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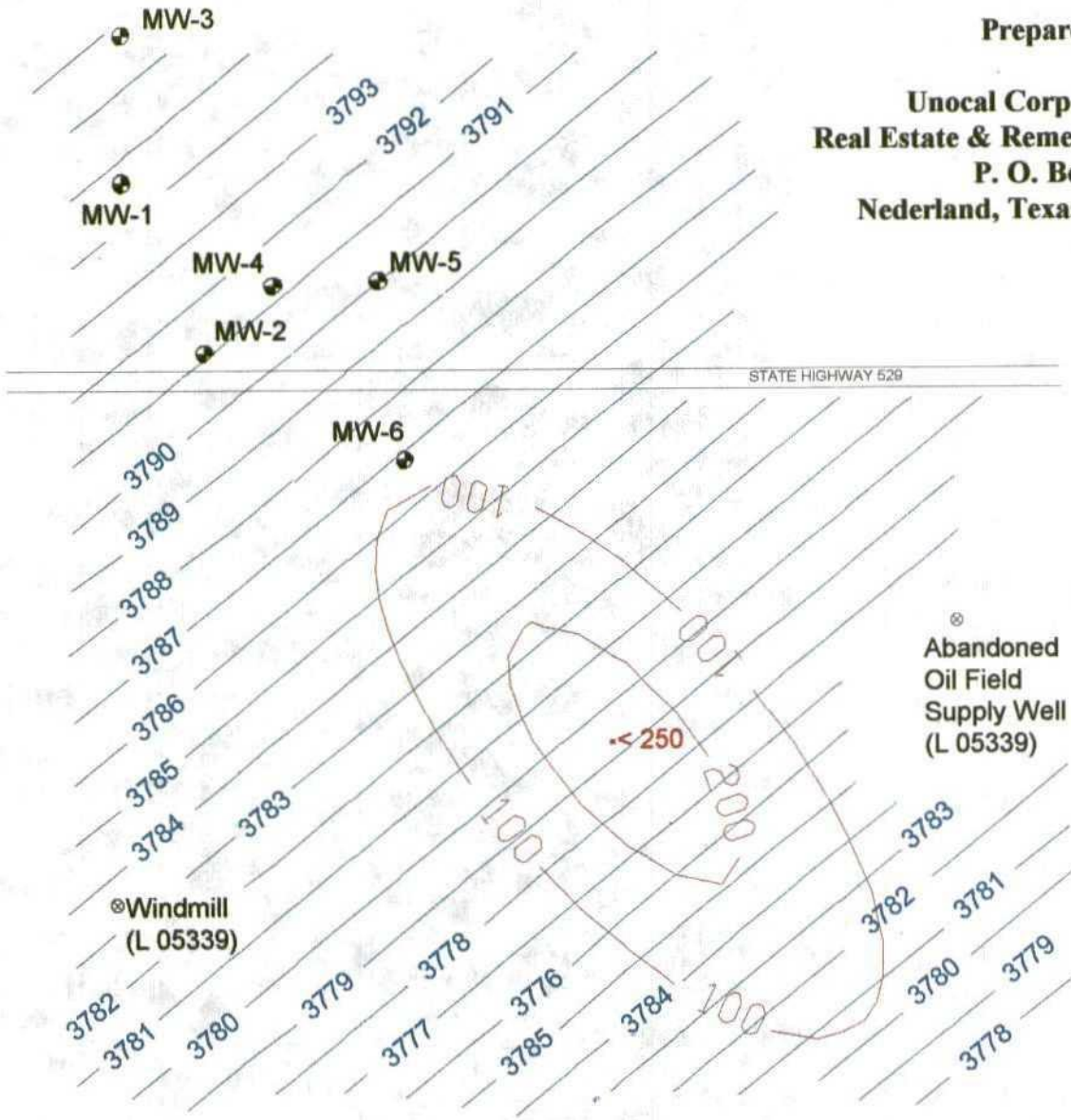
Oil Conservation Division
Environmental Bureau

UNOCAL CORPORATION
2003 ANNUAL GROUNDWATER MONITORING REPORT
FORMER UNOCAL SOUTH VACUUM UNIT
LEA COUNTY, NEW MEXICO

OCTOBER 24, 2003



Prepared For:

Unocal Corporation
Real Estate & Remediation
P. O. Box 1283
Nederland, Texas 77627

TRIDENT ENVIRONMENTAL

P. O. Box 7624
Midland, Texas 79708

IR0277

2003 Annual Groundwater Monitoring Report

Unocal Corporation

Real Estate and Remediation Services

Former Unocal South Vacuum Unit

Lea County, New Mexico

Prepared by:

Trident Environmental
P. O. Box 7624
Midland, Texas 79708
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SBMITTED BY:

Gilbert J. Van Deventer, REM
Project Manager

DATE:

10-24-03

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APPENDICES

1.0 Executive Summary

Trident Environmental (Trident) was retained by ENSR Corporation (ENSR) and Unocal Real Estate and Remediation Services (Unocal) to perform the 2003 annual groundwater sampling and monitoring operations at the Former Unocal South Vacuum Unit in Lea County, New Mexico. This report documents the 2003 annual sampling event performed by Trident at the site on July 2, 2003. This report also contains the historical groundwater elevation and analytical data and includes data from all monitoring wells (MW-1 through MW-6) on site. The sampling event was conducted in accordance with the November 2, 2000 Groundwater Remediation Plan submitted by Unocal and the requirements specified in the New Mexico Oil and Conservation Division (OCD) letter dated February 8, 2001.

Based on the sampling and monitoring data to date, the following conclusions relevant to groundwater conditions at the Former Unocal South Vacuum Unit are evident:

- Chloride and TDS concentrations in MW-1, near the source area, have generally decreased since 1996. Similarly, chloride and TDS levels have decreased in the closest downgradient well, MW-4, since 1999 when that well was installed. Chloride and TDS concentrations in the remaining wells (MW-2, MW-3, MW-5, and MW-6) have remained relatively consistent with previous levels.

- The fate and transport modeling results continue to support the contention that the chloride and total dissolved solids (TDS) plume is not likely to impact existing sources of water supply, the closest of which, a livestock well, lies approximately 3,200 feet south of the source.

- According to conservative model simulations, the chloride plume will travel a maximum of 3,460 feet southeast of the source in approximately 160 years before concentrations return to levels below the New Mexico Water Quality Control Commission (WQCC) standard of 250 mg/L. The same analysis indicates that the TDS plume will travel only 2,100 feet in approximately 90 years before concentrations return to levels below the WQCC standard of 1,000 mg/L.

- Based on the modeling results and predicted natural attenuation processes (advection and dispersion), there will be no adverse impact to human health and the environment nor will the livestock well exceed WQCC standards for chlorides or TDS due to the plume originating and traveling southeast, versus south, from the former emergency overflow pit.

- Groundwater elevations have been steadily decreasing at a rate of approximately 0.3 feet per year since the initial sampling event of monitoring well MW-1 in January 1995.

Unocal has performed exemplary remedial actions to the source area, including plugging of the SWD well in 1971 and encapsulating the former surface impoundment area with solidification material in 1995, thus eliminating the threat of any continued release from the source. Based on the identified potential receptor and fate and transport modeling results, the chloride/TDS plume at the site presents low risk to human health and the environment; therefore Trident recommends the following actions for site closure:

- Continue the natural attenuation annual monitoring program with groundwater sampling and analysis of chloride and TDS concentrations for each of the six monitoring wells.

- Update flow and transport model to confirm the plume is naturally attenuating as described.

- Submit the 2004 annual groundwater monitoring report to OCD in January 2005 to document natural attenuation conditions.

- Provide a means for supplying freshwater in the event there is a need for municipal, domestic, livestock, and/or irrigation water in the plume area.

2.0 Groundwater Sampling Procedures

Each of the six monitoring wells, MW-1 through MW-6, was gauged for depth to groundwater using a Solinst Model 101 electronic water indicator immediately prior to purging operations. A total of 35 gallons of groundwater was purged from each site monitoring well (5 to 9 gallons per well) using a decontaminated 2-inch diameter PVC bailer. After purging, groundwater samples were collected and parameters were measured using a Hydac Model 910 pH-Conductivity-Temperature meter. Water samples for each monitoring well were transferred into 500 milliliter (ml) plastic containers for laboratory analysis of total dissolved solids (TDS) (EPA Method 160.1) and chloride (EPA Method 325.3). For each set of samples, chain of custody forms documenting sample identification numbers, collection times, and delivery times to the laboratory were completed. All water samples were placed in an ice-filled cooler immediately after collection and transported to SPL, Inc. in Houston, Texas for analysis.

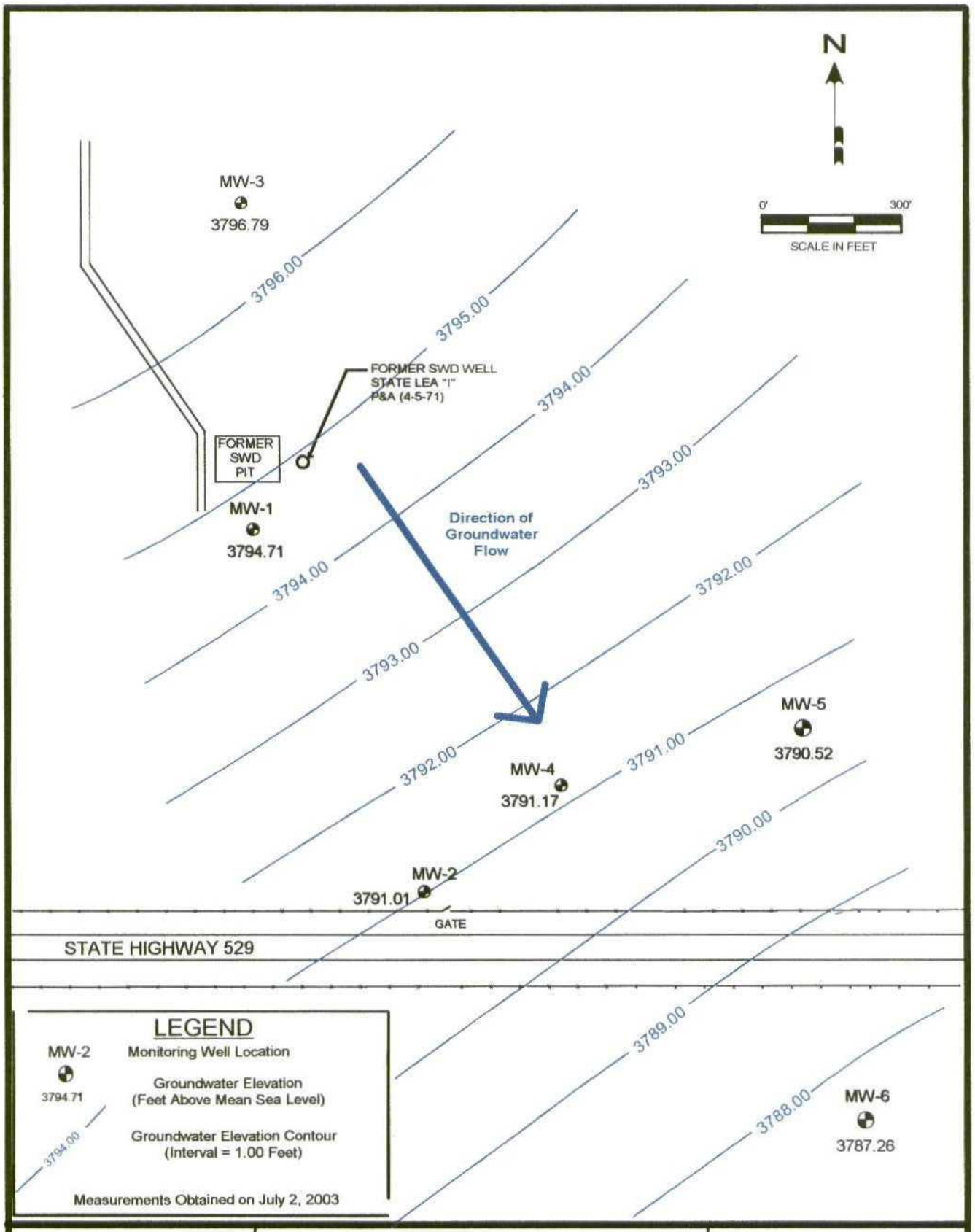
3.0 Groundwater Elevations, Hydraulic Gradient and Flow Direction

Depth to groundwater varies from approximately 48 to 68 feet below ground surface at the site. Groundwater elevations are summarized in Table 1. A groundwater gradient map indicating the direction of groundwater flow is illustrated in Figure 1. A historical groundwater elevation graph is shown in Figure 2. The groundwater gradient direction is to the southeast with a hydraulic gradient of approximately 0.004 ft/ft. According to published reports (*Ground-Water Conditions in Northern Lea County, New Mexico*, Ash, 1963 and *Geology and Ground-Water Conditions in Southern Lea County, New Mexico*, Nicholson and Clebsch, 1961) the groundwater encountered at the site is that of the Tertiary Ogallala Formation. The Ogallala Formation unconformably overlies the impermeable red-beds of the Triassic Chinle Formation at an elevation of approximately 3700 feet above mean sea level (AMSL). Based on the current groundwater elevations measured on site and published data referenced, the saturated thickness of the Ogallala Formation at the site ranges from approximately 87 to 97 feet.

Table 1
Summary of Groundwater Elevations and Chloride and TDS Concentrations
Former Unocal South Vacuum Unit

Monitoring Well	Sample Date	Ground Surface Elevation (feet AMSL)	Top of Casing Elevation (feet AMSL)	Depth to Groundwater (feet BTOC)	Groundwater Elevation (feet AMSL)	Chloride (mg/L)	TDS (mg/L)
MW-1	01/27/95	3856.76	3858.37	59.57	3798.80	**1174**	**2250**
	05/18/95	3856.76	3858.37	61.30	3797.07	**983**	**2251**
	08/28/96	3856.76	3858.37	61.57	3796.80	**1420**	**2730**
	08/13/97	3856.76	3858.37	61.75	3796.62	**1400**	**2800**
	12/14/98	3858.37	3858.37	NM	NM	**1400**	**2400**
	09/30/99	3856.76	3858.37	62.51	3795.86	**1094**	**2318**
	06/14/00	3856.76	3858.37	62.85	3795.52	**927**	**2040**
	06/18/01	3856.76	3858.37	63.07	3795.30	**813**	**1790**
	07/11/02	3856.76	3858.37	63.28	3795.09	**784**	**1680**
	07/02/03	3856.76	3858.37	63.66	3974.71	**715**	**2090**
MW-2	09/30/99	3839.11	3841.64	49.51	3792.13	**298**	922
	06/14/00	3839.11	3841.64	49.81	3791.83	**317**	852
	06/18/01	3839.11	3841.64	50.06	3791.58	**288**	878
	07/11/02	3839.11	3841.64	50.29	3791.35	**284**	808
	07/02/03	3839.11	3841.64	50.63	3791.01	**268**	859
MW-3	09/30/99	3862.20	3864.73	66.74	3797.99	73.6	427
	06/14/00	3862.20	3864.73	67.01	3797.72	75.5	433
	06/18/01	3862.20	3864.73	67.29	3797.44	86.4	495
	07/11/02	3862.20	3864.73	67.59	3797.14	103	509
	07/02/03	3862.20	3864.73	67.94	3796.79	98.3	588
MW-4	09/30/99	3849.87	3852.51	60.18	3792.33	**1576**	**2981**
	06/14/00	3849.87	3852.51	60.55	3791.96	**1500**	**2910**
	06/18/01	3849.87	3852.51	60.78	3791.73	**1530**	**3180**
	07/11/02	3849.87	3852.51	60.98	3791.53	**1290**	**2660**
	07/02/03	3849.87	3852.51	61.34	3791.17	**1250**	**2610**
MW-5	06/14/00	3856.59	3859.84	68.57	3791.27	13.7	274
	06/18/01	3856.59	3859.84	68.80	3791.04	13.6	322
	07/11/02	3856.59	3859.84	68.98	3790.86	15.5	308
	07/02/03	3856.59	3859.84	69.32	3790.52	12.5	359
MW-6	06/14/00	3855.32	3858.78	70.79	3787.99	48	382
	06/18/01	3855.32	3858.78	70.98	3787.80	50.8	431
	07/11/02	3855.32	3858.78	71.26	3787.52	50	422
	07/02/03	3855.32	3858.78	71.52	3787.26	46.5	471
Water Quality Control Commission (WQCC) Standards						250	1000

AMSL – Above Mean Sea Level; BTOC – Below Top of Casing; NM – No Measurement
Groundwater flow direction is to the southeast with a gradient of approximately 0.004 feet/foot.
Elevations and state plane coordinates surveyed by Basin Surveys, Hobbs, NM.



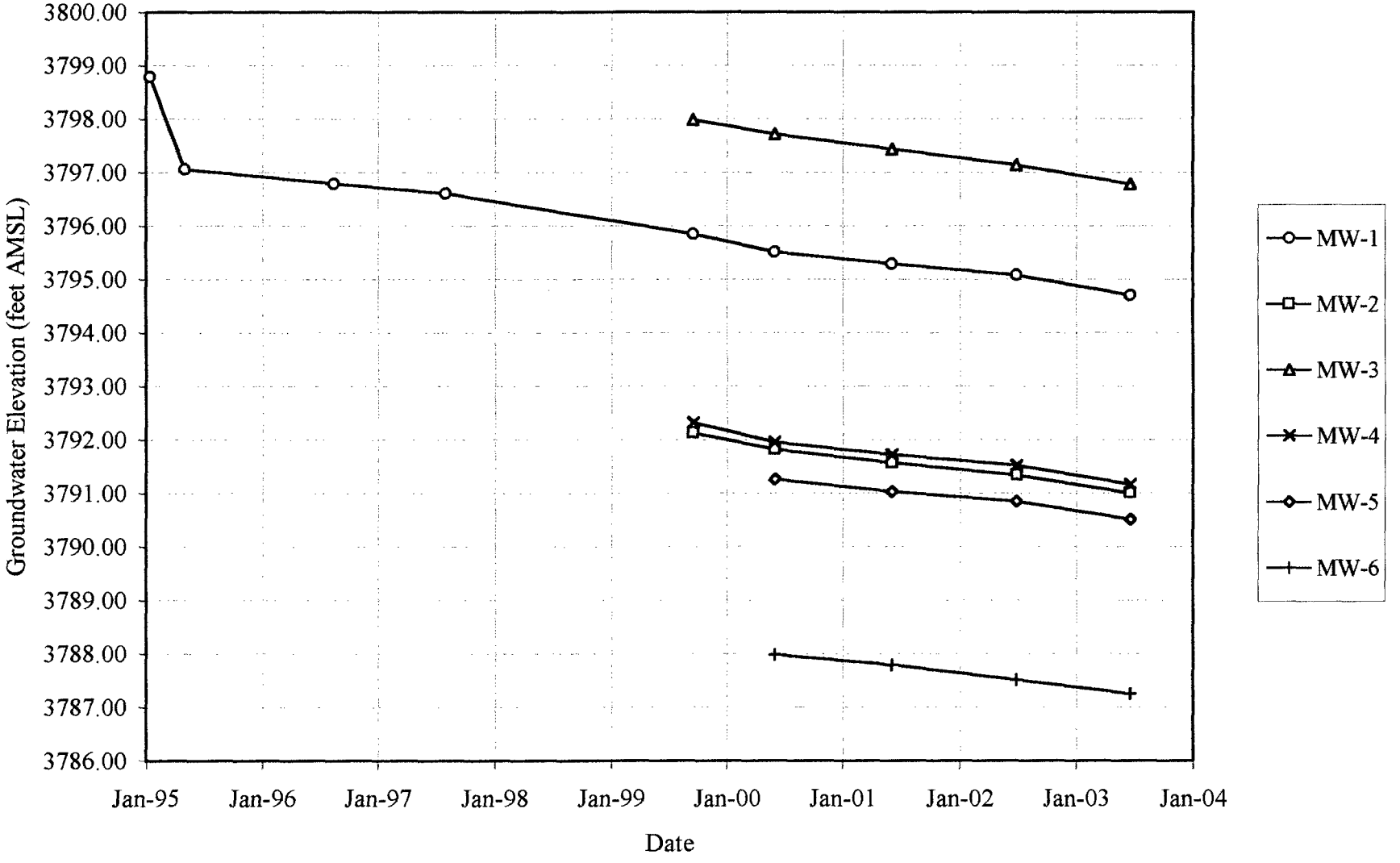
TRIDENT ENVIRONMENTAL

SITE: FORMER UNOCAL S. VACUUM UNIT	
DATE: 07/02/03	SCALE: 1 IN = 300 FT
AUTHOR: GJV	DRN BY: GJV
CK'D BY: DTL	FILE: VAC 2003

FIGURE 1

GROUNDWATER ELEVATION MAP

Figure 2
Historical Groundwater Elevations

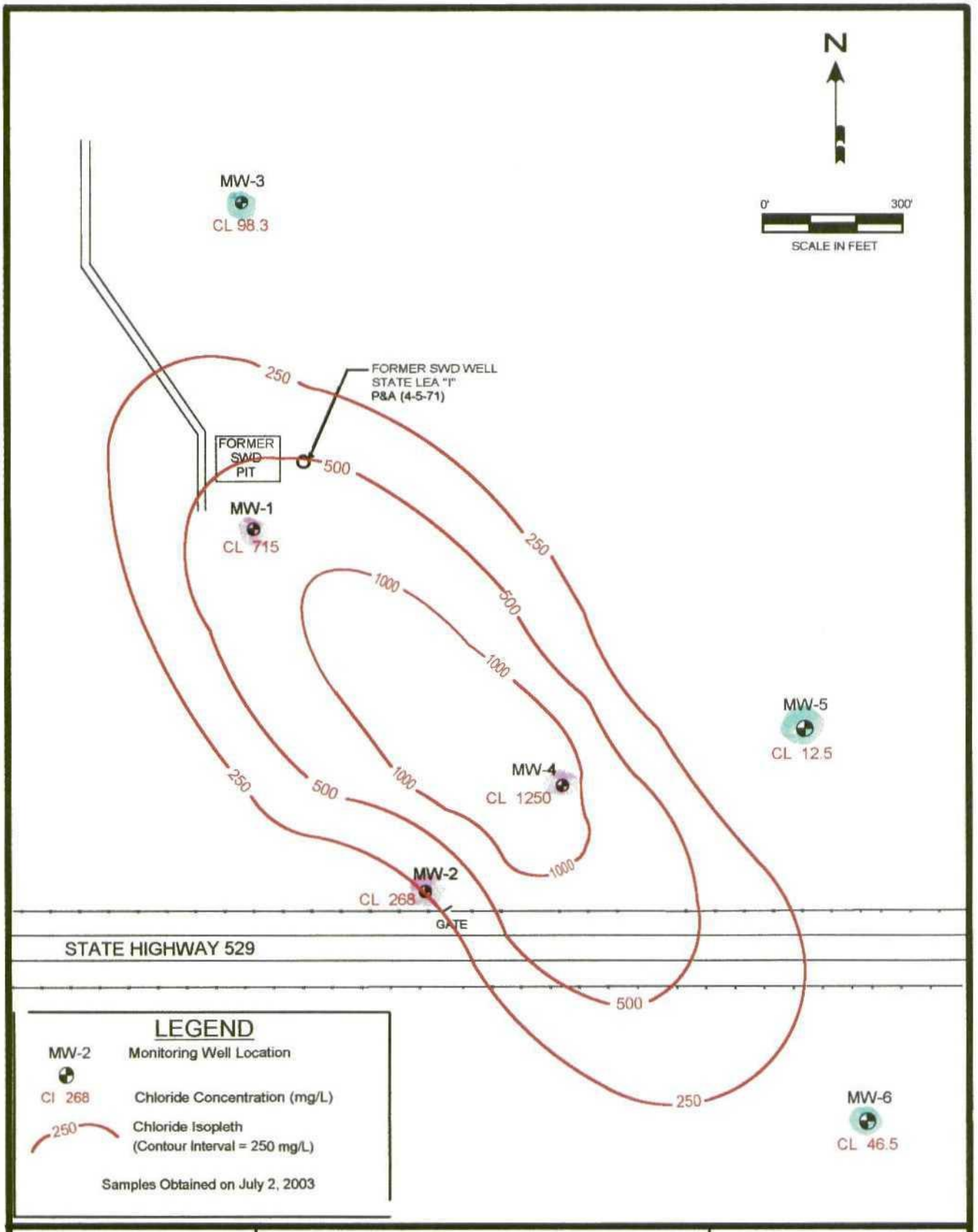


4.0 Groundwater Quality Conditions

Groundwater sample analytical results are presented in Table 1. The WQCC standards are presented for comparison. Those constituents that recorded concentrations above the WQCC standards are highlighted in boldface type. The WQCC standard of 250 mg/L for chloride was exceeded in MW-1 (715 mg/L), MW-2 (268 mg/L), and MW-4 (1,250 mg/L). The WQCC standard of 1,000 mg/L for TDS was exceeded in MW-1 (2,090 mg/L) and MW-4 (2,610 mg/L). The groundwater samples obtained from upgradient monitoring well MW-3 and downgradient wells MW-5 and MW-6 had chloride and TDS concentrations below WQCC standards.

The chloride and TDS concentrations are depicted graphically in Figure 3 and 4, respectively. The concentration isopleths were drawn utilizing the Surfer® (version 6.0) contour modeling program (Kriging method). Since this contouring program does not take into account the known groundwater gradient, some of the isopleths were manually converged into a more southeasterly orientation. Graphs depicting historical TDS and chloride concentrations in monitoring wells MW-1through MW-6 are shown in Figures 5 and 6.

Chloride and TDS concentrations in MW-1, near the source area, have consistently decreased since 1996, with the exception of an increase in TDS concentrations during the latest sampling event. Similarly, chloride and TDS levels have decreased in the closest downgradient well, MW-4, since 1999 when that well was installed. Chloride and TDS concentrations in the monitoring wells MW-3, MW-5, and MW-6 have slightly increased since 2000, whereas chloride and TDS levels in MW-2 have remained relatively consistent with previous years.



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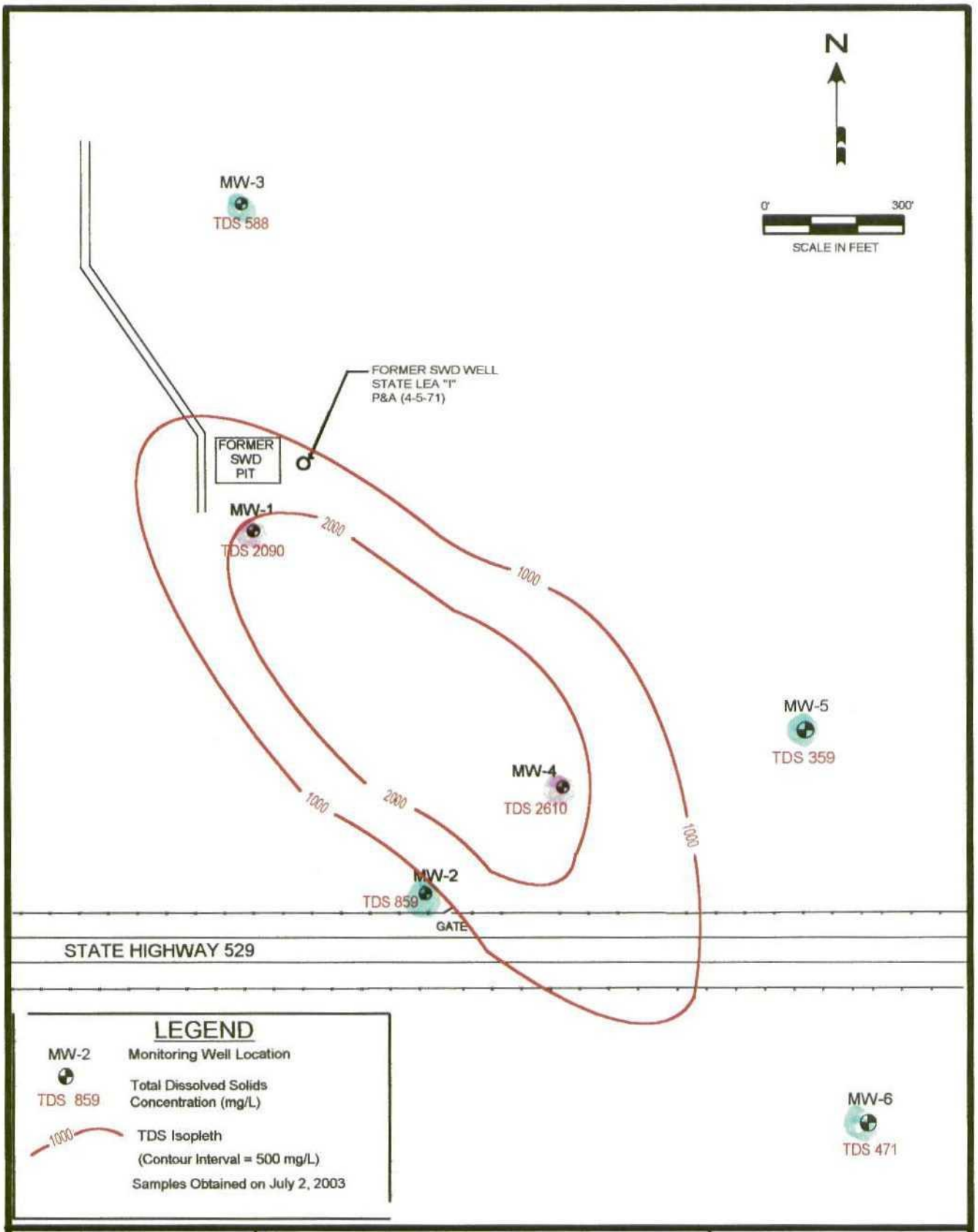
SITE: FORMER UNOCAL S. VACUUM UNIT	
DATE: 07/02/03	SCALE: 1 IN = 300 FT
AUTHOR: GJV	DRN BY: GJV
CK'D BY: DTL	FILE: VAC 2003

FIGURE 3

CHLORIDE CONCENTRATION MAP



TRIDENT ENVIRONMENTAL

SITE: FORMER UNOCAL S. VACUUM UNIT	
DATE: 07/02/03	SCALE: 1 IN = 300 FT
AUTHOR: GJV	DRN BY: GJV
CK'D BY: DTL	FILE: VAC 2003

FIGURE 4

TOTAL DISSOLVED SOLIDS CONCENTRATION MAP

Figure 5
Chloride Concentrations Versus Time Graph

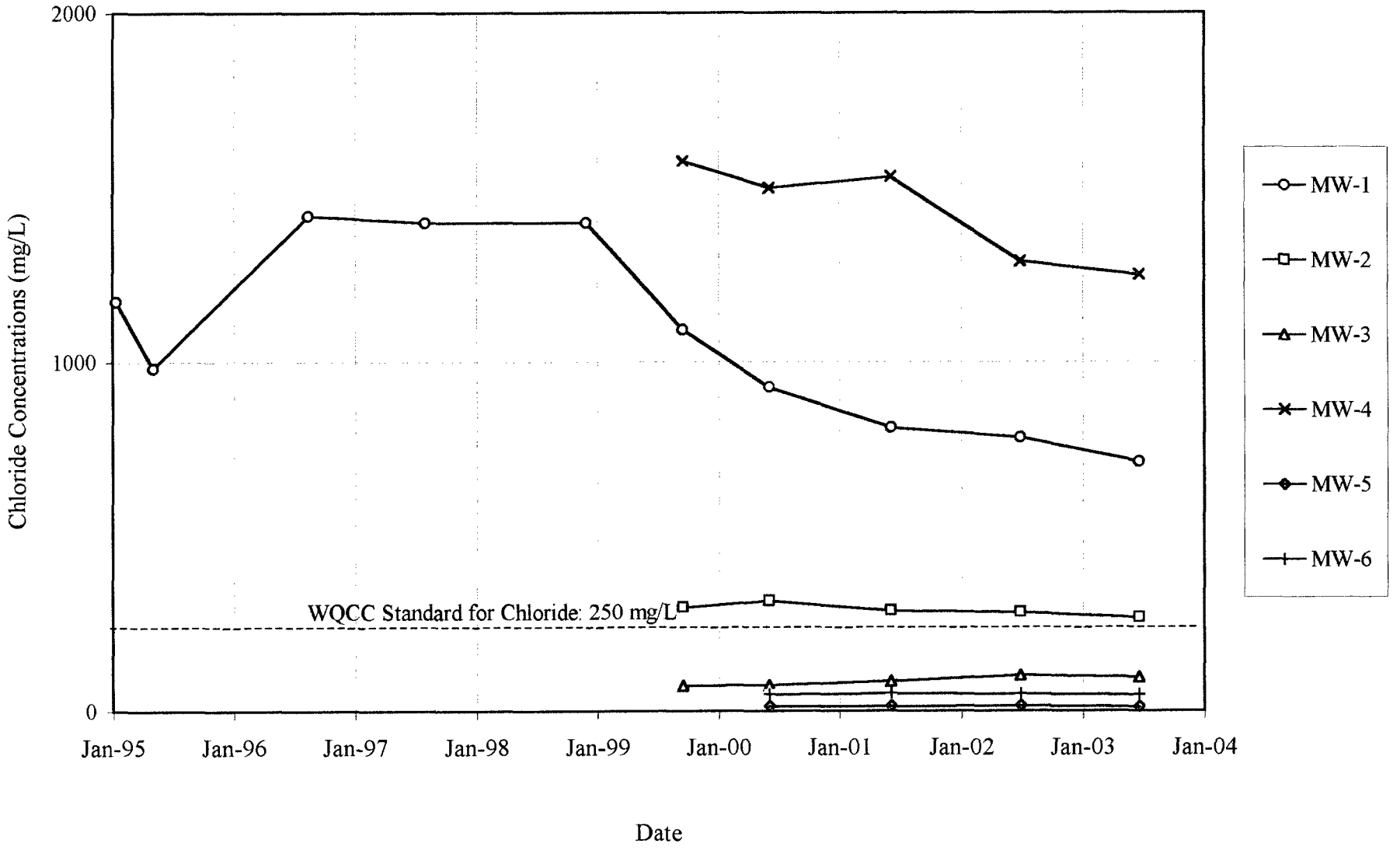
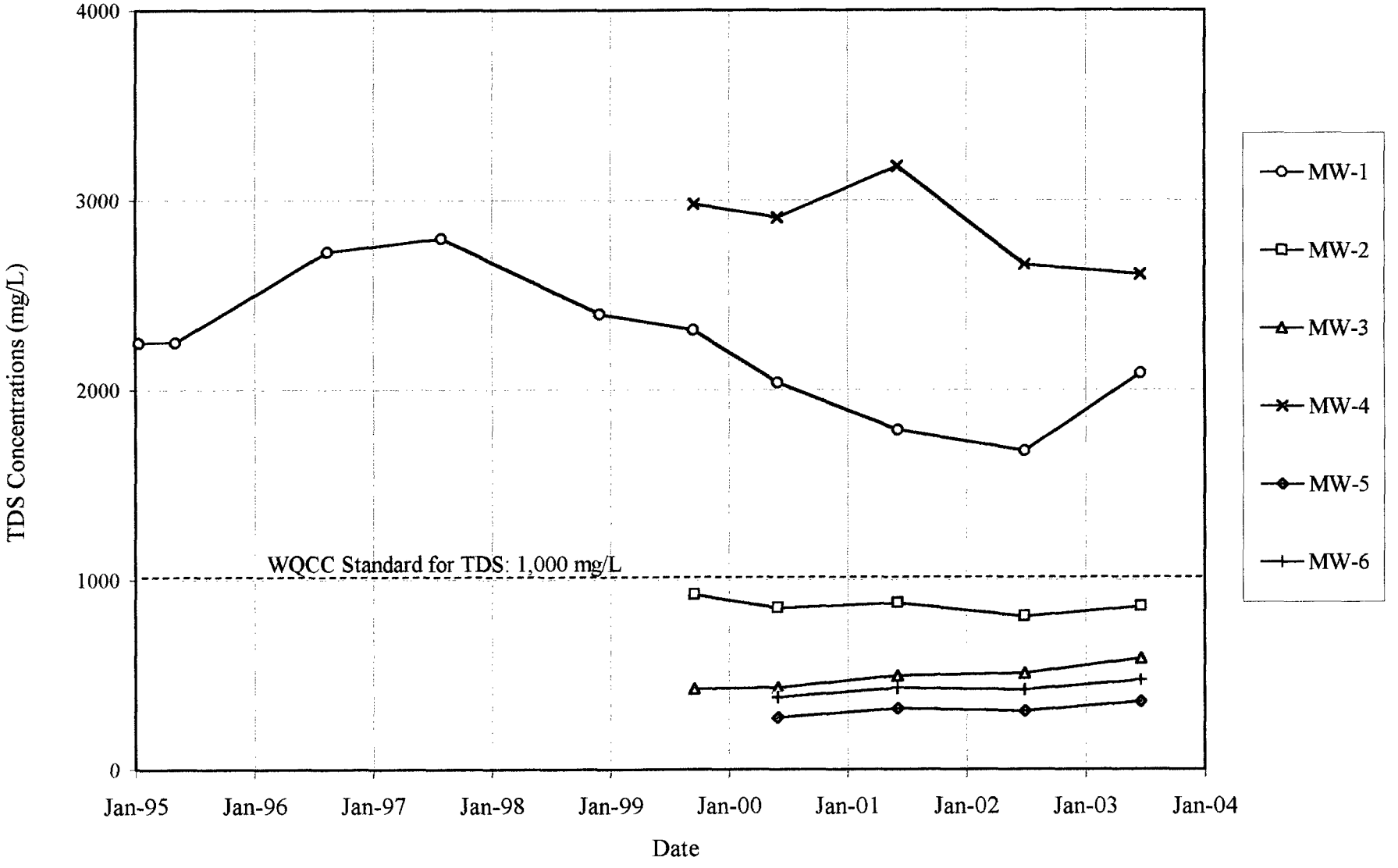


Figure 6
Total Dissolved Solids Concentrations Versus Time Graph



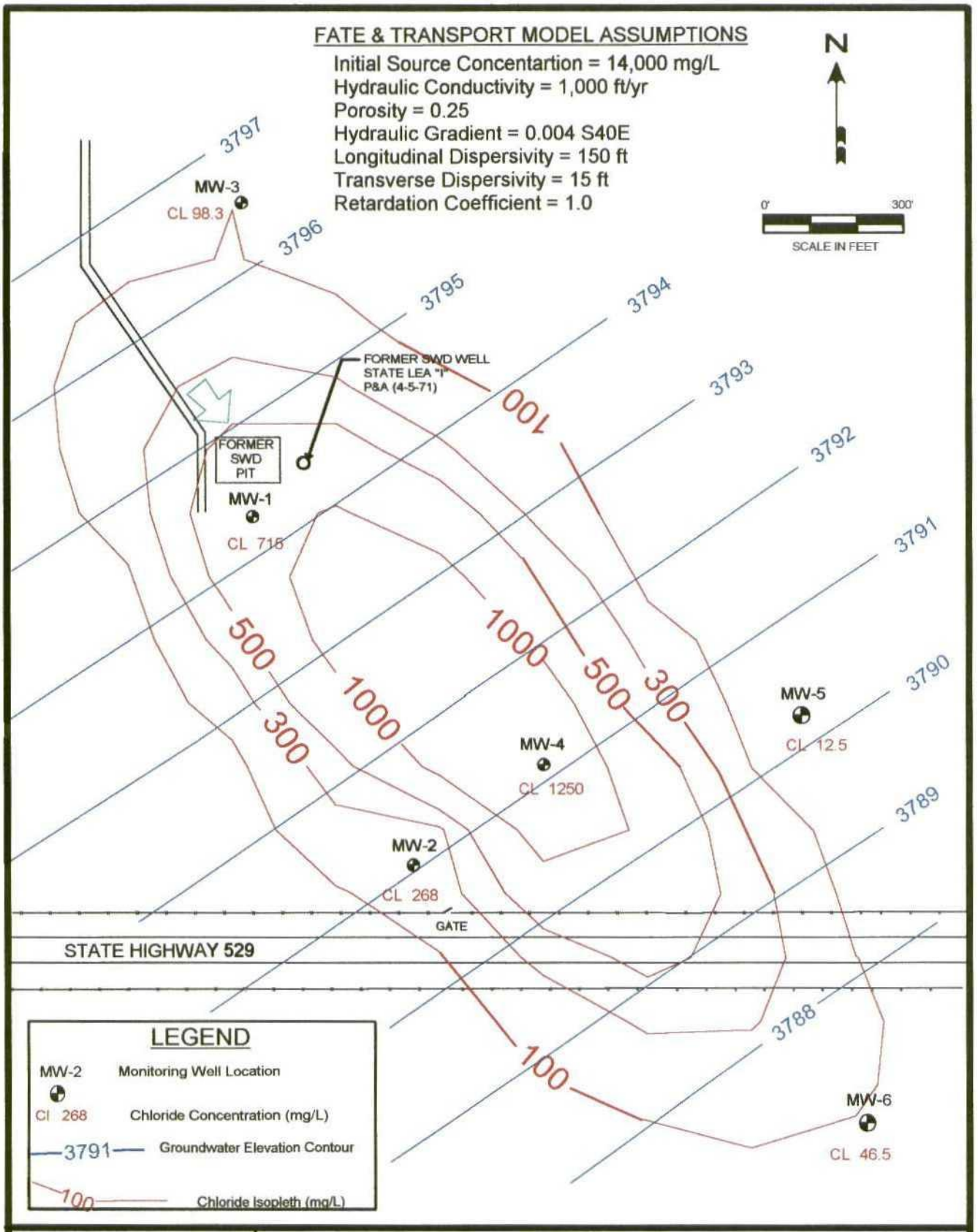
5.0 Fate and Transport Modeling Results

Fate and transport modeling was performed by Trident to simulate the movement of the chloride and TDS groundwater plume over time. Simulations were conducted using the two-dimensional groundwater flow and contaminant transport model WinTran, version 1.03 (1995) designed and distributed by Environmental Simulations, Inc. (ESI) of Herndon, Virginia. WinTran is built around a steady-state analytical element flow model, linked to a finite element contaminant transport model. A more detailed discussion of the flow and transport parameters used, assumptions, model calibrations, and simulation results are described in Appendix C.

Figures 7A and 7B show the close match achieved by the chloride and TDS modeling simulations as compared to the current observed plume (Figures 3 and 4). Hydrodynamic dispersion serves to broaden the dimensions of the plume while reducing the concentrations in the middle of the plume, as depicted in Figures 8A and 8B (50 years from now). Advective flow moves the center of plume mass downgradient by a distance of approximately 750 feet from the former SWD pit and approximately 300 feet upgradient from well MW-4.

Continued attenuation by dilution and dispersion of the plume, after the maximum chloride and TDS concentrations decrease to levels below WQCC standards, is shown in Figures 9A (year 2160) and 9B (year 2093), respectively. The center of the chloride plume is approximately 3,460 ft away from the pit and well source in the year 2160. The center of the TDS plume is approximately 2,100 ft away from the pit and well source in the year 2093.

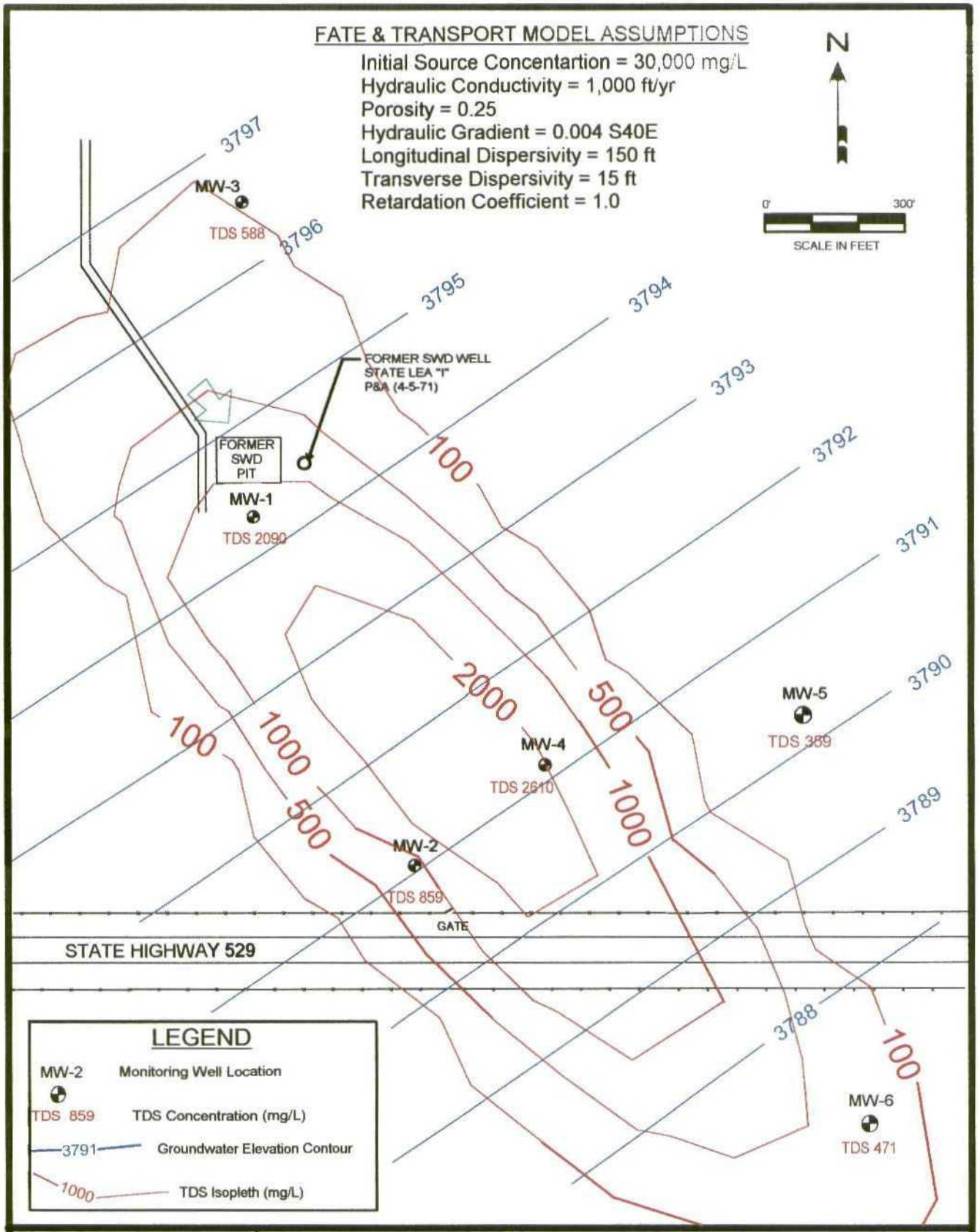
The portions of the chloride and TDS plumes that are above WQCC standards do not reach any of the identified potential receptors at any time during their attenuation. The updated fate and transport model is consistent with that determined in the two previous annual reports, however the plumes attenuate sooner and at a reduced terminal distance as a result of inputting the most recent chloride and TDS concentrations.



TRIDENT ENVIRONMENTAL

FIGURE 7A

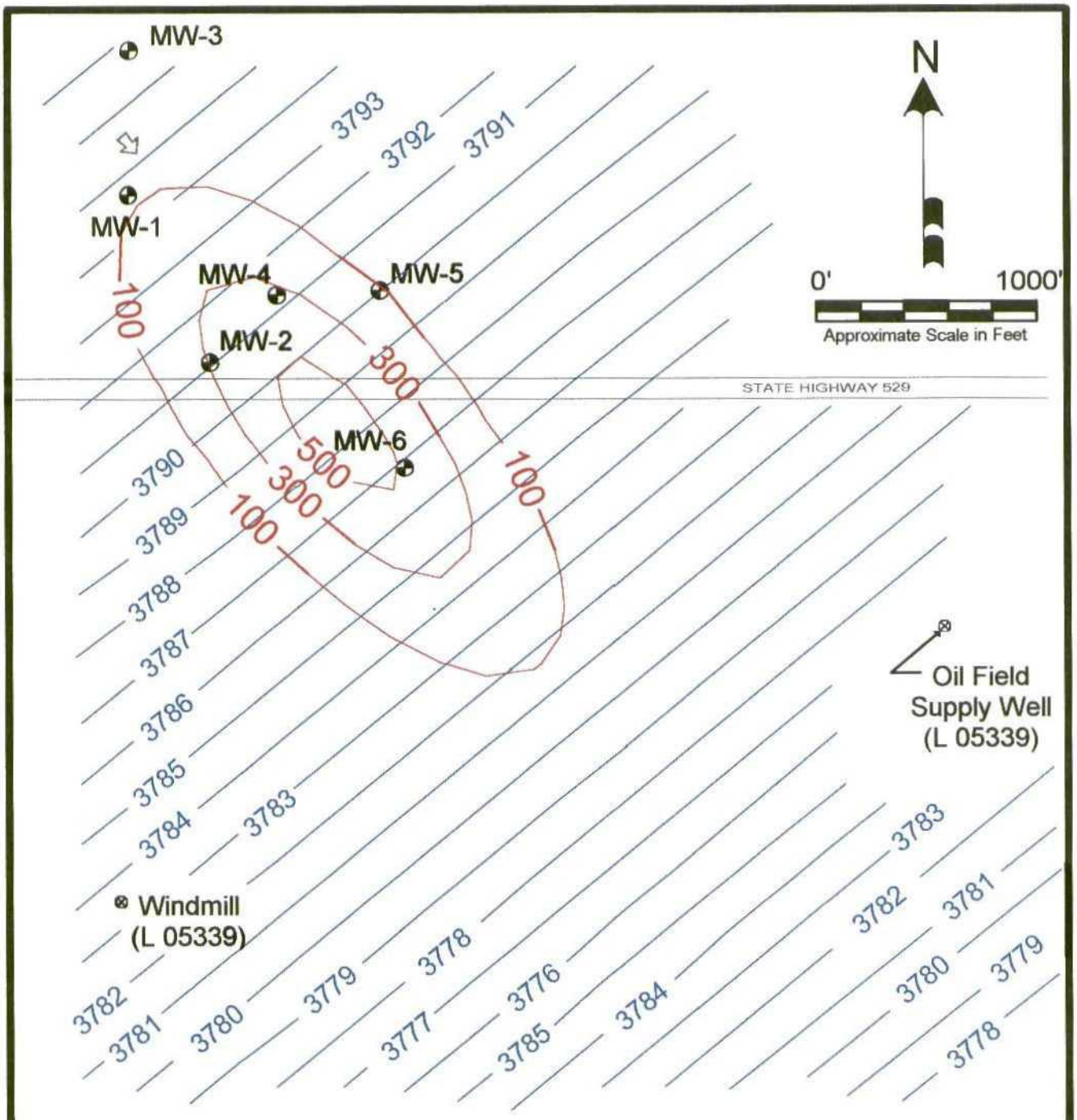
Former Unocal South Vacuum Unit
32-Year Chloride Plume Simulation (1971-2003)
Based on WinTran Modeling Results



TRIDENT ENVIRONMENTAL

FIGURE 7B

Former Unocal South Vacuum Unit
32-Year TDS Plume Simulation (1971-2003)
Based on WinTran Modeling Results



FATE & TRANSPORT MODEL ASSUMPTIONS

Initial Source Concentartion = 14,000 mg/L
Hydraulic Conductivity = 1,000 ft/yr
Porosity = 0.25
Hydraulic Gradient = 0.004 S40E
Longitudinal Dispersivity = 150 ft
Transverse Dispersivity = 15 ft
Retardation Coefficient = 1.0

LEGEND

MW-5 — Monitoring Well Location

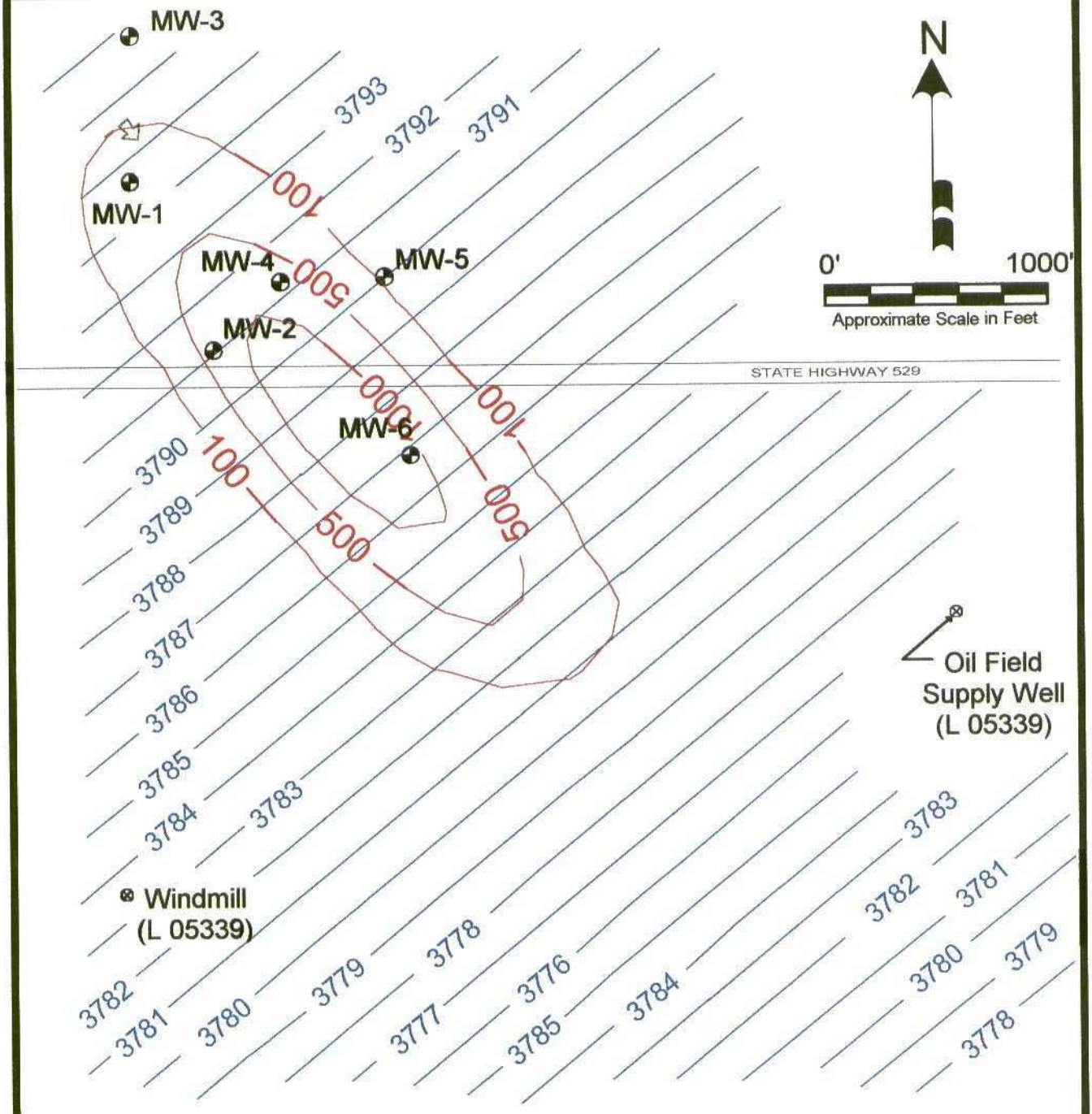
3785 — Groundwater Elevation Contour

100 — Chloride Isopleth (mg/L)

TRIDENT ENVIRONMENTAL

FIGURE 8A

Former Unocal South Vacuum Unit
50-Year Chloride Plume Simulation (2003-2053)
Based on WinTran Modeling Results



FATE & TRANSPORT MODEL ASSUMPTIONS

Initial Source Concentartion = 30000 mg/L
Hydraulic Conductivity = 1000 ft/yr
Porosity = 0.25
Hydraulic Gradient = 0.004 S40E
Longitudinal Dispersivity = 150 ft
Transverse Dispersivity = 15 ft
Retardation Coefficient = 1.0

LEGEND

MW-5 Monitoring Well Location

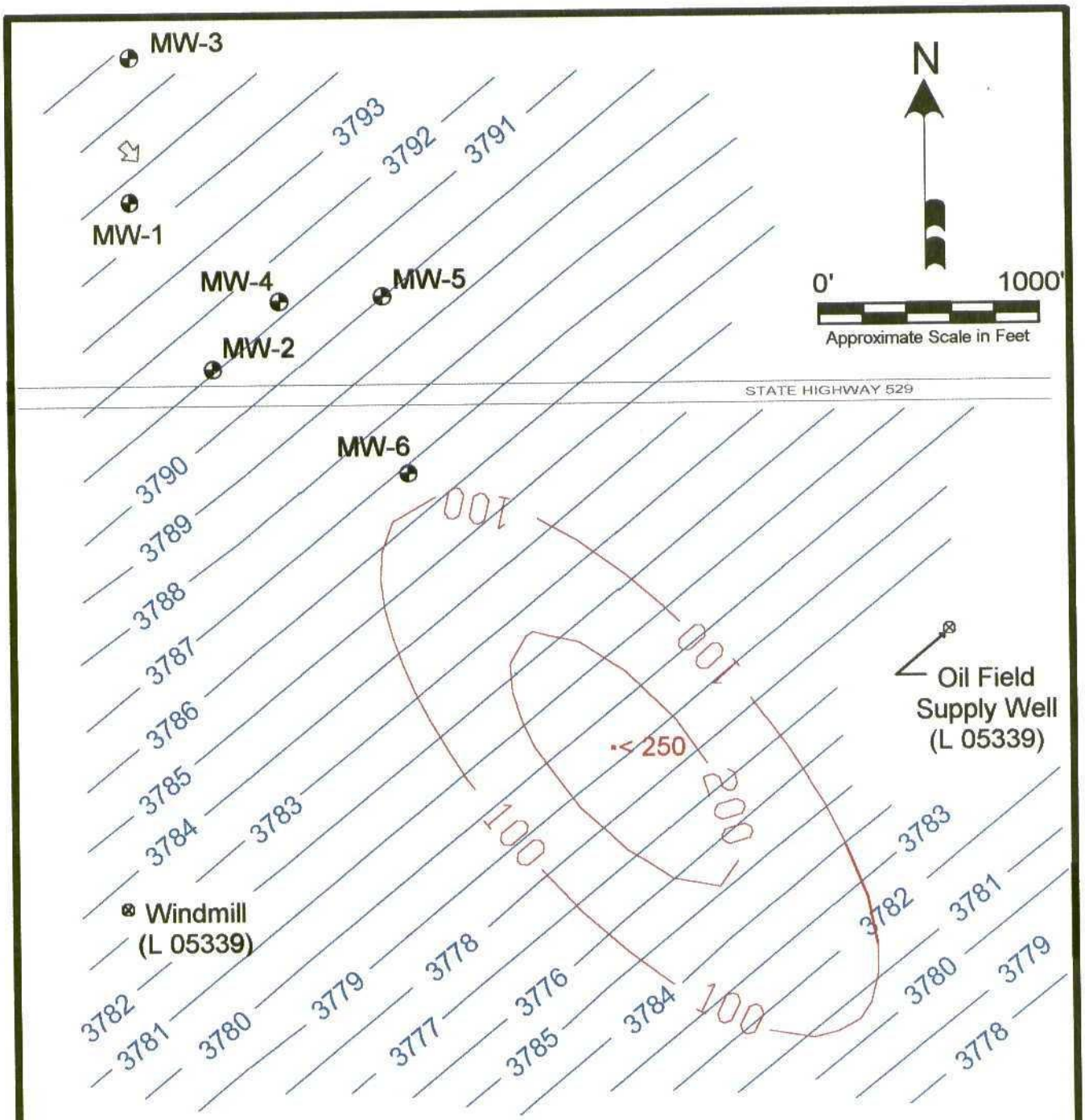
3778 Groundwater Elevation Contour

100 TDS Isopleth (mg/L)

TRIDENT ENVIRONMENTAL

FIGURE 8B

Former Unocal South Vacuum Unit
50-Year TDS Plume Simulation (2003-2053)
Based on WinTran Modeling Results



FATE & TRANSPORT MODEL ASSUMPTIONS

Initial Source Concentartion = 14,000 mg/L
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Porosity = 0.25
Hydraulic Gradient = 0.004 S40E
Longitudinal Dispersivity = 150 ft
Transverse Dispersivity = 15 ft
Retardation Coefficient = 1.0

LEGEND

MW-5 — Monitoring Well Location

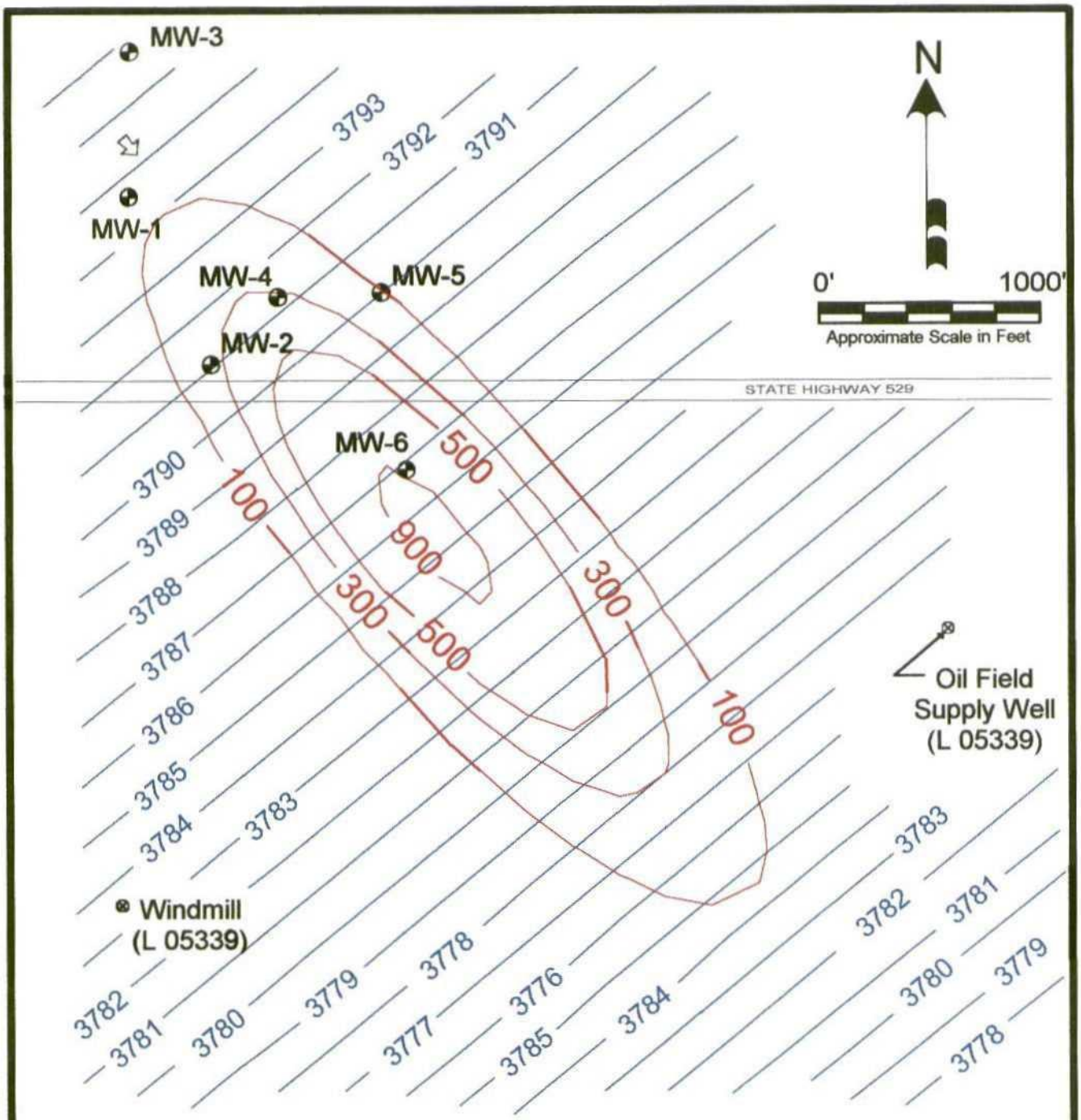
3785 — Groundwater Elevation Contour

100 — Chloride Isopleth (mg/L)

TRIDENT ENVIRONMENTAL

FIGURE 9A

Former Unocal South Vacuum Unit
160 Year Chloride Plume Simulation (2003-2163)
Based on WinTran Modeling Results



FATE & TRANSPORT MODEL ASSUMPTIONS

Initial Source Concentartion = 30000 mg/L
Hydraulic Conductivity = 1000 ft/yr
Porosity = 0.25
Hydraulic Gradient = 0.004 S40E
Longitudinal Dispersivity = 150 ft
Transverse Dispersivity = 15 ft
Retardation Coefficient = 1.0

LEGEND

MW-5 Monitoring Well Location

—3778— Groundwater Elevation Contour

100 TDS Isopleth (mg/L)

TRIDENT ENVIRONMENTAL

FIGURE 9B

Former Unocal South Vacuum Unit
90-Year TDS Plume Simulation (2003-2093)
Based on WinTran Modeling Results

6.0 Conclusions

Conclusions relevant to groundwater conditions and the remediation performance at the Former Unocal South Vacuum Unit are presented below.

- Chloride and TDS concentrations in MW-1, near the source area, have generally decreased since 1996. Similarly, chloride and TDS levels have decreased in the closest downgradient well, MW-4, since 1999 when that well was installed. Chloride and TDS concentrations in the remaining wells (MW-2, MW-3, MW-5, and MW-6) have remained relatively consistent with previous levels.

- The fate and transport modeling results continue to support the contention that the chloride and total dissolved solids (TDS) plume is not likely to impact existing sources of water supply, the closest of which, a livestock well, lies approximately 3,200 feet south of the source.

- According to conservative model simulations, the chloride plume will travel a maximum of 3,460 feet southeast of the source in approximately 160 years before concentrations return to levels below the New Mexico Water Quality Control Commission (WQCC) standard of 250 mg/L. The same analysis indicates that the TDS plume will travel only 2,100 feet in approximately 90 years before concentrations return to levels below the WQCC standard of 1,000 mg/L.

- Based on the modeling results and predicted natural attenuation processes (dispersion and dilution), there will be no adverse impact to human health and the environment nor will the livestock well exceed WQCC standards for chlorides or TDS due to the plume originating and traveling southeast, versus south, from the former emergency overflow pit.

- Groundwater elevations have been steadily decreasing at a rate of approximately 0.3 feet per year since the initial sampling event of monitoring well MW-1 in January 1995.

7.0 Recommendations

Unocal has performed exemplary remedial actions to the source area, including plugging of the SWD well in 1971 and encapsulating the former surface impoundment area with solidification material in 1995, thus eliminating the threat of any continued release from the source. Based on the identified potential receptor and fate and transport modeling results, the chloride/TDS plume at the site presents low risk to human health and the environment; therefore Trident recommends the following actions for site closure:

- Continue the natural attenuation annual monitoring program with groundwater sampling and analysis of chloride and TDS concentrations for each of the six monitoring wells.
- Update flow and transport model to confirm the plume is naturally attenuating as described.
- Submit the 2004 annual groundwater monitoring report to OCD in January 2005 to document natural attenuation conditions.
- Provide a means for supplying freshwater in the event there is a need for municipal, domestic, livestock, and/or irrigation water in the plume area.

APPENDICES

APPENDIX A

LABORATORY ANALYTICAL REPORTS

AND

CHAIN-OF-CUSTODY DOCUMENTATION

HOUSTON LABORATORY
8880 INTERCHANGE DRIVE
HOUSTON, TX 77054
(713) 660-0901

Unocal Corporation

Certificate of Analysis Number:

03070239

Report To:		Project Name:	Former Unocal South Vacuum Unit
Trident Environmental		Site:	Midland, TX
Gil Van Deventer		Site Address:	
P.O. Box 7624			
Midland		PO Number:	APS140OC
TX		State:	New Mexico
79708-7624		State Cert. No.:	
ph: (432) 682-0808	fax: (915) 682-0028	Date Reported:	7/11/2003

This Report Contains A Total Of 14 Pages

Excluding This Page

And

Chain Of Custody

7/11/2003

Date

HOUSTON LABORATORY
8880 INTERCHANGE DRIVE
HOUSTON, TX 77054
(713) 660-0901

Case Narrative for:

Unocal Corporation

Certificate of Analysis Number:

03070239

Report To:		Project Name:	Former Unocal South Vacuum Unit
Trident Environmental		Site:	Midland, TX
Gil Van Deventer		Site Address:	
P.O. Box 7624			
Midland		PO Number:	APS140OC
TX		State:	New Mexico
79708-7624		State Cert. No.:	
ph: (432) 682-0808	fax: (915) 682-0028	Date Reported:	7/11/2003

Matrix spike (MS) and matrix spike duplicate (MSD) samples are chosen and tested at random from an analytical batch of "like" matrix to check for possible matrix effect. The MS and MSD will provide site specific matrix data only for those samples which are spiked by the laboratory. Since the MS and MSD are chosen at random from an analytical batch, the sample chosen for spike purposes may or may not have been a sample submitted in this sample delivery group. The validity of the analytical procedures for which data is reported in this analytical report is determined by the Laboratory Control Sample (LCS) and the Method Blank (MB). The Laboratory Control Sample (LCS) and the Method Blank (MB) are processed with the samples and the MS/MSD to ensure method criteria are achieved throughout the entire analytical process.

Any other exceptions associated with this report will be footnoted in the analytical result page(s) or the quality control summary page(s).

Please do not hesitate to contact us if you have any questions or comments pertaining to this data report. Please reference the above Certificate of Analysis Number.

This report shall not be reproduced except in full, without the written approval of the laboratory. The reported results are only representative of the samples submitted for testing.

SPL, Inc. is pleased to be of service to you. We anticipate working with you in fulfilling all your current and future analytical needs.

Elessa Sommers
Senior Project Manager

7/11/2003
Date

HOUSTON LABORATORY
8880 INTERCHANGE DRIVE
HOUSTON, TX 77054
(713) 660-0901

Unocal Corporation

Certificate of Analysis Number:

03070239

Report To: Trident Environmental
Gil Van Deventer
P.O. Box 7624

Midland
TX
79708-7624
ph: (432) 682-0808 fax:

Fax To: Trident Environmental
Gil Van Deventer fax : (915) 682-0028

Project Name: Former Unocal South Vacuum Unit
Site: Midland, TX
Site Address:

PO Number: APS140OC
State: New Mexico
State Cert. No.:
Date Reported: 7/11/2003

Client Sample ID	Lab Sample ID	Matrix	Date Collected	Date Received	COC ID	HOLD
W-1	03070239-01	Water	7/2/2003 11:10:00 AM	7/8/2003 9:30:00 AM	10412	☐
W-2	03070239-02	Water	7/2/2003 9:10:00 AM	7/8/2003 9:30:00 AM	10412	☐
MW-3	03070239-03	Water	7/2/2003 11:00:00 AM	7/8/2003 9:30:00 AM	10412	☐
W-4	03070239-04	Water	7/2/2003 10:20:00 AM	7/8/2003 9:30:00 AM	10412	☐
W-5	03070239-05	Water	7/2/2003 10:10:00 AM	7/8/2003 9:30:00 AM	10412	☐
MW-6	03070239-06	Water	7/2/2003 12:20:00 PM	7/8/2003 9:30:00 AM	10412	☐

7/11/2003

ssa Sommers
Date
Senior Project Manager

Joel Grice
Laboratory Director

Ted Yen
Quality Assurance Officer

7/11/2003 8:04:41 AM

HOUSTON LABORATORY
8880 INTERCHANGE DRIVE
HOUSTON, TX 77054
(713) 660-0901

Client Sample ID MW-1 **Collected:** 07/02/2003 11:10 **SPL Sample ID:** 03070239-01

Site: Midland, TX

Analyses/Method	Result	Rep.Limit		Dil. Factor	QUAL	Date Analyzed	Analyst	Seq. #
CHLORIDE, TOTAL			**MCL**	**E325.3**		**Units: mg/L**		
Chloride	715	10		10		07/10/03 11:00	RA	1761372
TOTAL DISSOLVED SOLIDS			**MCL**	**E160.1**		**Units: mg/L**		
Total Dissolved Solids (Residue,Filterable)	2090	20		2		07/08/03 18:00	E_S	1758616

Qualifiers:

ND/U - Not Detected at the Reporting Limit
B - Analyte detected in the associated Method Blank
* - Surrogate Recovery Outside Advisable QC Limits
J - Estimated Value between MDL and PQL
>MCL - Result Over Maximum Contamination Limit(MCL)
D - Surrogate Recovery Unreportable due to Dilution
MI - Matrix Interference

HOUSTON LABORATORY
8880 INTERCHANGE DRIVE
HOUSTON, TX 77054
(713) 660-0901

Client Sample ID MW-2 **Collected:** 07/02/2003 9:10 **SPL Sample ID:** 03070239-02

Site: Midland, TX

Analyses/Method	Result	Rep.Limit		Dil. Factor	QUAL	Date Analyzed	Analyst	Seq. #
CHLORIDE, TOTAL			**MCL**	**E325.3**		**Units: mg/L**		
Chloride	268	10		10		07/10/03 11:00	RA	1761373
TOTAL DISSOLVED SOLIDS			**MCL**	**E160.1**		**Units: mg/L**		
Total Dissolved Solids (Residue,Filterable)	859	10		1		07/08/03 18:00	E_S	1758617

Qualifiers:

ND/U - Not Detected at the Reporting Limit
B - Analyte detected in the associated Method Blank
* - Surrogate Recovery Outside Advisable QC Limits
J - Estimated Value between MDL and PQL
>MCL - Result Over Maximum Contamination Limit(MCL)
D - Surrogate Recovery Unreportable due to Dilution
MI - Matrix Interference

HOUSTON LABORATORY
8880 INTERCHANGE DRIVE
HOUSTON, TX 77054
(713) 660-0901

Client Sample ID MW-3 **Collected:** 07/02/2003 11:00 **SPL Sample ID:** 03070239-03

Site: Midland, TX

Analyses/Method	Result	Rep.Limit	Dil. Factor	QUAL	Date Analyzed	Analyst	Seq. #
CHLORIDE, TOTAL		**MCL**	**E325.3**		**Units: mg/L**		
Chloride	98.3	1	1		07/10/03 11:00	RA	1761374
TOTAL DISSOLVED SOLIDS		**MCL**	**E160.1**		**Units: mg/L**		
Total Dissolved Solids (Residue,Filterable)	588	10	1		07/08/03 18:00	E_S	1758618

Qualifiers:

ND/U - Not Detected at the Reporting Limit
B - Analyte detected in the associated Method Blank
* - Surrogate Recovery Outside Advisable QC Limits
J - Estimated Value between MDL and PQL
>MCL - Result Over Maximum Contamination Limit(MCL)
D - Surrogate Recovery Unreportable due to Dilution
MI - Matrix Interference

HOUSTON LABORATORY
8880 INTERCHANGE DRIVE
HOUSTON, TX 77054
(713) 660-0901

Client Sample ID MW-4 **Collected:** 07/02/2003 10:20 **SPL Sample ID:** 03070239-04

Site: Midland, TX

Analyses/Method	Result	Rep.Limit		Dil. Factor	QUAL	Date Analyzed	Analyst	Seq. #
CHLORIDE, TOTAL			**MCL**	**E325.3**		**Units: mg/L**		
Chloride	1250	50		50		07/10/03 11:00	RA	1761375
TOTAL DISSOLVED SOLIDS			**MCL**	**E160.1**		**Units: mg/L**		
Total Dissolved Solids (Residue,Filterable)	2610	20		2		07/08/03 18:00	E_S	1758619

Qualifiers:

ND/U - Not Detected at the Reporting Limit
B - Analyte detected in the associated Method Blank
* - Surrogate Recovery Outside Advisable QC Limits
J - Estimated Value between MDL and PQL
>MCL - Result Over Maximum Contamination Limit(MCL)
D - Surrogate Recovery Unreportable due to Dilution
MI - Matrix Interference

HOUSTON LABORATORY
8880 INTERCHANGE DRIVE
HOUSTON, TX 77054
(713) 660-0901

Client Sample ID MW-5 **Collected:** 07/02/2003 10:10 **SPL Sample ID:** 03070239-05

Site: Midland, TX

Analyses/Method	Result	Rep.Limit	Dil. Factor	QUAL	Date Analyzed	Analyst	Seq. #
CHLORIDE, TOTAL		**MCL**	**E325.3**		**Units: mg/L**		
Chloride	12.5	1	1		07/10/03 11:00	RA	1761376
TOTAL DISSOLVED SOLIDS		**MCL**	**E160.1**		**Units: mg/L**		
Total Dissolved Solids (Residue,Filterable)	359	10	1		07/08/03 18:00	E_S	1758620

Qualifiers:

ND/U - Not Detected at the Reporting Limit
B - Analyte detected in the associated Method Blank
* - Surrogate Recovery Outside Advisable QC Limits
J - Estimated Value between MDL and PQL
>MCL - Result Over Maximum Contamination Limit(MCL)
D - Surrogate Recovery Unreportable due to Dilution
MI - Matrix Interference

HOUSTON LABORATORY
8880 INTERCHANGE DRIVE
HOUSTON, TX 77054
(713) 660-0901

Client Sample ID MW-6 **Collected:** 07/02/2003 12:20 **SPL Sample ID:** 03070239-06

Site: Midland, TX

Analyses/Method	Result	Rep.Limit		Dil. Factor	QUAL	Date Analyzed	Analyst	Seq. #
CHLORIDE, TOTAL			**MCL**	**E325.3**		**Units: mg/L**		
Chloride	46.5	1		1		07/10/03 11:00	RA	1761377
TOTAL DISSOLVED SOLIDS			**MCL**	**E160.1**		**Units: mg/L**		
Total Dissolved Solids (Residue,Filterable)	471	10		1		07/08/03 18:00	E_S	1758621

Qualifiers:

ND/U - Not Detected at the Reporting Limit
B - Analyte detected in the associated Method Blank
* - Surrogate Recovery Outside Advisable QC Limits
J - Estimated Value between MDL and PQL
>MCL - Result Over Maximum Contamination Limit(MCL)
D - Surrogate Recovery Unreportable due to Dilution
MI - Matrix Interference

Quality Control Documentation

HOUSTON LABORATORY
8880 INTERCHANGE DRIVE
HOUSTON, TX 77054
(713) 660-0901

Quality Control Report

Unocal Corporation

Former Unocal South Vacuum Unit

Analysis: Total Dissolved Solids
Method: E160.1
WorkOrder: 03070239
Lab Batch ID: R88990

Method Blank

RunID: WET_030708S-1758599 Units: mg/L
Analysis Date: 07/08/2003 18:00 Analyst: E_S

Samples in Analytical Batch:

Lab Sample ID	Client Sample ID
03070239-05A	MW-5

Analyte	Result	Rep Limit
Total Dissolved Solids (Residue,Filterable)	ND	10

Laboratory Control Sample (LCS)

RunID: WET_030708S-1758601 Units: mg/L
Analysis Date: 07/08/2003 18:00 Analyst: E_S

Analyte	Spike Added	Result	Percent Recovery	Lower Limit	Upper Limit
Total Dissolved Solids (Residue,Filtera	200	201	100	95	107

Sample Duplicate

Original Sample: 03070194-05
RunID: WET_030708S-1758602 Units: mg/L
Analysis Date: 07/08/2003 18:00 Analyst: E_S

Analyte	Sample Result	DUP Result	RPD	RPD Limit
Total Dissolved Solids (Residue,Filtera	ND	ND	0	20

Qualifiers:

ND/U - Not Detected at the Reporting Limit
B - Analyte detected in the associated Method Blank
J - Estimated value between MDL and PQL
MI - Matrix Interference
D - Recovery Unreportable due to Dilution
* - Recovery Outside Advisable QC Limits
N/C - Not Calculated - Sample concentration is greater than 4 times the amount of spike added. Control limits do not apply.

The percent recoveries for QC samples are correct as reported. Due to significant figures and rounding, the reported RPD may differ from the displayed RPD values but is correct as reported.

HOUSTON LABORATORY
8880 INTERCHANGE DRIVE
HOUSTON, TX 77054
(713) 660-0901

Quality Control Report

Unocal Corporation

Former Unocal South Vacuum Unit

Analysis: Total Dissolved Solids
Method: E160.1
WorkOrder: 03070239
Lab Batch ID: R88990A

Method Blank

RunID: WET_030708S-1758599 Units: mg/L
Analysis Date: 07/08/2003 18:00 Analyst: E_S

Analyte	Result	Rep Limit
Total Dissolved Solids (Residue,Filterable)	ND	10

Samples in Analytical Batch:

Lab Sample ID	Client Sample ID
03070239-01A	MW-1
03070239-02A	MW-2
03070239-03A	MW-3
03070239-04A	MW-4
03070239-06A	MW-6

Laboratory Control Sample (LCS)

RunID: WET_030708S-1758601 Units: mg/L
Analysis Date: 07/08/2003 18:00 Analyst: E_S

Analyte	Spike Added	Result	Percent Recovery	Lower Limit	Upper Limit
Total Dissolved Solids (Residue,Filtera	200	201	100	95	107

Sample Duplicate

Original Sample: 03070236-01
RunID: WET_030708S-1758613 Units: mg/L
Analysis Date: 07/08/2003 18:00 Analyst: E_S

Analyte	Sample Result	DUP Result	RPD	RPD Limit
Total Dissolved Solids (Residue,Filtera	19200	19320	1	20

Qualifiers:

ND/U - Not Detected at the Reporting Limit
B - Analyte detected in the associated Method Blank
J - Estimated value between MDL and PQL
MI - Matrix Interference
D - Recovery Unreportable due to Dilution
* - Recovery Outside Advisable QC Limits
N/C - Not Calculated - Sample concentration is greater than 4 times the amount of spike added. Control limits do not apply.

The percent recoveries for QC samples are correct as reported. Due to significant figures and rounding, the reported RPD may differ from the displayed RPD values but is correct as reported.

HOUSTON LABORATORY
8880 INTERCHANGE DRIVE
HOUSTON, TX 77054
(713) 660-0901

Quality Control Report

Unocal Corporation

Former Unocal South Vacuum Unit

Analysis: Chloride, Total
Method: E325.3
WorkOrder: 03070239
Lab Batch ID: R89135

Method Blank

RunID: WET_030710B-1761366 Units: mg/L
Analysis Date: 07/10/2003 11:00 Analyst: RA

Analyte	Result	Rep Limit
Chloride	ND	1.0

Samples in Analytical Batch:

Lab Sample ID	Client Sample ID
03070239-01A	MW-1
03070239-02A	MW-2
03070239-03A	MW-3
03070239-04A	MW-4
03070239-05A	MW-5
03070239-06A	MW-6

Laboratory Control Sample (LCS)

RunID: WET_030710B-1761368 Units: mg/L
Analysis Date: 07/10/2003 11:00 Analyst: RA

Analyte	Spike Added	Result	Percent Recovery	Lower Limit	Upper Limit
Chloride	233	232.3	100	90	110

Matrix Spike (MS) / Matrix Spike Duplicate (MSD)

Sample Spiked: 03070146-01
RunID: WET_030710B-1761370 Units: mg/L
Analysis Date: 07/10/2003 11:00 Analyst: RA

Analyte	Sample Result	MS Spike Added	MS Result	MS % Recovery	MSD Spike Added	MSD Result	MSD % Recovery	RPD	RPD Limit	Low Limit	High Limit
Chloride	42.88	50	94.69	103.6	50	94.69	103.6	0	20	85	115

Qualifiers:

ND/U - Not Detected at the Reporting Limit
B - Analyte detected in the associated Method Blank
J - Estimated value between MDL and PQL
N/C - Not Calculated - Sample concentration is greater than 4 times the amount of spike added. Control limits do not apply.
MI - Matrix Interference
D - Recovery Unreportable due to Dilution
* - Recovery Outside Advisable QC Limits

The percent recoveries for QC samples are correct as reported. Due to significant figures and rounding, the reported RPD may differ from the displayed RPD values but is correct as reported.

Sample Receipt Checklist

And

Chain of Custody

HOUSTON LABORATORY
8880 INTERCHANGE DRIVE
HOUSTON, TX 77054
(713) 660-0901

Sample Receipt Checklist

Workorder:	03070239	Received By:	R_R
Date and Time Received:	7/8/2003 9:30:00 AM	Carrier name:	FedEx
Temperature:	2	Chilled by:	Water Ice

1.	Shipping container/cooler in good condition?	Yes	☑	No	☐	Not Present ☐
2.	Custody seals intact on shippping container/cooler?	Yes	☑	No	☐	Not Present ☐
3.	Custody seals intact on sample bottles?	Yes	☐	No	☐	Not Present ☑
4.	Chain of custody present?	Yes	☑	No	☐	
5.	Chain of custody signed when relinquished and received?	Yes	☑	No	☐	
6.	Chain of custody agrees with sample labels?	Yes	☑	No	☐	
7.	Samples in proper container/bottle?	Yes	☑	No	☐	
8.	Sample containers intact?	Yes	☑	No	☐	
9.	Sufficient sample volume for indicated test?	Yes	☑	No	☐	
10.	All samples received within holding time?	Yes	☑	No	☐	
11.	Container/Temp Blank temperature in compliance?	Yes	☑	No	☐	
12.	Water - VOA vials have zero headspace?	Yes	☐	No	☐	Not Applicable ☑
13.	Water - pH acceptable upon receipt?	Yes	☐	No	☐	Not Applicable ☑

SPL Representative: **Contact Date & Time:**

Client Name Contacted:

Non Conformance Issues:

Client Instructions:

0307023

SPL Laboratories, Inc.

☐ 1511 East Orangethorpe Ave. Fullerton, CA 92631 (714) 447-6868 Fax:(714) 447-6800

☒ 8880 Interchange Drive Houston, Texas 77054 (713) 660-0901 Fax: (713) 660-8975

☐ 500 Ambassador Caffery Pkwy. Scott, Louisiana 70583 (318) 237-4775 Fax: (318) 237-7080

UNOCAL 76

Chain of Custody Record 10412

Company Name: Trident Environmental	Project Name: Former Unocal South Vacuum Unit
Address: PO Box 7624	UNOCAL Project Manager: Ben F. Terry
City: Midland State: Tx Zip Code: 79708-7624	AFE#: 8864-9924770-4675-64430
Telephone: 915-682-0008 FAX: 915-682-0727	Site #: 9924770
Report To: Gil VanDeventer Sampler: Gil Van Deventer	QC Data: ☒ Level D (Standard) ☐ Level C ☐ Level B ☐ Level A

Turnaround Time: (Calendar Days) ☒ 10 Days (Standard) ☐ 5 Days ☐ 3 Days ☐ 2 Days ☐ 1 Day

CODE: ☐ Misc. ☐ Detecl. ☐ Eval. ☐ Remed. ☐ Demol. ☐ Closure

☐ Drinking Water ☐ Waste Water ☒ Other

Analyses Requested

Client Sample I.D.	Date/Time Sampled	Matrix Desc.	# of Cont.	Cont. Type	Laboratory Sample #	Chloride (325.3)	TDS (160.1)	Comments
MW-1	7-2-03 1110	Water	1	P/500		X	X	
MW-2	7-2-03 0910	Water	1	P/500		X	X	
MW-3	7-2-03 1100	Water	1	P/500		X	X	
MW-4	7-2-03 1020	Water	1	P/500		X	X	
MW-5	7-2-03 1010	Water	1	P/500		X	X	
MW-6	7-2-03 1220	Water	1	P/500		X	X	

CS

Relinquished By:	Date: 7/3/03	Time: 1:52 pm	Received By:	Date: 7/3/03	Time: 1:52 pm
Relinquished By:	Date: 7/7/03	Time: 4:58 pm	Received By:	Date: 7-8-03	Time: 0930
Relinquished By:	Date:	Time:	Received By:	Date:	Time:

Were Samples Received in Good Condition? ☐ Yes ☐ No Samples on Ice? ☐ Yes ☐ No Method of Shipment _____ Page ____ of ____

2c

PINK - Client

YELLOW - Laboratory

WHITE - Laboratory

APPENDIX B

MONITORING WELL SAMPLING DATA FORMS

WELL SAMPLING DATA FORM

CLIENT: Unocal Corporation
WELL ID: **MW-1**
SITE NAME: Former Unocal S. Vacuum Unit
DATE: 7/2/03
PROJECT NO. V-107
SAMPLER: Van Deventer

PURGING METHOD: ☑ Hand Bailed ☐ Pump If Pump, Type: _____

SAMPLING METHOD: ☑ Disposable Bailer ☐ Direct from Discharge Hose ☐ Other: _____

DESCRIBE EQUIPMENT DECONTAMINATION METHOD BEFORE SAMPLING THE WELL:

☑ Gloves ☑ Alconox ☑ Distilled Water Rinse ☐ Other: _____

DISPOSAL METHOD OF PURGE WATER: ☐ Surface Discharge ☐ Drums ☑ Disposal Facility

TOTAL DEPTH OF WELL: 70.00 Feet
DEPTH TO WATER: 63.66 Feet
HEIGHT OF WATER COLUMN: 6.34 Feet
WELL DIAMETER: 2.0 Inch

3.1 *Minimum Gallons to purge 3 well volumes*

TIME	VOLUME PURGED	TEMP. °C / °F	COND. *m*S/cm	pH	DO mg/L	Turb	PHYSICAL APPEARANCE AND REMARKS
	2	79.0°F	2210	7.06			
	5	73.4°F	2090	6.99			
1110							Collected sample

COMMENTS: Sample collected at 1110, placed into 500 ml plastic container, and put on ice in cooler.
Parameters obtained using a Hydac Model 910 pH-Temperature-Conductivity meter.

WELL SAMPLING DATA FORM

CLIENT: Unocal Corporation
WELL ID: **MW-2**
SITE NAME: Former Unocal S. Vacuum Unit
DATE: 7/2/03
PROJECT NO. V-107
SAMPLER: Van Deventer

PURGING METHOD: ☑ Hand Bailed ☐ Pump If Pump, Type: _____

SAMPLING METHOD: ☑ Disposable Bailer ☐ Direct from Discharge Hose ☐ Other: _____

DESCRIBE EQUIPMENT DECONTAMINATION METHOD BEFORE SAMPLING THE WELL:

☑ Gloves ☑ Alconox ☑ Distilled Water Rinse ☐ Other: _____

DISPOSAL METHOD OF PURGE WATER: ☐ Surface Discharge ☐ Drums ☑ Disposal Facility

TOTAL DEPTH OF WELL: 71.00 Feet
DEPTH TO WATER: 50.63 Feet
HEIGHT OF WATER COLUMN: 20.37 Feet
WELL DIAMETER: 2.0 Inch

10.0 Minimum Gallons to purge 3 well volumes

TIME	VOLUME PURGED	TEMP. °C / °F	COND. *m*S/cm	pH	DO mg/L	Turb	PHYSICAL APPEARANCE AND REMARKS
	4	74.0°F	1014	8.37			
	10	73.2°F	1172	8.36			
0910							

COMMENTS: Sample collected at 0910, placed into 500 ml plastic container, and put on ice in cooler.

Parameters obtained using a Hydac Model 910 pH-Temperature-Conductivity meter.

WELL SAMPLING DATA FORM

CLIENT: Unocal Corporation
WELL ID: **MW-3**
SITE NAME: Former Unocal S. Vacuum Unit
DATE: 7/2/03
PROJECT NO. V-107
SAMPLER: Van Deventer

PURGING METHOD: ☑ Hand Bailed ☐ Pump If Pump, Type: _____

SAMPLING METHOD: ☑ Disposable Bailer ☐ Direct from Discharge Hose ☐ Other: _____

DESCRIBE EQUIPMENT DECONTAMINATION METHOD BEFORE SAMPLING THE WELL:

☑ Gloves ☑ Alconox ☑ Distilled Water Rinse ☐ Other: _____

DISPOSAL METHOD OF PURGE WATER: ☐ Surface Discharge ☐ Drums ☑ Disposal Facility

TOTAL DEPTH OF WELL: 77.00 Feet
DEPTH TO WATER: 67.94 Feet
HEIGHT OF WATER COLUMN: 9.06 Feet
WELL DIAMETER: 2.0 Inch

4.4 Minimum Gallons to purge 3 well volumes

TIME	VOLUME PURGED	TEMP. °C / °F	COND. *m*S/cm	pH	DO mg/L	Turb	PHYSICAL APPEARANCE AND REMARKS
	5	76.6°F	690	7.67			
1100							

COMMENTS: Sample collected at 1100, placed into 500 ml plastic container, and put on ice in cooler.
Parameters obtained using a Hydac Model 910 pH-Temperature-Conductivity meter.

WELL SAMPLING DATA FORM

CLIENT: Unocal Corporation
WELL ID: **MW-4**
SITE NAME: Former Unocal S. Vacuum Unit
DATE: 7/2/03
PROJECT NO. V-107
SAMPLER: Van Deventer

PURGING METHOD: ☑ Hand Bailed ☐ Pump If Pump, Type: _____

SAMPLING METHOD: ☑ Disposable Bailer ☐ Direct from Discharge Hose ☐ Other: _____

DESCRIBE EQUIPMENT DECONTAMINATION METHOD BEFORE SAMPLING THE WELL:

☑ Gloves ☑ Alconox ☑ Distilled Water Rinse ☐ Other: _____

DISPOSAL METHOD OF PURGE WATER: ☐ Surface Discharge ☐ Drums ☑ Disposal Facility

TOTAL DEPTH OF WELL: 71.00 Feet
DEPTH TO WATER: 61.34 Feet
HEIGHT OF WATER COLUMN: 9.66 Feet
WELL DIAMETER: 2.0 Inch

4.7 *Minimum Gallons to purge 3 well volumes*

TIME	VOLUME PURGED	TEMP. °C / °F	COND. *m*S/cm	pH	DO mg/L	Turb	PHYSICAL APPEARANCE AND REMARKS
	3	79.9°F	4110	7.53			
	6	75.2°F	3600	7.47			
1020							

COMMENTS: Sample collected at 1020, placed into 500 ml plastic container, and put on ice in cooler.
Parameters obtained using a Hydac Model 910 pH-Temperature-Conductivity meter.

WELL SAMPLING DATA FORM

CLIENT: Unocal Corporation
WELL ID: **MW-5**
SITE NAME: Former Unocal S. Vacuum Unit
DATE: 7/2/03
PROJECT NO. V-107
SAMPLER: Van Deventer

PURGING METHOD: ☑ Hand Bailed ☐ Pump If Pump, Type: _____

SAMPLING METHOD: ☑ Disposable Bailer ☐ Direct from Discharge Hose ☐ Other: _____

DESCRIBE EQUIPMENT DECONTAMINATION METHOD BEFORE SAMPLING THE WELL:

☑ Gloves ☑ Alconox ☑ Distilled Water Rinse ☐ Other: _____

DISPOSAL METHOD OF PURGE WATER: ☐ Surface Discharge ☐ Drums ☑ Disposal Facility

TOTAL DEPTH OF WELL: 75.00 Feet
DEPTH TO WATER: 69.32 Feet
HEIGHT OF WATER COLUMN: 5.68 Feet
WELL DIAMETER: 2.0 Inch

2.8 Minimum Gallons to purge 3 well volumes

TIME	VOLUME PURGED	TEMP. °C / °F	COND. *m*S/cm	pH	DO mg/L	Turb	PHYSICAL APPEARANCE AND REMARKS
	5	71.4°F	3600	7.60			
1010							

COMMENTS: Sample collected at 1010, placed into 500 ml plastic container, and put on ice in cooler.
Parameters obtained using a Hydac Model 910 pH-Temperature-Conductivity meter.

WELL SAMPLING DATA FORM

CLIENT: Unocal Corporation
WELL ID: **MW-6**
SITE NAME: Former Unocal S. Vacuum Unit
DATE: 7/2/03
PROJECT NO. V-107
SAMPLER: Van Deventer

PURGING METHOD: ☑ Hand Bailed ☐ Pump If Pump, Type: _____

SAMPLING METHOD: ☑ Disposable Bailer ☐ Direct from Discharge Hose ☐ Other: _____

DESCRIBE EQUIPMENT DECONTAMINATION METHOD BEFORE SAMPLING THE WELL:

☑ Gloves ☑ Alconox ☑ Distilled Water Rinse ☐ Other: _____

DISPOSAL METHOD OF PURGE WATER: ☐ Surface Discharge ☐ Drums ☑ Disposal Facility

TOTAL DEPTH OF WELL: 76.00 Feet
DEPTH TO WATER: 71.52 Feet
HEIGHT OF WATER COLUMN: 4.48 Feet
WELL DIAMETER: 2.0 Inch

2.2 Minimum Gallons to purge 3 well volumes

TIME	VOLUME PURGED	TEMP. °C / °F	COND. mS/cm	pH	DO mg/L	Turb	PHYSICAL APPEARANCE AND REMARKS
	2.5	73.1°F	51.3	7.39			
	5	73.0°F	51.0	7.51			
1220							

COMMENTS: Sample collected at 1220, placed into 500 ml plastic container, and put on ice in cooler.
Parameters obtained using a Hydac Model 910 pH-Temperature-Conductivity meter.

APPENDIX C

DESCRIPTION OF FATE AND TRANSPORT MODELING

Description of Fate and Transport Modeling

Conceptual Model

Produced water containing high concentrations of chloride, and resultant high levels of total dissolved solids (TDS), was reportedly discharged into a surface pit and adjoining injection well for a period of about 10 years, until the well was plugged and abandoned in1971. The chloride and TDS plume continued to migrate southeastwards for the next approximately 30 years after the source input was stopped, producing the configuration and constituent concentration distribution observed currently. Extrapolating from current conditions for decades into the future, taking account of both advective flow and attenuation by hydrodynamic dispersion, enables prediction of the probable distance that the residual plume will travel as well as the gradually declining concentrations in the plume.

Basic Site Data

Information about site conditions was obtained from data in a TRW Inc. "Report of Additional Groundwater Investigation, Former Unocal South Vacuum Unit, Lea County, New Mexico" (July 18, 2000). This included lithologic records from well installations, water level data, and water quality analytical results.

Simulation Model

Simulations were conducted with the two-dimensional groundwater flow and contaminant transport model WinTran, version 1.03 (1995) designed and distributed by Environmental Simulations, Inc. (ESI) of Herndon, Virginia. WinTran is built around a steady-state analytical element flow model, linked to a finite element contaminant transport model. The Windows interface allows for rapid data input, processing, parameter manipulation and optimization, and output in multiple formats. The fundamental mathematics of the model solutions, model verification (benchmarked against MODFLOW), and use of WinTran is documented in the "Guide to Using WinTran" published by ESI.

Base Map

A simplified site base map, edited with TurboCAD (Version 7), was exported to a universal drawing exchange file (DXF) file format. The DXF base map was imported into WinTran, which preserves the original units of measurement.

Flow Parameters

Input requirements for the steady-state groundwater flow simulation include: hydraulic gradient and direction of flow, hydraulic conductivity, aquifer top and bottom elevations, and reference head. The values used were based on the following sources:

- Hydraulic gradient – measured gradient of 0.004 feet/foot from July 2, 2003 site measurements reported by Trident.
- Direction of flow – measured direction of approximately S 40° E from July 2, 2003 site measurements reported by Trident.

- Hydraulic conductivity – no site measurements were available; therefore, a literature value based on the saturated zone lithology was selected. Typical lithology is described as silty sand and very fine sand. Fetter (1988, Table 4.5, p. 80) cites an average range of 10^{-5} to 10^{-3} cm/sec for hydraulic conductivity of silty sands and fine sands. A conservative upper limit was selected, and converted from S.I. unit to 2.8 ft/day, or approximately 1000 ft/yr.

- Aquifer top and bottom elevations – bottom elevation of Ogallala Formation at 3700 feet reported by Trident. The top elevation for an unconfined aquifer must be greater than the reference head. An elevation of 4000 feet was assumed.

- Reference head – measured unconfined head of 3795.5 feet adjacent to the former pit and upgradient well MW-1 from July 2003 measurements reported by Trident.

Transport Parameters

Input requirements for the contaminant transport numerical simulation include: longitudinal and transverse dispersivity, porosity, diffusion coefficient, contaminant half-life, and retardation coefficient. The values used were based on the following sources:

- Longitudinal and transverse dispersivity – no site measurements were available; therefore, a literature value based on the plume length was selected. Fetter (1993, Section 2.11, pp. 71-77) notes the apparent scale-dependency of longitudinal dispersivity, which typically may be about 0.1 times the flow length. For the current site scale and plume length of approximately 1500 feet, a value of 150 feet was selected for longitudinal dispersivity. According to the WinTran user's guide (ESI, 1995, p.11), longitudinal dispersivity is usually 5 to 10 times higher than transverse dispersivity; therefore, a value of 30 feet (i.e., one-fifth of the longitudinal value) was selected for transverse dispersivity.

- Porosity – no site measurements were available; therefore a literature value based on saturated zone lithology was selected. Typical lithology is described as silty sand and very fine sand. A range of 0.25 to 0.50 is typically given for unconsolidated "sand" (e.g., Freeze & Cherry, 1979, Table 2.4, p. 37); however, the Ogallala Formation is predominantly very fine grained, compacted and partly cemented, and may also fit within the range of 0.05 to 0.30 for sandstone. Fetter (1988, Table 4.3 and Figure 4.10, pp. 74-75) cites an average value of 0.20 for the specific yield of very fine sands. Specific retention of silty fine sand is approximately 0.05, for a total porosity of 0.25, which is the value selected for the transport modeling. WinTran uses the porosity term to estimate groundwater velocity, and actually requires an effective porosity value. Fetter (1988, Section 4.4, pp. 84-85) notes that pores of most sediments down to clay size are interconnected and that the effective porosity is virtually equal to the total porosity.

- Diffusion coefficient – this parameter is normally only relevant for very slow fluid movement, and is commonly assumed to be zero for advective-dominated transport, as in the present case.

- Contaminant half-life – this parameter accounts for chemical decay (e.g., radioisotopes, biological transformation of organic molecules); however, the species of interest in the present case are inorganic ions and are not expected to decay to any appreciable extent.

A conservative value of 1000 years was used, which produces a negligible decay coefficient of less than 0.001 yr^{-1}.

- Retardation coefficient – this parameter accounts for sorption processes that slow the movement of contaminants relative to the groundwater velocity. Inorganic ions such as chloride are commonly taken as conservative tracers in groundwater and are not considered to be retarded; therefore, a value of 1.0 was selected for the retardation coefficient.

Flow Model Calibration

The vicinity of the site where water level measurements were recorded in July 2, 2003 is simulated closely by the flow model. It is known that groundwater levels in the Ogallala Formation are decreasing slowly (less than 0.5 ft/yr), but this effect cannot be reproduced in the steady-state flow model. Water levels were probably somewhat higher than the present day during the period of brine disposal and initial transport. Even if the declining trend continues into the future, it does not affect the transport model solution for long extrapolation times, since sufficient saturated thickness remains (i.e., above the assumed aquifer base elevation of 3700 feet) for a valid flow and transport solution.

The average groundwater velocity may be estimated using the darcy expression: $v = (k \,.\, i) / n$ where k is the hydraulic conductivity (ft/yr), i is the hydraulic gradient (ft/foot), and n is the effective porosity (unitless). The resultant average velocity is 16 ft/yr.

Transport Model Calibration

The objective of the transport modeling was to first obtain a plume configuration with concentration values that closely match current observed values. This was done by simulating an initial contaminant release to groundwater for a period of 11 years (c. 1960 to 1971) with a constant source concentration located at the pit and injection well, then simulating a 28-year transport period (c. 1971 to 1999) with no further contaminant input but restarting the model from the end of Year 11 by retaining the mass of contaminant from the initial plume. The model was again run for 4 years (1999 to 2003) at one-year increments after entering in the known concentrations at each monitoring well. An iterative approach was needed to optimize the initial source concentration so that the plume at Year 39 resembled the actual plume conditions in 1999. An initial value of 14,000 mg/L for chloride and 30,000 mg/L for TDS were found to produce the best match. The initial chloride value was also chosen because it is typical of chloride concentrations within the producing formation (Devonian) in the South Vacuum Oil Field according to chemists at Martin Water Laboratories (verbal communication, 12-05-01). Actual disposal concentrations during the 1960s are unknown, and may have been higher than these values, but it is presumed that some attenuation and dilution may have occurred in the vadose zone, which is currently 48 to 68 feet thick. WinTran does not account for vadose zone transport, and the source input is treated as an injection well with instantaneous transfer of contaminant mass to groundwater.

Figures 7A and 7B show the close match achieved by the chloride and TDS simulations compared to the current observed plume.

Simulation of Fate and Transport

Estimation of chloride and TDS fate and transport was achieved by restarting the transport model from the end of Year 43 (2003) by retaining the distribution of contaminant mass and projecting for a further 50 years into the future. As depicted in Figures 8A and 8B, dispersion serves to broaden the dimensions of the plume while reducing the concentrations in the middle of the plume. Advective flow moves the center of plume mass downgradient by a distance of approximately 750 feet from the former source area (SWD pit) and approximately 300 feet upgradient from well MW-4.

Running the model for 160 years in the future (Year 2160) produces a chloride plume center concentration of 248 mg/L (below the WQCC standard of 250 mg/L) as shown in Figure 9A. The center of the chloride plume is approximately 3,460 ft away from the former pit and well source at that time.

Running the model for 93 years in the future (Year 2093) produces a TDS plume center concentration of 995 mg/L (below the WQCC standard of 1,000 mg/L) as shown in Figure 9B. The center of the TDS plume is approximately 2,100 ft away from the pit and well source at that time.

These results support the contention that the chloride and TDS plume is not likely to impact any existing sources of water supply, the closest of which is a windmill (NM File No. L05339) approximately 3,000 feet south of the source.

The trend of decreasing concentration is not linear (exponential e^{-kt} function). Interestingly, the center of the plume moves at a greater rate (22 feet/year) over successive time intervals than would be assumed from the groundwater velocity alone (16 feet/year), due to the added effect of dispersion.