1R - 277

REPORTS

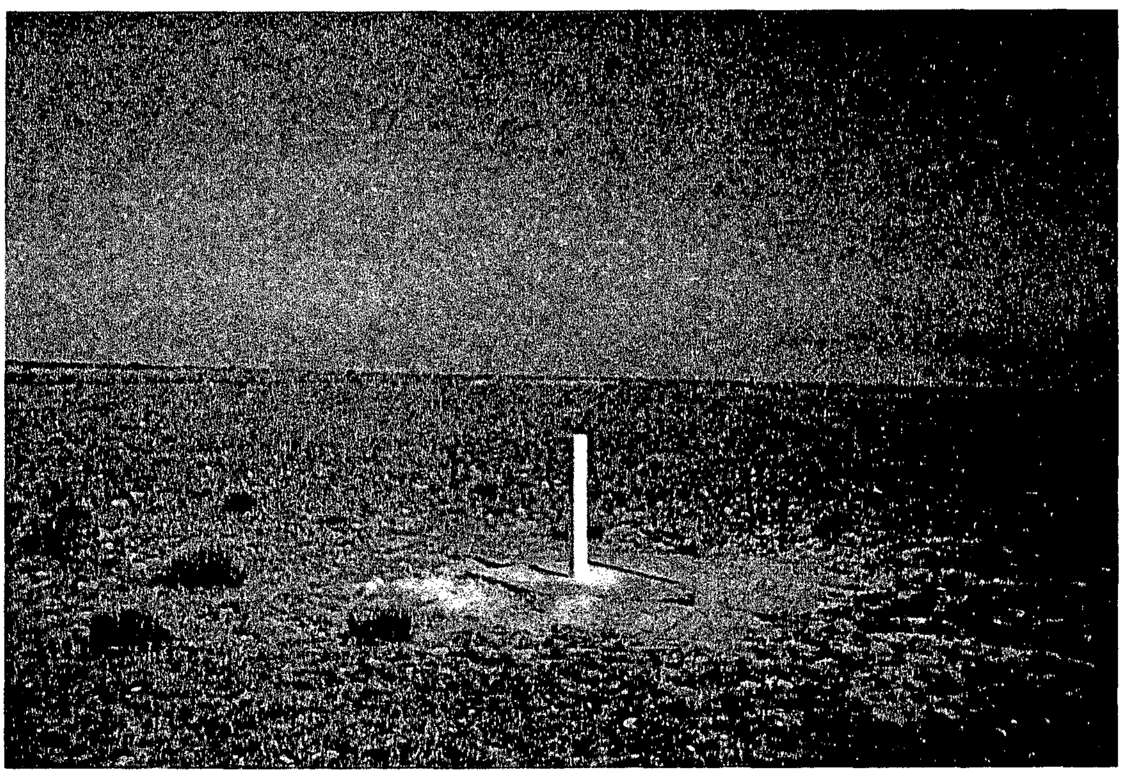
DATE:
2000

UNOCAL CORPORATION
GROUNDWATER REMEDIATION PLAN
FORMER UNOCAL SOUTH VACUUM UNIT
LEA COUNTY, NEW MEXICO

NOVEMBER 2, 2000

Prepared For:

Unocal Corporation
Asset Management Group
P. O. Box 1283
Nederland, Texas 77627



TRW

IR0277

TRW Systems & Information Technology Group
415 West Wall Street, Suite 1818
Midland, TX 79701

November 2, 2000

Mr. William C. Olson
New Mexico Energy, Minerals and Natural Resources Department
Oil Conservation Division
2040 S. Pacheco
Santa Fe, New Mexico 87505

RE: GROUNDWATER REMEDIATION PLAN
FORMER UNOCAL SOUTH VACUUM UNIT
LEA COUNTY, NEW MEXICO

Dear Mr. Olson:

TRW Inc. – Energy & Environmental Systems (TRW), on behalf of the Asset Management Group of Unocal Corporation (Unocal), is submitting this Groundwater Remediation Plan for the former Unocal South Vacuum Unit in Lea County, New Mexico. The purpose of this plan is to demonstrate the attainment of the abatement standards for chlorides and total dissolved solids (TDS) and requirements set forth in OCD Rule 19.B. This plan provides information which supports a natural attenuation strategy with annual groundwater monitoring to provide assurance that contaminants are not presenting a risk to human health and the environment. The included groundwater fate and transport modeling results and the low risk to potential receptors support a natural attenuation monitoring program.

Site Background and History

The South Vacuum Unit site is located in the SW¼ of the SW¼ (Unit M) of section 36, Township 18 South, and Range 35 East (Figure 1). An emergency overflow pit used for surface impoundment of produced water was located adjacent to a former saltwater disposal (SWD) well at the site. According to OCD records at the Hobbs District office, the State Lea "I" SWD well was initially completed as a dry hole and was plugged and abandoned by the Pure Oil Company, predecessor of Unocal, on June 1, 1960. The dry hole was re-entered and completed as a SWD well on September 22, 1962. The State Lea "I" SWD well was plugged and abandoned on April 5, 1971. In situ solidification of the adjacent SWD emergency overflow pit was completed on January 22, 1995 by Allstate Services. Between January 25, 1995, and June 12, 2000, three phases of groundwater investigation activities included the installation and sampling of six monitoring wells (MW-1 through MW-6) by TRW. The constituents of concern in the groundwater on site include chlorides and TDS, as they are the only known constituents to exceed the New Mexico Water Quality Control Commission (WQCC) standards. A summary of groundwater analytical results is provided in Table 1. The affected property is owned by the State of New Mexico.

TRW

Table 1
Summary of Groundwater Analytical Results

Monitoring Well	Sample Date	Chloride (mg/L)	TDS (mg/L)	Benzene (mg/L)	Toluene (mg/L)	Ethylbenzene (mg/L)	Xylenes (mg/L)
MW-1	01/27/95	**1174**	**2250**	< 0.001	< 0.001	< 0.001	< 0.001
	05/18/95	**983**	**2251**	NA	NA	NA	NA
	08/28/96	**1420**	**2730**	NA	NA	NA	NA
	08/13/97	**1400**	**2800**	NA	NA	NA	NA
	09/30/99	**1400**	**2400**	NA	NA	NA	NA
	06/14/00	**1094**	**2318**	NA	NA	NA	NA
		927	**2040**	< 0.001	< 0.001	< 0.001	< 0.001
MW-2	09/30/99	**298**	922	NA	NA	NA	NA
	06/14/00	**317**	852	< 0.001	< 0.001	< 0.001	< 0.001
MW-3	09/30/99	73.6	427	NA	NA	NA	NA
	06/14/00	75.5	433	< 0.001	< 0.001	< 0.001	< 0.001
MW-4	09/30/99	**1576**	**2981**	NA	NA	NA	NA
	06/14/00	**1500**	**2910**	< 0.001	< 0.001	< 0.001	< 0.001
MW-5	06/14/00	13.7	274	< 0.001	< 0.001	< 0.001	< 0.001
MW-6	06/14/00	48	382	< 0.001	< 0.001	< 0.001	< 0.001
WQCC Standards		250	1000	0.010	0.75	0.75	0.62

Total dissolved Solids (TDS), chloride, and BTEX concentrations listed in milligrams per liter (mg/L)
Analyses performed by Trace Analysis Inc., Lubbock, TX (1995-1998) and SPL Inc., Houston, TX (1999-2000).
Values in boldface type indicate concentrations exceed New Mexico Water Quality Control Commission (WQCC) standards.
NA indicates not analyzed for this constituent.

Hydrogeology

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). The southwestern limit of the Ogallala formation is approximately one mile south of the site.

The lithology of the subsurface soils in monitoring wells MW-1 through MW-6 is similar. Generally, the unsaturated zone is composed of a hard, weathered and fractured, light gray caliche layer to a depth of approximately 10 to 20 feet. Below the caliche layer, a tan to light gray siliceous sandstone layer interbedded with a fine-grained silty sand was encountered to a depth of approximately 27 feet; however the fine-grained silty sand layer gradually became more dominant with depth and the sandstone layers occurred as intermittent stringers to the bottom of the borings.

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 85 to 95 feet. Depth to groundwater varies from approximately 47 to 67 feet below ground surface at the site. The groundwater gradient direction is to the southeast with a hydraulic gradient of approximately 0.004 ft/ft.

The groundwater table in Lea County has been declining at the rate of approximately 0.5 to 1 foot per year for the past few decades and has no recharge (personal communication with Johnny Hernandez, Basin Supervisor, New Mexico Office of the State Engineer). Thus, the Ogallala aquifer in the site area has a maximum expected lifetime of approximately 100 years.

Potential Receptors

The nearest potential receptor is a stock water well (windmill) located approximately 3,000 feet south of the site (Section 1, T19S, R35E) as depicted in Figure 1. Based on a well data report obtained from the New Mexico Office of the State Engineer website (Attachment A), this well (State File No. L 05339) was completed to a depth of 128 feet by Hollands Water Well Service in 1964. The well has a reported water depth of 83 feet. Unocal collected a water sample from this well on January 16, 1995 for analysis of major ions by Martin Water Laboratories, Inc. The analysis (Attachment B) reported a chloride and TDS concentration of 43 mg/L and 460 mg/L, respectively. No other known potential groundwater receptors are located within a mile of the site with the exception of an oilfield water supply well (L 03945) located approximately 4,200 feet east-southeast of the site. This well is not considered a potential receptor since it is not directly downgradient from the site and the water is used for industrial (non-drinking) purposes.

Current use of groundwater in the site area is for oilfield water supply and livestock watering. Groundwater is not currently being used for human consumption or irrigation.

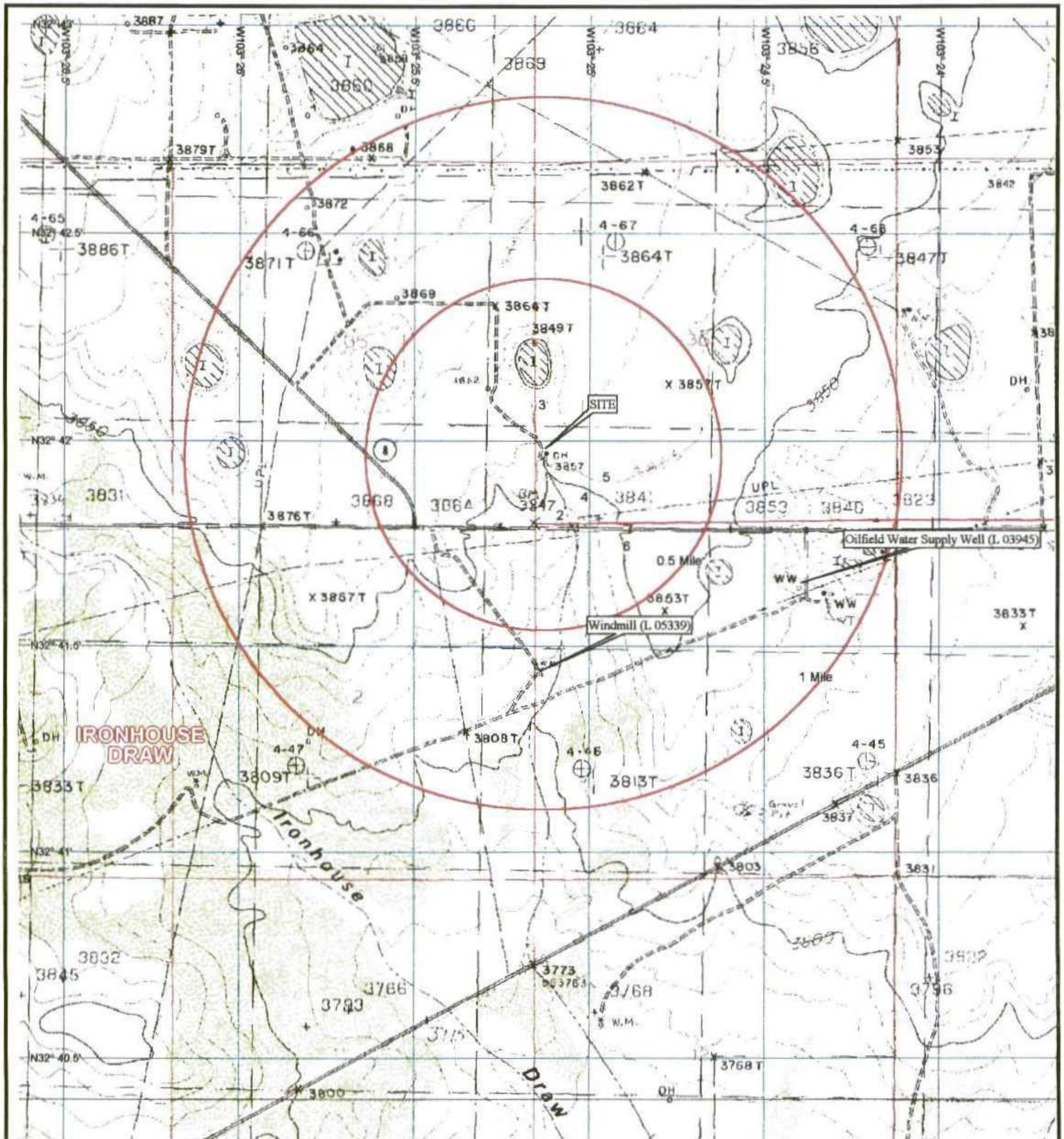
Fate and Transport Modeling Results

Fate and transport modeling was performed by TRW to simulate the movement of the chloride and TDS groundwater plume over time. 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. A more detailed discussion of the flow and transport parameters used, assumptions, model calibrations, and simulation results are described in Attachment C.

Figures 2A and 2B show the initial plume simulation at the end of 10 years' contaminant discharge (c. 1971). Figures 3A and 3B show the close match achieved by the chloride and TDS simulations compared to the current observed plume.

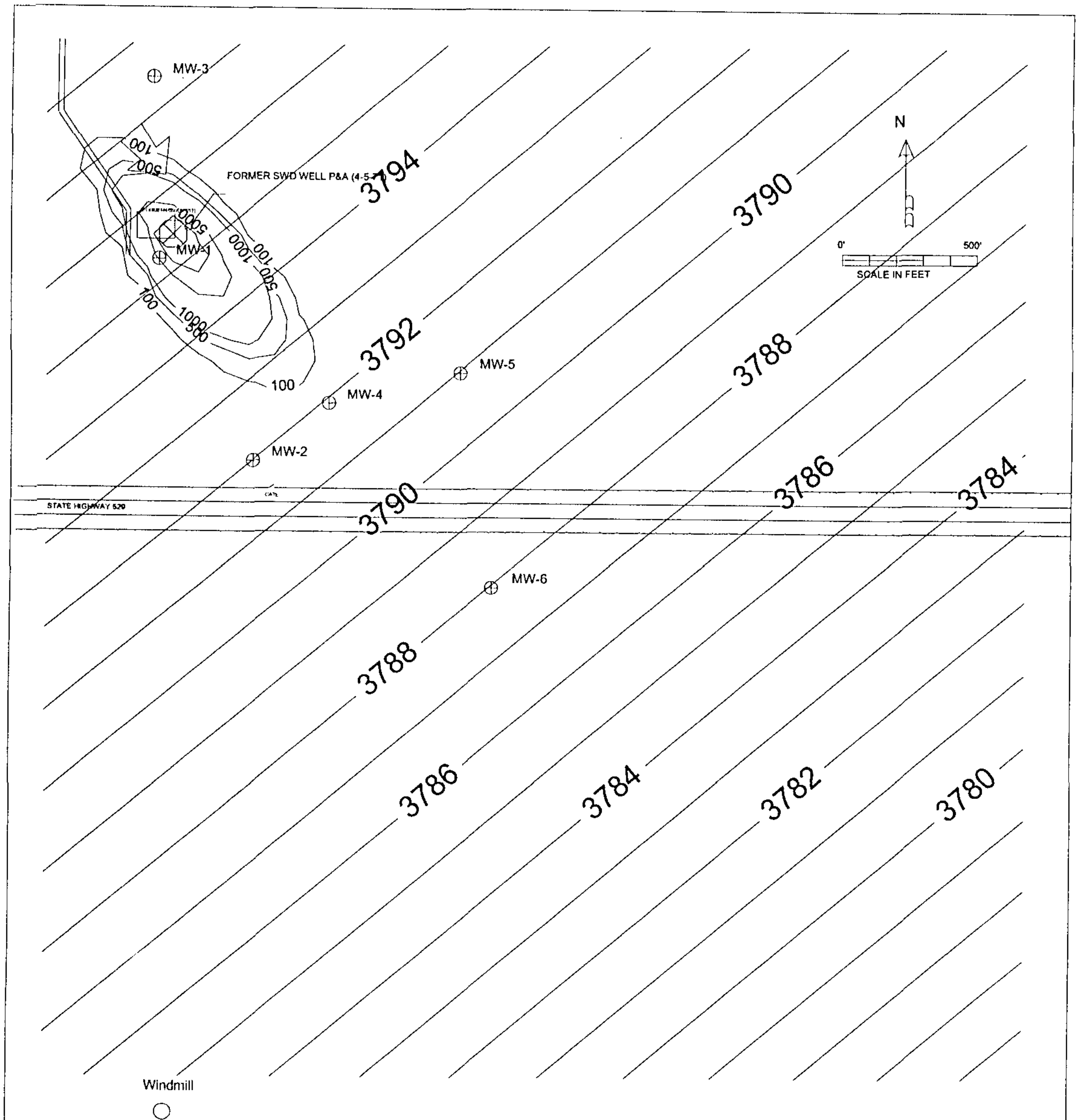
Dispersion serves to broaden the dimensions of the plume while reducing the concentrations in the middle of the plume, as depicted in Figures 4A and 4B (50 years from now). Advective flow moves the center of plume mass downgradient by a distance of approximately 800 feet from an initial current position just upgradient from well MW-4. Successive attenuation and dispersion of the plume after another 50 years is shown in Figures 5A and 5B (that is, a total of 100 years into the future). Time steps on the figures indicate the center of plume mass will have moved approximately 1,600 feet southeast of its current location by the end of the next century.

C:\A-PROJECTS\SOUTH VACUUM\TOPOMAP.XLS



Source Data: USGS Ironhorse Draw Quadrangle Topographic Map
3D TopoQuads Copyright 1999 DeLorme Yarmouth, ME 04096

TRW					FIGURE 1
	SITE:	Former Unocal South Vacuum Unit			
	DATE:	10/26/00	REV. NO.:	1	
	AUTHOR:	GJV	DRN BY:	GJV	SITE LOCATION MAP
	CK'D BY:	DTL	SCALE:	1" = 2000'	

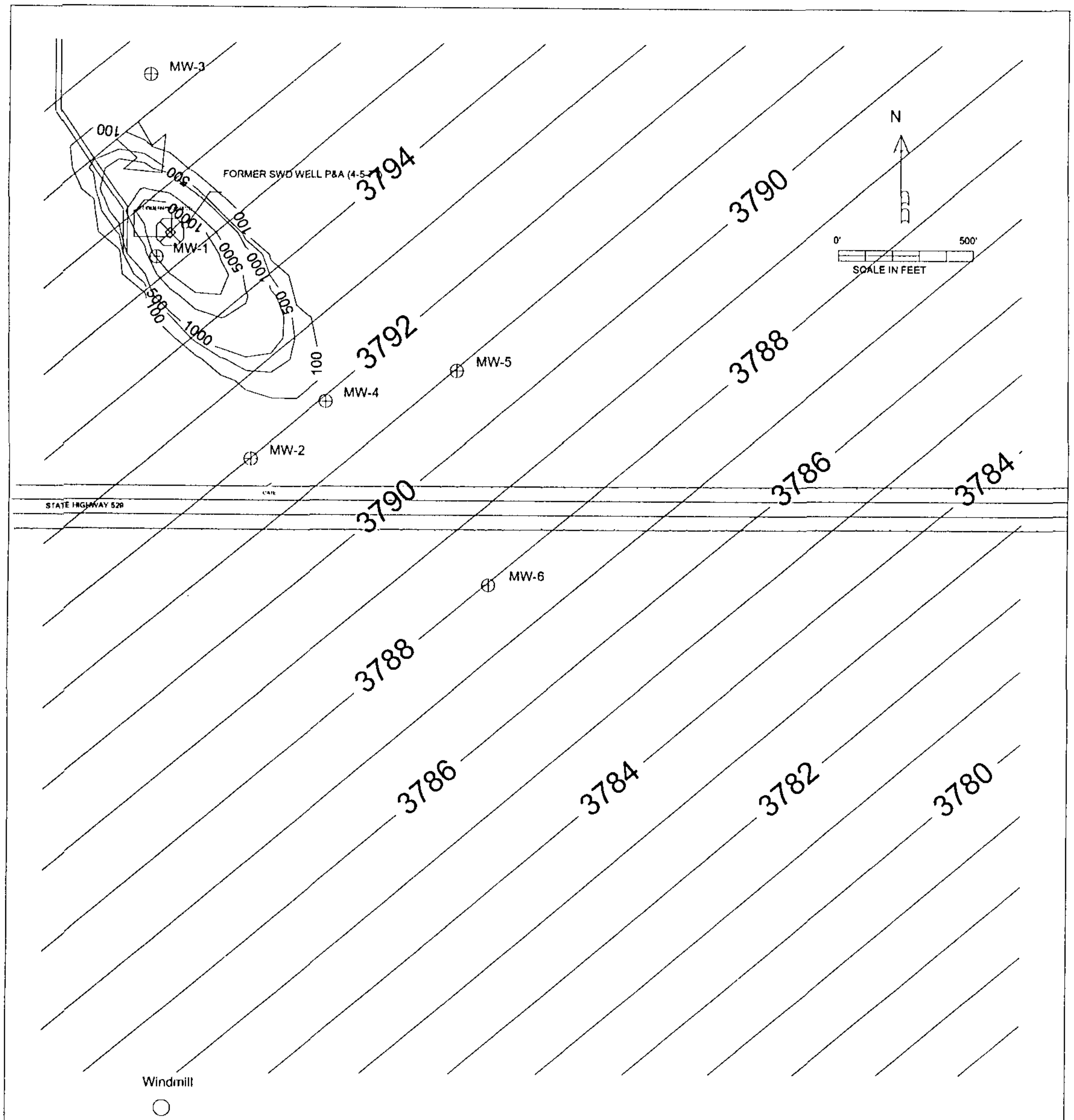


Assumed Source Concentration = 30,000 mg/L

k = 1000 ft/yr, n = 0.25, hyd.grad. = 0.004 S40E

dispL = 150 ft, dispT = 30 ft, R = 1.0

SITE: UNOCAL SOUTH VACUUM UNIT		FIGURE 2A
DATE: 06/14/00	REV. NO.: 102300	10-YEAR CHLORIDE
AUTHOR: GJV	DRN BY: GJV, MPC	SIMULATION (1960 - 1970)
CK'D BY: DTL	FILE: VACUUM1.DWG	FOR INITIAL PLUME

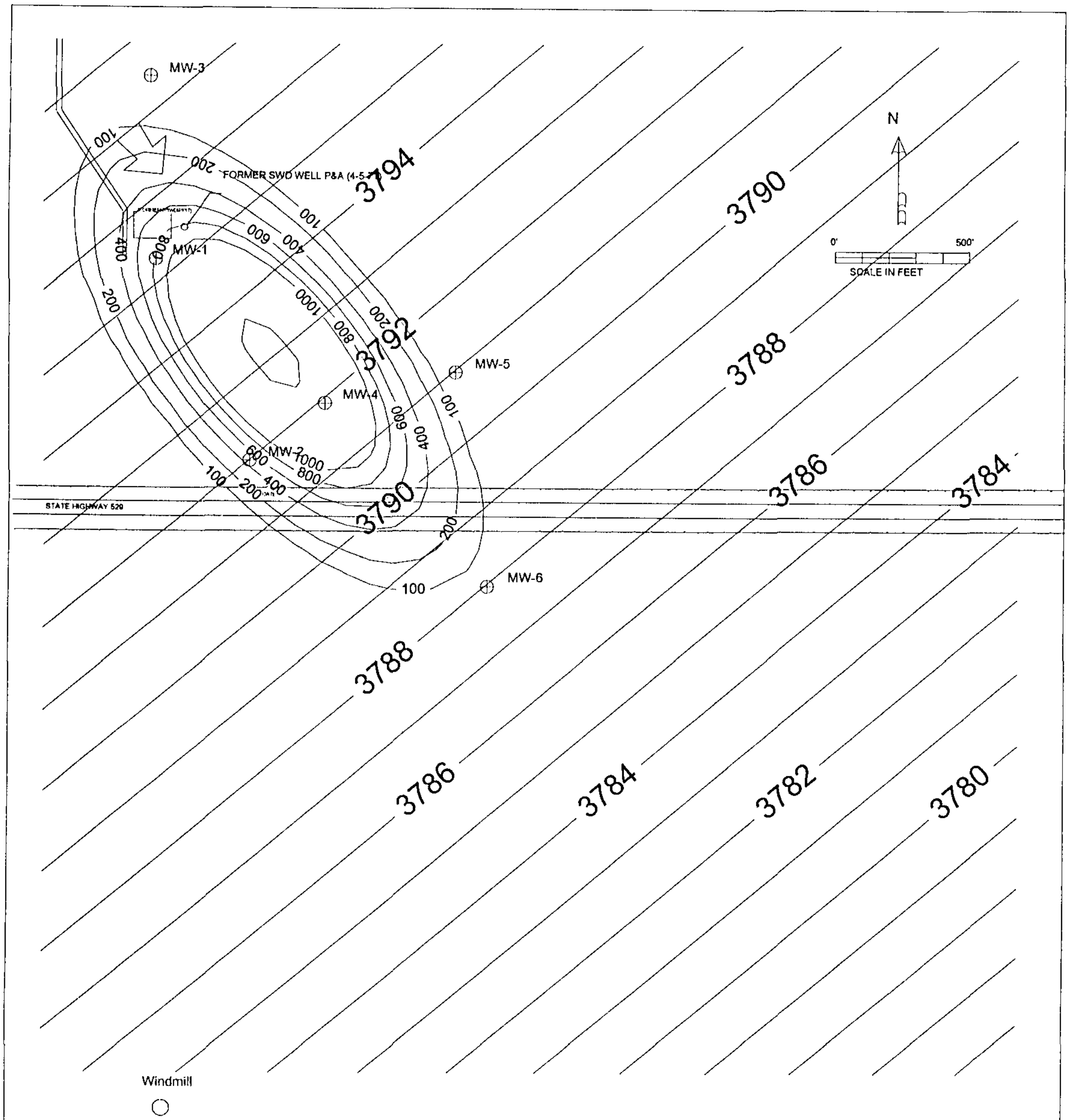


Assumed Source Concentration = 60,000 mg/L

k = 1000 ft/yr, n = 0.25, hyd.grad. = 0.004 S40E

dispL = 150 ft, dispT = 30 ft, R = 1.0

SITE: UNOCAL SOUTH VACUUM UNIT		FIGURE 2B 10-YEAR TDS SIMULATION (1960 - 1970) FOR INITIAL PLUME
DATE: 06/14/00	REV. NO.: 102300	
AUTHOR: GJV	DRN BY: GJV, MPC	
CK'D BY: DTL	FILE: VACUUM1.DWG	

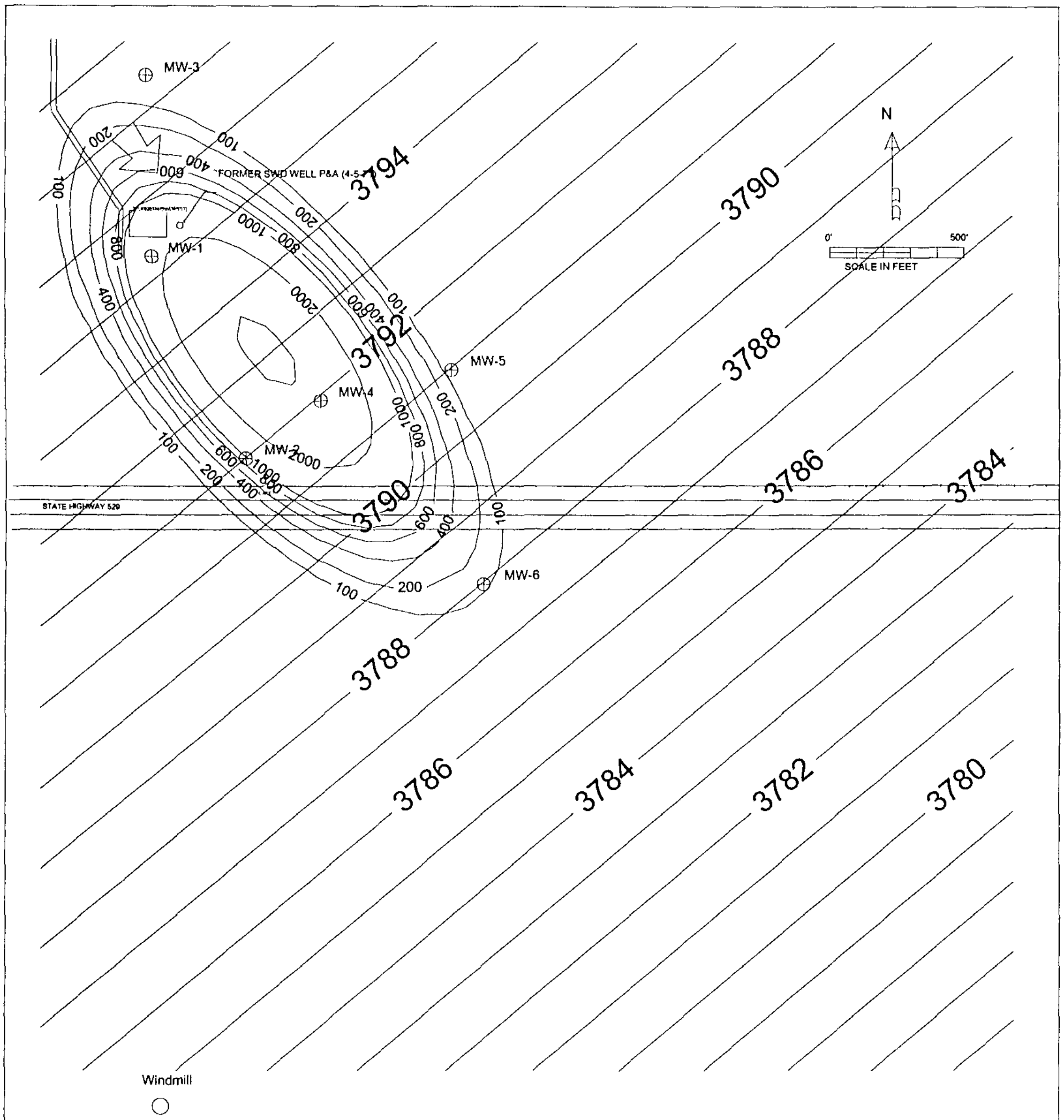


Plume Dispersion and Transport

k = 1000 ft/yr, n = 0.25, hyd.grad. = 0.004 S40E

dispL = 150 ft, dispT = 30 ft, R = 1.0

SITE: UNOCAL SOUTH VACUUM UNIT		FIGURE 3A
DATE: 06/14/00	REV. NO.: 102300	30-YEAR CHLORIDE
AUTHOR: GJV	DRN BY: GJV, MPC	SIMULATION (1970 - 2000)
CK'D BY: DTL	FILE: VACUUM1.DWG	AFTER WELL ABANDONMENT

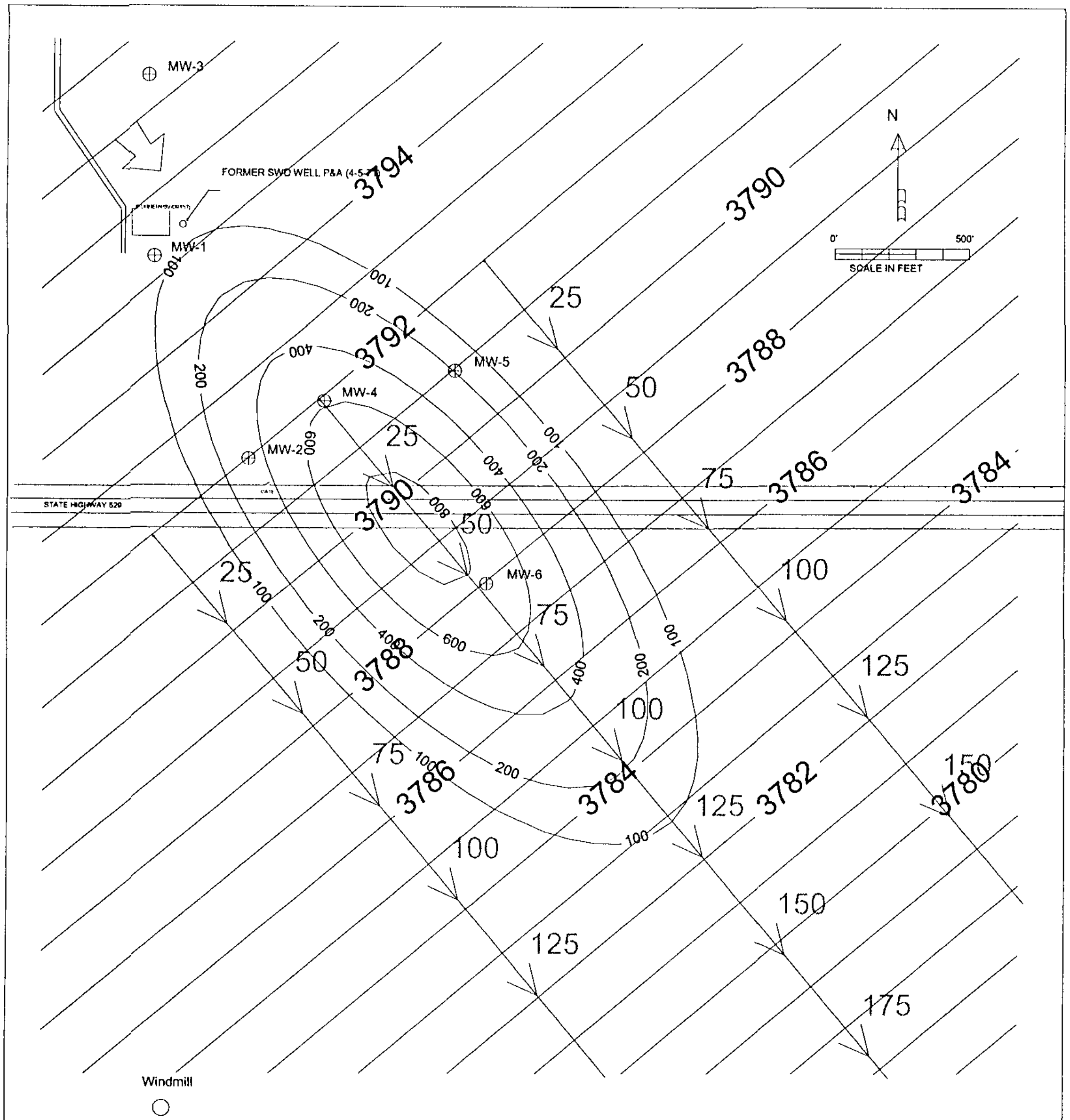


Plume Dispersion and Transport

k = 1000 ft/yr, n = 0.25, hyd.grad. = 0.004 S40E

dispL = 150 ft, dispT = 30 ft, R = 1.0

TRW	SITE: UNOCAL SOUTH VACUUM UNIT		FIGURE 3B
	DATE: 06/14/00	REV. NO.: 102300	30-YEAR TDS
	AUTHOR: GJV	DRN BY: GJV, MPC	SIMULATION (1970 - 2000)
	CK'D BY: DTL	FILE: VACUUM1.DWG	AFTER WELL ABANDONMENT

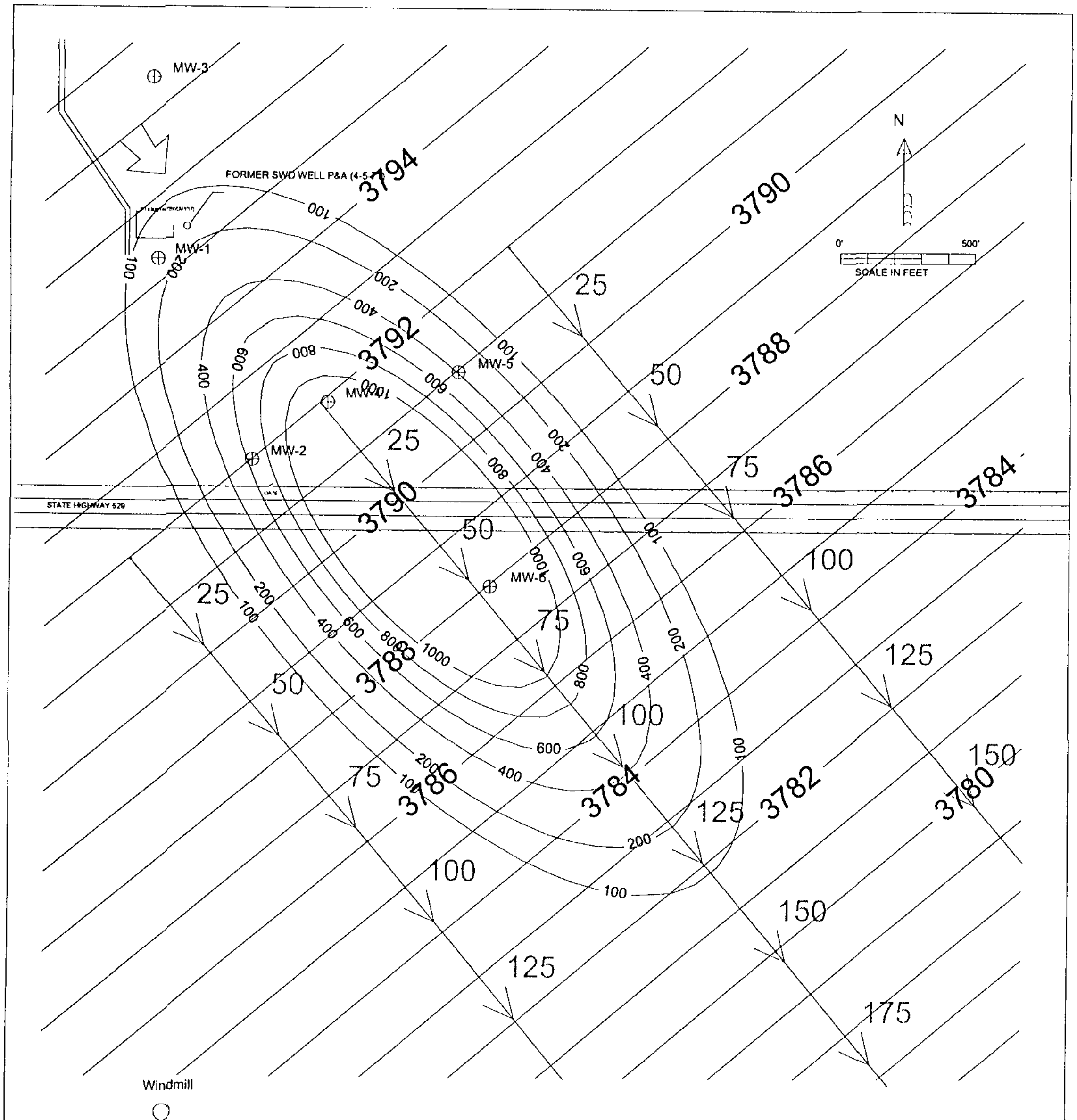


Plume Dispersion and Transport

k = 1000 ft/yr, n = 0.25, hyd.grad. = 0.004 S40E

dispL = 150 ft, dispT = 30 ft, R = 1.0

TRW	SITE: UNOCAL SOUTH VACUUM UNIT		FIGURE 4A 50-YEAR CHLORIDE SIMULATION (2000 - 2050) FROM CURRENT CONDITION
	DATE: 06/14/00	REV. NO.: 102300	
	AUTHOR: GJV	DRN BY: GJV, MPC	
	CK'D BY: DTL	FILE: VACUUM1.DWG	

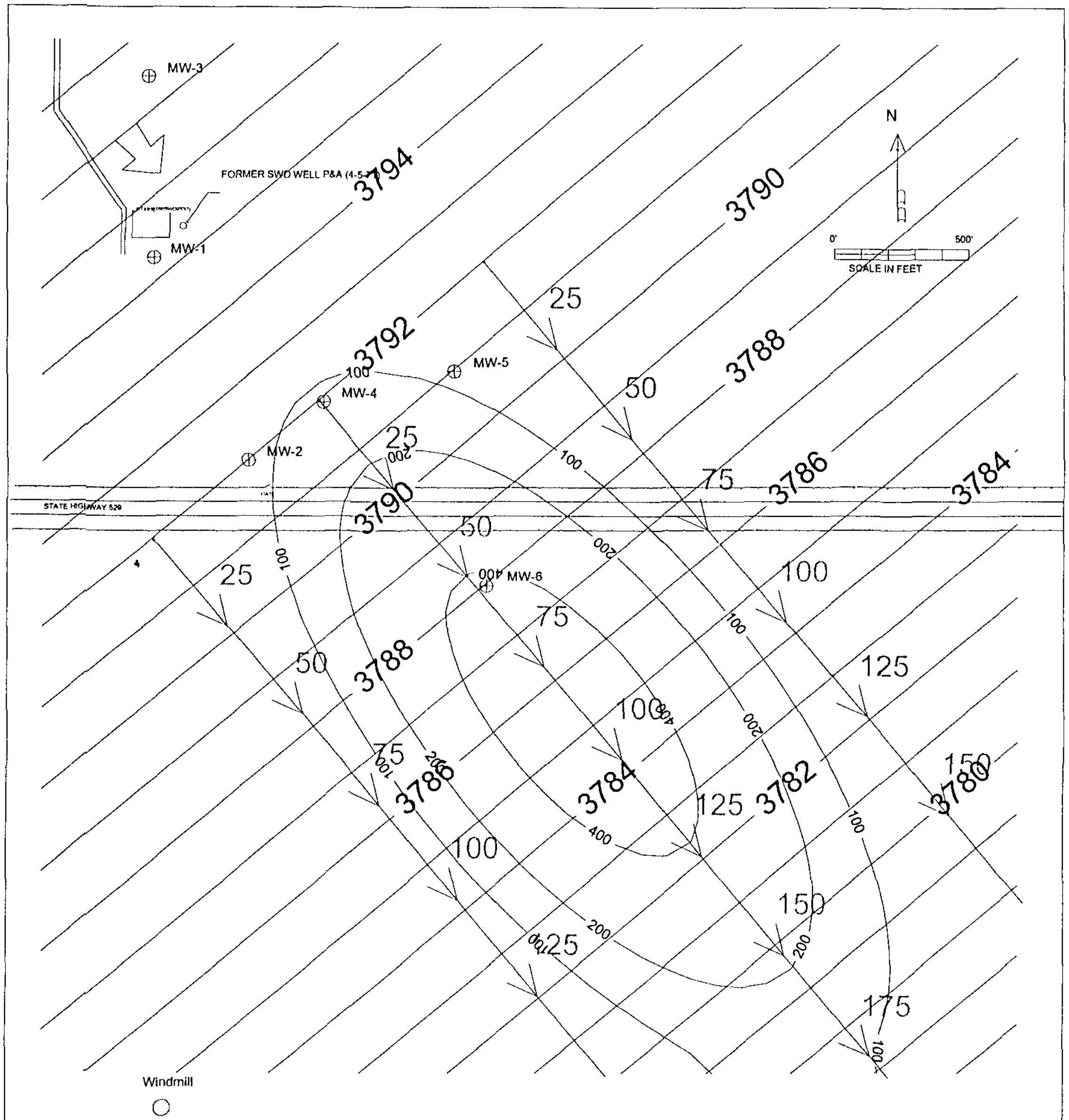


Plume Dispersion and Transport

k = 1000 ft/yr, n = 0.25, hyd.grad. = 0.004 S40E

dispL = 150 ft, dispT = 30 ft, R = 1.0

TRW	SITE: UNOCAL SOUTH VACUUM UNIT		FIGURE 4B
	DATE: 06/14/00	REV. NO.: 102300	50-YEAR TDS
	AUTHOR: GJV	DRN BY: GJV, MPC	SIMULATION (2000 - 2050)
	CK'D BY: DTL	FILE: VACUUM1.DWG	FROM CURRENT CONDITION

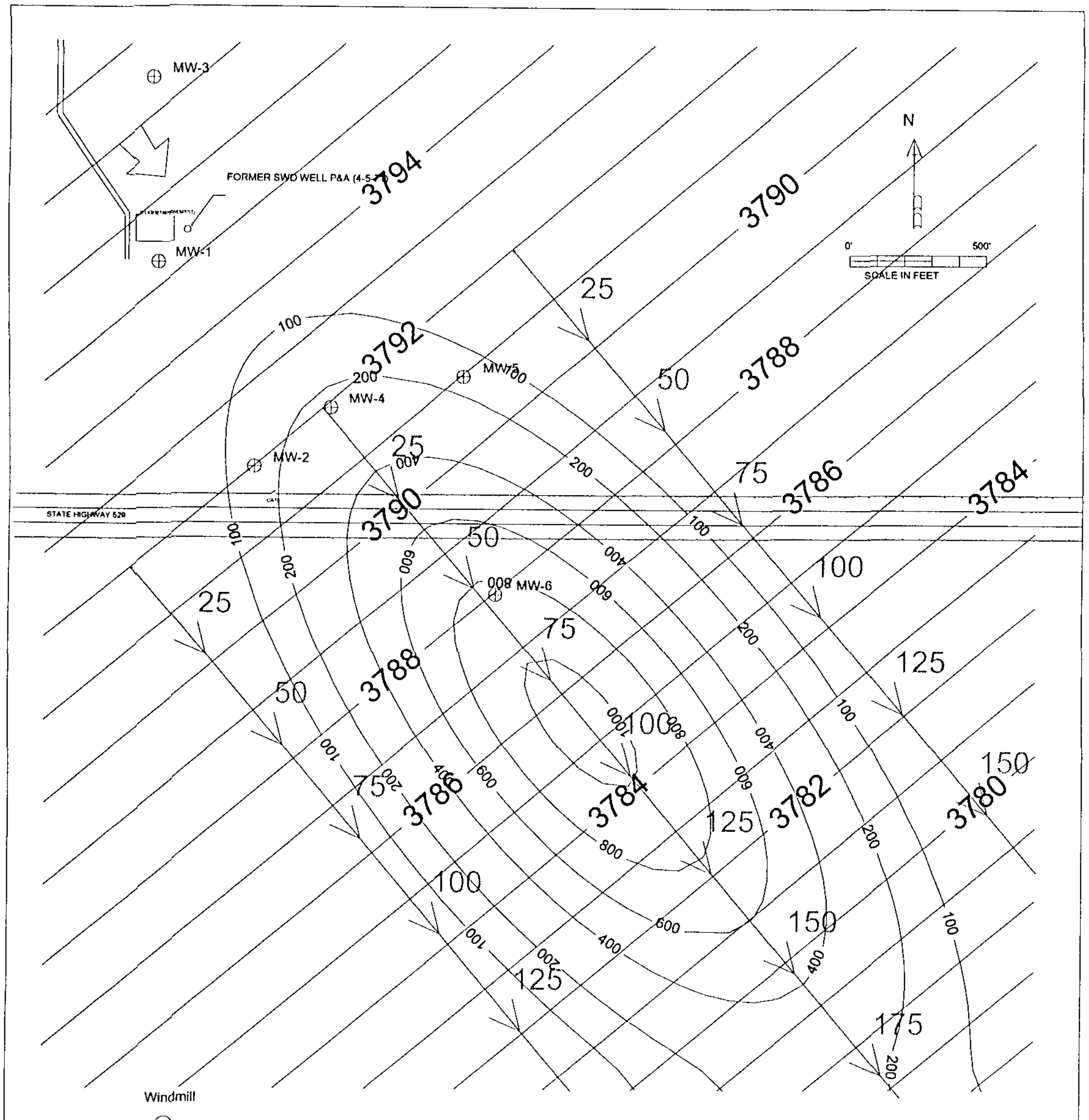


Plume Dispersion and Transport

k = 1000 ft/yr, n = 0.25, hyd.grad. = 0.004 S40E

dispL = 150 ft, dispT = 30 ft, R = 1.0

TRW	SITE: UNOCAL SOUTH VACUUM UNIT		FIGURE 5A
	DATE: 06/14/00	REV. NO.: 102300	100-YEAR CHLORIDE
	AUTHOR: GJV	DRN BY: GJV, MPC	SIMULATION (2000 - 2100)
	CK'D BY: DTL	FILE: VACUUM1.DWG	FROM CURRENT CONDITION



Plume Dispersion and Transport

k = 1000 ft/yr, n = 0.25, hyd.grad. = 0.004 S40E

dispL = 150 ft, dispT = 30 ft, R = 1.0

SITE: UNOCAL SOUTH VACUUM UNIT		FIGURE 5B
DATE: 06/14/00	REV. NO.: 102300	100-YEAR TDS
AUTHOR: GJV	DRN BY: GJV, MPC	SIMULATION (2000 - 2100)
CK'D BY: DTL	FILE: VACUUM1.DWG	FROM CURRENT CONDITION

TRW

Conclusions

The results of the groundwater fate and transport modeling at the former Unocal South Vacuum Unit are summarized as follows:

- Although the groundwater within the chloride and TDS plume may not be desirable for human consumption, it is suitable for agricultural and industrial use.
- Only one potential receptor has been identified, a windmill located 3,000 feet south of the site. The windmill is used for stock water and not for human consumption.
- The fate and transport modeling results support the contention that the chloride and TDS plume is not likely to impact existing sources of water supply, the closest of which, a stock well, lies approximately 3,000 feet south of the source.
- According to conservative model simulations, the chloride plume will travel a maximum of 5,400 feet southeast of the source in approximately 240 years before concentrations return to levels below the WQCC standard of 250 mg/L. The same analysis indicates that the TDS plume will travel only 2,500 feet in approximately 110 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 stock well exceed WQCC standards for chlorides or TDS due to the plume originating from the former emergency overflow pit.

Recommendations

Based on the identified potential receptor and fate and transport modeling results there is low risk to human health and the environment; therefore TRW recommends the following actions for site closure:

- Implement a natural attenuation monitoring program with two years of annual groundwater sampling and analysis of chloride and TDS concentrations for each of the six monitoring wells.
- After each year of monitoring, recalibrate flow and transport model to confirm the plume is naturally attenuating as described in this groundwater remediation plan.
- Submit annual monitoring reports to OCD to document natural attenuation conditions.
- If, after 2 years of monitoring, the plume is naturally attenuating as described, request no further action from OCD.

TRW

Unocal is prepared to proceed with the proposed natural attenuation program as recommended by TRW in this groundwater remediation plan upon approval from the OCD. Please contact Ben Terry at (409) 724-3291 with any questions or comments.

Sincerely,

Gilbert J. Van Deventer, REM

Attachments

xc: Ben Terry, Unocal – Houston, TX
Kevin Behrens, IT Group – Houston, TX
Donna Williams, OCD - Hobbs, NM

C:\A-PROJECTS\SOUTH VACUUM\VACUUM3A

ATTACHMENTS

ATTACHMENT A

NEW MEXICO OFFICE OF THE STATE ENGINEER

AVERAGE DEPTH OF WATER REPORT AND

POINT OF DIVERSION FOR NEAREST POTENTIAL RECEPTOR

New Mexico Office of the State Engineer
Well Reports and Downloads

AVERAGE DEPTH OF WATER REPORT 10/25/2000

Bsn	Tws	Rng	Sec	Zone	X	Y	Wells	(Depth Water in Feet) Min	Max	Avg
L	18S	35E	02				1	51	51	51
L	18S	35E	03				1	62	62	62
L	18S	35E	04				3	50	70	60
L	18S	35E	05				4	60	75	69
L	18S	35E	06				4	60	110	88
L	18S	35E	07				5	75	95	85
L	18S	35E	09				1	72	72	72
L	18S	35E	10				1	49	49	49
L	18S	35E	11				1	48	48	48
L	18S	35E	13				1	135	135	135
L	18S	35E	14				1	90	90	90
L	18S	35E	16				2	65	84	75
L	18S	35E	17				3	90	150	115
L	18S	35E	18				1	90	90	90
L	18S	35E	19				1	70	70	70
L	18S	35E	21				1	60	60	60
L	18S	35E	22				3	65	95	78
L	18S	35E	23				1	78	78	78
L	18S	35E	26				2	60	60	60
L	18S	35E	27				2	65	70	68
L	18S	35E	29				1	95	95	95
L	18S	35E	32				1	58	58	58
L	18S	35E	33				1	80	80	80
L	18S	35E	35				2	55	60	58
L	19S	35E	01				2	70	83	77
L	19S	35E	04				1	70	70	70
L	19S	35E	05				3	55	85	65
L	19S	35E	06				2	55	60	58
L	19S	35E	07				3	45	60	53
L	19S	35E	10				1	53	53	53
L	19S	35E	14				1	27	27	27
L	19S	35E	15				3	18	40	29
L	19S	35E	17				1	30	30	30
L	19S	35E	22				1	27	27	27

New Mexico Office of the State Engineer
Point of Diversion Summary

Back Windmill located ≈ 3,000 feet south of site

POD Number	Tws	Rng	Sec	q q q	Zone	X	Y
L 05339	19S	35E	01				

Driller Licence:
Driller Name: HOLLANDS WATER WELLL SERVICE
Source: Shallow
Drill Start Date: 01/27/1964
Drill Finish Date: 02/01/1964
Log File Date: 02/13/1964
PCW Received Date:
Pump Type:
Pipe Discharge Size:
Casing Size:
Estimated Yield:
Depth Well: 128
Depth Water: 83

New Mexico Office of the State Engineer
Point of Diversion Summary

Back Oilfield supply well located approximately 0.8 miles east-southeast of site

POD Number	Tws	Rng	Sec	q q q	Zone	X	Y
L 03945 APPRO	19S	35E	01	2 2 3			

Driller Licence: 46 ABBOTT BROS.
Driller Name:
Source: Shallow
Drill Start Date: 07/29/1958
Drill Finish Date: 07/29/1958
Log File Date: 08/06/1958
PCW Received Date:
Pump Type:
Pipe Discharge Size:
Casing Size:
Estimated Yield:
Depth Well: 125
Depth Water: 70

ATTACHMENT B

WATER ANALYSIS

TAKEN FROM WINDMILL

P. O. BOX 1468
MONAHANS, TEXAS 79756
PH. 943-3234 OR 563-1040

Martin Water Laboratories, Inc.

709 W. INDIANA
MIDLAND, TEXAS 79701
PHONE 683-4521

RESULT OF WATER ANALYSES

LABORATORY NO. 19597
SAMPLE RECEIVED 1-16-95
RESULTS REPORTED 1-18-95

TO: Mr. Jim Mason
P. O. Box 671, Midland, TX 79702

COMPANY Union Oil Company of California LEASE South Vacuum Unit
FIELD OR POOL South Vacuum
SECTION ____ BLOCK ____ SURVEY ____ COUNTY Lea STATE NM
SOURCE OF SAMPLE AND DATE TAKEN:
NO. 1 Raw water - taken from windmill. 1-16-95
NO. 2
NO. 3
NO. 4
REMARKS:

CHEMICAL AND PHYSICAL PROPERTIES

	NO. 1	NO. 2	NO. 3	NO. 4
Specific Gravity at 60° F.	1.0015			
pH When Sampled				
pH When Received	7.28			
Bicarbonate as HCO_3	234			
Supersaturation as $CaCO_3$				
Undersaturation as $CaCO_3$				
Total Hardness as $CaCO_3$	236			
Calcium as Ca	88			
Magnesium as Mg	4			
Sodium and/or Potassium	34			
Sulfate as SO_4	56			
Chloride as Cl	43			
Iron as Fe	0.04			
Barium as Ba				
Turbidity, Electric				
Color as Pt				
Total Solids, Calculated	460			
Temperature °F				
Carbon Dioxide, Calculated				
Dissolved Oxygen,				
Hydrogen Sulfide	0.0			
Resistivity, ohms/m at 77° F.	19.50			
Suspended Oil				
Filtrable Solids as mg/l				
Volume Filtered, ml				
Nitrate, as N	2.7			

Results Reported As Milligrams Per Liter

Additional Determinations And Remarks The undersigned certifies the above to be true and correct to the best of his knowledge and belief.

Form No. 3

By Waylan C. Martin, M.A.

ATTACHMENT 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 the emergency overflow pit and adjoining injection well for a period of about 10 years, until the well was plugged and abandoned in the early 1970s. 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 AutoCAD, 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 June 2000 site measurements reported by TRW.

- Direction of flow – measured direction of approximately S 40° E from June 2000 site measurements reported by TRW.

- 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 TRW. 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 3797 feet adjacent to the former pit and upgradient well MW-3 from June 2000 measurements reported by TRW.

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 < 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 June 2000 is simulated closely by the flow model. It is known that groundwater levels in the Ogallala Formation are decreasing slowly (approximately 0.5 to 1 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.

Flow lines with 25-year time steps show the distance that water moves perpendicular to the equipotential lines. The average groundwater velocity may be estimated using the darcy expression: $v = (k \cdot i) / n$ 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 10 years (c. 1960 to 1970) with a constant source concentration located at the pit and injection well, then simulating a 30-year transport period (c. 1970 to 2000) with no further contaminant input but restarting the model from the end of Year 10 by retaining the mass of contaminant from the initial plume. An iterative approach was needed to optimize the initial source concentration so that the plume at Year 40 resembled the current actual plume. Ultimately, values of 30,000 mg/L for chloride and 60,000 mg/L for TDS were found to produce the best match. 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 47 to 67 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 2A and 2B show the initial plume simulation at the end of 10 years' contaminant discharge. Figures 3A and 3B 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 40 by retaining the distribution of contaminant mass and projecting for a further 50 and 100 years into the future. As depicted in Figures 4A and 4B, 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 800 feet from an initial current position just upgradient from well MW-4. Successive attenuation and dispersion of the plume after another 50 years is shown in Figures 5A and 5B (i.e., a total of 100 years into the future).

Time steps on the figures indicate the center of plume mass will have moved approximately 1,600 feet southeast of its current location by the end of the next century. Running the model for 110 years in the future (Year 2110) produces a TDS plume center concentration of 976 mg/L (below the WQCC standard of 1,000 mg/L). The center of the TDS plume is 2,500 ft away from the pit and well source at that time. Chloride was more difficult to estimate because the plume ran off the edge of the map grid area before the center concentration dropped enough. Therefore, a series of steps from Year 2100 to Year 2190 was used to establish the trend, and time was extrapolated until the center value reached 250 mg/L. The trend of decreasing concentration is not linear (exponential e^{-kt} function). The best estimate for compliance of chloride (center of plume less than 250 mg/L) after about 240 years in the future, at which time the plume center would be about 5,400 ft away from the source. Interestingly, the center of the plume moves at a slightly greater rate (20 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.