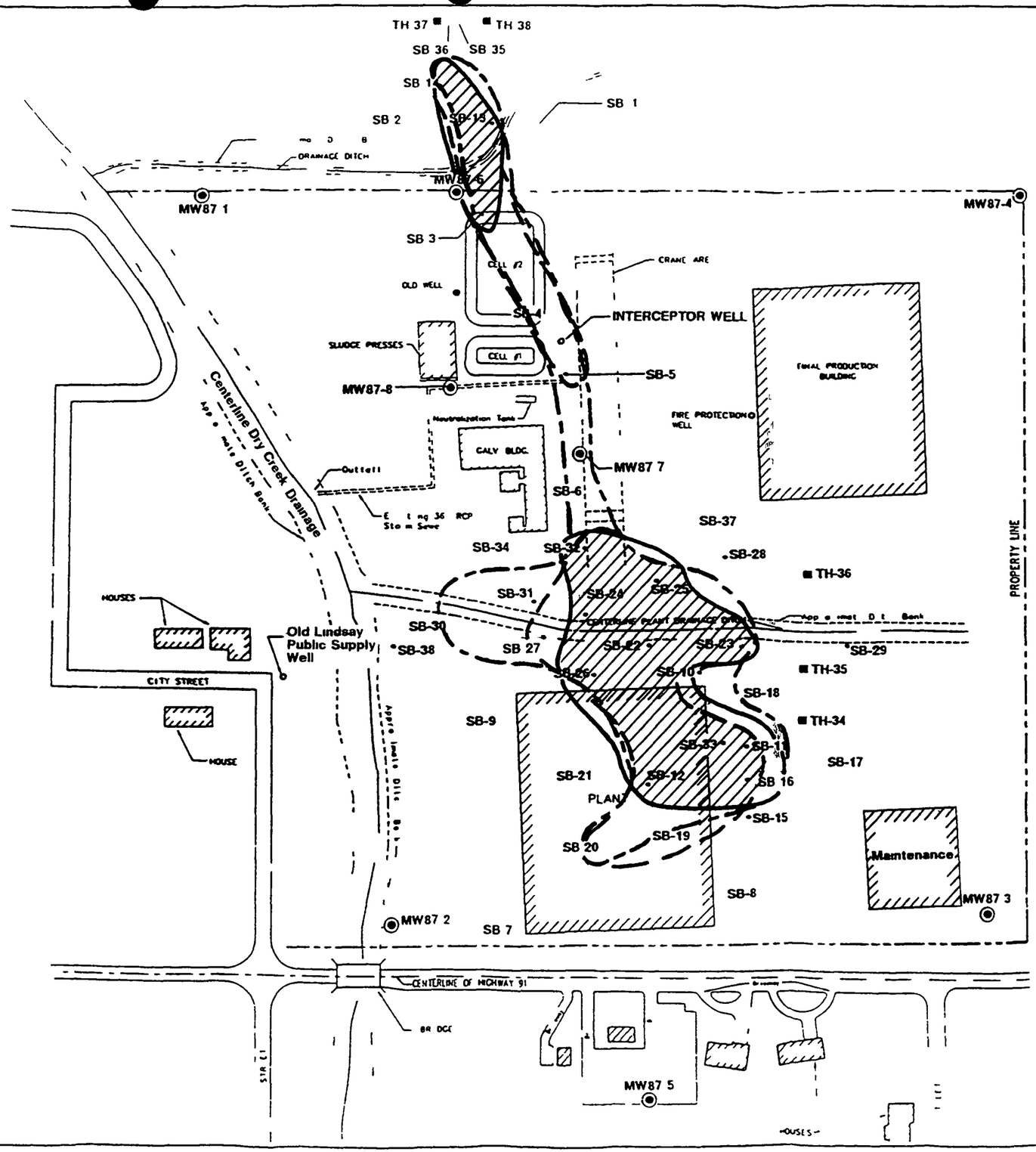


Legend

- Existing Production Wells
- Existing Piezometers
- Facility Monitoring Wells 1987
- Shallow Auger Borings 1988
- Test Holes 1988
- Approximate Horizontal Boundary of PCE Occurence
- Approximate Horizontal Boundary of TCA Occurence
- Approximate Horizontal Boundary of DCE Occurence
- Approximate Horizontal Area where PCE TCA and DCE Occur

Figure 4 2-4
Soil Borings Containing PCE, TCA, and DCE
June - August 1988
Lindsay Manufacturing Site
Dames & Moore

Job No 7 002 005

Rev 2/28/90

metals organics compounds and acidity in wells on and off-site Because of the dynamic hydrogeologic and geochemical conditions catalyzed by the mixing and pumping of waters the discussion is simplified and will be divided into separate conditions concerning the upper aquifer the lower aquifer and the entire aquifer

The naturally occurring ground waters at the site are typically calcium-bicarbonate type and can be classified as very hard Background water quality analyses prior to 1989 and recent samples in the fourth quarter 1989 and first quarter of 1990 (Appendix XI) are consistent with these classifications

Sand and gravel grains in the aquifer and sand in the perched sand channel are composed predominantly of silica with a 5 to 20 percent feldspar fraction (Appendix I-A&D) Both units are generally free of clays although the sand channel contains occasional interbedded silts and silty clay lenses The feldspars are a probable source of potassium and sodium cations in local ground waters In addition iron and manganese may be derived from minerals deposited as silts and clays in the aquitard The calcium is probably derived from a calcium carbonate cemented Niobrara bedrock aquitard below the aquifer or from similar silt and clay minerals in the aquitard

Between May 1983 and June 1987 the ground-water investigation focused primarily on zinc iron low pH measurements specific conductance sulfate and trace metals From May 1983 to June 1987 inorganic ground-water quality was monitored on a monthly basis and in June 1987 organic analyses were added to the monitoring program Inorganic and organic components were monitored on a monthly basis until September 1988 and on a quarterly basis thereafter In addition to and in conjunction with the quarterly monitoring program six one-month ground-water sampling rounds of select well locations were conducted between May and October 1989

Table 4 3-1 lists the on and off-site ground-water monitoring well locations included in the sampling and monitoring program between 1983 to January 1990 Well locations are shown in Figure 1 2-4 The monitoring well labeling system is patterned as follows

- 82-2M - monitoring well installed in 1982
- P-3 - piezometer (P)
- TMW88-5 - temporary monitoring well (TMW) installed in 1988
- MW87-3 - monitoring well (MW) installed in 1987
- MW89-12 - monitoring well installed in 1989

Table 4.3-1
Summary of On-Site Ground Water Monitoring Wells Sampled from 1983 - 1990

On-Site Wells	Screened Interval (Elevation)	Screened Portion of the Aquifer			
		Upper	Lower	Aquifer	Perced Sand Channel
82 1M	1623-1620	X			
82 2M	1631 1619	X			
82-3M	1631 1619	X			
82-4M	1630-1618	X			
MW89-12	1614 1605	X			
MW89-15	1626-1616	X			
P 1	1599-1589		X		
P 2	1597 1587		X		
P 3	1597 1587		X		
P-4	1597 1587		X		
P 5	1597 1587		X		
P-6	1597 1587		X		
P 7	1597 1587		X		
P-8	1596-1586		X		
P 9	1596 1586		X		
MW87 7	1583-1571		X		
MW87-8	1595-1572		X		
TMW88-3	1576-1573		X		
TMW88-4	1570-1567		X		
TMW88-5	1579-1576		X		
TMW88-8	1585-1582		X		
TMW88-9	1576-1573		X		
Old Well			X		
AIOW	1607 1577		X		
MW87 1	1622 1591			X	
MW87 2	1620-1574			X	
MW87 3	1620-1574			X	
MW87-4	1617 1571			X	
MW87-6	1627 1586			X	
OIW				X	
Fire Well				X	
MW89-13	1646-1636				X
MW89-14	1644 1634				X
Off Site Wells					
MW89-9A	1625-1610	X			
MW89-10A	1619-1604	X			
MW89-11A	1628-1611	X			
Moravec	1630-1620	X			
TMW88-1	1584 1581		X		
TMW88-6	1574 1571		X		
TMW88-7	1574 1571		X		
TMW88-10	1577 1574		X		
TMW88-11	1585-1582		X		
MW89-9B	1588-1578		X		
MW89-10B	1579-1569		X		
MW89-11B	1588 1578		X		
54278	1598-1546		X		
Beller Domestic	1570-1550		X		
Beller Stock	1570-1550		X		
33637	1601 1561		X		
MW87 5	1618-1573			X	
Old Lindsay Public Supply Well	1635-1579			X	
50378	1665-1565			X	

- MW89-9A - couplet monitoring wells installed in 1989 A is screened in the upper aquifer strata and B is screened in the lower aquifer strata

The monitoring wells listed in Table 4 3-2 are screened at four different intervals including a) the entire aquifer (screened throughout both the upper and lower portions) b) only the upper portion c) only the lower portion and d) only in the perched sand channel

Ground-water monitoring locations have changed over time due to the removal and abandonment of select wells installation of additional on-site and off-site wells and inclusion of additional wells into the monitoring program HWS collected ground-water samples from May 1983 through September 1988 Samples collected during this time were analyzed for inorganic and organic parameters by HWS A&L Laboratory and Wilson Laboratories using analytical methodologies outlined in Methods for Chemical Analysis of Water and Wastes EPA 600/4-79-20 Methods for Organic Chemical Analysis of Municipal and Industrial Wastewater EPA 600/4-82-057 and SW 846 second and third editions Although not all the laboratories used during this period were EPA contract laboratories (i e HWST and A&L) analyses were according to acceptable EPA methods where such methods were in place at the date of analyses The inorganic and organic ground-water laboratory data reports generated between 1983 and 1988 included sample data summary sheets and limited summaries of analytical quality assurance/quality control (QA/QC) results Although QA/QC data validation reviews of the raw data were not performed the data is considered to be acceptable based on the laboratory meeting the QA/QC specified for the EPA methodology utilized (see Section 4 2)

Ground-water samples were collected by Lindsay Manufacturing Co and Dames & Moore personnel between February 1989 and January 1990 All 1989 and 1990 ground-water samples were submitted to Cenref Labs and analyzed according to the inorganic and organic EPA Contract Laboratory Program (CLP) methodologies (RI Work Plan Appendix B) QA/QC data validation reviews were performed on the 1989 and 1990 analytical data sets in accordance with EPA inorganic and organic data validation guidelines (RI Work Plan Appendix B) QA/QC memorandum are provided in Appendix XI-F

The discussion of the nature and extent of inorganic and organic ground-water contamination is based on ground-water monitoring data collected from 1983 through January 1990 On-site and off-site well locations and associated well screen intervals are provided in Table 4 3-1

4 3 2 Inorganics

Table 4 3-2 lists the ground-water sampling locations monitored between May 1983 and January 1990 The inorganic ground-water monitoring data discussion is arranged first by the time periods listed in Table 4 3-2 with subsequent subsections divided by location and then the

Table 4.3-2

Inorganic Ground Water Monitoring
1983-1990

Well Location and Screened Portion of the Aquifer	Time Period		
	5/83 to 11/18/87	11/23/87 to 9/13/88	2/89 to 1/90
On-Site			
Upper	82 1M through 82 4M	82 2M	82 2M MW89 12 MW89 15
Lower	P 1 through P 9 Old Well	P 1 through P 9 MW87 7 MW87-8 TMW88 3 TMW88 4 TMW88 5 TMW88 9 Old Well	P 1 P 6 P 9 MW87 7 MW87-8 TMW88 5 TMW88 9
Aquifer	Fire Well	Fire Well MW87 1 through MW87-4 MW87 6	Fire Well MW87 1 through MW87-4 MW87 6
Perched Sand Channel	Not Monitored	Not Monitored	MW89 13 MW89 14
Off-Site			
Upper	Not Monitored	Not Monitored	Moravec Well MW89 9A MW89 10A MW89 11A
Lower	Not Monitored	TMW88 1 TMW88 6 TMW88 7 TMW88 8 TMW88 10 TMW88 11 54278 Beller Domestic Well 33637	TMW88 1 TMW88 6 TMW88 8 MW89 9B MW89 10B MW89 11B 54278 Beller Domestic Well 33637
Aquifer	Old Lindsay Public Supply Well	Old Lindsay Public Supply Well MW87 5 50378	Old Lindsay Public Supply Well MW87 5 50378

* Well screen interval includes upper and lower portion of the aquifer

screened portion of the aquifer Inorganic ground-water monitoring parameters and laboratory sample results are provided in Appendix XI-C

Four ground-water samples were collected from three off-site wells on January 1 1977 and January 28 1983 and one on-site well in August 1980 and December 1981 The samples were analyzed for select inorganic parameters and the results are summarized in Table 4 3-3 Samples results obtained from Old Lindsay Public Supply Well and registered irrigation wells #15261 and #15262 are considered to be representative of off-site background conditions in the aquifer associated with the site The Old Well sample results are considered to representative of on-site background conditions in the bottom of the aquifer prior to the installation of the four facility wells in December 1982

In addition a sample was collected from the spent acid disposal pit on March 29 1982 and analyzed for select inorganic parameters The results of this sample are also summarized in Table 4 3-3 This sample is considered to be representative of select inorganics present in the former disposal pit

4 3 2 1 May 1983 to November 18 1987

Between May 1983 and November 18 1987 ground-water samples were collected on a monthly basis from nine on-site monitoring wells screened in the upper and lower portion of the aquifer or over the entire aquifer In addition one off-site well was monitored in the aquifer (Table 4 3-2)

On-Site Ground-Water Quality

Upper Portion of the Aquifer

The following discussion relates only to on-site monitoring wells screened in the upper aquifer similar wells off-site were installed in 1989 The wells discussed in this section (82M Series Wells) although screened in the upper portion of the aquifer at that time were connected by high permeability conduits (Section 3 6) to the perched sand channel The sand channel is a residual source of contamination and Lindsay s site investigations have found that water samples from three of the 82M-Series Wells represent the commingling of residual metals and organic compounds with aquifer water

On-site monitoring wells screened in the upper portion of aquifer included 82-1M 82-2M 82-3M and 82-4M (Figure 1 2-4) Ground water was monitored at these locations on a monthly basis from May 1983 to July 16 1987 Monitoring wells 82-1M 82-3M and 82-4M were abandoned in July 1987 Inorganic data collected for this period indicates that pH specific

Table 4 3-3
Summary of Select Inorganic Analysis
Collected Between 1977 and January 1, 1983 (mg/l)

Analysis	Old Lindsay Public Supply Well (1/77)	Old Well (8/80)	Old Well (12/81)	Old Lindsay Public Supply Well (1/83)	Reg # 5261 (1/83)	Reg # 5262 (1/83)	Acid Pit (3/82)	Drinking Water Standards*
pH	7 4	7	7 2	7 2	7	7 1	1 4	
Specific Cond	NA	NA	NA	NA	600	675	NA	1600 (2)
Zinc	NA	3 2	2 6	NA	0 11	0 11	1994	5 0 (1)
Cadmium	NA	NA	NA	NA	NA	NA	0 08	0 010 (1)
Chromium	NA	NA	NA	NA	NA	NA	2	0 05 (1)
Lead	NA	NA	NA	NA	NA	NA	3 4	0 05 (1)
Mercury	NA	NA	NA	NA	NA	NA	0 0001	0 002 (1)
Selinium	NA	NA	NA	NA	NA	NA	<0 01	0 01 (1)
Silver	NA	NA	NA	NA	NA	NA	<0 05	0 05 (1)
Iron	NA	0 65	<0 09	0 1	0 3	0 15	NA	0 3 (2)
Barium	NA	NA	NA	NA	NA	NA	<2 0	1 0 (1)
Sulfate	NA	10 2	24	21	15	14	NA	500 (2)
Arsnic	NA	NA	NA	NA	0 2	0 38	<0 01	0 05 (1)
Manganese	NA	NA	NA	0 1	NA	NA	NA	0 05 (2)
Calcium	NA	NA	NA	99	77	65	NA	
Magnesium	NA	NA	NA	NA	72	56	NA	
Potassium	NA	NA	NA	NA	14	13	NA	
Sodium	NA	26	11 4	16	16	15	NA	
Carbonate	NA	0	0	NA	275	295	NA	
Bicarbonate	NA	258	220	NA	16 6	177	NA	
Chloride	NA	2	5	22	3 1	4 1	NA	500 (2)

NA Not Analyzed
Drinking Water Standards (1) Primary (2) Secondary

conductance zinc iron sulfate cadmium chromium, and lead were all present at concentrations greater than background levels or available drinking water standards Each parameter is discussed below

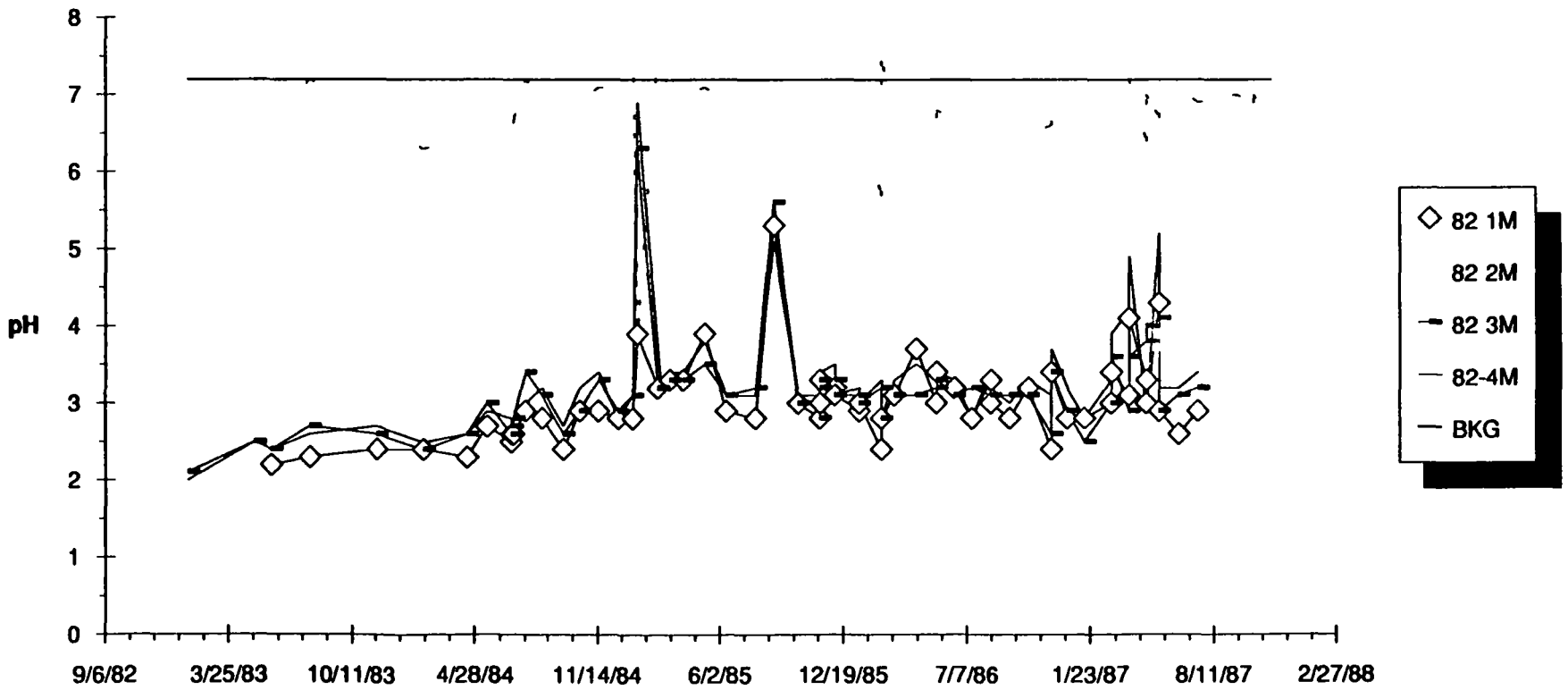
Field and laboratory pH levels measured in 82-1M 82-3M and 82-4M ranged from 2 2 to 3 8 standard units (SU) (Figure 4 3-1a) These wells are located northwest and southeast of the former disposal pit and the former burn pit As previously mentioned the investigation began in 1983 when these acidic conditions were discovered These pH levels were below the background ground-water pH established from on and off-site well water samples In 82-2M pH ranged from 6 3 SU to 7 7 SU which were near background pH levels (Table 4 3-3) During this time the acidic ground-water plume was centered near the former disposal pit as shown in Figure 4 3-1b

Specific conductivity levels measured in 82-1M 82-3M and 82-4M ranged from 2 160 umhos/cm to 26 000 umhos/cm The highest specific conductance levels were found in 82-1M and 82-3M and were 18 000 umhos/cm and 26 000 umhos/cm respectively In 82-2M levels ranged from 710 umhos/cm to 1600 umhos/cm Although the specific conductivity levels in 82-2M were above background conditions they were below secondary drinking water standards (SDWS) for specific conductivity (1600 umhos/cm) The presence of elevated specific conductivity measurements coincides with the low pH levels described above

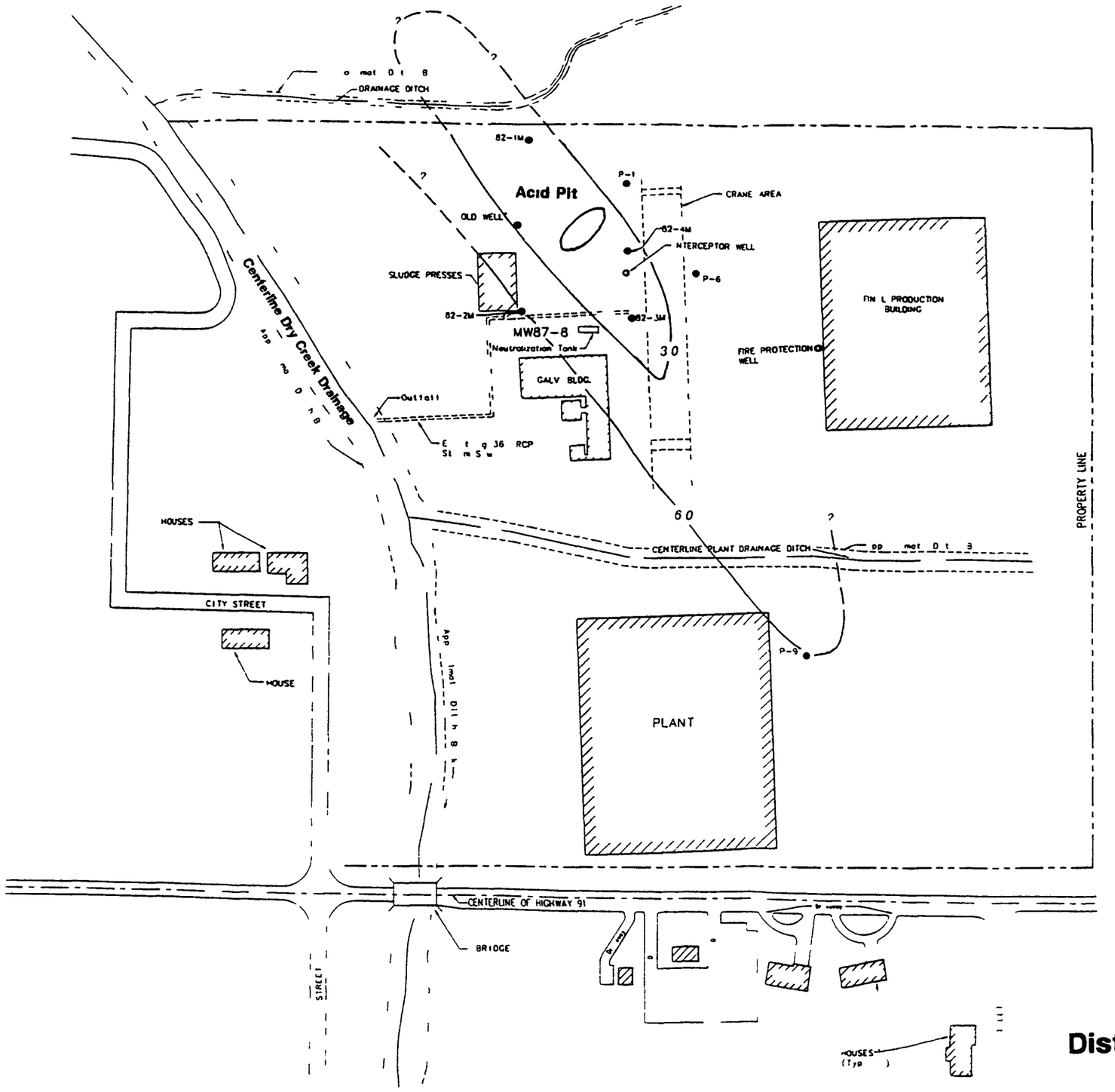
Zinc concentrations reported in 82-1M 82-3M and 82-4M ranged from 93 to 6 000 mg/l The highest zinc concentrations were reported in 82-1M (2 400 mg/l) and 82-3M (6 000 mg/l) In 82-2M zinc concentrations ranged between 0 017 mg/l to 12 8 mg/l (Figure 4 3-1c) Zinc levels in 82-1M 82-3M and 82-4M were well above the secondary drinking water standards (SDWS) (5 0 mg/l) and background zinc levels (Figure 4 3-1c) The elevated zinc levels coincide with the low pH levels reported above (Figure 4 3-1a) Zinc concentrations reported in 82-2M only exceeded secondary SDWS periodically between April 1984 and October 1985 An isoconcentration map of zinc occurrence during 1983 is presented in Figure 4 3-1d

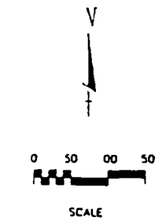
Iron concentrations reported in 82-1M 82-3M and 82-4M ranged from 104 mg/l to 5 400 mg/l The highest iron concentrations were reported in 82-1M (1 700 mg/l) and 82-3M (5 400 mg/l) Iron concentrations in 82-2M ranged from 0 03 mg/l to 195 mg/l (Figure 4 3-1e) Iron levels in 82-1M 82-3M and 82-4M were well above the SDWS (0 3 mg/l) Elevated iron levels found in these wells coincide with the low pH levels described above (Figure 4 3-1a) However iron concentrations reported in 82-2M were below the SDWS for iron periodically between November 1985 and January 1987 An isoconcentration map of iron occurrence during May through June 1983 is presented in Figure 4 3-f

Figure 4 3-1a
Time vs pH
On-Site Monitoring Wells
Screened in Upper Portion of Aquifer
Lindsay Mfg Co



BKG = Background





LEGEND

- ○ Existing Production Wells
- ● Existing Monitoring Wells
- —30— Field pH Contour (Standard Units)

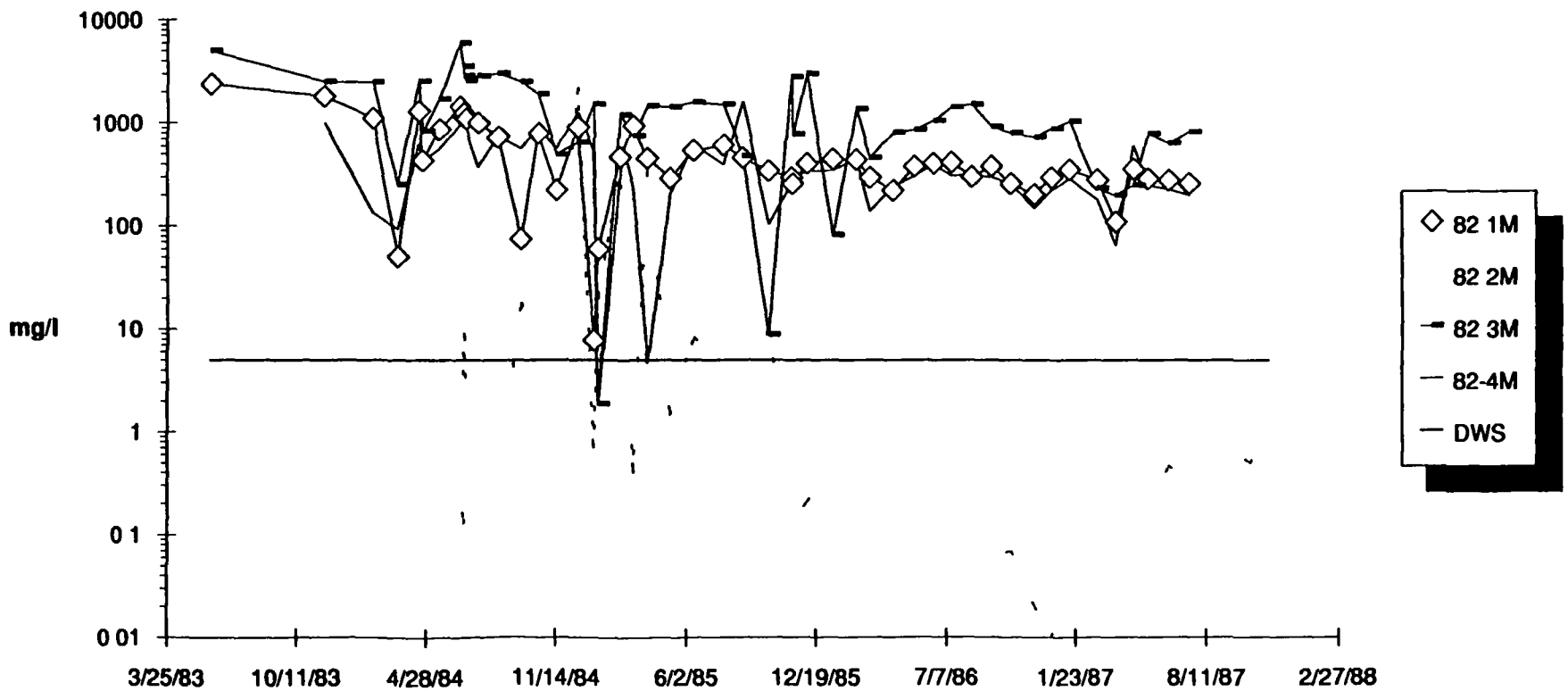
Figure 4 3 1b

Distribution of Field and Lab pH in Aquifer
May-June 1983
Lindsay Mfg. Site

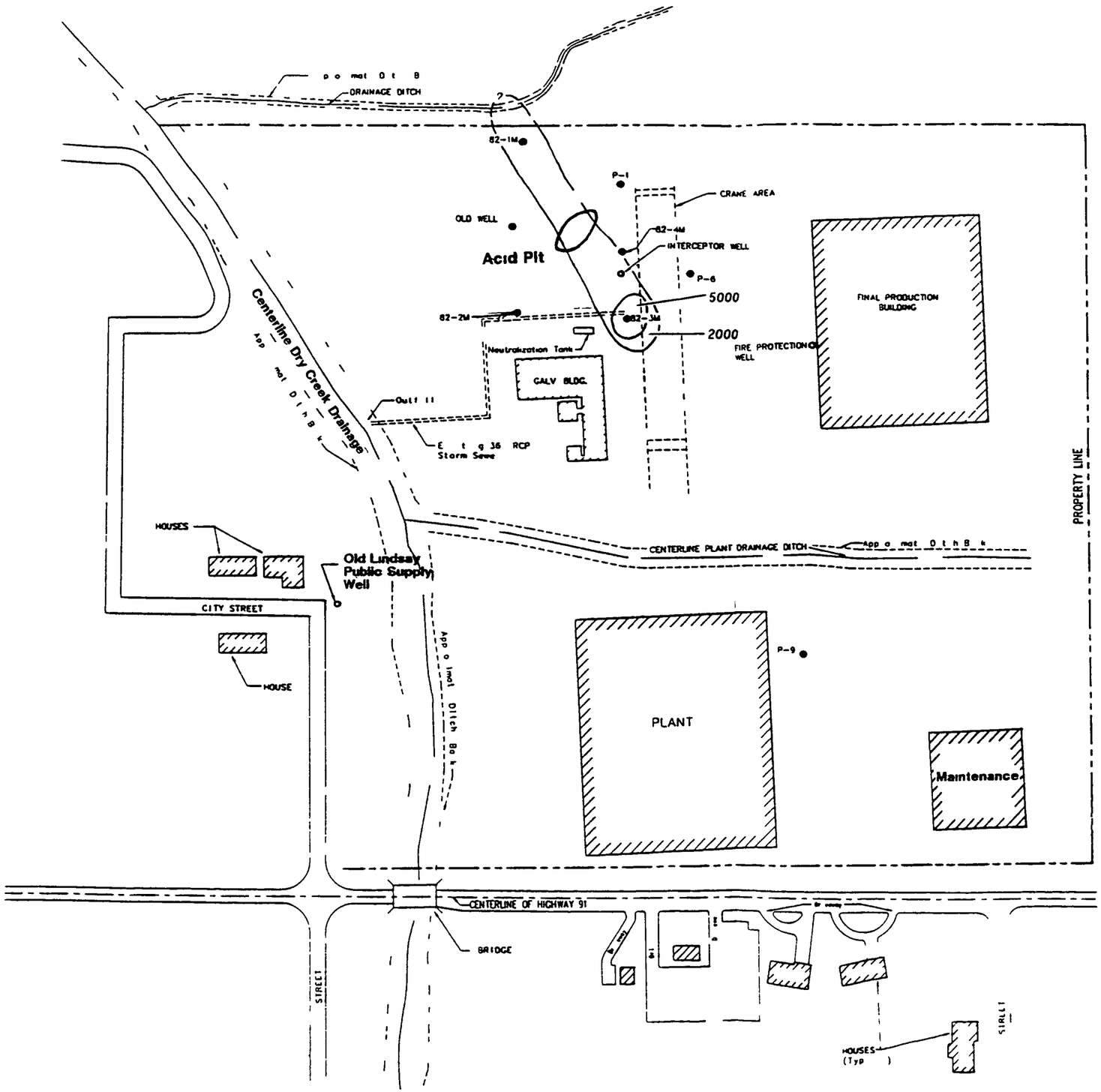
DAMES & MOORE

Rev 6/7/90

Figure 4 3-1c
Time vs Zinc
On-Site Monitoring Wells
Screened in Upper Portion of Aquifer
Lindsay Mfg Co



DWS = Drinking Water Standard



N

0 50 100 150

SCALE

LEGEND

- o Existing Production Wells
- • Existing Monitoring Wells
- —2000— Isoconcentration Lines (mg/l)

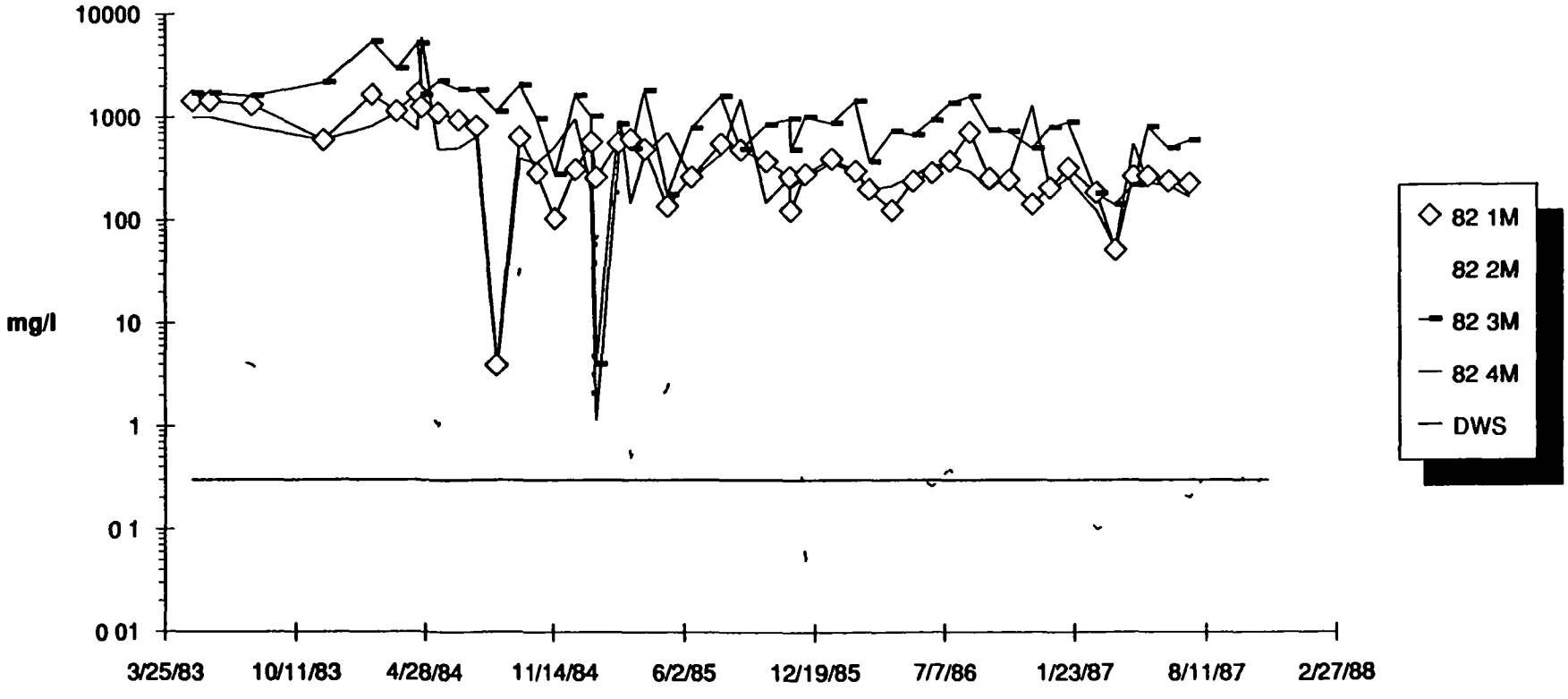
Figure 4 3-1d

Distribution of Zinc in Aquifer
May-June 1983
Lindsay Mfg. Site

DAMES & MOORE

Rev 2/28/99

Figure 4 3-1e
Time vs Iron
On-Site Monitoring Wells
Screened in Upper Portion of Aquifer
Lindsay Mfg Co



Sulfate concentrations reported in 82-1M 82-3M and 82-4M ranged from 1 240 mg/l to 165 000 mg/l The highest sulfate concentrations were reported in 82-3M (165 000 mg/l) and 82-4M (50 000 mg/l) Sulfate concentrations in 82-2M ranged from 30 mg/l to 5 000 mg/l (Figure 4 3-1g) Sulfate levels in 82-1M 82-2M 82-3M and 82-4M were above the SDWS for sulfate (250 mg/l) however sulfate reported in 82-2M periodically dropped below the SDWS between May 1983 and November 18 1987 An isoconcentration map of sulfate occurrence during May through June 1983 is presented in Figure 4 3-1h

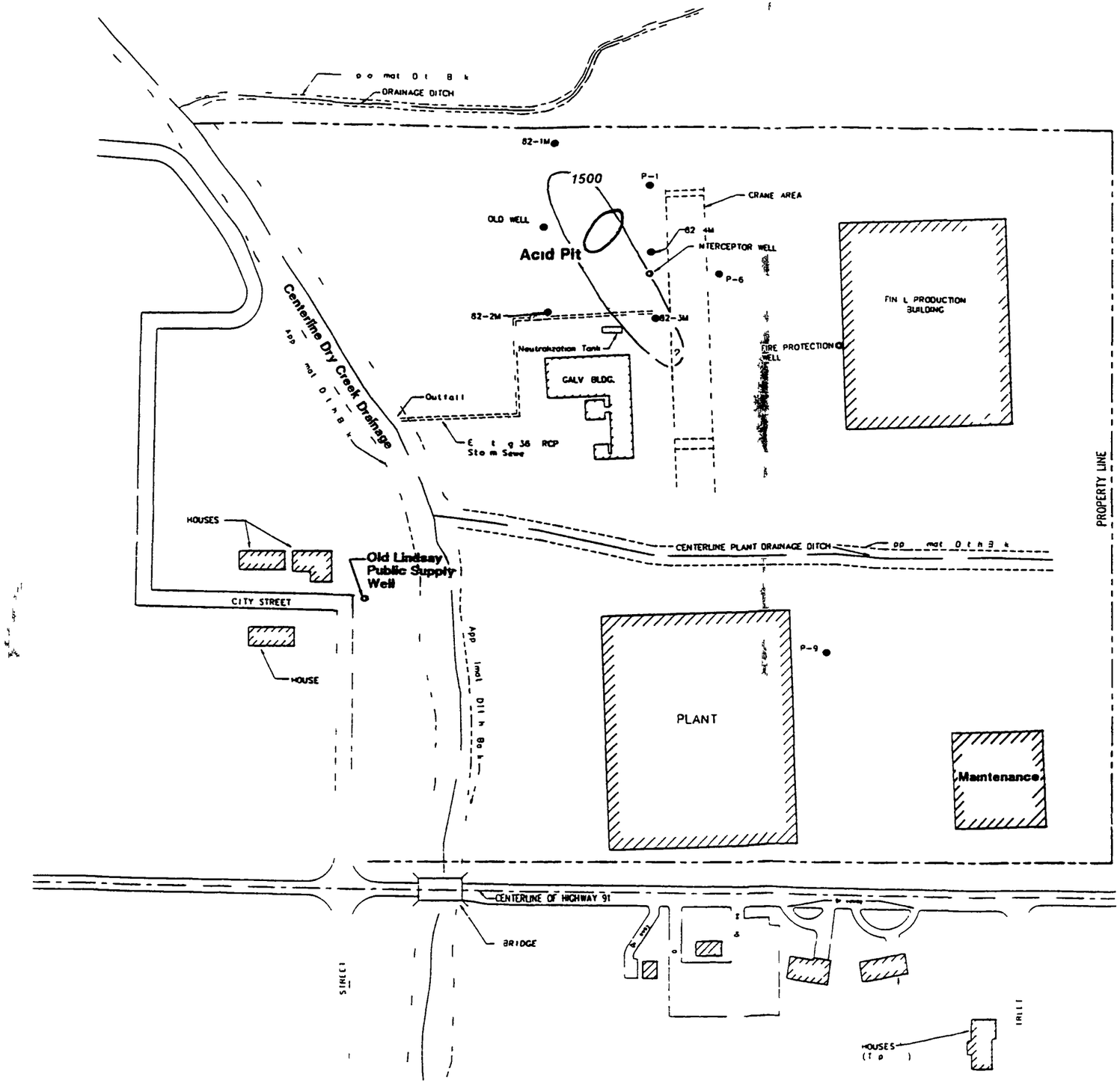
Cadmium concentrations reported in 82-1M 82-2M 82-3M and 82-4M ranged from 0 006 to 8 4 mg/l (Figure 4 3-1i) The highest cadmium level was reported in 82-2M 8 4 mg/l on August 4 1983 In general cadmium concentrations reported in all four wells periodically exceeded the primary drinking water standard (PDWS) of 0 01 mg/l by approximately one order of magnitude

Chromium concentrations reported in 82-1M 82-3M and 82-4M ranged from 0 11 mg/l to 2 35 mg/l Chromium concentrations reported in 82-2M ranged from 0 03 to 0 14 mg/l (Figure 4 3-1j) Chromium levels found in wells 82-1M 82-3M and 82-4M were above the PDWS (0 05 mg/l) during this time period however chromium concentrations reported in 82-2M were generally near or below the PDWS

Lead concentrations reported in 82-1M 82-2M 82-3M and 82-4M ranged from undetected to 0 5 mg/l (Figure 4 3-1k) On Figure 4 3-1k the lead concentration was plotted at the detection limits 0 1 mg/l and 0 01 mg/l therefore it is not always known if lead sample concentrations exceeded the PDWS (0 05 mg/l) In general lead levels found in 82-1M 82-2M 82-3M and 82-4M appear to have been greater than the PDWS from May 1983 to approximately July 1986 after which lead concentrations were below the PDWS

Manganese was periodically monitored between May 1983 and November 13 1987 (Appendix XI-C) Manganese concentrations reported in 82-1M 82-2M 82-3M and 82-4M ranged from undetected to 81 6 mg/l The highest individual manganese concentration was found at 82-1M 81 6 mg/l and the lowest range of manganese concentrations were reported in 82-2M During this time period manganese concentrations reported in these wells exceeded the SDWS (0 05 mg/l) and background concentration (0 1 mg/l)

Arsenic barium selenium silver and mercury were also periodically monitored during this time period Sample concentrations of these elements reported in all four wells were below PDWS for each element



N

0 50 00 150

SCALE

LEGEND

- ○ Existing Production Wells
- ● Existing Monitoring Wells
- —1500— Isoconcentration Lines (mg/l)

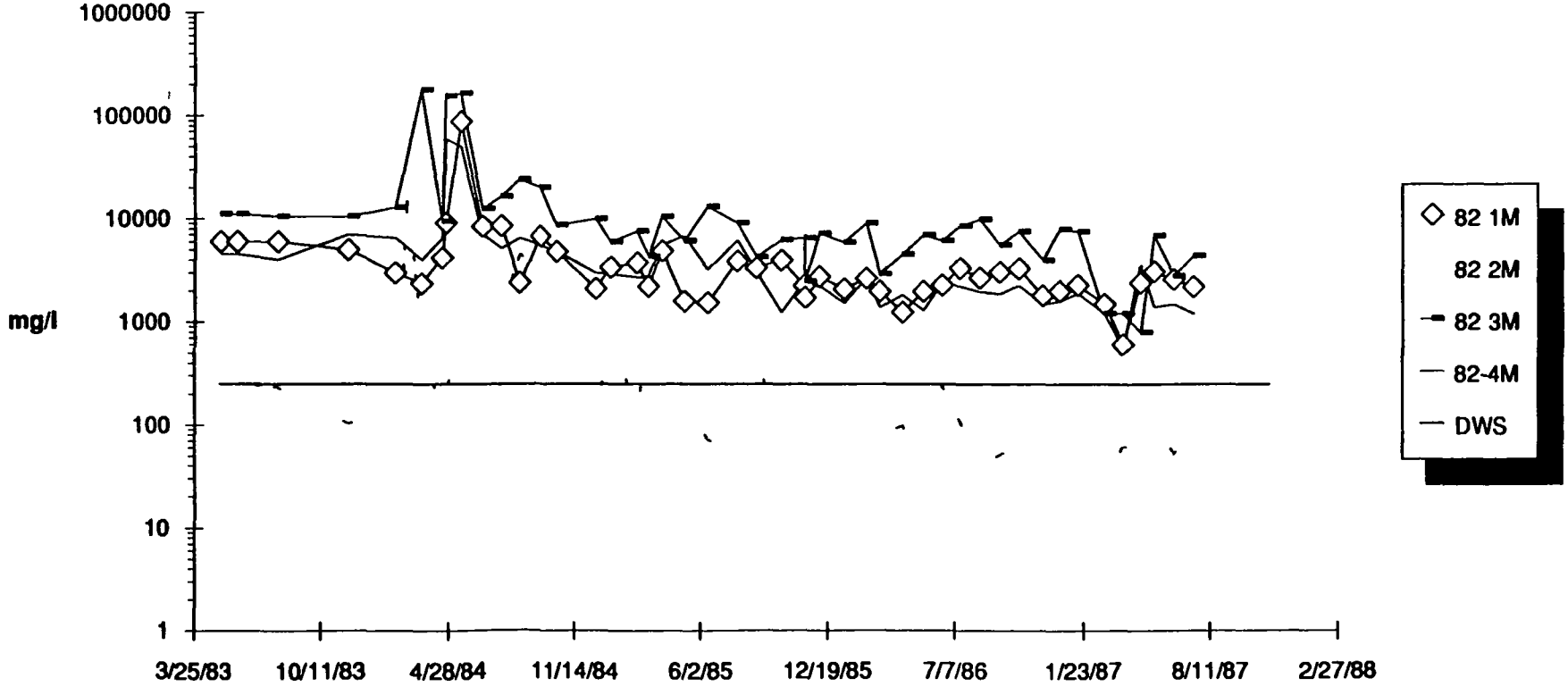
Figure 4 3-1f

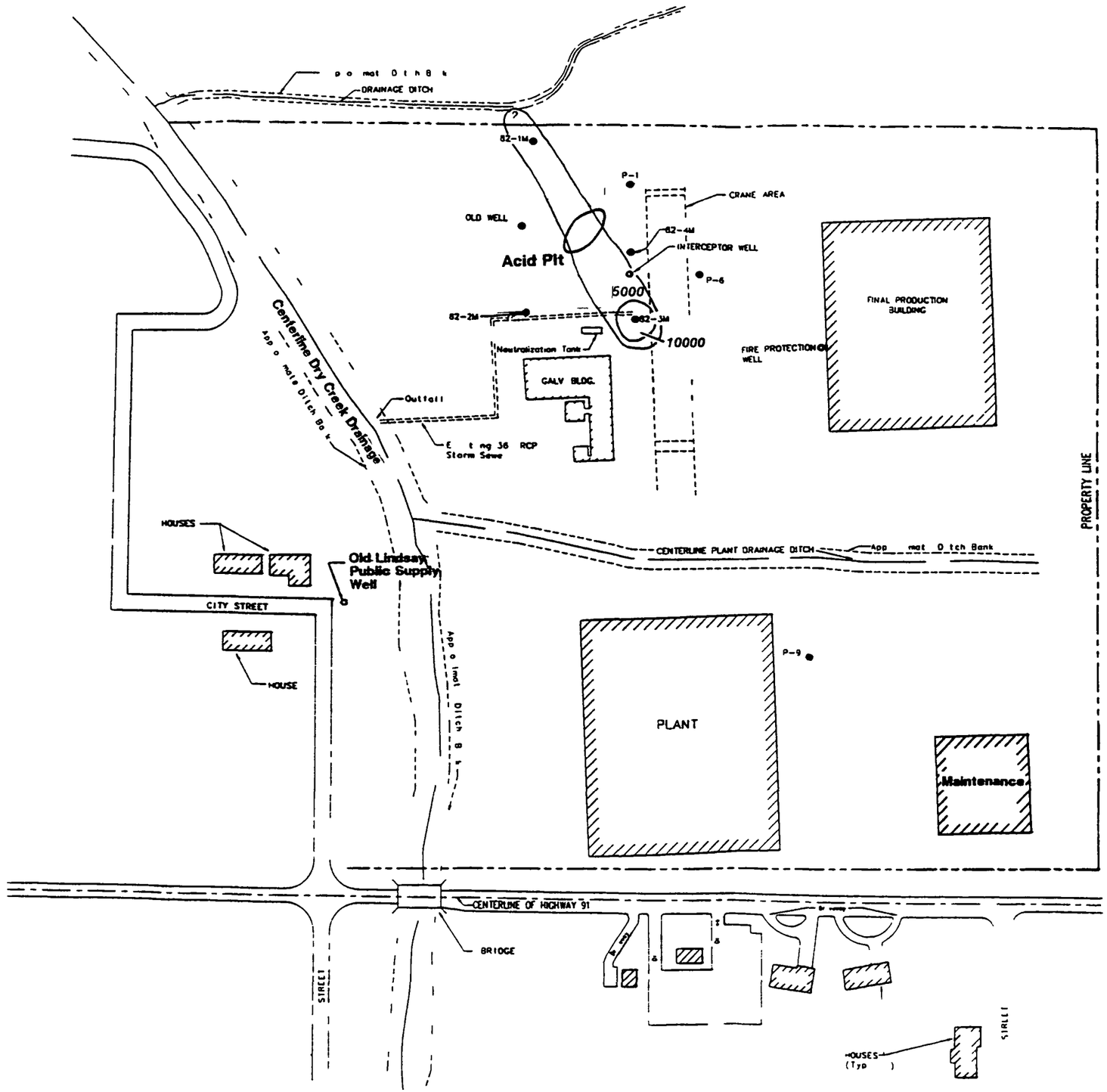
Distribution of Iron in Aquifer
May-June 1983
Lindsay Mfg. Site

DAMES & MOORE

Rev 2/28/90

Figure 4 3-1g
Time vs Sulfate
On-Site Monitoring Wells
Screened in Upper Portion of Aquifer
Lindsay Mfg Co





N

0 50 100 150

SCALE

LEGEND

- o Existing Production Wells
- • Existing Monitoring Wells
- —5000— Isoconcentration Lines (mg/l)

Figure 4.3-1h

Distribution of Sulfate in Aquifer
May-June 1983
Lindsay Mfg. Site

DAMES & MOORE

Rev 2/28/90

Figure 4 3-1i
Time vs Cadmium
On-Site Monitoring Wells
Screened in Upper Portion of Aquifer
Lindsay Mfg. Co

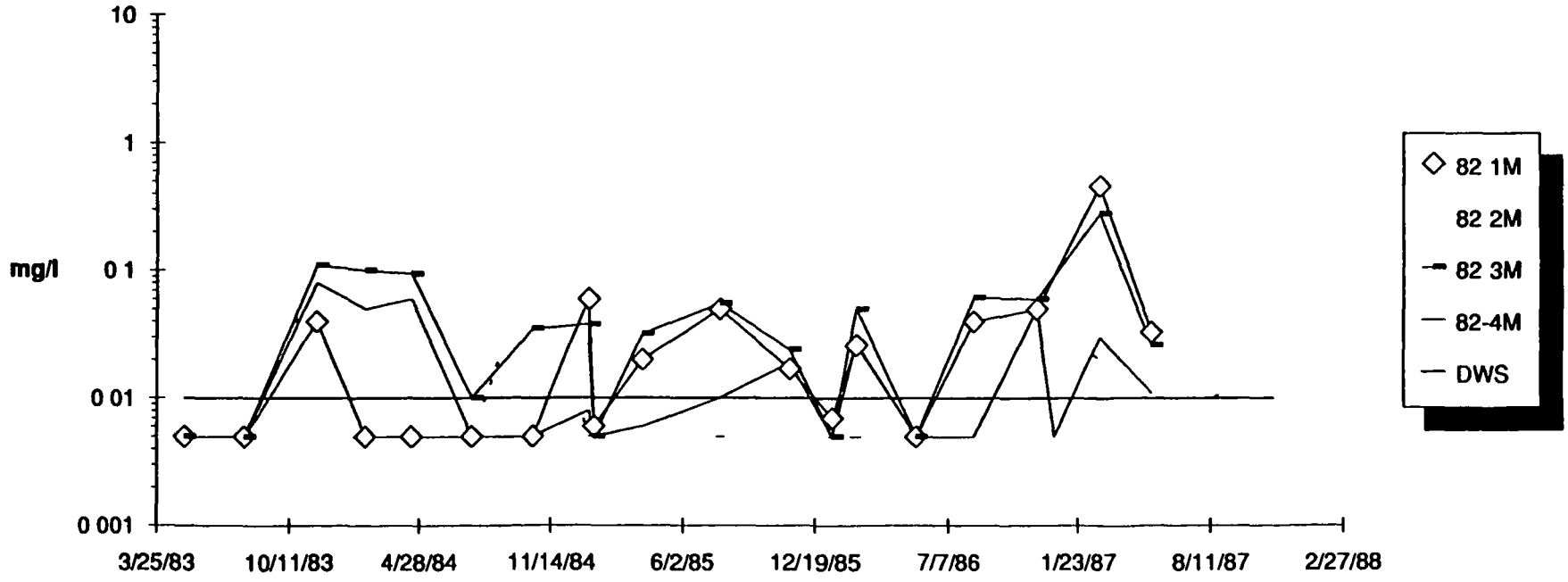


Figure 4 3-1j
Time vs Chromium
On-Site Monitoring Wells
Screened in Upper Portion of Aquifer
Lindsay Mfg Co

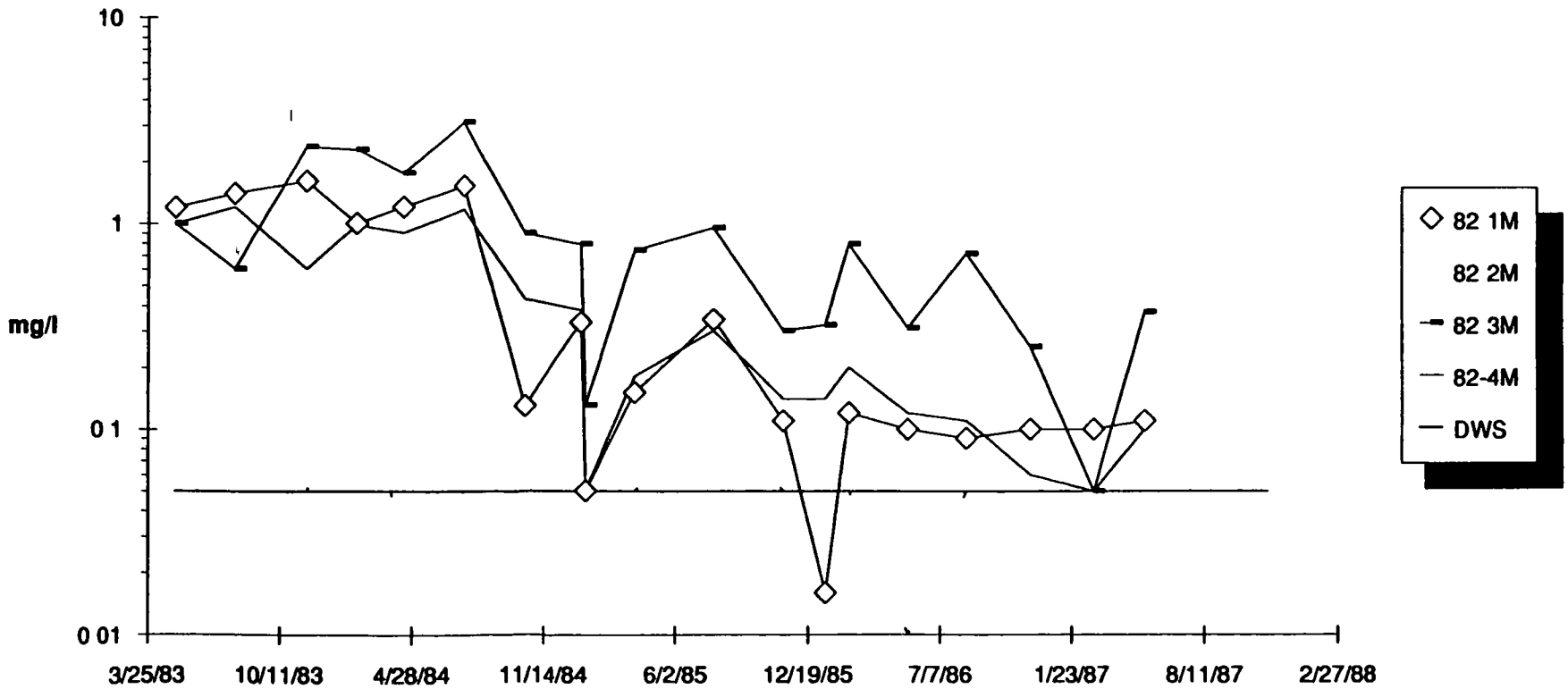
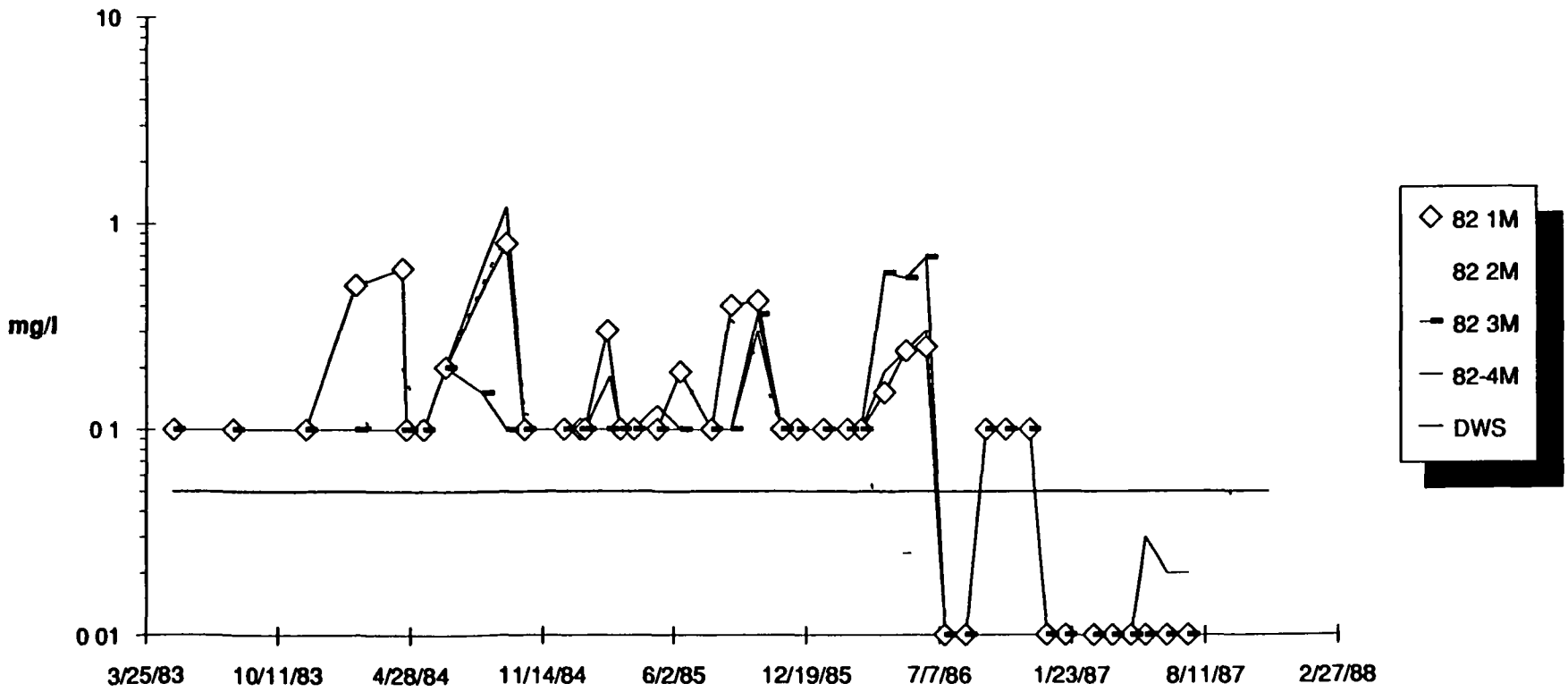


Figure 4 3-1k
Time vs Lead
On-Site Monitoring Wells
Screened in Upper Portion of Aquifer
Lindsay Mfg Co



Lower Portion of the Aquifer

On-site monitoring wells screened in the lower portion of the aquifer included piezometers P-1 through P-9 and the Old Well (Table 4 3-2) Two ground-water samples were collected from the Old Well in August 1980 and December 1981 and the results are listed in Table 4 3-3 The Old Well sample results collected at this time are considered to representative of on-site background conditions in the lower portion of the aquifer prior to the installation of the four facility wells in December 1982 Ground-water samples were collected for inorganic analyses from P-1 P-6 and P-9 in June 1983 June 1984 and August and November 1985 Then from January 14 1986 through November 18 1987 P-1 P-6 and P-9 were monitored on a monthly basis (Appendix XI-C) Ground-water samples were collected from P-2 P-3 P-4 P-5 P-7 and P-8 only on November 13 1987 The Old Well was initially included in the ground-water monitoring program on January 17 and June 3 1983

Field and laboratory pH levels measured in P-1 and P-6 ranged from 3 3 to 6 9 SU and in P-9 ranged from 5 7 SU to 7 1 SU Time versus pH levels for this time period are provided in Figure 4 3-2a The pH levels measured in P-1 and P-6 were acidic (< 5 0 SU) from May 1983 to June 1985 A pH of 7 2 SU was measured in the Old Well in 1981 but in May 1983 the pH had dropped significantly to 2 6 SU Between May 1983 and January 1986 pH in the Old Well gradually increased to near background conditions from June 1985 to December 1985 pH levels in P-6 increased significantly to and stayed within the 6 0 SU to 7 0 SU pH range Also pH levels measured in P-1 gradually increased to near 6 0 SU In P-9 pH was near background (Table 4 3-3) with the exception of November 1985 when the pH dropped to 5 2 SU The distribution of field and laboratory pH values from May to June 1983 is shown in Figure 4 3-1b On November 13 1985 pH levels measured in P-2 P-3 P-4 P-5 and P-7 were acidic and ranged from 3 9 to 4 6 SU P-1 through P-7 are located on the east and southeast sides of the former pit The pH levels in P-8 (6 3 SU) and P-9 suggest that the acid contaminants had not migrated to these locations which are further downgradient (southeast) of the former pit

Specific conductivity levels measured in P-1 P-3 P-7 P-8 P-9 and the Old Well ranged from 250 umhos/cm to 3 100 umhos/cm Although these levels were above background conditions they were generally below SDWS for specific conductivity (1600 umhos/cm) Specific conductivity levels measured in P-2 P-4 P-5 and P-6 ranged from 290 umhos/cm to 4 500 umhos/cm

Zinc concentrations reported in P-1 P-6 P-9 and the Old Well ranged from 0 9 mg/l to 585 mg/l (Figure 4 3-2b) Zinc levels found between October 1983 to approximately July 1986 were above the SDWS (5 0 mg/l) with the exception of the Old Well After this time zinc levels in all three piezometers fell below the SDWS An isoconcentration map of zinc occurrence during 1983 is presented in Figure 4 3-1d Zinc levels reported in P-2 through P-5 P-7 and P-8 on

Figure 4 3-2a
Time vs pH
On-Site Monitoring Wells
Screened in Lower Portion of Aquifer
Lindsay Mfg Co

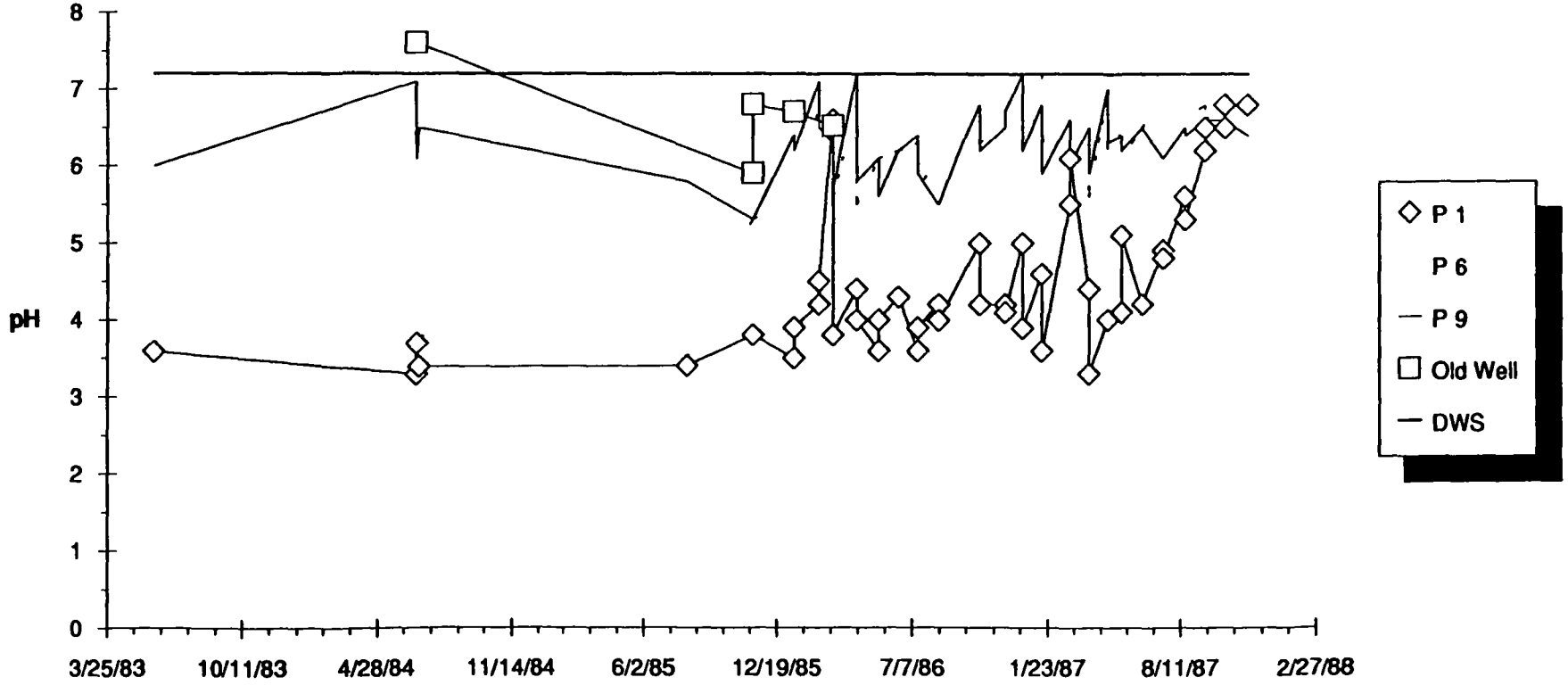
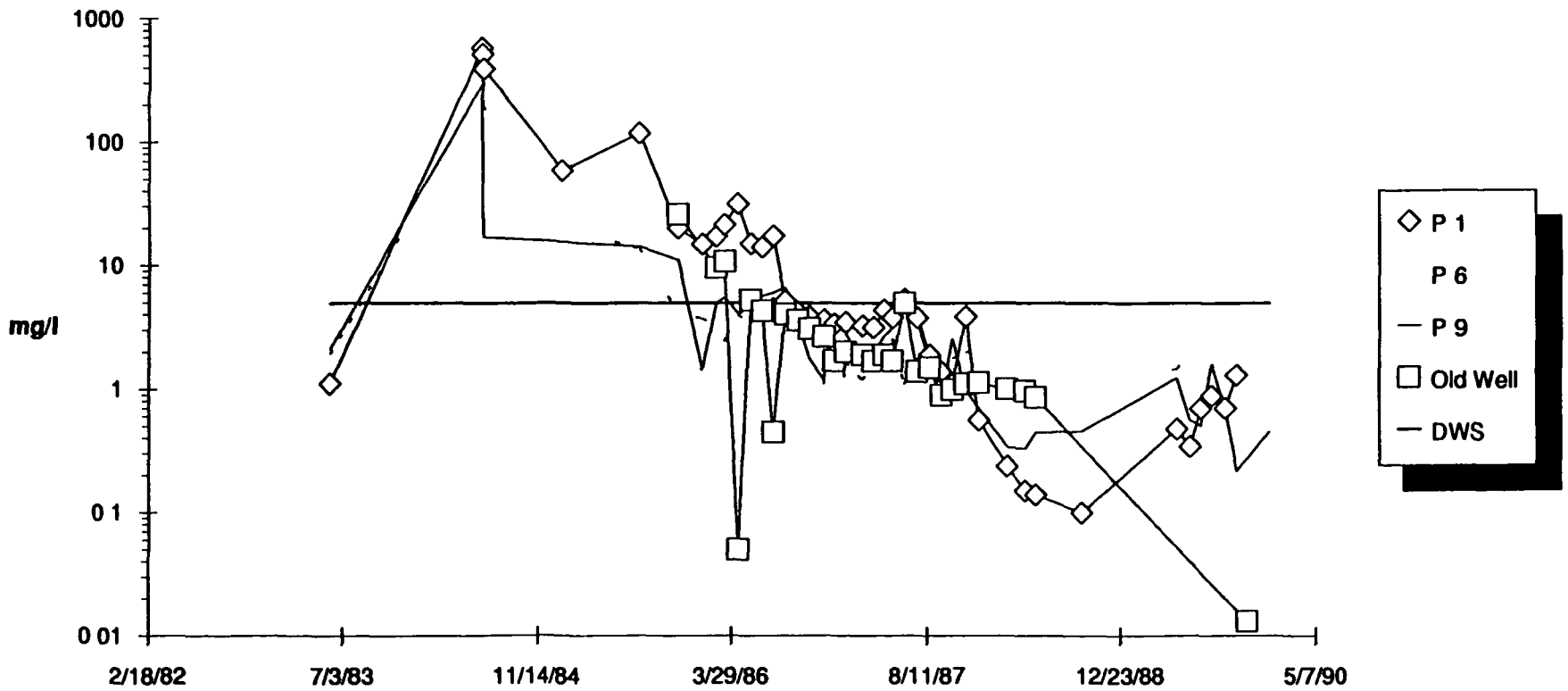


Figure 4 3-2b
Time vs Zinc
On-Site Monitoring Wells
Screened in Lower Portion of Aquifer
Lindsay Mfg Co



November 13 1985 ranged in concentration from 4 2 mg/l to 417 mg/l with the highest zinc concentration reported in P-5

Iron concentrations reported in P-1 P-6 P-9 and the Old Well ranged from undetected to 120 mg/l The highest iron concentration was reported in P-1 120 mg/l on August 6 1985 (Figure 4 3-2c) Iron concentrations reported in these piezometers were above the SDWS with exception of the Old Well however in general iron levels decreased over this time period An isoconcentration map of iron occurrence during May through June 1983 is presented in Figure 4 3-1f Iron concentrations reported in P-2 through P-5 P-7 and P-8 ranged in concentration from 0 98 mg/l to 107 mg/l with the highest concentrations found in P-5

Sulfate concentrations reported in P-1 P-6 P-9 and the Old Well ranged from 16 mg/l to 296 mg/l (Figure 4 3-2d) Sulfate levels were below and/or near the SDWS (250 mg/l) An iso-concentration map of sulfate occurrence during May through June 1983 is presented in Figure 4 3-1h Sulfate concentrations reported in P-2 through P-5 P-7 and P-8 ranged in concentration from 34 mg/l to 2 925 mg/l with the highest concentrations found at P-4 (1 250 mg/l) and P-5 (2 935 mg/l)

Cadmium chromium and lead were monitored in P-1 P-6 and P-9 on August 6 1985 Cadmium concentrations detected in P-1 and P-6 were 0 035 mg/l and 0 022 mg/l respectively and both exceeded the PDWS (0 01 mg/l) Chromium was detected in P-1 (0 11 mg/l) and P-9 (0 14 mg/l) which also exceeded the chromium PDWS (0 05 mg/l) Similarly lead was detected only in P-9 0 15 mg/l and it too exceeded the lead PDWS (0 05 mg/l)

Cadmium chromium lead barium manganese mercury selenium and silver concentrations were monitored in P-1 through P-9 and the Old Well Cadmium was detected in P-2 P-4 P-5 and the Old Well and ranged in concentration from 0 011 mg/l to 0 016 mg/l Chromium was detected in P-5 (0 17 mg/l) and in P-9 (0 35 mg/l) Lead was detected at P-9 (1 6 mg/l) only Manganese concentrations were reported in P-2 P-3 P-5 P-6 P-7 and the Old Well and ranged in concentration from 0 2 to 1 0 mg/l The elemental sample concentrations listed above exceeded PDWS for each specific individual element mentioned with the exception of barium mercury selenium or silver which were not detected during this time

Entire Aquifer

One onsite monitoring well (the Fire Well) which is screened over the entire aquifer (Table 4 3-2) was monitored during this time

The Fire Well was monitored once on November 13 1985 and then on a monthly basis from February 19 1986 to November 18 1987 (Appendix XI-C)

Figure 4 3-2c
Time vs Iron
On-Site Monitoring Wells
Screened in Lower Portion of Aquifer
Lindsay Mfg. Co

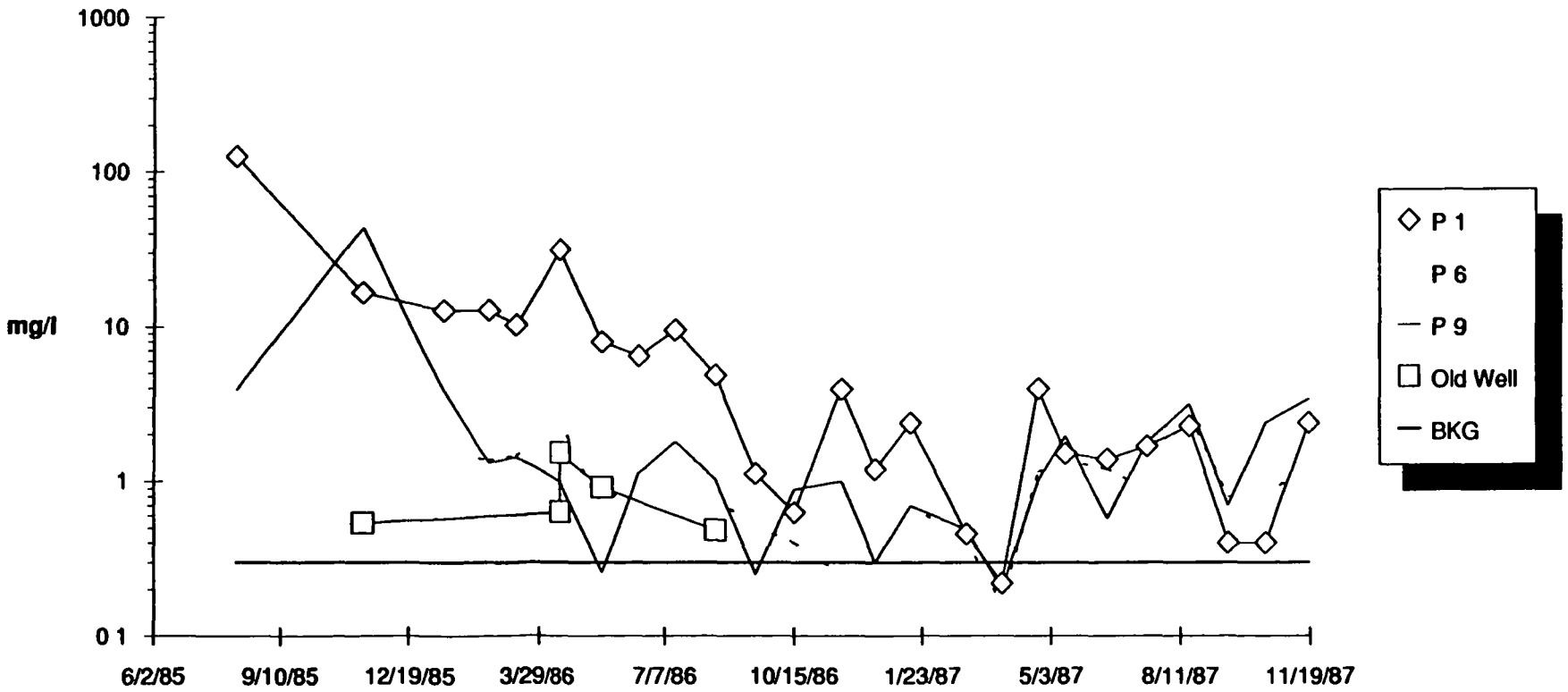
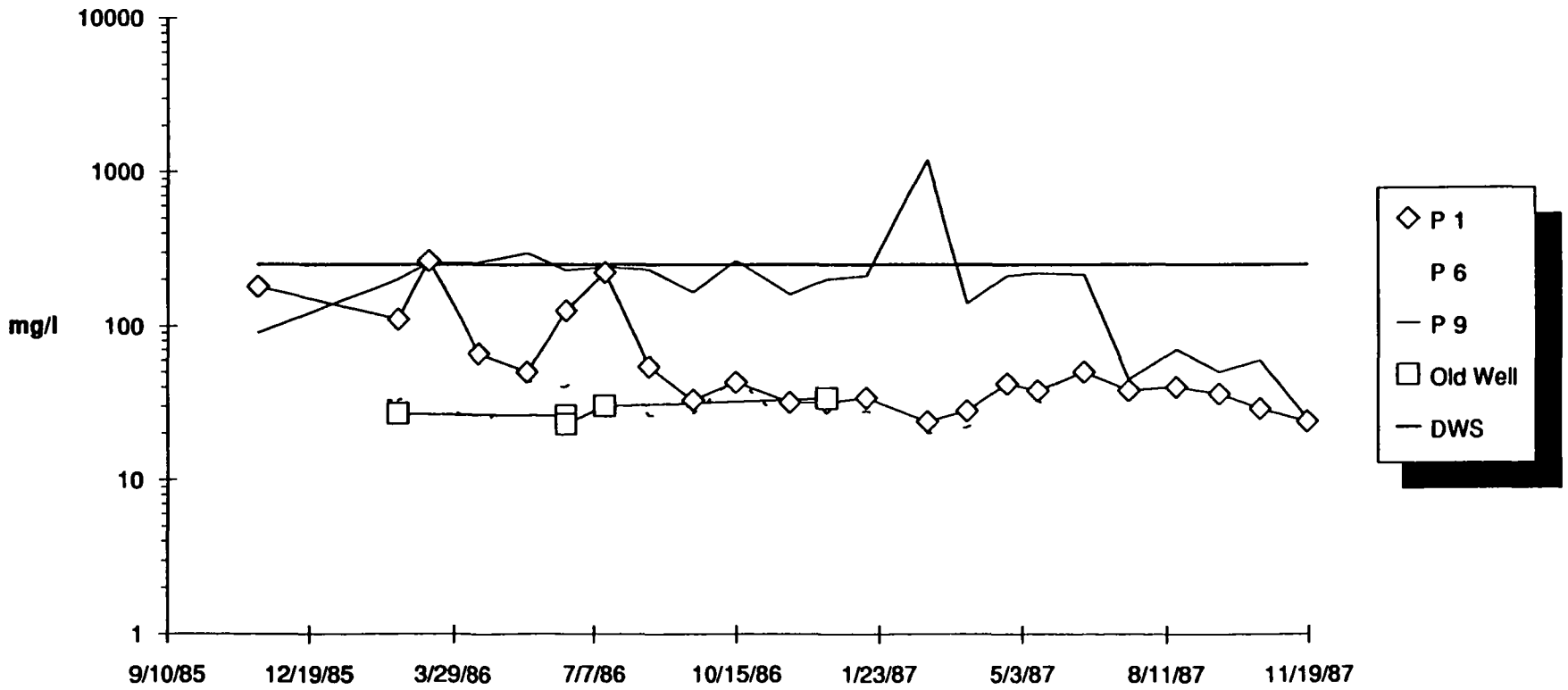


Figure 4 3-2d
Time vs Sulfate
On-Site Monitoring Wells
Screened in Lower Portion of Aquifer
Lindsay Mfg. Co



Field and laboratory pH levels measured in the Fire Well ranged from 5 0 SU to 7 0 SU and were within background pH levels (Figure 4 3-3a)

Specific conductivity levels measured in the Fire Well ranged from 635 umhos/cm to 2 055 umhos/cm which were near SDWS for specific conductivity (1600 umhos/cm)

Zinc ranged in concentration from 2 9 mg/l to 403 mg/l in the Fire Well and generally exceeded the SDWS during this time period (Figure 4 3-3b)

Iron concentrations reported in the Fire Well ranged from 2 1 mg/l to 132 mg/l and was generally above SDWS (Figure 4 3-3c)

Sulfate concentrations reported in the Fire Well ranged from 40 mg/l to 1300 mg/l (Figure 4 3-3d) Sulfate levels in the Fire Well decreased in concentration with time and were below the SDWS between November 26 1986 and July 16 1987

Cadmium concentrations in the Fire Well ranged from undetected to 0 04 mg/l and at various monitoring dates were slightly above the PDWS (0 01 mg/l) Chromium and lead were reported at concentrations below the PDWS for both elements at various dates during this time period Barium manganese mercury selenium and silver were monitored on November 13 1985 only and detected but were at concentrations below the PDWS

Off-Site Ground-Water Quality

Entire Aquifer

The Old Lindsay Public Supply Well was the only off-site monitoring well included in the ground-water monitoring program between May 1983 and November 13 1987 The Old Lindsay Public Supply Well is screened in the aquifer (Table 4 3-2) Table 4 3-3 lists the results of ground-water samples collected from this well prior to the installation of the four onsite facility wells in December 1982 and their introduction of acidic waters into the aquifer The samples results obtained from this well are considered to be representative of off-site background conditions in the aquifer associated with the site

Field pH levels measured in the Old Lindsay Public Supply Well ranged from 6 3 SU to 7 2 SU Time versus pH levels are provided in Figure 4 3-4a Old Lindsay Public Supply Well pH levels were at background pH levels during this time period

Zinc concentrations in the Old Lindsay Public Supply Well ranged from 0 01 mg/l to 3 4 mg/l iron concentrations ranged from 0 04 mg/l to 7 2 mg/l and sulfate concentrations ranged from

Figure 4 3-3a
Time vs pH
On-Site Monitoring Wells
Screened in Aquifer
Lindsay Mfg Co

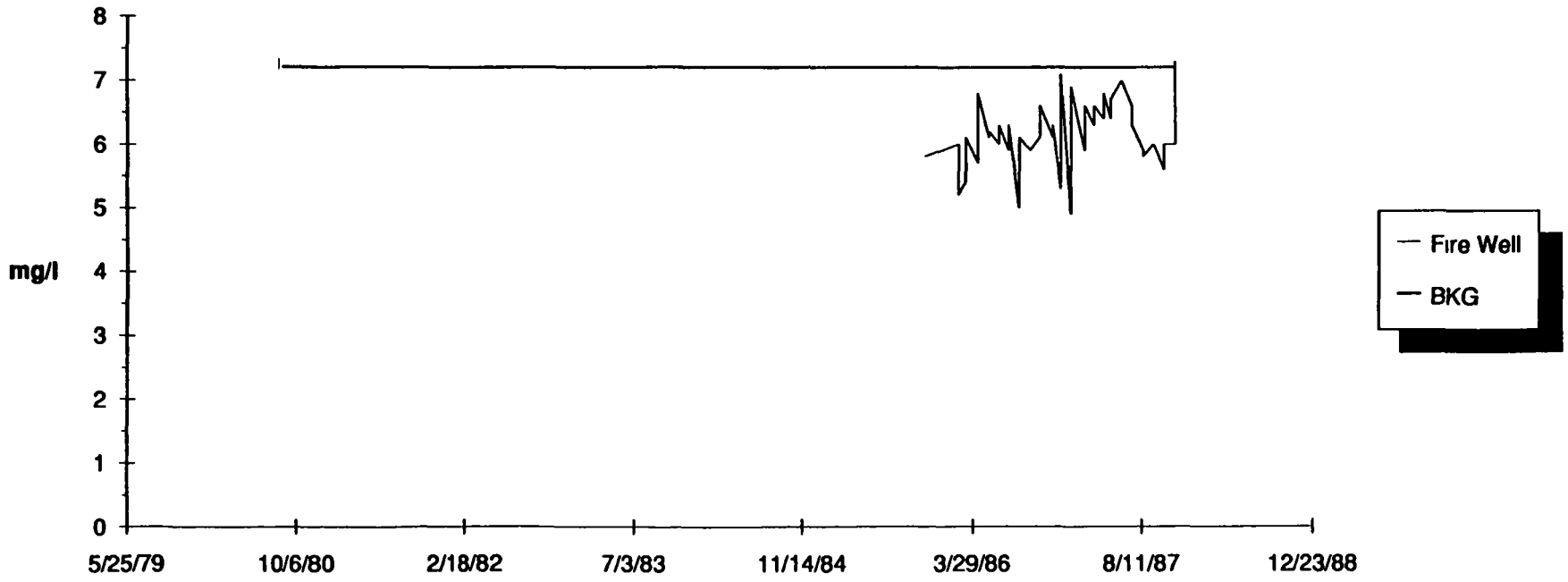


Figure 4 3-3b
Time vs Zinc
On-Site Monitoring Wells
Screened in Aquifer
Lindsay Mfg Co

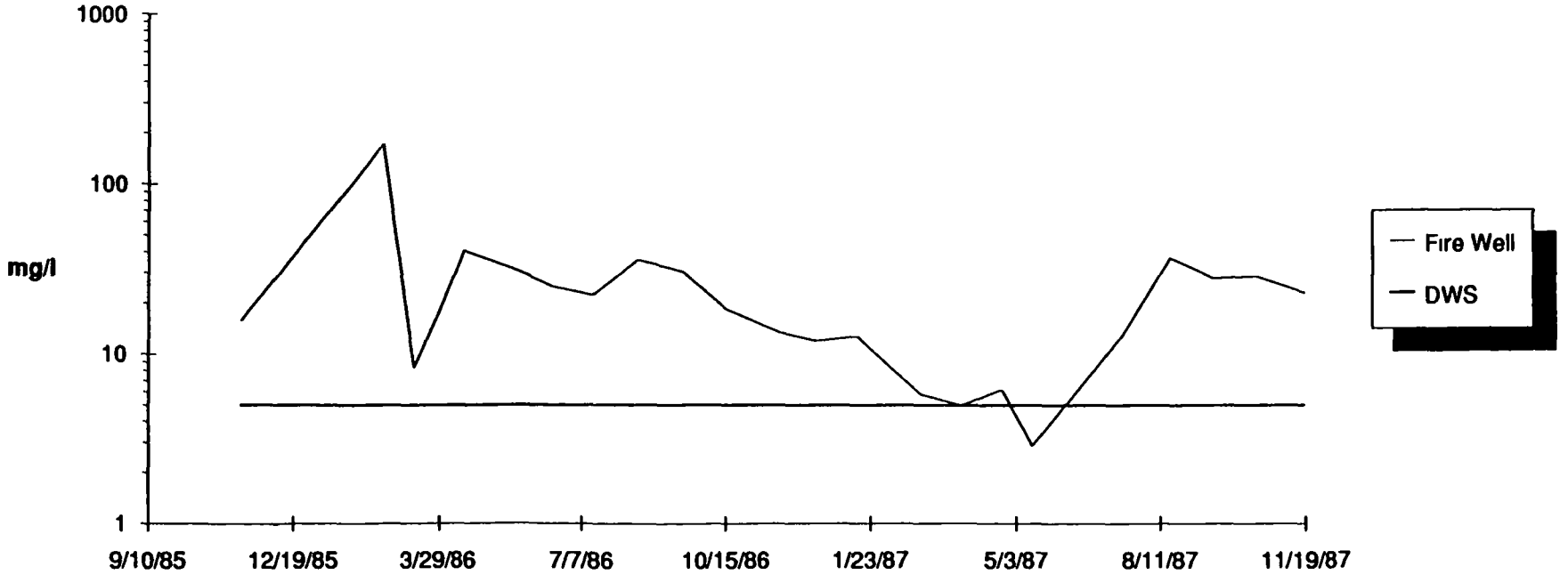


Figure 4 3-3c
Time vs Iron
On-Site Monitoring Wells
Screened in Aquifer
Lindsay Mfg Co

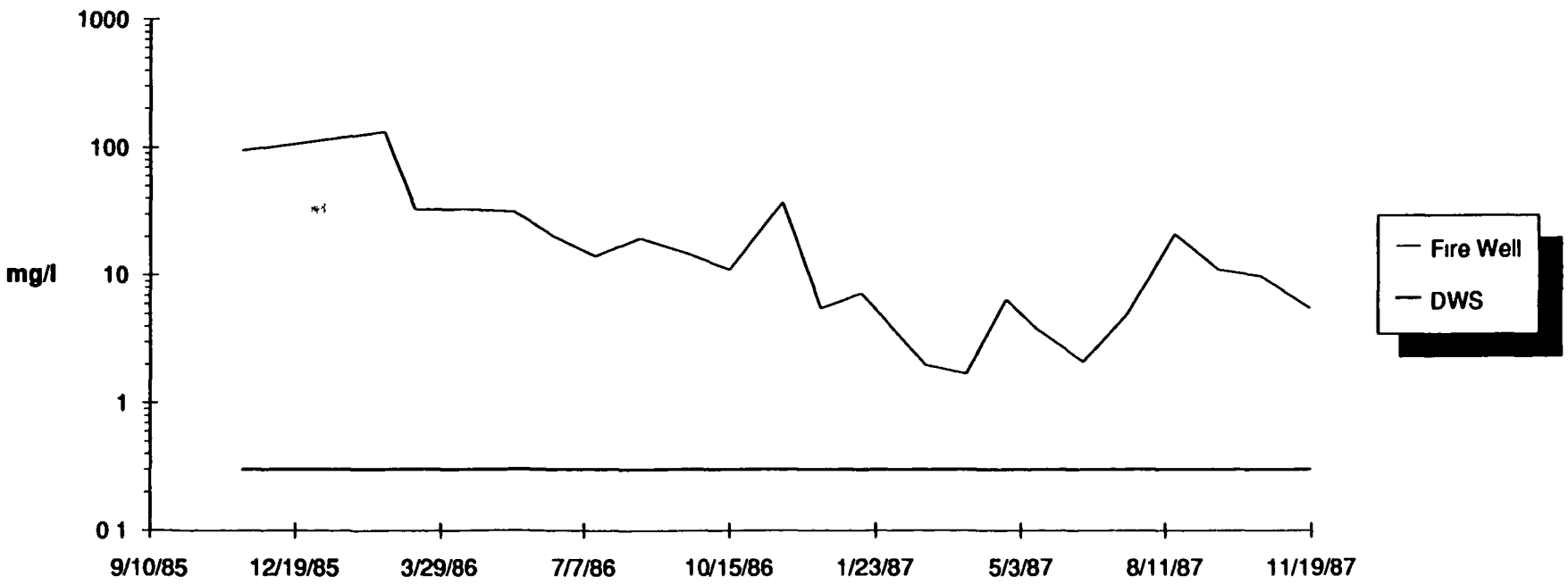


Figure 4 3-3d
Time vs Sulfate
On-Site Monitoring Wells
Screened in Aquifer
Lindsay Mfg Co

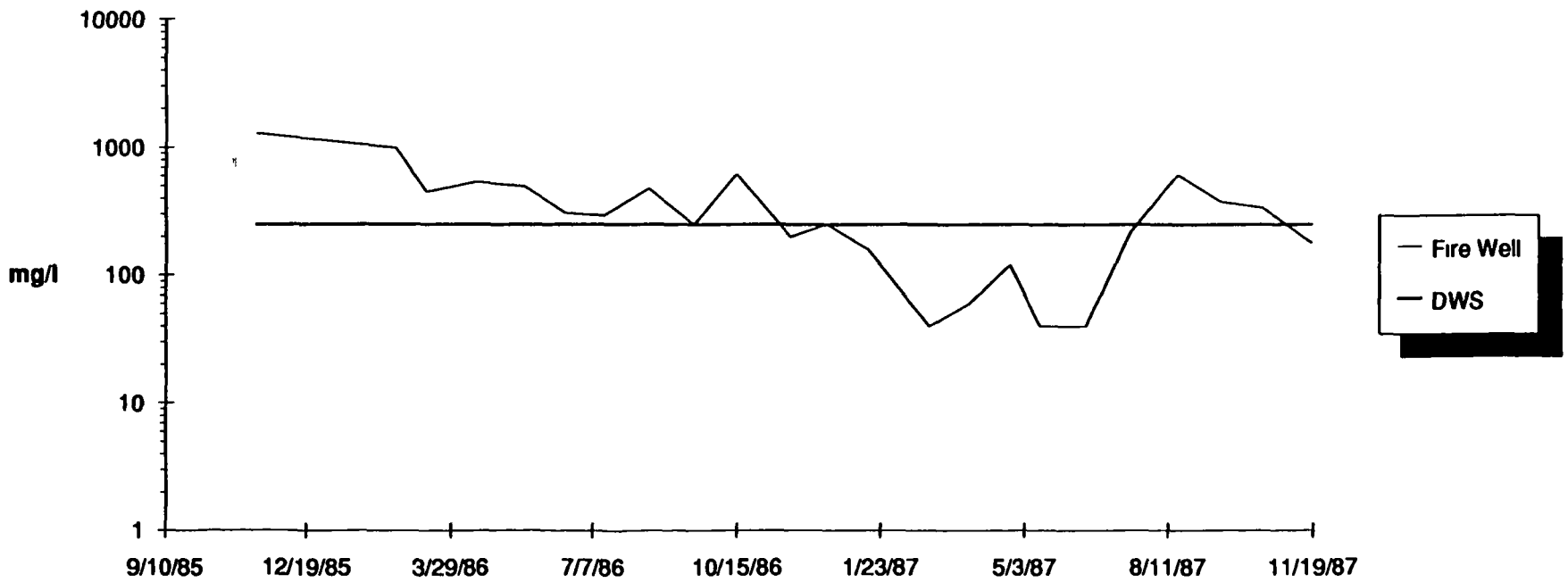
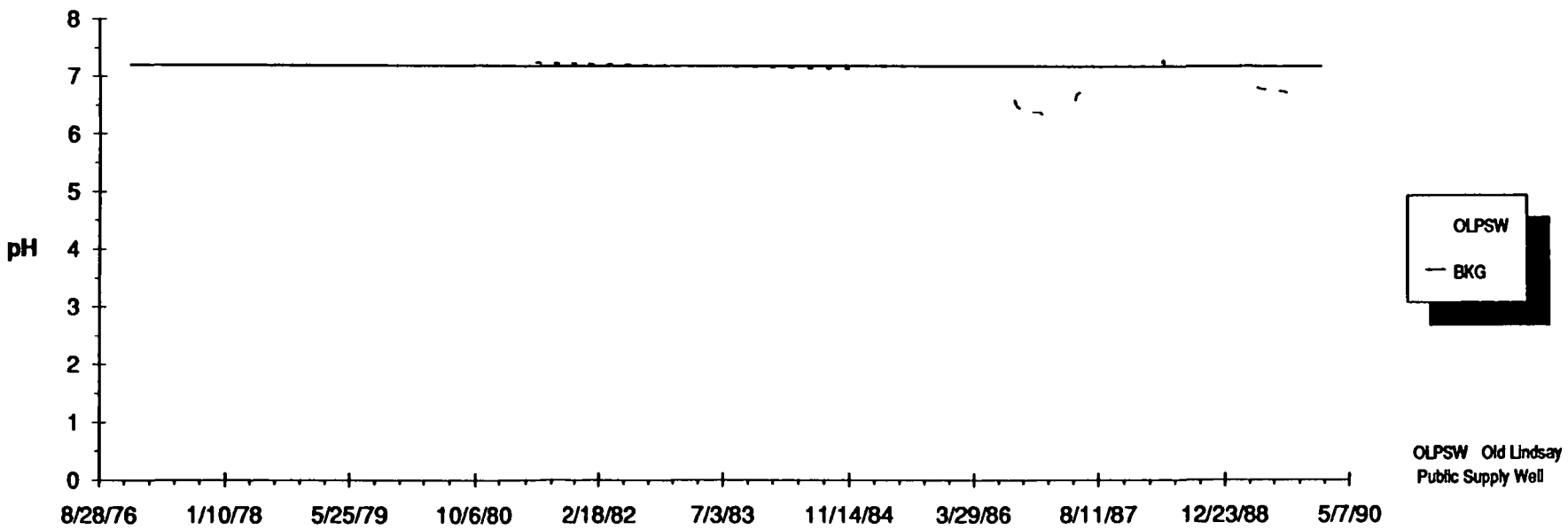


Figure 4 3-4a
Time vs pH
Off-Site Monitoring Well
Old Lindsay Public Supply Well
Screened in Aquifer
Lindsay Mfg Co



16 mg/l to 90 mg/l Zinc iron and sulfate levels for this time period are presented in Figure 4 3-4b Zinc and sulfate concentrations were below the SDWS for these elements Iron levels periodically exceeded the SDWS

Cadmium chromium and lead results reported in the Old Lindsay Public Supply Well were either undetected or below PDWS for these elements Barium manganese mercury selenium and silver were monitored in this well on January 14 1986 only Manganese (0 03 mg/l) was the only element detected

Summary

The presence of acidic pH levels and elevated concentrations of zinc iron and sulfate occurred on site in the upper portion of the aquifer (as indicated by the inorganic results of facility wells 82-1M 82-3M and 82-4M) between May 1983 and August 1987 These wells are located northwest and southeast of the pit Lindsay s site investigations have found that the acidic metal-laden ground water at these locations was the result of acidic metals in the perched sand channel which drained via the high permeability gravel packs following the installation of three facility monitoring wells (82-1M 82-3M and 82-4M) that punctured the confining clay layer beneath the sand channel The inorganic data collected during this time indicates that ground-water quality monitored in facility well 82-2M remained at background conditions This well did not penetrate the sand channel and could only receive metals dispersed upwards from the lower aquifer or laterally from the other three wells

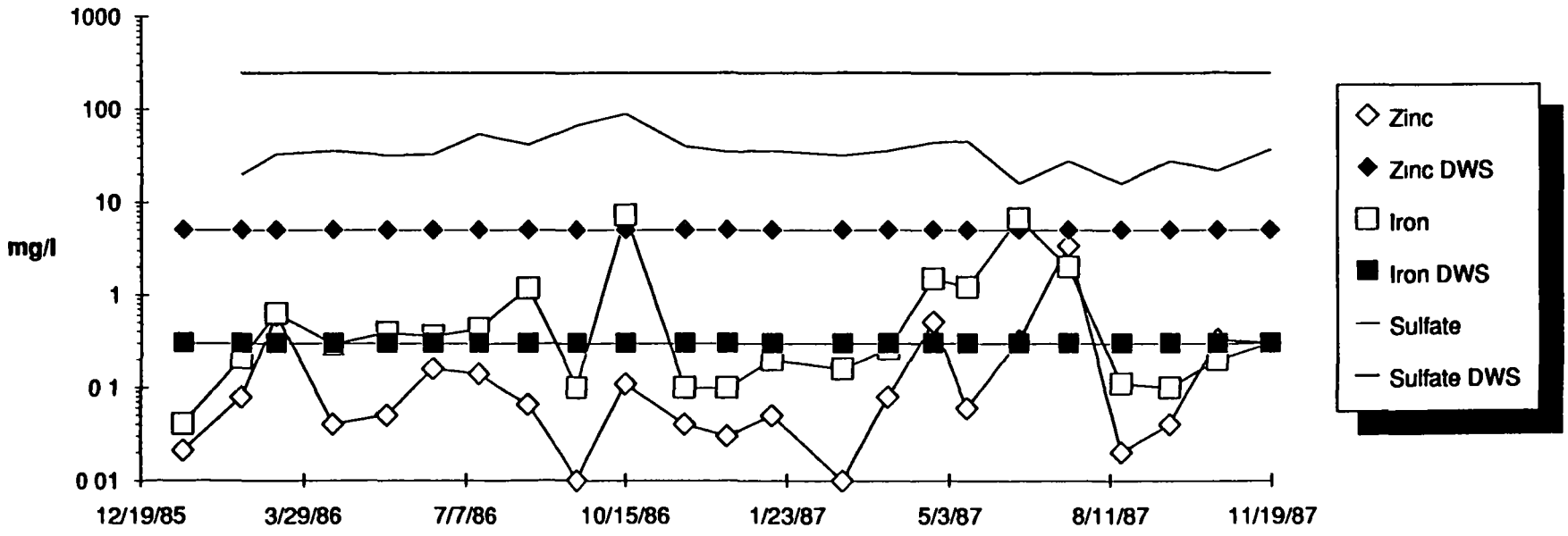
The inorganic data collected between May 5 1983 and November 18 1987 indicates that the acidic contaminants migrated to the bottom of the aquifer as indicated by the low pH levels observed in the Old Well P-1 and P-9 PH levels in the Old Well decreased from 7 2 SU on December 16 1981 to 2 6 SU on January 17 1983 thirty days after installation of the 82M series wells PH levels generally increased to background conditions in the Old Well P-1 and P-9 by November 18 1987

Off-site inorganic ground-water quality (Old Lindsay Public Supply well) remained at background conditions between May 5 1983 and November 18 1987

4 3 2 2 November 1987 to September 1988

A total of 23 onsite monitoring well locations and 12 off-site locations were included in the ground-water monitoring program between November 23 1987 and September 13 1988 (Table 4 3-2) Well locations are provided in Figure 1 2-4 Ground-water samples were collected from select wells at various dates during this period and are listed in Appendix XI-D Ground- water samples were collected in duplicate on March 4 1988 by HWS and sent to two independent

Figure 4 3-4b
Time vs Zinc, Iron, Sulfate
Off-Site Monitoring Well
Old Lindsay Public Supply Well
Screened in Aquifer
Lindsay Mfg Co



laboratories (A&L Labs or Wilson Laboratories) for inorganic analyses Samples were also analyzed by HWS This section does not address issues related to interlaboratory comparative duplicate sample results or field sample duplicate variability The highest individual sample concentration reported within duplicate sample analyses was selected for use in the following discussion

On-Site Ground Water Quality

Upper Portion of the Aquifer

On-site monitoring well 82-2M was the only on-site monitoring well screened in the upper portion of aquifer included in the ground-water monitoring program during this period Ground water was monitored at this location on December 22 1987 monthly from March 4 to June 21 1988 and on September 13 1988

Field pH levels measured in 82-2M ranged from 6 1 SU to 7 5 SU (Figure 4 3-5a) The pH levels in 82-2M were within background pH levels The distribution of field pH values on December 1987 is shown in Figure 4 3-5b

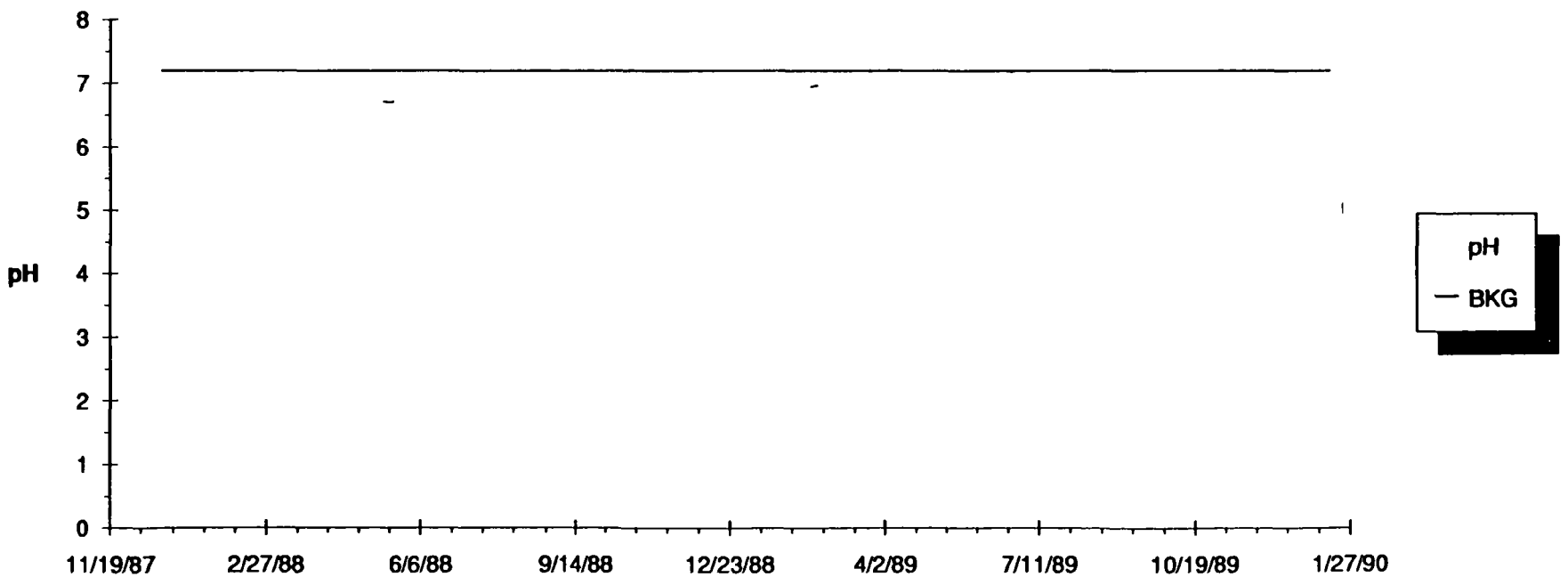
Specific conductivity levels measured in 82-2M during this period ranged from 670 umhos/cm to 1325 umhos/cm which are below the SDWS (1600 umhos/cm)

Zinc concentrations in 82-2M ranged from 0 01 mg/l to 0 22 mg/l iron concentrations ranged from 0 03 mg/l to 0 27 mg/l and sulfate concentrations ranged from 24 mg/l to 36 mg/l (Figure 4 3-5c) Zinc iron and sulfate levels reported in 82-2M were below or at the SDWS for these elements Isoconcentration maps of zinc iron and sulfate occurrence in the aquifer in December 1987 are provided in Figures 4 3-5d 4 3-5e and 4 3-5f respectively

Lower Portion of the Aquifer

On-site monitoring wells screened in the lower portion of aquifer included piezometers P-1 through P-9 monitoring wells MW87-7 and MW87-8 and temporary monitoring wells TMW88-3 TMW88-4 TMW88-5 and TMW88-9 (Table 4 3-2) Ground-water samples were collected from these locations at various monitoring dates between November 23 1987 and September 13 1988 (Appendix XI-C) Two ground-water samples were collected from MW87-7 and MW87-8 and MW87-6 on November 23 1987 one in the upper portion of the aquifer and one in the lower portion of the aquifer and were analyzed for inorganic parameters by HWS The results of these samples did not indicate a significant difference in elemental concentrations between the upper portion and lower portion of the aquifer in these wells

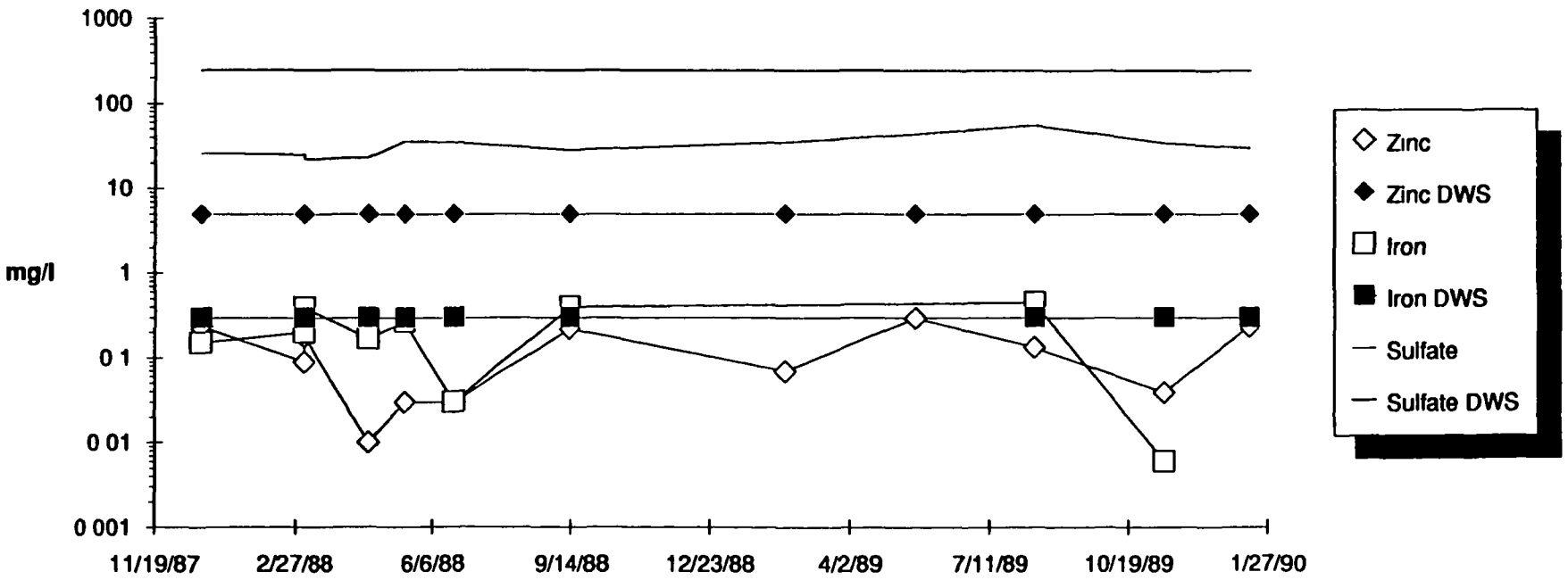
Figure 4 3-5a
Time vs pH
On-Site Monitoring Well (82-2M)
Screened in Upper Portion of Aquifer
Lindsay Mfg Co

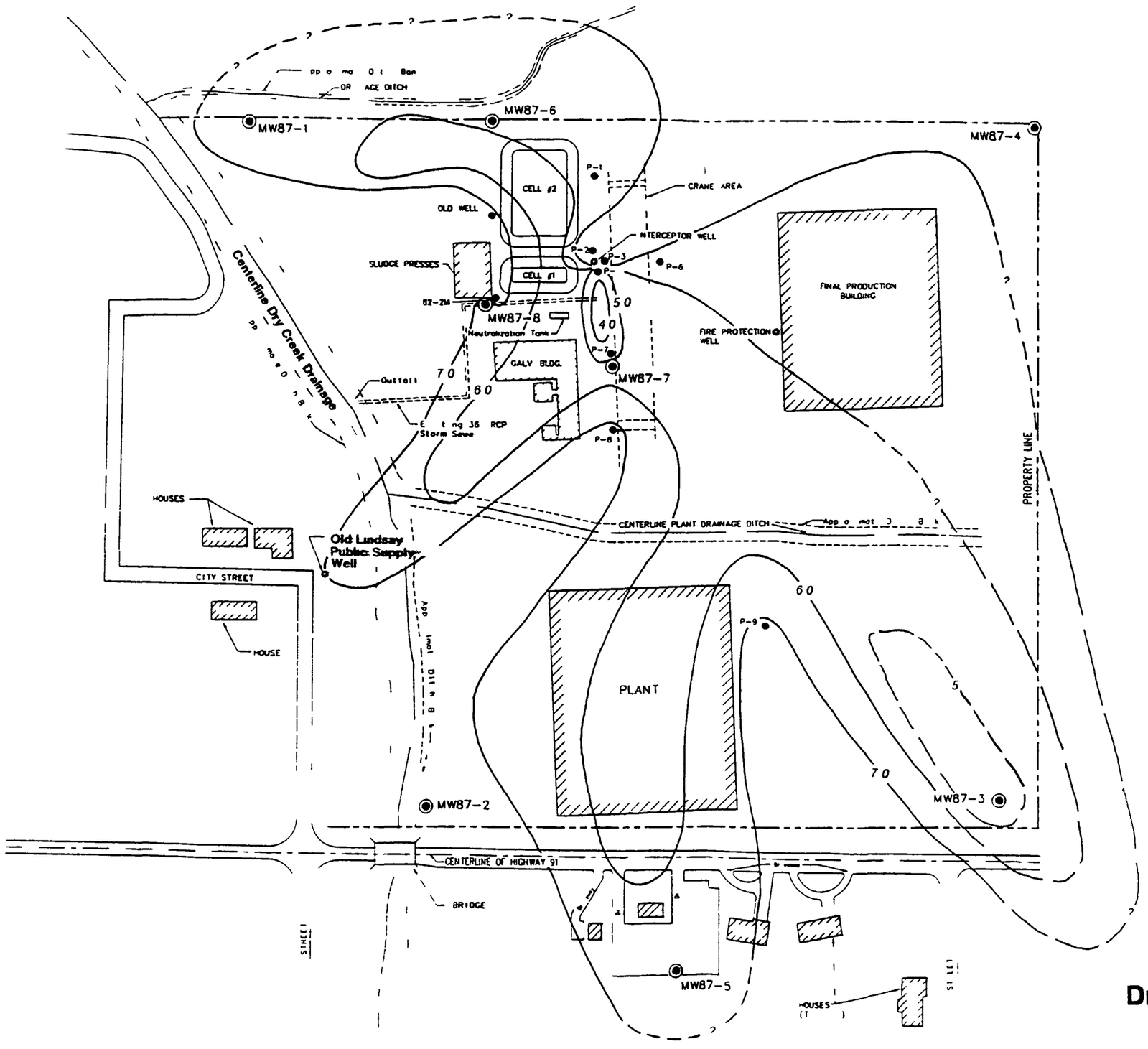


Job Number 16657 002 005

Dames & Moore

Figure 4 3-5c
Time vs Zinc, Iron, Sulfate
On-Site Monitoring Well (82-2M)
Screened in Upper Portion of Aquifer
Lindsay Mfg Co





N

0 50 00 50

SCALE

LEGEND

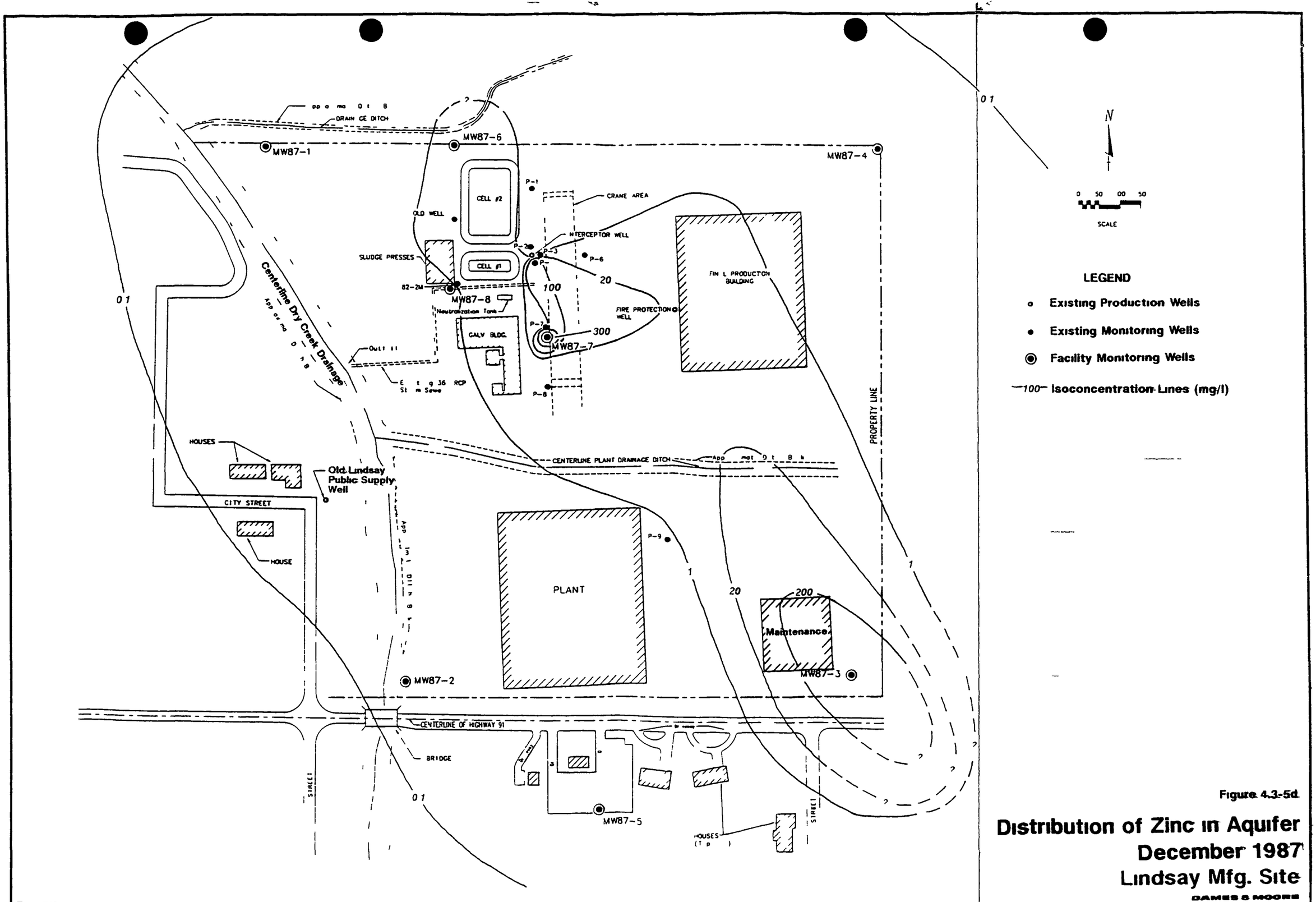
- o Existing Production Wells
- • Existing Monitoring Wells
- ◉ Facility Monitoring Wells
- —40— Field pH Contour (Standard Units)

Figure 4 3-5b

Distribution of Field pH in Aquifer
December 1987
Lindsay Mfg. Site

DAMES & MOORE

Rev 2/28/90

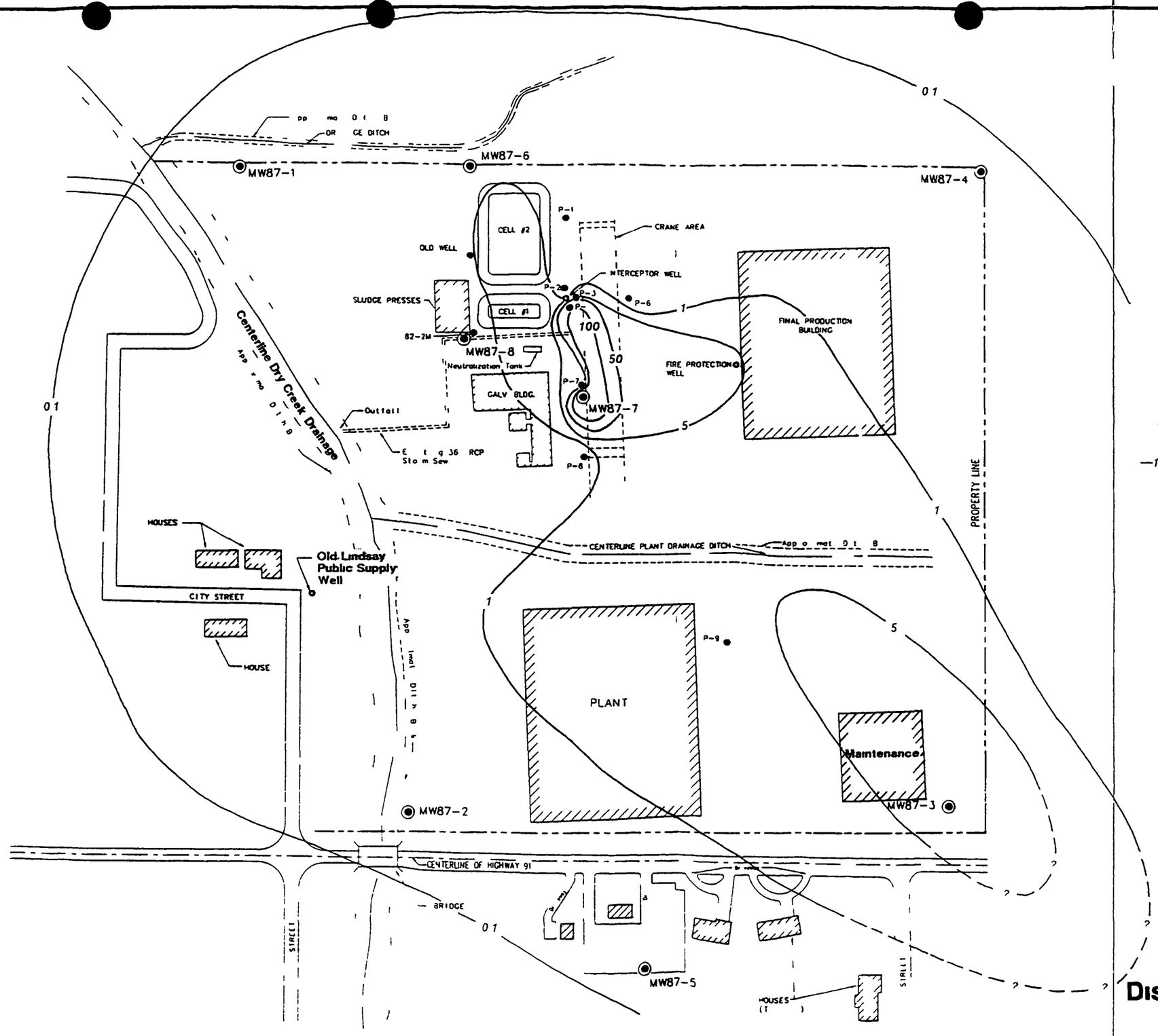


Rev 2/28/90

Figure 4.3-5d

Distribution of Zinc in Aquifer December 1987 Lindsay Mfg. Site

DAMES & MOORE



N

0 50 00 50

SCALE

LEGEND

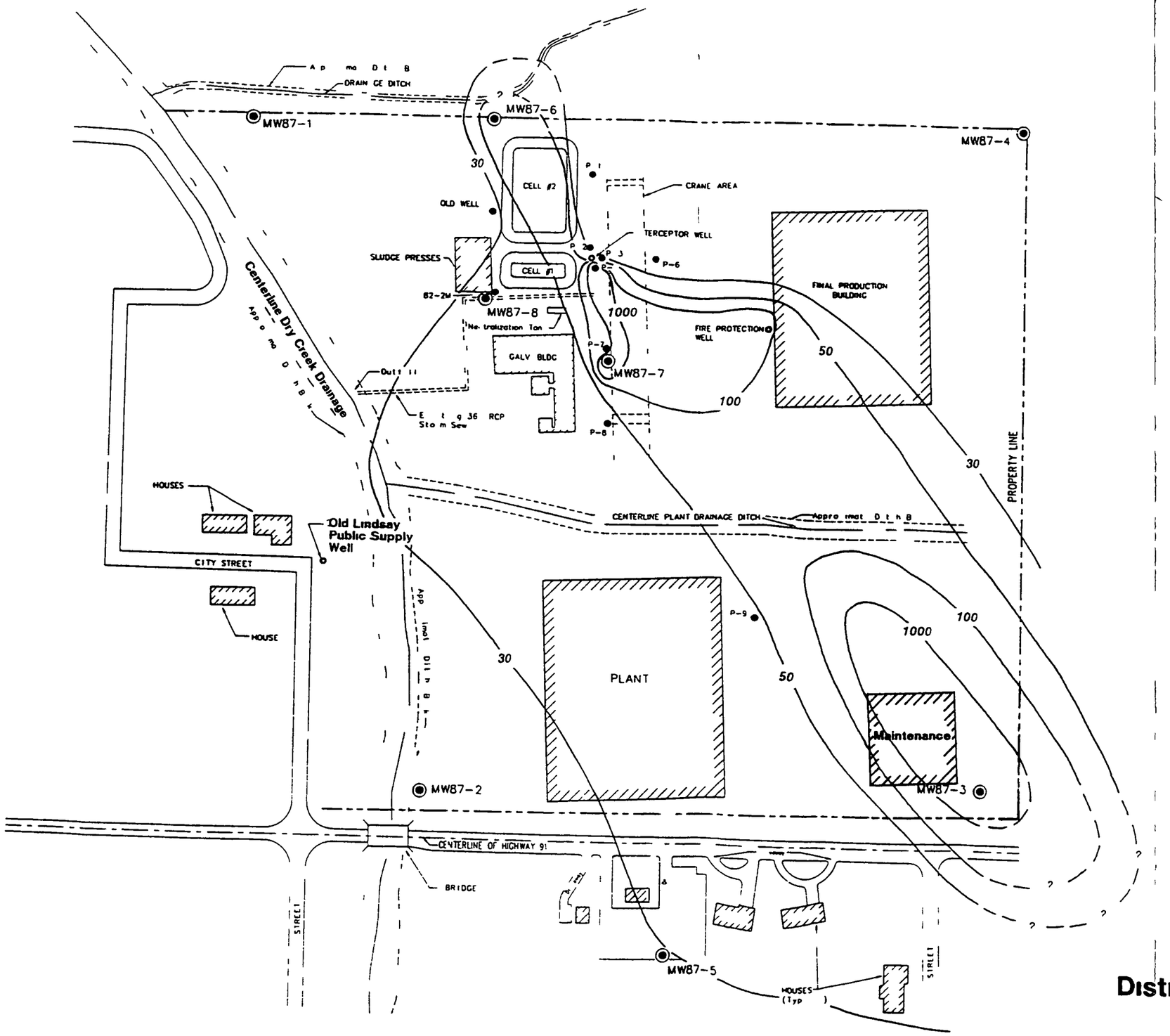
- Existing Production Wells
- Existing Monitoring Wells
- Facility Monitoring Wells
- —100— Isoconcentration Lines (mg/l)

Figure 4.3-5e

Distribution of Iron in Aquifer December 1987 Lindsay Mfg. Site

DAMES & MOORE

Rev 2/28/90



N

0 50 100 50

SCALE

LEGEND

- Existing Production Wells
- Existing Monitoring Wells
- Facility Monitoring Wells
- —100— Isoconcentration Lines (mg/l)

Figure 4 3-5f

Distribution of Sulfate in Aquifer
December 1987
Lindsay Mfg Site

DAMES & MOORE

Rev 2/28/90

Field pH levels measured in P-1 P-6 P-9 and MW87-8 ranged from 6 2 SU to 7 9 SU Field pH levels measured in TMW88-3 TMW88-4 TMW88-5 TMW88-9 and MW87-7 ranged from 3 8 SU to 7 0 SU Time versus pH levels measured in P-1 P-6 P-9 TMW88-5 and MW87-7 are provided in Figure 4 3-6a The pH levels reported in P-1 P-6 and P-9 were near background levels which is consistent with the levels measured from August 1987 (Figure 4 3-2a) The pH levels measured in TMW88-3 TMW88-4 TMW88-5 TMW88-9 and MW87-7 were generally acidic These wells are located southeast of the former acid disposal pit (Figure 1 2-4) Between June 21 1988 and September 13 1988 a significant increase in pH from 3 9 SU to 7 0 SU was observed (Figure 4 3-6a)

Specific conductivity levels measured in P-1 P-6 P-9 and MW87-8 ranged from 540 umhos/cm to 1 600 umhos/cm which are at or below the SDWS (1600 umhos/cm) Specific conductivity levels measured in TMW88-3 TMW88-4 TMW88-5 TMW88-9 and MW87-7 ranged from 660 umhos/cm to 5 500 umhos/cm The presence of elevated specific conductivity levels (greater than the SDWS) in these wells coincides with the low pH levels described above

Zinc concentrations reported in P-1 P-6 P-9 and MW87-8 ranged from 0 1 mg/l to 2 19 mg/l which is below the SDWS (5 0 mg/l) Zinc concentrations reported in TMW88-3 TMW88-4 TMW88-5 TMW88-9 and MW87-7 ranged from 9 7 mg/l to 654 mg/l which are well above the SDWS Zinc levels reported in P-1 P-6 P-9 TMW88-5 and MW87-7 during this period are depicted in Figure 4 3-6b Elevated zinc levels coincide with elevated pH and specific conductivity levels measured in TMW88-3 TMW88-4 TMW88-5 TMW88-9 and MW87-7 during this period

Iron concentrations reported in P-1 P-6 P-9 and MW87-8 ranged from undetected to 1 7 mg/l and were below or slightly above the SDWS (0 3 mg/l) Iron concentrations reported in TMW88-3 TMW88-4 TMW88-5 TMW88-9 and MW87-7 ranged from 5 5 mg/l to 660 mg/l which are above the SDWS Iron levels reported in P-1 P-6 P-9 TMW88-5 and MW87-7 during this period are plotted in Figure 4 3-6c

Sulfate concentrations reported in P-1 P-6, P-9 and MW87-8 ranged from 15 mg/l to 75 mg/l which were below the SDWS (250 mg/l) Sulfate concentrations reported in TMW88-3 TMW88-4 TMW88-5 TMW88-9 and MW87-7 ranged from 370 mg/l to 3 300 mg/l which are above the SDWS Sulfate levels reported in P-1 P-6 P-9 TMW88-5 and MW87-7 are plotted in Figure 4 3-6d A gradual decrease in sulfate concentration in MW87-7 was observed during this period

Cadmium concentrations reported in TMW88-5 (0 1 mg/l) TMW88-3 (0 06 mg/l) and TMW88-4 (0 06 mg/l) exceeded the PDWS (0 01 mg/l) Lead concentrations reported in TMW88-5 (0 31 mg/l) and TMW88-3 (0 21 mg/l) also exceeded the PDWS (0 05 mg/l) Chromium was

Figure 4 3-6a
Time vs pH
On-Site Monitoring Wells
Screened in Lower Portion of Aquifer
Lindsay Mfg Co

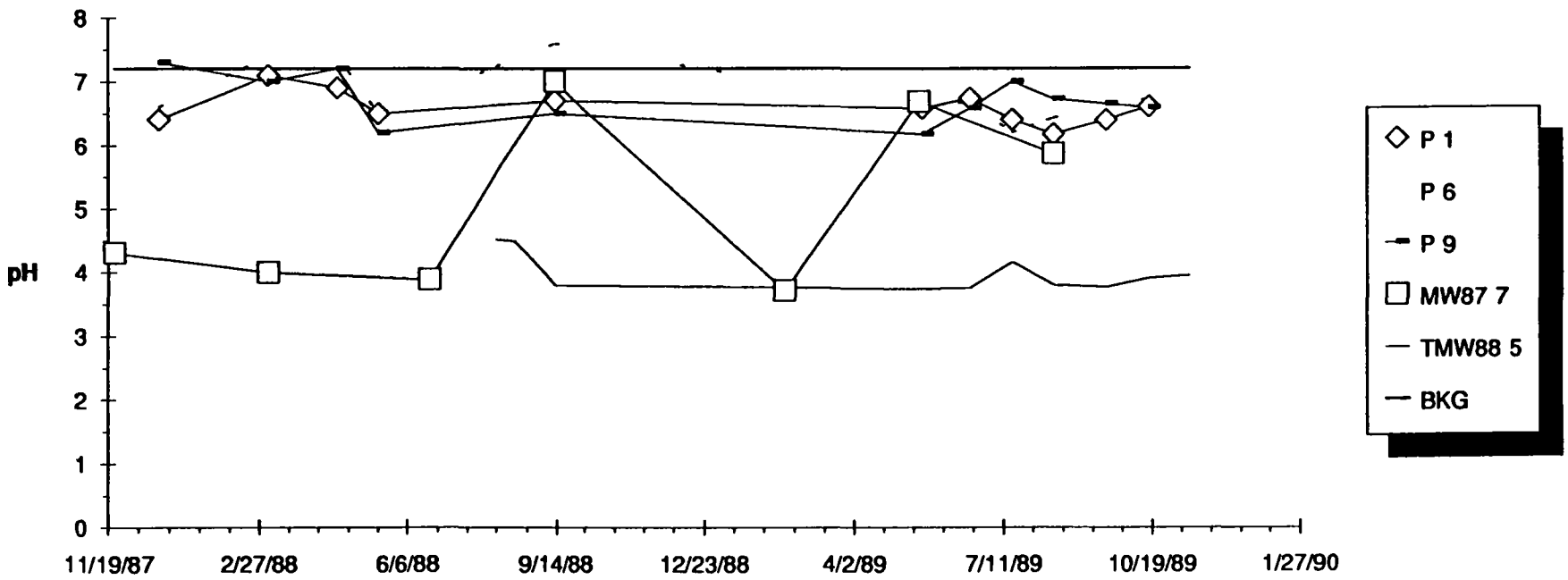


Figure 4 3-6b
Time vs Zinc
On-Site Monitoring Wells
Screened in Lower Portion of Aquifer
Lindsay Mfg Co

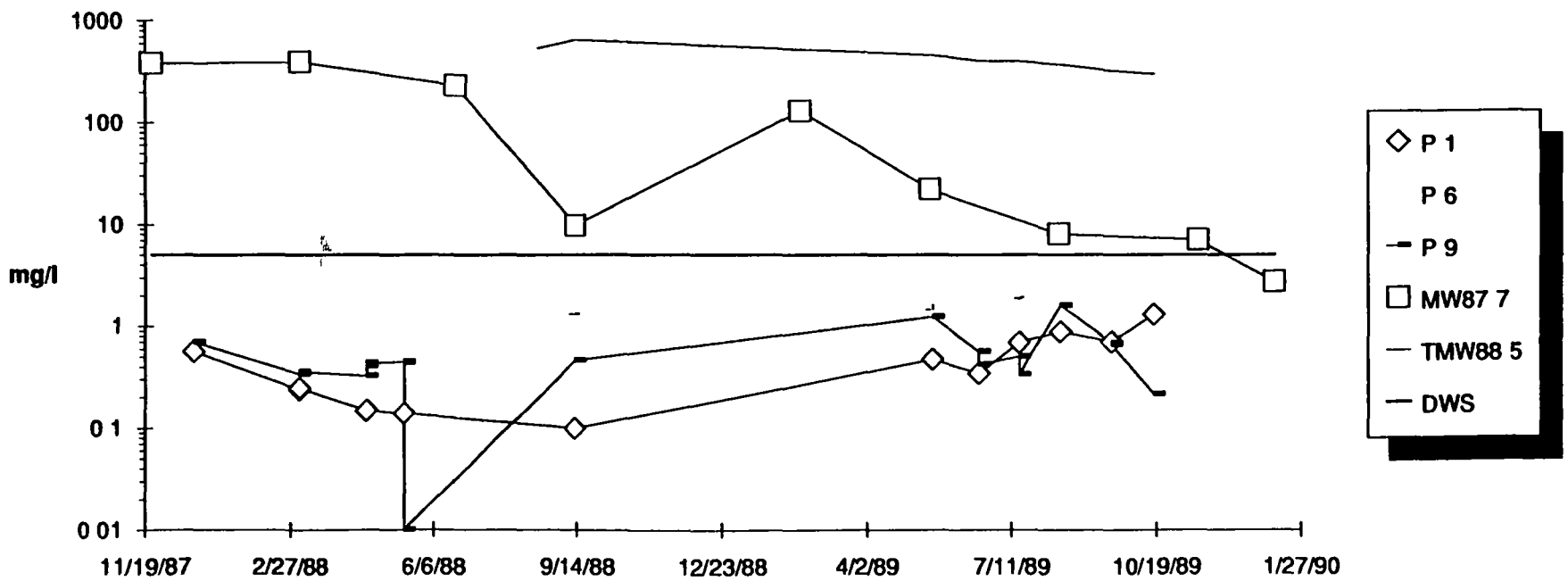


Figure 4 3-6c
Time vs Iron
On-Site Monitoring Wells
Screened in Lower Portion of Aquifer
Lindsay Mfg Co

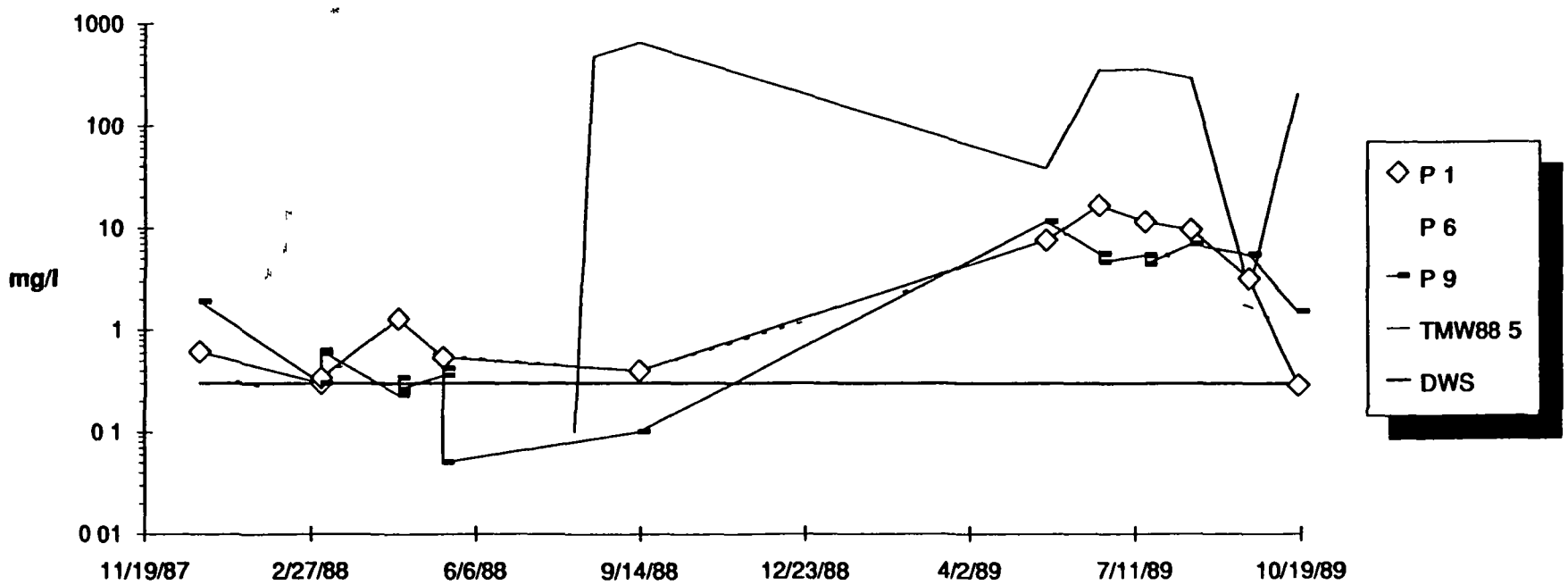


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Figure 4 3-6d
Time vs Sulfate
On-Site Monitoring Wells
Screened in Lower Portion of Aquifer
Lindsay Mfg Co

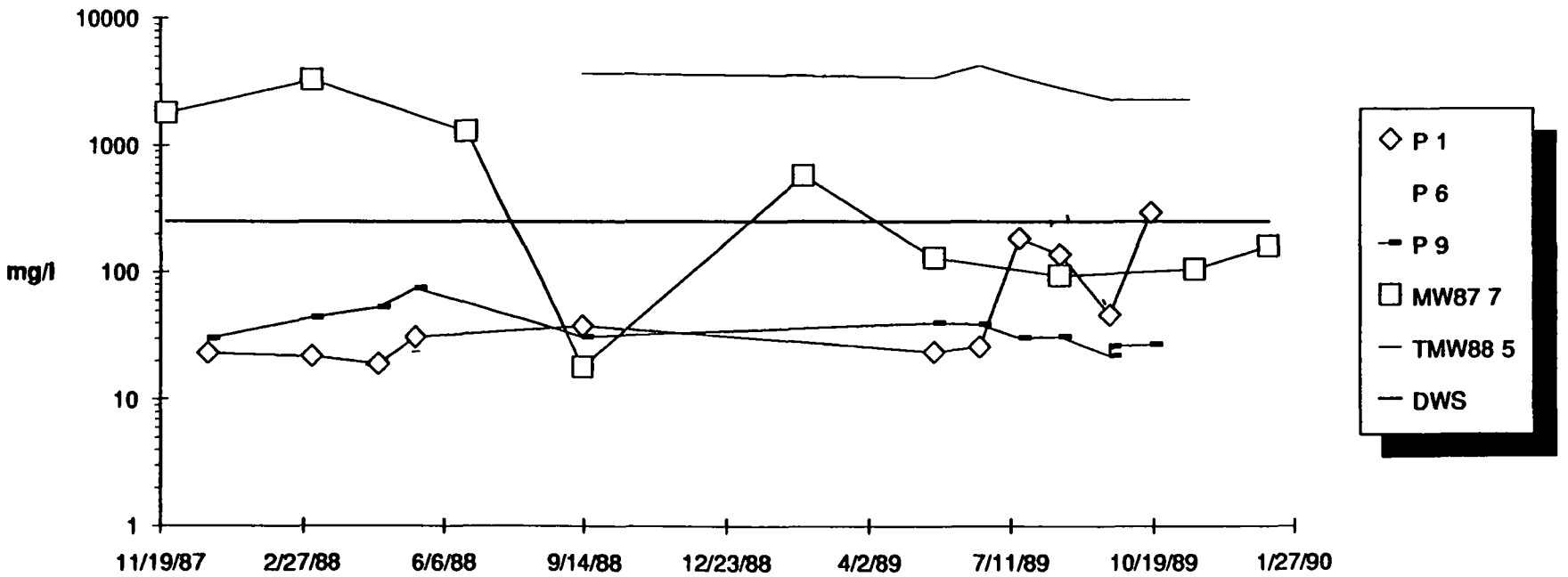


Table 4 3-4

Summary of Select Inorganic Results in On-Site Aquifer

November 23,1987

Monitoring Well	Sample Location in Well	Field pH	Field Specific Conductance	Zinc mg/l	Iron mg/l	Sulfate mg/l
MW87 2	Upper	6 9	630	0 6	0 1	35
	Lower	7 0	650	0 63	5 00	24
MW87 3	Upper	6 9	975	2 1	1 6	60
	Lower	7 0	2710(4800)	250(430)	5 5(360)	1700(3600)
MW87 5	Upper	6 8	780	0 9	0 2	24
	Lower	6 8	755	1 2	5 6	47
Secondary Drinking Water Standard		7.2a	1600	0 05	0 05	250

Note

Sample result from March 4 1988

(a) Background

the level reported on November 23 1988 There were no significant differences noted in specific conductivity levels reported in MW87-2 and MW87-5 (Table 4 3-4)

Zinc concentrations reported in MW87-1 MW87-2 MW87-4 and MW87-6 ranged from 0 01 mg/l to 7 6 mg/l which are near or below the SDWS (5 0 mg/l) Zinc concentrations reported in the Fire Well and MW87-3 ranged from 0 63 mg/l to 252 mg/l Time versus zinc concentrations reported in the Fire Well MW87-3 and MW87-6 are provided in Figure 4 3-7b Zinc concentrations reported in MW87-3 on November 23 1987 in the upper and lower portion of the aquifer indicate a significant difference in concentration from 2 1 mg/l to 250 mg/l (Table 4 3-4) The zinc level reported in MW87-3 on March 4 1988 (430 mg/l) indicates an increase in zinc concentration at the bottom of the aquifer at this well as compared to the concentration reported on November 23 1988 There were no significant differences noted in zinc concentrations reported in MW87-2 and MW87-5 (Table 4 3-4) An isoconcentration map of zinc occurrence during December 1987 is presented in Figure 4 3-5d

Iron concentrations reported in the Fire Well MW87-1 MW87-2 MW87-3 MW87-4 and MW87-6 ranged from 0 1 mg/l to 159 mg/l with the highest individual iron concentration detected in MW87-3 Time versus iron concentrations reported in the Fire Well MW87-3 and MW87-6 are provided in Figure 4 3-7c Iron concentrations reported in the upper and lower portion of the aquifer in MW87-2 MW87-3 and MW87-5 indicate that higher iron concentrations existed in the lower portion of the aquifer as compared to the concentrations reported in the upper portion in these wells (Table 4 3-4) The iron concentration reported in MW87-3 on March 4 1988 (360 mg/l) indicates a higher iron concentration at the bottom of the aquifer at this well as compared to the iron concentration reported on November 23 1988 (Table 4 3-4) An isoconcentration map of iron occurrence during December 1987 is presented in Figure 4 3-5e

Sulfate concentrations reported in the Fire Well MW87-1 MW87-2 MW87-3 MW87-4 and MW87-6 ranged from 11 mg/l to 1 500 mg/l with the highest individual sulfate concentration detected in MW87-3 (Figure 4 3-7d) In general sulfate concentrations were below the SDWS (250 mg/l) with the exception of MW87-3 which exceeded the SDWS at various dates during this period Sulfate concentrations reported in the upper and lower portion of the aquifer in MW87-3 indicate elevated sulfate conditions existed in the lower portion of the aquifer as compared to the concentrations reported in the upper portion (Table 4 3-4) The sulfate level in MW87-3 reported on March 4 1988 (3 600 mg/l) indicates a significant increase in sulfate concentration at the bottom of the aquifer at this well as compared to the sulfate concentration reported on November 23 1988 (Table 4 3-4) An isoconcentration map of sulfate occurrence during December 1987 is presented in Figure 4 3-5d

Chromium (0 06 mg/l) and lead (0 15 mg/l) reported in MW87-3 exceeded the PDWS (0 05 mg/l and 0 01 mg/l respectively) for these elements With the exception of the occurrence of the

Figure 4 3-7b
Time vs Zinc
On-Site Monitoring Wells
Screened in Aquifer
Lindsay Mfg Co

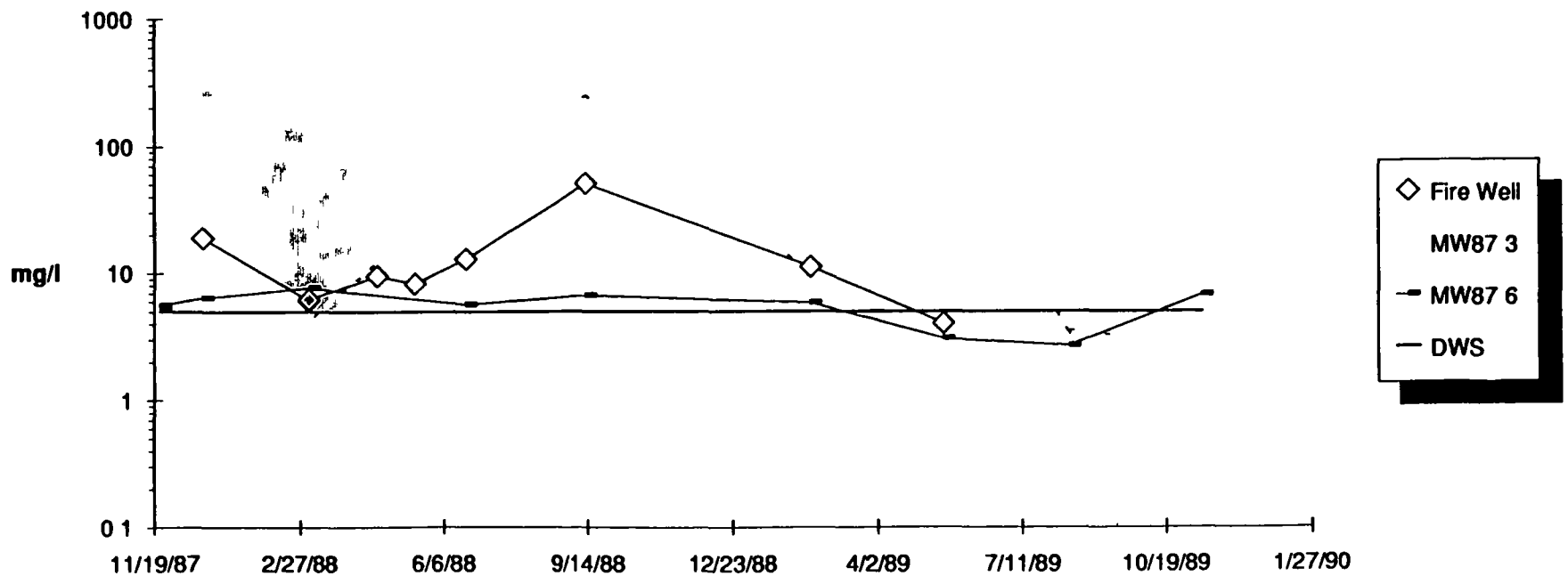


Figure 4 3-7c
Time vs Iron
On-Site Monitoring Wells
Screened in Aquifer
Lindsay Mfg Co

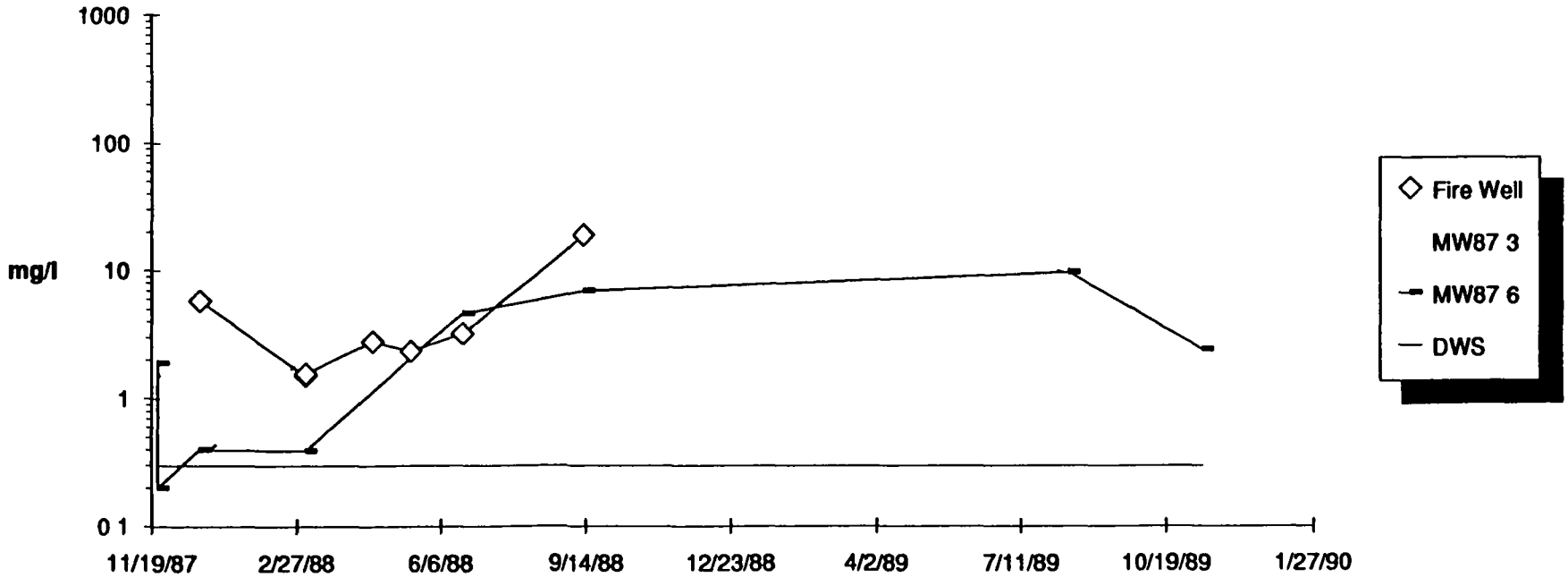
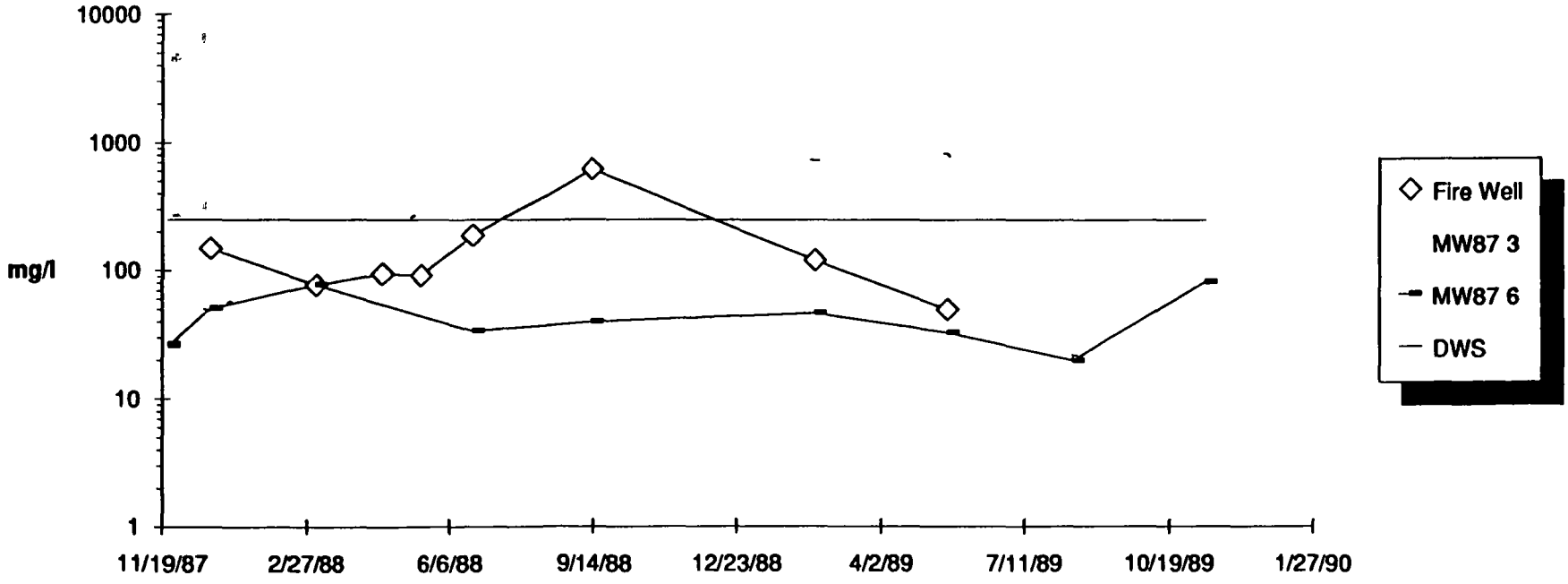


Figure 4 3-7d
Time vs Sulfate
On-Site Monitoring Wells
Screened in Aquifer
Lindsay Mfg Co



elements listed above cadmium chromium lead manganese barium selenium mercury and silver concentrations reported in these wells were either not detected or below the PDWS or SDWS associated with these metals

Off-Site Ground-Water Quality

Lower Portion of Aquifer

Six temporary wells irrigation well 54278 and irrigation well 33637 were monitored between November 18 1987 and September 13 1988 (Table 4 3-2) Field pH levels measured in TMW88-1 TMW88-6 TMW88-7 TMW88-8 TMW88-10 TMW88-11 irrigation wells 54278 and 33637 ranged from 4 4 SU to 7 4 SU Time versus pH levels for irrigation well 54278 TMW88-6 and TMW88-7 are provided in Figure 4 3-8a The pH levels reported in irrigation well 54278 and irrigation well 33637 were at background pH levels The pH levels reported in TMW88-6 and TMW88-7 were generally acidic (<5 0 SU) during this period

Specific conductivity values in these wells ranged from 575 umhos/cm to 6 000 umhos/cm Specific conductivity values in TMW88-1 TMW88-8 TMW88-11 and irrigation wells 54278 and 33637 were at or below the SDWS Specific conductivity values in TMW88-6 TMW88-7 and TMW88-10 were above the SDWS (1600 umhos/cm)

Zinc concentrations reported in TMW88-1 TMW88-6 TMW88-7 TMW88-8 TMW88-10 TMW88-11 irrigation well 54278 and irrigation well 33637 ranged from 0 10 to 606 mg/l Time versus zinc concentrations reported in the irrigation well 54278 TMW88-6 and TMW88-7 are provided in Figure 4 3-8b Zinc concentrations reported in these wells exceeded the SDWS (5 0 mg/l) with the exception of TMW88-1 The highest zinc concentrations reported during this period were found at TMW88-7

Iron concentrations reported in TMW88-1 TMW88-6 TMW88-7 TMW88-8 TMW88-10 TMW88-11 irrigation well 54278 and irrigation well 33637 ranged from 0 1 mg/l to 750 mg/l Time versus iron concentrations reported in irrigation well 54278 TMW88-6 and TMW88-7 are provided in Figure 4 3-8c Iron concentrations were below the SDWS for TMW88-8 irrigation well 54278 and irrigation well 33637 and slightly above the SDWS in TMW88-1 Iron levels found in TMW88-6 TMW88-7 TMW88-10 and TMW88-11 were above the SDWS The highest iron levels were found in TMW88-6 (750 mg/l) and TMW88-7 (445 mg/l)

Sulfate concentrations reported in TMW88-1 TMW88-6 TMW88-7 TMW88-8 TMW88-10 TMW88-11 irrigation well 54278 and irrigation well 33637 ranged from 20 mg/l to 3 670 mg/l Time versus iron concentrations reported in irrigation well 54278 TMW88-6 and TMW88-7 are provided in Figure 4 3-8d TMW88-1 and irrigation well 33637 sulfate concentrations were below

reported in TMW88-4 only (0 06 mg/l) and was slightly above the PDWS (0 05 mg/l) Manganese concentrations reported in P-1 (3 8 mg/l) P-9 (0 24 mg/l) and TMW88-5 (100 mg/l) exceeded the SDWS (0 05 mg/l) With the exception of the occurrence of the elements listed above cadmium chromium lead manganese barium selenium mercury and silver concentrations reported in the wells during this period were either not detected or below the PDWS or SDWS associated with these metals

Aquifer

Six on-site monitoring wells screened in the aquifer were monitored during this period (Table 4 3-2) The monitoring well locations are provided in Figure 1 2-4 On November 23 1987 two ground-water samples were collected from MW87-1 through MW87-4 and MW87-6 one in the upper portion of the aquifer and one in the lower portion of the aquifer Each sample was analyzed for inorganic parameters by HWS and is listed in Appendix XI-C The inorganic sample results of MW87-1 MW87-4 and MW87-6 on this date did not indicate a significant difference in elemental concentrations between the upper portion and lower portions of the aquifer in these wells On March 4 1988 three samples were collected from MW87-3 only two from the lower portion and one in the middle portion of the aquifer The results of this sampling effort are discussed below

Field pH levels measured in the Fire Well MW87-1 through MW87-4 and MW87-6 ranged from 5 9 SU to 7 1 SU Time versus pH levels for the Fire Well MW87-3 and MW87-6 are provided in Figure 4 3-7a Time versus pH levels measured in the Fire Well Old Well MW87-3 and MW87-6 are provided in Figure 4 3-7a Table 4 3-4 lists select inorganic results of samples collected on November 23 1988 from the upper and lower portion of the aquifer at MW87-2 MW87-3 and MW87-5 The pH levels detected in the lower portion of MW87-3 (4 9 SU) were significantly lower than pH found in the upper portion (6 9 SU) (The pH value used in Figure 4 3-7a for MW87-3 on November 23 1987 is from the sample collected from the upper portion of the aquifer) There were no significant differences noted in pH levels of MW87-2 and MW87-5 (Table 4 3-4) The pH levels in Old Well Fire Well MW87-1 MW87-2 MW87-4 and MW87-6 were generally near background pH levels with the exception of the lower portion of MW87-3 The distribution of field pH values from December 1987 is shown in Figure 4 3-5b

Specific conductivity values reported in the Fire Well MW87-1 MW87-3 MW87-4 and MW87-6 ranged from 560 umhos/cm to 1 275 umhos/cm and were below the SDWS (1600 umhos/cm) Specific conductivity values reported in MW87-3 ranged from 975 umhos/cm to 4 000 umhos/cm and were above the SDWS Specific conductivity values of MW87-3 in the upper and lower portion of the aquifer indicate a significant increase in concentration from 975 umhos/cm to 2 710 umhos/cm (Table 4 3-4) The specific conductivity value reported in MW87-3 on March 4 1988 indicates higher concentration at the bottom of the aquifer as compared to

Figure 4 3-7a
Time vs pH
On-Site Monitoring Wells
Screened in Aquifer
Lindsay Mfg Co

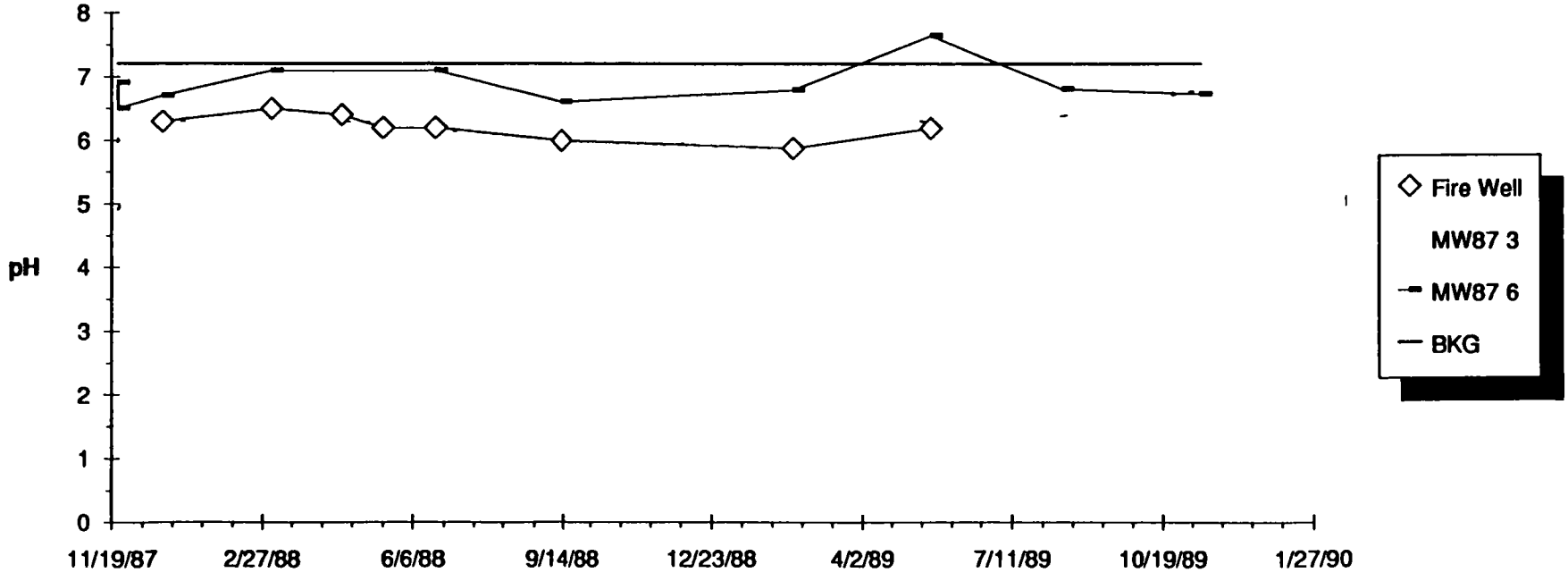


Figure 4.3-8a
Time vs. pH
Off-Site Monitoring Wells
Screened in Lower Portion of Aquifer
Lindsay Mfg. Co.

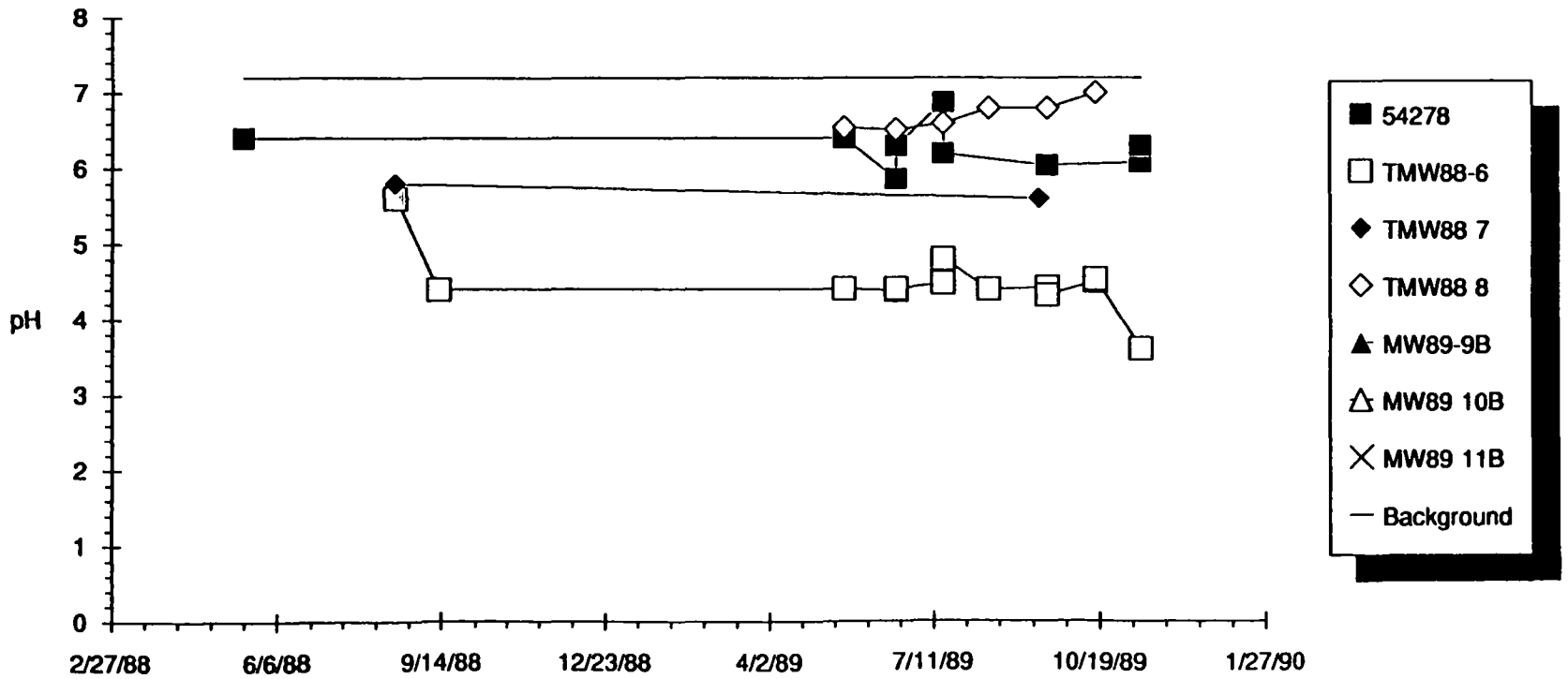


Figure 4 3-8b
Time vs. Zinc
Off-Site Monitoring Wells
Screened in Lower Portion of Aquifer
Lindsay Mfg. Co.

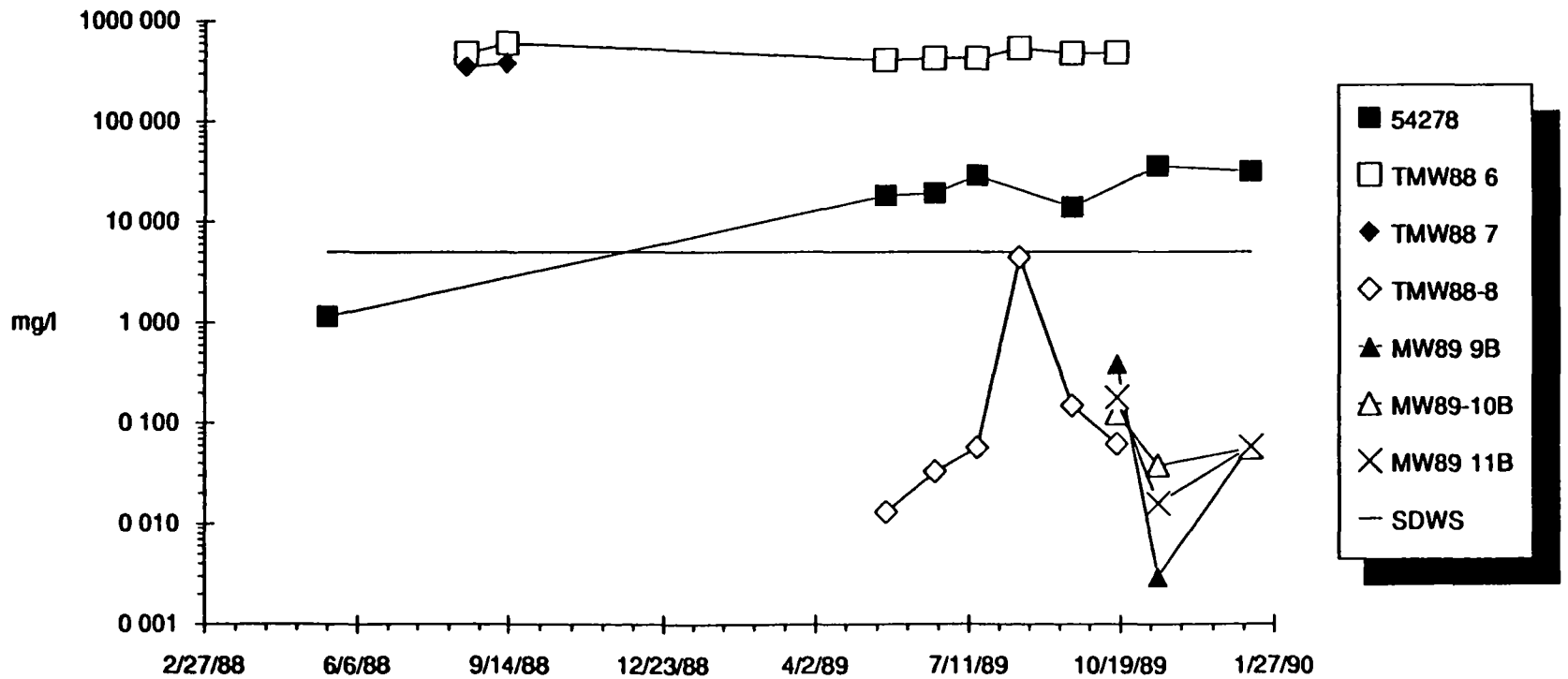


Figure 4 3-8c
Time vs Iron
Off-Site Monitoring Wells
Screened in Lower Portion of Aquifer
Lindsay Mfg. Co.

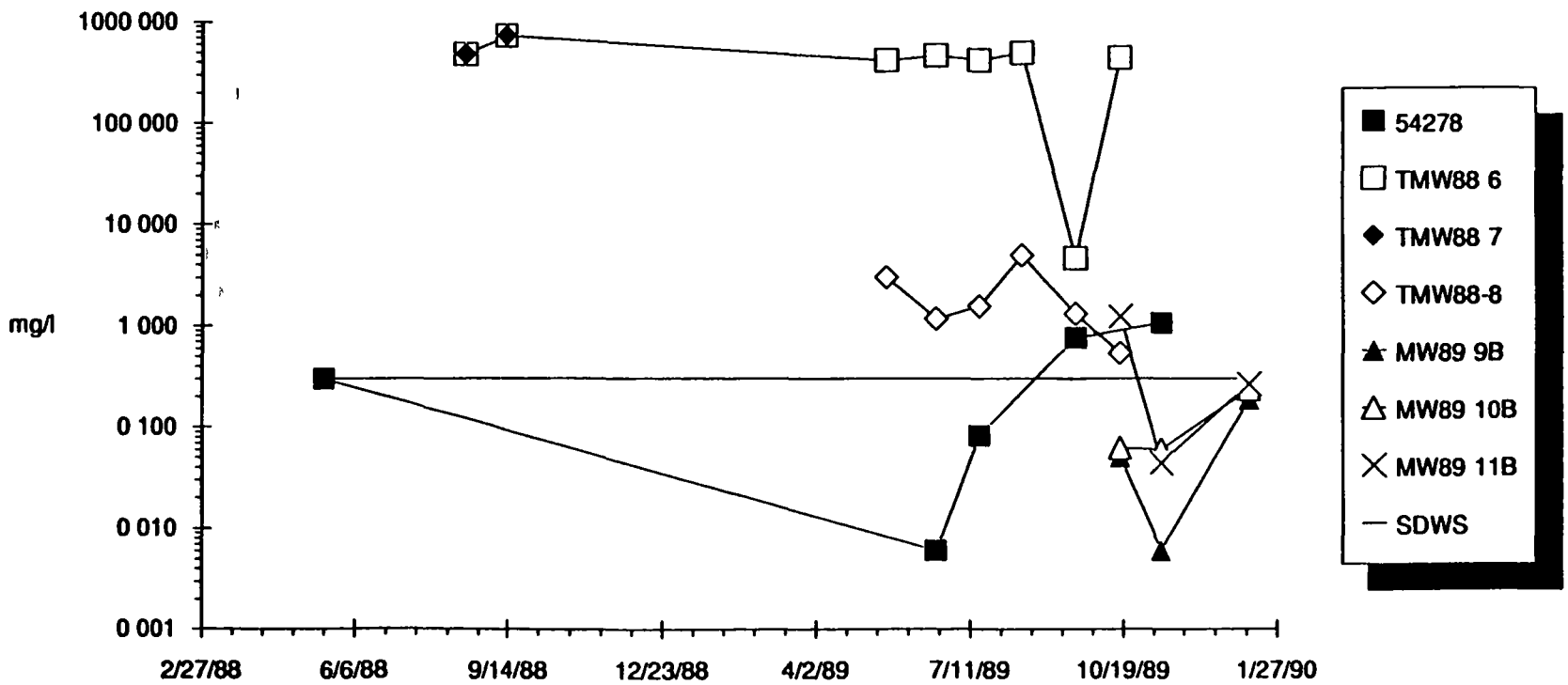
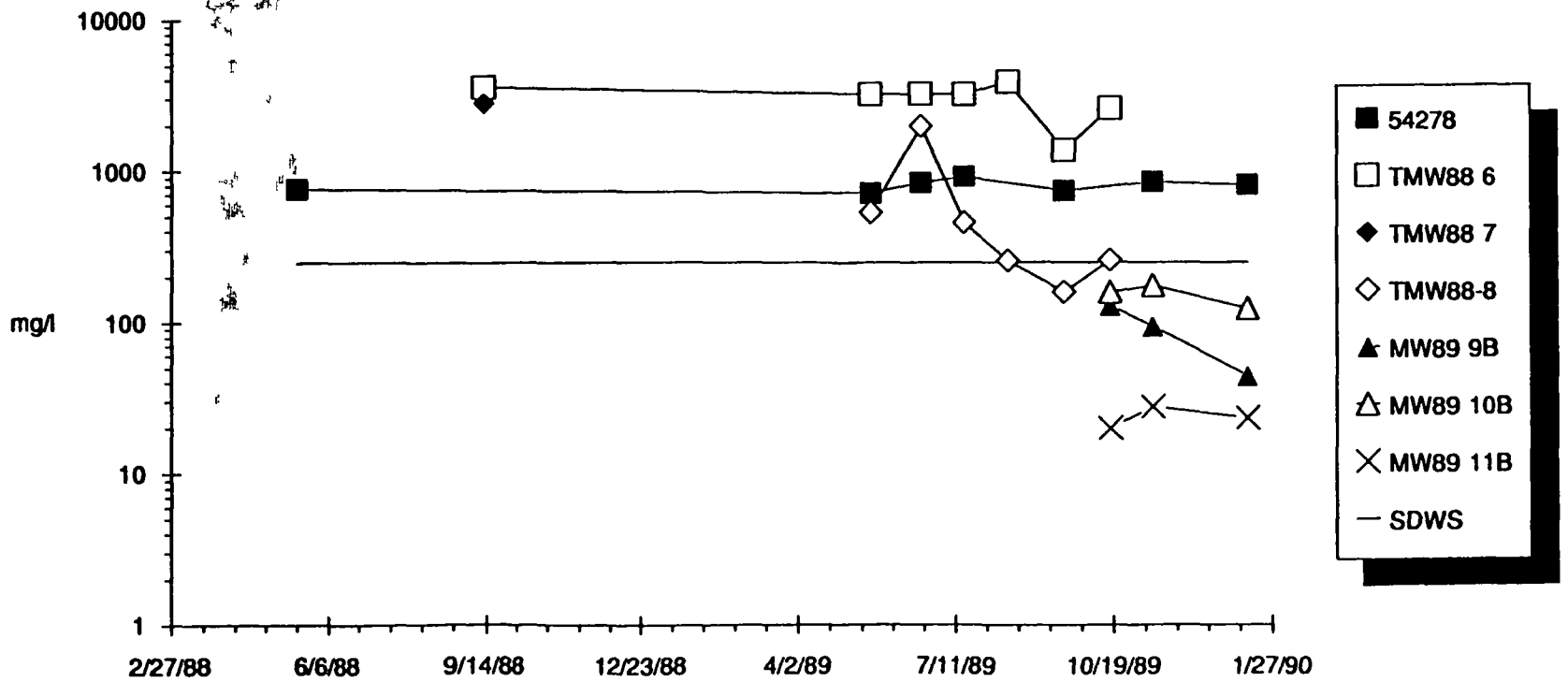


Figure 4 3-8d
Time vs. Sulfates
Off-Site Monitoring Wells
Screened in Lower Portion of Aquifer
Lindsay Mfg. Co.



the SDWS Sulfate levels reported in TMW88-6 TMW88-7 TMW88-8 TMW88-10 TMW88-11 and irrigation well 54278 were above the SDWS The highest sulfate levels were found at TMW88-6

Cadmium was reported in TMW88-6 TMW88-7 and TMW88-10 ranging in concentration from 0 06 mg/l to 0 14 mg/l which exceeded the PDWS (0 05 mg/l) Chromium was reported in TMW88-1 TMW88-8 TMW88-10 and TMW88-11 at concentrations ranging from 0 06 mg/l to 0 16 mg/l which also exceeded the PDWS (0 05 mg/l) Lead was reported in TMW88-11 (0 17 mg/l) only which exceeded the PDWS (0 05 mg/l) With the exception of the occurrence of the elements listed above cadmium chromium lead manganese barium selenium mercury and silver concentrations reported in TMW88-1 TMW88-6 TMW88-7 TMW88-8 TMW88-10 TMW88-11 irrigation well 54278 and irrigation well 33637 were either not detected or below the PDWS or SDWS associated with these metals

Aquifer

Three off-site wells the Old Lindsay Public Supply Well MW87-5 and irrigation well 50378 were included in the monitoring program during this period (Table 4 3-2) Field pH levels measured in the Old Lindsay Public Supply Well MW87-5 and irrigation well 50378 ranged from 6 5 SU to 7 4 SU (Figure 4 3-9a) were at background pH levels

Zinc concentrations in these wells ranged from 0 03 mg/l to 2 8 mg/l iron concentrations ranged from 0 01 mg/l to 4 1 mg/l and sulfate concentrations ranged from 11 mg/l to 54 mg/l (Figure 4 3-9b Figure 4 3-9c Figure 4 3-9d respectively) Zinc iron and sulfate concentrations reported in these wells were below the SDWS for each element

Cadmium (0 06 mg/l) and manganese (0 14 mg/l) were reported in the Old Lindsay Public Supply Well and were slightly above the PDWS and SDWS 0 01 mg/l and 0 05 mg/l respectively for these elements With the exception of the occurrence of the elements listed above cadmium chromium lead manganese barium selenium mercury and silver concentrations reported in the Old Lindsay Public Supply Well MW87-5 and irrigation well #50378 were either not detected or below the PDWS or SDWS associated with these metals

<u>Summary</u>

In summary between November 23 1987 and September 13 1988 inorganic ground-water quality in the aquifer and the upper portion of the aquifer on-site and off-site generally remained near background conditions with the exception of pH zinc iron sulfate and select trace metals found in MW87-3 which is located on the southeastern corner of the site (Figure 1 2-4)

During this period acidic pH levels elevated levels of zinc iron sulfate and select trace metals were found in the lower portion of the aquifer in on-site temporary monitoring wells TMW88-3 TMW88-4 TMW88-5 TMW88-9 and monitoring well MW87-7 which are located on the southeast corner of the site (Figure 1 2-4) This indicates that the acidic inorganic ground water that was found in the lower portion of the aquifer (P-1 P-6 and P-9) from 1983 to 1985 (Figure 4 3-2a) migrated southeast encompassing the area surrounding TMW88-3 TMW88-4 TMW88-5 TMW88-9 MW87-3 and MW87-7 (Figure 1 2-4) between 1985 and 1988

Inorganic ground-water monitoring of off-site monitoring wells screened in the lower portion of the aquifer (TMW88-6 TMW88-7 TMW88-10 and TMW88-11) during this period also showed acidic pH levels and elevated levels of zinc iron sulfate and select trace metals This indicates that the inorganic ground-water plume located in the lower portion of the aquifer had migrated off-site in a southeasterly direction and encompassed the area surrounding TMW88-6 TMW88-7 TMW88-10 and TMW88-11

4 3 2 3 February 15 1989 to January 1990

A total of 22 on-site and 15 off-site locations were included in the ground-water monitoring program between February 15 1989 and January 17 1990 (Table 4 3-2) Well locations are provided in Figure 1 2-4 Ground-water samples were collected on a quarterly monitoring schedule on the following dates February 15 1989 May 16 through 21 1989 August 14 through 16 1989 and November 17 1989 An additional round of well sampling included in the quarterly monitoring was conducted in January 1990 Select temporary wells and piezometers were monitored on a monthly basis from May 1989 through October 1989 Zinc iron chromium cadmium and iron were included in the quarterly and monthly monitoring plan during this period Two ground-water sampling rounds November 17 1989 and January 17 1990 included the analysis of cations and anions Inorganic sample results obtained during this time period are listed in Appendix XI-C QA/QC inorganic data validation reviews were performed on the data collected during this time period and are provided in Appendix XI-F

Isoconcentrations maps presenting the distribution of pH, zinc iron and sulfate concentrations in the bottom of the aquifer on February 15 1989 did not include sample results of temporary monitoring wells or piezometers because these locations were not monitored at that time

Figure 4 3-9a
Time vs pH
Off-Site Monitoring Wells
Screened in Aquifer
Lindsay Mfg Co

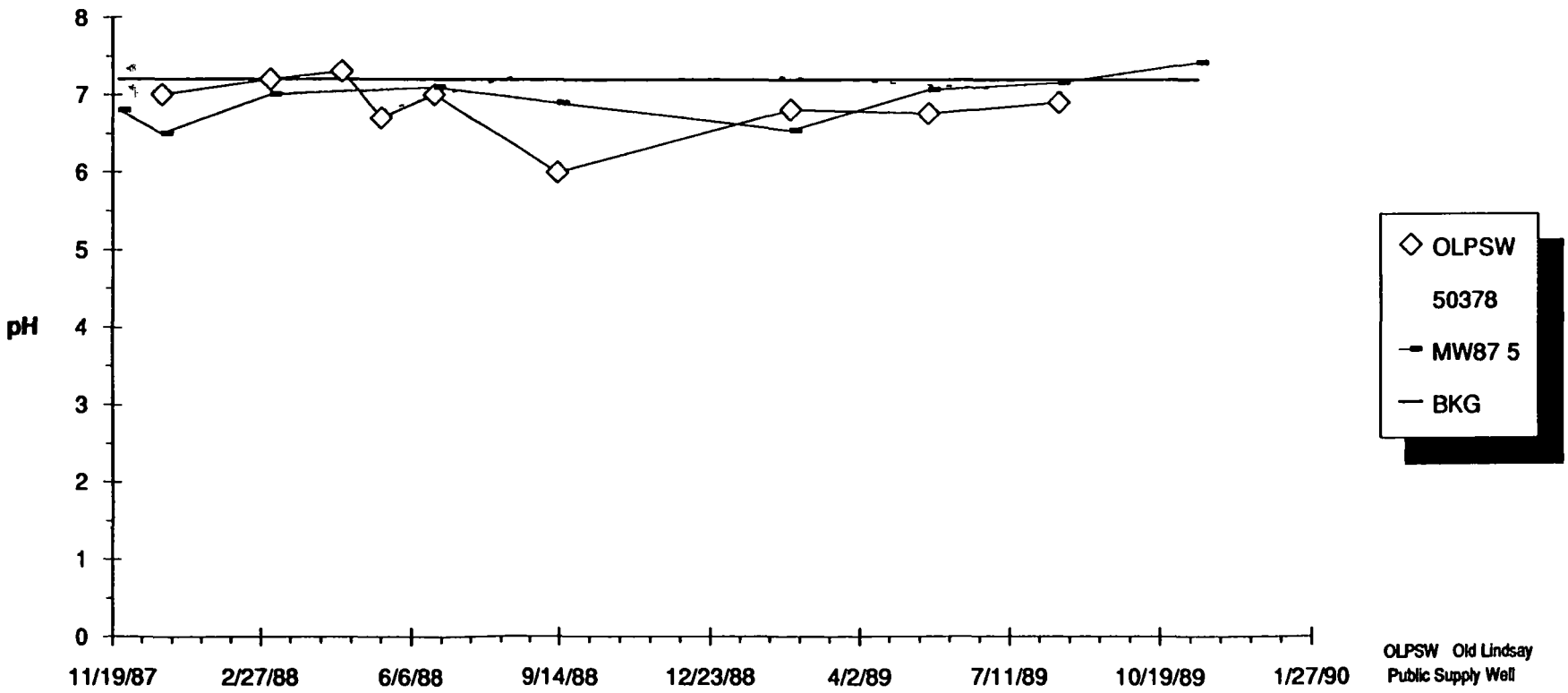


Figure 4 3-9b
Time vs Zinc
Off-Site Monitoring Wells
Screened in Aquifer
Lindsay Mfg Co

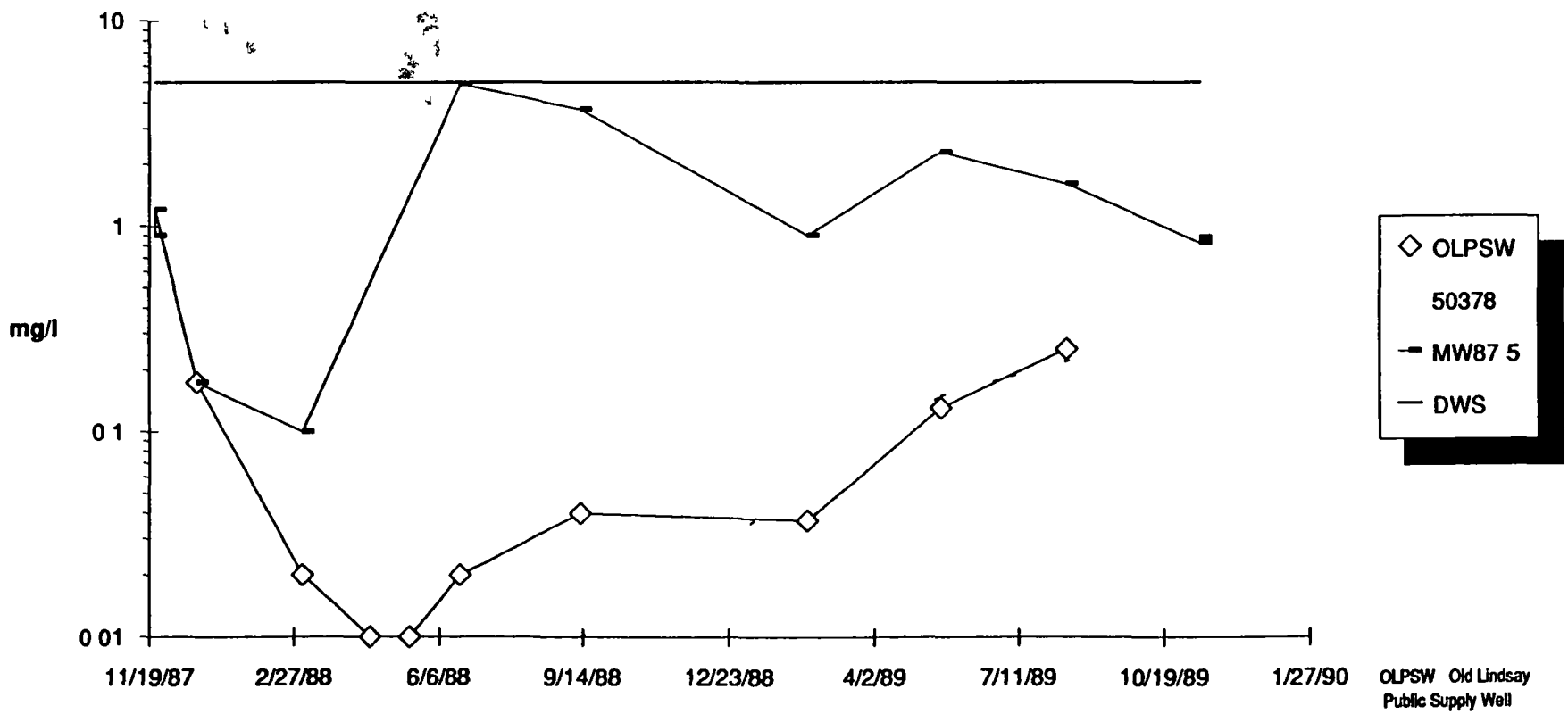


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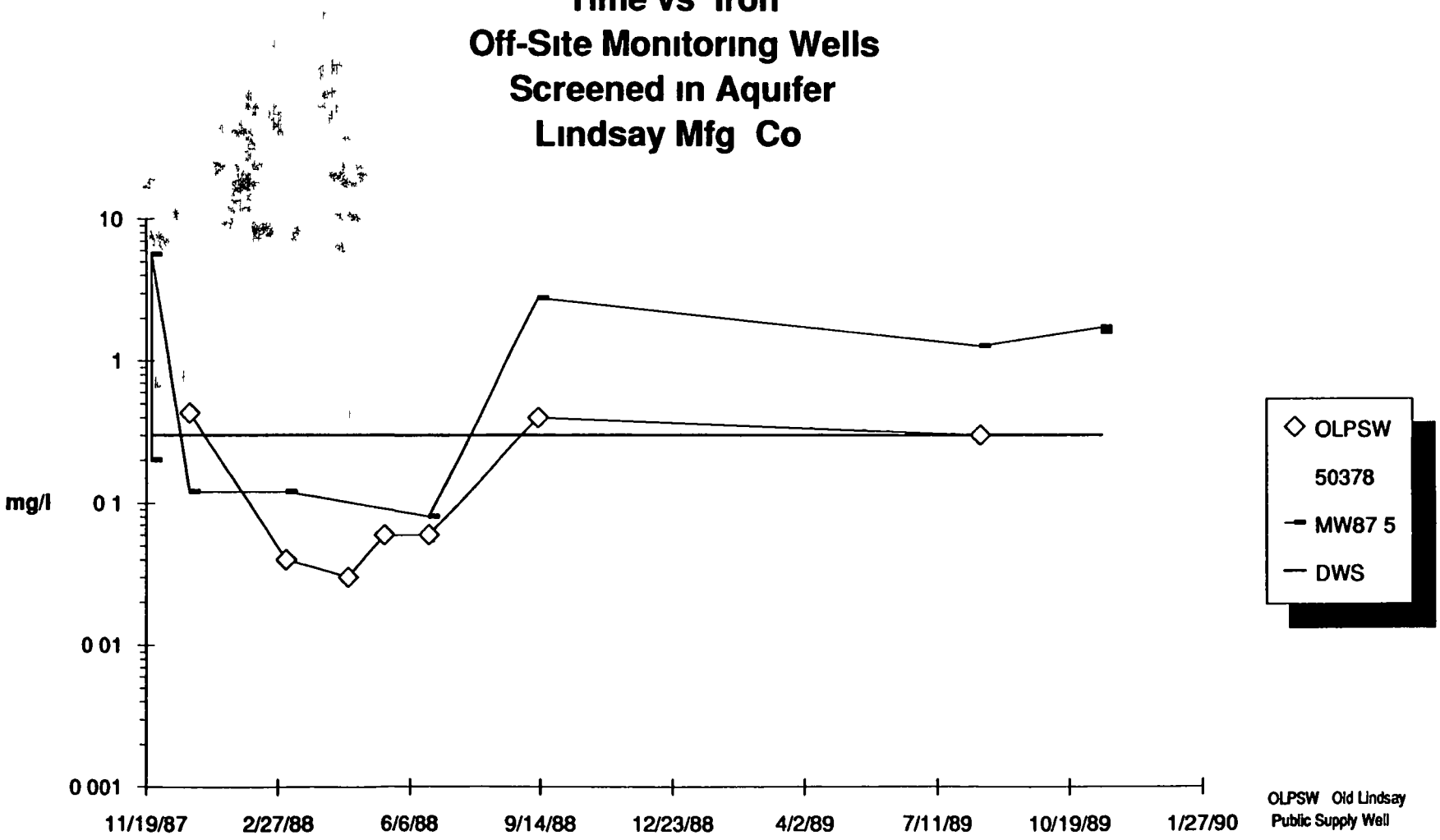
Figure 4 3-9c
Time vs Iron
Off-Site Monitoring Wells
Screened in Aquifer
Lindsay Mfg Co



Job Number 16657 002 005

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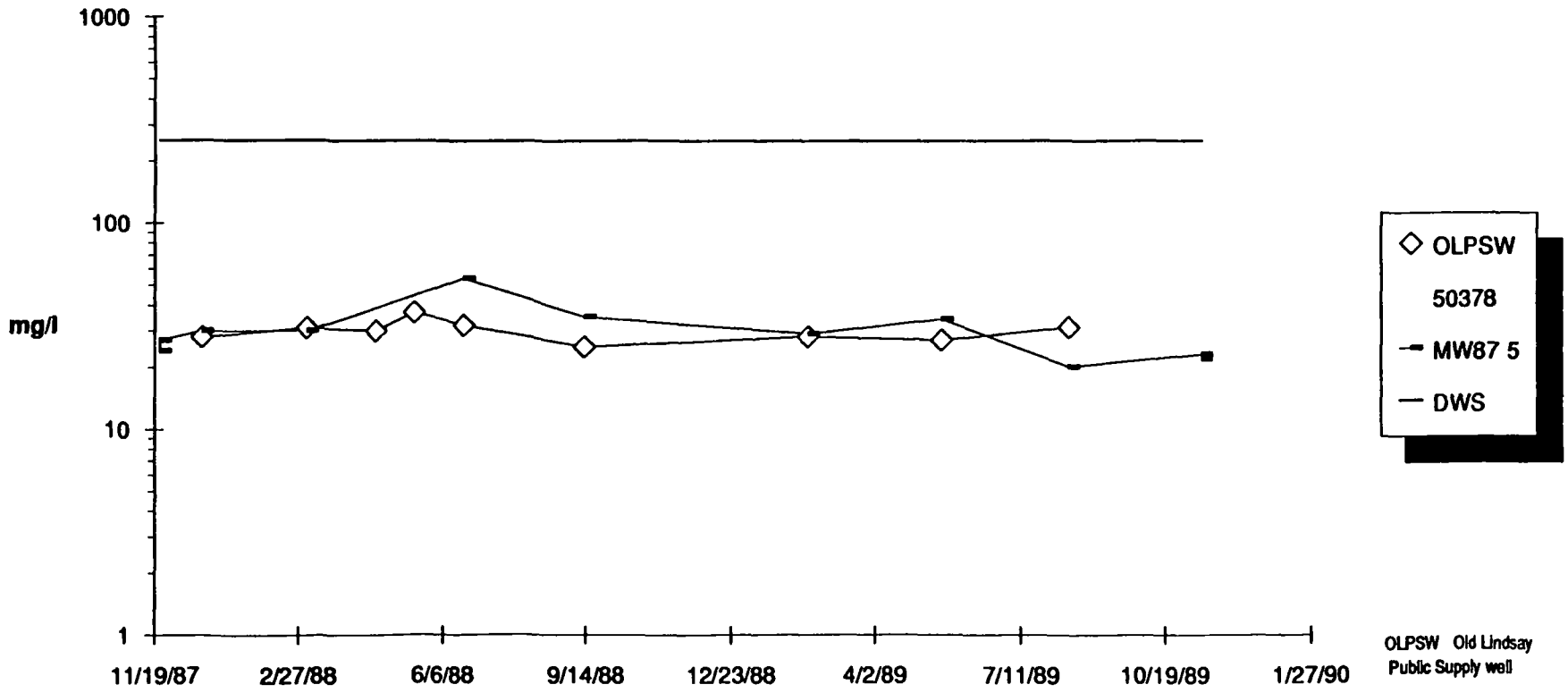
Figure 4 3-9d
Time vs Sulfate
Off-Site Monitoring Wells
Screened in Aquifer
Lindsay Mfg Co



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On-Site Ground-Water Quality

Upper Portion of the Aquifer

Onsite monitoring wells 82-2M MW89-12 and MW89-15 screened in the upper portion of the aquifer were included in the ground-water monitoring program during this period Ground-water quality was monitored at MW89-12 and MW89-15 on November 17 1989 and January 17 1990 only

Field pH levels measured in 82-2M MW89-12 and MW89-15 ranged from 6 1 SU to 7 4 SU (Figure 4 3-5a) The pH levels in these wells were within background pH levels The distributions of field pH values for each quarterly monitoring date are presented in Figures 4 3-10a 4 3-10b 4 3-10c and 4 3-10d respectively

Specific conductivity levels measured in 82-2M MW89-12 and MW89-15 during this period ranged from 600 umhos/cm to 1250 umhos/cm which are below SDWS (1600 umhos/cm)

Zinc concentrations reported in 82-2M MW89-12 and MW89-15 ranged from 0 81 mg/l to 68 1 mg/l iron concentrations ranged from 0 547 mg/l to 6 49 mg/l and sulfate concentrations ranged from 26 mg/l to 550 mg/l Zinc and iron concentrations in both wells exceeded the SDWS for these elements Sulfate concentrations reported in MW89-12 were below the SDWS (250 mg/l) and sulfate concentrations reported in MW89-15 exceeded the SDWS These values are indicative of chemical dispersal from the dense acidic contamination that had drained to the bottom of the aquifer

Cadmium chromium and lead were not detected in either well

Lower Portion of the Aquifer

On-site monitoring wells screened in the lower portion of aquifer included piezometers P-1 P-6 and P-9 monitoring wells MW87-7 and MW87-8 and temporary monitoring wells TMW88-5 and TMW88-9 (Table 4 3-2)

Field pH levels reported in P-1 P-6 P-9 and MW87-8 ranged from 6 1 SU to 7 5 SU and were within background levels pH levels reported in P-1 P-6 and P-9 TMW88-5 and MW87-7 during this period are depicted in Figure 4 3-6a The pH levels measured in MW87-7 TMW88-5 and TMW88-9 ranged from 3 7 SU to 5 86 SU with the exception of pH levels reported MW87-7 on November 17 1989 (6 1 SU) and January 1990 (6 46 SU) The pH levels measured in these wells were considered acidic during this period Lindsay s site investigation has found that these levels are indicative of the residual acid

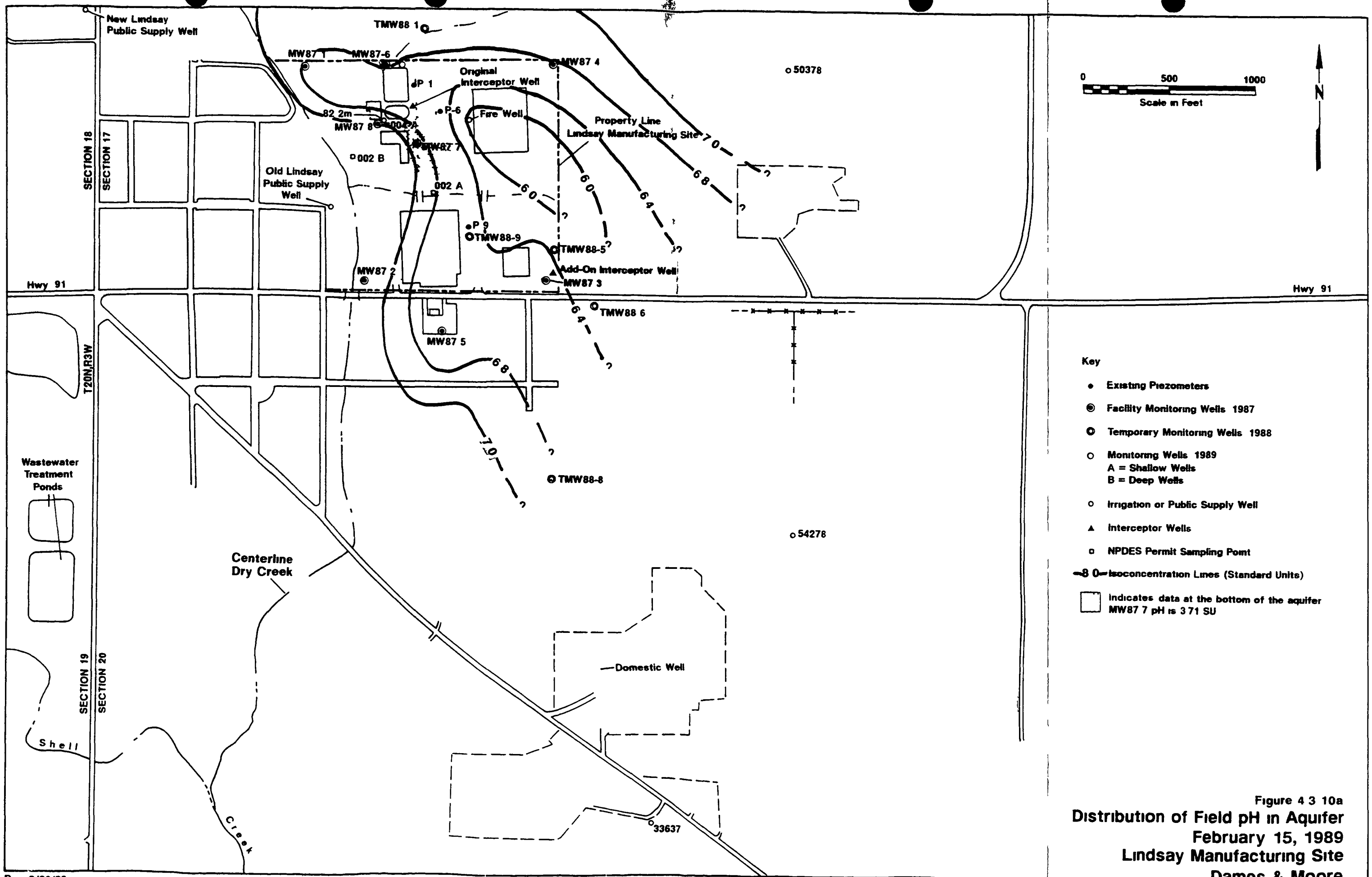

Figure 4 3 10a
Distribution of Field pH in Aquifer
February 15, 1989
Lindsay Manufacturing Site
Dames & Moore

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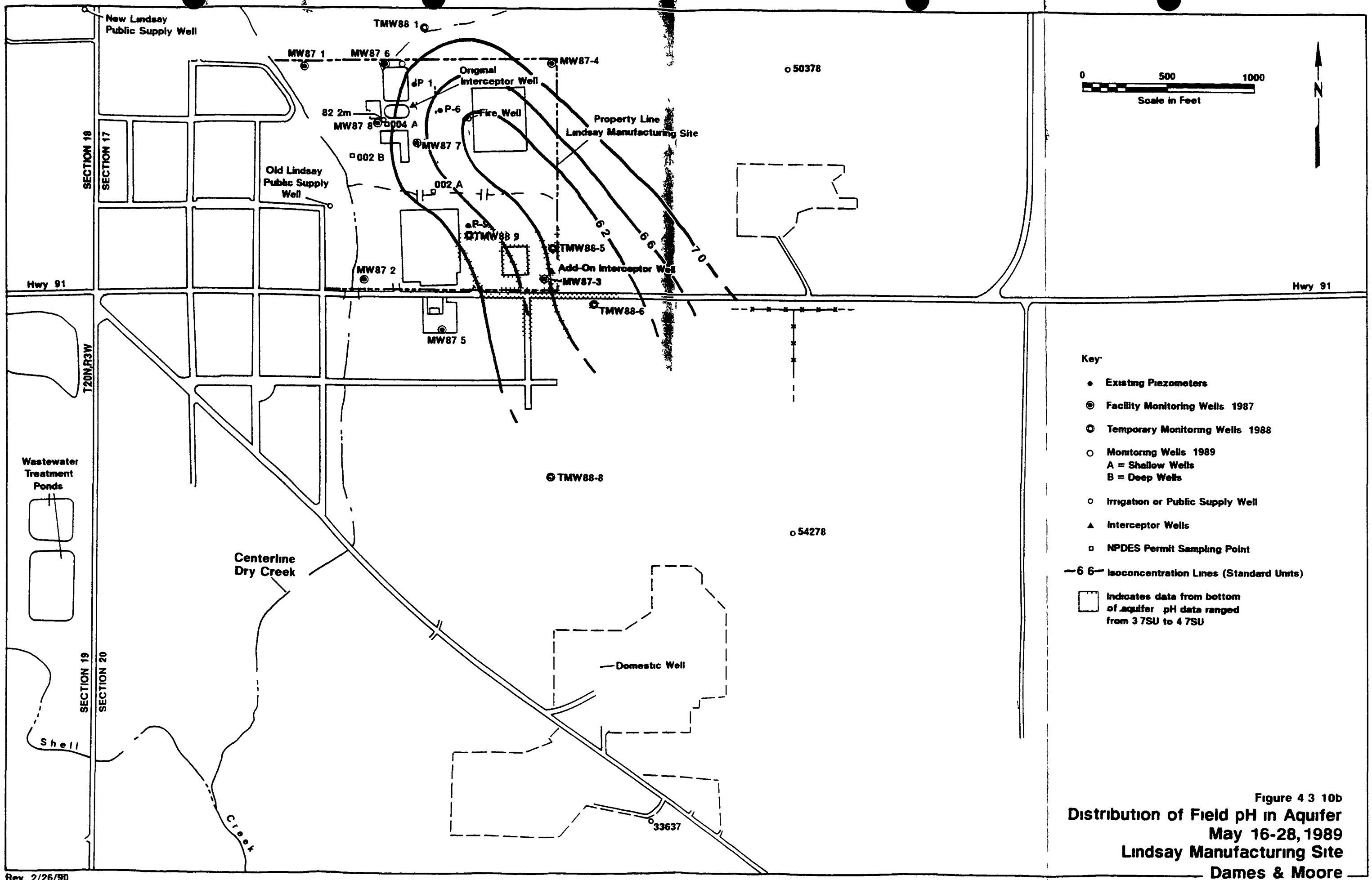

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Figure 4 3 10b
Distribution of Field pH in Aquifer
May 16-28, 1989
Lindsay Manufacturing Site
Dames & Moore

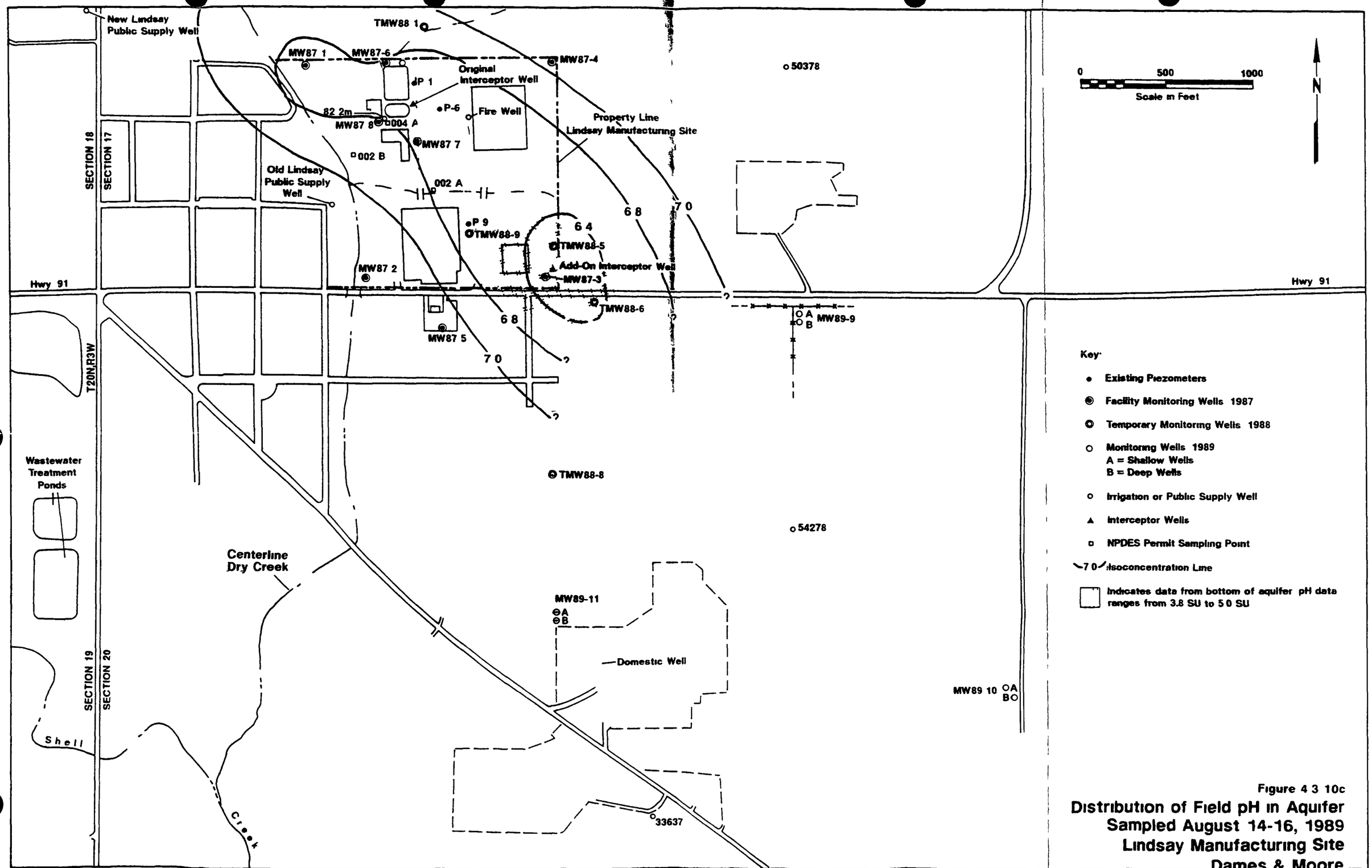

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Figure 4 3 10c

Distribution of Field pH in Aquifer Sampled August 14-16, 1989 Lindsay Manufacturing Site

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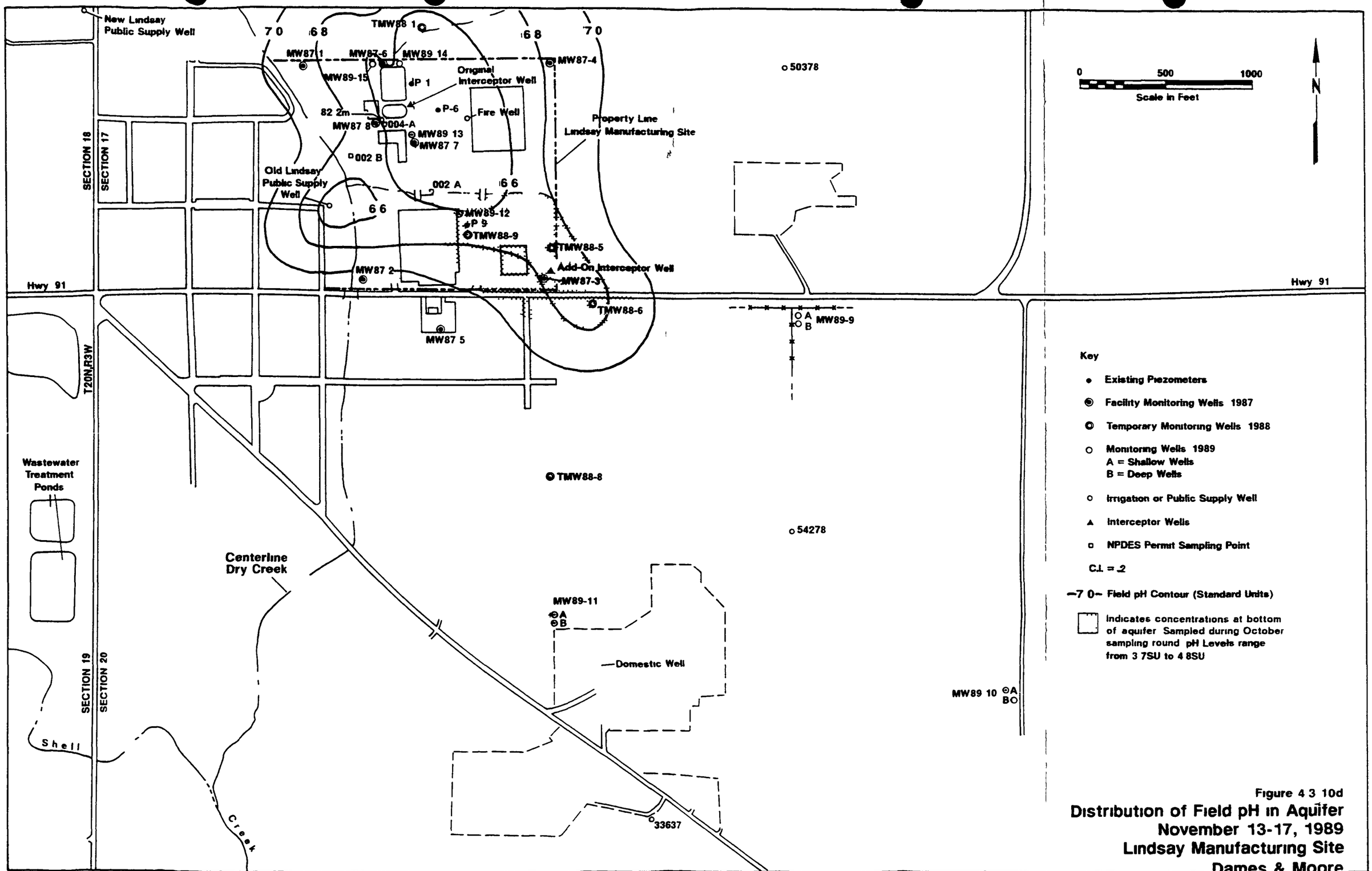

Figure 4 3 10d

Distribution of Field pH in Aquifer
November 13-17, 1989
Lindsay Manufacturing Site

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Specific conductivity values reported in P-1 P-6 P-9 MW87-7 MW87-8 and TMW88-9 generally ranged from 320 umhos/cm to 960 umhos/cm Specific conductivity values reported in TMW88-5 ranged from 1850 umhos/cm to 28 000 umhos/cm which exceeded the SDWS (1600 umhos/cm)

Zinc concentrations reported in P-1 P-6 P-9 MW87-8 TMW88-5 and TMW88-9 ranged from 0 07 mg/l to 466 mg/l Zinc levels reported in P-1 P-6 and P-9 TMW88-5 and MW87-7 during this period are depicted in Figure 4 3-6b Zinc concentrations reported in P-1 P-6 and P-9 were at or near the SDWS (0 05 mg/l) Zinc levels reported in TMW88-5 TMW88-9 and TMW87-7 exceeded the SDWS at various times during this period Isoconcentration maps of the distribution of zinc in the bottom of the aquifer for each quarterly monitoring date are presented in Figures 4 3-11a 4 3-11b 4 3-11c and 4 3-11d respectively

Iron concentrations reported in P-1 P-6 P-9 MW87-8 TMW88-5 and TMW88-9 ranged from 0 1 mg/l to 360 mg/l Iron levels reported in P-1 P-6 and P-9 TMW88-5 and MW87-7 during this period are depicted in Figure 4 3 6c Iron concentrations reported in P-1 MW87-7 and MW87-8 were at or near the SDWS (0 3 mg/l) Iron levels reported in P-6 P-9 TMW88-5 and TMW88-9 were primarily above the SDWS Isoconcentration maps of the distribution of iron in the bottom of the aquifer for each quarterly monitoring date are presented in Figures 4 3-12a 4 3-12b and 4 3-12c respectively

Sulfate concentrations reported in P-1 P-6 P-9 MW87-8 TMW88-5 and TMW88-9 ranged from 24 mg/l to 4 270 mg/l Sulfate levels reported in P-1 P-6 and P-9 TMW88-5 and MW87-7 during this period are depicted in Figure 4 3-6d Sulfate levels reported in these wells were generally below the SDWS (250 mg/l) with the exception of TMW88-6 and TMW88-9 which exceeded the SDWS Isoconcentration maps of the distribution of sulfate in the bottom of the aquifer on each quarterly monitoring date are presented in Figures 4 3-13a 4 3-13b 4 3-13c and 4 3-13d respectively

Lead was reported at various monitoring dates in P-1 P-6 and P-9 and ranged in concentration from 0 07 mg/l to 1 6 mg/l which exceeded the PDWS (0 05 mg/l) Lead levels reported in these piezometers were below the PDWS (0 05 mg/l) by October 1989 and have remained so through January 17 1990 With the exception of the occurrence of lead in the piezometers listed above cadmium chromium lead manganese barium selenium mercury and silver concentrations reported in these wells were either undetected or below the PDWS or SDWS associated with these metals

Lindsay s site investigation has found that the zinc iron sulfate and lead occurrences are indicative of residual concentrations of these elements on the bottom of the aquifer

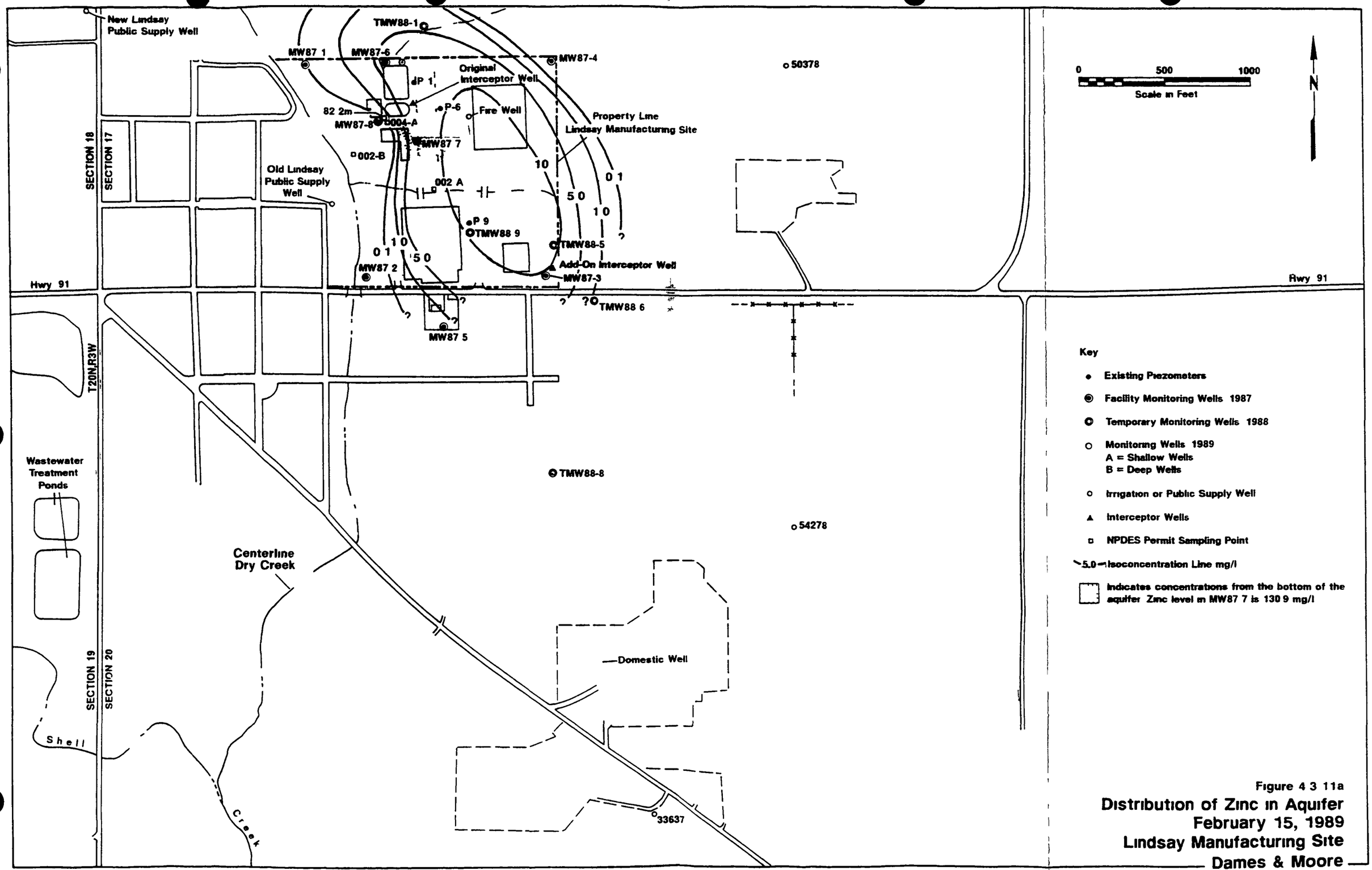

Figure 4 3 11a
Distribution of Zinc in Aquifer
February 15, 1989
Lindsay Manufacturing Site
Dames & Moore

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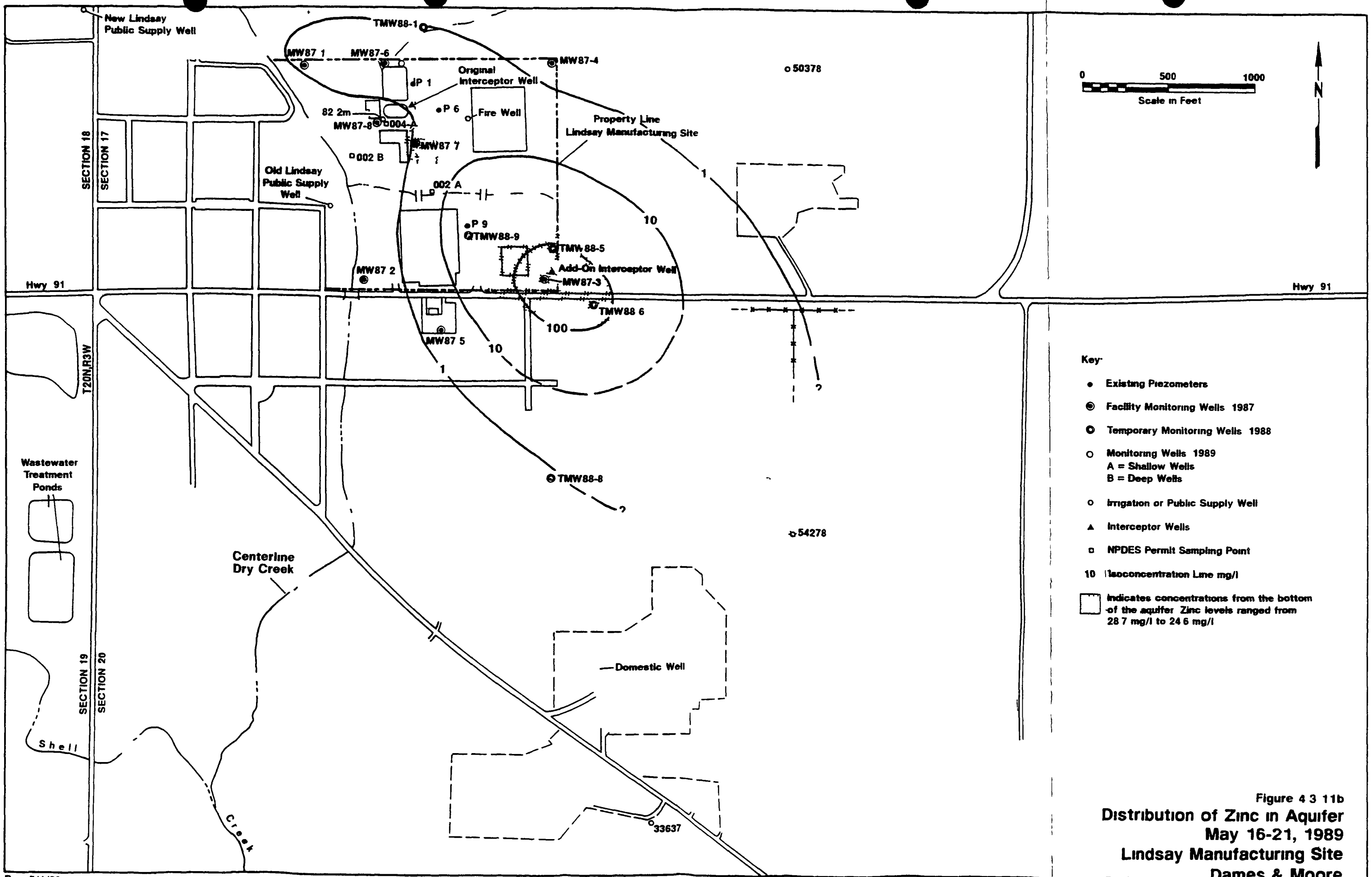

Figure 4 3 11b
Distribution of Zinc in Aquifer
May 16-21, 1989
Lindsay Manufacturing Site
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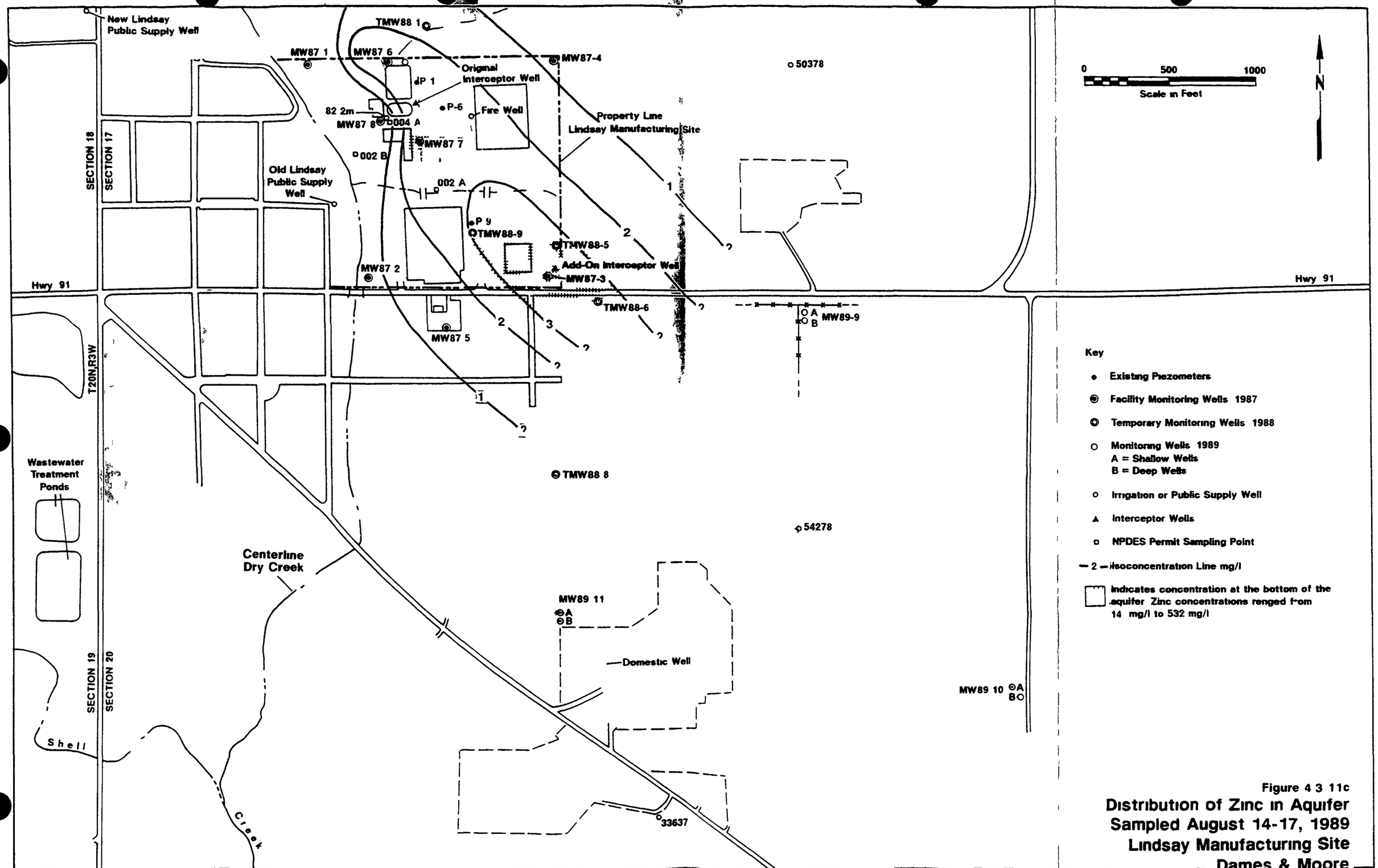

Figure 4 3 11c
Distribution of Zinc in Aquifer Sampled August 14-17, 1989
Lindsay Manufacturing Site
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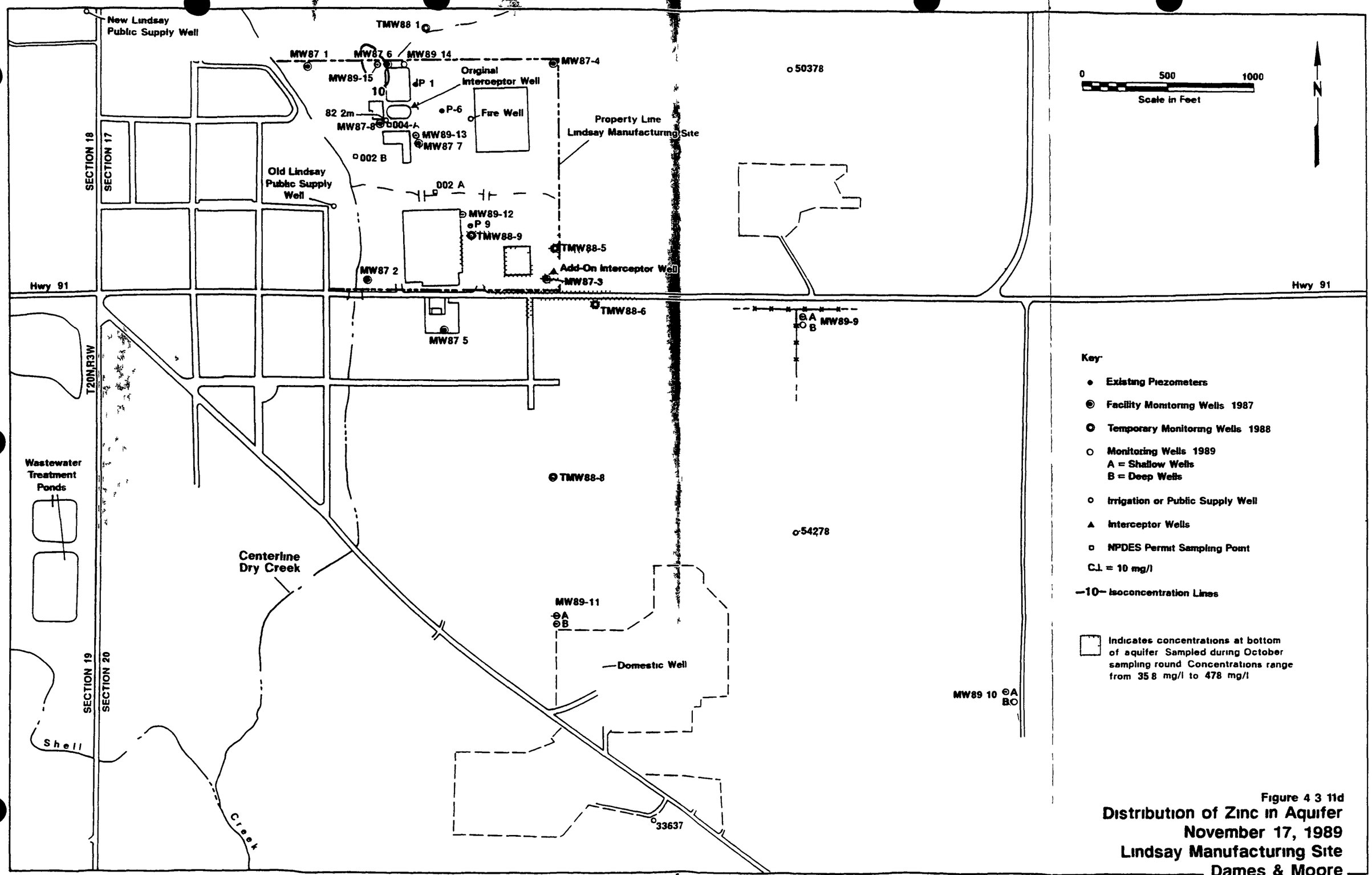

Figure 4 3 11d
Distribution of Zinc in Aquifer
November 17, 1989
Lindsay Manufacturing Site
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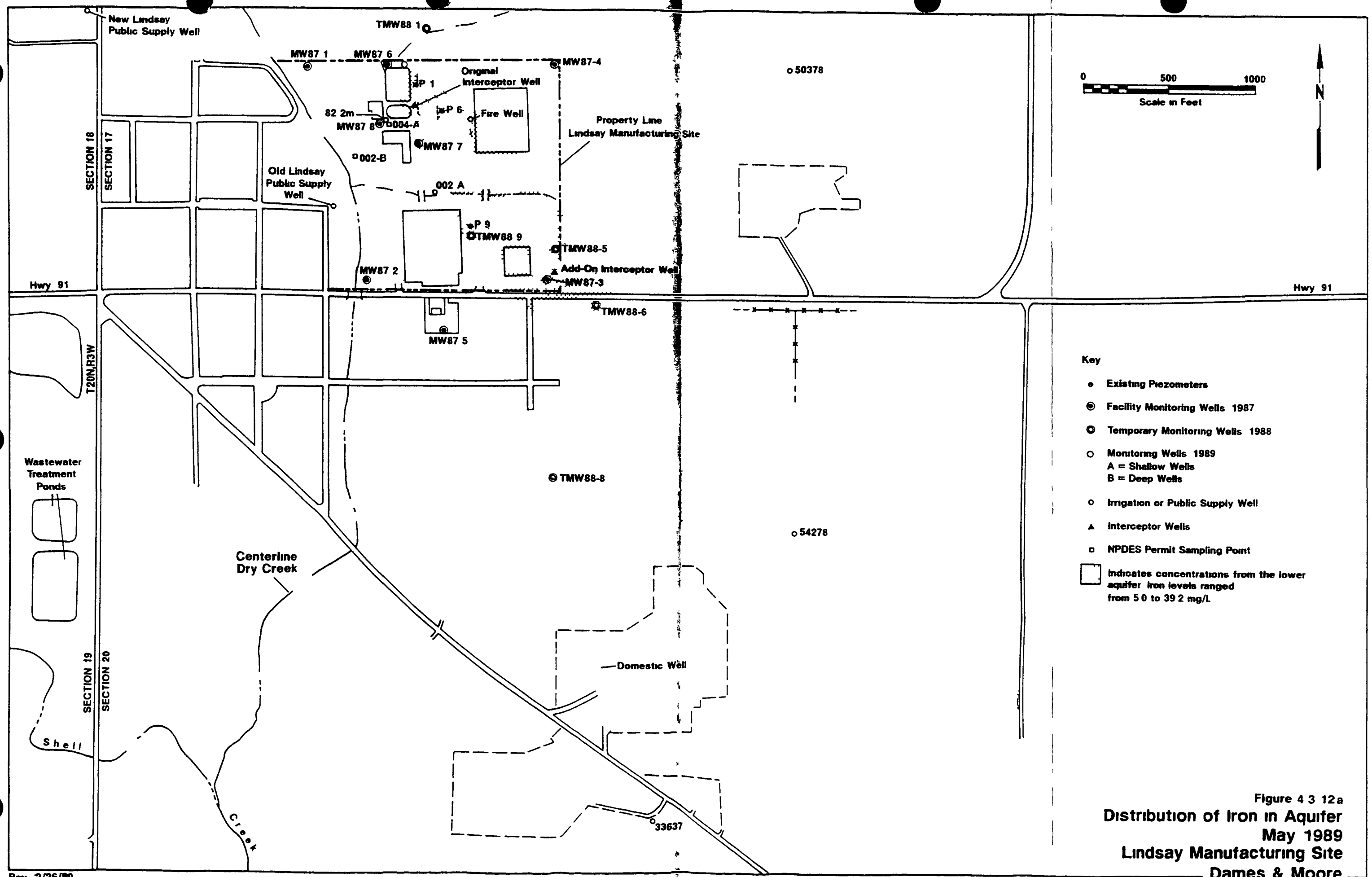

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Figure 4 3 12a
Distribution of Iron in Aquifer
May 1989
Lindsay Manufacturing Site
Dames & Moore

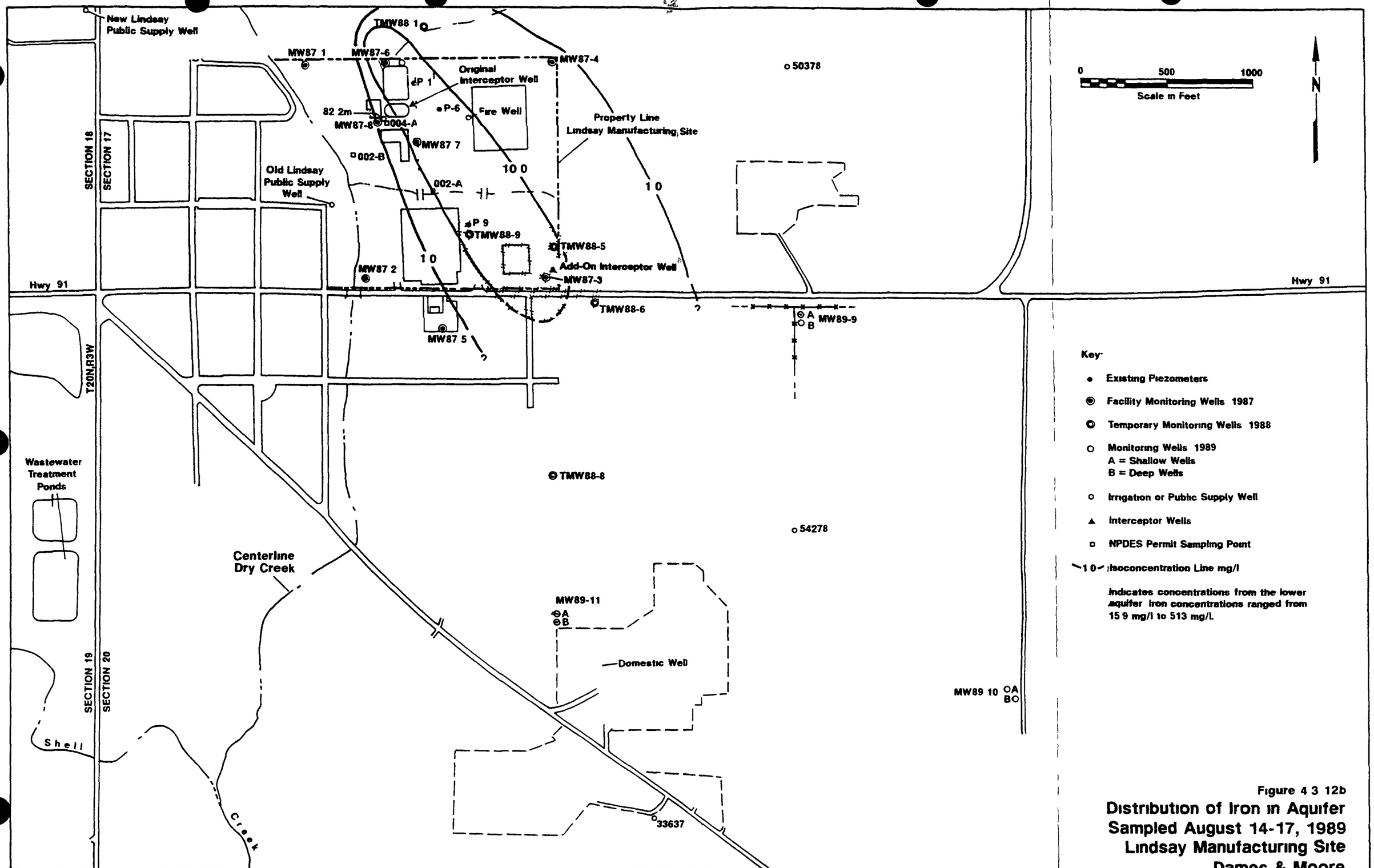

Figure 4 3 12b

Distribution of Iron in Aquifer Sampled August 14-17, 1989 Lindsay Manufacturing Site

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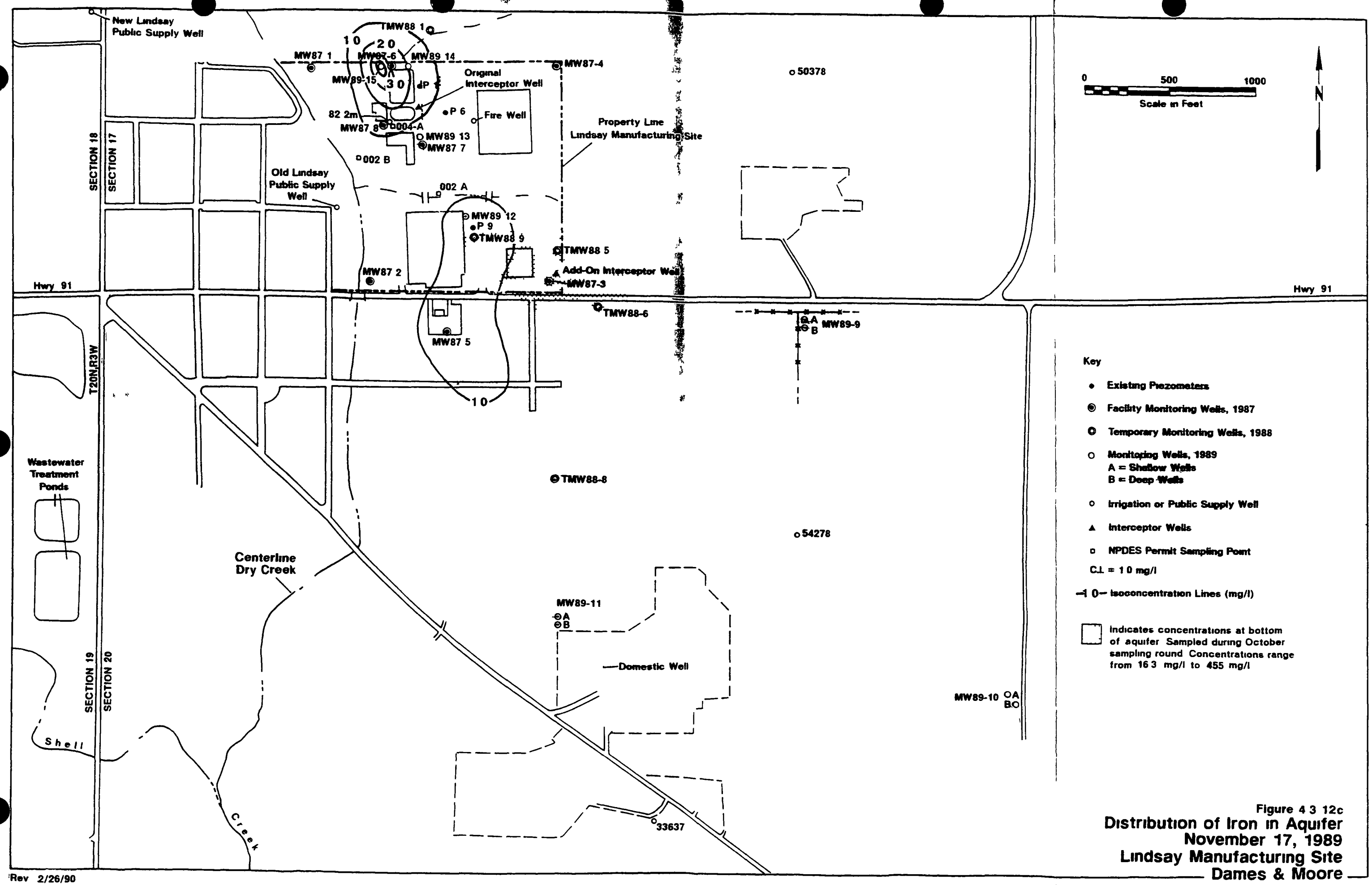

Figure 4 3 12c
Distribution of Iron in Aquifer
November 17, 1989
Lindsay Manufacturing Site
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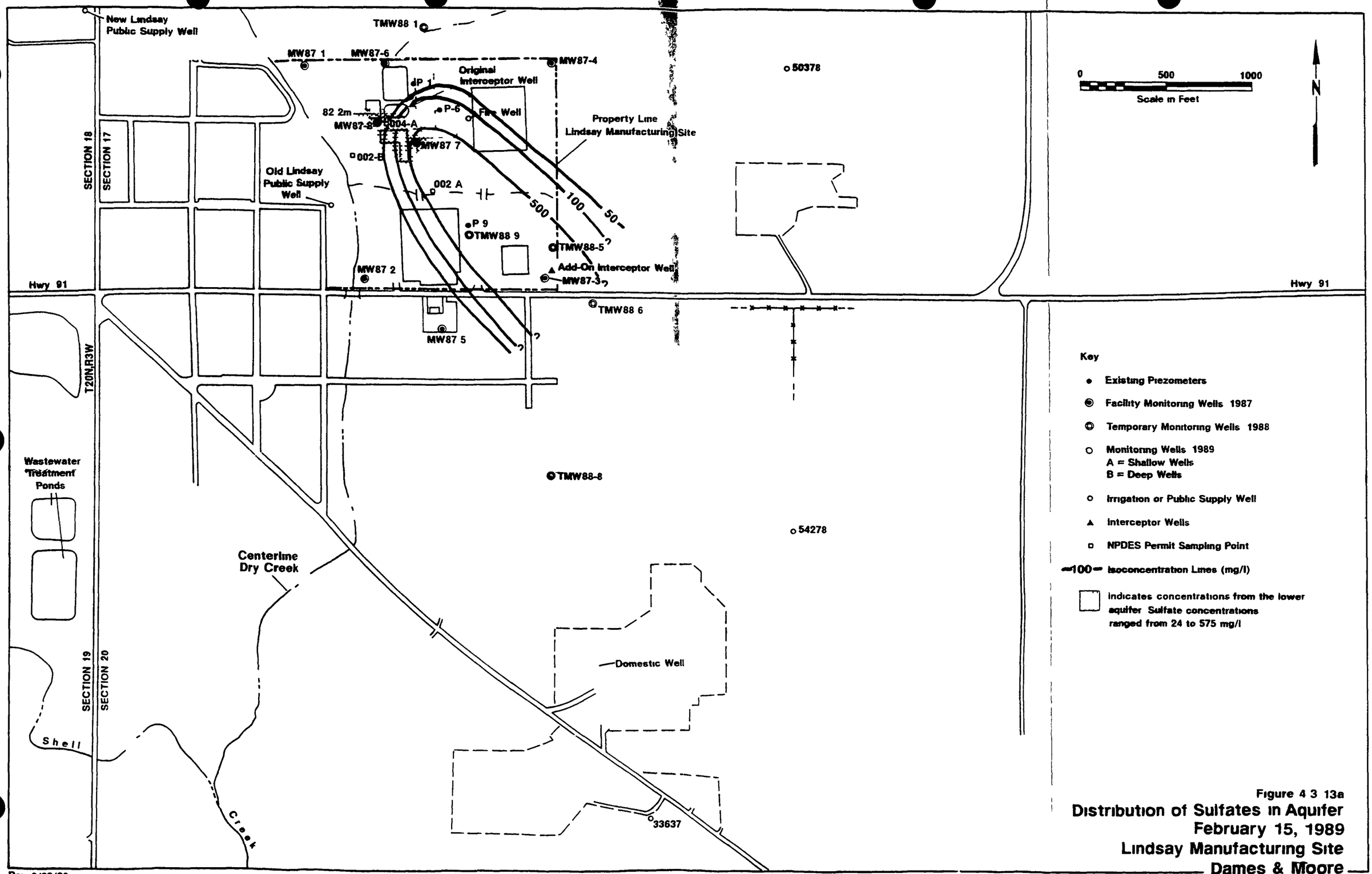

Figure 4 3 13a
Distribution of Sulfates in Aquifer
February 15, 1989
Lindsay Manufacturing Site
Dames & Moore

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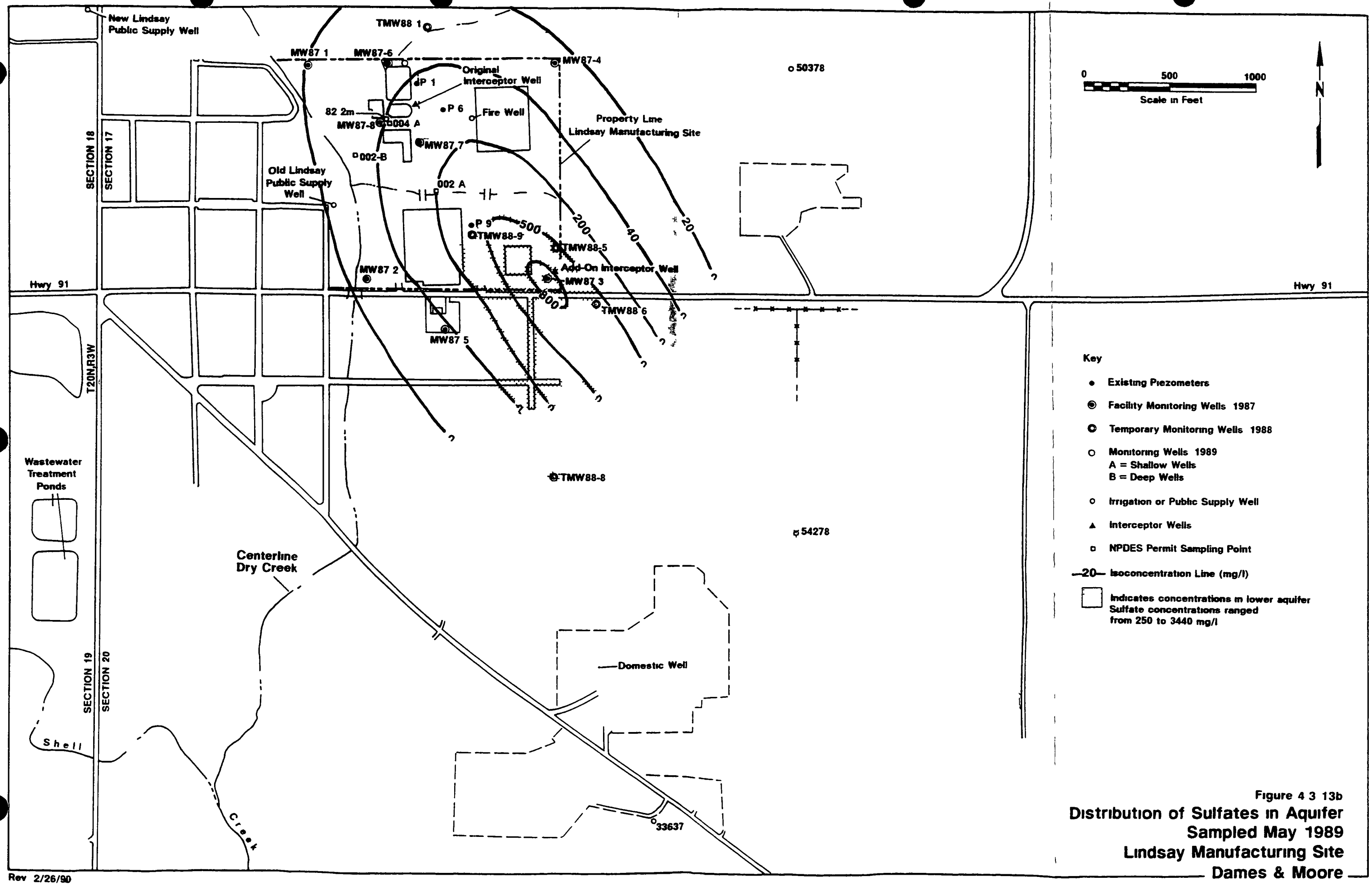

Figure 4 3 13b
Distribution of Sulfates in Aquifer
Sampled May 1989
Lindsay Manufacturing Site
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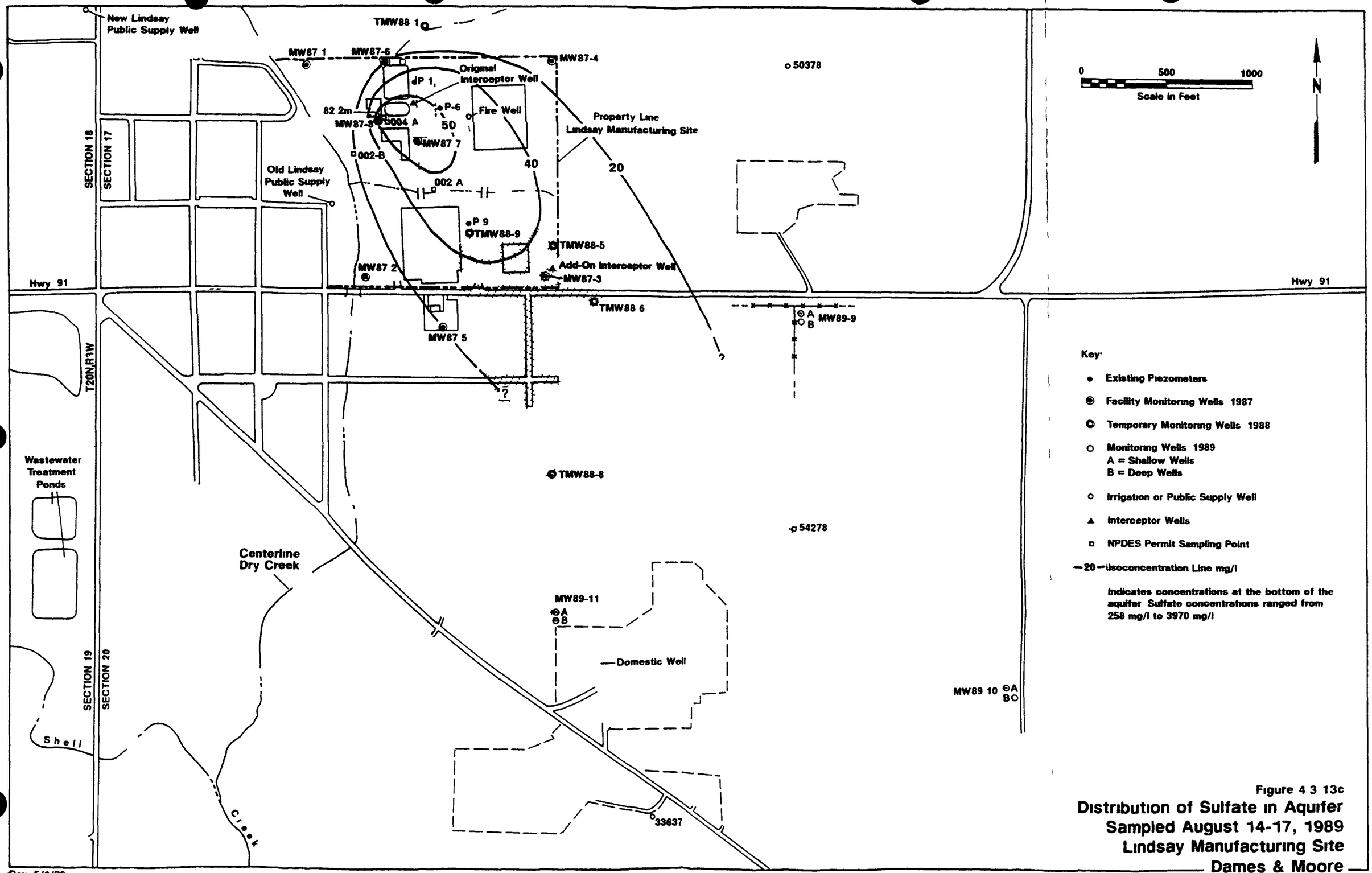

Figure 4 3 13c
Distribution of Sulfate in Aquifer
Sampled August 14-17, 1989
Lindsay Manufacturing Site
Dames & Moore

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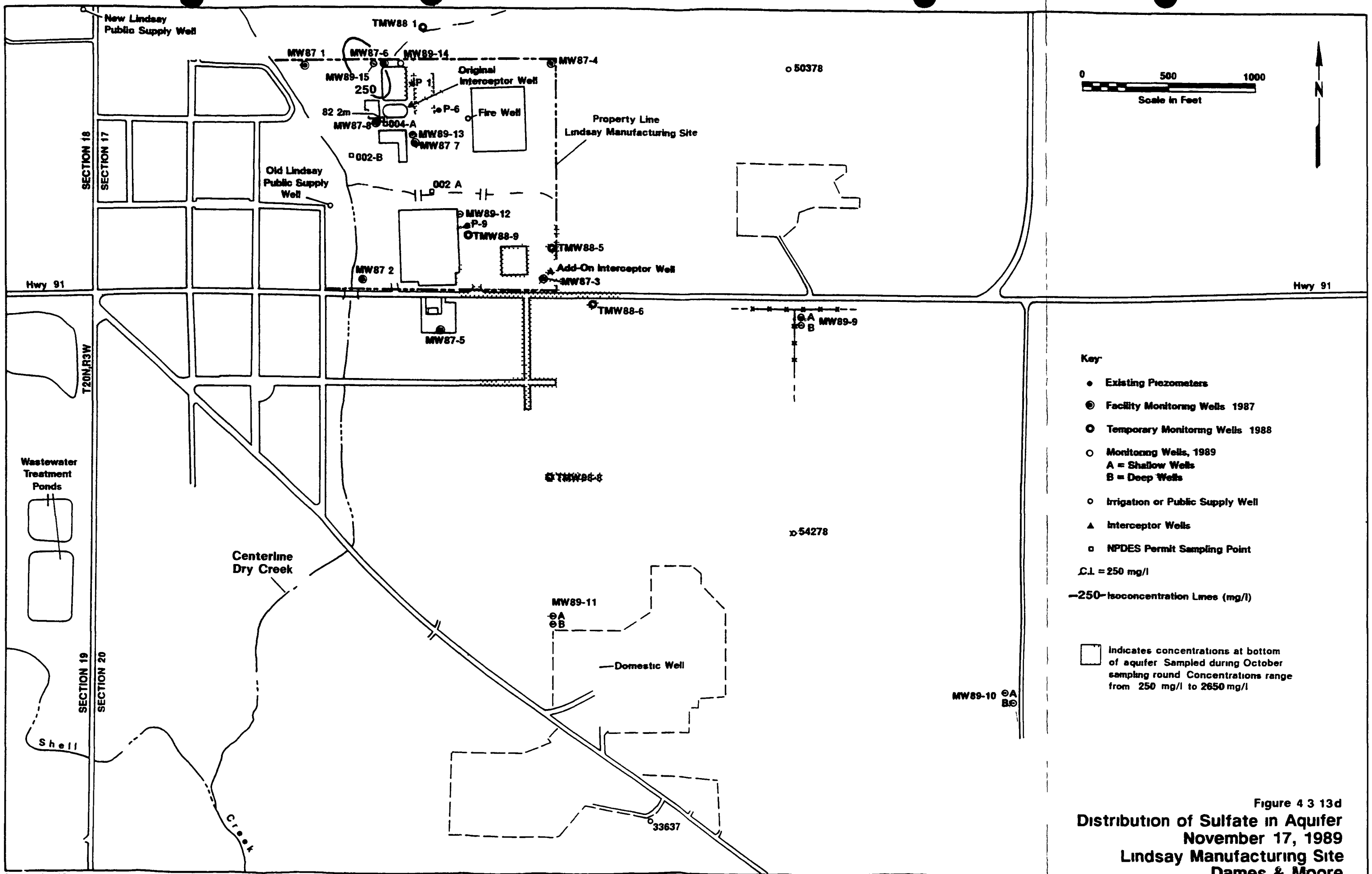

Figure 4 3 13d
Distribution of Sulfate in Aquifer
November 17, 1989
Lindsay Manufacturing Site
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Aquifer

Seven on-site monitoring wells screened in the aquifer were monitored during this period (Table 4 3-2) Monitoring well locations are provided in Figure 1 2-4

Field pH levels measured in the Fire Well MW87-1 through MW87-4 and MW87-6 ranged from 5 9 SU to 7 1 SU and were at or near background pH levels (Table 4 3-3) Time versus pH levels for the Fire Well MW87-3 and MW87-6 are provided in Figure 4 3-7a The distribution of field pH in the aquifer during this period are presented in Figures 4 3-10a 4 3-10b 4 3-10c and 4 3-10d

Specific conductivity values reported in the Fire Well MW87-1 MW87-3 MW87-4 and MW87-6 ranged from 410 umhos/cm to 1200 umhos/cm and were below the SDWS (1600 umhos/cm)

Zinc concentrations reported in MW87-1 MW87-2 and MW87-4 ranged from 0 009 mg/l to 1 6 mg/l which were near or below the SDWS Zinc concentrations reported in the Fire Well MW87-3 and MW87-6 ranged from 0 87 mg/l to 155 mg/l Time versus zinc concentrations reported in the Fire Well MW87-3 and MW87-6 are provided in Figure 4 3-7b Zinc concentrations reported in the Fire Well and MW87-3 were above the SDWS periodically during this period but were below the SDWS at various times between May 1989 and January 1990 Zinc levels in MW87-6 were below the SDWS from February 1989 to December 1989 and the rose above the SDWS to 20 mg/l on January 1990 Isoconcentration maps of the distribution of sulfate in the aquifer during this period are provided in Figures 4 3-11a 4 3-11b 4 3-11c and 4 3-11d

Iron concentrations reported in the Fire Well MW87-1 MW87-2 MW87-3 MW87-4 and MW87-6 ranged from undetected to 1 61 mg/l which were near or below the SDWS (0 3 mg/l) Time versus iron concentrations reported in the Fire Well MW87-3 and MW87-6 are provided in Figure 4 3-7c Iron levels reported in MW87-5 and MW87-6 were above the SDWS during this period Isoconcentration maps of the distribution of iron in the aquifer during this period are provided in Figures 4 3-12a 4 3-12b and 4 3-12c

Sulfate concentrations reported in the Fire Well MW87-1 MW87-2 MW87-4 and MW87-6 ranged from 13 mg/l to 120 mg/l which were below the SDWS (250 mg/l) Sulfate concentrations reported in MW87-3 ranged from 22 mg/l to 825 mg/l Time versus sulfate concentrations reported in the Fire Well MW87-3 and MW87-6 are provided in Figure 4 3-7c Sulfate levels reported in MW87-3 were above the SDWS between February and June 1989 but were below the SDWS from June 1989 to January 1990 Isoconcentration maps of the distribution of sulfate in the aquifer during this period are provided in Figures 4 3-13a 4 3-13b 4 3-13c and 4 3-13d

Chromium was detected at various monitoring dates in MW87-4 and MW87-6 and ranged in concentration from 0 127 mg/l to 0 277 mg/l Chromium levels in these wells were below the PDWS (0 05 mg/l) by January 1990 With the exception of the occurrence of chromium in the wells listed above cadmium and lead concentrations reported in these wells were either undetected or below the PDWS or SDWS associated with these metals

The aquifer occurrences of zinc iron and sulfates are coincidental trending from the northwest to southeast Occasional traces of these compounds and chromium are associated with dispersed transport (Section 5)

Perched Sand Channel

Two monitoring wells MW89-13 and MW89-14 screened in the perched sand channel were monitored on November 17 1989 and January 13 1990 The well locations are provided in Figure 1 2-4

Field pH levels measured in MW89-13 and MW89-14 ranged from 4 8 SU to 5 7 SU and are considered to be acidic The distribution of pH in the perched sand channel on November 17 1989 is presented in Figure 4 3-14a

Specific conductivity values measured in these wells ranged from 2 000 umhos/cm to 7 300 umhos/cm with the highest values found at MW89-13 These levels are above the SDWS for specific conductivity (1600 umhos/cm)

Zinc concentrations reported in these wells ranged in concentration from 24 9 mg/l to 78 6 mg/l iron concentrations ranged from 10 5 mg/l to 39 8 mg/l and sulfate concentrations ranged from 1 070 mg/l to 1 303 mg/l Zinc iron and sulfate levels were above the SDWS for these elements in these wells on both monitoring dates The distribution of zinc iron and sulfate concentrations in the perched sand channel on November 17 1989 is presented in Figures 4 3-14b 4 3-14c and 4 3-14d respectively

Off-Site Ground-Water Quality

Upper Portion of Aquifer

Four off-site monitoring wells screened in the upper portion of the aquifer were monitored between February 1989 and January 1990 Moravec Domestic Well MW89-9A MW89-10A and MW89-11A The pH levels measured in these wells ranged from 6 4 SU to 7 2 SU which were at background levels (Table 4 3-3) Zinc concentrations reported in these wells ranged from undetected to 0 27 mg/l iron concentrations ranged from undetected to 10 8 mg/l and sulfate

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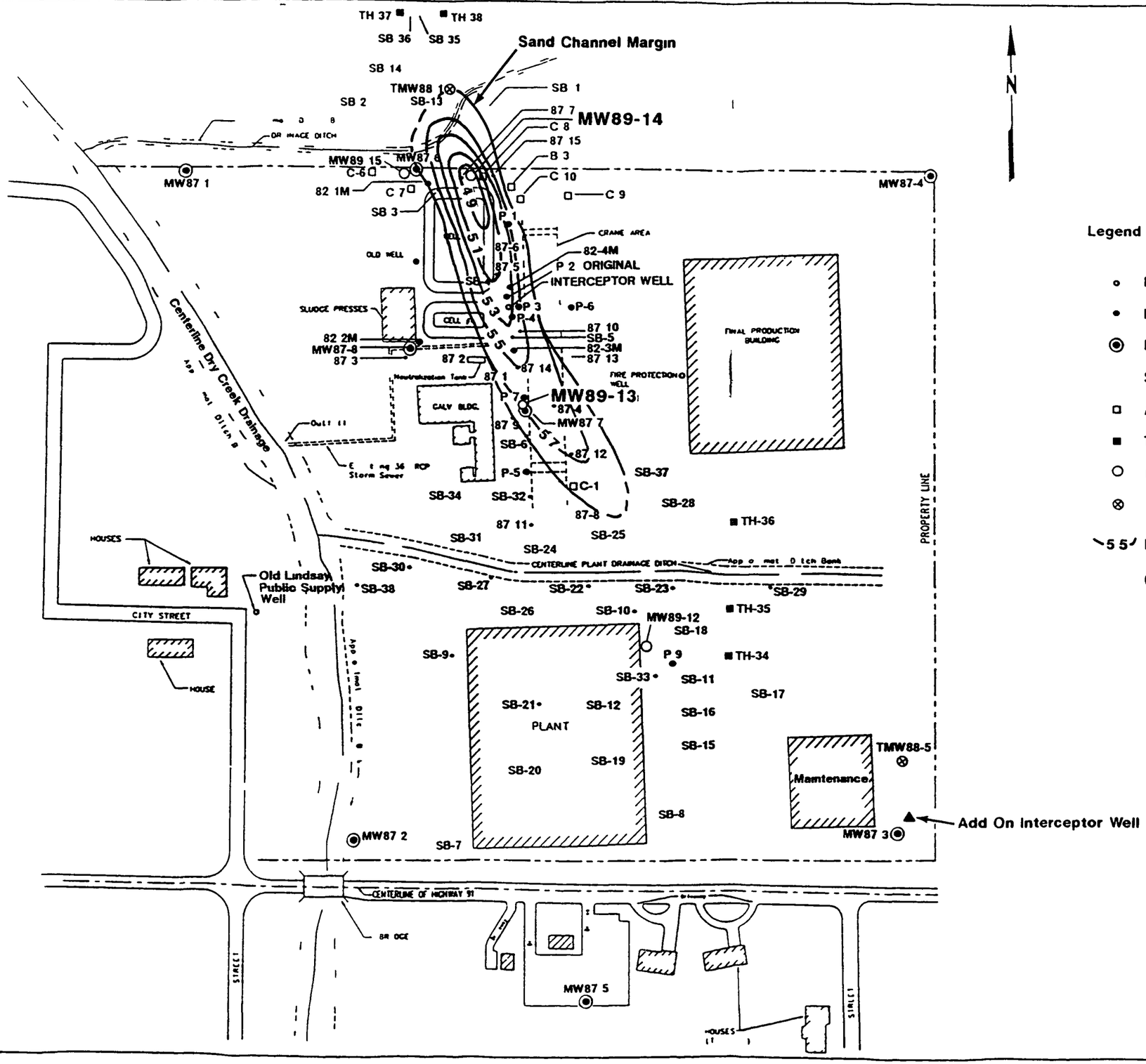

Legend

- Existing Production Wells
- Existing Piezometers
- Facility Monitoring Wells 1987
- Shallow Auger Borings 1988
- Auger Borings 1983
- Test Holes 1988
- Facility Monitoring Wells, 1989
- Temporary Monitoring Wells, 1988
- 5 5 Isoconcentration Lines

Contour Interval = 2

Figure 4 3 14a

Distribution of Field pH in Sand Channel Based on MW89-13 and MW89-14 November 17, 1989 Lindsay Manufacturing Site

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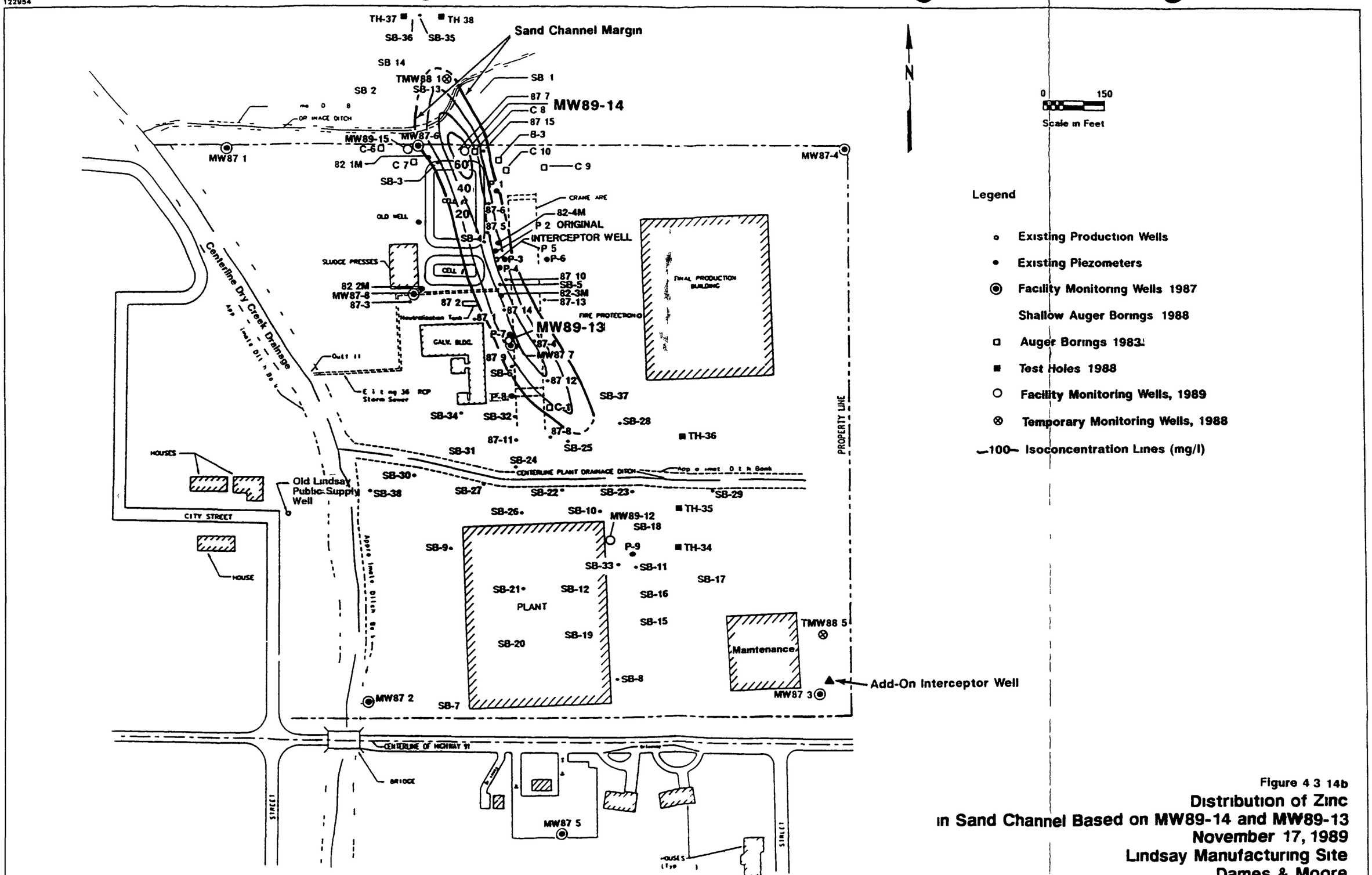

Figure 4 3 14b
Distribution of Zinc
in Sand Channel Based on MW89-14 and MW89-13
November 17, 1989
Lindsay Manufacturing Site
Dames & Moore

Job No 16657 002

Rev 2/28/90

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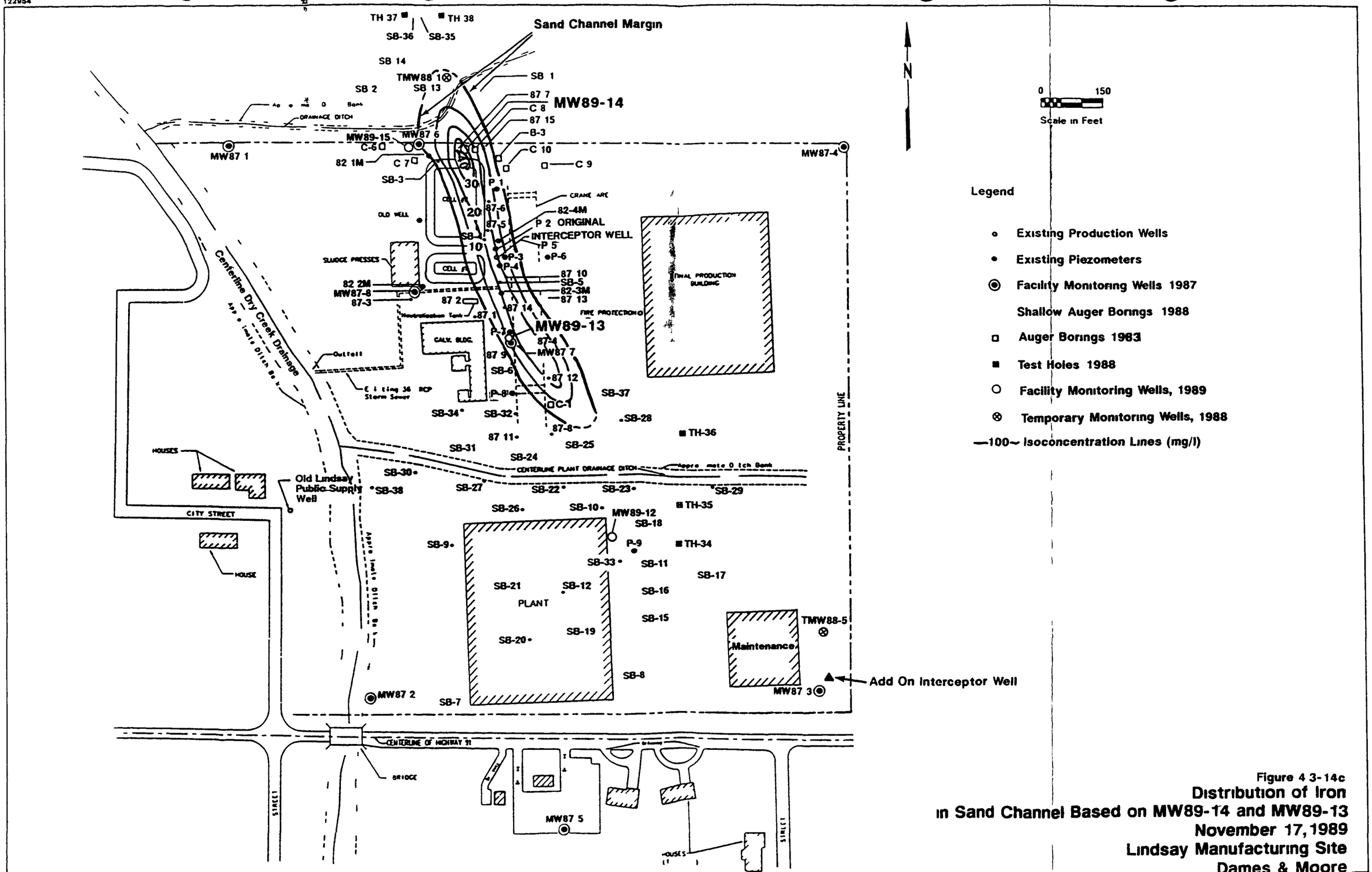

Figure 4 3-14c
Distribution of Iron
in Sand Channel Based on MW89-14 and MW89-13
November 17, 1989
Lindsay Manufacturing Site
Dames & Moore

Job No 16657 002

Rev 2/28/90

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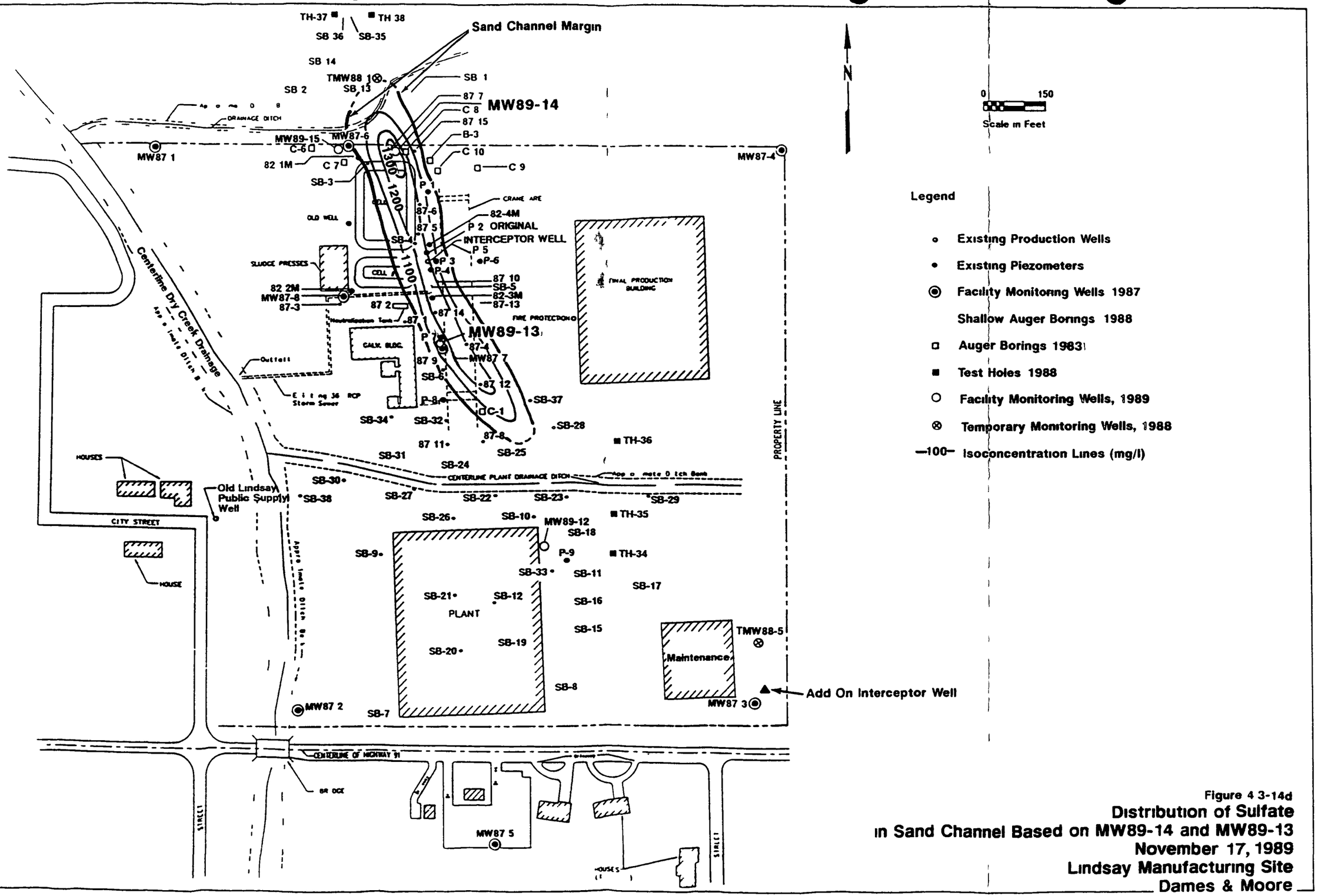

Figure 4 3-14d
Distribution of Sulfate in Sand Channel Based on MW89-14 and MW89-13
November 17, 1989
Lindsay Manufacturing Site
Dames & Moore

Job No 16657 002

Rev 2/28/90

concentrations ranged from 5 mg/l to 30 2 mg/l Zinc iron and sulfate levels reported in these wells were below SDWS for each element with the exception of iron 10 8 mg/l reported in MW89-10A on November 17 1989

Cadmium chromium and lead were either undetected or the reported sample concentrations were less than PDWS for these elements

Lower Portion of Aquifer

Three temporary wells three monitoring wells irrigation wells #54278 and #33637 and Beller domestic well were monitored during this period (Table 4 3-2) Field pH levels measured in the TMW88-1 TMW88-8 MW89-9B MW89-10B MW89-11B irrigation well #54278 Beller domestic well and irrigation well #33637 ranged from 6 04 SU to 7 36 SU Time versus pH levels for TMW88-6 TMW88-8 and irrigation well #54278 are provided in Figure 4 3-9a PH levels reported in the wells monitored were at background pH levels with the exception of TMW88-6 PH levels reported in TMW88-6 during this period ranged from 4 2 SU to 4 8 SU and are considered acidic The distribution of pH in the bottom of the aquifer during this period on each quarterly monitoring date are presented in Figures 4 3-10a 4 3-10b 4 3-10c and 4 3-10d respectively

Specific conductivity values in TMW88-1 TMW88-8 MW89-9B MW89-10B MW89-11B irrigation well #54278 Beller domestic well and irrigation well #33637 ranged from 390 umhos/cm to 1 480 umhos/cm which are below the SDWS (1600 umhos/cm) Specific conductivity values reported in TMW88-6 ranged from 1900 umhos/cm to 4 600 umhos/cm which were above the SDWS

Zinc concentrations reported in TMW88-1 MW89-9B MW89-10B MW89-11B Beller domestic well and irrigation well #33637 ranged from undetected to 0 47 mg/l Time versus zinc concentrations reported in the irrigation well #54278 TMW88-6 TMW88-8 MW89-9B MW89-10B and MW89-11B are provided in Figure 4 3-9b Zinc concentrations reported in irrigation well #54278 and TMW88-6 exceeded the SDWS (5 0 mg/l) The highest zinc concentrations reported during this time period were found at TMW88-6 The distributions of zinc in the bottom of the aquifer for the quarterly monitoring dates are presented in Figures 4 3-11a 4 3-11b 4 3-11c 4 3-11d and 4 3-11e respectively

Iron concentrations reported in TMW88-1 TMW88-8 MW89-9B MW89-10B MW89-11B irrigation well #54278 Beller domestic well and irrigation well #33637 ranged from undetected to 5 25 mg/l Time versus iron concentrations reported in irrigation well #54278 TMW88-6 TMW88-8 MW89-9B MW89-10B and MW89-11B are provided in Figure 4 3-9c Iron concentrations were near or below the SDWS (0 3 mg/l) with the exception of TMW88-6 Iron

levels found in TMW88-6 ranged from 432 mg/l to 513 mg/l which exceed the SDWS Isoconcentrations maps of the distribution of iron in the bottom of the aquifer for each quarterly monitoring date are presented in Figures 4 3-12a 4 3-12b and 4 3-12c respectively

Sulfate concentrations reported in TMW88-1 TMW88-6 TMW88-8 MW89-9B MW89-10B MW89-11B irrigation well #54278 Beller domestic well and irrigation well #33637 ranged from 17 mg/l to 3 970 mg/l Time versus sulfate concentrations reported in irrigation well #54278 TMW88-6 TMW88-8 MW89-9B MW89-10B and MW89-11B are provided in Figure 4 3-9d Sulfate concentrations reported in TMW88-1 MW89-9B MW89-10B MW89-11B Beller domestic well and irrigation well #33637 were below the SDWS (250 mg/l) Sulfate levels in TMW88-6 and irrigation well #54278 exceeded the SDWS Isoconcentrations maps of the distribution of sulfate in the bottom of the aquifer during this time period are presented in Figures 4 3-13a 4 3-13b 4 3-13c 4 3-13d respectively

Cadmium chromium and lead were either undetected or the sample concentrations reported were less than PDWS for these elements

Aquifer

Three off-site wells the Old Lindsay Public Supply Well MW87-5 and irrigation well #50378 were included in the monitoring program during this period (Table 4 3-2) Field pH levels measured in the Old Lindsay Public Supply Well MW87-5 and irrigation well #50378 ranged from 6 4 SU to 7 5 SU and were at background pH levels Zinc concentrations reported in these wells ranged from 0 03 mg/l to 2 6 mg/l iron concentrations ranged from undetected to 1 2 mg/l and sulfate concentrations ranged from 4 mg/l to 34 mg/l Zinc iron and sulfate levels reported in these wells were below SDWS for each element

Cadmium chromium and lead were either undetected or reported concentrations were less than PDWS for these elements

As a precautionary measure during the operation of irrigation well #54278 Lindsay Manufacturing sampled the Beller stock and domestic well This well water sample collection was not a component of the RI monitoring plan however the analytical data collected will be included in the inorganic results discussion of the off-site lower portion of the aquifer Table 4 3-5 is a summary of the water sample results from May 1989 to October 1989 All the wells exhibit background pH except the irrigation well which exhibits fluctuation in pH near background The sulfate levels in the domestic well are at background however the stock well exhibited an elevated level in spring reducing through the summer irrigation season This same trend is exhibited by zinc levels in the stock well Water quality in the domestic well met applicable drinking water standards throughout the entire period The irrigation well exhibited elevated sulfates and zinc

Table 4 3-5

Laboratory Results
Beller Wells (mg/l)

Sample	Date	pH	Sulfate	Zinc
Beller Stock	5/18 21/89	6 4	725	18 21
	6/19 21/89	7 0	164	0 015
	7/17 19/89	7 1	122	0 03
	7/26/89	7 0	114	0 059
	8/17/89	7 1	61	0 079
Irrigation Well # 54278	12/87	6 9	750	2 2
	5/17 18/88	6 4	774	1 14
	6/19 21/89	6 3	855	19 1
	7/17 19/89	6 2	933	28 7
	7/26/89	7 3	835	15 3
	9/20/89	6 1	750	14
Beller Domestic	5/17 18/88	6 9	38	0 01
	5/18 21/89	7 1	27	0 17
	6/19 21/89	7 1	27 9	<0 003
	7/17 19/89	7 1	31 3	0 906
	7/26/89	7 2	29 7	0 013
	8/17/89	7 23	31	0 227
Drinking Water Standard		NA	250	5

ND Not Detected
NA Not Applicable

these compounds rose during the summer peaked and began to decline at the end of the irrigation season These trends are indicative of the irrigation well s capacity to disperse the acidic waters and to recover the metal and organics that were transported toward the stock well during the non-irrigation season

Summary

On-site and off-site inorganic ground-water quality monitored in the upper portion of the aquifer and entire aquifer between February 1989 and January 1990 was generally within background levels for all parameters with the exception of select metal results reported in on-site monitoring wells MW87-3 and MW87-6

On-site wells screened in the perched sand channel contained acidic pH levels and elevated levels of zinc iron and sulfate (concentrations exceeded the SDWS for these elements)

Ground-water quality on site in the lower portion of the aquifer contains acidic pH levels and elevated levels of zinc iron and sulfate only on the southeast corner of the site as shown in Figures 4 3 -10a b c and d through 4 3-13 a b c and d This acidic contamination with its organic components extends off-site to the southeast and encompasses TMW88-6 Elevated levels of zinc and sulfate only were found at irrigation well #54278 during this period which indicates a southeastern end of the occurrence between TMW88-6 and irrigation well #54278 The limited set of compounds at well #54278 indicate the occurrence is a dispersion of the contamination by the well

As of the conclusion of the irrigation season (October 1989) water quality in the Beller domestic well met applicable inorganic water standards The stock well water quality exhibited elevated zinc concentrations in May which rapidly dropped and remained within applicable drinking water standards by June

4 3 3 Organics

Table 4 3-6 lists the ground-water sampling locations monitored between June 1987 and January 1990 For purposes of this discussion the organic ground-water monitoring data will be discussed according to location screened interval and the time periods listed in Table 4 3-6 Organic ground-water monitoring parameters and laboratory sample results are provided in Appendix XI-D

Table 4 3-6
Organic Ground Water Monitoring
1987-1990

Well Location and Screened Portion of the Aquifer	Time Period	
	6/16/87 to 10/21/88	2/15/89 to 1/90
On-Site		
Upper Portion	82 1M 82 2M 82 3M 82-4M	82 2M MW89 12 MW89 15
Lower Portion	P 1 through P-4 P-6 through P 9 MW87 7 MW87 8 TMW88 3 TMW88 4 TMW88 5 TMW88 9 Old Well	P 1 P 6 P 9 MW87 7 MW87 8 TMW88 5 TMW88 9
Aquifer	Fire Well MW87 1 through MW87-4 MW87 6	Fire Well MW87 1 through MW87-4 MW87 6
Perched Sand Channel	Not Monitored	MW89 13 MW89 14
Off-Site		
Upper Portion	Not Monitored	Moravec Well MW89 9A MW89 10A MW89 11A
Lower Portion	TMW88 1 TMW88 6 TMW88 7 TMW88 8 TMW88 10 TMW88 11 54278 Beller Domestic Well 33637	TMW88 1 TMW88 6 TMW88 8 MW89 9B MW89 10B MW89 11B 54278 Beller Domestic Well 33637
Aquifer	Old Lindsay Public Supply Well MW87 5 50378	Old Lindsay Public Supply Well MW87 5 50378

Well screen interval includes upper and lower portions of the aquifer

4 3 3 1 June 16 1987 to September 21 1988

On-Site Ground-Water Quality

Between June 1987 and September 1988 ground-water samples were collected at various dates from 28 on-site and 12 off-site monitoring wells screened in the upper and lower portion of the aquifer and in the aquifer (Table 4 3-5)

Although not all the laboratories used during this period were EPA contract laboratories (i e HWST and A&L) the analyses were according to acceptable EPA methods at the date of analyses

The presence of chloroform and methylene chloride in select ground-water samples collected on various dates during this period has been attributed to laboratory contamination or artificial introduction (presence in transport blank samples)

Upper Portion of the Aquifer

On-site monitoring wells screened in the upper portion of aquifer included 82-1M 82-2M 82-3M and 82-4M (Figure 1 2-4) Ground water was monitored at these locations only on July 16 1987 Monitoring well 82-2M was included in the ground-water monitoring program at various dates between June 1987 and September 1988 As previously discussed Lindsay s study has found that Wells 82-1M 3M and 4M act as drains to the perched sand channel The compounds occurring at these three wells are indicative of the water quality of the perched water table in the sand channel at that time

A summary of organic results of these wells and associated maximum contaminant levels (MCLs) are listed in Table 4 3-7 A total of ten organic compounds were detected in various wells at this time 1 2-DCE TCA PCE and toluene concentration were reported in 82-1M 82-3M and 82-4M and ranged in concentrations from 0 012 mg/l to 6 1 mg/l Concentrations of 1 1-DCE and PCE exceeded the MCL and the proposed MCL respectively in these monitoring wells The ground-water sample collected from 82-1M contained the highest individual organic concentrations reported at this time In addition to 1 1-DCE and PCE concentrations reported in 82-1M 1 2-DCE 1 2-DCA and TCA concentrations reported in this sample also exceeded the MCL for each compound Concentrations of ethylbenzene and toluene reported at this time were below the MCL for these compounds

There were no organic compounds detected in monitoring well 82-2M during this time period This well did not penetrate the sand channel

Table 4 3-7
Summary of Volatile Organic Results
Water Samples Collected from Initial Facility Wells
June 16,1987
(mg/l)

Compound	Well Location				MCL
	82 1M	82 2M	82 3M	82-4M	
1 1 DCE	1 6	0 005U	0 093	0 051	0 007
1 2 DCE	0 078	0 005U	0 005U	0 005U	0 07
1 1 DCA	0 14	0 005U	0 005U	0 005U	NS
1 2 DCA	0 015	0 005U	0 005U	0 005U	0 005
1 1 1 TCA	6 5	0 005U	0 19	0 18	0 20
1 1 2 TCA	0 017	0 005U	0 005U	0 005U	NS
PCE	1 2	0 005U	0 26	0 19	0 005
TCE	0 012	0 005U	0 005U	0 005U	NS
Ethylbenzene	0 022	0 005U	0 005U	0 005U	0 7
Toluene	0 13	0 005U	0 012	0 026	2 00

U Undetected
MCL Maximum Contaminant Level
NS No Standard Available

An isoconcentration map depicting the distribution of total organics in the aquifer from March 1988 through August 1988 is provided in Figure 4 3-15

Lower Portion of the Aquifer

On-site monitoring wells screened in the lower portion of aquifer included 8 piezometers 3 monitoring wells and 6 temporary monitoring wells (Table 4 3-6) The well locations are provided in Figure 1 2-4 Piezometers and temporary monitoring wells were monitored intermittently and the monitoring wells were monitored on a quarterly basis during this period

1 1-DCE concentrations reported in P-1 through P-4 P-6 through P-9 MW87-7 MW87-8 TMW88-3 through TMW88-5 TMW88-9 and the Old Well ranged from undetected (0 005 mg/l detection limit) to 0 15 mg/l Time versus 1 1-DCE concentrations reported in P-1 P-9 MW87-7 TMW88-5 TMW88-9 during this period are provided in Figure 4 3-16a 1 1-DCE concentrations reported in all wells screened in the lower portion of the aquifer at various monitoring dates during this period exceeded the MCL (0 007 mg/l) with the exception of MW87-8 P-3 P-6 P-7 and the Old Well

TCA concentrations reported in P-1 through P-4 P-6 through P-9 MW87-7 MW87-8 TMW88-3 through TMW88-5 TMW88-9 and the Old Well ranged from undetected (0 005 mg/l detection limit) to 1 23 mg/l TCA concentrations reported in P-4 and P-9 exceeded the MCL (0 2 mg/l) at various monitoring dates during this period Time versus TCA concentrations reported in P-1 P-6 P-9 TMW88-5 TMW88-9 and MW87-7 are provided in Figure 4 3-16b TCA concentrations reported in P-2 through P-4 P-7 P-8 MW87-8 TMW88-3 and TMW88-4 were below the MCL

PCE concentrations reported in P-1 through P-4 P-6 through P-9 MW87-7 MW87-8 TMW88-3 through TMW88-5 and TMW88-9 ranged from undetected (0 005 mg/l detection limit) to 0 23 mg/l Time versus PCE concentrations reported in P-1 P-6 P-9 TMW88-5 TMW88-9 and MW87-7 are provided in Figure 4 3-16c PCE concentrations reported in all wells screened in the lower portion of the aquifer at various monitoring dates during this period exceeded the proposed MCL (0 005 mg/l) with the exception of MW87-7 PCE was not detected in MW87-7 during this period Neither EPA nor the State of Nebraska has promulgated a final MCL for PCE

Other organic compounds detected during this period included benzene 1 2-DCE 1 1 2-TCA 1 2-DCA bromoform ethylbenzene and toluene and were reported in select piezometers Benzene was reported in P-4 (0 035 mg/l) P-9 (0 08 mg/l) and the Old Well (0 022 mg/l) on March 10 and March 11 1988 only 1 2-DCE (0 01 mg/l) was reported in P-4 only on March 10 1988 and was below the MCL (0 07 mg/l) 1 1 2-TCA bromoform 1 2-DCA ethylbenzene and toluene were reported in P-9 on March 11 1988 only and ranged in concentration from 0 002

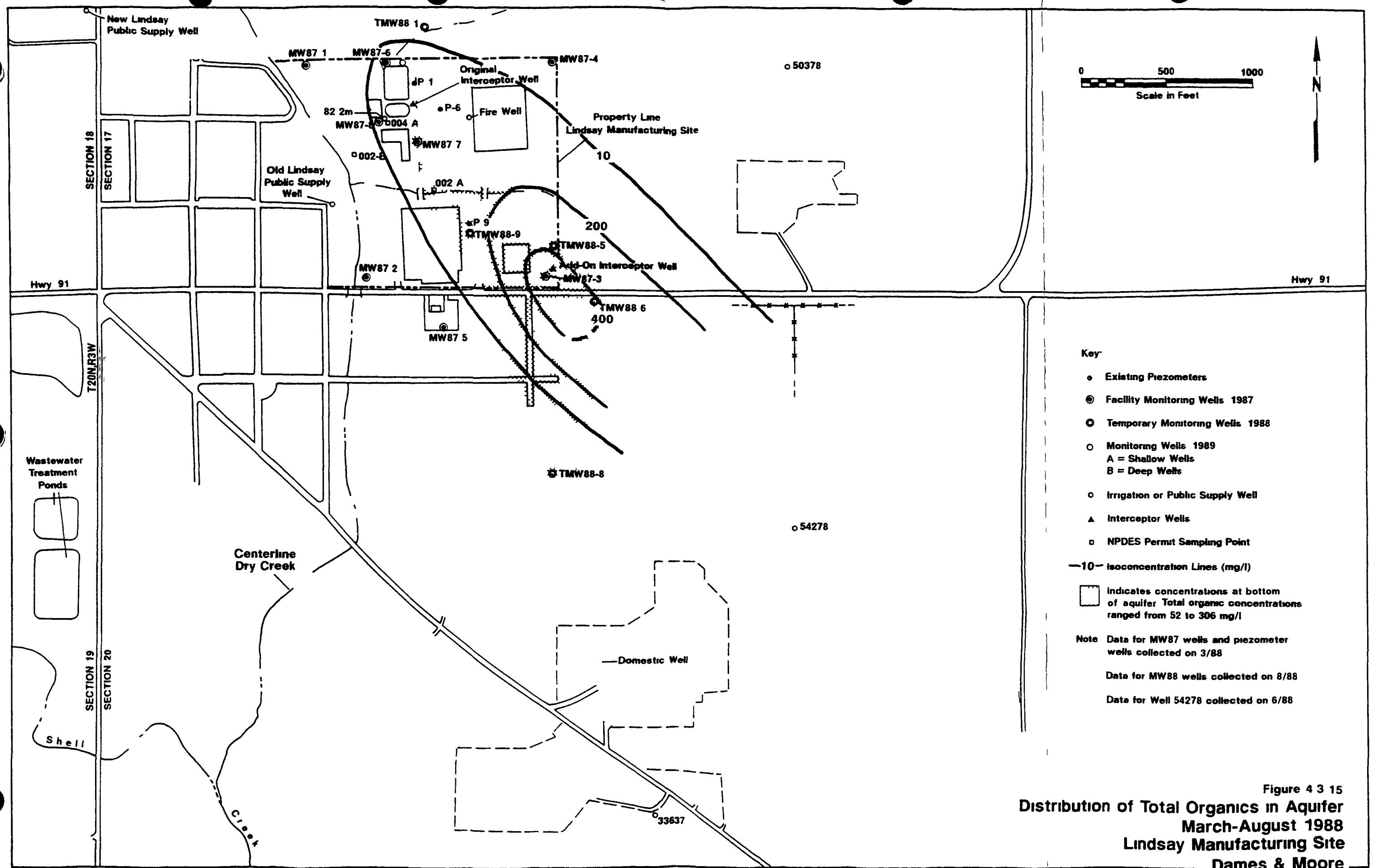

Figure 4 3 15
Distribution of Total Organics in Aquifer
March-August 1988
Lindsay Manufacturing Site
Dames & Moore

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Figure 4 3-16a
Time vs 1,1-DCE
On-Site Monitoring Wells
Screened in Lower Portion of Aquifer

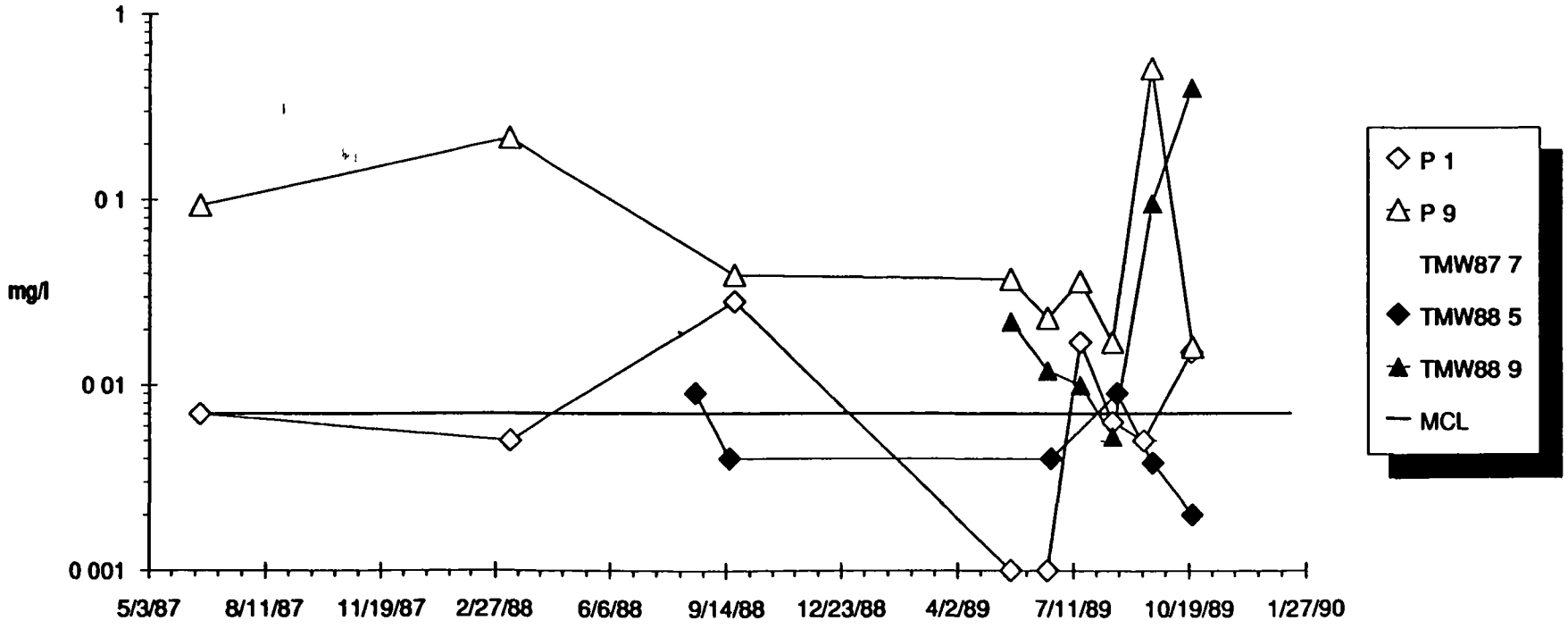


Figure 4 3-16b
Time vs 1,1,1-TCA
On-Site Monitoring Wells
Screened in Lower Portion of Aquifer

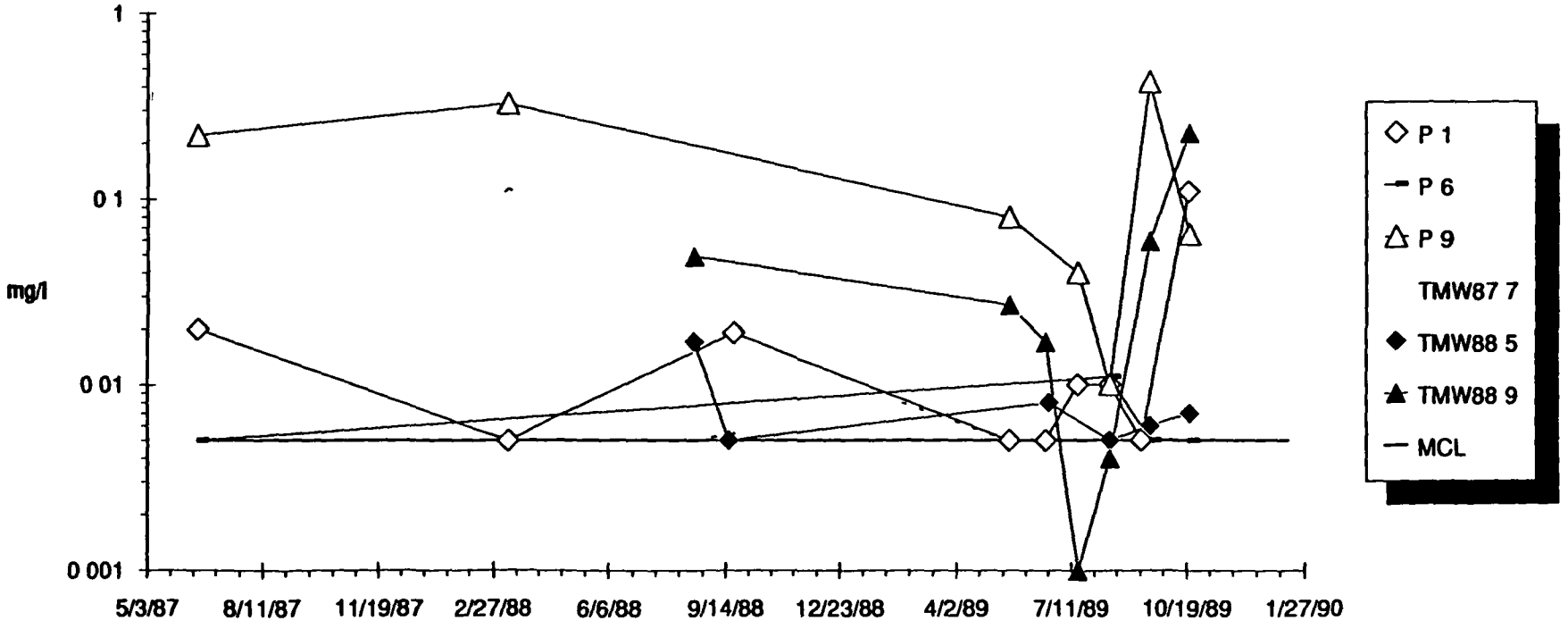
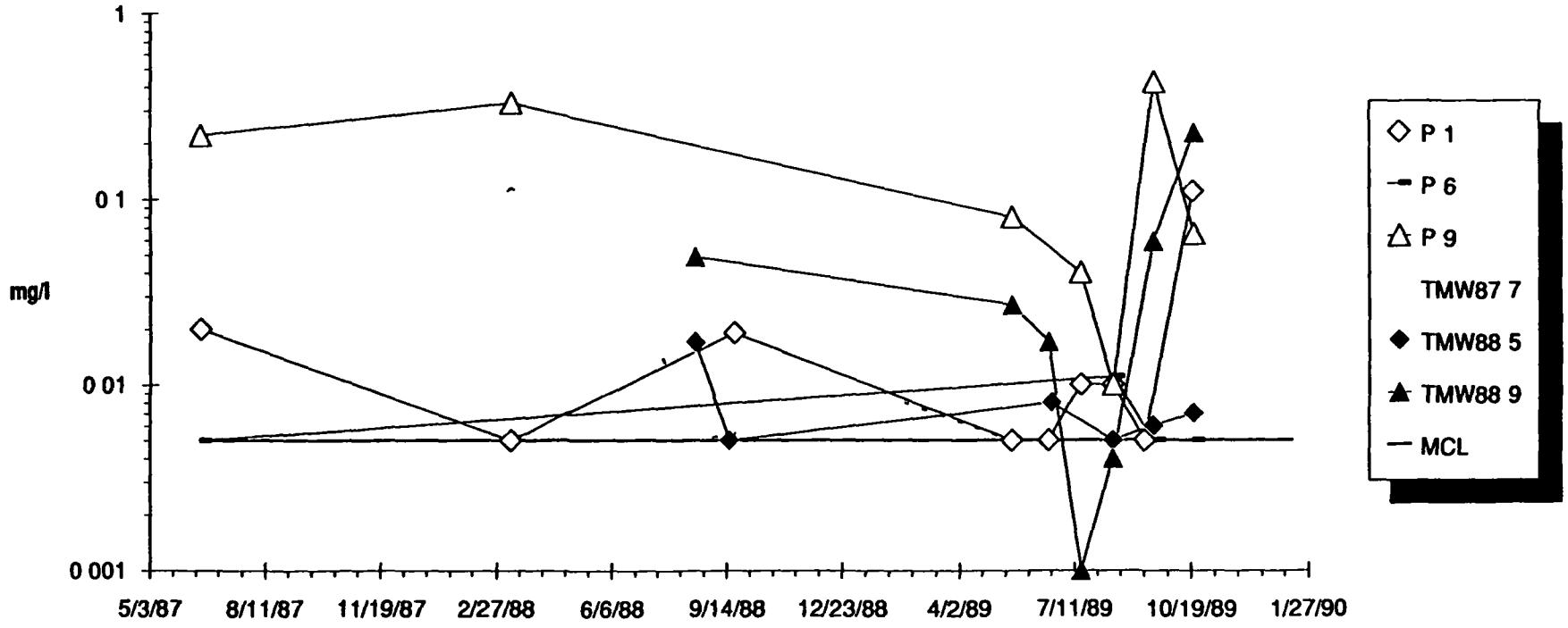


Figure 4 3-16c
Time vs PCE
On-Site Monitoring Wells
Screened in Lower Portion of Aquifer



mg/l to 0 007 mg/l 1 2-DCE ethylbenzene and toluene concentrations reported in P-9 were below the MCLs for these compounds There are no available MCLs for 1 1 2-TCA and bromoform although only trace levels of these compounds were detected

An isoconcentration map depicting the distribution of total organics in the bottom of the aquifer from March 1988 through August 1988 is provided in Figure 4 3-15

Aquifer

On-site monitoring wells Fire Well MW87-1 through MW87-4 and MW87-6 screened in the aquifer were monitored on a quarterly basis between June 1987 and September 1988 (Table 4 3-6)

1 1-DCE concentrations reported in Fire Well Old Well MW87-1 through MW87-5 and MW87-6 ranged from undetected to 0 26 mg/l TCA concentrations ranged from undetected to 2 0 mg/l and PCE concentrations ranged from undetected to 0 44 mg/l 1 1-DCE TCA and PCE were not detected in the Fire Well MW87-1 and MW87-4 during this period

1 1-DCE concentrations reported in MW87-3 and MW87-6 exceeded the MCL (0 007 mg/l) during this period 1 1-DCE concentrations reported in MW87-6 were undetected from March 1988 through September 1988

TCA and PCE concentrations reported in MW87-3 exceeded the MCLs for these compounds during this period Time versus 1 1-DCE TCA and PCE concentrations reported in MW87-3 during this period are provided in Figure 4 3-17 1 1 1-TCA and PCE were reported in MW87-6 at various monitoring dates but were below the MCL for 1 1 1-TCA and the proposed MCL for PCE

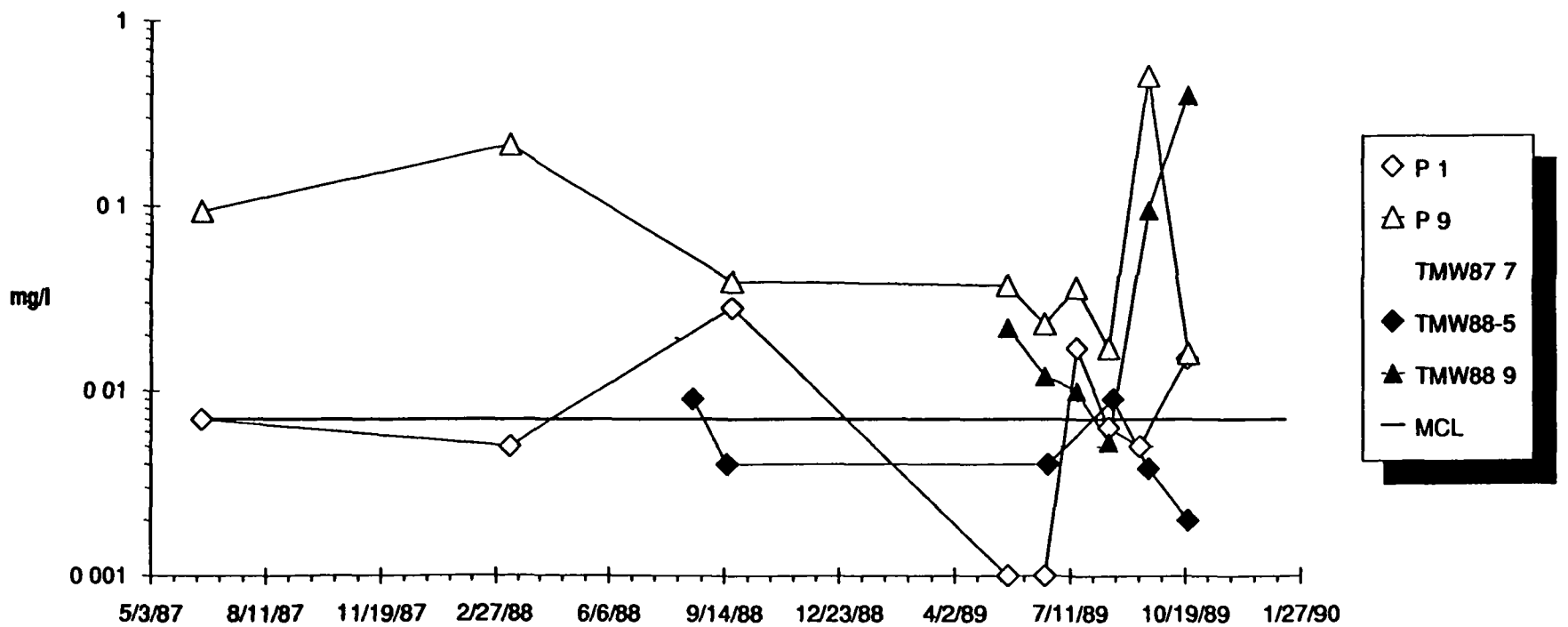
An isoconcentration map depicting the distribution of total organics in the aquifer from March 1988 through August 1988 is provided in Figure 4 3-15

Off-Site Ground-Water Quality

Lower Portion of the Aquifer

Six temporary wells irrigation well 54278 Beller domestic well and irrigation well 33637 were included in the ground-water monitoring program (Table 4 3-6) Temporary wells were monitored twice and the two irrigation wells and Beller domestic well were monitored once during this period

Figure 4 3-17a
Time vs 1,1-DCE
On-Site Monitoring Wells
Screened in Lower Portion of Aquifer



1 1-DCE concentrations reported in TMW88-6 TMW88-7 TMW88-8 TMW88-10 TMW88-11 and irrigation well #54278 ranged from 0 006 mg/l to 0 165 mg/l 1 1-DCE concentrations reported in TMW88-6 exceeded the MCL (0 007 mg/l) 1 1-DCE (0 006 mg/l) was reported in irrigation well 54278 on June 21 1988 and was below the MCL Time versus 1 1-DCE concentrations reported in TMW88-6 and irrigation well 54278 during this period are presented in Figures 4 3-18a and 4 3-18b respectively

1 1 1-TCA concentrations reported in TMW88-6 TMW88-7 TMW88-8 TMW88-10 TMW88-11 irrigation well 54278 Beller domestic well and irrigation well 33637 ranged from undetected to 0 16 mg/l 1 1 1-TCA concentrations reported in these wells were either undetected or below the MCL (0 2 mg/l) with the exception of TMW88-6 Time versus 1 1 1-TCA concentrations reported in TMW88-6 and irrigation well 52478 during this period are presented in Figures 4 3-18a and 4 3-18b respectively

PCE concentrations reported in TMW88-1 TMW88-6 TMW88-7 TMW88-8 TMW88-10 TMW88-11 irrigation well #54278 Beller domestic well and irrigation well #33637 ranged from undetected to 0 17 mg/l during this period PCE concentrations reported in irrigation well #54278 and TMW88-6 exceeded the proposed MCL (0 007 mg/l) during this period Time versus PCE concentrations reported in TMW88-6 and irrigation well #54278 during this time period are presented in Figures 4 3-18a and 4 3-18b respectively

An isoconcentration map depicting the distribution of total organics in the aquifer from March 1988 through August 1988 is provided in Figure 4 3-15

Aquifer

Offsite monitoring wells screened in the aquifer that were included in the ground-water monitoring program between June 1987 and September 1988 include Old Lindsay Public Supply Well MW87-5 and irrigation well #50378 The Old Lindsay Public Supply Well and MW87-5 were monitored on a quarterly basis and irrigation well #50378 was monitored once

1 1-DCE 1 1 1-TCA and PCE were not detected in the Old Lindsay Public Supply Well and irrigation well #50378 during this period 1 1-DCE and PCE concentrations reported in MW87-5 were either undetected or less than the MCL for 1 1-DCE and the proposed MCL for PCE 1 1 1-TCA concentrations reported in MW87-5 ranged from 0 006 mg/l to 0 021 mg/l PCE was reported in MW87-5 in March 1988 and was undetected from June 1988 to September 1988

There were no additional organics detected in Old Lindsay Public Supply Well MW87-5 and irrigation well #50378 during this period

Figure 4 3-18a
Time vs 1,1-DCE, 1,1,1-TCA, PCE
Off-Site Monitoring Well (MW88-6)
Screened in Lower Portion of Aquifer

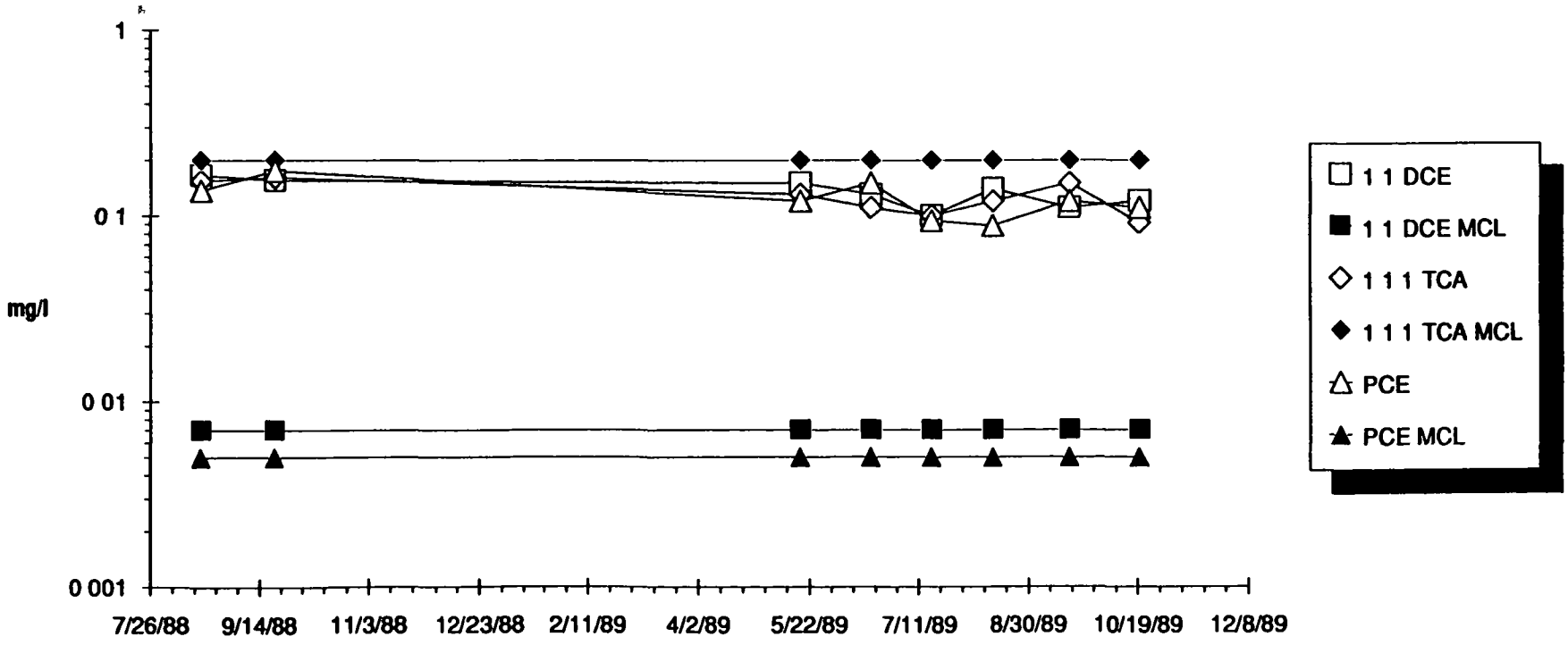
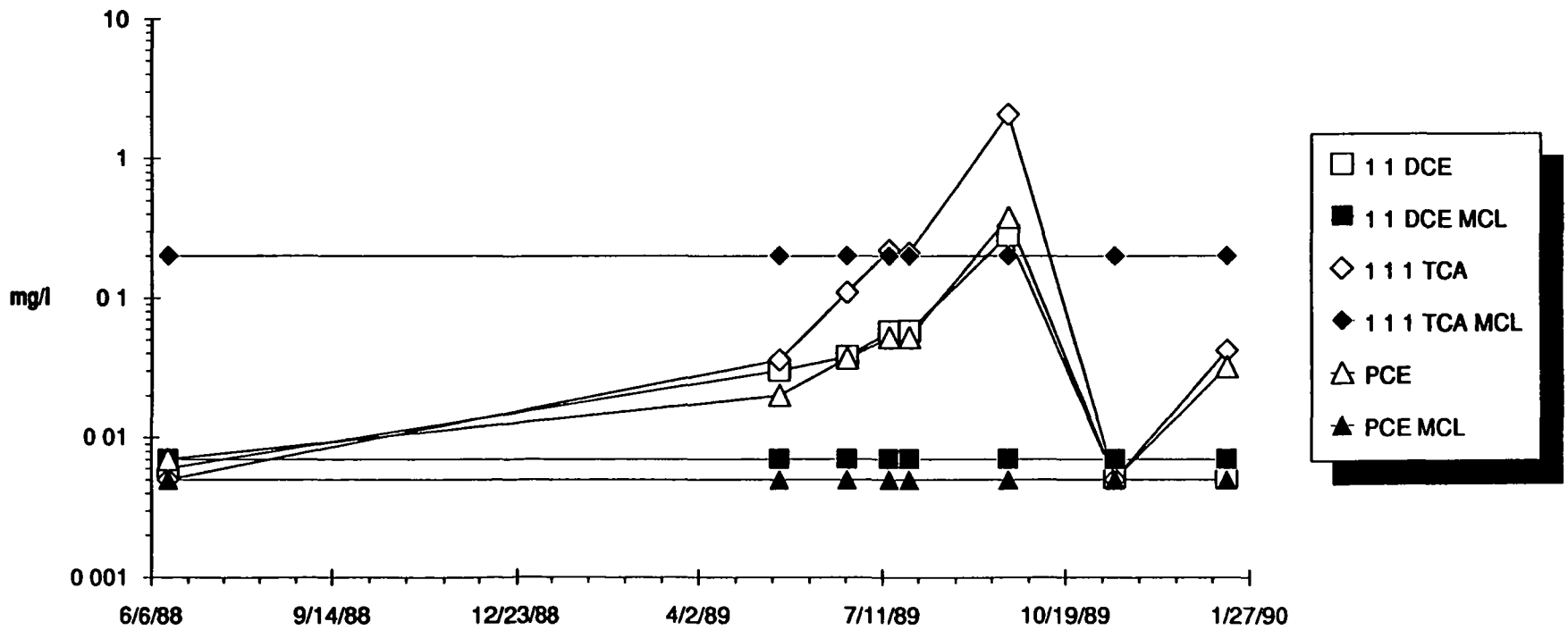


Figure 4 3-18b
Time vs 1,1-DCE, 1,1,1-TCA, PCE
Off-Site Monitoring Well (54278)
Screened in Lower Portion of Aquifer



An isoconcentration map depicting the distribution of total organics in the aquifer from March 1988 through August 1988 is provided in Figure 4 3-15

Summary

On-site monitoring wells 82-1M 82-3M and 82-4M screened in the upper aquifer and monitored in June 1988 contained elevated levels (> 1 mg/l) of 1 1-DCE 1 1 1-TCA and PCE Additional trace organic compounds were also found in these wells at this time These wells surrounded the former disposal pit and also contained elevated inorganic compounds as discussed in Section 4 3 2 Ground-water quality in 82-2M remained free of organic compounds between June 1987 and September 1988 On-site monitoring wells screened in the aquifer were generally within MCLs for organics between June 1987 and September 1988 with the exception of MW87-3 and MW87-6 which are located on the southeast corner and northern side (respectively) of the site

On-site monitoring wells screened in the lower portion of the aquifer contained concentrations of 1 1-DCE 1 1 1-TCA and PCE which exceeded the MCLs for these compounds or in the case of PCE the proposed MCL The presence of total organic compounds extended from MW87-7 southeast to MW87-3 during this period The highest concentration of total organics was found in the southeast corner of the site Organic occurrence extended off site to the southeast and encompassed TMW88-6 and TMW88-8 which also contained concentrations of select organics above the MCL Organics at or slightly above the detection limit in June 1988 indicated that organic contamination from the bottom of the aquifer had begun to disperse southeast to irrigation well #54278 (Figure 1 2-4)

The occurrence of organics on-site in the upper aquifer and in the bottom of the aquifer on-site and off-site coincides with the presence of elevated concentrations of inorganics found at these locations during the same period

4 3 3 2 February 15 1989 to January 17 1990

A total of 18 on-site and 16 off-site monitoring locations were included in the ground-water monitoring program between February 15 1989 and January 1990 (Table 4 3-6) Well locations are provided in Figure 1 2-4 Ground-water samples were collected on a quarterly monitoring schedule on the following dates February 15 1989 May 16 through 21 1989 August 14 through 16 1989 and November 17 1989 An additional round of well sampling included in the quarterly monitoring was conducted between January 8-17 1990 Select temporary wells and piezometers were monitored on a monthly basis from May 1989 through October 1989

Organic sample results obtained during this period are listed in Appendix XI-E QA/QC organic data validation reviews were performed on the data collected during this period and are provided in Appendix XI-F

Isoconcentrations maps presenting the distribution of total organics in the bottom of the aquifer on February 15 1989 did not included sample results of temporary monitoring wells or piezometers because these locations were not monitored at this time

On-Site Ground-Water Quality

Upper Portion of the Aquifer

On-site monitoring wells 82-2M MW89-12 MW89-15 screened in the upper portion of the aquifer were included in the ground-water monitoring program during this period Ground-water quality was monitored at MW89-12 and MW89-15 on November 17 1989 and January 8 to 17 1990 only

1 1 -DCE concentrations reported in MW89-12 and MW89-15 ranged from 0 05 mg/l to 0 98 mg/l TCA concentrations ranged from 0 18 mg/l to 0 32 mg/l and PCE concentrations ranged from 0 04 mg/l to 0 270 mg/l 1 1-DCE TCA and PCE concentrations reported in these wells exceeded the MCLs for 1 1-DCE and TCA and the proposed MCL for PCE during this period (0 007 mg/l 0 2 mg/l 0 005 mg/l respectively)

TCE was reported in MW89-12 ranging in concentration from 0 003 mg/l to 0 004 mg/l 1 2-DCE and 1 1-DCA were also reported in this well at 0 01 mg/l and 0 049 mg/l respectively during this period

Isoconcentration maps of the distribution of total organics in the aquifer for February 15 1989 May 16 through 21 1989 August 14 through 17 1989 and November 17 1989 are presented in Figures 4 3-19a 4 3-19b 4 3-19c and 4 3-19d

Lower Portion of the Aquifer

On-site monitoring wells screened in the lower portion of aquifer included Old Well piezometers P-1 P-6 and P-9 monitoring wells MW87-7 and MW87-8 and temporary monitoring wells TMW88-5 and TMW88-9 (Table 4 3-6)

1 1-DCE concentrations reported in P-1 P-6 P-9 MW87-7 TMW88-5 and TMW88-9 ranged from 0 002 mg/l to 0 51 mg/l 1 1-DCE was not detected in MW87-7 and MW87-8 during this period 1 1-DCE concentrations reported in P-1 P-6 P-9 TMW88-5 and TMW88-9

exceeded the MCL (0 007 mg/l) at various monitoring dates during this period Time versus 1 1-DCE concentrations reported in P-1 P-9 MW87-7 TMW88-5 and TMW88-9 during this period are provided in Figure 4 3-16a

TCA concentrations reported in P-1 P-6 P-9 MW87-7 TMW88-5 and TMW88-9 ranged from 0 005 mg/l to 2 9 mg/l TCA concentrations reported in MW87-7 P-1 and P-6 were below the MCL (0 2 mg/l) Time versus TCA concentrations reported in P-1 P-6 P-9 TMW88-5 TMW88-9 and MW87-7 are provided in Figure 4 3-16b TCA concentrations reported in P-9 and TMW88-9 exceeded the MCL (0 2 mg/l) at various monitoring dates during this period TCA concentrations reported in P-2 through P-4 P-7 P-8 MW87-8 TMW88-3 and TMW88-4 were below the MCL The highest individual TCA concentration was found in P-9 on September 18 1989

PCE concentrations reported in P-1 P-6 P-9 MW87-7 TMW88-5 and TMW88-9 ranged from 0 007 mg/l to 0 43 mg/l Time versus PCE concentrations reported in P-1 P-6 P-9 TMW88-5 TMW88-9 and MW87-7 are provided in Figure 4 3-16c PCE concentrations reported in all wells screened in the lower portion of the aquifer at various monitoring dates during this time period exceeded the proposed MCL (0 005 mg/l)

1 1-DCA TCE 1 2-DCE 1 2-DCA and ethylbenzene were reported at P-6 P-9 TMW88-5 and TMW88-9 ranging in concentration from 0 0008 mg/l to 0 024 mg/l 1 1 -DCA was reported in P-9 from May 1989 to October 1989 and was reported periodically at P-6 TMW88-5 and TMW88-9

In October 1989 1 1-DCA and TCE concentrations were reported in P-9 (0 009 mg/l) TCE was reported in P-9 and TMW88-5 in June 1989 and ranged in concentration from 0 0008 mg/l to 0 0012 mg/l TCE was reported only in P-9 in August 1989 (0 0009 mg/l) and September 1989 (0 005 mg/l) and was not detected in October 1989

1 2-DCE and 1 2-DCA were detected in P-9 only in June August and September 1989 and ranged in concentration from 0 006 mg/l to 0 024 mg/l with the highest concentrations occurring in September 1989 P-9 sample concentrations of 1 2-DCE were below the MCL (0 07 mg/l) and were above the MCL for 1 2-DCA (0 005 mg/l)

Ethylbenzene was reported in P-9 (0 003 mg/l) in June 1989 and in TMW88-5 (0 0022 mg/l) in September 1989 These levels were below the MCL (0 70 mg/l) for this compound

Isoconcentration maps of the distribution of total organics in the bottom of the aquifer for February 15 1989 May 16 through 21 1989 August 14 through 17 1989 and November 17 1989 are presented in Figures 4 3-19a 4 3-19b 4 3-19c and 4 3-19d

Aquifer

Six on-site monitoring wells screened in the aquifer were monitored during this period (Table 4 3-6) Monitoring well locations are provided in Figure 1 2-4

1 1-DCE concentrations reported in MW87-3 and MW87-6 ranged from undetected to 0 2 mg/l 1 1-DCE levels reported in MW87-6 only exceeded the MCL (0 007 mg/l) on November 17 1989 1 1-DCE was undetected in this well prior to this date 1 1-DCE concentrations reported in MW87-3 ranged from undetected to 0 26 and exceeded the MCL on various monitoring dates during this period 1 1-DCE concentration reported in MW87-3 during this time period are provided in Figure 4 3-17

TCA concentrations reported in MW87-6 were below the MCL (0 2 mg/l) during this period TCA concentrations reported in MW87-3 ranged from 0 013 mg/l to 0 29 mg/l TCA concentrations in this well exceeded the MCL between February 1989 and May 1989 and decreased below the MCL after that period TCA concentrations reported in MW87-3 during this period are provided in Figure 4 3-17

PCE concentrations reported in MW87-3 and MW87-6 ranged from undetected to 0 061 mg/l PCE concentrations reported in these wells were either at or near the proposed MCL (0 005 mg/l) with the exception of PCE levels reported in MW87-3 on February 15 1989 (0 037 mg/l) and May 16 1989 (0 061 mg/l) PCE concentrations reported in MW87-3 during this period are provided in Figure 4 3-17

Isoconcentration maps of the distribution of total organics in the aquifer for February 15 1989 May 16 through 21 1989 August 14 through 17 1989 and November 17 1989 are presented in Figures 4 3-19a 4 3-19b 4 3-19c and 4 3-19d

Perched Sand Channel

Two on-site monitoring wells MW89-13 and MW89-14 screened in the perched sand channel were monitored on November 17 1989 and January 17, 1990 during this time period Well locations are provided in Figure 1 2-4

1 1-DCE concentrations reported in MW89-13 and MW89-14 ranged from 0 01 mg/l to 0 053 mg/l which exceeded the MCL (0 007 mg/l) on both monitoring dates TCA concentrations reported in these wells ranged from undetected to 0 2 mg/l TCA concentrations detected in MW89-13 were either undetected or below the MCL (0 2 mg/l) TCA concentrations reported in MW89-14 exceeded the MCL PCE concentrations reported in both wells ranged from 0 015 mg/l to 0 19 mg/l and exceeded the proposed MCL (0 005 mg/l) for both dates monitored during this period

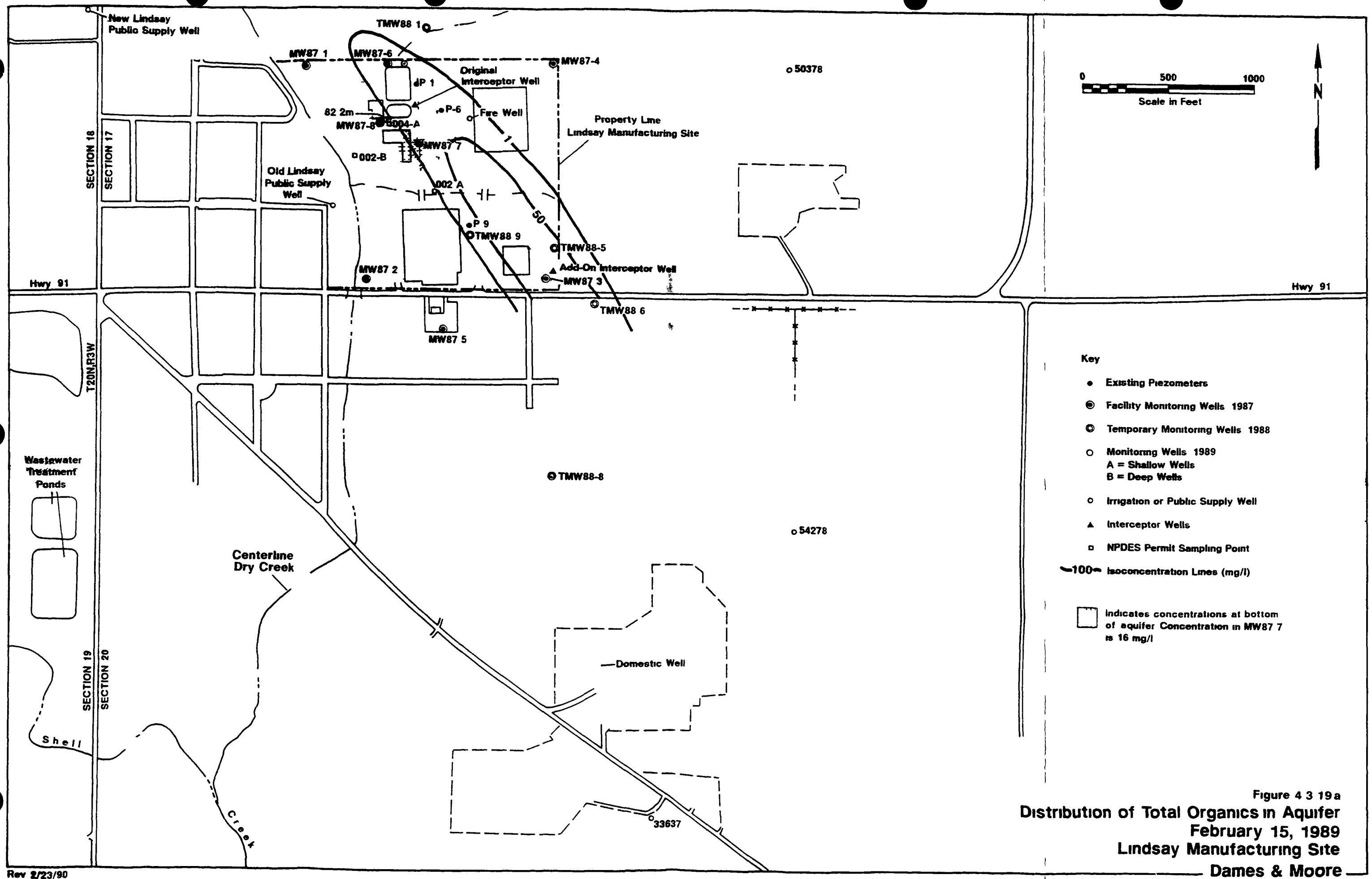


Figure 4 3 19a
Distribution of Total Organics in Aquifer
February 15, 1989
Lindsay Manufacturing Site
Dames & Moore

Rev 2/23/90

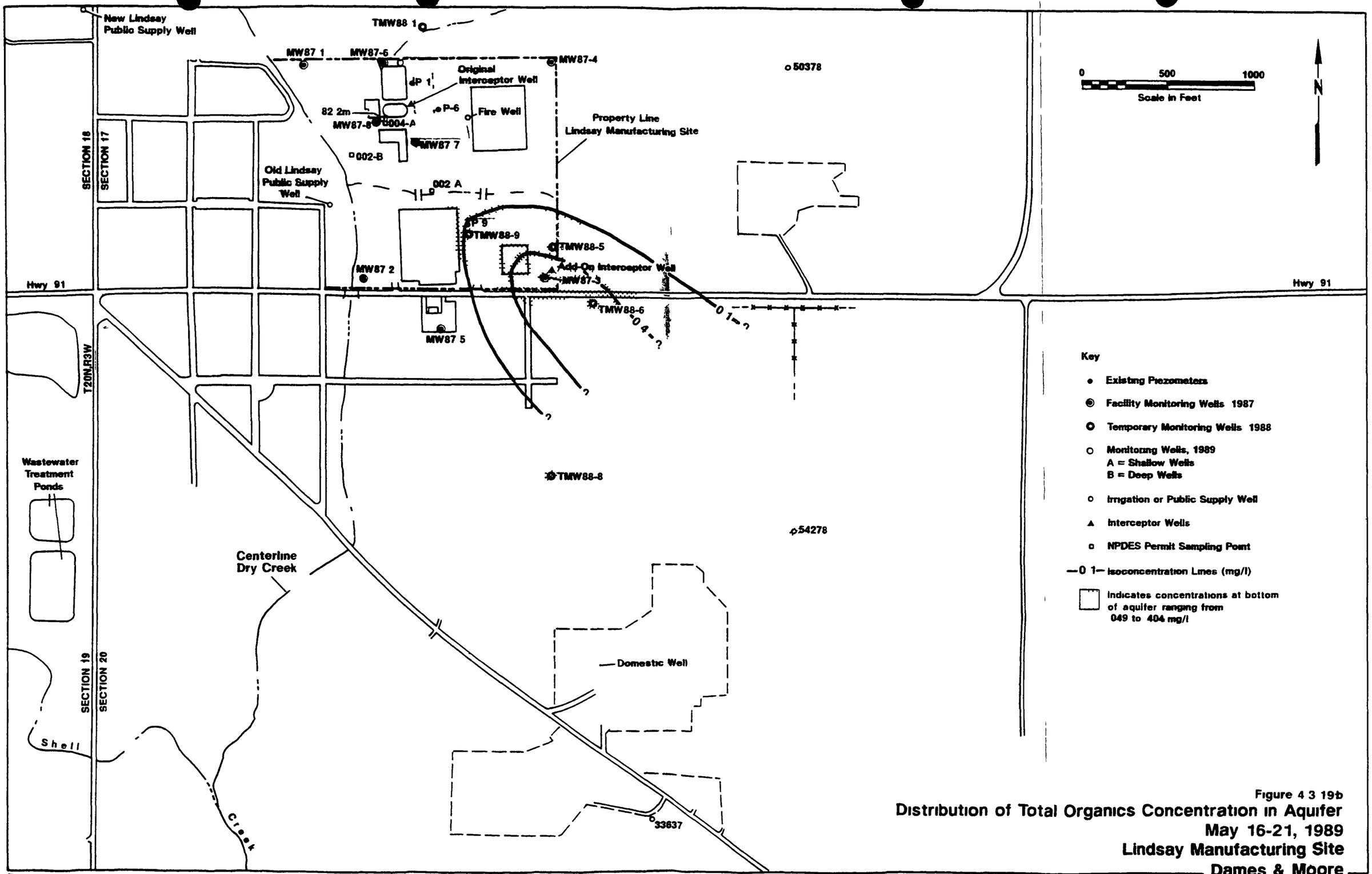


Figure 4 3 19b
Distribution of Total Organics Concentration in Aquifer
May 16-21, 1989
Lindsay Manufacturing Site
Dames & Moore

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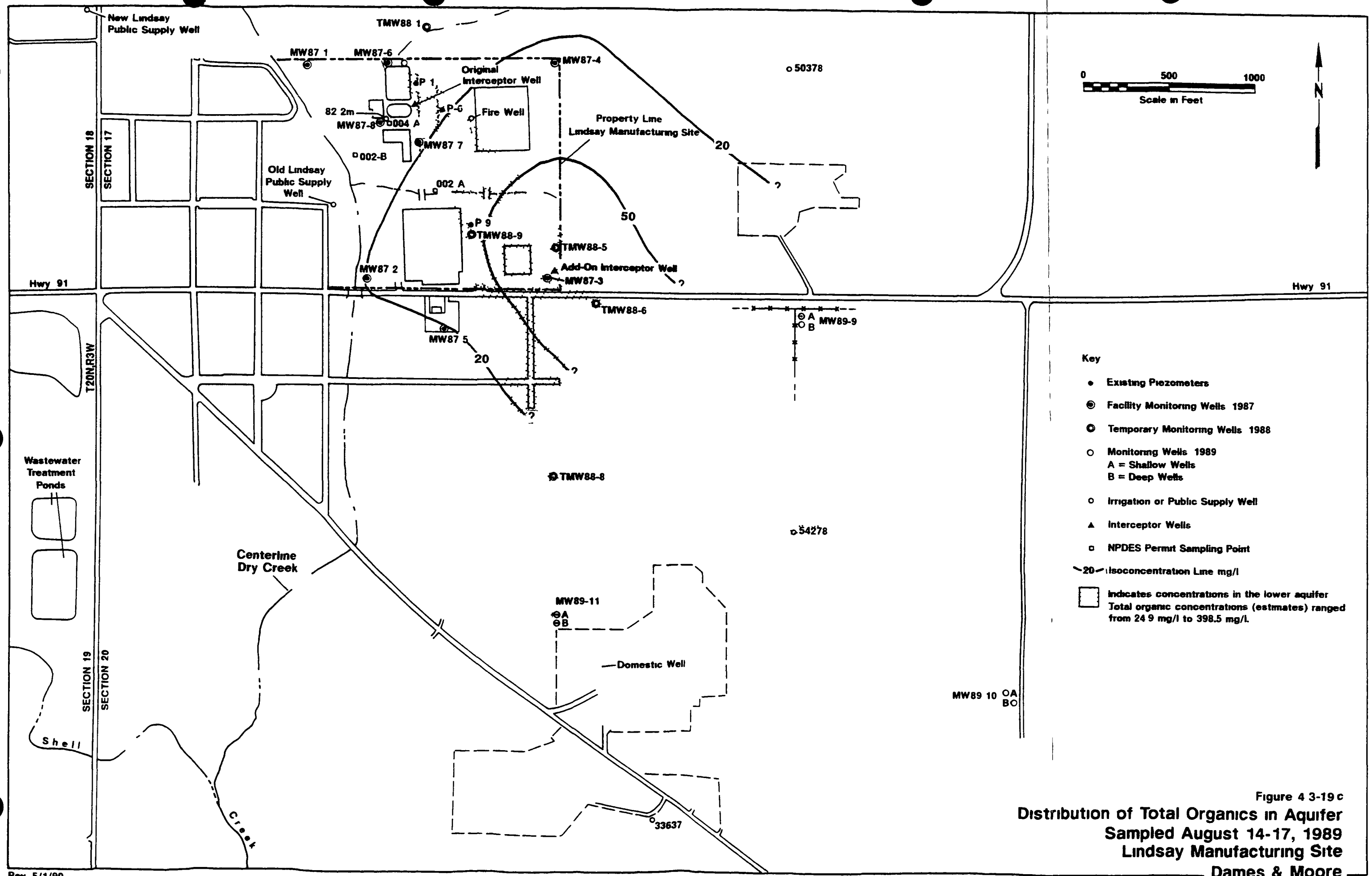

Figure 4 3-19 c

Distribution of Total Organics in Aquifer Sampled August 14-17, 1989 Lindsay Manufacturing Site

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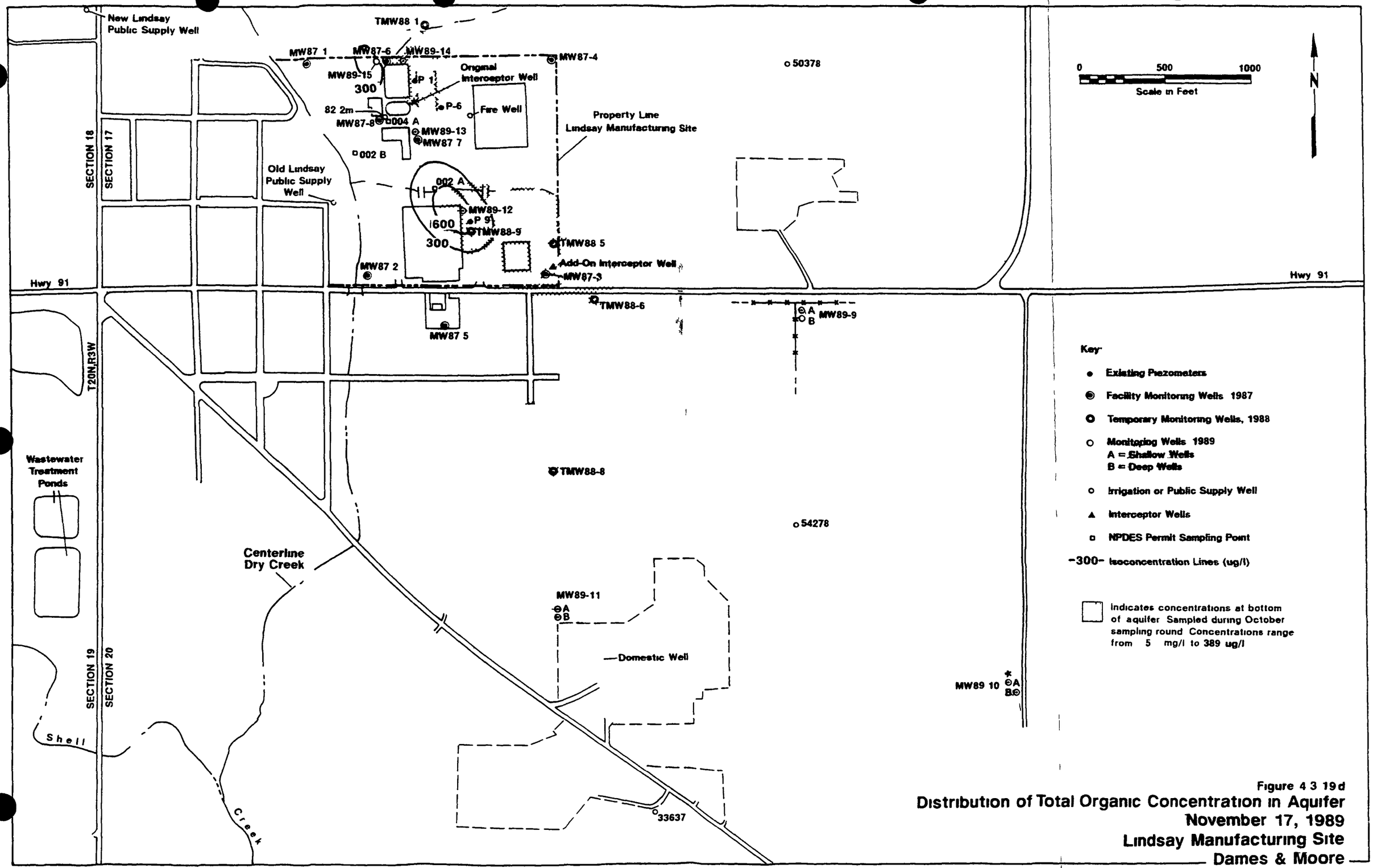

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Figure 4 3 19d

Distribution of Total Organic Concentration in Aquifer
November 17, 1989
Lindsay Manufacturing Site
Dames & Moore

1 1-DCA was also detected in MW89-14 (0 006 mg/l) on January 17 1990 only There is no available MCL for 1 1-DCA

Isoconcentration maps depicting the distribution of total organics in the perched sand channel on November 24 1989 is provided in Figure 4 3-19e

Off-Site Ground-Water Quality

Upper Portion of Aquifer

Four off-site wells Moravec domestic well MW89-9A MW89-10A and MW89-11A were included in the monitoring program during this period Organics were not detected in these wells during this period

Lower Portion of Aquifer

A total of 9 off-site wells screened in the aquifer were monitored during this period (Table 4 3-6)

1 1-DCE concentrations reported in irrigation well #54278 and TMW88-6 ranged from undetected to 0 28 mg/l Time versus 1 1-DCE concentrations reported in TMW88-6 and irrigation well #54278 during this period are presented in Figures 4 3-18a and 4 3-18b respectively 1 1-DCE concentrations reported in irrigation well #54278 were above the MCL (0 007 mg/l) between May 1989 and September 1989 but were not detected thereafter

1 1-DCE concentrations reported in TMW88-6 ranged from 0 1 mg/l to 0 15 mg/l which exceeded the MCL

TCA concentrations reported in TMW88-6 and irrigation well #54278 ranged from 0 03 mg/l to 2 1 mg/l TCA concentrations reported in TMW88-6 were below the MCL (0 2 mg/l) TCA concentrations reported in irrigation well #54278 exceeded the MCL at various monitoring dates during this time period Time versus TCA concentrations reported in TMW88-6 and irrigation well #54278 during this period are presented in Figures 4 3-18a and 4 3-18b respectively

PCE concentrations reported in TMW88-6 and irrigation well #54278 ranged from 0 02 mg/l to 0 38 mg/l which exceeded the proposed MCL (0 005 mg/l) during this period Time versus PCE concentrations reported in TMW88-6 and Well #54278 during this period are presented in Figures 4 3-18a and 4 3-18b respectively

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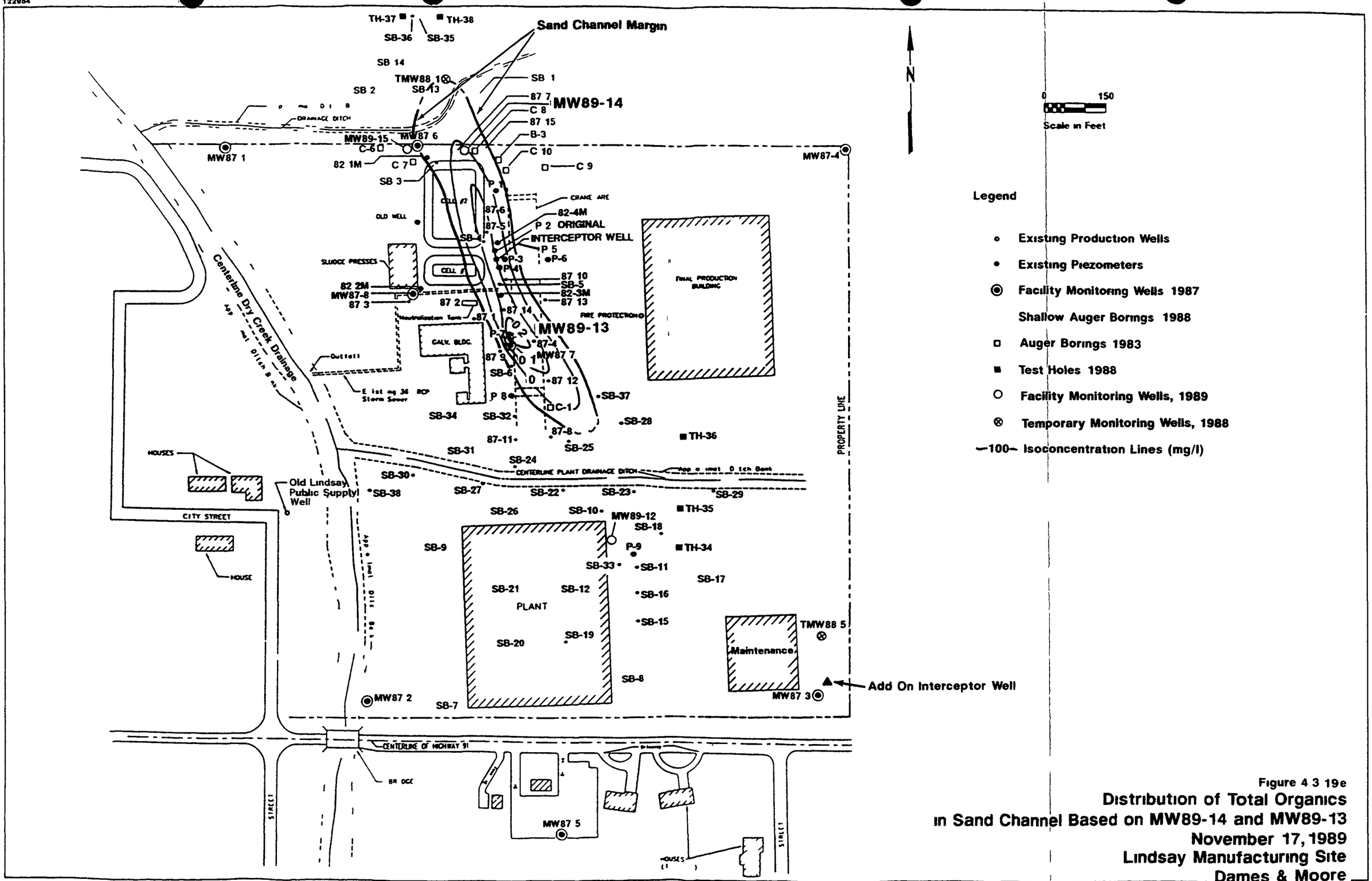

Figure 4 3 19e
Distribution of Total Organics
in Sand Channel Based on MW89-14 and MW89-13
November 17, 1989
Lindsay Manufacturing Site
Dames & Moore

Job No 7 002

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Isoconcentration maps of the distribution of total organics in the bottom of the aquifer for February 15 1989 May 16 through 21 1989 August 14 through 17 1989 and November 17 1989 are presented in Figures 4 3-19a 4 3-19b 4 3-19c and 4 3-19d

Aquifer

Off-site monitoring wells Old Lindsay Public Supply Well MW87-5 and irrigation well #50378 were included in the ground-water monitoring program between February 15 1989 and January 1990 (Table 4 5-6) Organics were either undetected or below the MCLs in these wells

Additional Sampling

As a precautionary measure during the operation of the irrigation well #54278 Lindsay Manufacturing sampled the Beller stock domestic well This sampling event was not a component of the RI monitoring program however the analytical data collected will be included in the organic results discussion of the off-site lower portion of the aquifer

Table 4 3-8 provides a summary of organic results obtained during the sampling of the Beller stock well irrigation well #54278 and Beller domestic well through May 18 1989 and October 1989

Organic ground-water quality in the Beller domestic well has been and remains below drinking water standards (MCLs) The Beller stock well showed evidence of dispersed organic compounds between May 1989 and October 1989 During this period organic concentrations reported in the Beller stock well decreased in concentration as a result of capture by the irrigation well #54278 Organic ground-water quality in the Beller stock well was within the available MCLs for organic compounds after June 1989

The occurrence of dispersed organic and inorganic compounds at the Beller stock well and irrigation well are indicative of previous influence on the deep residual contamination centered at the southeast corner of the site Lindsay s installation and operation of the AOIW is recovering the deep contaminants and capturing the dispersed compounds as evidenced by the post-irrigation season reduction in organic and inorganic levels at the irrigation well This trend is predictable based on the computer model (Appendix IX) Figure 29(b) which shows the zone of capture of the AOIW during the post-irrigation season

Table 4.3-8

Organic Laboratory Results
1987 through 1989
Beller Wells (mg/l)

Sample	Date	1,1 DCE	1,1,1 TCA	PCE	1,1 DCA	TCE	1,2 DCA	1,2, DCE
Beller Stock	5/18 21/89	0 03	0 036	0 02	ND	ND	ND	ND
	6/19-21/89	0 013	0 048	0 04	0 0093	0 0008	ND	0 0092
	7/17 19/89	0 004	0 025	0 018	0 005	ND	ND	ND
	7/26/89	0 0042	0 02	0 014	0 0044	ND	0 0041	ND
	8/8/89	0 0027	0 013	0 011	0 0027	ND	ND	0 0022
	8/17/89	0 0032	0 0096	0 0069	0 0018	ND	ND	0 0016
	8/23/89	0 0029	0 016	0 0092	0 0025	ND	ND	0 0015
	8/30/89	ND	0 0069	0 0045	0 0013	ND	ND	0 0012
	9/6/89	0 0014	0 0084	0 0057	0 0018	0 0006	ND	0 0013
	9/12/89	ND	0 0081	0 0052	0 0013	ND	ND	0 0009
	9/20/89	ND	0 0091	0 005	0 0015	ND	ND	0 0012
	9/28/89	ND	0 0078	0 0038	0 0012	ND	ND	0 0007
	10/3/89	ND	0 0061	0 004	0 0011	ND	ND	0 0007
Irrigation Well # 54278	12/87	0 007	0 012	ND	ND	ND	ND	ND
	5/17 18/88	0 006	0 007	ND	ND	ND	ND	ND
	6/19 21/89	0 038	0 11	0 037	0 0006	ND	0 0011	ND
	7/17 19/89	0 057	0 22	0 054	ND	ND	ND	ND
	7/26/89	0 058	0 21	0 052	0 0022	ND	0 0022	ND
	9/20/89	0 28	2 1	0 38	0 02	0 003	0 0028	0 0031
Beller Domestic	5/17 18/88	ND	0 008	ND	ND	ND	ND	ND
	5/18 21/89	ND	ND	ND	ND	ND	ND	ND
	6/19 21/89	ND	0 0016	ND	ND	ND	ND	ND
	7/17 19/89	ND	ND	ND	ND	ND	ND	ND
	7/26/89	ND	0 0014	ND	ND	0 0007	ND	ND
	8/8/89	ND	0 0012	ND	ND	ND	ND	ND
	8/17/89	ND	0 0011	ND	ND	ND	ND	ND
	8/26/89	ND	0 0017	ND	ND	ND	ND	ND
	8/30/89	ND	0 0006	ND	ND	ND	ND	ND
	9/6/89	ND	0 0012	ND	ND	0 0006	ND	ND
	9/12/89	ND	0 0007	ND	ND	ND	ND	ND
	9/20/89	ND	0 0007	ND	ND	ND	ND	ND
	9/28/89	ND	0 0007	ND	ND	ND	ND	ND
	10/3/89	ND	0 0008	ND	ND	ND	ND	ND
Drinking Water Standard		0 007	0 2	NE	NE	0 005	0 005	NE

ND Not Detected
NE Not Established

Summary

Aquifer water quality is steadily improving with ongoing remedial pumping of the AOIW and OIW Organic and inorganic compounds in acidic pH waters occurs at the bottom of the aquifer defined in a zone from the north central site boundary to the southeast site corner ending between MW87-3 and irrigation well #54278 This zone is not more than a 1 000 feet wide and has been significantly reduced in extent and concentration during 1989 by remedial pumping

A dispersal of organics and inorganics from the southern end of the occurrence toward irrigation well #54278 is evidenced by fluctuating sulfate and zinc concentrations in 1988 and the occurrence of organics and rising zinc levels during the irrigation season of 1989 The AOIW operation has reversed this trend by capturing metals and organics and reversing the flow of dispersed compounds Some fraction of the dispersed compounds will however remain at the irrigation well until the 1990 irrigation season at which time they will be recovered by that well Since their recovery will be diluted by waters not containing these compounds it is expected that the concentrations will be below 1989 levels

Water quality in the Beller domestic well met applicable organic drinking water standards during the entire period Water quality in the stock well exhibited fluctuating concentrations of organics but as of June 1989 was below or within applicable drinking water standards

4 4 SEDIMENT SAMPLE RESULTS

Dames & Moore collected sediment samples from an on-site and off-site upland drainage channel immediately north and central to the site Sediment sample locations are presented in Figure 2 4-1 Six sediment samples were collected from the centrally located drainage channel and three from the northern drainage channel The sediment samples were submitted to Cenref Labs for analysis of inorganics and organics by EPA CLP methodologies Inorganic and organic sediment sample results are provided in Appendix XI-E Sediment samples collected from the central drainage channel are labeled DS and samples collected from the northern channel are labeled NDS QA/QC inorganic and organic data validation reviews are performed on this data are and provided in Appendix XI-F

Inorganic

Laboratory pH levels reported in sediment samples DS-1 through DS-6 and NDS-1 through NDS-3 ranged from 5 23 SU to 8 23 SU The lowest pH level was found at NDS-3 Zinc concentrations ranged from 61 6 mg/kg to 4 881 mg/kg iron ranged from 9 879 mg/kg to 21 130 mg/kg chromium ranged from 1 1 mg/kg to 8 3 mg/kg and lead ranged from undetected to 65 8 mg/kg

Organic

There were no organic compounds detected in the sediment samples collected from either drainage channel with the exception of trace levels of 1 1-DCE and toluene 0 008 mg/kg and 0 008 mg/kg respectively reported in DS-4 Sediment sample DS-4 is located in the central drainage channel on site (Figure 2 4-1) DS-4 also contained trace levels of decane 0 019 mg/kg and undecane 0 034 mg/k These compounds are associated with petroleum products The probable source of these trace petroleum compounds is runoff from the traffic areas nearby Acetone a common laboratory contaminant was also detected in DS4 and DS-6 however the presence of this compound was attributed to laboratory contamination

4 5 SURFACE WATER

The source of surface water found on site is predominantly from ground-water treatment facility operations which discharges into Dry Creek at outfall 004A (on-site) and is monitored by an NPDES permit Two other outfalls 001A Boiler Blowdown and 002A cooling water from the Tube Mill also contribute flow and are monitored according to the NPDES permit Dry Creek is an intermittent drainage which naturally flows only during runoff events such as rain showers or occasionally snowmelt The only naturally occurring surface water is found southwest of the site at Shell Creek NPDES data collected from 1983 to the present is provided in Appendix H

The NPDES data records from February 1989 to March 1990 provide a period of comparison of the influent and effluent water quality as well as the operational compliance of the wastewater treatment facility

The current relationship of influent and effluent water quality at the waste-water treatment plant is presented in Table 4-5 The data indicates that the facility is effective in treating all constituents including both metals and organic compounds to levels below the NPDES permit limits During the February 1989 to March 1990 period two zinc exceedences recurred on April 26 1989 and August 31 1989 The zinc exceedences were associated with a seasonal change in aquifer stress at the beginning and ending of the irrigation season Changes in stress result in changes in aquifer hydraulic pressure and the flow of water to the interceptor wells In each case Lindsay rapidly responded by adjusting the treatment for the change in influent water quality These zinc exceedences have been infrequent as demonstrated by the data base (Appendix H) and represent levels close to the permit limit Thus the ground water treated in the wastewater treatment facility as an element of the interim remediation has been discharged pursuant to the state-authorized NPDES permit and the treatment system has effectively reduced the concentrations of organics and inorganics in the pumped ground water to levels within or only infrequently slightly above the relevant parameters

Table 4-5

Influent/Effluent Water Quality at the Waste Water Treatment Facility, February 1989 to March 1990

Lindsay Mfg Co

Parameter	Date	AOIW	OIW	Cell #2 Discharge	Permit Limits Daily Average	Permit Limits Daily Maximum
pH	3/28/90	6 02	5 6	9[2]	6	9
Cadmium	2/15/89	0 015			0 26	0 69
	4/4/89			ND		
	4/24/89	0 005				
Chromium	8/31/89	ND	0 006	ND	1 71	2 77
	3/28/90	0 02		*		
Copper	4/29/89	0 037		ND	2 07	3 38
Lead	8/31/89	ND	0 005	0 008	0 43	0 69
	10/27/89	0 886				
Nickel	4/24/89	0 25		ND	2 38	3 98
Zinc	2/15/89	114 12	*	0 44[1]	1 48	2 61
	4/4/89	*		0 233		
	4/24/89	122 00		0 36[1]		
	4/26/89			2 72		
	8/31/89	54 30	321 0	5 0		
	3/28/90	29 80	127 0			
Total Organics	4/24/89	0 573				2 13
	4/26/89	*		0 429		
	5/8/89			0 024		
	5/20/89			0 287		
	5/25/89			0 224		
	8/31/89	0 318	0 038	0 057		
	3/28/90	0 384	0 378			

Notes

[1] Daily average
[2] Maximum for 12/89
Not assessed
ND Not detected

4 6 OFF-SITE SURFACE SOIL AND GRASS SAMPLES

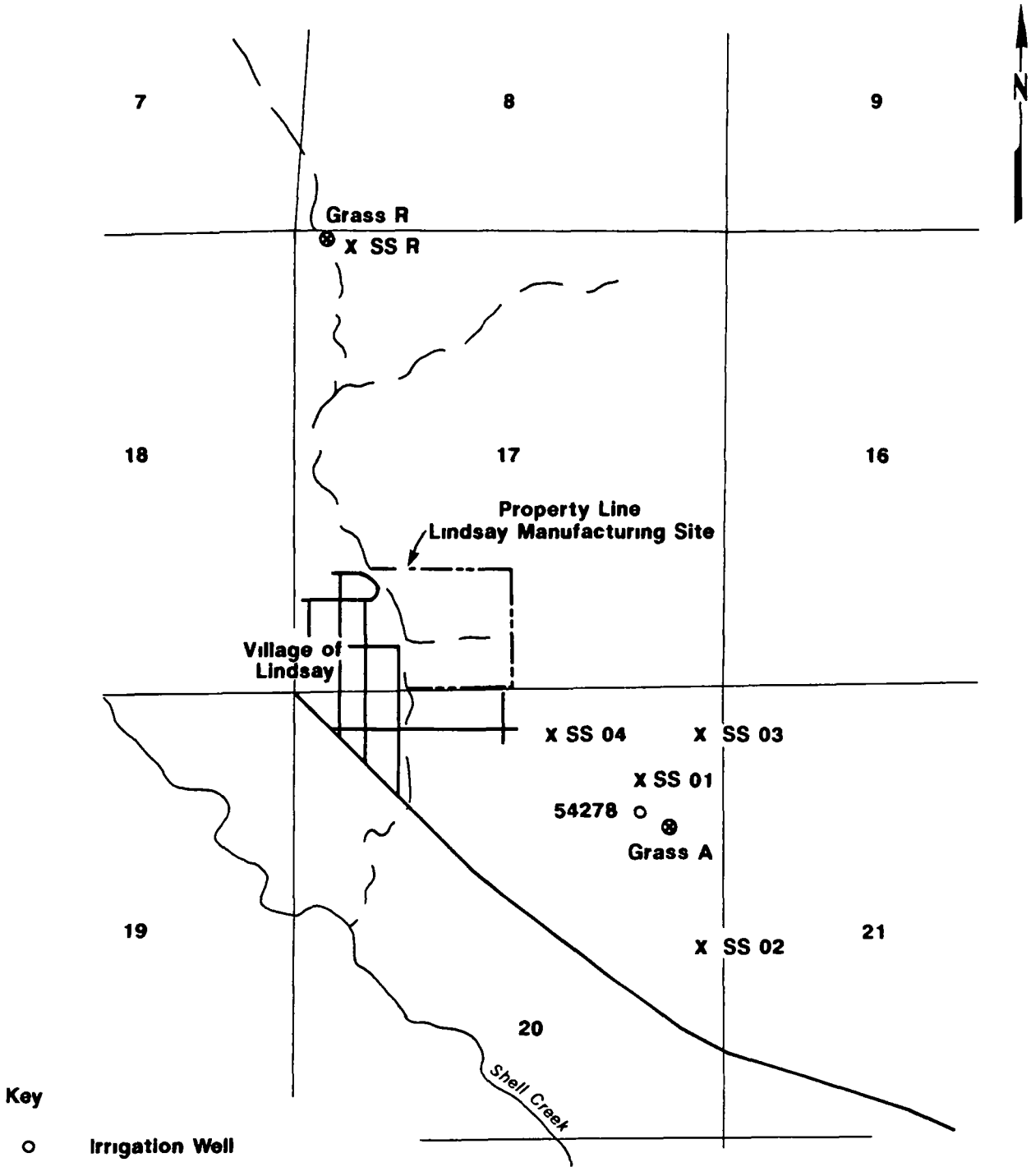
Five off-site surface soil samples and two off-site grass samples were collected on May 15 1990 from the fields irrigated by well #54278 and submitted for zinc cadmium and lead analysis The sample locations are provided in Figure 4 6-1 Soil sample SSR and grass sample GRASS-R were collected approximately 1 mile north of the site from a non-irrigated field east of Dry Creek and are considered to be representative of background conditions The background condition sampling location is referred to as reference area in the Risk Assessment (Section 6) Zinc cadmium and lead results are provided in Appendix X-I

Zinc concentrations in surface soil samples SS-01 through SS-04 collected from the irrigated field ranged in concentration from 49 mg/kg to 60 mg/kg which are at or near the background zinc surface soil concentration (49 mg/kg) According to a draft report of a study by Holmgren et al Cadmium Lead Zinc Copper and Nickel in Agricultural Soils of the United States (1989) the mean zinc concentration of soils in Nebraska is 58 mg/kg and the reported standard deviation in zinc concentrations is 25 The irrigated field soil samples average 57 mg/kg which is not significantly different than the Nebraska average and is slightly lower The non-irrigated field sample is lower than the Nebraska average but within the expected range for Nebraska soils The maximum zinc level in the irrigated soils is only slightly above the average and within the expected range for Nebraska soils

Similarly the grass sample collected from the irrigation field contained zinc at 6 5 mg/kg which was also near the background grass sample with a zinc concentration of 5 3 mg/kg The grass sample value is not indicative of either elevated or excess zinc Based on a personal communication with Dr Ralph Clark (U S Department of Agriculture Lincoln Nebraska) values of 20 to 50 mg/kg in plant tissue are generally considered to be within a normal range Values less than 20 mg/kg may indicate zinc deficiency

Cadmium was not detected in either soil or grass samples from either the irrigated or the non-irrigated fields The detection limit for cadmium is 1 mg/kg

Lead was detected in only one soil sample in the irrigated field at 11 mg/kg which is below the Nebraska average of 14 mg/kg according to Holmgren et al 1989 Lead was not detected in either grass sample



Key

- ○ Irrigation Well
- X Surface Soil Sample Location
- ⊗ Grass Sample Location

0 2000 4000

Scale in Feet

Figure 4 6 1

Approximate Location of Offsite Soil and Grass Samples Lindsay Manufacturing Site

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5 0 CONTAMINANT TRANSPORT AND FATE

This section provides a general discussion of the natural processes and physical mechanisms that may control the movement and determine the ultimate fate of contaminants at the site First Section 5 1 examines the processes that control chemical compound migration in the environment Environmental contaminants can be transported in ground water or surface water in the atmosphere or in the bulk movement of either a distinct liquid phase or a contaminated sediment This section focuses on the transport processes of importance at the site Section 5 2 discusses those chemical characteristics of individual site contaminants that govern their behavior Compounds which are discussed in this section are

Metals

- Zinc
- Cadmium
- Lead
- Chromium

Organic Compounds

- Dichloroethane (DCA)
- Dichloroethene (DCE)
- Trichloroethane (TCA)
- Tetrachloroethene (PCE)

Other Inorganic Compounds

- Acidity (pH)
- Sulfate

Finally Section 5 3 describes the probable range of transport and fate mechanisms operating at the Lindsay site and indicates how these mechanisms influence the behavior of site contaminants

5 1 ENVIRONMENTAL TRANSPORT AND FATE PROCESSES

As discussed in Section 4 0 residual concentrations of chemical compounds at the site are located deep within the geologic sediments Because of the depth of occurrence the primary operable route of contaminant migration lies in the ground water While some atmospheric dispersion of compounds may potentially have occurred in the past further transport into the atmosphere through either volatilization or mechanical dispersion is unlikely because the source areas are capped or paved and the residual concentrations are at low levels and dispersed The

transport of site contaminants by surface water is similarly unlikely because of the surface control of runoff by paving and drains

On the other hand human activities such as ground-water pumping and irrigation could lead to the recovery and dispersion of residual chemicals in ground water Irrigation could potentially disperse metals and organic compounds into the atmosphere Subsequent deposition of suspended or dissolved contaminants from the atmosphere could potentially enter surrounding soils Runoff of excess irrigation water could provide a route for such drainage to surface waters such as Shell Creek as well Thus human activities could add potential secondary routes for contaminant migration to the existing potential route of migration in ground water

The movement of nonreactive solutes in ground water is primarily controlled by two physical processes advection and dispersion (Freeze and Cherry 1979) Advection refers to the portion of solute transport that is attributable to ground-water flow Thus a solute that is transported solely by advection moves at the same rate as the ground water Dispersion is used to account for a number of molecular- and micro-scale processes that act to disturb advective transport Where ground-water velocities are low dispersion occurs mainly through molecular diffusion At higher velocities mechanical mixing adds to and may predominate over molecular diffusion and the amount of dispersion will be affected by properties of the aquifer such as differing pore geometries which cause flow lines to diverge around soil particles and induce velocity variations within the soil pore spaces (EPA 1989a)

The transport of nonreactive solutes is of interest at the site because they will be more mobile in ground water than reactive solutes Thus they can be used to determine the limits and detect the continued movement of the residual leachate

Other properties of an aquifer can have a significant affect on the movement of both soluble and insoluble chemical compounds In heterogeneous aquifers solutes will move more rapidly along layers of high permeability and more slowly along layers of lesser permeability The differential movement of solutes in adjacent layers of an aquifer produces dispersion on a macroscopic scale Where the hydraulic flow lines within an aquifer diverge, solutes will spread over a larger area by advection In addition seasonal changes in ground-water flow patterns may contribute to the dispersion of ground-water contaminants (EPA 1989a)

At the site the aquifer has been characterized as a highly transmissive semi-confined to confined condition with seasonal changes in ground water flow patterns associated with the summer irrigation well pumping period (Section 3 6)

The chemical properties of a solute also affect its transport in ground water Interactions with aquifer materials can significantly retard contaminant transport Freeze and Cherry (1979) list six categories of chemical and biochemical interactions that may affect the dispersion of ground-

water contaminants adsorption acid-base reactions precipitation and dissolution oxidation-reduction reactions ion exchange or complexation reactions and biological transformations

Adsorption is the term used to describe the affinity of a solute for the surface of a solid Many organic compounds will form a hydrophobic bond with natural organic material present in soils (EPA 1989a) Many inorganic compounds will likewise associate with mineral groups at the soil surface

Many of the chemical reactions that may occur in ground-water systems including acid-base reactions precipitation and dissolution oxidation-reduction reactions ion exchange and complexation may be characterized by the law of mass action The law of mass action characterizes the distribution between reactants and products of the chemical species that participate in a reaction Thus for the general reaction

$$aA + bB = cC + dD$$

the distribution of the participants between the reactants A and B and the products C and D may be characterized by a thermodynamic equilibrium constant K This constant is defined by the law of mass action

$$K = \frac{[C]^c[D]^d}{[A]^a[B]^b}$$

For precipitation and dissolution reactions the thermodynamic equilibrium constant K is known as the solubility product K_{sp} Although square brackets as used in the above equation typically refer to concentration the equilibrium constant is properly determined from the thermodynamically effective concentration or activity

The law of mass action provides information on the equilibrium state of a reacting system However the law provides no information on the rate of reaction In ground-water systems reactions may reach equilibrium almost immediately or only after many years have passed

Acids and bases are characterized primarily by their propensity to donate or accept protons in solution Strong acids tend to dissociate in solution losing a proton and forming the conjugate base The dissociation reaction of a strong acid in aqueous solution is an acid-base reaction between the acid and water and follows the formula

$$HA + H_2O \text{ --> } A + H_3O^+$$

In this reaction the strong acid HA and the (relatively) strong base H_2O react to form the weaker acid H_3O^+ and the weaker base A Conversely a strong base will react in water to form a weaker acid-base pair

One class of acid-base reaction that can be important as a degradation process for certain organic compounds is hydrolysis The hydrolysis of a chlorinated compound produces an alcohol (EPA 1989a)

$$RX + H_2O \text{ --> } ROH + HX$$

EPA (1989a) cites another reaction of potential importance for halogenated organic compounds

```
H  X
|  |
C - C --> C = C + HX
```

Under laboratory conditions this reaction which is called dehydrohalogenation requires basic conditions and elevated temperatures to proceed (Solomons 1984) It is unlikely that this reaction will occur in the site aquifer due to acidic ground-water conditions

Oxidation-reduction reactions involve the exchange of electrons between an oxidizing agent and a reducing agent The reducing agent supplies electrons to the oxidizing agent and is itself oxidized Conversely the oxidizing agent accepts electrons from the reducing agent and is itself reduced Nearly all of the important oxidation-reduction reactions that take place in ground-water systems are catalyzed by microorganisms (Freeze and Cherry 1979)

In geologic media ion exchange reactions take place almost entirely on the surfaces of colloidal particles (Freeze and Cherry 1979) Individual colloidal particles have diameters of between 10^{3} to 10^{6} mm but colloids may exist as coatings on the surfaces of larger particles Colloidal particles participate in ion exchange reactions because they possess a net electrical charge The charge of a colloidal particle may be due to imperfections in its lattice or to dissociation reactions at its surface In either case the charge at the surface of the particle is balanced by an accumulation of ions of the opposite charge (Freeze and Cherry 1979) These ions can be exchanged for ions present in solution

Most clays consist of particles in the collodial size range and are capable of participating in ion exchange reactions Oxide minerals can also develop a charged layer in aqueous surroundings through dissociation reactions An adsorbed layer of counterions that balances the charged layer at the mineral surface may contain exchangeable ions In both of these cases the makeup of the charged layer and its ion-exchange activity is a function of pH (Freeze and Cherry 1979)

Complexation refers to the reaction of a metal ion with an anionic ligand to form a soluble compound called a complex (EPA 1989a) Transition metals form the most stable complexes while alkaline earth metals form less stable complexes and the alkali metals form virtually no complexes (EPA 1989a) Common inorganic ligands are OH CO_3^{2} CN SO_4^{2} S^{2} Cl F NH_3 PO_4^{3} and polyphosphates Common organic ligands include amines pyridines and phenols as well as humic substances Organic ligands often form stronger complexes with a given metal than inorganic ligands (EPA 1989a)

A number of biological processes occur in the subsurface including biodegradation of organic compounds nitrification and denitrification oxidation and reduction of sulfur and iron oxidation of manganese and methanogenesis (EPA 1989a) Freeze and Cherry (1979) point out that ground-water systems tend to become depleted in oxygen due to hydrochemical reactions and to the activity of microorganisms The loss of oxygen gradually creates a reducing environment Under these conditions inorganic constituents may be reduced through reactions that are catalyzed by bacterial enzymes These reactions oxidize organic matter and release energy for cell metabolism

In the unsaturated region above the water table which is known as the vadose zone the migration of chemicals proceeds at a different rate than in the underlying aquifer due largely to chemical and physical interactions The vadose zone can contain larger fractions of organic matter and metal oxides than the saturated zone Many compounds will sorb onto these materials and sorption inhibits their downward progress Also air spaces within the unsaturated region form a pathway for the movement of gases and vapors In addition microorganisms are generally thought to be more active in the vadose zone than they are below the water table (EPA 1989a) At the Lindsay site the vadose zone extends to a depth of between 15 and 35 feet Soils in the vadose zone have been characterized in Sections 3 5 & 3 6 as generally lean silty clays with scattered secondary calcium carbonate concretions iron and manganese oxide concretions and little or no organic matter

Both diffusion and advection affect the movement of gases and vapors in the vadose zone (EPA 1989a) However the lack of interactions between gas molecules leads to significant rates of diffusion Gases and vapors that are transported through the vadose zone by diffusion may reach the surface and escape into the atmosphere On the other hand barriers at the soil surface such as parking lots streets and foundations can interfere with the diffusion of gases from the soil Furthermore certain organic compounds if present in sufficient concentration can increase the bulk density of the gas phase in the soil leading to the transport of these compounds downward towards the water table (EPA 1989a)

The organic compounds found in soils at the Lindsay site are only slightly soluble in water If sufficient amounts of these compounds were present they could potentially exist as a separate non-aqueous liquid phase however there is no evidence that this condition has existed or does

exist at the site The organic compounds listed in the Stipulation and Agreement including DCA TCA and PCE are generally classified as dense non-aqueous phase liquids (DNAPLs) Because of their low viscosity high density and low solubility these compounds can be fairly mobile in the subsurface (EPA 1989a) The EPA (1989a) has characterized the behavior of DNAPLs spilled to the soil as follows

- Under the influence of gravity the DNAPL flows through the vadose zone towards the water table If the amount of the spill is limited flow continues until a stable condition of residual saturation is reached

- If sufficient quantities of the DNAPL are present volatilization creates a dense vapor phase that may sink to the capillary fringe Vapors will also move laterally through the surrounding soils and upwards out of the soil column and into the atmosphere

- In the vadose zone infiltrating water dissolves portions of both the liquid- and vapor-phase DNAPL and transports it to the water table

- Where the amount of the spill is large the liquid DNAPL may advance to the capillary fringe above the water table Water in the capillary fringe will be displaced by the advancing front of the liquid DNAPL

- Pooling of the DNAPL at the surface of the water table creates an unstable condition as the DNAPL phase overlies a less-dense aqueous phase However the liquid DNAPL cannot displace the water in the aquifer until enough has accumulated to overcome the effects of surface tension Depending on the magnitude of the interfacial tension between the DNAPL and the water the size of the pore spaces and the size of the density difference the height of the DNAPL pool required to overcome the effects of surface tension may range from a few centimeters to many meters

- Even though DNAPLs are relatively insoluble contact between the DNAPL and the aquifer will result in some dissolution of the DNAPL The concentration of the DNAPL in the contaminated aquifer may be controlled by the solubility of the DNAPL or it may be controlled by the kinetics of the dissolution reaction Whether solubility or dissolution kinetics controls the concentration of the DNAPL in the aquifer depends on both the area and the time of contact between the liquid DNAPL and the aqueous phase Transport of the dissolved DNAPL will occur through advection and dispersion

- Where the amount of liquid DNAPL is large the DNAPL may flow through the aquifer and pool on intercepted confining layers If the confining layers are tilted the DNAPL will flow along the slope of the layers in response to gravity

The behavior of spilled DNAPLs as characterized above will be complicated by soil conditions in the vadose zone and the aquifer such as heterogeneity or layering At the site only gravity volatilization dissolution and soil conditions are believed to be significant to the transport and fate of the organic compounds in the soils and aquitard

5 2 CHARACTERISTICS OF SITE CONTAMINANTS

5 2 1 Characteristics of Metals

For most metals similar factors control environmental transport and fate For example most metals in aqueous systems will tend to interact with hydroxyl ions to form hydrolyzed species or with inorganic anions such as HCO_3 CO_3^2 NO_3 SO_4^2 Cl and F to form complexed species (Freeze and Cherry 1979) These interactions may well yield species of lesser or greater solubility than the unassociated metal Many hydrolyzed metals are sparingly soluble Hydrolysis may induce precipitation thereby affecting the fate of the metal On the other hand complexation may increase solubility thereby affecting the transport of the metal The fate of metallic species in the environment is primarily dependent upon such factors as sorption chemical speciation and complexation biological transformation and bioaccumulation

5 2 1 1 Characteristics of Zinc and Cadmium

Zinc and cadmium are isoelectronic which is to say that they possess identical outer-shell or valence electron structures The identical electronic structures of these two elements mean that they will behave similarly in similar surroundings Both zinc and cadmium are elemental constituents of the earth s crust Although less abundant than zinc cadmium is often present at detectable levels in soil surface water and ground water Cadmium is present in most zinc-bearing ores and may be recovered as a byproduct when these ores are refined (EPA 1989b)

Most of the zinc and cadmium that are released to the environment tend to collect in water soil and sediments In aqueous media both zinc and cadmium exist primarily in the +2 valence state (Lindsay 1979 EPA 1989b) In acidic water the predominant zinc species is the hydrated Zn^{2+} cation while in strongly basic water the predominant zinc species is the zincate anion ($Zn(OH)_4^2$) Both metals form a number of complexes with organic and inorganic ligands The solubility of these metals can be increased by complexation (Callahan et al 1979)

The transport of zinc and cadmium in ground water is dependent on a number of factors including the pH temperature the ionization potential of the water and the dissolved concentration of the metal Soluble forms of these metals such as zinc sulfate are fairly mobile in most soils However under aerobic conditions zinc and cadmium will tend to sorb onto hydrated iron and manganese oxides clays and organic matter In fact the sorption of zinc by

clays and organic materials is probably the dominant mechanism controlling zinc availability in the environment (Callahan et al 1979) The tendency of either zinc or cadmium to sorb is affected by the nature and concentration of the sorbent by pH and salinity Precipitation of zinc compounds appears to occur only in highly reducing environments and is largely controlled by the solubility of zinc carbonate $ZnCO_3$ and zinc hydroxide $Zn(OH)_2$ (NRC 1977) The sulfides of both zinc and cadmium exhibit very low solubilities so that reducing conditions that produce sulfides will favor the precipitation of these metals

Zinc is bioaccumulated by all organisms as an essential nutrient Bioaccumulation of zinc can occur even when the concentration of zinc is low However organisms constitute a minor reservoir for zinc compared to aquatic sediments On the other hand biological processes can affect the mobility of zinc in aquatic environments (Callahan et al 1979) Cadmium is also strongly accumulated by organisms (EPA 1989b)

Both zinc and cadmium are nonvolatile and once released into the atmosphere will generally form stable compounds such as zinc oxide and cadmium oxide The lifetimes of these compounds are expected to be relatively short with removal occurring through surface deposition (EPA 1980 EPA 1989b)

5 2 1 2 *Characteristics of Chromium*

Of the several oxidation states available to chromium the trivalent Cr^{3+} state is the most stable and important in aqueous media Trivalent chromium is relatively insoluble and evidences little toxicity (EPA 1989a) It forms a number of complexes with organic and inorganic ligands including water sulfate and ammonia Cr^{2+} is stable only in the absence of oxygen The hexavalent Cr^{6+} state may exist as the hydrochromate ($HCrO_4$) chromate (CrO_4^{2}) or dichromate ($Cr_2O_7^{2}$) the speciation is dependent on pH with the dichromate predominating at very low pH and the chromate predominating at basic to neutral pH In the pH ranges typical of natural waters the chromate and hydrochromate forms of Cr^{6+} are favored It should be noted that in acid solution Cr^{3+} is difficult to oxidize to the Cr^{6+} state and oxidation requires such strong oxidizing agents as concentrated $HClO_4$ sodium bismuthate or permanganate (EPA 1984b) In addition Cr^{6+} is readily reduced by organic matter Chromium may also be transported in surface and ground water in particulate form Studies have shown that chromium-containing sediments do not release significant amounts of deposited chromium under either oxidizing or reducing conditions (EPA 1984b)

Chromium may be present in the soil column in the form of precipitated mineral and adsorbed species Organic matter in soil will tend to reduce soluble chromium to the insoluble Cr_2O_3 so that the likely form of chromium in soil is the hydrated oxide $Cr_2O_3\ nH_20$ (EPA 1984b)

Airborne chromium is associated primarily with industrial activity and soil-borne aerosols Removal of the chromium from the atmosphere occurs through wet and dry deposition Depending on particle size suspended chromium may persist in the air for long periods of time and be transported over large distances (EPA 1984b)

5 2 1 3 Characteristics of Lead

The lead species that is the most prevalent in the environment is the bivalent cation Pb^{2+} In water lead may also be present in particulate form Dissolved lead is subject to precipitation as the carbonate sulfide and sulfate species $PbCO_3$ PbS and $PbSO_4$ and to adsorption onto hydrous iron and manganese oxides or organic matter (EPA 1984c) Lead migration in aqueous media is primarily dependent on pH but it may be significantly inhibited by adsorption onto soil Lead solubility increases at the extremes of pH and exhibits a minimum in the moderate pH range

In soil lead compounds will be transformed to the insoluble $PbSO_4$ $Pb_3(PO_4)_2$ PbS and PbO salts In these forms lead will not migrate through the soil column However complexation by organic matter can in some cases mobilize lead (EPA 1984c)

Aquatic organisms evidence a tendency towards bioaccumulation of lead Also biological activity may transform lead through biomethylation Certain anaerobic bacteria metabolize lead producing methylated forms of lead including tetraethyl lead Methylated lead compounds are more mobile and volatile than the dissolved or sorbed forms of the metal

Stationary and mobile sources of atmospheric lead emissions produce a variety of lead compounds The various emitted compounds are subject to a number of transformations but the principal mechanism for removal from the atmosphere is deposition The half-life of airborne lead depends primarily on particle size Submicron particulate may persist in the atmosphere for more than a week (EPA 1984c)

5 2 2 Characteristics of Organic Compounds

The organic compounds listed at the beginning of Section 5 2 are all of similar structure and consist of a two-carbon backbone to which differing numbers of chlorine atoms are attached DCE and PCE are unsaturated compounds that is the two carbons that form the backbone of these compounds are joined by a double bond DCA and TCA on the other hand are saturated compounds the two carbons in these compounds are joined by a single bond

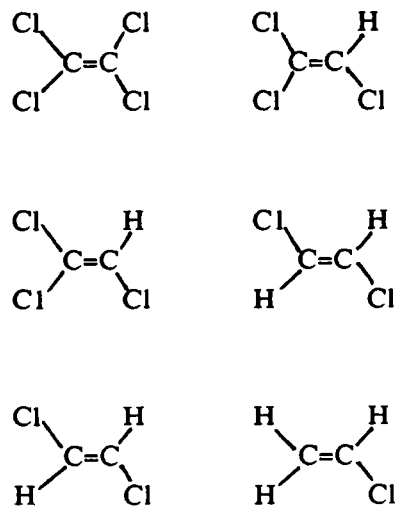
Reaction with photochemically produced hydroxyl radicals acts to remove chlorinated ethanes and ethenes like DCA DCE TCA and PCE from the atmosphere Based on estimates of the concentration of and rate of reaction with hydroxyl radicals the lifetime of TCA in the atmosphere has been calculated to be between 5 and 10 years Some evidence suggests that

significant amounts of TCA may also be conveyed to the stratosphere (EPA 1984a) The tropospheric half-life for the transformation of 1 2-DCA through reaction with hydroxyl radicals has been calculated to range between 36 and 127 days (EPA 1985) Since the half-life for atmospheric reaction is so short it is unlikely that substantial amounts of DCA will be transported to the stratosphere Removal of DCA from the atmosphere by absorption in raindrops and by dry deposition are also not expected to be important transport mechanisms (EPA 1985)

In aqueous environments volatilization is in general likely to be the principal means of removal for chlorinated organics (EPA 1985 WHO 1984) It has been estimated that PCE has a half-life of between 3 to 30 days in river systems and between 30 and 300 days in lakes and ground-water systems (WHO 1984) Similarly degradation of DCA by either photolysis or hydrolysis is reported to be insignificant as is chemical oxidation (EPA 1985) Degradation of PCE by hydrolysis also appears to be an insignificant process in the environment (WHO 1984) Since dehydrogenation generally requires basic conditions and elevated temperatures it also is not expected to constitute a significant process for degradation of chlorinated ethanes or ethenes due to acidic ground-water conditions at the site

DCA and other of the chlorinated ethanes and ethenes are not expected to adsorb strongly onto soils particularly if the soils do not contain much organic matter (EPA 1985) Spills of chlorinated ethanes or ethenes may therefore slowly percolate through the soil On the other hand volatilization will act to remove chlorinated ethanes and ethenes from soil In fact volatilization may be one of the most important mechanisms for transport of low molecular weight chlorinated organics in soil (EPA 1985)

Laboratory studies have revealed biodegradation of TCA occurs under anaerobic conditions and provided a half-life of about 16 days Biodegradation was observed to proceed through 1 1-dichloroethane (EPA 1984a) Under certain conditions biodegradation of DCA has also been observed typically the degradation proceeds most rapidly under anaerobic conditions (EPA 1985) Studies of biodegradation of PCE are conflicting but investigators have reported biotransformation under both anaerobic and aerobic aquatic conditions (WHO 1984) The reaction pathway for biodegradation of PCE is similar to the reaction pathway for biodegradation of TCE and in fact includes TCE as one of its products EPA (1989a) depicts this reaction pathway as follows



Adsorption of non-polar substances on polar mineral surfaces is often thought to be relatively unimportant in regarding the transport rate (Schwille 1988 Mingelgrin and Prost 1989) However Mingelgrin and Prost (1989) point out that when the interactions between two very slightly soluble liquids are very strong significant absorption of the non-polar solvent may occur even on polar (charged) surfaces

5 2 3 Transport and Fate of Other Inorganic Compounds

5 2 3 1 Acidity

Acidity expressed as pH is a measure of hydrogen ion concentration It plays an important role in the transport and fate of many natural and man-made substances The solubility of most metals is strongly dependent on pH In natural systems a pH exists for which a metal exhibits a minimum solubility at both lower and higher pH the solubility of most metals increases Ion exchange reactions are also dependent on pH since the charge at the surface of colloidal particles varies with pH At low pH these surfaces become protonated and take on a positive charge At high pH the surfaces lose their protons and take on a negative charge The adsorbed layer of exchangeable counterions which balances these surface charges will change in response to these variations at the surface of the colloid Should the pH of the surroundings change from acidic through neutral to basic one set of anionic counterions would be lost and a different set of cationic counterions would be gained

Acidity can also limit the activity of microorganisms Microorganisms can live only within a narrow range of pH and are most active under conditions of near neutrality

5 2 3 2 Sulfate

Sulfate appears in ground water due to the dissolution of sulfate-containing minerals and to the oxidation of sulfide-containing minerals The typical range of sulfate concentration in ground water lies between 5 and 200 mg/L (Kemmer 1988) Most metallic sulfates with the exception of barium sulfate are soluble Thus sulfate is not generally subject to precipitation and will tend to persist in ground-water systems The persistence of sulfate makes it a good tracer of contaminant migration

Under anaerobic conditions certain bacteria may use sulfate to supply energy for cell metabolism Using organic materials as electron donors these bacteria reduce sulfate and generate sulfide as illustrated by the simplified reaction

$$CH_2O + \tfrac{1}{2}SO_4^{2} = \tfrac{1}{2}HS + HCO_3 + \tfrac{1}{2}H^+$$

Since many metal sulfides are insoluble the presence of sulfide in ground water can act to limit the dissolved concentration and therefore the transport of many metals

5 3 TRANSPORT AND FATE OF CONTAMINANTS AT THE LINDSAY SITE

At the Lindsay Manufacturing site the contaminants are distributed in several media as discussed in Section 4 0 above Inorganic compounds are present at the bottom of sand and gravel aquifer They have also been found in elevated concentrations in the perched sand channel Some organic compounds have been found in the vadose zone the sand channel aquifer the saturated portion of the aquitard beneath the sand channel and the sand and gravel aquifer Organic compounds are associated with two areas of the site where plant personnel have reported that some disposal of spent organics occurred one in the central area of the site near the main plant building and the other in the vicinity of the former disposal pit (Sec 1 & 4)

As indicated above a number of factors can affect the transport of ground-water contaminants including the area of contact between the ground water and the contaminant source pH temperature relative density the presence or absence of reactive chemicals and physical and chemical state Thus the assessment and prediction of contaminant transport and fate is both site-specific and chemical-specific

Nonreactive solutes move largely in response to ground-water flow In actuality each of the contaminants at the site are to some extent reactive However acidity and sulfate may behave approximately as nonreactive solutes Both are present in relatively large quantities as compared to the constituents which would lead to their depletion Thus the use of either acidity or sulfate to determine the limits and to detect the continued movement of the residual chemicals is justified

A ground-water model has been used to understand and predict the movement of the acidic plume in the sand and gravel aquifer which suggests that the movement of the plume is largely governed by hydraulic forces

Adsorption and desorption are not incorporated into the aquifer model on the basis that (1) the pH of the leachate is acidic (2) the aquifer material is low in clay content thus providing little adsorptive material and the sand and gravels are relatively inert minerals in the range of pH occurring at the site

Zinc was selected as the most conservative of the metals to model since it participates to a lesser degree than the other trace metals in co-precipiation processes and is relatively mobile in acidic conditions

Organic compounds which dissolved in ground water in the sand and gravel aquifer may also behave as nonreactive solutes since they are not apt to adsorb and are not subject to reactions by hydrolysis or dehydrohalogenation in the acidic leachate environment In the area near the pit it is reported that organics were either introduced directly into the pit or they were spilled to the soil near the pit In either case contact and mixing with the acidic leachate would have occurred quickly Further transport of these organics would then have occurred in conjunction with the leachate Both the amount of these organics that were introduced to the ground water and their solubilities are low so that their use as tracers is infeasible and they have not been selected as solutes for modeling

Additionally the potential for the organics to salt out in solutions with high sulfate concentrations is possible (Dr Charles Grigsby of Los Alamos Laboratories New Mexico personal communication) This reversible phenomena is related to effects of low pH on the minerals of the sand channel and aquifer (quartz and feldspars) in combination with the high sulfate concentrations It is expected that the residual organics should absorb more strongly in the presence of the initial low pH high sulfate front at the monitoring wells 82-1M 3M 4M and the original interceptor well With the recovery of the leachate the decline in ground-water sulfate concentrations and rise in pH levels has occurred which resulted in the desorption of organic compounds

The aquifer has been previously described in Section 3 6 and in previous investigations The results of recent deep drilling and monitoring well installations have refined but not significantly changed previous interpretations of the aquifer characteristics by HWST and Dames & Moore The predominant characteristics of the aquifer are as follows

- Relatively high transmissivity and low storativity

- Rapid and distant response of aquifer flow direction to high capacity well pumping

- Relatively uniform permeable and uncemented aquifer materials and

- Confined water occurrence

These characteristics are the basis for the aquifer model presented in Appendix IX the findings of which are discussed in Section 3 6

In general the model exhibits the trends of zinc occurrence and ground water flow directions as measured in this and previous investigations It can be used as a predictive model for the feasibility study

Ground-water flow in the sand and gravel aquifer has been complicated by the action of numerous wells in the vicinity The flow may be further complicated by density effects In general where the local ground water density has been raised by the presence of a contaminant the dense fluid will move downward relative to the surrounding ground water The vertical velocity can be estimated by

$$v_g = \frac{-K_{zz}}{-t} \left(\frac{P}{P_o} - 1 \right)$$

where K_{zz} is the vertical hydraulic conductivity n is the soil porosity p is the density of the leachate and p_o is the density of the ground water (EPA 1989a) According to this relationship the vertical velocity is proportional to both the vertical hydraulic conductivity and the density ratio between the leachate and the uncontaminated ground water Thus a dense contaminant in the aquitard at the Lindsay site would exhibit a low vertical velocity because of the limited vertical hydraulic conductivity of the medium A dense contaminant entering the sand and gravel aquifer on the other hand might exhibit a sizeable vertical velocity even if the density ratio was close to 1 0

Obviously any action which increased the vertical hydraulic conductivity of a soil would also increase the vertical velocity of the contaminant For example during the construction of monitoring well 82-1M a four-inch hole was completed to the bottom of the aquifer prior to well completion If that hole was allowed to fill with aquifer sloughings or if it was filled with road gravel or other coarse materials a conduit with an extremely large vertical conductivity would have been created A dense liquid introduced into this conduit would flow to the bottom of the aquifer at a fairly high velocity in accordance with the relationship given above

Nonreactive solutes in the sand channel move with the perched ground water During the years in which the former disposal pit was in use leachate that entered the perched sand channel flowed to the north and south away from the mound produced by the leachate head (HWS 1983) When the pit was closed the leachate source and hydraulic head were eliminated and the flow

outward stopped Currently ground-water movement in the sand channel is toward and controlled by the OIW (Section 3 6 3)

Residual acid contaminants in the perched sand channel was identified in the May 1987 soils study The residual contaminant has been perched in the sand channel by underlying clays Hydraulic conduits produced by monitoring wells that connected the perched sand channel to the lower aquifer were plugged in the summer of 1987 The OIW designed to drain and intercept residual leachate remains in place

If a porosity of 20 percent is assumed for the sand channel the potential specific storage of the channel may be estimated to be 630 000 cubic feet or 4 700 000 gallons The maximum volume of acid leachate in the sand channel is estimated to be equivalent to the potential specific storage In the 1987 Interim Status Report the volume of acidic leachate in the sand channel was estimated to amount to 3 2 million gallons In January 1990 the volume of acidic leachate in the sand channel is estimated at 900 000 gallons The reduction in volume as well as a rise in pH from approximately 2 6 in 1983 to about 5 3 in 1990 is ascribed to capture at the OIW and in-place dilution by deeply infiltrating rain water and snowmelt

Studies that have characterized the ground water at the site (HWS 1983 HWST 1987 Dames & Moore 1988) indicate that natural processes are active in diluting and neutralizing the chemicals in the sand channel These processes include dilution by deeply infiltrating rain fall and snowmelt and neutralization by calcium carbonate dissolved in the ground waters

Reactive solutes also respond to ground-water flow but their movement is affected by interactions with soil materials Reactive solutes include most metallic compounds Important interactions which were summarized above include adsorption acid-base reactions precipitation and dissolution oxidation-reduction reactions ion exchange or complexation reactions and biological transformations At the site the aquifer materials are relatively inert composed of silica and feldspar minerals thus reducing the likelihood of chemical interaction The transport and fate of zinc and cadmium may be influenced by adsorption precipitation and complexation Adsorption is considered the most important mechanism controlling the availability of zinc and cadmium in the environment Rising pH associated with the dilution of the acidic plume in the perched sand channel may also lead to precipitation of zinc and cadmium carbonates Also under the appropriate conditions the reduction of sulfate to sulfide may cause the precipitation of much of the available zinc and cadmium as sulfides Precipitation of zinc and cadmium sulfides may be occurring where the residual acidic plume contacts the calcium and carbonate cemented bedrock (see 3 2) on the bottom of the aquifer The contact at the bedrock surface represents the most significant point of chemical interaction for the acidic residuum

The current distribution of zinc (January 1990) in the bottom of the aquifer correlates with low pH values and is centered in an area between TMW88-5 and TMW88-6 According to

samples collected in November 1989 the maximum zinc concentration is 590 mg/L The horizontal concentration gradient of zinc in the residuum is steep dropping from a maximum of roughly 478 mg/L to less than 1 mg/L in 1 000 feet or less Traces of zinc occur along limited dispersion fronts above the residual acid leachate at the bottom of the aquifer

The transport and fate of chromium may for the most part be controlled by oxidation-reduction and precipitation reactions In the reducing environment of the sand and gravel aquifer the hexavalent Cr^{6+} species may be reduced to the relatively insoluble trivalent ion

The availability of sulfate in the acidic plume may promote the precipitation of lead as $PbSO_4$ which is considered to be an insoluble species Rising pH will lead to increasing precipitation of lead species

In models used to predict contaminant transport the effects of chemical interactions are sometimes accounted for using a single retardation constant In reality retardation is seldom constant-valued because mechanisms such as adsorption precipitation and dissolution are complicated functions of such variables as temperature pH and the chemical makeup of both the soil and ground water Any of these variables can change over time or from place to place in an aquifer Therefore more rigorous expressions for contaminant transport account for the effects of the various categories of chemical interaction individually

Adsorption is typically measured at constant temperature and the results of adsorption experiments are generally displayed as plots of the dissolved concentration of the sorbate versus the sorbed concentration S These plots are known as adsorption isotherms In dealing with the adsorption of nonpolar organic compounds which are only present in ground water at low concentrations the distribution of the sorbate between the aqueous phase and the soil surface can sometimes be expressed by the relation (EPA 1989a)

$$S = K_d C$$

where K_d is termed a distribution or partition coefficient This expression is valid only if adsorption is rapid compared to the time of contact between the soil particles and ground water adsorption is reversible and the adsorption isotherm is linear (Freeze and Cherry 1979) In many systems that involve the interaction of solutes with aquifer solids these limits are met However more complicated relationships between S and C are encountered often enough that the above relation cannot be assumed Freeze and Cherry (1979) report that distribution coefficients can range from near zero to greater than 10^3 ml/g Distribution coefficients very much larger than 1 ml/g imply that the solute will be very nearly immobile (Freeze and Cherry 1979)

Section 5 1 included a review of the behavior of DNAPLs released to the soil At the Lindsay Manufacturing site DNAPLs were reportedly released in small quantities over a long period of

time Due to the limited quantities only certain of the mechanisms discussed in Section 5 1 are deemed to be of importance at the site Organic compounds found in the soils at the site may have been transported for short distances by saturated flow However volatilization would have quickly reduced the initial amounts of the spilled organics so that further transport would have occurred only by transport in infiltrating rainwater or by gaseous diffusion The estimated distribution of selected organic compounds in site soils is presented on Table 5 3-1 The three selected compounds PCE DCE and TCA represent the predominate organic compounds detected on-site Other organic compounds were either only detected in one or two borings at low levels by field screening and not verified by the laboratory analysis or occurred in only one soil sample In the area near the main plant building the existing distribution of organic compounds suggests that these compounds moved laterally and vertically by gaseous diffusion and vertically by transport in infiltrating rainwater Because of their hydrophobic character gaseous and liquid organics that came in contact with the capillary fringe would likely accumulate Further movement of these compounds into the ground water would then be limited by their solubility

No evidence has been found of pooling of organic compounds at the lower surface of the silty clay aquitard therefore there is not pressure head to drive these compounds against surface tension and the only probable mechanism for deep migration into the aquifer is molecular diffusion The low levels of DNAPL concentrations in the soils and aquitard are consistent with diffusion or drainage from the aquitard into the aquifer Drainage between the capped areas occurs only when the pressure head in the aquifer is reduced for sufficient time to induce gravity drainage This condition has only begun to develop since 1987 with nearly continuous interceptor well pumping The low levels of DNAPL concentrations in the soils and aquitard are consistent with transport by diffusion

Table 5.3-1

Estimated Distribution of Selected Organic Compounds in Site Soils
Lindsay Mfg Co

Compound	Geologic Material	Condition	Phase: Vapor (µg/l air)	Phase: Solution*** (µg/l solution)	Phase: Sorbed** (µg/kg)	Mean Balance*** (g/m²)	Key to Lines
PCE	Clay	Unsaturated	7 7	9 3	169 3	0 16	Minimum
			70 5	84 9	1 545 2	1 44	Mean
			274	330 1	6 007 8	5 62	Maximum
		Saturated	10	12 0	219 3	0 20	Minimum
			208 4	251 1	4 569 7	4 18	Mean
			3140	3 783 1	68 853 0	63 04	Maximum
	Sand	Unsaturated	8 3	10 00	109 00	0 14	Minimum
			30 16	36 34	396 08	0 49	Mean
			69	83 13	906 14	1 13	Maximum
		Saturated				**	Minimum
							Mean
							Maximum
TCE	Clay	Unsaturated	12 3	31 54	198 7	0 19	Minimum
			26 1	66 92	421 60	0 40	Mean
			36	92 31	581 55	0 55	Maximum
		Saturated	6 3	16 15	101 75	0 10	Minimum
			14 3	36 67	231 02	0 23	Mean
			28	71 79	452 28	0 44	Maximum
	Sand	Unsaturated	TCE not found in soil Air in sand materials				Minimum
							Mean
							Maximum
		Saturated					Minimum
							Mean
							Maximum
DCE	Clay	Unsaturated	8 5	6 1	20 13	0 022	Minimum
			94 7	68 1	224 7	0 24	Mean
			426	306 5	1 011 5	1 09	Maximum
		Saturated	5 2	3 7	12 2	0 013	Minimum
			119 8	86 2	284 5	0 295	Mean
			845	607 9	2 006 7	2.020	Maximum
	Sand	Unsaturated	6 9	4 96	9 92	0 014	Minimum
			11 3	8 13	16 26	0 023	Mean
			19	13 67	27 34	0 039	Maximum
		Saturated				**	Minimum
							Mean
							Maximum
TCA	Clay	Unsaturated	434	735 6	5 590 5	5 3	Minimum
			2297 8	3 894 6	29 598 9	27 9	Mean
			6958	11 793 2	89 628 5	85 3	Maximum
		Saturated	507	859 3	6 530 7	6 3	Minimum
			1487 4	2 521 1	19 160 1	18 6	Mean
			2309	3 913 6	29 743 1	28 8	Maximum
	Sand	Unsaturated	TCE not found in soil Air in sand materials				Minimum
							Mean
							Maximum
		Saturated					Minimum
							Mean
							Maximum

Notes

Field measurement.

** *Sand channel not depicted as saturated*

** Calculated

6 0 BASELINE RISK ASSESSMENT

This section addresses potential human health and ecological risk associated with currently existing (i e baseline) as well as potential future conditions at the site This approach is consistent with the most recent revision of the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) (55 Fed Reg 8666 at 8848 (3/8/90)) which defines the purpose of the site-specific baseline risk assessment as to characterize the current and potential threats to human health and the environment As described in both the preamble to the NCP and in the most recent EPA guidance manual on risk assessment (EPA 1989a) the objective of a baseline risk assessment is to provide decision makers when ARARs are not available with a measure of potential current and future site risk in order to assess the need for and scope of appropriate remedial measures The Reasonable Maximum Exposure (RME) scenario hypothetically assumes that a single individual could be exposed at constant levels for a specified long-term duration to all identified chemical compounds within all potential exposure pathways Although a wide range of risk outcomes are possible at any site it is the RME scenario designed to conservatively address the potential for current and future risk at a site which generally forms the basis for assessing the need for and scope of remedial action in a baseline risk assessment In this case interim remediation is occurring and the potential for risk is steadily being reduced by such action

The two principal components of the baseline risk assessment are the exposure assessment and the toxicity assessment These components in turn are predicated upon the measured concentrations of identified compounds in various chemical media including air water and soil This data base is discussed in Section 6 1 The exposure assessment (Section 6 2) involves the estimation of the nature and magnitude of potential human exposure to chemicals which have originated from the site These estimated exposure values are then combined with chemical-specific toxicity information (discussed in Section 6 3) to characterize the potential risk to human receptor populations (Sections 6 4) Section 6 5 presents a discussion of the uncertainties inherent in the exposure and toxicity components of the risk assessment process Section 6 6 presents an evaluation of the potential for ecological risk associated with the site

The intent of the RME scenario is to estimate a conservative exposure case (i e greater than the anticipated mean exposure) that is within the range of possible exposure conditions (EPA 1989a) based on current site conditions The RME scenario includes as a fundamental component the hypothetical assumption that no future remedial action will be taken at a site In other words the baseline risk assessment evaluation looks at potential site conditions that might occur if on-going or future remedial measures were not continued or implemented Each of the components and assumptions applied to the risk assessment including the data base the exposure assessment and the toxicity assessment is discussed in the following sections

6 1 EVALUATION OF DATA BASE

The data base used for quantitative exposure evaluation of the site is derived from measured chemical concentrations of identified constituents in ground water off-site soils and modelled airborne particulate concentrations Following is a discussion of the approach used for each of the individual data bases incorporated into the risk assessment

Ground Water

Ground-water data used for evaluation of potential exposure pathways to off-site human receptors is based on the 1989 ground-water data base from both on-site and off-site wells which represents the most complete and appropriate environmental measurements taken in the site area

The ground-water data base was developed

- From both on-site and off-site ground-water sampling locations representing both upgradient and downgradient conditions

- From high quality data subject to EPA Quality Assurance/Quality Control criteria as established in the Remedial Investigation Sampling Plan

- From wells monitored both monthly and quarterly and covering a complete annual hydrologic cycle including the summer irrigation season during which aquifer stress is the greatest

- From a body of data representing current and potential future (i e in the absence of further remediation) chemical concentrations in ground water and

- From samples screened at the upper and lower portions of the aquifer as well as through the entire aquifer

A discussion follows of the approach taken in using this data base in order to represent the human exposure potential to site-related chemical compounds Both on-site (i e beneath the site) and off-site monitoring data were used to address the potential for off-site exposures principally because on-site data best represent conservative (i e worst-case) potential exposure scenarios to populations dwelling off-site This approach in fact is overly conservative because the on-site data represent an occurrence of chemicals (i e stratified and concentrated chemicals) that is significantly different from the actual occurrence off-site (i e dispersed front of chemicals) Additionally the 1989 off-site monitoring has indicated that the domestic well water southeast of the site has consistently met applicable drinking water standards and the stock well water which initially exhibited both some zinc and organics and subsequently has met drinking water

standards posed no hazard to domestic stock Both of these wells are currently protected by the additional upgradient monitoring wells

During the course of ground-water data analysis it was observed that chemical distribution in ground water did not follow a typical vertical distribution pattern The expected vertical distribution of these compounds would include both metals and organics throughout the aquifer in the pathway of transport rather than the distinctly stratified actual occurrence For example various organic compounds have been identified from samples screened only in the lower aquifer The distribution of metals including zinc iron lead cadmium and organics including TCA DCE and PCE is attributed to their combined occurrence in the source fluids and their simultaneous transport into the aquifer Lindsay s site investigations have found that since the onset of this drainage the transport of both metals and organics has been predominantly to the bottom of the aquifer and to the southeast where interception has captured and/or caused the dilution of the metals and organics

Because of this site-specific distribution trend wells screened throughout the aquifer (i e at the upper and lower portions and throughout the entire aquifer) were used for the exposure assessment

Wells monitored both monthly and quarterly during 1989 (see discussion on monitoring well sampling design in Section 2-7) were included in the exposure assessment because this combination more fully documents and describes the contaminant occurrence and seasonal aquifer stress than either monthly or quarterly samples alone The data representing both frequencies taken together best represent the spatial distribution of both on-site and off-site wells screened at all vertical depths throughout the aquifer

A summary of the ground-water data base is presented in Table 6 2-2 with the actual data included in Appendix IX(h) Additionally plots of probability distribution for cadmium lead zinc and 1 1-DCE are shown on Figures IX(h)-1 through IX(h)-4 As stated in section 6 5 1 of the EPA Risk Assessment Guidance for Superfund the 95 percent upper confidence limit on the arithmetic mean chemical concentration is a conservative and widely accepted means of estimating the statistical distribution of a monitoring data base especially when a data base is sufficiently robust (i e when n>30 see discussion by Gilbert (1987) There are greater than 160 individual samples for each compound in ground water which were incorporated into the Lindsay risk assessment

The 95th percentile value is estimated based on sample size as it is highly influenced by the standard deviation and the t statistic For fewer than 20 samples this value is calculated based on the highest of the maximum detected values and the estimated 95th percentile of the data As the sample size increases the value of the t statistic value declines and the difference between the average and 95th percentile value ranges from 2 to 3 standard deviations The Lindsay data

base was judged adequate to use the estimated 95th percentile value based on the large sample size

The 95th percentile is computed for non-log transformed data by the following equation

$$X_{0.95} = M + t_{(0.95, n-1)}S$$

where

$X_{0.95}$ = the 95th percentile

M = the average value for non-transformed or log-transformed data

$t_{(0.95, n-1)}$ = the 95th percentile of a central t distribution with n-1 degrees of freedom

n = the sample size and

S = standard deviation of the non-transformed or log-transformed data

Risk assessment as with other forms of quantitative analysis requires the estimate of several important statistical parameters including description of the data distribution type the statistical mean standard deviation distribution percentiles and other statistical measures Cornell (1973) has reported that in many environmental applications the mean and variance of a data base in lieu of its complete probability density function is acceptable especially in cases where derivation of the probability density function is difficult This approach is consistent with established EPA policy (e g Section 6 5 1 of EPA (1989a)

Off-Site Soils and Grass

Off-site soils are irrigated with ground water which includes an irrigation well in which dispersed metals and organics have occurred The off-site soils data base is based on analysis for trace metals only because the trace organic compounds identified in on-site monitoring well water are known to disperse upon contact with the atmosphere Accordingly it is assumed that no organic compounds would be present in off-site soils as a result of irrigation with ground water or by any other means The metals for which analyses were conducted include cadmium lead and zinc Surface soil and grass samples were collected from four representative locations on the farm immediately to the southeast of the site The reference area selected for this sampling designed to represent surface soils which are upgradient and uninfluenced by the site is located a mile to the north of the site All sampling locations are plotted on Figure 4 6-1

The data from this sampling are summarized in Table 6 2-3 Cadmium was not detected in either off-site soils or grass lead was detected at only one of the soil samples at 11 mg/kg (detection limit of 10 mg/kg) and was not detected in any grass sample No lead was detected at the reference area indicating that background levels of lead are at or below the detection limit For quantification of soil-related exposure pathways for purposes of the RME scenario the value of 11 mg/kg lead was therefore used at the maximum value This value is comparable to the Nebraska average value for lead in surficial soils of 14 mg/kg (Holmgren et al 1989)

Zinc was detected at a maximum soil concentration of 61 mg/kg with the reference area registering slightly less than this concentration at 49 mg/kg The arithmetic mean of all surface soil analyses for zinc is 57 3 which is within the expected deviation from background (Holmgren et al 1989) These values were used for the quantitative analysis for mean and maximum values respectively Zinc was detected in grass from the reference area at 5 3 mg/kg and at 6 5 mg/kg from the sample analyzed near irrigation well #54278 These values are lower than reported normal zinc plant tissue concentrations (Sec 4) and although the sample size is insufficient to conduct a statistical test this value indicates that no bioaccumulation of zinc into plant tissue has occurred as a result of irrigation water uptake by plants from soils

Airborne Particulates

In order to evaluate potential inhalation exposures to airborne particulates annual average and worst-case 24-hour metals concentrations in air were estimated based on measured off-site soils concentrations These concentrations presented in Tables 6 2-3 and 6 2-4 were applied in the exposure assessment as mean and RME values respectively These estimated values conservatively based on local windspeed and other factors are applied in lieu of measured air monitoring data

Results of the modelling effort indicated that negligible concentrations of metals are present in airborne particulates off-site as a result of the pumping of irrigation water Due to the deep sand channel occurrence of metals on-site and the capping of this area no reasonable pathway exists for on-site metals to become airborne

Sediment

Data from ditch sediment on-site have been collected (see Section 4-4) These data were not quantitively evaluated for the present assessment because (a) sediments occur in only a small area of the ditch and were not expected to contribute to potential exposure (b) the on-site data is not believed to be representative of off-site conditions where potential exposure could occur and (c) there is little or no indication from the analyses of the presence of organics or inorganics associated with the ground-water discharge

6 2 ASSESSMENT OF POTENTIAL HUMAN EXPOSURE

A fundamental component of the baseline risk assessment is the exposure assessment which estimates the potential human exposure to chemical compounds that are present at or have migrated from the site Exposure assessment consists of characterization of the local setting identification of potential exposure pathways and quantification of potential exposure expressed in toxicological terms as dose per unit time

The characterization of the local potential exposure setting is based on site information used in part to identify the potential exposed population The subsequent identification of potential exposure pathways describes in qualitative terms the course a target chemical could under the assumed RME scenario take from the site to potential receptor populations The final quantification of potential exposure details the hypothetical mean included for the purpose of uncertainty analysis and upperbound RME estimates of each identified potential exposure pathway

6 2 1 Potentially Exposed Populations

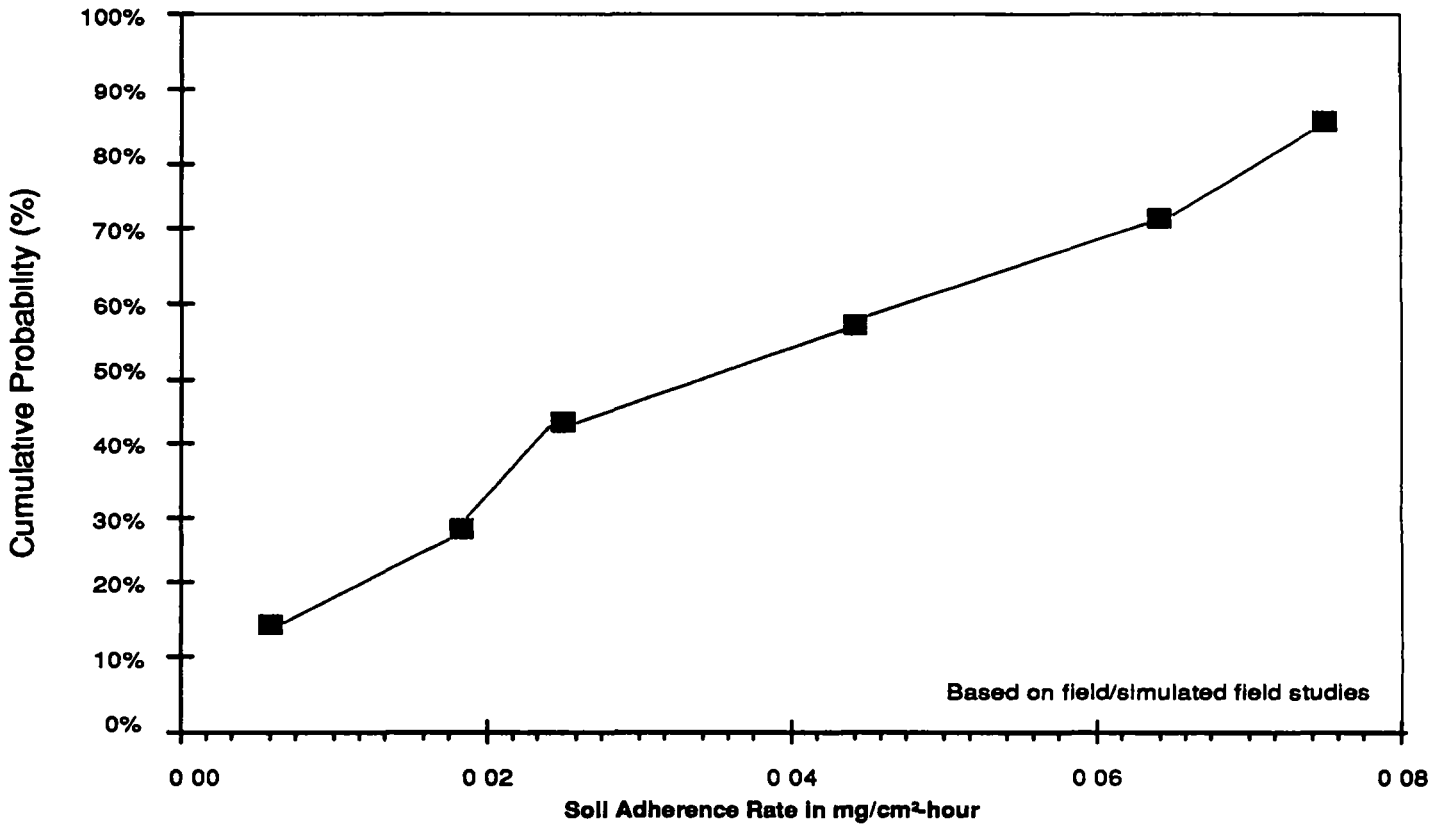
Access to the facility is restricted and off limits to the general public No children are allowed access into this restricted area A locked fence presently surrounds the entire site which serves as a physical deterrent to access by the public and to most forms of wildlife Restricted accessibility of this nature is expected to continue well into the foreseeable future

The closest residential community to the Lindsay site is the village of Lindsay located immediately to the west (see Figure 1 2-1 & 3 7-0) To the east and south of the facility are farms Both existing and projected land use within the immediate area is rural and agricultural with predominantly single-family residences

The current water supply for both the site and village is located hydraulically upgradient of the facility therefore the village of Lindsay was not included in the exposure assessment Because there are presently no permitting restrictions on private house or stock wells there is the potential although low of new construction of private water wells in and around the village of Lindsay However only high capacity off-site wells sited at certain locations would be hydraulically capable of influencing ground-water flow from the site against the southeastern ground-water gradient and/or the on-site interceptor wells Lower capacity wells such as private or stock wells are not built to such capacities Since prevailing ground-water flow is toward the area southeast of the site the rural population southeast of the site thus constitutes the primary potential receptor population Because no hospitals day-care centers or other potentially sensitive land-use activities are located in the path of ground-water flow from the site it was not necessary to assume that any unusually sensitive receptor populations occupied this off-site area

Figure 6.2-1

In-Situ Dermal Adherence of Soil



Summary of In-Situ Dermal Contact Exposures

Average measured Skin Accumulation of Dust [1] (mg/hr)	Average Measured Unit Dust Adherence (mg/cm²)	Adult Skin Surface Area [1] (m²)	Exposure Duration [2] (hr)	Average In-Situ Soil Adherence Rate (mg/cm²-hr)	Source
64		0.33		0 019	Hawley (1985)-citing Wolfe and Armstrong (1971)
20		0.33		0.006	Hawley (1985)-citing Wolfe et al (1978)
	0 4		8	0.044	Hawley (1985)-citing Roels et al (1980)
	0.5		8	0 064	Lepow et al (1974)
	0.2		8	0 025	Que-Hee (1985)
	0 6		8	0 075	Driver et al (1989)
			Average	0.039	
			Std Dev	0.027	
			CV	46	
			T-value	2.02	
			Adj SD	0.033	
			95%-tile	0 093	

NOTES

Average exposed body area based on hands, forearms, and head.

Potential exposure duration based on an average 8 hour period each day that the skin was washed.

The land use surrounding the site consists largely of farming operations although there is limited habitat for a variety of wildlife (Section 3 8) Part of this surrounding area is also occasionally used for recreational game hunting As a result the potential exposure associated with consumption of game is briefly discussed in Section 6 2 3 8 The potential for effects on wildlife is further discussed in Section 6 6 (Assessment of Potential Ecological Risk)

6 2 2 Exposure Pathways

A complete exposure pathway is necessary to link chemicals of potential concern identified in site media with potentially exposed populations (EPA 1989a) An exposure pathway is considered complete if there is (1) a chemical release from a source (2) a physical point of contact at which exposure can occur (3) a route by which exposure can occur and (4) an existing receptor for the route When these conditions are met the exposure pathway is appropriately considered in the baseline risk assessment

From a reasonable list of all potential exposure pathways in and around the site complete pathways are screened for inclusion in the quantitative exposure assessment This screening evaluation including the basis for inclusion or exclusion is summarized in Table 6 2-1

For example the potential scenario of human consumption of meat (i e from game) was not considered further because (1) it appeared unlikely that more than one animal potentially exposed to these compounds would be consumed by hunters within a moderate period of time (b) it appeared far more likely that individuals would be potentially exposed to higher concentrations of chemical compounds over longer periods of time via different routes (i e drinking water and vegetable ingestion) and (c) none of the compounds of potential concern are known to biomagnify (i e greatly accumulate throughout a food chain)

A key criterion for selection of a potential pathway for quantitative exposure assessment is the analytical detection of a specific chemical In situations where a specific chemical is not detected in any samples from a medium and when all data suggest that the likelihood of occurrence at environmentally significant concentrations is remote EPA (1989a) guidelines recommend that such exposure pathways not be considered in the quantitative assessment This guidance has been adhered to throughout the present assessment

For the RME scenario review of the off-site rural population adjacent to the site all age groups were assumed to potentially be exposed to compounds released from the site The hypothetical exposure pathways retained for quantitative exposure assessment presented in Table 6 2-1 are generally located to the southeast of the Lindsay site because (a) a farm lies in the general direction of ground-water flow (b) there are ground-water data in the area of the farm and (c) there are wells present on the property which have been analyzed and have indicated

evidence of ground-water transport from the site These potential exposure pathways include the following

- Potential incidental ingestion of soil surrounding the farm as a result of play gardening or other activities
- Potential dermal contact with soil and consequent absorption of site chemicals
- Potential ingestion of drinking water from wells hydraulically downgradient of the site
- Potential inhalation of vapors (particularly organic compounds during showering or bathing activities) from drinking water sources
- Potential ingestion of domestically produced fruits and vegetables irrigated with ground water and
- Potential inhalation of wind-driven particulate dust from off-site

The scenario of workers potentially exposed during work activities was not considered realistic for the present assessment for the following reasons (1) most of the site is currently paved thus reducing the potential for exposure to windborne or airborne contaminants from surrounding soils (2) the current water supply to Lindsay Manufacturing is drawn from upgradient of the site and is free of site-related chemicals and (3) site workers would not be expected to consume game from the site or ingest produce grown at the site

6 2 3 Exposure Factors

This section summarizes the scientific basis and/or derivation of each exposure factor used in the risk assessment A summary of the hypothetical mean and upper-bound (i e RME) values applied as exposure factors for potentially exposed populations for all potential exposure pathways is presented in Table 6 5

6 2 3 1 General Considerations

The reasonable maximum exposure (RME) scenario developed by EPA (1989a) forming the general basis from which baseline risk assessment is conducted represents a conditional probabilistic method of estimating site risk The equations used to perform exposure calculations are presented and discussed in Appendix X(j) Variables considered in the assessment include the chemical concentration (i e the data base) the potential exposure duration and frequency the rate of contact and other specific parameters

All exposure factors particularly those requiring professional judgment were derived and/or selected to eliminate to the extent possible the potential for underestimation of risk The rationale for selecting these exposure factors are discussed in the subsections which follow

6 2 3 2 Pathway I Potential Exposure via Incidental Soil Ingestion

As discussed above the hypothetical population believed to be most likely to ingest soil potentially affected by site activities is the population living to the southeast of the site This ingestion may not occur intentionally but rather incidentally and is addressed accordingly Following is a discussion of exposure factors and assumptions related to this potential pathway

In deriving estimates of soil ingestion exposure consideration is given to soil concentration gastrointestinal absorption rate soil ingestion rate frequency and duration of soil contact and body weight The rationale for selection of each numeric factor used in the exposure calculations including the statistical range is discussed below

Soil Concentrations

The principal potential mode of off-site transport of target chemicals in soil is believed to be via ground water (e g local irrigation water) It does not appear possible that site residual chemicals could be transported in substantial quantities off-site in the soil itself (e g through surface runoff or via windborne dust) This assumption appears to be verified by recent off-site soil measurements further discussed in Section 6 1

Quantitative analysis for all potential soil-related pathways including incidental ingestion (Pathway I) dermal absorption (Pathway II) homegrown produce (Pathway III) and inhalation of airborne particulates (Pathway IV) is based on the off-site soils database presented in Table 6-3 These data include results of cadmium lead and zinc analyses the metal constituents identified during monitoring of off-site ground water and thus available for potential transport to off-site soil via irrigation Because of the limited sample size for all constituents no upper-bound value was calculated rather the arithmetic mean and simple measured maximum for all three compounds were applied in the quantitative analysis

It is unlikely that trace organics would be present in off-site surface soils as they are not expected to remain in solution during irrigation These compounds are expected to volatilize upon contact with air and therefore would not be available for potential transport to off-site soils

Body Weight

A universal term of the exposure and dose equation is body weight as it applies to all potential exposure pathways A summary of average body weights by age increment is presented on Table 6-5 For adults body weight was based on statistical summaries of adults between the ages of 18 and 75 (EPA 1989b) Based on these data the average adult weighs approximately 70 kg Following EPA (1989a) recommendations the RME scenario was calculated using this average value Because a smaller person would not be expected to be more exposed to contamination (i e through greater consumption rates ventilation rate etc) the 70 kg weight was used as a lower-bound weight as well

For the 0 to 6 year age class body weight estimates were also based on EPA (1990) The average and lower-bound weight values for this age class was 14 5 kg and for the 6 to 18 age class it was determined to be 45 5 kg (see Table 6-5 for distribution by age increments)

Gastrointestinal Absorption Rate

Toxicological criteria for oral exposure to trace metals such as lead are based on ingestion of drinking water (EPA 1988 1989) However the relative absorption efficiency of trace metals consumed in water is expected to be higher than that in soil due to binding of metals to soil particles Several investigators (e g Klaassen et al 1986 Goyer 1986) report that healthy adults absorb from 5 to 15 percent of lead ingested with soil relative to that in water ATSDR (1989) reports that 20 to 30 percent of all ingested zinc is absorbed from the gastrointestinal tract following ingestion Lower adult absorption rates of 1 to 2 percent have also been reported for other metals such as cadmium

In order to provide a conservative estimate of absorption from ingested soils to sensitive subpopulations an upper-bound gastrointestinal absorption efficiency of 50 percent was assumed for all trace metals under the RME scenario following the guidance of EPA (1990) For the purposes of uncertainty analyses the average absorption was assumed to be 10 percent

Although a number of studies have been conducted with respect to gastrointestinal absorption of trace organics from soils these data were not applied because no organics are believed to be transported from the site to off-site soils

Soil Ingestion Rate

Empirical data on the ingestion rate of soil have only been reported for young children between the ages of 1 and 6 because such children are considered most likely to ingest soil (Binder et al 1986 Clausing et al 1987 EPA 1989) Soil ingestion by older children and adults is generally considered to occur at some fraction of the rate of young children

For the purposes of the present assessment the rate of 100 mg/day was conservatively assumed to represent both the mean and the upper 95th percentile value of hypothetical adult soil ingestion per recommendations of EPA (1989b) and (1990) and on the findings of Clausing et al (1987) and Hawley (1985) For young children aged 0 to 6 values of 200 and 800 mg/day were selected as the mean and upper-bound parameters respectively

Frequency and Duration of Soil Exposure

The average amount of time that adults work outdoors at their homes is 0 4 hr/day (EPA 1989b - citing University of Michigan 1976) Based on the reported statistical distribution for such activities the upper 95th percentile exposure for this group of individuals is 1 6 hr/day These values may be viewed as conservative statistical estimates of the potential contact frequency with soils in the off-site area

The frequency of soil/sediment contact under a residential scenario is predicted to be highest for young children aged 0 to 6 years (EPA 1989b - citing numerous references) For these individuals contact may potentially occur at an average frequency of 4 hr/day with an upper-bound frequency of 8 hr/day For older children the frequency was assumed to be intermediate between adults and young children (i e 2 2 and 4 8 hr/day as mean and upper-bound values respectively)

The assumed lifetime duration of residential exposures was based on EPA compilations (EPA 1989a and 1989c) Based on an assessment of the mobility of the U S population EPA (1989c) concluded that the average length of time that an individual may reside at a given residence is approximately 9 years or 12 percent of an average lifetime The upper-bound duration is generally evaluated at the average life expectancy of 75 years The duration of exposure (i e mobility) is assumed to be independent of age class

6 2 3 3 Pathway II Potential Exposure via Dermal Contact

Dermal absorption resulting from skin contact with soils may be a potential exposure pathway for some chemicals This exposure route has been incorporated into the current assessment for metals in off-site soils using conservative assumptions to account for inherent uncertainties in exposure estimates As discussed in Section 6 2 3 2 trace organic compounds are not expected in surface soils as a result of irrigation or any other means Accordingly these compounds were not further evaluated

In deriving estimates of potential dermal exposure consideration is given to the following parameters specific to the pathway soil concentration dermal absorption rate exposed skin surface area soil adherence rate frequency and duration of soil contact and body weight Of these soil concentrations and body weight have previously been discussed All of these factors

with their associated degree of uncertainty provide the basis for estimates of potential exposure via the dermal absorption route The rationale for selection of each numeric factor used in the exposure calculation is briefly summarized below

Soil Concentration

Off-site soil concentrations are described in Section 6 2 3 2 (Potential Exposure via Soil Ingestion)

Body Weight

The assumed values regarding body weight are identical to those used for the Soil Ingestion Pathway (Potential Pathway I)

Dermal Absorption Rate

Dermal absorption of chemicals is a relatively complex area of exposure assessment for which not all complexities have yet been delineated Therefore a higher level of uncertainty is expected to accompany this exposure factor

The reported dermal absorption of chemicals applied directly to the skin spans a wide range especially when in contact with the skin in a soil or dust matrix Chemical bonding and physical incorporation of compounds with the soil matrix complicates the analysis of dermal transfer

Metals in a soil matrix are primarily present in a complexed form which provides relatively strong stable bonds In addition because of the relatively high affinity for solids and low fat solubility the dermal transfer rate is generally much lower than that of organics

Based on a review of available data Ryan et al (1987) concluded that dermal absorption rates of soil-bound metals may range from approximately 0 1 to 1 0 percent An approximate 24-hour dermal absorption rate based on data reviewed by Ryan et al (1987) is roughly 0 2 percent For the RME scenario therefore a conservative estimate of the dermal absorption of metals was assumed to be 1 0 percent

Dermal Contact Rate

The dermal contact rate is computed here as the product of the exposed dermal surface area and the soil adherence rate Each factor is discussed individually below

Exposed Dermal Surface Area

Exposed skin surface area has been relatively well characterized for adults and children by total body area and individual body parts (EPA 1989b) For the hypothetical average (i e mean) scenario soil contact with the hands head and forearms was assumed For the hypothetical upper-bound exposure scenario exposure of the head hands arms (total) lower legs and feet was assumed

Based on data summarized by EPA (1989b) the average exposed skin area of an adult under the above condition is 3 000 cm^2 with an upper-bound value of 6 200 cm^2 For young children aged 0 to 6 years the average and upper-bound surface areas are 1 250 and 3 900 cm^2 respectively (EPA 1989b) For older children aged 6 to 18 years the average and upper-bound surface areas are 2 500 and 7 800 cm^2 respectively These values are presented in Table 6-5 The upper-bound surface area assumptions formed the basis for the RME estimate

Soil Adherence Rate

The adherence of soil onto skin is necessary to complete the dermal transfer of contaminants This adherence is known to be dependent upon a variety of factors including particle size and moisture content of soils (Hawley 1985) Generally smaller sized particles such as clay exhibit a grater tendency for adherence to the skin than coarser particles such as sands Behavioral patterns such as hand washing and showering also determine the soil adherence rate since these activities reduce the amount of time that soil is in contact with the skin

Lepow et al (1975) employed a method of determining the degree of adherence of soil to skin He assumed that all material recovered was soil and determined an approximate mean rate of 0 5 mg soil/cm2 of skin Driver et al (1989) compiled several such studies which ranged from 0 2 to 0 6 mg/cm2 When these data are plotted (see Figure 6-1) they yield an approximate mean and upper-bound soil adherence rate of 0 6 and 0 9 mg/cm^2 respectively These factors were adopted for the purposes of the exposure assessment

Frequency and Duration of Soil Exposure

The daily frequency and duration of potential soil ingestion exposures were assumed to be identical for all age groups to those described previously for soil ingestion exposures

6 2 3 4 Pathway III Potential Exposure via Drinking Water Consumption

Potential human exposure to chemicals present at the site may occur via hydrologic releases into the local ground water and subsequent hypothetical transport to drinking water supply wells

This route of exposure was included in the risk assessment incorporating conservative assumptions to account for associated uncertainties

Residents of the village of Lindsay currently obtain their water supply from a public supply well located upgradient of the site No chemical compounds from the site are ever expected to occur in this hydraulically upgradient well However chemical compounds in ground water from the site may potentially be transported to hydraulically downgradient sources A domestic well has been identified in this area Accordingly individuals residing hydraulically downgradient of the site are regarded conservatively as a potentially exposed off-site population for the potential drinking water pathway This potential has been analyzed despite the existence of actual data for the domestic well which indicates that the water quality has consistently met applicable drinking water criteria as well as the existence of two monitoring wells directly upgradient which also show water quality to be consistently within drinking water standards

In deriving estimates of potential drinking water exposures consideration is given to the following parameters specific to the adult and childhood exposure scenarios ground-water monitoring data internal (gastrointestinal) absorption rate tap water consumption rate frequency and duration of exposure and body weight The rationale for selection of each numeric exposure parameter used in the exposure calculation (including the statistical range) is briefly summarized below It should be noted that the ground-water data used is representative of on-site as well as off-site data as discussed in Section 6 1 This conservative application of on-site data is not indicative of actual measurements of water quality at the private off-site wells sampled downgradient of the site

Ground-Water Concentrations

The entire ground-water data base for 1989 discussed in Section 6 1 3 1 and summarized in Table 6 2-2 was used for the RME scenario assessment of exposure potential to ground water

Body Weight

The assumed values regarding body weight are identical to those used for the Soil Ingestion Pathway (Potential Pathway I)

Gastrointestinal Absorption Rate

Water-borne chemicals are often relatively available for internal absorption (EPA 1989) Moreover many of the available toxicological criteria for oral exposures were developed using drinking water administration of the chemical dose (see Tables 6-8 and 6-9) Accordingly the most conservative approach to estimating potential internal absorption was to designate both the

average and upper-bound (RME) potential gastrointestinal absorption of drinking water-borne chemical compounds at 100 percent

Tap Water Consumption Rate

A variety of studies have been conducted on drinking water consumption rates for adults Most of the reported studies have been based on large population surveys and other scientifically based data

One of the best available studies of drinking water consumption was conducted by the National Academy of Sciences (NAS 1977) The results of this study suggest that the average adult consumes approximately 1 6 liters per day of tap water and water-based drinks

Statistical upper-bound rates were not reported in the NAS (1977) study However based on data reported by Gillies and Paulin (1983) the upper 95th percentile water consumption rate for adults is estimated at approximately 2 2 liters/day The distribution of adult water consumption rates are reportedly normal (based on Gillies and Paulin 1983 and Cantor et al 1987)

Based on these data the average and upper 95th percentile consumption rates for children aged 0 to 6 years are approximately 0 635 and 0 92 liters/day respectively The average and upper 95th percentile consumption rates for children age 6 to 18 years are approximately 1 2 and 2 0 liters/day respectively while the ingestion rates for adults are assumed to be 1 4 and 2 0 (mean and upper-bound respectively)

Frequency and Duration of Exposure

The potential daily frequency and lifetime duration of off-site inhalation exposures was based on activity patterns of the general U S population Findings indicate an average of 14 hr/day or 58 percent of the time spent during the day at home The upper 95th percentile domestic (off-site) exposure frequency for local residents was conservatively assumed to be 24 hr/day or 100 percent of the time

For the childhood scenario exposure frequency estimates were based on the average and upper-bound period of time spent at home Since children spend an approximately equal period of time at home as do adults (EPA 1989b) the domestic frequencies summarized above also applied to children The average and upper 95th percentile frequencies for children are thus 14 and 24 hr/day respectively

The assumed duration of drinking water exposures under the adult and childhood exposure scenarios was based on an assessment of data on the U S population which indicated that the average length of time an individual may resident a given residence is approximately nine years

or 12 percent of a human lifetime The upper-bound highly conservative duration recommended for risk assessment purposes is the average life expectancy of 75 years

6 2 3 5 Pathway IV Potential Exposure via Inhalation of Vapors from Drinking Water

This pathway potentially may occur in association with showering or bathing as heated turbulent water may facilitate volatilization of organic compounds normally dissolved in the water It is assumed for risk assessment purposes that such a phase transfer is facilitated during such conditions

In deriving estimates of potential drinking water exposures consideration is given to the same exposure parameters specific to the adult and childhood exposure scenarios with the addition of ventilation (i e inhalation) rate a phase transfer coefficient and frequency and duration associated with bathing and showering The rationale for selection of each numeric exposure parameter used in the exposure calculation (including the statistical range) is briefly summarized below

Body Weight

The assumed values regarding body weight are identical to those used for the Soil Ingestion Pathway (Potential Pathway I)

Frequency and Duration of Exposure

The frequency of showering is based on a statistical summary by EPA (1989) in which mean and upper-bound values for the length of a shower are 7 and 12 minutes/day respectively Duration (i e the period of exposure over a lifetime) are assumed to be the same as that of other pathways (i e 9 and 75 years as mean and upper-bound values respectively) These values are assumed to be independent of age-class

Ventilation Rate

Although the ventilation rate is known to vary with age sex and level of activity the latter factor appears to account for most of the total reported variation in this parameter (EPA 1985) In order to derive a cumulative average and upper 95th percentile ventilation rate appropriate to the RME scenario the rates reported in the literature and EPA (1989) were used to develop an average and upper-bound ventilation rates of 20 and 30 m^3/day respectively (regardless of age class)

Phase Transfer Coefficient

Andelman et al (1986) used a simple one compartment indoor air model to estimate indoor air concentrations resulting from volatilization of various compounds from potable water Based on standard conditions and the assumption of 100 percent volatilization they predicted that about 60 percent of a dissolved volatile constituent would transfer to the gas phase They also report that if the typical 50 percent volatilization rate from all indoor water uses was assumed then only about 30 percent of the dissolved compound can be expected to transfer phases This relationship is expressed as

$$C_A = 0\ 6\ C_W$$

where

C_W = concentration in water mass per liter results in

C_A = concentration in air mass per m^3

Such relationships can be utilized for volatilization potential of individual constituents to predict concentrations in indoor air Based on this research it was judged appropriate to apply the phase transfer values of 0 3 (30%) and 0 6 (60%) as the mean and upper-bound values respectively (see Table 6 2-4)

6 2 3 6 Pathway V Potential Exposure via Consumption of Homegrown Fruits and Vegetables

In deriving estimates of potential produce ingestion exposure associated with the site consideration is given to frequency and duration of exposure consumption rate of homegrown produce soil concentration plant accumulation of compounds from soil and gastrointestinal absorption rate These factors with their associated uncertainty provide the basis for potential exposure estimates via this route The rationale for selection of each numeric exposure factor used in the exposure calculation including its statistical range of variability is briefly summarized below

Soil Concentrations

The potential for uptake of identified metal compounds into plant tissue was addressed by using the off-site soil data base presented in Table 6-3 Individual plant bioaccumulation factors are discussed below

Body Weight

The assumed values regarding body weight are identical to those used for the Soil Ingestion Pathway (Potential Pathway I)

Frequency of Exposure

The daily frequency of ingestion of homegrown produce was based on the assumption that an average of 25 percent of total produce was obtained from the domestic garden or orchard This value has been recommended by EPA (1989a) for the proportion of a variety of foodstuffs derived from a single source For the upper 95th percentile condition 100 percent of the produce consumption was assumed to be homegrown and consumed from the garden or orchard

The assumed lifetime duration over a lifetime of produce consumption exposures under the RME scenario was equivalent to the factors used for the exposure pathways discussed above The average and upper-bound duration of exposure is 9 and 75 years respectively

Homegrown Produce Consumption Rate

Ingestion rates of homegrown produce have been reported for various regions of the U S by the Food and Drug Administration (FDA 1981) and by Pennington (1983) These and other data have been summarized by EPA (1989a 1989b)

The principal homegrown crops considered in the risk assessment include root crops leafy vegetables and garden fruits EPA recommends a general consumption rate of 1 790 2 020 and 4 810 mg/day dry wt respectively for root crops leafy vegetables and garden fruit (see Table 6 2-2) It has been reported that the above consumption rate is valid for ages five and up Accordingly the mean and upper-bound consumption rate for these plant groups was divided by a factor of five for early childhood (ages 0 to 6)

In consideration of the data uncertainty for this exposure factor EPA (1989a) recommends that the consumption rates summarized above be used to address both the mean and RME scenario as they are conservatively derived and expected to be adequately protective

Plant Accumulation Factors

Chemical compounds may potentially be taken up by plants via transpiration of water through the tissues and/or by fallout by dust (Travis and Arms 1988) In both cases a characteristic concentration ratio between plant and soil (denoted the plant accumulation factor) is assumed to govern this relationship

For the purposes of the current evaluation plant accumulation of metals was based upon data from several sources including results of studies of plant accumulation in urban gardens The potential importance of species variation on accumulation factors is not well understood

Accumulation factors used for the plant uptake exposure pathway were based on studies by Fitzgerald (1979) Upper-bound estimates were calculated as the upper 95th percentile of the presumed distribution The mean and upper-bound accumulation factors used for cadmium lead and zinc are 2 and 4 0 01 and 0 05 and 0 13 and 0 49 respectively based on this study

Gastrointestinal Absorption

Similar to chemical compounds present in drinking water tissue residues of chemical compounds are relatively available for internal absorption following ingestion Accordingly both the average and upper-bound internal absorption of plant tissue chemicals was assumed to be 100 percent

6 2 3 7 Pathway VI Potential Exposure via Inhalation of Particulates

Potential exposure to airborne emissions of particulates and dusts in the vicinity of the site was evaluated as a potential pathway In order to quantitatively estimate potential exposure via this pathway it was necessary first to model airborne emissions based on concentrations in soil (Table 6-3) This modeling effort is described in Section 6 2 3 7 and Appendix XI(J) Exposure factors relating to the inhalation pathway are discussed below

Body Weight

The assumed values regarding body weight are identical to those used for the Soil Ingestion Pathway (Potential Pathway I)

Frequency and Duration of Exposure

The statistical range of frequency and duration of potential exposure for off-site receptors was obtained from EPA (1990a) and is based on estimated time spent at home A conservative estimate of this parameter for all age groups is 18 hours per day and 24 hours per day respectively for average and upper-bound exposure frequencies Residential and occupational exposure duration are identical to those described for soil ingestion exposures

Ventilation Rate

Although the ventilation rate is known to vary with age sex and level of activity the latter factor appears to account for most of the total reported variation in this parameter (EPA 1985)

In order to derive a cumulative average and upper 95th percentile ventilation rate appropriate to the RME scenario the rates reported in the literature and EPA guidance were used to develop an average and upper-bound value of 20 and 30 m^3/day respectively (regardless of age class) for off-site exposures

Pulmonary Retention

Because available compound-specific information on pulmonary retention is sporadic a conservative estimate of 100 percent retention of respired vapors and particulates was assumed for this exposure pathway

6 2 3 8 Airborne Emissions and Dispersion of Soil Contaminants

Airborne exposure-related parameters were estimated to facilitate quantitative analysis of potential exposure to off-site residents under potential Exposure Pathway VI (Inhalation) This involved airborne emission and dispersion modeling of soil-associated site compounds The effort was conducted as follows

- airborne concentrations of particulates less than 10 microns (PM10) were calculated using Gillette wind erosion models and dispersion techniques presented by Cowherd (Rapid Assessment of Exposure to Particulate Emissions from Surface Contamination Sites EPA 1985)
- particulate emissions resulting from both wind erosion and agricultural tilling were estimated
- soils data for Platte County Nebraska were obtained from U S Department of Agriculture (USDA 1988)
- meteorological data for 1960-1964 from Offutt Air Force Base in Omaha Nebraska were used
- cultivated lands were assumed to be tilled 6 times per year
- off-site soil chemical concentrations were used to provide a basis for estimating chemical concentrations in airborne particulate and
- these estimated airborne concentrations were incorporated into the risk assessment model to estimate potential inhaled doses by off-site receptor groups

Both annual average airborne concentrations and worst-case 24-hour concentrations were estimated Tables 6 2-5 and 6 2-6 present the mean and upper-bound estimated airborne concentrations respectively

6 2 3 9 Consumption of Game

Potential exposure to site chemical compounds via consumption of game and fowl was not quantitatively included in the risk assessment for the following reasons (1) the habitat surrounding the Lindsay site is limited and is not expected to support abundant game (2) if game were taken near the area of the site it is believed that the majority of an individual animal s lifetime would have been spent away from the site and (3) the site is fenced and access-controlled

6 3 TOXICITY ASSESSMENT

This section summarizes the toxicologic basis for all compound-specific toxicity criteria using available does-response information An overview of environmental fate properties for each compound was presented in Section 5

Toxicity and risk assessment vary for different chemicals depending upon whether non-carcinogenic or carcinogenic endpoints (i e responses) are used to assess potential risk These criteria in turn are based on the endpoint observed from laboratory or epidemiological studies of the compounds Some chemicals of concern may result in both non-carcinogenic and carcinogenic effects although in most cases the EPA has published toxicity criteria for only the most sensitive type of toxic effect supporting the most restrictive criteria

When EPA completes verification of the chronic (i e non-carcinogenic) toxicity of a specific chemical it establishes a reference dose (RfD) The RfD is used by the EPA for evaluating potential long-term non-carcinogenic risk This acceptable dose is compared to the potential expected dose to determine whether chronic effects would be expected based on the exposure assumptions applied If predicted exposure concentrations are below the level of the regulatory criteria no adverse chronic health effects would be expected

Chemicals classified by EPA as potential human carcinogens are evaluated differently The upper-bound cancer risk associated with a given dose is calculated by multiplying the dose from a given route of exposure by a cancer potency factor or potency slope EPA derives potency slopes from the upper 95th percentile confidence limit of the slope of an extrapolated dose-response curve Both because of the non-threshold assumption and the 95th percentile confidence limit the use of published SF values provides a conservative upper-bound estimate of potential risk associated with assumed exposure conditions

For the purposes of the present assessment the toxicological characterization of indicator compounds was confined to chronic (i e lifetime) exposures The types of potential exposure at the Lindsay site under the hypothetical RME scenario are most appropriately addressed in the context of long-term (i e chronic) doses

Oral and Inhalation Values

The oral and inhalation RfD or potency slope values used in the risk assessment are summarized on Tables 6 3-1 and 6 3-2 All values when available are derived from a single (i e principal) study or bioassay according to standard procedures Values which have been verified by the EPA RfD Work Group (for non-carcinogens) and the EPA CRAVE Group (for carcinogens) are interpreted as final EPA values (i e not likely to be changed in the near future)

In order to summarize the quality of the toxicological data base for each compound the toxicological basis used to derive risk assessment criteria is provided in the tables For non-carcinogenic compounds this includes in addition to the numeric RfD values (a) the qualitative level of confidence EPA places in the numeric value (b) the medium used for the principal study (c) the test species used for the principal study (i e clinical animal studies vs clinical human exposure etc) (d) the critical effect or target organ effect which is then used to evaluate the potential for human toxicity and (e) uncertainty factors used to derive the value

The two most important toxicological parameters discussed above as related to human risk assessment are the latter two (i e critical effect and the uncertainty factors) The primary target organ or critical effect is important for non-carcinogens because it is the most significant indicator of whether non-carcinogenic risks may be assumed to be additive Uncertainty factors are directly related to the level of confidence placed in the data base and because they are generally applied in ten-fold increments may contribute to a sharp increase or decrease (indicating greater or lesser toxicity) in the numeric value

Table 6 3-2 summarizes the data base for potential carcinogens In addition to the oral slope factors (SFs) some details relating to the toxicological basis for deriving this value include (a) the weight-of-evidence classification for the compound (see Table 6 2-6 for specific definitions of assigned values) (b) the type of cancer observed in laboratory animals and (c) the medium used for the principal study For potential carcinogens it is assumed that carcinogenic compounds are systemic (i e may affect any organ) and are therefore additive rather than target organ-specific

6 4 RISK CHARACTERIZATION

The exposure and toxicity assessments of target chemicals presented in Sections 6 2 and 6 3 6 6 form the basis for the characterization of potential risk posed by the site under the RME scenario This section presents the results of the risk characterization calculations The uncertainties associated with the risk characterization are briefly addressed in Section 6 5

Analysis of Potential Non-Carcinogenic Effects

As discussed above potential non-carcinogenic and carcinogenic risk are evaluated differently in a baseline risk assessment For non-carcinogens the projected daily dose resulting from site exposure is divided by the reference dose (RfD) values to compute the Hazard Index (HI) This approach is considered non-probabilistic in that it reflects the assumption that a toxicity threshold generally exists for non-carcinogens and that the risk can be represented by the quotient of the dose and the allowable RfD guideline (i e the oral or inhalation RfD)

The HI was developed by EPA to assess the overall potential for non-carcinogenic effects posed by multiple chemical exposures (EPA 1986 51 Fed Reg 185 (9/24/88)) although each individual toxicant is evaluated individually The Index is not designed as a mathematical prediction of the severity of the non-carcinogenic effects (for example a Hazard Index of 1×10^{3} does not signify a 1-in-1 000 chance of toxicity occurrence) rather it is an indication of potential adverse effects in view of established RfD criteria for specific chemical compounds

The preliminary evaluation of the Index assumes that all effects are additive However if the cumulative Hazard Index exceeds 1 0 the compounds may be grouped by similar critical effects For compounds with different critical effects (or target organic effect on which the criteria are based) HIs are recalculated after the compounds have been grouped by critical effects in order to derive a more accurate estimate of the additivity of the non-carcinogenic effects (EPA 1986 EPA 1989a) If the Index does not exceed 1 0 then non-carcinogenic adverse health effects are not expected to occur For the purposes of the present assessment both the hypothetical mean and RME (i e worst case) HIs were calculated in order to develop estimates of uncertainty The RME values represent a relatively extreme potential exposure scenario this scenario is included in this risk assessment in order to evaluate the most conservative scenario possible rather than the most likely

Index values are estimated for various age classes For this report three age classes were considered 1) 0 to 6 years 2) 6 to 18 years and 3) 18 to 75 years Division by age class is useful because (a) it allows use of more appropriate age-specific exposure factors (2) it provides an indication of which age group may be at the greatest potential risk and (3) it allows examination of the potentially most significant exposure pathways This age class division is consistent with general EPA guidelines for conducting baseline risk assessment (EPA 1989a)

For the purposes of the present assessment RfDs developed for oral exposures were assumed to be representative of dermal contact exposures as well, when these exposures are corrected for absorption The assumption of similar toxicity is supported by the observation that toxic effects due to oral exposure tend to affect target organs distant from the point of absorption This extrapolation is consistent with EPA guidance (EPA 1989a)

Analysis of Potential Carcinogenic Effects

None of the identified organic compounds are known human carcinogens Instead they are classified by the EPA as potential carcinogens These are compounds for which studies to date are not considered sufficient for EPA to classify them as human carcinogens EPA classification is based on animal studies only and indicates that these compounds are only possible carcinogens However it was conservatively assumed for purposes of conducting the risk assessment that all compounds of EPA Classification C and above (see Table 6 3-2 for explanation of classification) represent compounds which are potentially carcinogenic and were included in the quantitative analysis The baseline risk assessment is used to evaluate whether any of the chemicals has a carcingenic potential over a lifetime under the RME scenario This involves application of a probabilistic approach based on a toxicological model which assumes no threshold at which carcinogenesis may be initiated (i e a linear dose-response relationship) and further assumes that the carcinogenesis is equally likely to occur at all growth stages of the test animal (i e multi-stage)

The generalized relationship for conducting these calculations involves the projected chemical dose the absorption efficiency which varies with exposure pathway and the cancer potency slope which represents an upper-bound estimate of carcinogenic potency The specific equation is presented in greater detail in Appendix XI(K)

Using this model the cancer risk potential is expressed as the probability for an individual to contract cancer over a lifetime as a result of hypothetical RME scenario exposure to a specific chemical compound As discussed above this conservative model assumes no toxicity threshold and unlike the non-carcinogens evaluated using the HI these risks are assumed to be additive in nature both within and among individual age-classes This model addresses carcinogenic effects as systemic rather than target organ-specific in nature and assumes that potential effects are additive over a lifetime

The general range of lifetime potential cancer risk considered by EPA to be acceptable is between 1×10^{4} and 1×10^{6} or 1 in 10 000 to 1 in 1 000 000 Guidance for this range is provided in the revised NCP (40 CFR Part 300 55 Fed Reg 8666 at 8848 (3/8/90)) This range was determined to be the most appropriate goal for the purposes of the Lindsay RI and the FS

For the purposes of this risk assessment the cancer potency or slope factor (SF) values (see Table 6-9) associated with potential dermal contact exposures were assumed to be equivalent to oral SFs As with non-carcinogens this toxicological extrapolation is consistent with current EPA guidelines for risk assessment (EPA 1989a) However it should be recognized that uncertainty is inherent in the extrapolation of oral SF values to dermal exposures

6 4 1 Results of Exposure Assessment

Table 6-10 presents the estimation of hypothetical mean and RME (i e worst-case) potential exposures to off-site residents living near the Lindsay site These exposures represent the six potential pathways considered during the current evaluation which are (I) ingestion of drinking water (II) inhalation of organic vapors from the water (III) incidental ingestion and (IV) dermal contact with soils irrigated by well water (V) ingestion of irrigated homegrown produce and (VI) inhalation of airborne particulates The exposure assessment is based on hypothetical conditions that have not occurred and are unlikely to ever occur given current conditions

Results of the exposure assessment are categorized by target chemical age class and by oral (including dermal) and inhalation exposures Both the hypothetical mean exposure as well as the RME (i e worst-case) scenarios are presented This approach was selected because it provides a measure of data distribution and a conservative perspective on data uncertainty

Table 6 4-1 identifies zinc as posing the greatest potential exposure (i e greater than 95 percent) for all three age classes The majority of this potential exposure is under the hypothetical RME exposure scenario expected to occur during the early childhood years (ages 0 to 6) Zinc is the compound from which the single greatest potential exposure could occur (up to 15 mg/kg for ages 0 to 6) Among the organic compounds 1 1 1-TCA poses the highest individual potential exposure (up to 0 048 mg/kg-day for ages 0 to 6) It is noted from Table 6 4-1 that potential inhalation exposures are expected to be far less than potential oral exposures The results of the hypothetical RME scenario for evaluating potential exposure for either zinc or 1 1 1-TCA are not evident in actual sampling analysis for the domestic well water and the two monitoring wells upgradient of the domestic well and between the site and the domestic well Zinc and 1 1 1-TCA occurrences in these wells were well below the drinking water standards for these compounds This potential exposure is based on a highly conservative and improbable scenario for which adequate monitoring safeguards exist

6 4 2 Potential Non-carcinogenic Hazards

The results of the chronic non-carcinogenic HI evaluation under the hypothetical RME scenario are presented in Table 6 4-2 These values represent the quotient of the total potential exposures (i e from all potential pathways) and the established non-carcinogenic toxicity for

target compounds It is therefore possible that compounds for which potential exposure may be highest may have the lowest HI due to a lesser degree of toxicity (e g in the case of 1 1 1-TCA)

Table 6 4-2 indicates that under the RME scenario none of the estimated HI values for inhalation exceeded 1 0 for any age-class while estimated RME oral HI values exceeded 1 0 for all age classes The greatest potential HI value is expected from early childhood (ages 0 to 6) Approximately 78 percent of the potential HI value for this age-class occurs as a result of the RME scenario-based potential exposure to zinc with approximately 11 percent from lead As discussed above nearly all of the potential non-carcinogenic exposure is estimated from oral rather than inhalation exposures

6 4 3 Potential Cancer Risks

Table 6 4-3 presents the results of the RME scenario risk characterization for possible carcinogens identified during the monitoring program including certain organics and metals As discussed in Section 6 3 these compounds include 1 1- and 1 2-DCA 1 1-DCE PCE and TCE identified by EPA as possible carcinogens These are compounds for which studies to date are not considered sufficient for EPA to classify them as human carcinogens EPA classification is based on animal studies only and indicates that these compounds are only possible carcinogens Cadmium is included in the RME carcinogenic risk characterization because it can be evaluated as a possible carcinogen through inhalation None of the other metals are deemed to be possible carcinogens and therefore they were not included

Only the upper-bound risk estimates are included in the table This is a conservative approach consistent with the EPA approach to evaluating carcinogenic compounds (cf Chapter 7 of EPA 1989a) This is because the toxicological model upon which the carcinogenic evaluation is based is probablistic in nature and is designed to address a highly conservative exposure scenario Table 6-12 presents the hypothetical RME scenario-based potential cancer risk for all age classes including both oral and inhalation potential exposure routes The potential cumulative lifetime oral and inhalation cancer risk for hypothetical RME-based potential exposure to all compounds including potential carcinogens combined for all age classes and for both routes is estimated to be $1\ 6 \times 10^{2}$ This upper-bound value is based on a set of RME-scenario assumed occurrences conditions at the domestic well that have not in fact occurred and are not likely to ever occur since on- and off-site organic concentrations are dropping with on-going remediation and the domestic well has consistently met drinking water criteria and is adequately safeguarded by the upgradient monitoring wells

As noted from Table 6 4-3 the majority of this RME-based potential risk is calculated from 1 1-DCE because of its relatively potent carcinogenic properties in laboratory animals (potency slope of 0 6 mg/kg-day ^{1}) This chemical has never been detected at the domestic well or in the monitoring wells between the domestic well and the site Projected potential cancer risk for this

individual compound is estimated to potentially exceed 10^{4} for all age groups under the hypothetical RME scenario Other individual compounds estimated to potentially exceed the 10^{4} guideline under the RME scenario are 1 1-DCA (ages 0 to 6 only) and PCE (all age groups) Neither of these compounds have ever been detected at the domestic well and only once at a level well below the drinking water standards at the two upgradient monitoring wells between the domestic well and the site None of these organic compounds has been classified as a human carcinogen under EPA weight of evidence criteria

Total Potential Exposure to Target Chemicals by Potential Pathway

Table 6 4-4 represents total RME scenario potential exposure expressed as a dose in units per day by age-class (i e both oral and inhalation routes combined) target chemical and potential exposure pathway It is noted from the table that the dominant potential pathway is via ingestion of drinking water for both metals and organics for all age groups The potential for cadmium exposure due to its high oral toxicity to occur by ingestion of homegrown produce irrigated with ground water is included However actual soil and plant sample analyses from the field irrigated with well water have not detected cadmium (Section 4)

This finding strongly suggests that overall potential exposure in the vicinity of the Lindsay site is highly dependent upon ground-water quality (as represented by both the ingestion and vapor inhalation pathways) such potential exposure and associated estimated risk potential are based on a hypothetical future RME scenario rather than actual current conditions

6 4 4 Additivity of Risks in Different Areas

As noted from Table 6 4-2 the majority of the potential non-carcinogenic HI value is associated with zinc with lesser contributions from cadmium and lead The primary toxicological effect generating the interim oral RfD value of 0 2 mg/kg-day for zinc was anemia while the primary effect associated with oral exposure to cadmium is renal effects It therefore may not be appropriate to simply add the potential HI values for these two compounds when the toxicological effects of concern are different

The primary toxicological effects of concern for both lead and zinc relate to the blood as a target organ system (i e one of the target organs for lead is the hematopoietic system) Accordingly the two compounds are assumed to be additive However it must be noted that the interim oral RfD value for lead (0 0014 mg/kg-day) is not a verified value and has in fact been withdrawn by the EPA RfD Work Group It was applied only in the absence of other dose-response information It is not known at this time whether this value represents an over-conservative toxicological assessment of the chronic effects of orally administered lead in humans

6 5 UNCERTAINTY ANALYSIS

Although there are many sources of uncertainty inherent in the risk assessment process the results may provide a useful indication of the significance of potential exposure pathways Identifying the sources and effects of uncertainty assists in evaluating health risk estimates highlighting the uncertainty in the conclusions and minimizing subjective interpretation of potential risk The assumptions applied in the risk assessment are designed to be conservative so that risk is more likely overestimated than underestimated

This section addresses the major qualitative and quantitative sources of uncertainty which contribute to the potential risk characterization presented in Section 6 4 The analysis focuses on those potential exposure pathways contributing most to estimates of overall risk potential

6 5 1 Assessment of Uncertainty - Toxicity

Uncertainty in the toxicity evaluation of the primary chemical compounds of potential concern including zinc 1 1-DCE PCE lead and cadmium are discussed below Sources of toxicological uncertainty typically include individual studies the size or quality of the overall toxicological data base extrapolation factors used to derive estimates and other considerations

Zinc The fact that no oral RfD value has been verified for quantitative risk assessment of zinc indicates a low degree of confidence in the interim value suggested by EPA and used during the present assessment The value used (0 2 mg/kg-day) to address chronic exposures to this compound is uncertain because of the limited extent of the overall data base and the validity of the measured toxicological response

1,1-dichloroethylene As discussed in Section 6 3 dose-response information for 1 1-dichloroethylene has been deemed adequate by EPA to support the derivation and verification of slope factors for both oral and inhalation exposure routes Accordingly this value represents a relatively high degree of confidence

Cadmium As discussed in Section 6 3 dose-response information for cadmium has been deemed adequate by EPA to support the derivation and verification of slope factors for both oral and inhalation exposure routes

Lead In contrast the toxicological information for lead is a highly controversial body of information within EPA and other scientific circles This is due in large part to the lack of understanding of the basic mode of toxicologic action associated with oral exposure to lead It is therefore believed that the interim oral RfD of 0 0014 mg/kg-day represents a highly uncertain value which materially contributes to uncertainty within the risk assessment

One of the most significant sources of uncertainty in the estimation of potential cancer risk is the linearized multistage cancer model discussed in Section 6 4 Specifically the use of published slope factors is expected to generally overestimate actual cancer risk in part because of the upper-bound statistical methods used to derive this value Cancer risks derived using this model are most appropriately denoted upper-bound estimates particularly under lower exposure conditions

6 5 2 Assessment of Uncertainty - Exposure

One of the principal objectives of exposure modeling and of risk assessment in general is to estimate the probable range of exposure outcomes which may potentially be associated with site conditions Quantification or at least estimation of confidence limits may enhance the decision making process

Development of both a mean and upper-bound value for exposure factors and assumptions used to address exposure provides a greater understanding of the range of uncertainty inherent in predicting potential exposure to contaminants Moreover by developing an RME (i e most conservative worst-case) value for each average exposure factor a greater degree of protection is ensured thus minimizing the chances for underestimating risk potential

Use of nationally-based studies are necessary when site-specific exposure information is lacking By using both mean and upper-bound values the chances of adequately (i e protectively) addressing exposure potential at an individual site such as the Lindsay site are increased

The following section presents a brief discussion of the uncertainty believed to exist in the potentially predominant exposure pathways

Potential Exposure to Ground Water via Ingestion

Exposure via this route is highly uncertain As discussed previously in the RI applicable drinking water standards have been met at the domestic well as well as the upgradient monitoring wells Concentrations actually detected in ground water were detected on site or in the area of deep chemical occurrences which are stratified (Section 4) These ground-water occurrences are substantially different from actual sampling results for the domestic or stock wells downgradient of the site where the occurrences if any are low in concentration and dispersed Moreover the deep stratified occurrences are in the capture zone of the interceptor wells and the concentrations are diminishing with remediation Exposure to ground water using the 1989 data base thus represents a conservative hypothetical future scenario which is not reflected in actual off-site sampling at the domestic well and is highly improbable

In summary the risk characterization indicates that the baseline cancer risk for potential exposure pathways to organic compounds is based on a hypothetical worst case scenario that would require occurrence of these compounds at a domestic well in which these compounds are either not present or occur only at levels well within the drinking water standards This well is situated downgradient of a set of monitoring wells placed between the well and the site The chemical occurrences in the deep stratified area at the southeast corner of the site are in the zone of capture of the interceptor wells and continue to decrease in concentration Exposure factors used for the RME scenario are generic in nature rather than site-specific The effect of this assumption is expected to be an overestimation of potential risk associated with the site The potential non-carcinogenic risk is based on an exposure to cadmium lead and zinc resulting from irrigation water This assessment also assumes a hypothetical worst case scenario which does not take into account the ongoing remediation and actual off-site conditions demonstrated through sampling

6 6 ASSESSMENT OF POTENTIAL ECOLOGICAL RISK

Introduction

The purpose of this section is to address the potential for ecological impacts to wildlife inhabiting the area around the Lindsay facility The appropriate area of study is southeast of the site because of the prevailing ground-water flow Individual compounds of potential concern are based on those identified in the 1989 ground-water data base (Table 6 2-1) and include zinc cadmium and lead Trace organic compounds are not expected to represent significant exposure potential because they are expected to disperse into the atmosphere following pumping of ground water to the surface

Surface soils most accurately represent the potential exposure of wildlife to this area as there is no direct means by which wildlife may come into long-term contact with ground water There are generally no bodies of standing water to the southeast of the site with the exception of ponded rain or irrigation water on a temporary basis Accordingly the off-site soil data base (discussed in Section 6 1 and presented in Table 6 2-3) is the most representative data base for potential wildlife exposure The most plausible pathway for potential wildlife exposure is the pumping of metal compounds via ground water and subsequent retention in soils

The metal concentrations to be evaluated are based on actual soil data discussed in Section 6 1 (Table 6 2-3) These dissolved metals could potentially be taken up into plant tissue The potential for uptake is represented by the plant tissue data base presented in Table 6 2-3 Irrigation water from well #54278 is not expected to run off from tilled fields and does not constitute an exposure pathway to wildlife However it is conceivable that irrigation waters from well #54278 may drain to a small woodlot to the north and west of the field Since free water is a strong attractant to wildlife, particularly in a semiarid region such as Nebraska any ponded

water from irrigation is expected to be available to wildlife although exposure duration is expected to be brief rather than extended in nature due to the limited and temporary nature of its occurrence Ground water pumped at the site is treated and discharged pursuant to the terms of an NPDES permit which establishes discharge limitations for specific parameters and authorizes discharge to an intermittent stream on-site The permit reissued in 1988 by the NDEC NPDES permits division includes biomonitoring criteria for certain organisms The invertebrate criteria are currently under reevaluation by NDEC Discharge of ground water from the treatment facility is thus regulated by water quality provisions established by the state-issued NPDES permit Therefore irrigation is the only other pathway of potential exposure to ground water from the site There are a few scattered trees along the western fence rows that could also receive irrigation water It is highly unlikely that this water could reach local creeks since they must drain across fields tilled in part to retain moisture Wildlife habitat thus potentially affected could include the soils and crops under the center pivots the trees along the fence row on the western side of those fields the wild grasses that may be growing between the center pivot fields and along the road verge and possibly the woodlot near the feedlot

Wildlife Potentially Affected

There is a wide variety of animals that are reported to live in and around the fields potentially impacted by irrigation well #54278 Few species would fulfill all of their habitat requirements entirely within these areas as crops and field borders would be expected to be used only for a fraction of their lifetime and of their home range (see discussion in Section 3 8) The amount of exposure would vary depending on the habits of an individual species Animals such as small rodents that live primarily within the field could be potentially to exposured while those inhabiting the field borders or which only occasionally use the areas such as deer and raccoon would be less likely to be exposed

Animals inhabiting soils which consume soil organic detritus such as earthworms and other invertebrate soil organisms as well as various rodents could be exposed to concentrations of metals in soils although off-site soil measurements taken in the area indicate that concentrations are not elevated above background Accordingly soil-dwelling organisms are not expected to be exposed

Field crops irrigated with ground water may take up metals both through the roots and the above-ground plant parts It is assumed that metals are stored in all parts of the plant In the Lindsay area wildlife that could be potentially exposed to elevated metal concentrations through consumption of crops include insects birds (including quail pheasant and songbirds) and mammals such as rodents rabbits skunks deer raccoons and coyotes Predatory species could conceivably be exposed to metals through feeding upon previously exposed prey species Such exposures however are negligible based on off-site measured surface soil concentrations

Potential Exposure Levels

Elevated concentrations of cadmium lead and zinc were observed from a local irrigation well during the 1989 season as discussed in earlier sections However because no direct exposure pathways especially on a chronic basis to ground water are believed to exist (i e any exposure would be temporary) it is more appropriate to evaluate these exposures on the basis of measured off-site soil concentrations of lead cadmium and zinc In contrast it is not appropriate to address the measured irrigation well concentrations as a potential exposure to wildlife as there are no standing bodies of water in the irrigated area with the possible exception of temporary rain water or temporary ponding of irrigation water with which wildlife could come into long-term contact

In the absence of toxicity guidelines specific to the wildlife species known to inhabit the site (especially for black-tailed mule deer which are known to inhabit the area) it is judged appropriate to consider an estimated oral RfD value for zinc for cows a physiologically similar ruminant species to deer for which a Maximum Safe Level for zinc has been developed This level has been set at a dietary concentration of 500 mg zinc/kg food (National Research Council 1978) Application of assumed uncertainty and exposure factors for cows (upper bound values of 909 9 kg body weight 18 2 kg/food-day [pers comm with the Washington Dairy Association for steers raised on feed corn] and 80 percent contribution to overall intake via the dietary route) yields an approximate oral RfD value of 17 6 mg/kg-day This estimated chronic value represents a daily dose of approximately two orders of magnitude greater than the human oral RfD value of 0 2 mg/kg-day It is noted however that wildlife are mobile and would not be expected to obtain their entire dietary intake from a single location as would domestic stock Home ranges for wildlife (e g for deer) may be 1 to 2 miles in diameter That is an individual animal may travel up to 2 miles a day searching for food and water Since water is readily available from several sources in the Lindsay area it is very unlikely that an individual animal would obtain all of this water from a single area or individual farm

Toxic effects in wildlife ingesting irrigated plants are not expected because zinc the most concentrated of the metals present in ground water is a micronutrient necessary for health of animals and plants Based on measured zinc in a grass sample located near the irrigation well there is no evidence of elevated levels in plant tissues relative to reference levels (see Table 6 2-3) In fact depletion may occur in both plants and animals in central Nebraska zinc is commonly added to fertilizers to supplement zinc deficient soils In addition wildlife are unlikely to depend exclusively on plants which have taken up irrigation water from a single source

As discussed in Section 6 2 measurements taken from off-site soils have indicated that neither lead nor cadmium are elevated relative to reference concentrations When the plant bioaccumulation factor for zinc as a maximally conservative indicator chemical (discussed in Section 6 2) is applied the resulting estimated upper-bound dietary concentration of 30 mg/kg does not approach the Maximum Safe Level for zinc in cows discussed above Accordingly no toxicity thresholds for wildlife are expected to be exceeded for cadmium lead or zinc as a result of feeding upon irrigated plants

Table 6 2-1

Selection of Potential Pathways for Quantitative Exposure Assessment

Lindsay Mfg Co

Potentially Exposed Population	Route Medium and Exposure Point	Pathway Selected for Quantitative Evaluation?	Basis for Selection or Exclusion
Village population	Groundwater ingestion from local wells	No	Water supply to village residents is hydraulically upgradient of the site and does not contain site-associated compounds
Village population	Inhalation of organic vapors from public water supply during showering and bathing	No	Water supply to village residents is hydraulically upgradient of the site and does not contain site-associated compounds
Inhabitants of village or of surrounding farms	Inhalation of chemicals contained in vapors transported off site	No	This potential route is considered highly unlikely and was judged insignificant (see text)
Population to southeast of site	Groundwater ingestion from local wells	Yes	This pathway is conservatively addressed using EPA recommended RME scenario exposure assumptions and a ground water data base which represents both on-site and off site data for 1989
Population to southeast of site	Inhalation of organic vapors from domestic water supply during showering and bathing	Yes	This pathway is conservatively addressed using EPA-recommended RME scenario exposure assumptions and a ground water data base which represents both on-site and off site data for 1989
Population to southeast of site	Incidental ingestion of off site soils irrigated with water downgradient of site	Yes	This pathway is conservatively addressed using EPA recommended RME scenario exposure assumptions and a measured off site surface soil data base
Population to southeast of site	Dermal contact with off-site soils irrigated with water downgradient of site	Yes	This pathway is conservatively addressed using EPA recommended RME scenario exposure assumptions and a measured off site surface soil data base
Population to southeast of site	Ingestion of homegrown fruits and vegetables irrigated with water downgradient of site	Yes	This pathway is conservatively addressed using EPA recommended RME scenario exposure assumptions and a measured off site surface soil data base
Inhabitants of village or of surrounding farms	Inhalation of airborne particulates driven by wind from off site soils	Yes	This pathway is conservatively addressed using EPA recommended RME scenario exposure assumptions and a measured off site surface soil data base
Inhabitants of village or of surrounding farms	Inhalation of organic vapors from off site soils	No	No organic vapors are present off site due to atmospheric dispersion following pumping to surface
Inhabitants of village or of surrounding farms	Incidental ingestion of or dermal contact with surface drainage	No	Site access is restricted and discharge is regulated by NPDES permit.
Inhabitants of village or of surrounding farms	Ingestion of fish or other food from surface drainage	No	Flow is generally too low and inconsistent to support fish population site access is restricted and flow discharge is regulated by NPDES permit.
Inhabitants of village or of surrounding farms	Ingestion of game taken from surrounding areas	No	Game is highly mobile not expected to remain stationary exposure is very limited and target chemicals do not biomagnify

Table 6.2-2

Summary of 1989 Groundwater Data Used for Baseline Assessment

Lindsay Mfg Co

Compound	Frequency of Detection	Ground Water Concentration (µg/l)				
		Average	Standard Deviation	Upper 95th percentile	Maximum	Sample Size
Trace Metals						
Cadmium	32/160	8 44	25 15	49 82	180	160
Chromium	13/159	8 88	29 97	58 18	277	159
Lead	77/160	20 23	127 99	230 78	1 600	160
Zinc	150/161	44 734 47	115 920 38	235 423 49	532 000	161
Trace Organics						
1 1-dichloroethane	35/173	5 31	9 08	20 24	72	173
1 2-dichloroethane	9/173	3 46	2 81	8 09	25	173
1 1-dichloroethylene	69/173	28 65	67 84	140 26	510	173
1 2-dichloroethylene	11/173	4 04	3 48	9 77	25	173
1 1 1 trichloroethane	82/173	107 94	395 50	758 54	2 900	173
Tetrachloroethylene	71/173	32.09	68 44	144 67	430	173
Trichloroethylene	9/173	2 80	1 57	5 39	5	173

Table 6.2-3

Summary of Off-Site Soil and Grass Metals Concentrations

Lindsay Mfg Co

Compound	Concentrations mg/kg dry wt Average		Maximum		Sample size (n)	Detection Limit
SOILS						
Cadmium	ND	(a)	ND	(a)	4	1 0
(reference area)	ND	(b)	ND	(b)	1	1 0
Lead	ND	(a)	11		4	10 0
(reference area)	ND	(b)	ND	(b)	1	10 0
Zinc	57 25		61		4	1 0
(reference area)	49				1	1 0
GRASS						
Cadmium	ND	(b)	ND	(b)	1	1 0
(reference area)	ND	(b)	ND	(b)	1	1 0
Lead	ND	(b)	ND	(b)	1	10 0
(reference area)	ND	(b)	ND	(b)	1	10 0
Zinc	6 5		6 5		1	1 0
(reference area)	5 3		5 3		1	1 0

NOTES
(a) Not detected but ½ the sample quantitation limit was incorporated into the quantitative analysis
(b) Not detected at the indicated level
ND = Not Detected

Table 6 2-4

Summary Of Exposure Factors Used For Quantitative Exposure Assessment Lindsay Site (a)

Exposure Factor	Units	Average Condition	RME Condition
Body Weight			
0 to 3 years	kg	12	12
3 to 6 years	kg	17	17
6 to 9 years	kg	25	25
9 to 12 years	kg	36	36
12 to 15 years	kg	51	51
15 to 18 years	kg	70	70
18 to 75 years	kg	70	70
I Incidental Soil Ingestion			
a) Ingestion Rate			
0 to 6 years	mg/d	200	800
6 to 18 years	mg/d	100	100
18 to 75 years	mg/d	100	100
b) Absorption			
Metals	by wt	10%	50%
Organics	by wt	50%	100%
c) Frequency			
0 to 6 years	hr/day	4	8
6 to 18 years	hr/day	2 2	4 8
18 to 75 years	hr/day	0 4	1 6
d) Duration	years	9	75
II Dermal Absorption of Soils			
a) Skin Surface Area			
0 to 6 years	cm2	1250	3900
6 to 18 years	cm2	2500	7800
18 to 75 years	cm2	3000	6200
b) Soil Adherence Rate	mg/cm2	0 6	0 9
c) Absorption			
Metals	by wt	0 10%	1%
Organics	by wt	40%	80%
d) Frequency			
0 to 6 years	hr/day	4	8
6 to 18 years	hr/day	2 2	4 8
18 to 75 years	hr/day	0 4	1 6
e) Duration	years	9	75
III Consumption of Homegrown Produce			
a) Frequency	by source	25 /	100%
b) Duration	years	9	75
c) Consumption Rate			
0 to 6 years			
Root Crops	mg/day	358	358
Leafy Vegetables	mg/day	404	404
Garden fruits	mg/day	962	962
6 to 18 &18 to 75 years			
Root Crops	mg/day	1 710	1 710
Leafy Vegetables	mg/day	2 020	2 020
Garden fruits	mg/day	4 810	4 810
d) Plant Accumulation			
Cadmium	by wt	2 00	4 00
Lead	by wt	0 01	0 05
Zinc	by wt	0 13	0 49
e) Internal Absorption	(/)	100%	100%

Table 6 2-4 (continued)

Summary Of Exposure Factors Used For Quantitative Exposure Assessment Lindsay Site (a)

Exposure Factor	Units	Average Condition	RME Condition
IV Groundwater Ingestion			
a) Consumption Rate			
0 to 6 years	L/day	0 64	0 92
6 to 18 years	L/day	1 2	2
18 to 75 years	L/day	1 4	2
b) Absorption	by wt	100%	100%
c) Frequency	days/yr	75 /	100%
d) Time at home	hr/day	14	24
e) Duration	years	9	75
V Vapor Inhalation during Showering and Bathing			
a) Ventilation Rate	m3/day	20	30
(all ages see discussion in text regarding activity patterns)			
b) Pulmonary Absorption	by wt	100%	100%
c) Phase transfer coefficient (b)	(/)	30%	60%
d) Frequency	(as % of day)	0 49%	0 83%
e) Duration	years	9	75
VI Inhalation of Particulates			
a) Ventilation Rate	m3/day	20	30
(all ages see discussion in text regarding activity patterns)			
b) Pulmonary Absorption	by wt	100%	100%
c) Frequency	days/yr	75 %	100%
d) Duration	years	9	75

FOOTNOTES

(a) Exposure factors used to compute the Reasonable MaximumExpsoure scenario were based on EPA guidelines (EPA 1989) the Exposure Factors Handbook and EPA (1990)

(b) Based on Henry's Law and the indoor air pollution model presented by Andelman et a (1986) see discussion in text

Table 6.2-5

Off-site Ambient Air Concentrations Based on Mean Soil Contaminant Concentrations

Parameter	Units	Annual Average	Worst-Case 24 hour
Total Dust	ug/m3	1 38E+01	2 22E+03
Zinc	ug/m3	7 92E 04	1 27E 01
1,1-dichloroethylene	ug/m3	N/A	N/A
1,1,1 trichloroethane	ug/m3	N/A	N/A
Tetrachloroethylene	ug/m3	N/A	N/A

Table 6.2-6

Off-site Ambient Air Concentrations Based on 95% Percentile Soil Contaminant Concentrations

Parameter	Units	Annual Average	Worst-Case 24 hour
Total Dust	ug/m3	1 38E+01	2 22E+03
Zinc	ug/m3	8 44E 04	1 35E 01
1,1-dichloroethylene	ug/m3	N/A	N/A
1 1 1-trichloroethane	ug/m3	N/A	N/A
Tetrachloroethylene	ug/m3	N/A	N/A

Table 6 3-1

Summary of Non-carcinogenic Chronic RfD Values (a)
Lindsay Mfg Site

ORAL VALUES COMPOUND	Chronic Oral RfD (b) (mg/kg-day)	Status/ Reference	Confidence Level (c)	Medium/basis (d) and Test Species	Critical Effect	Uncertainty and Modifying Factors (UF/MF)(e)	
TRACE METALS							
Cadmium (and Compounds)	0 0005	(f)	high	drinking water/ human	Renal damage (proteinuria)	UF = 10 for MF = 1	H
Chromium III (and Compounds)	1	(f)	low	diet/ rat	Spleen/liver weight reduction	UF = 100 for MF = 10	H A
Chromium VI (and Compounds)	0 005	(f)	low	drinking water/ rat	No effects observed	UF = 500 for MF = 1	H A S
Lead (Inorganic and Compounds)	0 0014	(g)		diet/ rat	Blood pressure and cardiac effects	--	
Zinc (and Compounds)	0 2	(h)		diet/rat	Anemia	--	
TRACE ORGANICS							
1 1 dichloroethane	0 1	(h)	--	diet/ rat	No effects observed	UF = 1000	
1 2 dichloroethane	0 1(i)	(h)	--	diet/ rat	No effects observed	UF = 1000	
1 1 dichloroethylene	0 009	(f)	medium	diet/ rat	Hepatic lesions	UF = 1000 for MF = 1	H A L
1 2-dichloroethylene	0 02	(f)	low	drinking water\ mouse	Increased enzyme activities	UF = 1000 for MF = 1	H A S
1 1 1 trichloroethane	0 09	(f)	medium	inhalation/ guinea pig	Hepatotoxicity/ growth impairment	UF = 1000 for MF = 1	H A S
Tetrachloroethylene	0 01	(f)	medium	diet/ mouse	Apparent adverse effects to liver	UF = 1000 for MF = 1	H A L
Trichloroethylene	(j)	--	--	--			

Table 6 3-1 (continued)

Summary of Non-carcinogenic Chronic RfD Values (a)

Lindsay Mfg Site

INHALATION VALUES COMPOUND	Chronic Inhalation RfD (b) (mg/kg-day)	Status/ Reference	Confidence Level (c)	Medium/ basis (d) and Test Species	Critical Effect	Uncertainty and Modifying Factors (UF/MF)(e)	
TRACE METALS							
Cadmium (and Compounds)	none	(g)		--	--	--	
Chromium III (and Compounds)	0 0051	(i)	--	--	--	--	
Chromium VI (and Compounds)	none	(g)	--	--	--	--	
Lead (Inorganic and Compounds)	0 00043	(i)	--	--	--	--	
Zinc (and Compounds)	0 01	(i)					
TRACE ORGANICS							
1 1-dichloroethane	0 1	(f)		inhalation/ cat	Kidney damage	UF = 1000	
1 2 dichloroethane	0 1 (i)	(f)	--	inhalation/ cat	Kidney damage	UF = 1000	
1 1 dichloroethylene	--		--	--	--	--	
1 2 dichloroethylene			--	--	--	--	
1 1 1 trichloroethane	0 13	(f)	medium	inhalation/ guinea pig	Hepatotoxicity/ growth impairment	UF = 1000 for MF = 1	H A S
Tetrachloroethylene	--		--		--	--	
Trichloroethylene	(j)	--	--	--	--	--	

FOOTNOTES

(a) See discussion in Section 6 3 for details of toxicological data base

(b) The term Reference Dose (RfD) is used when verified by EPA (1989b) or when developed through EPA Health Effects Assessment documents Values which have not been verified by EPA are interim RfD values

(c) Confidence level in RfD value as determined by the EPA RfD Work Group (EPA 1989b) reported as high medium or low

(d) RfD expressed as administered dose in drinking water with assumed absorption fraction of 1 0

(e) Uncertainty adjustment of 1 000 of H A S and L extrapolations Uncertainty adjustments

A = animal to human extrapolation Q = analogy to a structurally similar compound
H = variation in human sensitivity R = lack of subchronic and reproductive toxicity data
L = extrapolation from LOAEL to NOAEL. S = extrapolation from subchronic to chronic NOAEL

(f) This is a verified RfD value as documented by the EPA Integrated Risk Information System (EPA 1989b)

(g) Health Effects Assessment value

(h) EPA 1990b Health Effects Assessment Summary Tables

(i) This value was derived for 1 1-dichloroethane

(j) Chronic exposures to this compound via this route are addressed via the carcinogenic slope factor (see Table 6 3-2)

Table 6 3-2

Summary of Carcinogenic Slope Factors

Lindsay Mfg Site

COMPOUND	ORAL SLOPE FACTOR (a) (mg/kg-day) 1	Weight-of Evidence Classification (b) (Oral exp)	Type of Cancer/ Basis	REFERENCE
TRACE METALS				
Cadmium (and Compounds)	ND (c)			
Chromium III (and Compounds)	ND (c)			
Chromium VI (and Compounds)	ND (c)			
Lead (Inorganic and Compounds)	ND (c)	B2		
Zinc (and Compounds)	ND (c)			
TRACE ORGANICS				
1 1 Dichloroethane	0 091	B2	hemangiosarcoma/ gavage	(d)
1 2 Dichloroethane	0 091	B2	circulatory system/ gavage	(d)
1 1 Dichloroethylene	0 6	C	adrenal/ gavage	(d)
1 2 Dichloroethylene	(c f)			
1 1 1 trichloroethane	(c)	D		
Tetrachloroethylene	0 051	B2	liver tumor/ gavage	(d)
Trichloroethylene	0 011	B2	liver tumor/ gavage	(c d)

ND = Not Determined

Table 6 3-2 (continued)

Summary of Carcinogenic Slope Factors

Lindsay Mfg Site

COMPOUND	INHALATION SLOPE FACTOR (a) (mg/kg-day) 1	Weight-of Evidence Classification (b) (Inhal exp)	Type of Cancer/ Basis	REFERENCE
TRACE METALS				
Cadmium (and Compounds)	6 1	B1	Human lung trachea bronchus/Inhalation	(d)
Chromium III (and Compounds)	ND		Human lung/ inhalation	(d)
Chromium VI (and Compounds)	41	A	Human lung inhalation	(d)
Lead (Inorganic and Compounds)	ND	B2		(d)
Zinc (and Compounds)	ND			(e)
TRACE ORGANICS				
1 1 Dichloroethane	ND		circulatory system/ gavage	(e)
1 2 Dichloroethane	0 000026	B2	kidney adenocarcinoma inhalation	(d)
1 1 Dichloroethylene	1 2	C		(e)
1 2 Dichloroethylene	(c f)		liver leukemia/ inhalation	
1 1 1 trichloroethane	(c)	D	lung tumor/ inhalation	(e)
Tetrachloroethylene	0 0033	B2		
Trichloroethylene	0 017	B2		

FOOTNOTES

ND = Not Determined

(a) Section 6 3 presents a more detailed discussion of the toxicological data base including the adequacy of scientific documentation in rendering these carcinogenic assessments

(b) Weight of evidence clasifications are assigned using the information shown on the following table

Human Evidence	Animal Evidence				
	Sufficient	Limited	Inadequate	No data	No evidence
Sufficient	A	A	A	A	A
Limited	B1	B1	B1	B1	B1
Inadequate	B2	C	D	D	D
No data	B2	C	D	D	E
No evidence	B2	C	D	D	E

Based on 51 Fed Reg 34000 (9/24/86)

(c) Chronic exposures to this compound are most appropriately addressed using non-carcinogenic toxicological endpoints (see Table 6 3-1)

(d) The carcinogenic status of this compound has been verified by the EPA CRAVE Work Group as documented by the Integrated Risk Information System (EPA 1989)

(e) As documented by the Health Effects Assessment Summary Tables (EPA 1990b)

(f) Toxicity information for 1 2DCE is inadequate for quanitative risk assessment although oral exposures are addressed using a non-carcinogenic response (See Table 6 3-1)

Table 6.4-1

Summary of Potential Total Exposure (i e , dose) to Off-Site Receptors By Age Class

Lindsay Mfg Co

Compounds	AGE 0 to 6				AGE 6 to 18				AGE 18 to 75			
	ORAL (mg/kg-day)		INHAL (mg/kg-day)		ORAL (mg/kg day)		INHAL (mg/kg-day)		ORAL (mg/kg-day)		INHAL (mg/kg-day)	
	Average	RME	Average	RME	Average	RME	Average	RME	Average	RME	Average	RME
Trace Metals												
Cadmium	3 1E-04	3 4E-03	7 1E-09	1 4E-08	1 6E-04	2 6E-03	1 7E-09	4 5E-09	2 5E-05	1 7E 03	2 3E 10	3 0E-09
Chromium	2 9E-04	3 7E-03			1 3E-04	2 6E-03			2 1E-05	1 7E-03		
Lead	6 7E-04	1 5E-02	9 2E-08	3 1E-07	3 0E-04	1 0E-02	2 2E-08	9 9E-08	4 8E-05	6 7E-03	3 0E 09	6 4E-08
Zinc	1 5E+00	1 5E+01	8 2E 07	1 7E-06	6 6E-01	1 0E+01	2 0E-07	5 5E 07	1 1E-01	6 7E+00	2 7E 08	3 6E-07
Trace Organics												
1 1-dichloroethane	1 7E-04	1 3E-03	1 2E-05	2 1E-04	7 9E-05	8 9E-04	2 6E-06	6 7E 05	1 3E 05	5 8E-04	3 5E 07	4 3E-05
1 2-dichloroethane	1 1E-04	5 1E-04	7 0E-06	8 4E-05	5 1E-05	3 6E-04	1 7E-06	2 7E-05	8 2E-06	2 3E 04	2 3E 07	1 7E 05
1 1-dichloroethylene	9 4E-04	8 9E-03	5 8E-05	1 5E-03	4 3E-04	6 2E-03	1 4E-05	4 6E 04	6 8E-05	4 0E 03	1 9E 06	3 0E-04
1 2-dichloroethylene	1 3E-04	6 2E-04	8 1E-06	1 0E-04	6 0E-05	4 3E-04	1 9E-06	3 2E 05	9 6E-06	2 8E-04	2 7E-07	2 1E-05
1 1 1 trichloroethane	3 5E-03	4 8E-02	2 2E-04	7 8E-03	1 6E-03	3 3E-02	5 2E-05	2 5E-03	2 6E-04	2 2E-02	7 1E 06	1 6E-03
Tetrachloroethylene	1 1E-03	9 2E-03	6 5E-05	1 5E-03	4 8E-04	6 4E-03	1 5E-05	4 8E 04	7 6E-05	4 1E-03	2 1E 06	3 1E-04
Trichloroethylene	9 2E-05	3 4E-04	5 6E 06	5 6E-05	4 2E-05	2 4E-04	1 3E-06	1 8E 05	6 6E-06	1 5E-04	1 8E 07	1 2E-05

Table 6 4-2

Summary of Potential Hazard Characterization for Non-Carcinogenic Compounds
RME Scenario, Off-Site Receptors
Lindsay Mfg Co

Compounds	Age 0 to 6			Age 6 to 18			Age 18 to 75		
	Oral	Inhal	Total	Oral	Inhal	Total	Oral	Inhal	Total
TRACE METALS									
Cadmium	6 81		6 81	5 13		5 13	3 33		3 33
Chromium	0 74		0 74	0 51		0 51	0 33		0 33
Lead	10 59	<0 01[1]	10 59	7 32	<0 01	7 32	4 76	<0 01	4 76
Zinc	74 71	<0 01	74 71	51 77	<0 01	51 77	33 65	<0 01	33 65
TRACE ORGANICS									
1 1-dichloroethane	0 01	<0 01	0 01	<0 01	<0 01	<0 01	<0 01	<0 01	<0 01
1 2-dichloroethane	<0 01		<0 01	<0 01		<0 01	<0 01		<0 01
1 1-dichloroethylene	0 99		0 99	0 69		0 69	0 45		0 45
1 2-dichloroethylene	0 03	<0 01	0 03	0 02	<0 01	0 02	0 01	<0 01	0 01
1 1 1 trichloroethane	0 53	0 09	0 62	0 37	0 03	0 40	0 24	0 02	0 26
Tetrachloroethylene	0 92		0 92	0 64		0 64	0 41		0 41
Trichloroethylene									
Potential Cumulative Hazard Index [2]	95 3	0 09	95 4	66 4	0 03	66 5	43 2	0 02	43 2

[1] <0 01 signifies a Hazard Index too low to accurately quantify
[2] The cumulative Hazard Index was computed here using complete additivity of non-carcinogenic effects

Table 6.4-3

Summary of Potential Cancer Risk Characterization Reasonable Maximum Exposure Scenario Cancer Risk, Off-Site Receptors

Lindsay Mfg Co

COMPOUND[1]	Age 0 to 6		Age 6 to 18		Age 18 to 75	
	ORAL	INHAL.	ORAL	INHAL.	ORAL	INHAL.
TRACE METALS						
Cadmium	N/A	8 7E-08	N/A	2 8E 08	N/A	1 8E 08
Chromium	N/A	N/A	N/A	N/A	N/A	N/A
Lead	N/A	N/A	N/A	N/A	N/A	N/A
Zinc	N/A	N/A	N/A	N/A	N/A	N/A
TRACE ORGANICS						
1 1-dichloroethane	1 2E-04	N/A	8 1E-05	N/A	5 3E-05	N/A
1 2-dichloroethane	4 7E-05	2 2E 09	3 2E 05	6 9E 10	2 1E-05	4 5E 10
1 1-dichloroethylene	5 3E 03	1 7E 03	3 7E 03	5 5E-04	2 4E-03	3 6E-04
1 2-dichloroethylene	N/A	N/A	N/A	N/A	N/A	N/A
1 1 1 trichloroethane	N/A	N/A	N/A	N/A	N/A	N/A
Tetrachloroethylene	4 7E-04	4 9E 06	3 2E-04	1 6E-06	2 1E-04	1 0E-06
Trichloroethylene	3 8E-06	9 5E 07	2 6E-06	3 0E 07	1 7E-06	2 0E-07
Cumulative Potential Cancer Risk	6 0E 03	1 7E-03	4 1E-03	5 6E-04	2 7E 03	3 6E-04
Age-class Specific		7 7E-03		4 7E-03		3 1E 03
LIFETIME POTENTIAL CANCER RISK						1 6E 02

N/A = Not applicable These compounds are most appropriately addressed using non-carcinogenic toxicological endpoints (Table 6 4 2)

[1] All compounds are possible or probable" carcinogens for which "inadequate human data exist (see Table 6 3 2 for description of these compounds)

Table 6.4-4

Exposure to Individual Contaminants by Age Class and Pathway Off-Site Receptors
Lindsay Mfg Co

			PERCENTAGE OF TOTAL EXPOSURE											
			I		II		III		IV		V		VI	
CONTAMINANT	TOTAL EXPOSURE (both oral and inhal)		Soil Ingestion		Dermal Contact		Vegetable Consumption		Drinking Water Ingestion		Organic Vapor Inhalation		Inhalation of Particulates	
	Mean	RME	Mean	RME	Mean	RME	Mean	RME	Mean	RME	Mean	RME	Mean	RME
Ages 0 to 6	Mean	RME												
TRACE METALS														
Cadmium	3 1E 04	3 4E-03	0%	0%	0%	0%	10%	7%	90%	93%			0%	0%
Chromium	2 9E 04	3 7E-03							100%	100%				
Lead	6 7E 04	1 5E-02	0%	1%	0%	0%	0%	0%	99%	99%			0%	0%
Zinc	1 5E+00	1 5E+01	0%	0%	0%	0%	0%	0%	100%	100%			0%	0%
TRACE ORGANICS														
1 1 dichloroethane	1 9E-04	1 5E-03							94%	86%	6%	14%		
1 2 dichloroethane	1.2E 04	6 0E-04							94%	86%	6%	14%		
1 1 dichloroethylene	1 0E 03	1 0E-02							94%	86%	6%	14%		
1,2 dichloroethylene	1 4E 04	7 2E-04							94%	86%	6%	14%		
1 1 1 trichloroethane	3 8E 03	5 6E-02							94%	86%	6%	14%		
Tetrachloroethylene	1 1E 03	1 1E-02							94%	86%	6%	14%		
Trichloroethylene	9 8E 05	4 0E-04							94%	86%	6%	14%		
Ages 6 to 18	Mean	RME												
TRACE METALS														
Cadmium	1.6E-04	2 6E-03	0%	0%	0%	0%	22%	15%	78%	85%			0%	0%
Chromium	1 3E 04	2 6E-03							100%	100%				
Lead	3 0E 04	1 0E-02	0%	0%	0%	0%	1%	1%	99%	99%			0%	0%
Zinc	6 6E-01	1 0E+01	0%	0%	0%	0%	0%	0%	100%	100%			0%	0%
TRACE ORGANICS														
1 1-dichloroethane	8 1E 05	9 6E-04							97%	93%	3%	7%		
1,2-dichloroethane	5.3E 05	3 8E-04							97%	93%	3%	7%		
1 1-dichloroethylene	4 4E-04	6 6E-03							97%	93%	3%	7%		
1,2 dichloroethylene	6.2E-05	4 6E-04							97%	93%	3%	7%		
1 1 1 trichloroethane	1 7E-03	3 6E-02							97%	93%	3%	7%		
Tetrachloroethylene	4 9E-04	6 8E-03							97%	93%	3%	7%		
Trichloroethylene	4 3E-05	2 5E-04							97%	93%	3%	7%		
Ages 18 to 75	Mean	RME												
TRACE METALS														
Cadmium	2 5E 05	1 7E-03	0%	0%	0%	0%	19%	15%	81%	85%			0%	0%
Chromium	2 1E 05	1 7E-03							100%	100%				
Lead	4 8E 05	6 7E-03	0%	0%	0%	0%	1%	1%	99%	99%			0%	0%
Zinc	1 1E 01	6 7E+00	0%	0%	0%	0%	0%	0%	100%	100%			0%	0%
TRACE ORGANICS														
1 1 dichloroethane	1 3E-05	6 2E-04							97%	93%	3%	7%		
1 2 dichloroethane	8 4E-06	2 5E-04							97%	93%	3%	7%		
1 1 dichloroethylene	7 0E-05	4 3E-03							97%	93%	3%	7%		
1,2 dichloroethylene	9 8E-06	3 0E-04							97%	93%	3%	7%		
1 1 1 trichloroethane	2.6E-04	2.3E-02							97%	93%	3%	7%		
Tetrachloroethylene	7 8E-05	4 4E-03							97%	93%	3%	7%		
Trichloroethylene	6 8E-06	1 7E-04							97%	93%	3%	7%		

7 0 SUMMARY AND CONCLUSIONS

This report summarizes the Lindsay Manufacturing investigations from 1983 to January 1990 and reports and documents prepared pursuant to the RI Work Plan The following summary and conclusions are based on a comprehensive evaluation of monitoring data collected throughout the period of investigation and collected during interim remedial activities

7 1 SUMMARY

7 1 1 Nature and Extent of Contamination

The vertical and horizontal extent of organic and inorganic compounds have been defined by the investigations In general the organic and metal compounds are found in association in the aquifer occurring as defined pockets at the bottom of the aquifer A dispersed zone of inorganic compounds predominantly zinc iron and sulfates occurs in an oval shape from approximately the center of the north central site boundary southeast to irrigation well #54278 This oval is not more than 1 000 feet wide at its widest and is significantly reduced in size and concentration of compounds since January 1989 This zone also contains certain organic compounds The area of deep pockets occurs within the dispersed ovate zone and is ringed by the monitoring well network Two zones of chemicals occur on-site in soils above the site aquifer The first is a sand channel in the center of the north one-half of the site This channel is perched above the aquifer by a low permeability silty clay and its drainage is controlled by the OIW Lindsay s site investigations found that the sand channel contains a residue of inorganic and organic compounds which are significantly reduced in concentration from previous sampling periods in 1988 1987 and 1983 Limited occurrences of these same organic and inorganic compounds occur north of the source (old disposal pit) due to gravity drainage in the perched sand channel to the north This perched ground-water flow and dispersion of compounds occurred exclusive of the regional aquifer flow direction which is to the south The exclusion results from confinement of the aquifer pressure head by an aquitard The aquitard also perches a shallow water table in the sand channel

The second zone of chemical occurrence in site soils is an area in the center of the site This area contains low soil concentrations of organic compounds probably resulting from historic disposal of spent degreasers in the rear of the manufacturing plant prior to 1972 This area has been paved since 1972 which has reduced the infiltration of rain and snowmelt The only unpaved area is a drainage ditch which receives the plant cooling water outfall Soils in this ditch have been sampled and found generally free of organics except traces of petroleum fuel products probably related to runoff of the traffic area A trace at the detection level of DCE was found in sediment sample DS-4 in the central site drainage ditch Organics were not detected in the drainage north of the site

Both areas where the organic and inorganic compounds occur in soils are within the ring of monitoring wells Additional monitoring wells have been placed in the perched sand channel (MW89-13 & 14) and two monitoring wells have been placed in the upper portion of the aquifer beneath each soil zone (MW89-12 & 15) Two rounds of sampling have been performed at these new well sites

The inorganic ground-water quality as monitored by wells screened throughout the aquifer and the upper portion of the aquifer between February 1989 and January 1990 was generally within background levels for all parameters with the exception of select metal results reported at various dates in on-site monitoring wells MW87-3 and MW87-6 Zinc and iron concentrations reported in these wells in January 1990 were at or near the SDWS for these elements

Ground-water quality on-site in the lower portion of the aquifer contains acidic pH levels and elevated levels of zinc iron and sulfate only at the southeast corner of the site

Ground-water quality off-site in the lower portion of the aquifer exhibits acidic pH and elevated levels of zinc iron and sulfates in a trend from the southeast portion of the site to irrigation well #54278 The concentrations of these compounds are dropping in response to Lindsay s ongoing remediation

The organic ground-water quality as monitored between February 1989 and January 1990 by wells screened in the aquifer contained low levels of organics on-site with the exception of MW87-3 and MW87-6 which are located in the zone of acidic water containing concentrations of metals in the lower portion of the aquifer

Organics were not detected in off-site wells screened in the full aquifer or upper aquifer Organics are found in the lower aquifer from the southeast corner of the site to irrigation well #54278 and some of these organics were exhibited at substantially lesser levels in the down gradient stock and domestic wells The domestic well water quality remained well within drinking water standards The stock well water quality exhibited some elevated organics at the beginning of the irrigation season which dropped and remained within applicable drinking water standards by July Off-site organics in the area of deep pockets on the bottom of the aquifer (TMW88-6) exhibit a gradual decline At irrigation well #54278 the organics exhibited a general rise in response to the 1989 irrigation season followed by a general decline in the autumn

The occurrence and response of organic compounds in the aquifer on and off-site correspond to that of the inorganics The organics are found in the lower aquifer in the same areas as the inorganics the 1989 irrigation dispersal of limited inorganics to irrigation well #54278 included organic compounds and the trend of decline by interception of inorganics with interim remedial system is repeated by the organics These trends are consistent with a common source

7 1 2 Fate and Transport

The fate of the acidic metal-laden ground water (with its dissolved organic components) which Lindsay s site investigations have found to have drained rapidly from the perched sand channel initially in December 1982 has been subject to several driving forces These forces include density differences between the metal-laden waters and the aquifer waters chemical gradients and variable hydraulic gradients resulting from high capacity well operations In addition the concentration of the acidic waters has been subject to the influences of dilution and neutralization Forces that are probably of little or no influence in the aquifer are solute chemical reaction and adsorption-desorption These forces are generally weak because of the relatively inert nature of the aquifer matrix

Because of the relatively low reactive potential of the organic and inorganic compounds within the aquifer these compounds are transported by and can be intercepted or recovered in the ground water This fluid transport the gradual dispersion and the recovery of the chemical compounds have been traced through time in the monitoring well water samples results The transport of the chemicals from 1982 to January 1990 has been documented in section 4 of this report and reproduced by a model of the aquifer The model can be applied within the limits of its methods to the Feasibility Study The full extent of current chemical occurrence on-site whether in soils the perched sand channel or the aquifer is within the capture zone of the AOIW or OIW

The off-site occurrence of the organic and inorganic compounds is also within the capture zone of the AOIW with the exception of a small dispersed occurrence at irrigation well #54278 A stagnant zone can develop between the AOIW and irrigation well #54278 during the summer irrigation season when the wells are operating simultaneously This temporary stagnant zone currently contains metals and organics at the bottom of the aquifer as detected in monitoring wells MW88-6 and 88-8 and is the source of the dispersed metals and organics at irrigation well #54278 Since the dispersed metals and organics have only reached irrigation well #54278 during the period of the RI (spring and summer 1989) and interim remediation continues to recover these waters during the nine-month idle period (between irrigation seasons), it is unknown if another dispersal event can occur next irrigation season It is known however that the metals and organics are being reduced in concentration and extent if repeated in summer 1990 it is expected to be at a lower concentration Monitoring of deep aquifer water quality at TMW88-6 and 88-8 or in the same area will provide a measure of the rate of residual reduction

7 1 3 Risk Characterization

A baseline risk assessment was performed as part of the Remedial Investigation This quantitative evaluation was based on the RI 1989 database (current conditions) and did not

incorporate the reductions in the concentrations of the metals and organics that are occurring and will continue to occur through the ongoing interim remediation

The Reasonable Maximum Exposure (RME) scenario Hazard Index a conservative measure of potential risk from exposure to non-carcinogens indicated that the greatest potential non-carcinogenic exposures could be generated from the occurrence of zinc in off-site ground water Using highly conservative exposure assumptions the worst-case HI exceeded the guideline value of 1 0 suggesting that if hypothetically no further remediation is performed the possibility exists that an individual could potentially experience some toxicity (e g anemia) as a result of continued exposure to zinc through ingestion were each of the stated RME scenario conditions to occur However these composite worst-case assumptions are not deemed probable in part because the likelihood of occurrence of each of these assumptions is remote and also because continued groundwater remediation is reducing zinc concentrations with attendant decreasing exposure potential

The anticipated baseline cancer risk was also evaluated using the RME scenario Results indicated a potential cumulative cancer risk for all age groups including all evaluated compounds of approximately 1 6 x 10-2 were each of the stated RME scenario conditions to occur None of the evaluated compounds are in fact designated as human carcinogens by EPA some of the organics have been designated as probable carcinogens which denotes that these are compounds for which studies are not considered sufficient for EPA to classify them as human carcinogens The estimated value is largely based on the unlikely occurrence and persistence of 1 1-DCE at the domestic well This compound has never been detected at this well where water quality analysis has consistently met applicable drinking water standards Moreover this well is adequately protected from potential exposure by the upgradient monitoring wells Therefore the RME value is considered overly conservative in comparison to actual observed conditions Sufficiently conservative assumptions are believed to have been built into the risk assessment model to protect individuals potentially exposed even at the most conservative levels As noted above the combined occurrence of each of these RME worst-case assumptions is unlikely and ongoing remediation acts to reduce exposure potential

A baseline ecological assessment was also conducted Results based in large part on measured surface soil concentrations off site indicated no significant potential exposure of wildlife inhabiting the vicinity of the Lindsay site to site-related chemical compounds

The baseline risk assessment assumes an extraordinary condition that is not likely at the site i e that all remediation is stopped and that the irrigation water would increase in concentration to the maximum levels detected on-site in 1989 and be sustained at such levels for prolonged periods This contrasts directly with actual circumstances Lindsay Manufacturing continues to recover the metal and organic chemicals and correspondingly ground-water concentrations and attendant exposure potential are continuing to decline The risk assessment assumes long-term

future maximum exposure potential contrary to remediation efforts in effect which are expected to restore the aquifer to acceptable levels in a relatively short period The Feasibility Study prepared for this site will assess the effectiveness and appropriateness of the ongoing interim remediation system or alternative future remedial actions in addressing site conditions to ensure that human health and the environment are adequately protected

7 2 CONCLUSIONS

The RI has defined the nature and extent of organic and inorganic compounds in site soils and ground water and the effectiveness of interim remediation The fate and transport of these compounds have been identified and accurately modeled The following conclusions summarize the RI effort

- The organic and inorganic chemical components in the site aquifer occur within a ring of monitoring wells The extent and concentrations are declining as a result of the pump and treat remedial action performed by Lindsay Manufacturing

- The remedial efforts by Lindsay including the pumping and treating of over 800 million gallons have been effective in intercepting a majority of these chemical compounds Interim remedial efforts are recommended to be continued during the completion of the Feasibility Study

- A zone of low pH occurs in the lower portion of the aquifer in the southeast area of the site centering at or near the AOIW This zone is associated with residual zinc iron sulfates and certain organic compounds

- A zone of dispersed metals and organic compounds occurs in ground water between the AOIW and irrigation well #54278 As an alternative to temporary monitoring well sites TMW88-6 and TMW88-8 the efficiency of this recovery may be monitored effectively by permanent well installations at these locations and monitoring of irrigation well #54278

- The NPDES data records the operational compliance of the wastewater treatment facility and its effective reduction of both metal and organic compounds in the pumped ground water Biomonitoring criteria are currently being evaluated by Lindsay Manufacturing and NDEC

7 3 REMEDIAL OBJECTIVES

Remedial action objectives consist of medium-specific goals for protecting human health and the environment Objectives specify the chemicals of interest the potential exposure routes and

protective remediation goals For the Lindsay site the baseline risk assessment identified potential future ingestion of ground water as the most important potential exposure pathway and zinc lead cadmium 1 1-dichloroethene and tetrachloroethylene as the chemicals which under the hypothetical worst-case exposure scenario are the most important in the calculation of potential risks No significant potential risks associated with exposure to soil or air were identified through the risk assessment

Because the risk assessment identified the potential future use of ground water as drinking water under the RME scenario as the only potentially significant exposure pathway with air and soil determined not to be significant exposure pathways the remedial action objectives chosen for the Lindsay site focus on providing ground water of drinking water quality for potential future users

The health-based federal and state Maximum Contaminant Levels (MCLs) (also known as primary drinking water standards (PDWS)) and the aesthetically-based secondary drinking water standards (SDWS or secondary MCLs) applied to ground water were identified as the appropriate remedial objectives to be achieved for the Lindsay site These standards were established by the federal Safe Drinking Water Act (42 U S C 300f et seq) and the NDEC Ground-Water Quality Standards and Use Classification (Title 118) Primary MCLs have been promulgated by both EPA and the state of Nebraska for cadmium (0 01 mg/l) lead (0 05 mg/l) and 1 1 1-trichloroethane (0 2 mg/l) and 1 1-dichloroethene (0 007 mg/l) There is currently no Nebraska or EPA MCL established for tetrachloroethylene (PCE) Both Nebraska and EPA have proposed an MCL for PCE (0 005 mg/l) but have not promulgated MCL regulations The remedial action objectives developed for the Lindsay site include attainment of the proposed MCL for PCE in ground water Secondary drinking water standards or secondary MCLs have been established for certain other drinking water constituents These standards were developed for non-toxic constituents in order to maintain the odor color and taste of drinking water sources Both EPA and the State of Nebraska have developed secondary drinking water standards for zinc (5 mg/l) iron (0 3 mg/l) and sulfates (250 mg/l)

EPA guidance suggests that remedial action objectives be consistent with applicable relevant and appropriate requirements or ARARs The most important ARARs for the Lindsay site are the primary and secondary MCLs discussed above These ARARs are the principal remedial action objectives where not already attained to be established as remediation goals for the ground water for this site Other ARARs for the Lindsay site will depend on the specific remedial actions to be implemented Potential ARARs for the site depending on the selected type of remedial action include

- Clean Water Act
- Nebraska Water Quality Standards
- Nebraska NPDES Permits

- Clean Air Act
- Nebraska Air Pollution Control
- Safe Drinking Water Act
- Nebraska Ground-Water Protection Standards
- Nebraska Underground Injection Control

An evaluation of which ARARs apply to specific remedial alternatives will be performed during the Feasibility Study

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