GW - 4

WORK PLANS

Chromate Remediation Pilot Study Work Plan

ChevronTexaco
Eunice, New Mexico

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June 18, 2003

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ChevronTexaco Exploration & Production

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Chromate Remediation Pilot Study Work Plan

ChevronTexaco
Eunice, New Mexico

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Our Ref.:
MT000700.0005.00002

Date:
June 18, 2003

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Introduction

ChevronTexaco Exploration and Production Inc. (ChevronTexaco) has retained ARCADIS G&M (ARCADIS) to conduct remedial activities at the Eunice #2 (North) Gas Plant (Site). The purpose of this work plan is to define the implementation of a series of field scale pilot tests for chromate remediation. This includes the initial structure of the test with regards to layout, injection program, and monitoring.

The use of injectable soluble carbon substrates for the remediation of chromate impacted groundwater at the Eunice facility must take into account the effects of the following site-specific factors:

- Hydrogeology at the macro and micro scale.Geochemistry of the groundwater and mineral matrix.
- Microbial consortia present in the subsurface and the dynamic processes that can be stimulated in them.

The most efficient design and implementation of a remediation program requires accommodation for the above conditions. When the size of the impacted area is large the most economic and accurate method to gather data concerning the three key characteristics is to perform field scale pilot tests. This work plan describes how the pilot tests will be conducted.

Background and Site Location

The site was constructed in the 1940's, subsequently modified and currently operates as a compressor station. The site is located approximately 0.25 miles north of Eunice, New Mexico, in the southeast quarter (SE/4), of the northeast quarter (NE/4), and the NE/4 of the SE/4, Section 21, Township 21 South, and Range 37 East. Figure 1 presents a site location map and Figure 2 presents a site plan map, with structures, water wells and groundwater monitoring wells.

Geologic Setting

The plant site lies within the Eunice Plain, which extends north and south from the Texas-New Mexico state line to midway between Hobbs and Eunice. It extends east and west from the Texas-New Mexico state line to the San Simon Ridge, west of Eunice about 20 miles. The geologic formations of interest at the site include from oldest to youngest, the Triassic Chinle, Cretaceous undifferentiated, Tertiary Ogallala and Quaternary alluvium, designated the Blackwater Draw formation. Of particular interest with regard to the impact of a chromate release to groundwater are the Tertiary Ogallala and Quaternary alluvium.

Resting directly upon an erosional surface carved into the Triassic Chinle formation under the site, the Tertiary Ogallala formation is composed of a heterogeneous combination of clay, silt, sand and gravel. The fluvial sediments were deposited on a sloping plain in the form of coalescing alluvial fans, by streams that originated in the Rocky Mountains to the west and northwest. The Ogallala was deposited in laterally restricted lenses of material, predominantly medium to yellowish-gray conglomeratic sandstone and fine to medium-grained well sorted sandstone. The primary fresh water bearing formation under and in the vicinity of the plant site is the Ogallala formation.

In contrast to the fluvial deposition of the lower Ogallala sediments, the upper part of the Ogallala (and all of the Blackwater Draw formation overlying the Ogallala) are windblown deposits.

The Blackwater Draw formation occurs near the surface at the plant site. It contains reddish sediments composed of up to six well-developed buried soils with similar features of lithology and morphology. It has been determined that the Blackwater Draw formation was deposited during the Quaternary time period. Throughout the depositional time of the Blackwater Draw Formation, laterally restricted lenticular patterns of eolian and playa or lacustrine facies were formed. The soil development occurred during periods of landscape stability, separated by intermittent periods of deposition, or by deflation that stripped surface horizons from newly developed soils.

Site Specific Hydrology

The lowest geologic unit described in site investigations is a firm red silty clay. Overlying this is a 5 to 10 foot interval of gravel/sand/clay, which is the deep water-bearing zone at the site. The gravel unit is in turn overlain by a red to yellow sand that exhibits strong vertical heterogeneity with alternating layers of loose and well-lithified sand. This is the unit that contains the shallow water-bearing zone. Wells screened in the gravel unit have 40 to 50 feet of hydraulic head. Wells screened in the shallow water-bearing zone have screens that intersect the groundwater table and typically have 10 to 15 feet of saturation. Overall depth to groundwater varies roughly with local topography and ranges from 38 to 72 feet below the surface. Groundwater gradients in the shallow water-bearing zone are relatively flat. The groundwater gradient in the vicinity of the site is shown on Figure 3.

The primary aquifer containing fresh water at the site is contained in the Ogallala formation. (The groundwater in the area may extend close enough to the land surface to reside in the eolian portion of the upper Ogallala, but lies below the Blackwater Draw Formation.) The water contained in the Ogallala is technically under unconfined conditions. However, if a well is screened in the lower portion of the aquifer and is subjected to a short (generally less than 72 hour) pump test, the test data indicates confined storage coefficients. This is due to the poor vertical to horizontal permeabilities, and the lenticular nature of the deposition of the sediments.

Within the Ogallala, it has been found that the poor vertical and horizontal permeability from releases at the plant site has resulted in a wide difference in the occurrence of the chromium in the groundwater from releases at the plant site. The shallow and deep groundwater isoconcentrations for hexavalent chromium are shown on Figures 4 and 5, respectively. The shallow zone of the water bearing unit is comprised of the shallow and a middle zone. For purposes of this remediation, the shallow zone is treated as a single unit. The chromium plume is of much smaller areal extent in the deep portion of the aquifer than in the shallowest portion of the aquifer. This is the result of the poor vertical permeability, as well as the poor horizontal permeability that appears to occur in the lower portion of the aquifer. Based on pumping tests conducted in the shallow and the deep zones of the aquifer, the groundwater velocity is almost 100 times greater in the shallow zone than in the deep zone, 23 to 33 ft/yr and 0.4 to 0.5 ft/yr respectively.

The hydraulic gradient (and the elevation of the water levels) in the shallow and deep zones are quite similar, indicating that there is hydraulic conductivity between the zones (Figure 3). In fact, when the pumping tests were conducted on both the shallow and deep zones, even though there were not any observed responses in the other zone during testing, the middle zone between the shallow and deep zones reflected the pumping of the separate individual shallow and deep zones.

As discussed above, the shallow and deep zones reflect similar water level elevations and hydraulic gradients, exhibiting a hydraulic high in the potentiometric surface southeast of the plant. The hydraulic gradient from this hydraulic high is to the southwest, west, northwest, north and northeast. The high is very likely due to the importation of water from outside the area of Eunice (from the Hobbs area), and the infiltration of return flow from park and residential lawn irrigation. Many cities in the arid southwest such as Midland and Lubbock demonstrate this mounding water table in the shallow aquifers beneath the parks and residential areas. This mounding alters the regional southeast hydraulic gradient that has been documented in the Eunice area in the past. This phenomenon will have to be considered in any remediation efforts conducted at the site that will be dependant on the local hydraulic gradient.

In Situ Chromate Remediation

Remediation at the site is currently taking place via natural attenuation processes that remove both petroleum hydrocarbons and chromate. In areas were chromate and petroleum hydrocarbon impacts intermix, chromate has been removed by biochemical reduction driven by reactions with the petroleum hydrocarbon constituents. Chromate is also removed to a lesser degree by reaction with limited concentrations of native organic carbon, and limited concentrations of reducing inorganic constituents such as ferrous iron.

In the case of the chromate, in situ biological stimulation will be utilized to convert Cr^{+6} to insoluble and innocuous Cr^{+3}, exploiting some processes that are unique to the biological systems as well as processes more akin to those utilized for the treatment of chromate laden industrial waste water.

Remediation of groundwater impacted with chromate will be implemented by the use of injection wells through which reagents will be introduced to stimulate biological activity that will cause the reduction of Cr^{+6} to insoluble Cr^{+3} by primary and secondary processes. The primary reagents will be soluble carbon substrates that will serve to stimulate biological activity, that will in turn produce low redox conditions. A variety of carbon substrates are available for use. Molasses and other soluble sugars are quick reacting, rapidly establishing the desired reducing conditions. Other carbon substrates, such as whey, offer similar reaction chemistry, but in a slow release form. Other materials have even slower reaction chemistry allowing increased active life in the aquifer and increased transport distances from individual injection.

Chromate reduction will also take place by reaction with reduced inorganic species produced as a by-product of the stimulated primary bacterial activity. The dominant inorganic species produced by this process will be ferrous iron, with lesser concentrations of sulfides. Both can be produced by microbial action on iron and sulfate containing minerals in the native mineral matrix. Additional sources of reducing iron and sulfur species will naturally reside in the carbon substrates utilized, particularly in molasses. In the areas of the chromate plume that are the most distal from the injection points, the stimulated chromate reducing reactions are likely to be dominated by the presence of these reduced inorganic species. In some cases the economics offered by an enhanced radius of influence may justify the use of intentional supplementation of the injected carbon substrate with soluble iron or sulfate salts. The efficacy of iron as an inorganic reducing agent is particularly high for this type of application. When the ferrous iron reacts with chromate to form the Cr^{+3} species it is oxidized to ferric iron. The ferric iron in the presence of a soluble carbon substrate is in turn biologically reduced to ferrous iron, beginning the chromate remediation cycle anew. This process works with great efficiency and significantly minimizes the requirement for supplemental inorganic reagents.

Configuration of the Field Pilot Study

The physical key to the injection program is the design and location of the injection well arrays. It is possible that four distinct vertical zones of injection will be required. One is likely to be sufficient for the upper and middle zones of the Ogallala Sand.

The implementation of the injection system for the underlying clayey gravel unit is likely to be more complex. This unit is relatively thin, with a typical thickness of ten to fifteen feet. At its bottom it is in unconformable contact with Triassic clays and silts, at its top it is in contact with the Ogallala Sand. It is not uncommon in units of this type, with high permeability contrasts, for there to be zones of preferential transport at the contact. The pumping tests performed to date indicate that the hydraulic conductivity of the clayey gravel is approximately three orders of magnitude less than that of the overlying Ogallala Sand. While no direct testing has been done, it is likely that the hydraulic conductivity of the Triassic clays and silts is at least another three orders of magnitude less than that of the clayey gravel. With such contrasts in hydraulic conductivity, it may be necessary to have injection wells that are discretely screened at either the upper or lower contacts of the clayey gravel, discreetly across the core of the clayey gravel, or (the simplest option if possible) with a continuous screen across the lower contact, the vertical extent of the clayey gravel layer, and its upper contact.

The site assessment has shown a distribution of chromate within lower clayey gravel unit that is not possible (given the time frames of the release and groundwater velocities that are in the range of 0.1 foot per year) assuming that transport has simply been horizontally through the interior of the unit. It is most likely that transport has taken place through secondary porosity that vertically transects the clayey gravel unit. The ideal injection program will be designed to naturally exploit these features, if present. This would consist of a focus for the injection of the reactive solutions along the lower and upper contact. With sufficient volumes and reagent concentrations, secondary porosity could be exploited. In addition, high chemical concentration gradients will stimulate high rates of diffusion and osmotic flow (possible because of the clay constituents) into the interior.

The pilot evaluation of the injection of soluble carbon substrates for in-situ remediation of soluble chromate must include determination of key design parameters that fall into general categories, as well as, specific issues within each. These include:

- The hydrodynamics of the water bearing zones to be treated.
    - The magnitude of lateral dispersion as injection solutions are carried away from an injection point.
    - The impact of vertical and horizontal heterogeneity under pressure injection conditions.
    - The possible impact of hydraulic gradients induced by proximal extraction wells or water flood injection wells.
- The impact of the injected carbon substrates on the biogeochemical state of the treatment zones and ultimate efficacy of chromate remediation.
    - How long will it take to create oxidation reduction potential (ORP) conditions that are at a minimum iron reducing?
    - Will the rate of chromate reduction vary with continued decreases of ORP, the use of supplemental iron, or type of carbon substrate?
        - What is the most cost effective approach (taking into account reagent costs versus duration of effort)?
- The transport properties of the carbon substrate.
    - The rate of carbon substrate consumption under relatively static flow conditions.
        - This is driven by the rate at which the indigenous bacterial populations can grow given stimulation.
    - The rate of carbon substrate consumption under flowing conditions.
        - This is driven by the above, as well as the effective porosity of the treatment zone, and the existing bacterial population numbers.
- The effect of the chemistry of the carbon substrate on the rate of biological utilization.

- It must be sufficiently bioactive to stimulate the required ORP conditions given the local groundwater velocity.
- It should not be so bioactive that it is consumed within a short distance from the injection point.
- The attenuation rates of chromate under treatment conditions and the geochemical parameters which will govern the reduction of soluble hexavalent chromium to the insoluble trivalent form.

The answers to the above issues are in many cases interrelated. A pilot study is by definition a largely empirical process that is designed to cost effectively yield the design parameters required given the complexity of the inter-related processes described above. The injection arrays are located and screened to exploit these physical chemical processes using an iterative process that evaluates the effect of injection wells as they are installed and operated.

Injection and Monitor Well Layout

The complex water-bearing zone will be evaluated with three separate injection locations. Detailed maps of the three injection sites (MW011, MW012 and MW008A) with total and hexavalent chromium concentrations are presented in Figures 6 through 8, respectively.

The configuration of the three pilot systems can be outlined as follows:

<u>MW011 Area</u>

- Injection Well 1 (IW001) – Screened between 40 to 95 feet.
    - Terminates at surface of clayey gravel.
  - Monitor Well 11 (MW011) – Screened between 47 and 62 feet.
    - Terminates in sand unit.
    - Located 38 feet from the injection well.
  - Monitor Well 11M (MW011M) – Screened between 80 to 90 feet.
    - Terminates in sand unit.
    - Located 36 feet from the injection well.
  - Monitor Well 11A (MW011A) – Screened between 107.5 and 115.0 feet.
    - Terminates in Triassic redbed.
    - Located 40 feet from the injection well.
  - Recovery Well 2 (RW002) – Screened between 48 and 68 feet.
    - Terminates in sand unit.
    - Located 15 feet from the injection well.

MW012 Area

- Injection Well 2 (IW002) – Screened between 40 to 90 feet.
    - Terminates two feet above lower clayey gravel.
  - Monitor Well 12 (MW012) – Screened between 45 and 65 feet.
    - Terminates in sand unit.
    - Located 36 feet from the injection well.
  - Monitor Well 12M (MW012M) – Screened between 80 and 90 feet.
    - Terminates in sand unit.
    - Located 38 feet from the injection well.
  - Monitor Well 12A (MW012A) – Screened between 106.1 and 113.6 feet.
    - Terminates in Triassic redbed.
    - Located 28 feet from the injection well.
  - Recovery Well 3 (RW003) – Screened between 45 and 65 feet.
    - Terminates in sand unit.
    - Located 15 feet from the injection well.

MW008A Area

- Injection Well is Recovery Well 004A (RW004A) – Screened between 95 and 115 feet.
    - Terminates in Triassic redbed.
  - Monitor Well 8 (MW008) – Screened between 46.6 and 66.1 feet
    - Terminates in sand unit.
    - Located 28 feet from the injection well.
  - Monitor Well 8M (MW008A) – Screened between 75 to 85 feet
    - Terminates in sand unit.
    - Located 24 feet from the injection well.
  - Monitor Well 8A (MW008A) – Screened between 105.5 and 113.4 feet
    - Terminates in Triassic redbed.
    - Located 16 feet from the injection well.

This configuration is designed to evaluate the hydraulic character of the upper and mid levels of the sand unit (Shallow Zone) as well as the intrinsic character of the gravelly clay (Deep Zone) and its relationship with the overlying sand unit. The primary difference between the three systems is the screened interval of the injection well. Injection Well 1 contacts the upper surface of clayey gravel. Injection Well 2 is screened only in the sand unit. Injection Well 3 terminates in the Triassic redbed and completely transects the clayey gravel.

Injection Program

A Gant chart has been prepared as Figure 9 to illustrate the initially anticipated injection and monitoring program. The injection program will start with the injection of 200 gallons of 10% molasses into each of the three injection wells.

Based on the size of the chromate plume, and given the relatively flat hydraulic gradients at the site, it is possible that there is heterogeneity expressed as preferential pathways either in the sand unit, the clayey gravel unit, or where the sand unit contacts the clayey sand unit.

This complex hydrogeologic system has been previously evaluated with the performance of a series of pumping tests. The hydraulic performance of the system under injection conditions could be distinctly different than that seen under pumping conditions. This difference is due to the effect of an injection head versus localized head reduction under pumping conditions. Under pumping conditions an extreme hydraulic gradient may be on the order of 0.5 foot of vertical gradient to one foot of horizontal distance (0.5 foot per foot). This is two orders of magnitude greater than gradient commonly seen under natural flow conditions (i.e., 0.01 foot per foot).

Under injection conditions the maximum pressure of injection will be approximately one pound per square inch (PSI) per foot of depth to prevent the stimulation of hydrofracturing. Assuming the distance to the water table from the land surface is 30 feet, an injection pressure of 30 PSI would be generated. Each PSI is equivalent to approximately 2.4 feet of hydraulic head. Therefore, approximately 72 feet of head would be applied in the well bore, or two orders of magnitude above that achieved under pumping conditions and four orders of magnitude above natural flow conditions.

Aside from hydraulic gradient, two additional factors affecting the groundwater velocity are porosity and hydraulic conductivity. The porosity is typically 20 to 30%. However, the hydraulic conductivity can vary over seven orders of magnitude. Providing a source of hydraulic head that may be up to four orders of magnitude above the natural gradient can possibly result in significant preferential transport within the aquifer over significant distances. This in turn can have significant impact on the ultimate spacing of injection wells and injection well arrays.

The initial monitoring interval is designed to detect this type of preferential transport in the system. As the pilot program matures, the initial effects of any preferential transport will be overwhelmed by the general stimulation between the preferential pathways in the geologic matrix. Sampling intervals will be appropriately lengthened.

As an additional aid to this hydrogeologic evaluation, a bromide tracer will be used during the initial injection event and possibly during selected subsequent injection events. The use of a conservative tracer may offer an enhanced transport signal between the injection wells and the various screened intervals in the monitor well networks.

If it appears that there is significant preferential transport, there may be some effort in the latter stages of the test to evaluate the potential of rapid injection transport between the individual injection set-ups. During the course of the pilot study, wells used for pumping tests can be used to create enhanced flow conditions by pumping, if required.

Monitoring Program

The pilot test will be designed to yield the desired information in a 24-week test interval.

In addition to monitoring water levels it will be critical to monitor the biogeochemistry of the groundwater in the pilot test treatment zone. This will allow for the quantitative evaluation of the type of carbon substrate that will be required, the concentration of carbon substrate injection solutions, and the interval between injection events. The monitoring program will fall into two broad categories. The first are field parameters and the second are parameters that require laboratory analysis. Table 1 summarizes both types of parameters, as they are likely to be applied during the pilot test.

The need and use for each of the analytical parameters can be outlined as follows:

- The field parameters will provide instant data on conditions that in many cases are so sensitive to ambient ORP conditions that they would not remain stable during shipment to the laboratory. In particular this includes the ORP, dissolved oxygen, ferrous iron, and sulfides. Low flow sampling procedures and a multiprobe sampling head will be used to further facilitate the evaluation of these sensitive parameters.

- Analyses of total and dissolved chromium will evaluate the effectiveness of the chromium removal process. These analyses will speciate the chromium (differentiate between Cr^{+6} and Cr^{+3}).

- Total alkalinity, TDS, Chlorides, calcium, sodium, magnesium, and potassium will provide information concerning general groundwater quality as well as aid in identifying groundwaters that may be of different origins.
- Bromide will be part of the tracer program.
- Analysis for arsenic will evaluate the potential impact of the program on other oxy-anionic species present in the mineral matrix.
- Nitrate, nitrite, ammonia, and phosphate analysis will provide information on trace nutrient levels in the treatment zone as well as the Redox impact of nitrate.
- Iron, manganese, sulfate, and sulfides analyses will be important indicators of the redox state of the water bearing zones before and after treatment.
- Total organic carbon will provide information on the condition and concentration of the soluble carbon substrate.
- The permanent gases will provide information on the level of biologic activity, as well as the type of activity.

As the pilot-testing program is implemented and dynamic biogeochemical feedback becomes available, the monitoring and injection program may be modified appropriately.

Conclusion

This pilot test program for in situ chromate remediation has been designed to evaluate a potentially complex multi-layer groundwater system. The exploitation of the site hydrodynamics and biogeochemistry will be optimized in order to design and implement a full-scale system in the most cost effective and rapid manner possible. During the course of the pilot study, brief quarterly reports will be produced to provide an outline of the progress of the study. At the end of one year of operation, a full report on the results will be prepared. A design for the full-scale remediation system will also be prepared at that time.

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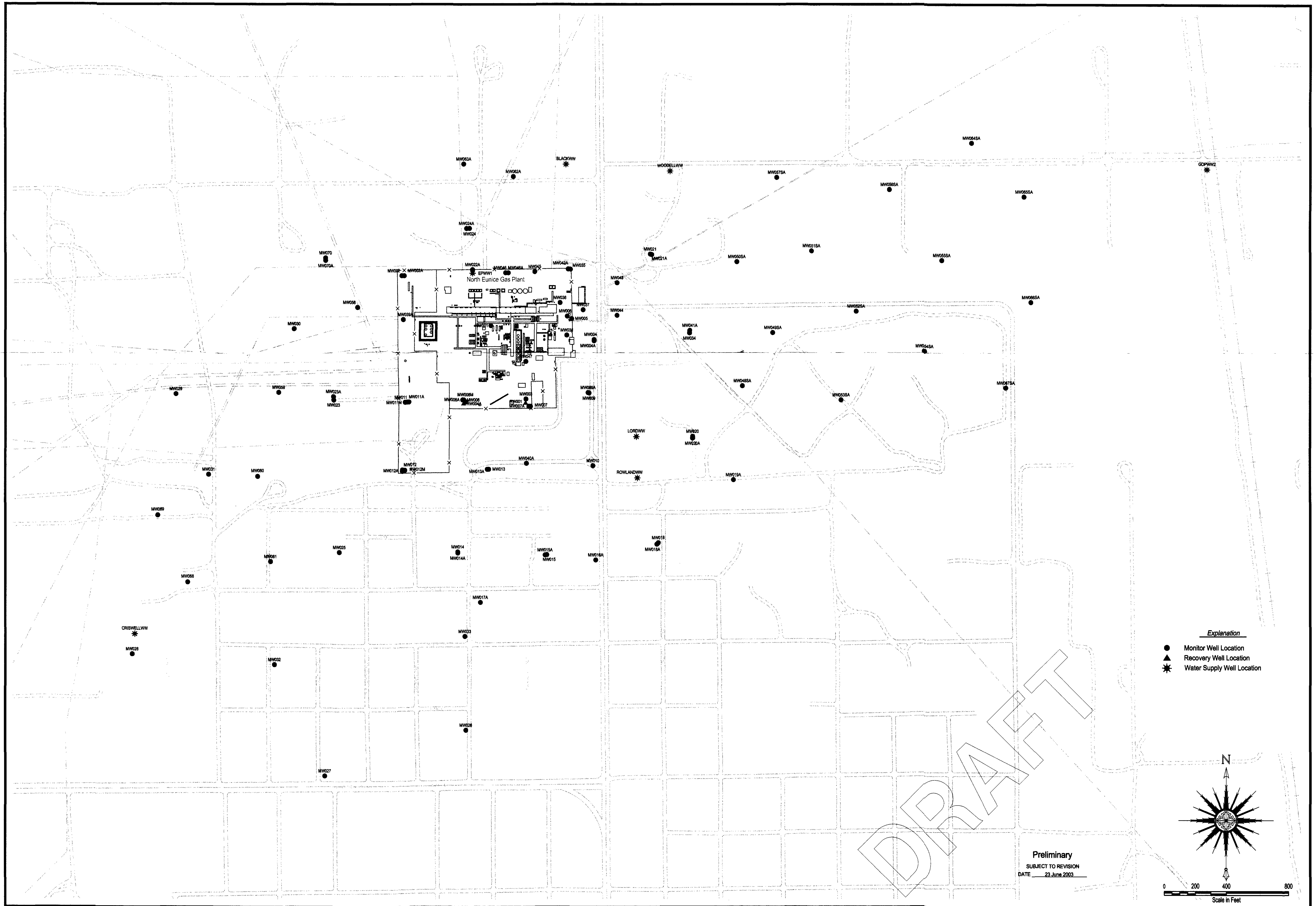
Table 1
Laboratory Analyte List
Chromate Remediation Pilot Study Work Plan
ChevronTexaco N. Eunice Plant
Eunice, Lea County, New Mexico

Parameter	Analytical Method	Container and Preservation	Holding Times	Reporting Limits (mg/L)
Field Parameters				
Dissolved Oxygen	Field Probe	NA	Immediate	NA
Redox potential	Field Probe	NA	Immediate	NA
pH	Field Probe	NA	Immediate	NA
Temperature	Field Probe	NA	Immediate	NA
Specific Conductance	Field Probe	NA	Immediate	NA
Iron, ferrous	HACH Kit	NA	Immediate	NA
Hydrogen Sulfide	HACH Kit	NA	Immediate	NA
Laboratory Analyses				
Organic Analyses				
Total Organic Carbon	EPA 415.1	250-ml plastic/H3PO4	28 days	1.00
Inorganic Analyses				
Total Chromium	SW-846 6010B	500-ml plastic/HNO3	6 Months	0.05
Hexavalent Chromium	SW-846 7197	1-Liter plastic/Neat	Immediate	0.005
Total Arsenic	SW-846 6010B	500-ml plastic/HNO3	6 Months	0.05
Nitrate/Nitrite	EPA 300.0	250-ml plastic/H2SO4	28 Days	1.00
Total Alkalinity	SM2320B	1-Liter plastic/Neat	14 Days	5.00
Carbonate	SM2320B	1-Liter plastic/Neat	14 Days	5.00
Bicarbonate	SM2320B	1-Liter plastic/Neat	14 Days	5.00
Sulfate	EPA 300.0	1-Liter plastic/Neat	28 days	40.0
Sulfide	EPA 376.2	1-Liter plastic/ZnAc/NaOH	7 Days	0.05
Chlorides	EPA 300.0	1-Liter plastic/Neat	28 days	20.0
Bromide	EPA 300.0	1-Liter plastic/Neat	28 days	2.0
Calcium	SW-846 6010B	500-ml plastic/HNO3	6 Months	1.00
Sodium	SW-846 6010B	500-ml plastic/HNO3	6 Months	1.00
Magnesium	SW-846 6010B	500-ml plastic/HNO3	6 Months	0.05
Potassium	SW-846 6010B	500-ml plastic/HNO3	6 Months	1.00
Total Iron	SW-846 6010B	500-ml plastic/HNO3	6 Months	0.10
Dissolved Iron	SW-846 6010B	500-ml plastic/HNO3	6 Months	0.10
Ferrous Iron	Speciated Iron	500-ml plastic/HNO3	6 Months	0.025
Total Manganese	SW-846 6010B	500-ml plastic/HNO3	6 Months	0.05
Dissolved Manganese	SW-846 6010B	500-ml plastic/HNO3	6 Months	0.05
Oxygen	Headspace	40-ml vial/Neat	14 Days	1.00
Nitrogen	Headspace	40-ml vial/Neat	14 Days	1.00
Carbon Dioxide	Headspace	40-ml vial/Neat	14 Days	1.00
Methane	Headspace	40-ml vial/Neat	14 Days	0.01



Preliminary
SUBJECT TO REVISION
DATE 23 June 2003

No.	Date	Revision Description	By	Ckd

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Drawn By	Drawing Date	File Location	File Name	Unique Number	Project Director	Area Manager
H. Clardy	18 June 2003	\AutoCAD\DWG\ChevronTexaco\North Eunice\MT000700.005	MT700506.dwg	31-014-00505	A.J. Reed	A. Schmidt

ChevronTexaco Exploration & Production Company
Chromate Remediation Pilot Study Work Plan

Site Plan

Eunice #2 (North) Gas Plant, Lea County, New Mexico

Task Manager
H. McConnell

Technical Review
S. Tischer

Project Number
MT000700.0005

Figure
2

Explanation

- ● Monitor Well Location
- ▲ Recovery Well Location
- ✱ Water Supply Well Location
- Groundwater Elevation Contour
- 3,371.18' Groundwater Elevation (Feet Above Mean Sea Level) Contour Interval = 1.0 Foot
- Contour Interval Change

No.	Date	Revision Description	By	Ckd

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Drawn By	Drawing Date	File Location	File Name	Unique Number	Project Director	Area Manager
H. Clardy	13 June 2003	\AutoCAD\DWG\ChevronTexaco\North Eunice\MT000700.005	MT700505.dwg	31-014-00502	A.J. Reed	A. Schmidt

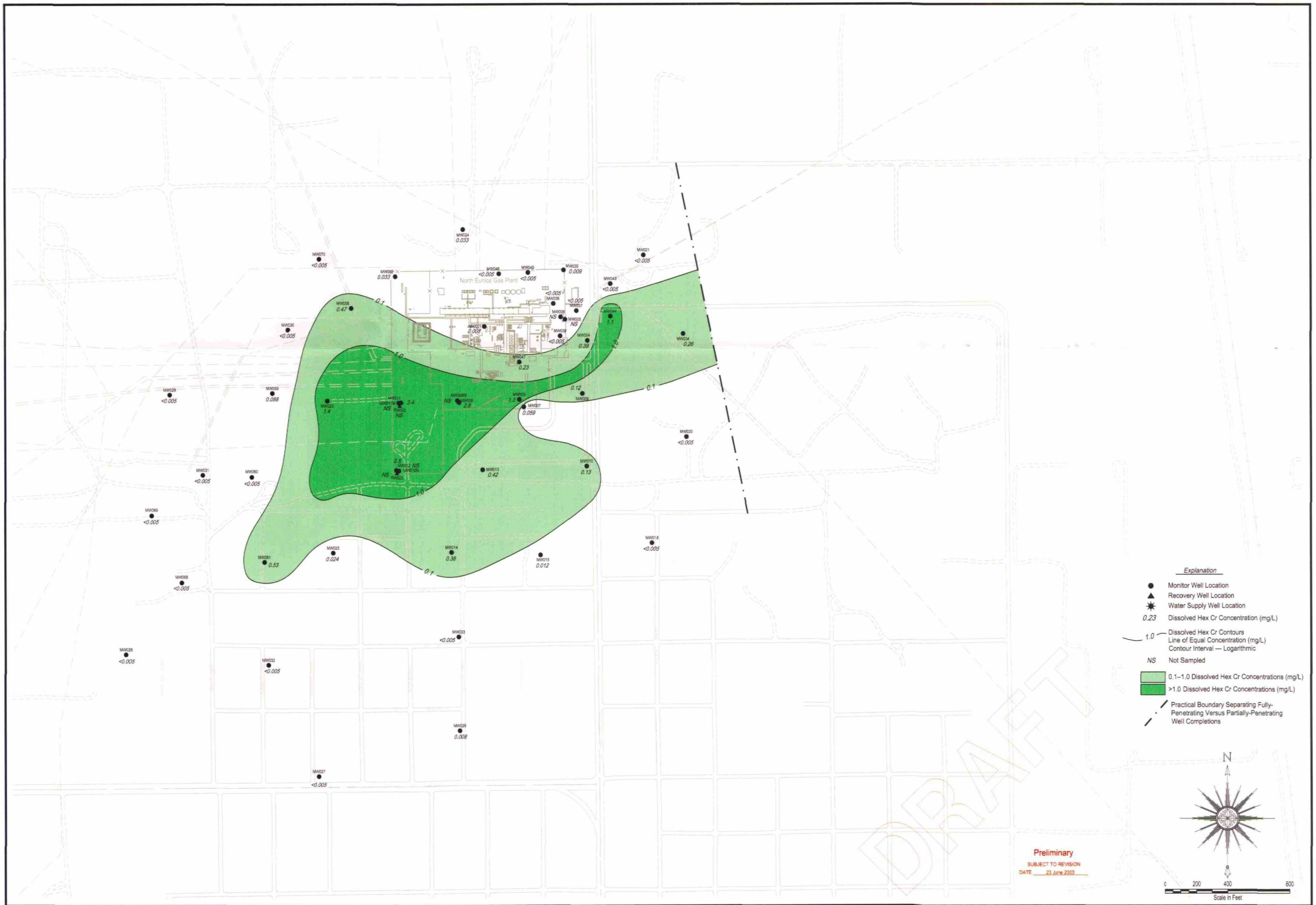
ChevronTexaco Exploration & Production Company
Chromate Remediation Pilot Study Work Plan

Hydraulic Gradient Map (March, 2003)

Eunice #2 (North) Gas Plant, Lea County, New Mexico

Task Manager	Technical Review
H. McConnell	S. Tischer

Project Number	Figure
MT000700.0005	3



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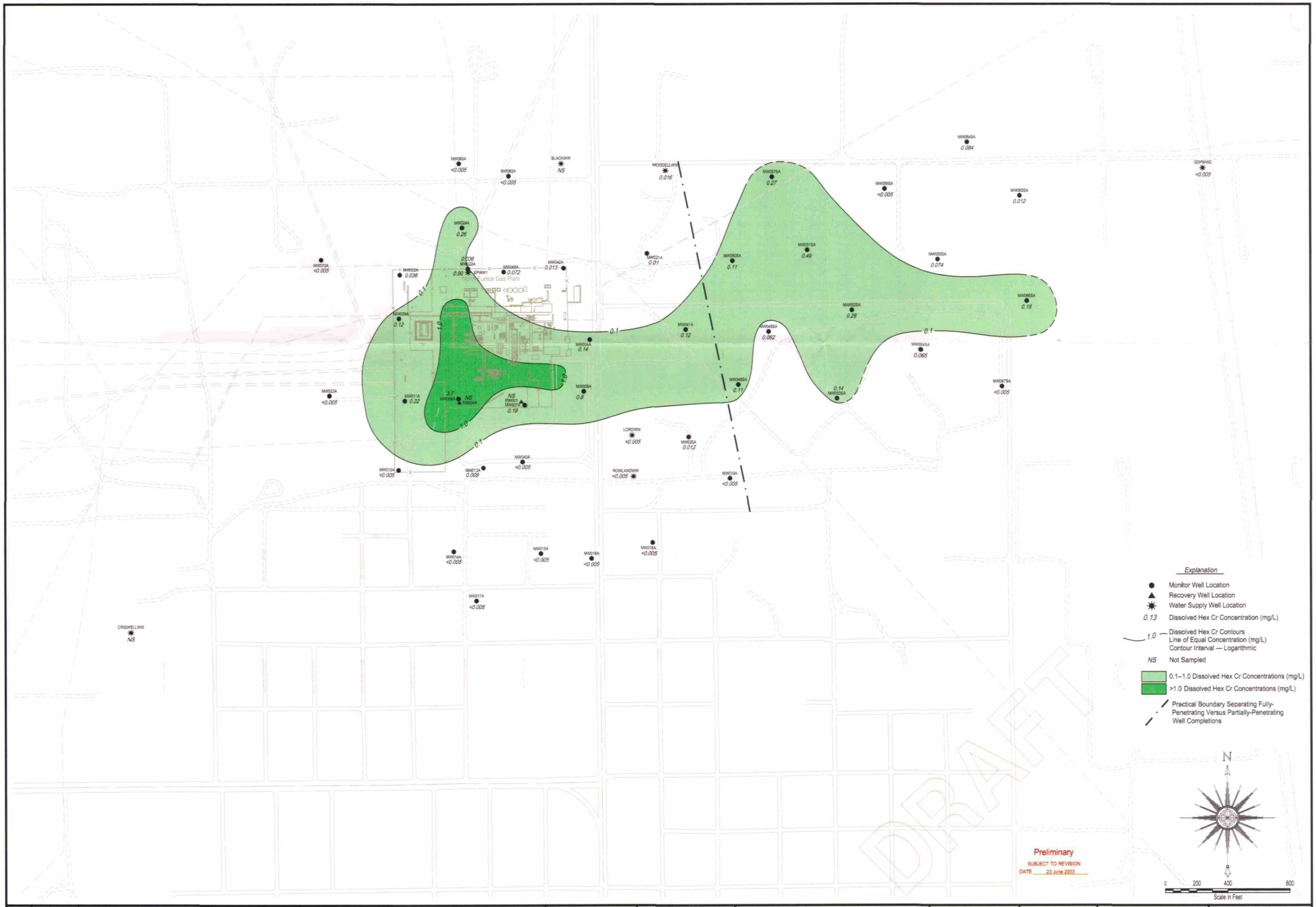
Drawn By H. Clardy	Drawing Date 13 June 2003	File Location \AutoCAD\DWG\ChevronTexaco\North Eunice\MT000700.005	File Name MT700504.dwg	Unique Number 31-014-00503	Project Director A.J. Reed	Area Manager A. Schmidt
					Task Manager H. McConnell	Technical Review S. Tischer
					Project Number MT000700.0005	Figure 4

ChevronTexaco Exploration & Production Company
Chromate Remediation Pilot Study Work Plan

Shallow Groundwater Isoconcentration Map (March, 2003)
Dissolved Hexavalent Chromium (mg/L)

Eunice #2 (North) Gas Plant, Lea County, New Mexico



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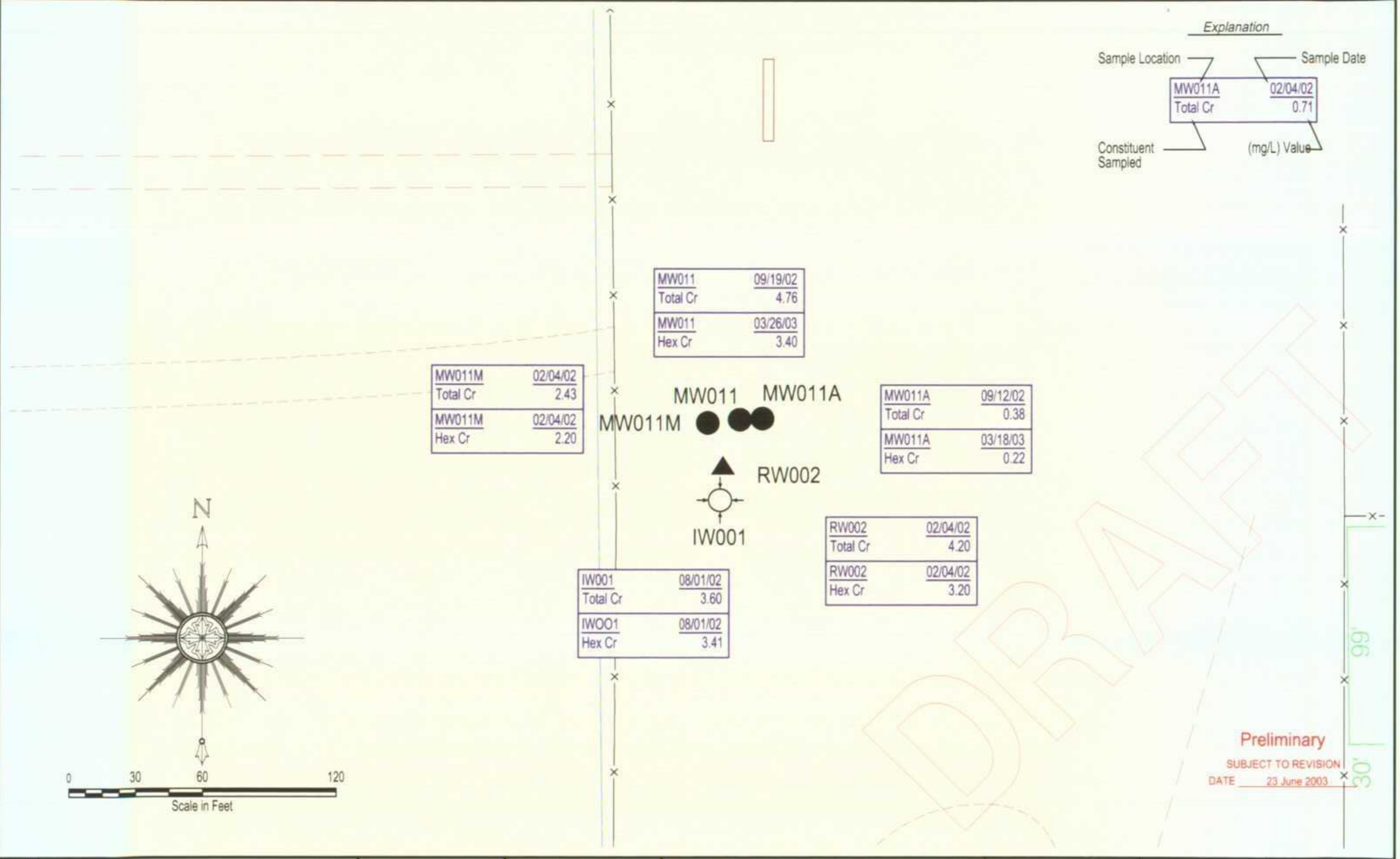
					Task Manager H. McConnell	Technical Review S. Tischer
					Project Number MT000700.0005	Figure 5

ChevronTexaco Exploration & Production Company
Chromate Remediation Pilot Study Work Plan

Deep Groundwater Isoconcentration Map (March, 2003)
Dissolved Hexavalent Chromium (mg/L)

Eunice #2 (North) Gas Plant, Lea County, New Mexico



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SUBJECT TO REVISION
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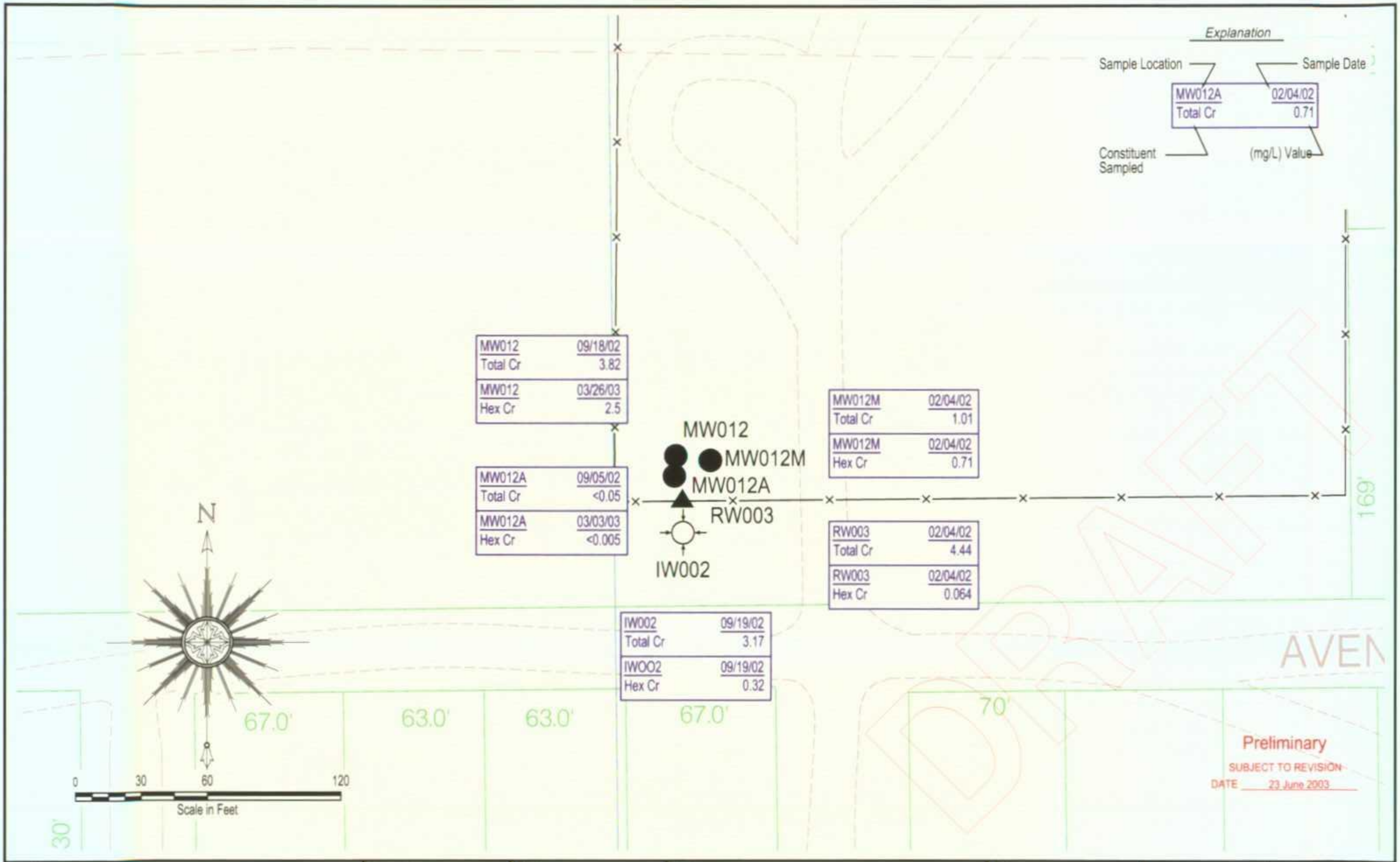
Drawing Date	21 May 2003
File Name	MT700501.dwg
File Location	G:\AutoCAD\DWG\ChevronTexaco\North Eunice\MT000700.005
Task Manager	L. Markham
Project Director	H. McConnell
Area Manager	A. Schmidt
Technical Review	S. Tischer
Unique Number	31-014-00500
Project Number	MT000700.0005
Figure	6

ChevronTexaco Exploration and Production Company
Chromate Remediation Pilot Study Work Plan
MW011 Area
Well Locations and Dissolved Total Cr and Dissolved Hex Cr Concentrations (mg/L)
Eunice #2 (North) Gas Plant, Lea County, New Mexico



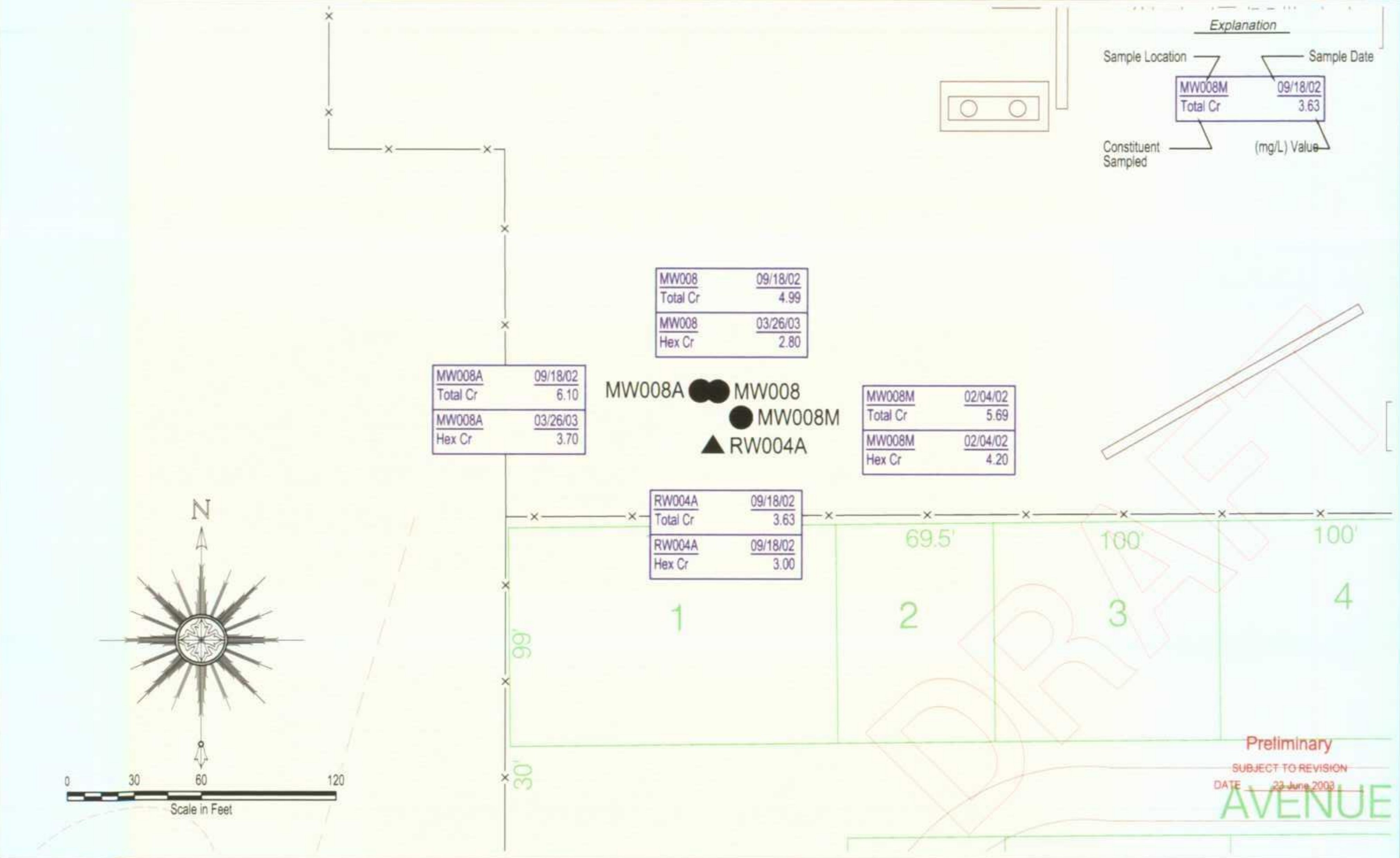
Preliminary
SUBJECT TO REVISION
DATE 23 June 2003

ARCADIS

1004 N. Big Spring Street, Suite 300
Midland, TX 79701-3383
Tel: 432 687 5400 Fax: 432 687 5401

Drawing Date 21 May 2003	File Name MT700500.dwg	File Location G:\AutoCAD\DWG\ChevronTexaco\North Eunice\MT000700.005	Task Manager L. Markham	Project Director H. McConnell	Area Manager A. Schmidt
				Technical Review S. Tischer	Unique Number 31-014-00499
				Project Number MT000700.0005	Figure 7

ChevronTexaco Exploration and Production Company
Chromate Remediation Pilot Study Work Plan
MW012 Area
Well Locations and Dissolved Total Cr and Dissolved Hex Cr Concentrations (mg/L)
Eunice #2 (North) Gas Plant, Lea County, New Mexico



Preliminary
SUBJECT TO REVISION
DATE 23 June 2003

ARCADIS

1004 N. Big Spring Street, Suite 300
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Drawing Date: 21 May 2003
File Name: MT700502.dwg
File Location: G:\AutoCAD\DWG\ChevronTexaco\North Eunice\MT000700.005
Task Manager: L. Markham
Project Director: H. McConnell
Area Manager: A. Schmidt
Technical Review: S. Tischer
Unique Number: 31-014-00501

ChevronTexaco Exploration and Production Company
Chromate Remediation Pilot Study Work Plan
MW008A Area
Well Locations and Dissolved Total Cr and Dissolved Hex Cr Concentrations (mg/L)
Eunice #2 (North) Gas Plant, Lea County, New Mexico

Project Number: MT000700.0005
Figure: 8

ARCADIS

Figure 9
Project Schedule
Chromate Remediation Pilot Study Work Plan
ChevronTexaco N. Eunice Plant
Eunice, Lea County, New Mexico

Tasks	Week																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	91	20	21	22	23	24
Site Inspection	▨																							
Field Preparation		▨																						
System Installation			▨																					
AREA MW008A																								
Field Parameter Collecting				▨	▨	▨		▨		▨		▨		▨		▨				▨				▨
Analytical Parameter Collecting				▨	▨	▨		▨				▨				▨				▨				▨
Carbon Substrate Injecting				▨	▨	▨		▨				▨				▨				▨				▨
AREA MW011																								
Field Parameter Collecting				▨	▨	▨		▨		▨		▨		▨		▨				▨				▨
Analytical Parameter Collecting				▨	▨	▨		▨				▨				▨				▨				▨
Carbon Substrate Injecting				▨	▨	▨		▨				▨				▨				▨				▨
AREA MW012																								
Field Parameter Collecting				▨	▨	▨		▨		▨		▨		▨		▨				▨				▨
Analytical Parameter Collecting				▨	▨	▨		▨				▨				▨				▨				▨
Carbon Substrate Injecting				▨	▨	▨		▨				▨				▨				▨				▨
Analytical Data Reduction							▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Analytical Data Anlaysis							▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Graphics Generation							▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨

APPENDIX A

Appendix A

Sodium Bromide Material Safety Data Sheets

Material Safety Data Sheets

Division of Facilities Services

DOD Hazardous Material Information (ANSI Format) For Cornell University Convenience Only

SODIUM BROMIDE, PRODUCT NO C4627R

Section 1 - Product and Company Identification
SODIUM BROMIDE, PRODUCT NO C4627R

Product Identification: SODIUM BROMIDE, PRODUCT NO C4627R
Date of MSDS: 12/27/1994 **Technical Review Date:** 02/08/2000
FSC: NIIN: EMPTY
Submitter: D DG
Status Code: A
MFN: 01
Article: N
Kit Part: N

Manufacturer's Information

Manufacturer's Name: SARGENT WELCH VWR SCIENTIFIC
Manufacturer's Address1: 911 COMMERCE COURT
Manufacturer's Address2: BUFFALO GROVE, IL 60089-2375
Manufacturer's Country: US
General Information Telephone: 800-727-4368
Emergency Telephone: 800-727-4368
Other Number for MSDS Information: WLC4627R
Emergency Telephone: 800-727-4368
MSDS Preparer's Name: STEVEN C. QUANDT
Chemtec Telephone: (800)424-9300
Proprietary: N
Reviewed: Y
Published: Y
CAGE: TO505

Contractor Information

Contractor's Name: SARGENT WELCH VWR SCIENTIFIC
Contractor's Address1: 911 COMMERCE COURT
Contractor's Address2: BUFFALO GROVE, IL 60089-2375
Contractor's Telephone: 800-727-4368
Contractor's CAGE: TO505

Contractor Information

Contractor's Name: WARDS NATURAL SCIENCE ESTABLISHMENT INC
Post Office Box: 92912
Contractor's Address1: 5100 W HENRIETTA RD
Contractor's Address2: ROCHESTER, NY 14692-9012
Contractor's Telephone: (716) 359-2502
Contract Number: MDA414-99A-0024-0023
Contractor's CAGE: 63759

Section 2 - Compositon/Information on Ingredients
SODIUM BROMIDE, PRODUCT NO C4627R

Ingredient Name: SODIUM BROMIDE (NABR)
Ingredient CAS Number: 7647-15-6 **Ingredient CAS Code:** T
RTECS Number: VZ3150000 **RTECS Code:** T
=WT: 99.9 **=WT Code:** M
=Volume: =Volume Code:
>WT: >WT Code:
>Volume: >Volume Code:
<WT: <WT Code:
<Volume: <Volume Code:
% Low WT: % Low WT Code:
% High WT: % High WT Code:
% Low Volume: % Low Volume Code:
% High Volume: % High Volume Code:

% Text:
% Enviromental Weight:
Other REC Limits: N/P
OSHA PEL: N/P **OSHA PEL Code:**
OSHA STEL: N/P **OSHA STEL Code:**
ACGIH TLV: N/P **ACGIH TLV Code:**
ACGIH STEL: N/P **ACGIH STEL Code:**
EPA Reporting Quantity:
DOT Reporting Quantity:
Ozone Depleting Chemical: N

Section 3 - Hazards Identification, Including Emergency Overview
SODIUM BROMIDE, PRODUCT NO C4627R

Health Hazards Acute & Chronic: MAY CAUSE MILD IRRITATION TO SKIN, EYES AND RESPIRATORY SYSTEM. INGESTION OF LARGE DOSES OF BROMIDE CAUSE NAUSEA, VOMITING, ABDOMINAL PAIN, COMA AND PARALYSIS. PROLONGED EXPOSURE TO DUST MAY CAUSE BRO NCHITIS

Signs & Symptoms of Overexposure:
SEE HEALTH EFFECTS SECTION

Medical Conditions Aggravated by Exposure:
NOT PROVIDED

LD50 LC50 Mixture: N/P

Route of Entry Indicators:
- **Inhalation:** N/P
- **Skin:** N/P
- **Ingestion:** N/P

Carcenogenicity Indicators
- **NTP:** N/P
- **IARC:** N/P
- **OSHA:** N/P

Carcinogenicity Explanation: NOT PROVIDED

Section 4 - First Aid Measures
SODIUM BROMIDE, PRODUCT NO C4627R

First Aid:
CALL A PHYSICIAN. EYES AND SKIN: IMMEDIATELY FLUSH WITH PLANTY OF WATER FOR AT LEAST 15 MINUTES. INHALATION: REMOVE TO FRESH AIR. INGESTION: GIVE TWO GLASSES OF WATER AND INDUCE VOMITING IF CONSCIOUS

Section 5 - Fire Fighting Measures
SODIUM BROMIDE, PRODUCT NO C4627R

Fire Fighting Procedures:
WEAR SELF-CONTAINED BREATING APPARATUS
Unusual Fire or Explosion Hazard:
NONE
Extinguishing Media:
USE MEANS SUITABLE TO EXTINGUISH THE SUPPORTING FLAME
Flash Point: Flash Point Text: NONE

Autoignition Temperature:
Autoignition Temperature Text: N/P
Lower Limit(s): N/A
Upper Limit(s): N/A

Section 6 - Accidental Release Measures
SODIUM BROMIDE, PRODUCT NO C4627R

Spill Release Procedures:
WEAR APPROPRIATE SAFETY EQUIPMENT. SWEEP UP AND CONTAINERIZE FOR DISPOSAL. FLUSH RESIDUE WITH LARGE AMOUNTS OF WATER.

Section 7 - Handling and Storage
SODIUM BROMIDE, PRODUCT NO C4627R

Handling and Storage Precautions:

Other Precautions:

Section 8 - Exposure Controls & Personal Protection
SODIUM BROMIDE, PRODUCT NO C4627R

Repiratory Protection:
NIOSH APPROVED DUST RESPIRATOR IF NEEDED
Ventilation:
LOCAL EXHAUSE RECOMMENDED
Protective Gloves:
RUBBER GLOVES
Eye Protection: SAFETY GOGGLES
Other Protective Equipment: LAB COAT OR APRON
Work Hygenic Practices: NOT PROVIDED
Supplemental Health & Safety Information: NOT RELEVANT

Section 9 - Physical & Chemical Properties
SODIUM BROMIDE, PRODUCT NO C4627R

HCC: N1
NRC/State License Number:
Net Property Weight for Ammo:
Boiling Point: =1390.C, 2534.F **Boiling Point Text:**
Melting/Freezing Point: =747.C, ######F **Melting/Freezing Text:**
Decomposition Point: Decomposition Text: N/P

Vapor Pressure: N/A **Vapor Density:** N/A
Percent Volatile Organic Content:
Specific Gravity: 3.21
Volatile Organic Content Pounds per Gallon:
pH: N/P
Volatile Organic Content Grams per Liter:
Viscosity: N/P
Evaporation Weight and Reference: N/A
Solubility in Water: 116% BY WEIGHT @ 50C
Appearance and Odor: WHITE CRYSTALLINE SOLID, ODORLESS
Percent Volatiles by Volume: 0
Corrosion Rate: N/P

Section 10 - Stability & Reactivity Data
SODIUM BROMIDE, PRODUCT NO C4627R

Stability Indicator: YES
Materials to Avoid:
STRONG OXIDIZING AGENTS; ACIDS CAN PRODUCE HYDROGEN BROMIDE, ALKALOIDIAL AND HEAVY METAL SALTS
Stability Condition to Avoid:
NOT APPLICABLE
Hazardous Decomposition Products:
NONE
Hazardous Polymerization Indicator: NO
Conditions to Avoid Polymerization:
NOT APPLICABLE

Section 11 - Toxicological Information
SODIUM BROMIDE, PRODUCT NO C4627R

Toxicological Information:
NOT PROVIDED

Section 12 - Ecological Information
SODIUM BROMIDE, PRODUCT NO C4627R

Ecological Information:
NOT PROVIDED

Section 13 - Disposal Considerations
SODIUM BROMIDE, PRODUCT NO C4627R

Waste Disposal Methods:
DISCHARGE, TREATMENT OR DISPOSAL MAY BE SUBJECT TO FEDERAL, STATE OR LOCAL LAWS. THESE DISPOSAL GUIDELINES ARE INTENDED FOR THE DISPOSAL OF CATALOG-SIZE QUANTITIES ONLY.

Section 14 - MSDS Transport Information
SODIUM BROMIDE, PRODUCT NO C4627R

Transport Information:

SEE TRANSPORTATION DATA.

Section 15 - Regulatory Information
SODIUM BROMIDE, PRODUCT NO C4627R

SARA Title III Information:
NOT PROVIDED
Federal Regulatory Information:
NOT PROVIDED
State Regulatory Information:
NOT PROVIDED

Section 16 - Other Information
SODIUM BROMIDE, PRODUCT NO C4627R

Other Information:
NOT RELEVANT

HMIS Transportation Information

Product Identification: SODIUM BROMIDE, PRODUCT NO C4627R
Transporation ID Number: 151391
Responsible Party CAGE: TO505
Date MSDS Prepared: 12/27/1994
Date MSDS Reviewed: 02/08/2000
MFN: 02/08/2000
Submitter: D DG
Status Code: A

Container Information
    Unit of Issue: NK
    Container Quantity: NK
    Type of Container:
    Net Unit Weight:

Article without MSDS: N
Technical Entry NOS Shipping Number:
Radioactivity:
Form:
Net Explosive Weight:
Coast Guard Ammunition Code:
Magnetism:
AF MMAC Code:
DOD Exemption Number: N/A
Limited Quantity Indicator: N
Multiple Kit Number: 0
Kit Indicator: N
Kit Part Indicator: N
Review Indicator: N
Additional Data:

Department of Transportation Information

DOT Proper Shipping Name: NOT REGULATED BY THIS MODE OF TRANSPORTATION
DOT PSN Code: ZZZ
Symbols: N/R
DOT PSN Modifier:
Hazard Class: N/R
UN ID Number: N/R
DOT Packaging Group: N/R
Label: N/R
Special Provision(s): N/R
Packaging Exception: N/R
Non Bulk Packaging: N/R
Bulk Packaging: N/R
Maximimum Quanity in Passenger Area: N/R
Maximimum Quanity in Cargo Area: N/R
Stow in Vessel Requirements: N/R
Requirements Water/Sp/Other: N/R

IMO Detail Information

IMO Proper Shipping Name: NOT REGULATED FOR THIS MODE OF TRANSPORTATION
IMO PSN Code: ZZZ
IMO PSN Modifier:
IMDG Page Number: N/R
UN Number: N/R
UN Hazard Class: N/R
IMO Packaging Group: N/R
Subsidiary Risk Label: N/R
EMS Number: N/R
Medical First Aid Guide Number: N/R

IATA Detail Information

IATA Proper Shipping Name: NOT REGULATED BY THIS MODE OF TRANSPORTATION
IATA PSN Code: ZZZ
IATA PSN Modifier:
IATA UN Id Number: N/R
IATA UN Class: N/R
Subsidiary Risk Class: N/R
UN Packaging Group: N/R
IATA Label: N/R
Packaging Note for Passengers: N/R
Maximum Quantity for Passengers: N/R
Packaging Note for Cargo: N/R
Maximum Quantity for Cargo: N/R
Exceptions: N/R

AFI Detail Information

AFI Proper Shipping Name: NOT REGULATED BY THIS MODE OF TRANSPORTATION
AFI Symbols:
AFI PSN Code: ZZZ
AFI PSN Modifier:
AFI UN Id Number: N/R
AFI Hazard Class: N/R
AFI Packing Group: N/R
AFI Label: N/R
Special Provisions: N/A

Back Pack Reference: N/A

HAZCOM Label Information

Product Identification: SODIUM BROMIDE, PRODUCT NO C4627R
CAGE: TO505
Assigned Individual: Y
Company Name: SARGENT WELCH VWR SCIENTIFIC
Company PO Box:
Company Street Address1: 911 COMMERCE COURT
Company Street Address2: BUFFALO GROVE, IL 60089-2375 US
Health Emergency Telephone: 800-727-4368
Label Required Indicator: Y
Date Label Reviewed: 02/08/2000
Status Code: A
Manufacturer's Label Number:
Date of Label:
Year Procured: N/K
Organization Code: F
Chronic Hazard Indicator: N/P
Eye Protection Indicator: YES
Skin Protection Indicator: YES
Respiratory Protection Indicator: YES
Signal Word: CAUTION
Health Hazard: Slight
Contact Hazard: Slight
Fire Hazard: None
Reactivity Hazard: None

8/9/2002 11:08:11 AM

Groundwater Remediation Work Plan

Eunice #2 (North) Gas Plant
Eunice, New Mexico

RECEIVED
DEC 13 2000
ENVIRONMENTAL BUREAU
OIL CONSERVATION DIVISION

ARCADIS
GERAGHTY & MILLER

12 December 2000

PREPARED FOR

Texaco Exploration and
Production Inc.
P.O. Box 3109
Midland, Texas 79702

ARCADIS GERAGHTY & MILLER

Groundwater Remediation Work Plan

Eunice #2 (North) Gas Plant
Eunice, New Mexico

Prepared for:

Texaco Exploration and Production Inc.
P.O. Box 3109
Midland, Texas 79702

Prepared by:

ARCADIS Geraghty & Miller Inc
1030 Andrews Hwy.
Suite 120
Midland
Texas 79701
Tel 915 699 1381
Fax 915 699 1978

Our Ref.:

MT000700.0001

Date:

12 December 2000

Figures

Tables

Appendices

Introduction

This is a work plan to remediate groundwater at the Texaco Eunice #2 (North) Gas Plant, Eunice, New Mexico. The work plan is based on information provided in a report by Highlander Environmental Corporation for Texaco titled "Final Groundwater *Plume Delineation Report, Eunice #2 (North) Gas Plant, Eunice, New Mexico*", *dated* March 2000. The primary constituents of concern are dissolved chromate in an area under and in the vicinity of the plant and petroleum hydrocarbons present as free and dissolved phase around monitoring wells MW-5 and MW-6. Chlorides, sulfate and TDS are also elevated in some areas underlying the plant site and adjacent areas. Both shallow and deep impacted water-bearing zones exist and are addressed in this work plan.

For planning purposes, it was necessary to assume a range of hydraulic conductivities for the shallow and deep water-bearing zones. For the shallow water-bearing zone, the hydraulic conductivity was assumed to range from 7.5 to 75 gallons/day/ft^2 (1 to 10 feet/day). The hydraulic conductivity for the deep zone was estimated to range from 75 to 750 gallons/day/ft^2 (10 to 100 feet/day).

Before remediation systems can be finalized for the site, it will be necessary to refine the vertical and horizontal extents of the chromate plume, to conduct pumping tests on both the shallow and deep zones of the aquifer, and to prepare a three dimensional model of the aquifer system. Pumping tests will be conducted on both the shallow and deep portions of the aquifer, model simulations of the proposed remediation systems will be performed, and pilot studies for the proposed systems will be conducted to ensure that the remediation systems will be properly designed to meet cleanup goals. Off-site access must be available for the installation and operation of the remediation system pilot test described in this work plan.

The selection of the final remediation design will depend on the simulation models, the actual hydraulic parameters of the two zones and the pilot test data. Existing data available for the aquifer systems include the potentiometric surface maps which indicate that the deep zone apparently is not in good hydraulic communication with the shallow zone, at least in the vicinity of water supply well WW-1. This is apparent from the cone of depression created by the pumping of WW-1, and the lack of response from the shallow zone (Figures 5 and 6 of the Highlander report, attached).

All water wells in the vicinity of the remediation system must be identified. All abandoned water wells must be plugged and all active wells must be monitored.

Site Setting

The site is located on the north side of Eunice, New Mexico, as shown on Figure 1 of the Highlander report. Figure 2 of the same report shows the plant configuration and certain area water wells. Monitoring wells installed during previous studies are also shown.

The lowest geologic unit described in the Highlander investigation is a firm red silty clay. Overlying this is a 5 to 10 foot interval of gravel/sand/clay, which is the deep water-bearing zone at the site. The gravel unit is in turn overlain by a red to yellow sand that exhibits strong vertical heterogeneity with alternating layers of loose and well *lithified sand. This is the unit that contains the shallow water-bearing zone.* Wells screened in the gravel unit have 40 to 50 feet of hydraulic head. Wells screened in the shallow water-bearing zone have screens that intersect the groundwater table and typically have 10 to 15 feet of saturation. In the southern portion of the site, the potentiometric surfaces of the shallow and deep zones are almost identical. In the northern portion of the site the potentiometric surface of the deep water-bearing zone is 10 feet or more below the water surface of the shallow water bearing zone due to pumping from well WW-1, indicating a poor hydraulic communication between the shallow and the deep zones in the aquifer, at least in this area. Overall depth to groundwater varies roughly with local topography and ranges from 38 to 72 feet below the surface.

The chromate plume in the shallow water-bearing zone covers the southern half of the site and extends off site slightly to the east and significantly to the southwest (Figure 7 of the Highlander report). Chromate concentrations as high as 6 mg/L are found in this plume with two zones of high concentration, one in the southwest corner of the site and a second in the southwest corner of the southwest off-site plume. The chromate plume in the deep water-bearing zone is of more limited areal extent and underlies the central portion of the site (Figure 8 of the Highlander report). Lobes extend from the core of the plume (with chromate concentrations as high as 3 mg/L) to the north, drawn by pumping well WW-1, and to the southeast (off-site) drawn probably by historical pumping of the Lord and Rowland water wells.

The chromate plume in the shallow water-bearing zone has an approximate areal extent of 5.1 million square feet or 117 acres. The approximate areal extent of the chromate plume in the deep water-bearing zone is 1.3 million square feet (30 acres).

Free-phase petroleum hydrocarbons have been found in monitoring wells MW-5 and MW-6. The respective apparent product thickness is 0.38 and 2.75 feet. Low levels (below regulatory concern) of dissolved BTEX constituents have been consistently reported in monitoring well MW-1 which is located approximately 700 feet to the west (cross and slightly [0.75 feet] up-gradient) of monitoring wells MW-5 and MW-6. Elevated chloride values have been noted under, northeast and southeast of the plant site in the deep zone and off site to the south and southwest in the shallow zone. The elevated chlorides in the deep zone under and southeast of the plant site may be related to plant operations. The elevated chlorides northeast of the plant site in the deep zone and south and southwest of the plant site in the shallow zone do not appear to be related to plant operations.

Groundwater gradients in the shallow water-bearing zone are relatively flat in the southern off-site portion of the plume, with gradients increasing to the north. A similar situation exists for the deep water-bearing zone with gradients in the northern portion of the plume further accentuated by the pumping of WW-1.

Using the assumed values for hydraulic conductivity for the shallow and deep water bearing zones (7.5 to 75 gallons/day/ft^2 [1 to 10 feet/day] and 75 to 750 gallons/day/ft^2 [10 to 100 feet/day] respectively) with the current configuration of the water table, estimated groundwater velocities range from 0.4 to 12 feet/year in the shallow water-bearing zone and 120 or more feet/year in the deep water-bearing zone. For the shallow water-bearing zone, if it is assumed that the facility has been in operation for 50 years and it is given that the shallow chromate plume extends 2,400 feet from the cooling towers source, velocity of the plume movement is approximately 50 feet per year. It is apparent that the wide distribution of the chromate in the shallow water-bearing zone may not have occurred under current groundwater conditions. The impact of the pumping well WW-1 on the groundwater gradient in the deep water-bearing zone is significant, and indicates that there is poor communication between the shallow and deep aquifer zones. Pumping from wells completed in the shallow zone, dually completed in both the deep and shallow zone or in areas where the two zones are naturally in communication, in conjunction with groundwater mounding from the source of the chromate laden water (most likely cooling towers) may have served as hydraulic drivers for the chromate impacting the shallow water bearing zone.

Chromate Remediation Approach

The selected remediation approach for the chromate plumes is the creation of an in-situ reactive zone (IRZ). The IRZ is a remediation technique in which subsurface conditions are modified (or enhanced) to bring about the reduction of soluble hexavalent chromium (Cr^{+6}) to insoluble trivalent chromium (Cr^{+3}). There are various methods of stimulating the process for in-situ chromate reduction. In addition, there are variations in the procedures that can be used for the hydraulic injection of the required solutions.

The selected method to create the saturated zone IRZ involves the injection of soluble, degradable organic carbon. The indigenous microbial population utilizes the organic carbon as a primary substrate. As the carbon is degraded the bacterial population utilizes natural available electron acceptors creating a reducing environment and the subsequent reduction of Cr^{+6} to Cr^{+3}. (See Appendix A for specific details on the biogeochemistry involved with the in-situ chromate reduction process. Additional documentation of IRZ technology may be found in Appendix B).

Assessment to Develop In-Situ Remediation Design Parameters

The implementation of an in-situ remediation approach is critically dependent upon site information that is not currently available. The first step of the remediation program will be to perform background biogeochemical and hydrogeologic evaluations, pumping tests, modeling and pilot tests to determine the following:

- The hydraulic parameters of both water bearing units;
    - Native groundwater velocities
    - Radius of influence of pumping wells
    - Recovery rates required to induce the required hydraulic gradients
    - Resultant well design requirements and spacing
- The assimilation capacity of the water-bearing units for soluble carbon substrates;
    - How far a carbon source can travel in the water-bearing zone before being consumed.
    - How long a carbon substrate can reside in the water-bearing zone under relatively static flow conditions.
- The attenuation rates of chromate under treatment conditions; and
- The geochemical parameters which will govern the reduction of soluble hexavalent chromium to the insoluble trivalent form.

Site Biogeochemical Assessment

To aid in the design of an IRZ pilot study and the design of a site-wide remediation system after the completion of the IRZ pilot study, the biogeochemical character of the two water bearing zones (shallow and deep) needs to be assessed. The parameters that would be included in this screening program are listed in Table 1. This assessment will provide answers to the following questions:

- Does the geochemistry of water bearing zone(s) and the site geologic matrix have constituents that will support the IRZ processes?
- Are there site conditions that could interfere with the IRZ process?
- Are the biogeochemical conditions consistent over the site or do they vary with depth or areal location?

The following program is designed to provide answers to the above questions. It has two prime components: 1) the biogeochemical parameters that will be measured and 2) the wells which will be sampled.

BioGeoChemical Conditions

The rational for the analysis of each of the biochemical parameters tested is as follows:

- A screen of total chromium, Cr^{+3}, and Cr^{+6} provides information regarding sources of chromium as well as an assessment of the natural chromate reduction processes that may be taking place in the two water bearing zones
- Nitrate and sulfate can be used as electron acceptors by anaerobic bacteria. These constituents are consumed in the process. The presence of these compounds indicates potential to support anaerobic biological activity. Their attenuation is indicative of such activity.
- Low concentrations of hydrogen sulfide may be generated as a daughter product of sulfate reduction. However, most often the low concentrations of hydrogen sulfide react with the iron in the formation and no hydrogen sulfide can be detected.

- Iron and manganese are the reactants and products of anaerobic redox couples that use iron or manganese minerals in the aquifer matrix. Speciation of the iron and manganese is an important part of the evaluation.
- Chlorides will provide information concerning variations in general water quality.
- Trace gases are also indicative of existing microbial activity.
    - Methane is indicative of anaerobic redox reactions, particularly methanogenesis.
    - Nitrogen is an end-product of the reduction of nitrates and nitrites.
    - Carbon dioxide and carbon monoxide are indicators of hydrocarbon biodegradation.
    - Dissolved oxygen is an indicator of redox conditions in addition to Eh.
- Ammonia, nitrite, and phosphate indicate the presence of trace nutrients as well as specific bacterial reactions in some instances.
- Alkalinity is a general indicator of aquifer geochemistry and may increase under high levels of biodegradation activity.
- Total Dissolved Solids, pH, temperature, and specific conductance are standard indicators of geochemical conditions in the aquifer.
- Total organic carbon provides information regarding the carbon load and carbon utilization in the aquifer.
- Calcium, magnesium, potassium, and sodium are background cations that are indicative of general aquifer chemistry and would reflect the presence of groundwater from radically different sources.

The majority of these parameters will be determined by laboratory analysis (see Table 1). However, pH, temperature, and specific conductance will be measured in association with the well purging process. Dissolved oxygen, ferrous iron, sulfate, hydrogen sulfide, chromate and redox potential (ORP or Eh) will also be measured in the field because of the highly sensitive and reactive nature of these parameters.

In addition, as part of the assessment of the site and design of the remediation system the capacity for Cr(III) oxidation of the site sediments will be evaluated. There are two tests that will be performed (these tests are not EPA protocol tests, but are remediation design tests that are chemically valid). One will evaluate the direct oxidation potential of wet sediments that are suspended in solution to which soluble Cr(III) is added.

The second will involve the extraction of dry sediments with hydroquinone which will reduce insoluble Mn(IV) species to soluble Mn(II) species. The extract is then analyzed for Mn by atomic adsorption. These two tests will allow for the prediction of any potential oxidation problems. In addition, the nature of the site (sands) and the method of treatment (soluble carbon substrates) are conditions that will minimize if not eliminate Cr(III) oxidation.

It has also been found that no oxidation of Cr(III) takes place in soils with low levels of organic carbon present. The evaluation of the carbon content of the natural soils will be used to assess this balance.

The following wells will be sampled as part of the biogeochemical assessment:

For the shallow water bearing zone:

- MW-25 in the core of the SW lobe of the chromate plume
- MW-8 in the core of the on-site lobe of the chromate plume
- MW-23 on the west periphery of the plume
- MW-14 on the east periphery of the southern lobe of the plume
- MW-4 on the east periphery of the northern lobe of the plume
- MW-15 an up-gradient un-impacted well
- MW-1, 5 and 6 in BTEX area

For the deep water bearing zone:

- MW-8A in the core of the chromate plume
- MW-22A on the north periphery of the plume

- MW-9A on the east periphery of the plume
- MW-13A and up-gradient un-impacted well

Testing of Soil

In addition to testing the groundwater of the respective water bearing zones, limited soil testing will be done. Three wells will be installed for the pumping tests. Samples from each of these wells from the shallow and deep water bearing zones will be tested for available iron, total organic carbon, and manganese chemistry.

Groundwater Sampling Protocols

The purpose of any sampling event is to obtain samples and testing results that will closely as possible replicate the aquifer conditions in the formation adjacent to the well bore. This goal is particularly critical with regard to many of the parameters measured for the evaluation of processes associated with the manipulation of redox conditions. Iron speciation, dissolved oxygen, sulfide concentration, redox potential, and concentration of trace gases are extremely susceptible to rapid changes upon exposure to atmospheric conditions. Volatilization and chemical reactions in some cases are almost instantaneous.

Purging of a well through the rapid removal of multiple well volumes will not generate samples that are representative of the conditions the testing program is designed to evaluate. Low flow purging and sampling procedures will be followed. The sampling train will include an instrument that will provide dissolved oxygen, pH, Eh, and specific conductivity from a single multi-probe head.

Hydrogeologic Evaluation

At this juncture the precise hydrodynamic behavior of the shallow and deep groundwater-bearing zones is unknown. There could be significant differences between the conditions assumed and the actual conditions at the site. With a plume of this areal extent, small differences in hydraulic character can have an impact on the practicality of methodologies to implement an IRZ program designed to remediate the chromate plumes. Thus pumping tests must be performed to define the actual hydraulic conditions in the shallow and deep water-bearing zones.

The pumping tests will generate the aquifer coefficient values necessary to perform detailed hydraulic modeling of the aquifer to define the best available design for remediation. It is anticipated that two pumping tests will be conducted near the location of monitor wells MW-11 and MW-25 in the shallow aquifer. One pumping test will be conducted near the location of MW-8A in the deep zone. It will be necessary to drill production wells at each of the three locations and utilize existing monitor wells for water level observation points.

It would be prudent to discontinue production from WW-1. Should groundwater production for supply purposes still be required, WW-1 should be plugged and new wells located in the most impacted portion of the deep zone, and along the eastern side of the plume directly up gradient of the irrigation wells that apparently caused the plume to migrate to the east-southeast.

Pumping Tests

Three separate 24-hour pumping tests will be conducted on each of the completed production wells. Water level measurements in the pumping production well will be measured for the entire 24-hour aquifer test. Water levels in monitor wells in close proximity to each production well (i.e. MW-8A, MW-11, MW-25 and the shallow and deep nested monitoring wells at each location) will be continuously monitored using a Hermit® datalogger during the pumping test.

After 24 hours, the pump will be turned off and water level measurements will be recorded in both the production well and adjacent monitor wells. Groundwater recovery measurements will continue for 24 hours or until the wells recover to original static water level conditions.

Data generated from the pumping tests will be used to establish hydraulic conductivity and transmissivity of both the shallow and deep aquifers and evaluate vertical hydraulic conductivities. That data will subsequently be used to develop a groundwater model for both aquifers.

Water produced during the pumping tests will be containerized in holding tanks with secondary containment. It is anticipated that the produced water will be pumped from the holding tanks into a pipeline and used as makeup water in plant operations or will be directly disposed into a disposal well.

Modeling

The data generated from the pumping tests will be entered into a groundwater model to perform three dimensional groundwater flow and contaminant transport simulations.

ARCADIS Geraghty & Miller will utilize Waterloo Hydrogeologic's Visual Modflow® to produce graphic hydraulic data which will assist in the appropriate placement of IRZ injection and monitoring wells. Visual Modflow® is a proven interactive data management and processing software system developed from the U.S. Geological Survey's industry standard finite-difference groundwater flow model.

IRZ Chromate Reduction Pilot Test

The configuration of a pilot study that would provide data to develop the final design parameters of a full scale remediation system for the shallow and deep chromate impacted water bearing zones is contingent on the completion of the baseline biogeochemical sampling and the pumping tests. The latter are needed to provide specific data concerning the hydrogeologic properties of each of the water bearing zones. In addition to hydraulic conductivity, the gradients across the site are also variable resulting in significant variations in groundwater velocity across the site. The ranges for groundwater velocity at the site are estimated to be 0.4 to 12 feet per year for the shallow water bearing zone and 120 or more feet per year for the deep water bearing zone. The results of the pumping test will be critical for the determination of the specific methodology used in the injection program. Appendix C outlines various injection program options.

The pilot evaluation of the injection of soluble carbon substrates for in-situ remediation of soluble chromate must include determination of key design parameters that fall into general categories as well as specific issues within each. These include:

- The hydrodynamics of the water bearing zones to be treated
    - The magnitude of lateral dispersion as injection solutions are carried away from an injection point
    - The impact of vertical and horizontal heterogeneity under pressure injection conditions
    - The impact of hydraulic gradients induced by proximal extraction wells or water flood injection wells
- The impact of the injected carbon substrates on the biogeochemical state of the treatment zones and ultimate efficacy of chromate remediation

  - How long will it take to create oxidation reduction potential (ORP) conditions that are at a minimum iron reducing
  - Will the rate of chromate reduction vary with continued decreases of ORP, the use of supplemental iron, or type of carbon substrate
    - What is the most cost effective approach (taking into account reagent costs versus duration of effort)
- The transport properties of the carbon substrate
  - The rate of carbon substrate consumption under relatively static flow conditions
    - This is driven by the rate at which the indigenous bacterial populations can grow given stimulation
  - The rate of carbon substrate consumption under flowing conditions
    - This is driven by the above as well and the effective porosity of the treatment zone and the existing bacterial population numbers
- The effect of the chemistry of the carbon substrate on the rate of biological utilization
  - It must be sufficiently bioactive to stimulate the required ORP conditions given the local groundwater velocity
  - It should not be so bioactive that it is consumed within a short distance from the injection point.

The answers to the above issues are in many cases interrelated. A pilot study is by definition a largely empirical process that is designed to cost effectively yield the design parameters required given the complexity of the inter-related processes described above.

In general the monitor well arrays for an in-situ reactive zone (IRZ) pilot test are designed to intercept groundwater amended with the injected solutions at a minimum of 30 days from the injection event and a maximum of 90 days from an injection event.

Given that time requirement, a minimum groundwater velocity is approximately 40 feet per year (this would allow for a monitor well 10 feet away to detect an injection event approximately 90 days after it occurred).

If the range of groundwater velocities assumed for the shallow water bearing zone are accurate (0.4 to 12 feet per year) the pilot test monitoring wells must be designed to evaluate the effects of pressure injection and the effects of artificial enhancement of gradients through pumping or water mounding adjacent to the injection well. Groundwater velocities are sufficiently high in the deep water bearing zone (probably due to on-going pumping) that a purely passive approach could be used during the pilot test, although it would still be of value to evaluate the effects of pressure injection.

In the deep water bearing zone the minimum apparent groundwater velocity assumed would allow the placement of the nearest monitor well 10 to 30 feet from the injection.

In each of the monitor well arrays for each of the water bearing zones (deep and shallow), there will be a second set of monitor wells located approximately twice the distance from the injection point as the first set of monitor wells. This will allow for a more accurate assessment of rate of utilization of the carbon substrates that are evaluated during the test.

The use of existing monitor wells will be considered as part of the pilot test. In particular, the monitor well arrays can be configured around existing monitor wells such that the value for lateral dispersion in each of the respective water bearing zones can be evaluated. In addition, the existing monitor well arrays will be of value during the pressure injection portion of the test. The wells selected and their spacing will be determined upon completion of the biogeochemical baseline sampling and the hydraulic testing and modeling. The pilot test will be designed to yield the desired information in a one year test interval.

Monitoring the biogeochemistry of the groundwater in the pilot test treatment zone is critical. This sampling provides the means for completing the quantitative evaluation of the concentration of carbon substrate injection solutions, the type of carbon substrate that will be required, and the interval between injection events. The monitoring program will fall into two broad categories. The first are field parameters and the second are parameters that require laboratory analysis. The parameters outlined for the biogeochemical assessment in Table 1 summarizes both as they are likely to be applied during the pilot test.

The need and use for each of the analytical parameters can be outlined as follows:

- The field parameters will provide instant data on conditions that in many cases are so sensitive to ambient redox conditions that they would not remain stable during shipment to the laboratory. In particular this includes the ORP, dissolved oxygen, ferrous iron, and sulfides. Low flow sampling procedures and a multiprobe sampling head will be used to further facilitate the evaluation of these sensitive parameters.

- Analyses of total and dissolved chromium will evaluate the effectiveness of the chromium removal process. These analyses will speciate the chromium (differentiate between Cr^{+6} and Cr^{+3}).

- Total alkalinity, bicarbonate, TDS, chlorides, calcium, sodium, magnesium, and potassium will provide information concerning general groundwater quality as well as aid in identifying groundwaters that may be of different origins.

- Nitrate, nitrite, ammonia, and phosphate analysis will provide information on trace nutrient levels in the treatment zone as well as the IRZ's impact on nitrate.

- Iron, manganese, sulfate, and sulfides analyses will be important indicators of the redox state of the water bearing zones before and after treatment

- Total organic carbon will provide information on the condition and concentration of the soluble carbon substrate.

- The permanent gases will provide information on the level of biological activity, as well as the type of activity.

The specific design parameters of the pilot study must await the completion of the initial biogeochemical assessment as well as the pump testing program. The biogeochemical state and the hydrogeologic character of the shallow and deeper water bearing zones will govern specifics of the pilot testing program such as:

- The location and number of injection and monitor wells

- Carbon substrate injection frequency, type of carbon substrate utilized, as well as the volume and concentration of injection reagents

- Sampling frequency

- The inclusion of additional sampling protocols or parameters

Remediation of Petroleum Hydrocarbon and Chloride/Sulfate/TDS Impact

As with treatment of the chromate plumes, there are delineation issues that must be resolved before a final remediation program can be properly designed for the petroleum hydrocarbon impacts observed near MW-5 and MW-6 and elevated chlorides beneath the plant site. Of concern is the great distance (over 700 feet) between MW-1, MW-5 and MW-6. Although, BTEX hydrocarbon concentrations in MW-1 do not exceed regulatory limits, the consistent presence of BTEX at low concentrations hints at other possible source areas besides MW-5 and MW-6. Delineation of these impacts can proceed in phased work conducted separately from the IRZ pilot test program discussed in this work plan. The biogeochemical assessment will evaluate ongoing natural attenuation of BTEX hydrocarbon. In addition, the attenuation effect of BTEX hydrocarbon on the dissolved chromate will also be evaluated. Also, additional water well inventory work in the surrounding area needs to be completed to determine the location of pumping wells and whether well completions in multiple zones exist.

At MW-5 and MW-6 an interim free product recovery system may be put into place to begin capture of the free product and control of its movement. The number and type of wells will be determined based on the biogeochemical and hydrogeological testing proposed above.

If during the biogeochemical assessment it is found that natural attenuation degradation kinetics are not rapid enough to treat the BTEX dissolved phase and soil-sorbed impacts, air sparging coupled with vapor extraction is likely to be the most preferable approach. However, if permeability contrasts are too high, it may be necessary to use water table depression in conjunction with SVE.

Remediation efforts for the chromium treatment process will be coordinated with this recovery effort to maximize benefits and to eliminate conflicting goals. The treatment of the residual dissolved plume and adsorbed phases and chlorides will depend upon the hydrodynamics of the site and may be addressed contemporaneously or following chromate remediation.

Hydraulic containment and use of water for industrial purposes may be one of the best approaches to use with the chloride-impacted water in the deep zone beneath the plant site. It may be necessary to isolate remediation efforts from chloride contamination caused by non-plant related activities by the use of hydraulic induced barriers. These conditions will be addressed in the models and pilot studies.

Conclusion

Following the completion of the tasks laid out in this work plan, a hybrid pressure injection and groundwater recovery system is likely to be the ultimate remediation approach for the chromate plumes. This system will be comprised of hydraulic control recovery wells in the center of the chromate plumes, possible beneficial utilization of the recovered groundwater by the operating plants for make-up process and cooling tower water in lieu of uncontaminated groundwater, direct disposal, carbon substrate injection wells around the perimeter of the chromate plumes for chromate remediation, phase-separated hydrocarbon recovery wells possibly coupled with air sparge/vapor extraction wells for the hydrocarbon remediation, and possible additional hydraulic control for the chloride plume. The likely ideal system will balance the minimal amount of groundwater recovery required to stimulate adequate flow rates with the minimum number of injection wells that will maximize the amount of in-situ chromate treatment.

References

Highlander Environmental Corporation, March 2000, Final Groundwater Plume Delineation Report, Eunice #2 Gas Plant, Eunice New Mexico.

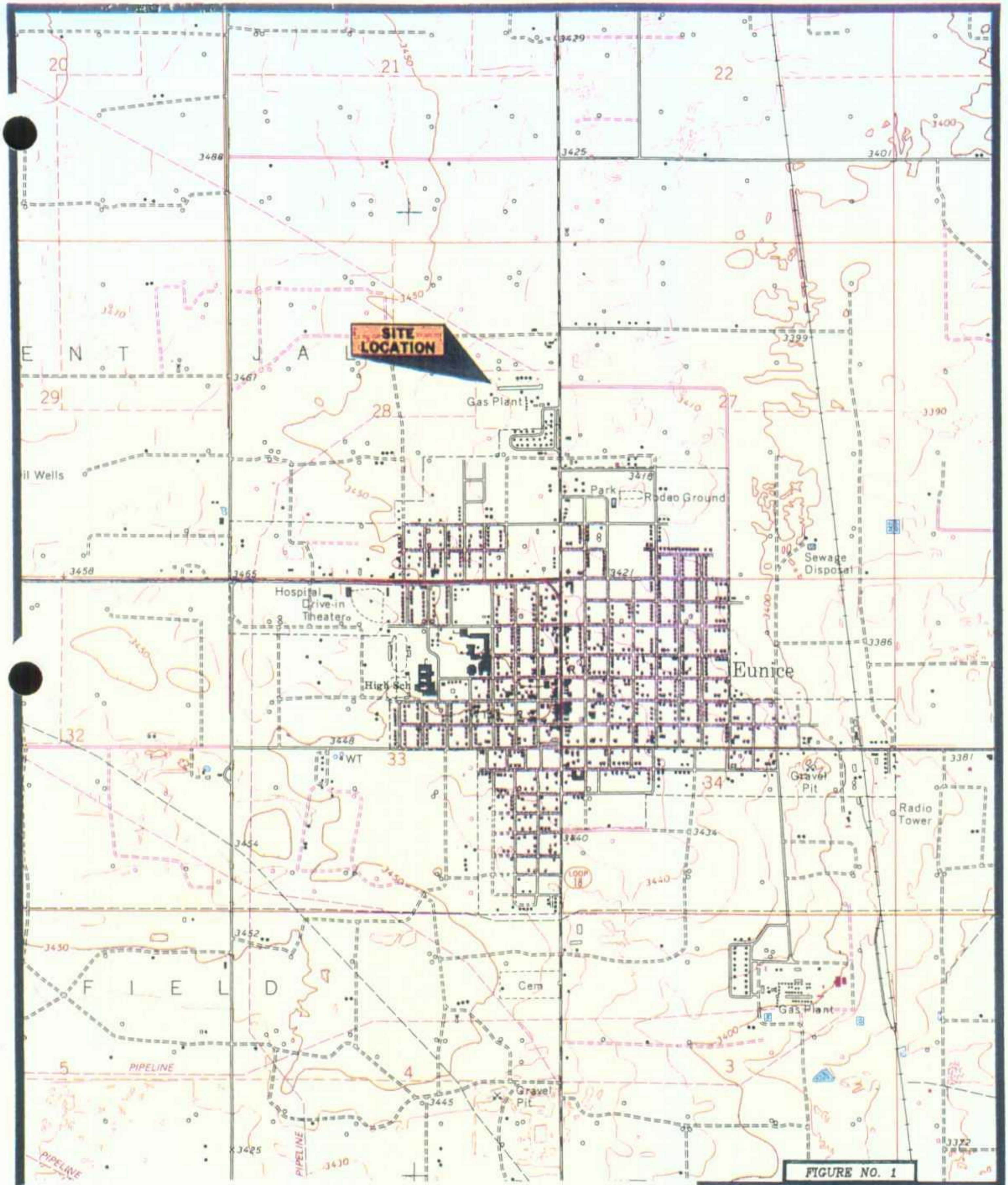


FIGURE NO. 1

LEA COUNTY, NEW MEXICO

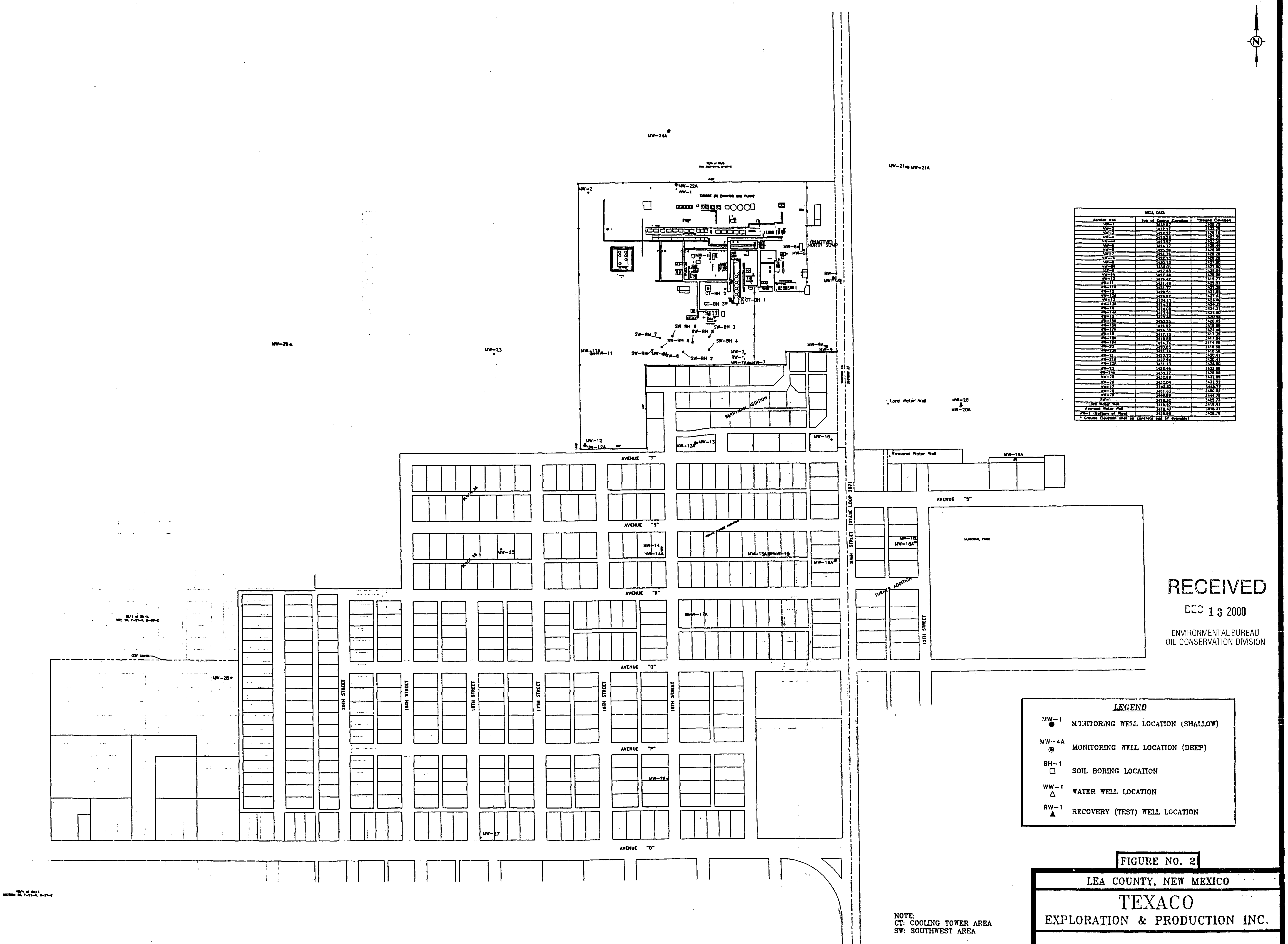
TEXACO
EXPLORATION AND PRODUCTION

TOPOGRAPHIC
MAP

HIGHLANDER ENVIRONMENTAL
MIDLAND, TEXAS

TAKEN FROM U.S.G.S.
EUNICE, NEW MEXICO
7.5' QUADRANGLE

SCALE: 1"=2,000'



WELL DATA		
Monitor Well	Top of Casing Elevation	*Ground Elevation
MW-1	3428.57	3428.79
MW-2	3432.17	3432.29
MW-3	3428.27	3428.10
MW-4	3423.38	3423.59
MW-4A	3423.57	3423.59
MW-5	3424.77	3425.49
MW-6	3425.28	3425.09
MW-7	3428.39	3428.28
MW-7A	3428.13	3428.28
MW-8	3430.13	3427.90
MW-8A	3430.01	3427.90
MW-9	3427.63	3425.09
MW-9A	3427.48	3425.09
MW-10	3418.42	3418.77
MW-11	3431.49	3429.07
MW-11A	3431.77	3429.28
MW-12	3429.51	3427.69
MW-12A	3429.92	3427.42
MW-13	3424.11	3424.40
MW-13A	3424.25	3424.38
MW-14	3424.08	3424.31
MW-14A	3423.90	3424.50
MW-15	3420.40	3420.55
MW-15A	3420.55	3420.65
MW-16A	3419.92	3419.99
MW-17A	3424.38	3424.48
MW-18	3417.15	3417.39
MW-18A	3418.88	3417.04
MW-19A	3414.74	3414.95
MW-20	3420.65	3418.50
MW-20A	3421.14	3418.50
MW-21	3422.72	3420.41
MW-21A	3422.94	3420.41
MW-22A	3431.13	3428.50
MW-23	3438.44	3433.99
MW-24A	3430.77	3428.98
MW-25	3432.69	3432.89
MW-26	3432.04	3432.52
MW-27	3443.33	3443.72
MW-28	3451.63	3450.02
MW-29	3446.89	3444.78
RW-1	3428.32	3425.73
*Lord Water Well	3419.97	3419.47
Rowland Water Well	3418.47	3418.47
WW-1 (Bottom of Pipe)	3429.95	3428.78

* Ground Elevation shot on concrete pad (if available)

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ENVIRONMENTAL BUREAU
OIL CONSERVATION DIVISION

LEGEND

MW-1 ●	MONITORING WELL LOCATION (SHALLOW)
MW-4A ⊙	MONITORING WELL LOCATION (DEEP)
BH-1 ☐	SOIL BORING LOCATION
WW-1 △	WATER WELL LOCATION
RW-1 ▲	RECOVERY (TEST) WELL LOCATION

NOTE:
CT: COOLING TOWER AREA
SW: SOUTHWEST AREA

Elevations shown are based on Monitor Wells 7, 8, and 9 as shown in letter by Ronald J. Eidson of West Engineering Co. September 3, 1997.

GRAPHIC SCALE IN FEET
0 200 400 600
Original Plotted at Scale: 1"=200'

FIGURE NO. 2

LEA COUNTY, NEW MEXICO

TEXACO
EXPLORATION & PRODUCTION INC.

EUNICE #2 (NORTH) GAS PLANT
BASE MAP

DATE: 6/30/99
DWN. BY: JDA
FILE: C:\787\BASE

HIGHLANDER ENVIRONMENTAL CORP.
MIDLAND, TEXAS

TABLE 1

Field and Laboratory Analytical Parameters for BioGeoChemical Evaluation

Parameter	Analytical Method[1]
Field Parameters	
Dissolved Oxygen	Field Probe
Redox potential	Field Probe
pH	Field Probe
Temperature	Field Probe
Specific Conductance	Field Probe
Iron, ferrous	Hach
Sulfate	Hach
Sulfides	Hach
Chromate	Hach
Laboratory Analyses	
Chromate, total Chromium, and Cr III	7196
Total Alkalinity	310.1
Bicarbonate	SM2320B
Total Dissolved Solids	160.1
Nitrate	353.2
Nitrite	353.2
Nitrogen, Ammonia	350.3
Phosphate	200.7
Iron, total	6010B
Iron, dissolved	6010B
Iron, ferrous	3500-FE D[3]
Iron, ferric	3500-FE D[3]
Total Manganese	6010B
Dissolved Manganese	6010B
Sulfate	375.4
Sulfides	376.1
Chlorides	352.2
Total Organic Carbon	9060 Modified[2]
Bromide	300
Iodide	4500-I[3]
Calcium	6010B
Sodium	6010B
Magnesium	6010B
Potassium	6010B
Permanent Gases	
Carbon Dioxide	Microseeps[4]
Oxygen	Microseeps[4]
Nitrogen	Microseeps[4]
Methane	Microseeps[4]

[1] Analyses will be conducted in accordance with "Methods for Chemical Analysis of Water and Wastes," USEPA, USEPA 600/4-79-020, Revised March 1983, unless otherwise indicated.

[2] "Test Methods for Evaluating Solid Waste, Physical/Chemical Methods," USEPA, SW-846, 3rd Edition, November 1990.

[3] "Standard Methods for the Examination of Water and Wastewater," APHA-AWWA-WPCF, 17th Edition, 1989 and 1991 Supplement.

[4] Method developed by the contract laboratory, Microseeps.

APPENDIX A

IN-SITU CHROMATE REDUCTION PROCESSES

APPENDIX A

IN-SITU CHROMATE REDUCTION PROCESSES

Chromium Chemistry

Remediation of chromate in groundwater by in-situ reduction is a process that is driven by the nature of the aqueous chemistry of chromium. In the +6 oxidation state (chromate) chromium is an oxyanionic complex that is soluble throughout all ranges of pH and that undergoes changes in complexation based on pH and concentration as follows:

- Below pH 0.9 it is the form H_2CrO_4;
- Above pH 6.4 it is in the form CrO_4^{2-};
- Between pH 0.9 and 6.4 and a concentration lower than 1,000 mg/L it takes the form of $HCrO_4^-$; and
- Between pH 0.9 and 6.4 and a concentration above 1,000 mg/L it takes the form of $Cr_2O_7^{2-}$.

Each of the above forms of the chromate complex is soluble. The conversion of the chromate to the Cr (III) ion is a transformation into an insoluble form. In groundwater, Cr (III) exists as the soluble Cr^{+3} ion at a pH below 4.5. With increasing pH, Cr (III) hydroxides are produced. In the pH range of 5 to 12 the aqueous solubility limit of Cr (III) is less than 0.05 mg/L.

The most common method of chromate remediation in groundwater (as well as in surface chromate waste water treatment systems) is through the exploitation of the reaction of chromate with the ferrous iron cation as follows:

- $HCrO_4^- + 3Fe^{2+} + 7H^+ = Cr^{3+} + 3Fe^{3+} + 4H_2O$

This reaction is extremely fast, taking place within 5 minutes. In addition, Cr (III) forms a solid solution with the precipitating ferric iron (Fe^{3+}) that further reduces the solubility of the precipitated Cr (III).

Ferrous ions can be generated in-situ through three methods:

1. The direct addition of soluble ferrous iron salts (most typically sulfate).
    - This has the disadvantage of high reagent cost, the requirement for significant pH modification (to less than 4.5), and a significant contribution to TDS from the pH adjustment as well as the ferrous iron counter anion (sulfate or chloride).
2. The production of ferrous ions from the in-situ geologic matrix through the additions of dithionite salts (typically the sodium salt).
    - In most instances (and at this site, also, based on the description of the "red sands" in the boring logs) there is native iron mineralogy to allow this approach to work.

- However, it has the disadvantage of requiring significant pH adjustment to alkaline conditions and subsequent readjustment to normal pH conditions. The pH adjustment steps contribute to increases in TDS as well as the contribution from the sulfate that is the ultimate end product of the dithionite anion. In plumes of large areal extent, reagent costs are a significant factor.

3. Ferrous iron can also be produced from the geologic matrix through the stimulation of indigenous iron reducing bacterial populations that exploit the ferric/ferrous iron redox couple. This requires the injection of a soluble carbon substrate such as diluted molasses that can be used by the bacteria to consume the native dissolved oxygen in the water bearing unit being treated, followed by further bacterial action to achieve iron reducing conditions. The end product of this process is carbon dioxide (the ultimate fate of the soluble carbon substrate). The solubilized iron ultimately returns to the geologic matrix as insoluble ferric iron.

    - In addition to the reduction of chromate by the biological production of ferrous iron, an in-situ reactive (IRZ) zone also reduces chromate to insoluble Cr (III) by other abiotic processes produced under aerobic conditions, reactions with extracellular enzymes that reduce chromate, similar reactions with bacterial cell walls, and lastly, direct chromate reduction through direct reactions with the soluble carbon substrate.

It is also important to realize that it is almost certain that there have already been significant amounts of chromate reduced to Cr(III) driven by natural abiotic and biological processes in the impacted aquifer. Unless extremely radical action is taken such as pH adjustment to less than 2.0 or flushing with high concentration of complexing agents, the Cr(III) already deposited in the aquifer matrix will stay in place. One consequence of the proposed approach will be to evaluate the stability of that material. The envisioned remediation plan which will generate ferrous and then solid phase ferric iron will also serve to provide further stabilization of the existing Cr(III) through chromium/iron solid solution reactions as well as contributions to the TOC of the water-bearing zones.

References

Bartlett, R.J. and Kimble, J.M., 1976. Behavior of Chromium in soils: I. Trivalent Forms, J. Environ. Qual., Vol. 5, no. 4, pp. 379-383.

Bartlett, Richmond and James, Bruce, 1979. Behavior of Chromium in soils: III. Oxidation, J. Environ. Qual. Vol. 8, no. 1, pp. 31-35.

Koruh, N., Stupar, J., and Gorenc, B., 2000. Reduction and Oxidation Processes of Chromium in Soils, Environmental Science and Technology, Vol. 34, No. 1, pp. 112-119.

APPENDIX B

CHROMATE REMEDIATION SYSTEM TECHNOLOGY DOCUMENTATION

COST AND PERFORMANCE REPORT

Anaerobic In-situ Reactive Zone at an Abandoned Manufacturing Facility, Emeryville, California

March 2000

EPA
U.S. Environmental Protection Agency
Office of Solid Waste and Emergency Response
Technology Innovation Office

Anaerobic In-situ Reactive Zone at an Abandoned Manufacturing Facility, Emeryville, California

Summary Information

Site Name, Location	Abandoned Manufacturing Facility, Emeryville, California
EPA ID Number	Not Applicable
Mechanism(s)	Anaerobic Reductive Dechlorination and Metal Precipitation
Technology	Electron Donor Addition (Molasses)
Configuration	Direct Injection
Technology Scale	Pilot and Full scale
Media/Matrix Treated	Groundwater
Contaminants Targeted	TCE, hexavalent chromium
Period of Operation	Pilot study – August 1995 to February 1996 Full scale system-ongoing, data available from April 1997 to October 1998

Site History/Source of Contamination [1]

From 1952 until 1995, metal plating operations, including nickel plating, were performed at a manufacturing facility located in Emeryville, California (actual site name confidential). Solvents were used in degreasing operations until 1992, when they were replaced with a liquid-alkaline soak process. Plating operations were discontinued in 1995, and the associated plating equipment has subsequently been removed from the site. Operations at the site resulted in the groundwater becoming contaminated with chlorinated solvents and metals.

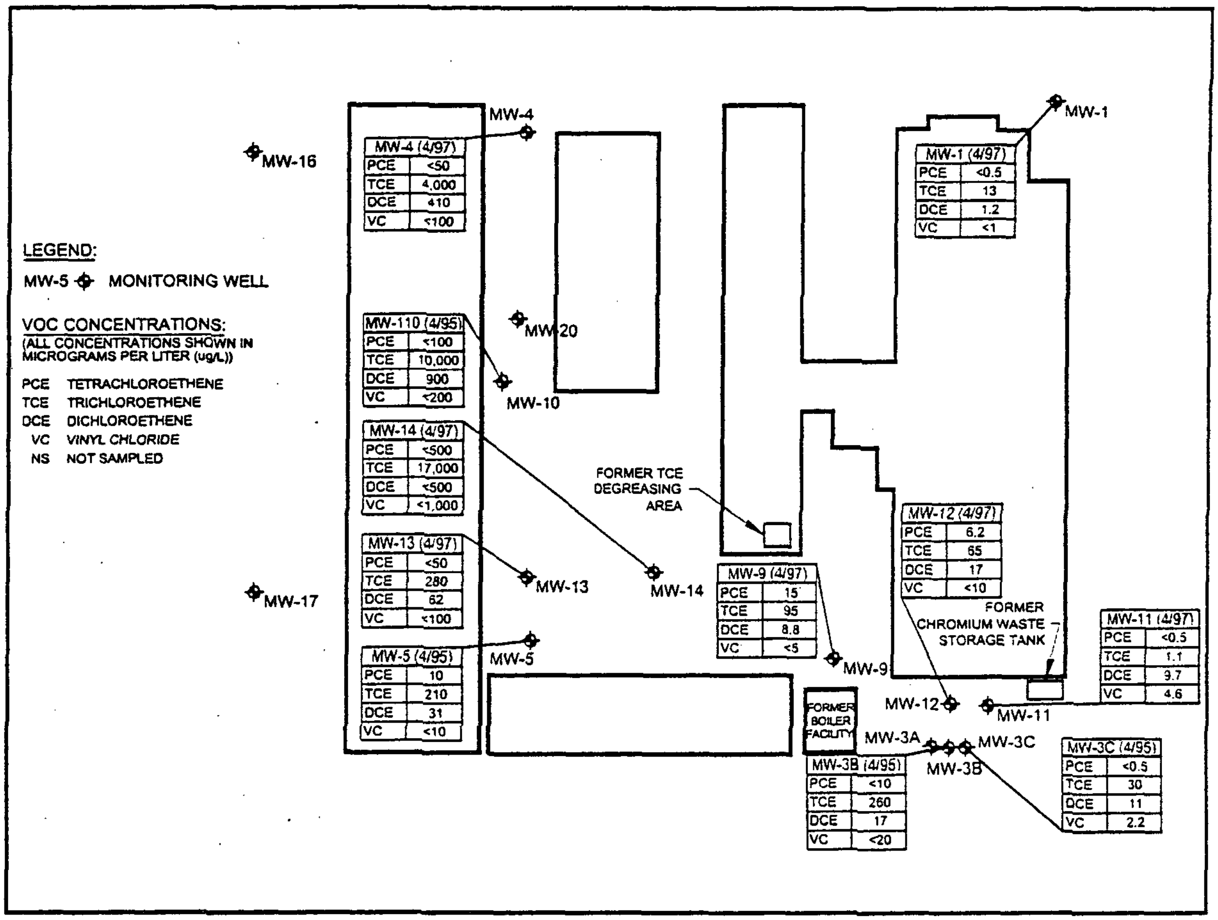
Between 1977 and 1985, 24 groundwater monitoring wells were installed at the site and on adjacent properties. Figure 1 shows the location of the 14 on-site monitoring wells. Elevated levels of chromium and trichloroethene (TCE) was detected in groundwater in the late 1970s and early 1980s. The cleanup of the site is being completed under a state voluntary cleanup program. In 1995, the site owner initiated a pilot study to evaluate anaerobic reductive dechlorination and metals precipitation via an in-situ reactive zone as a possible remedy for the site (as a potential alternative to a conventional pump and system). The following case study primarily focuses on the reductive dechlorination of TCE; limited data on the precipitation of hexavalent chromium was provided in the available references.

Geology/Hydrogeology/Contaminant Characteristics [1]

The geology of the site geology consists of interbedded sand and clay units. Groundwater is found at depths of 3.5 to 8 feet below ground surface (bgs). Groundwater velocity is estimated to be 60 feet per year.

TCE and chromium are the primary contaminants in the groundwater at the site. TCE concentrations from April 1995 (prior to initiation of the pilot study) were as high as 17,000 ug/L (Well MW-14). Historical groundwater data from on-site wells indicated that, over the past 10 years, TCE concentrations have been slowly decreasing. For example, TCE concentrations in Well MW-10 were 12,000 μg/L during a June 1985 sampling event and 10,000 μg/L during an April 1995 sampling event.

Figure 1: Pre-Injection CAH Concentrations, Abandoned Manufacturing Facility, Emeryville, California (April 1995) [1]



Matrix Characteristics at Abandoned Manufacturing Building [1]

Parameter	Value
Soil Type	Interbedded sand and clay units
Depth to Groundwater	Approximately 3.5 to 8 feet
Thickness of Aquifer	Not available
Fraction of Organic Carbon	Not available
DNAPL Presence	Not Indicated
Hydraulic Conductivity	Not available
Groundwater Velocity	60 feet per year

Technology Description [1,3]

Pilot Study

The pilot study was conducted between August 1995 and February 1996. The pilot study was performed to determine if the rate of TCE degradation and metals precipitation could be enhanced by an anaerobic in-situ reactive zone. Groundwater monitoring data, collected prior to the start of the pilot study, indicated that limited reductive dechlorination of TCE to cis-1,2-dichloroethene (DCE) was occurring, but that the rate of dechlorination was limited due to the biogeochemical conditions at the site (the organic carbon source was depleted or the environment was not sufficiently reducing). Vinyl chloride (VC), the degradation product of cis-1,2-DCE, was either not detected or was sporadically detected in many of the wells. According to the site contractor, DCE and VC may have been present in some wells prior to start of the pilot study, but were not detected because of high method detection limits (e.g., 1,000 µg/L for DCE and 2,000 µg/L for VC).

To establish the anaerobic reactive zone, a mixture of molasses, biologically inoculated solution (supernatent), and tap water was injected into the subsurface. Injection of the supernatent was needed because of low plate counts observed in one well during a baseline sampling event. The supernatent used for the pilot study was from the anaerobic treatment system of a local municipal authority.

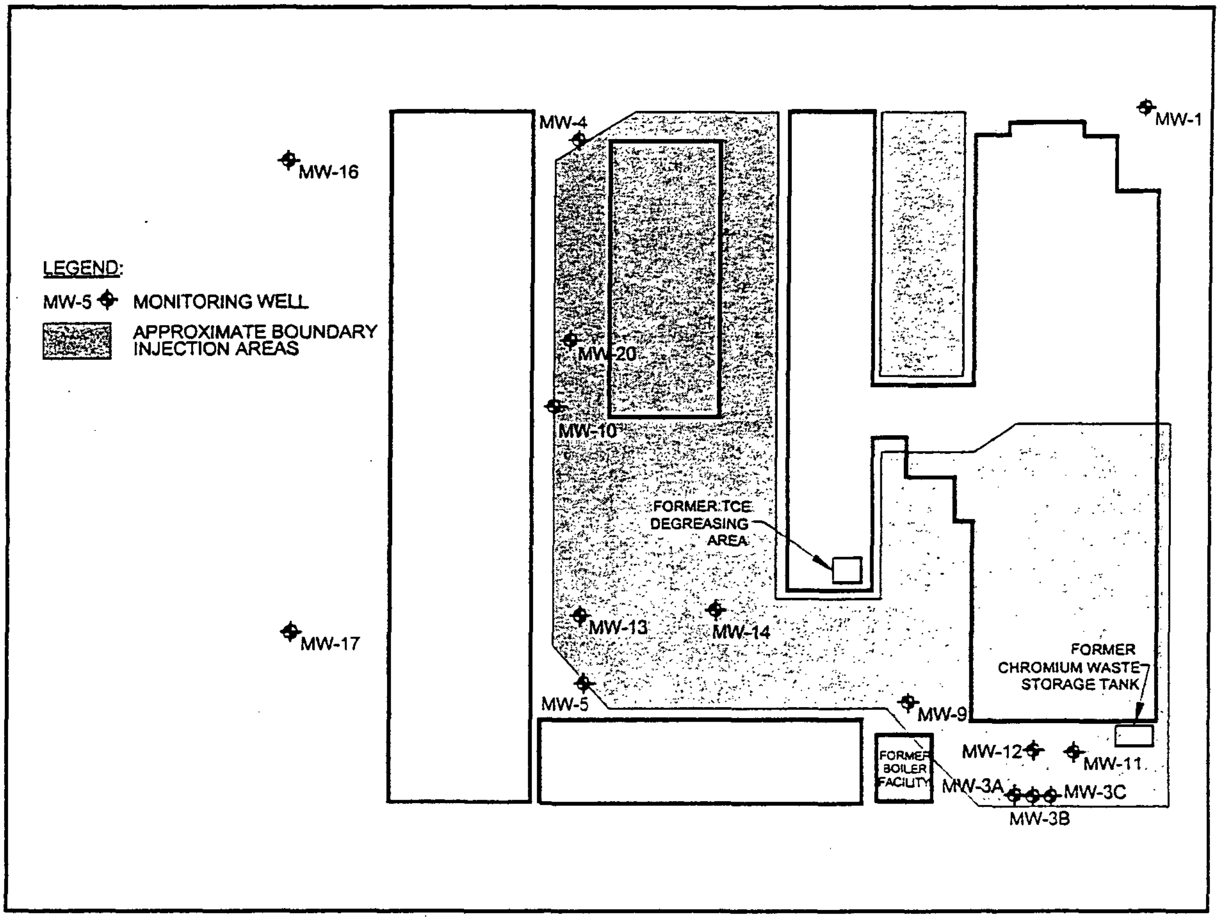
The results of the pilot study indicated that the historical reductive dechlorination rate at the site could be enhanced via the injection of the molasses solution. For example, TCE concentrations in Well MW-10 were reduced from 10,000 µg/L in April 1995 to 4,200 µg/L in February 1996.

Full-Scale System

In April 1997, ninety-one temporary injection points were installed at the site, as shown in Figure 2. The injection points are located in two areas due to the location of existing buildings. Each injection points was installed to a depth of 24 feet bgs.

The full-scale system has been operating since April 1997 and data are available through October 1998. Two molasses injection events have been performed at the site, in April 1997 and in February 1998. Each molasses injection event included a mixture of water, molasses, and a small amount of supernatent (to provide additional bacteria capable of degrading TCE). During the first injection event, each injection point received 25 gallons of molasses, 1 gallon of supernatent, and 125 gallons of water. Information about the volume and composition of the solution used in the second injection event was not available. The reagent was mixed on-site and manually injected into the subsurface using a centrifugal pump.

Figure 2: Full-Scale Injection Area, Abandoned Manufacturing Facility, Emeryville, California [2]



Technology Performance [1,2]

Performance data are available through October 1998. Figure 3 presents the data on concentrations of PCE, TCE, DCE, and VC in on-site wells as of October 1998. Figures 4 and 5 show the change in concentrations of TCE, DCE, and VC from December 1996 through October 1998 for Wells MW-4 and MW-14, respectively. Well MW-14 is located in the source area and MW-4 is in the mid-plume area. Figure 6 shows the average TCE, DCE and VC concentrations in the on-site monitoring wells within the remediation area (MW-4, MW-10, W-13, and MW-14).

As shown in Figure 3, the maximum contaminant concentrations measured in groundwater at the site as of October 1998 were PCE (0.75 ug/L), TCE (17 ug/L), DCE (1,400 ug/L), and VC (180 ug/L). Figures 4 and 5 show that TCE, DCE, and VC concentrations in wells MW-14 and MW-4 were reduced to below the detectable levels by October 1998. Initial DCE and VC concentrations increased following the first reagent injection, but then declined by October 1998. According to the site contractor, the trends for TCE degradation products (DCE and VC) indicate that TCE is being reductively dechlorinated to ethene. As shown in Figure 6, concentrations of TCE in wells located within the remediation area have decreased by 99% (3,040 µg/L in April 1995 to 4 µg/L in October 1998).

Figure 3: CAH Concentrations - October 1998, Abandoned Manufacturing Facility, Emeryville, California [2]

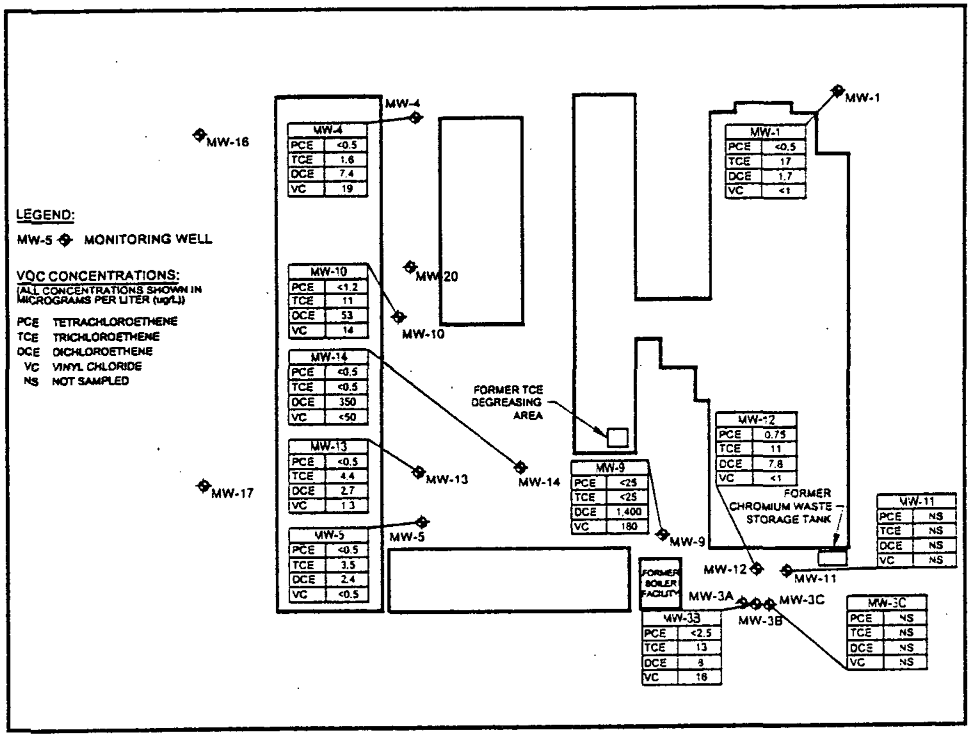


Figure 4: Analytical Results for Well MW-4, Abandoned Manufacturing Facility, Emeryville, California [2]

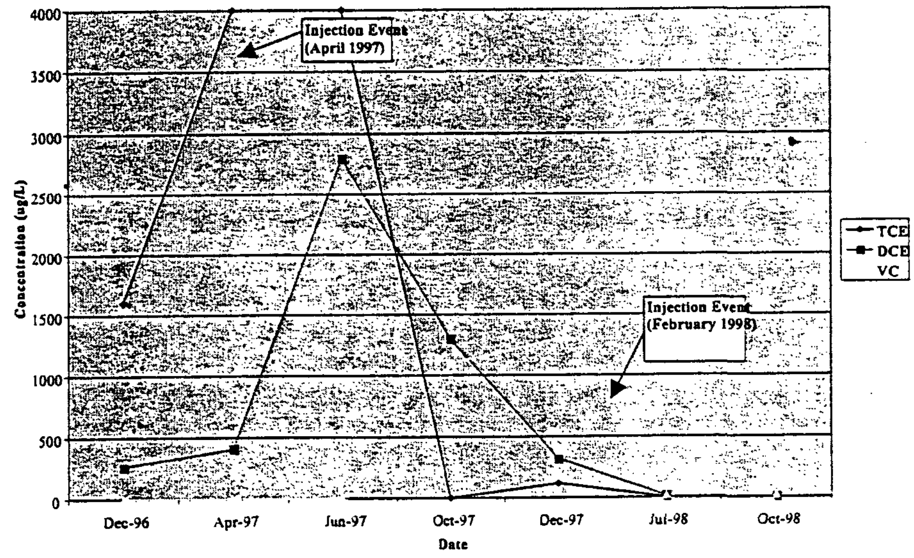


Figure 5: Analytical Results for Well MW-14, Abandoned Manufacturing Facility, Emeryville, California [2]

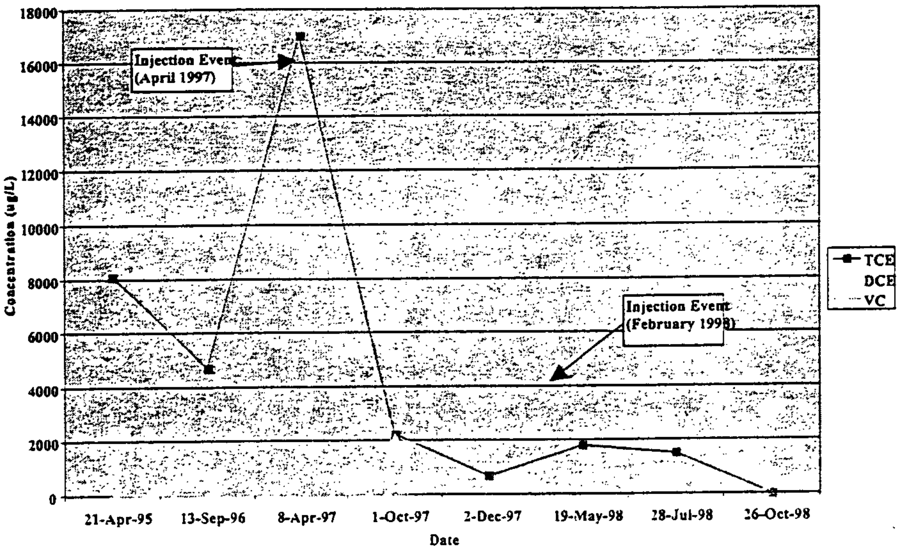
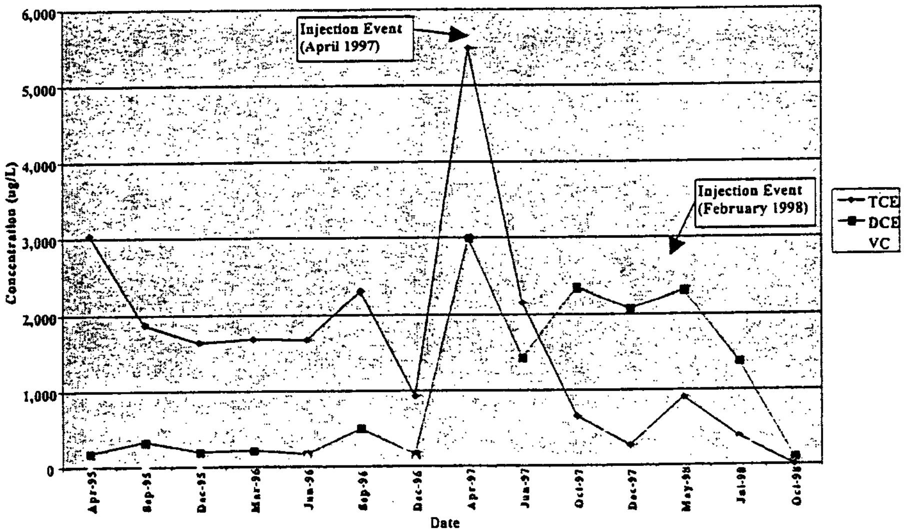


Figure 6: Average Concentrations, On-Site Wells in Remediation Area, Abandoned Manufacturing Facility, Emeryville, California [2]



Data includes values for wells MW-4, MW-10, MW-13. And MW-14

In addition, the average concentrations of total chromium and hexavalent chromium in the injection area have been reduced by approximately 98% and 99%, respectively, and some of the wells where historic hexavalent chromium concentrations were in excess of 100,000 µg/L are now less than the detection limit (5 µg/L).

Technology Costs [1]

The overall project cost is approximately $400,000. No further information was provided about the components of this cost, such as a breakdown of capital or operations and maintenance (O&M) costs.

Summary Observation and Lessons Learned [1,2,3]

The injection of molasses reagent solution created conditions favorable for the reduction in TCE, DCE, VC, and chromium concentrations in the subsurface. During an 18-month period of full-scale operation, average concentrations of TCE were reduced by 99%, from more than 3,000 ug/L to 4 ug/L. Average concentrations of hexavalent chromiumwere were reduced by 99% to below detection levels.

The solution of molasses, supernatent, and water was injected through 91 temporary injection points installed using a Geoprobe™. According to the remediation contractor, the use of a Geoprobe™ allowed the injection points to be installed relatively quickly and at low cost.

A pilot study was conducted prior to the full-scale operation. The pilot study showed that the rate of reductive dechlorination could be enhanced with the use of an injected molasses solution.

Contact Information

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References:

1. E-mail Transmittal from Dan Jacobs, ARCADIS Geraghty & Miller, to Richard Weisman, Tetra Tech EM Inc. 1999. California Text - ECI EPA.doc. March 24.

2. E-mail Transmittal from Dan Jacobs, ARCADIS Geraghty & Miller, to Richard Weisman, Tetra Tech EM Inc. 1999. California Text - ECI Figures.xls. March 24.

3. Fax Transmittal from Dan Jacobs, ARCADIS Geraghty & Miller, to Kathy Yager, EPA. 1998. Site 3 - Abandoned Manuafacturing Facility, Emeryville, California. May 18.

INNOVATIVE TECHNOLOGY
Summary Report

DOE/EM-0499

In Situ Redox Manipulation

Subsurface Contaminants Focus Area

Prepared for
U.S. Department of Energy
Office of Environmental Management
Office of Science and Technology

January 2000

INNOVATIVE TECHNOLOGY
Summary Report

In Situ Redox Manipulation

OST/TMS ID 15

Subsurface Contaminants Focus Area

Demonstrated at
Hanford Site
Richland, Washington

INNOVATIVE TECHNOLOGY
Summary Report

Purpose of this document

Innovative Technology Summary Reports are designed to provide potential users with the information they need to quickly determine whether a technology would apply to a particular environmental management problem. They are also designed for readers who may recommend that a technology be considered by prospective users.

Each report describes a technology, system, or process that has been developed and tested with funding from DOE's Office of Science and Technology (OST). A report presents the full range of problems that a technology, system, or process will address and its advantages to the DOE cleanup in terms of system performance, cost, and cleanup effectiveness. Most reports include comparisons to baseline technologies as well as other competing technologies. Information about commercial availability and technology readiness for implementation is also included. Innovative Technology Summary Reports are intended to provide summary information. References for more detailed information are provided in an appendix.

Efforts have been made to provide key data describing the performance, cost, and regulatory acceptance of the technology. If this information was not available at the time of publication, the omission is noted.

All published Innovative Technology Summary Reports are available on the OST Web site at http://ost.em.doe.gov under "Publications."

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SECTION 1

SUMMARY

Technology Summary

Problem

Operations have contributed contamination to the subsurface at a number of DOE sites. These contaminants have migrated to the groundwater at these sites. Contaminants in the groundwater are often laterally dispersed over large areas and located vertically at depths up to hundreds of feet below the ground surface. Groundwater contaminants are difficult to treat; the baseline techniques of excavation and/or pump and treat are very expensive over the life-cycle of the project, often projected to be in excess of 30-200 years.

How It Works

In Situ Redox Manipulation (ISRM) is a technology based upon the in situ manipulation of natural processes to change the mobility or form of contaminants in the subsurface. ISRM was developed to remediate groundwater that contains chemically reducible metallic and organic contaminants. ISRM creates a permeable treatment zone by injection of chemical reagents and/or microbial nutrients into the subsurface downgradient of the contaminant source. The type of reagent is selected according to its ability to alter the oxidation/reduction state of the groundwater, thereby destroying or immobilizing specific contaminants. Because unconfined aquifers are usually oxidizing environments and many of the contaminants in these aquifers are mobile under oxidizing conditions, appropriate manipulation of the redox potential can result in the immobilization of redox-sensitive inorganic contaminants and the destruction of organic contaminants. This concept requires the presence of natural iron, which can be reduced from its oxidized state in the aquifer sediments to serve as a long-term reducing agent. The figure below depicts the ISRM concept.

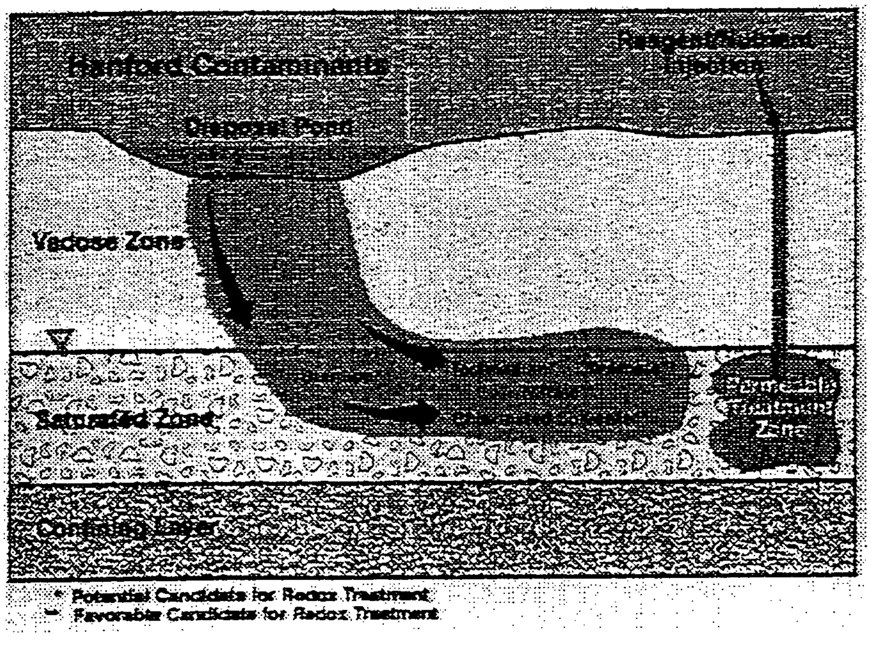

Figure 1. ISRM Concept

- A chemical reducing agent such as sodium dithionite is injected into the aquifer through a standard groundwater well.
- The reducing agent reacts with iron naturally present in the aquifer sediments in the form of various minerals (clays, oxides, etc.).
- Reaction products from the dithionite (largely sulfate) and any mobilized trace metals are withdrawn from the aquifer and disposed.
- Redox sensitive contaminants that migrate through the reduced zone in the aquifer become immobilized (metals) or destroyed (organic solvents). Potential contaminants for treatment with ISRM include: chromate, uranium, technetium, and chlorinated solvents.
- ISRM is a passive barrier technique, with no pumping or above-ground treatment required once the treatment zone is installed. For this reason, the operation and maintenance costs after installation are very low.

Potential Markets

Potential markets include sites where groundwater contamination (redox-sensitive metals, such as chromium, uranium and technetium, inorganic ions, radionuclides, and chlorinated hydrocarbons) is dispersed over large areas and is deeper than 30 feet below the surface.

Advantages over Baseline

- A permeable treatment zone would be a permanent solution for groundwater remediation.
- The technology is expected to be cheaper than the pump-and- treat baseline because the cost of installation for both options is comparable. but long-term operation and maintenance costs are significantly less with ISRM.
- The treatment zone remains active in the subsurface, where it is available to treat contaminants that seep slowly from less permeable zones.
- ISRM minimizes human exposure to contaminants during remediation because neither contaminated groundwater nor matrix material are brought above ground.
- The barrier is renewable if the original emplacement does not meet performance standards

Demonstration Summary

This report covers demonstrations that took place between September 1995 and September 1998 at the DOE Hanford Site in Washington State. Performance of the technology is based upon the initial "proof of principle" demonstration at the Hanford Site's 100-H Area in 1995 and the Treatability Test in 1997-1998 at the 100-D Area. The 100 Area of the Hanford Site, the site of nine nuclear reactors, is located in the north-central part of the site near the Columbia River. During reactor operations, chromium was introduced to the soil and, ultimately, the groundwater in this area. Aqueous chromate concentrations in the reduced zones in the 100-H Area were 60 parts per billion (ppb) and 910 ppb in the 100-D Area prior to the ISRM tests. Depth to the uppermost unconfined aquifer at the 100-H area is approximately 50 feet, while it is approximately 85 feet at the 100 D area. The unconfined aquifer is approximately 15-20 feet thick in the 100 Area.

- The initial demonstration was designed as a "Proof of Principle" field test:
    1) to demonstrate that a pilot-scale reduced zone could be created in the Hanford unconfined aquifer;
    2) to demonstrate feasibility of scale-up from laboratory to pilot-scale in-situ conditions;
    3) to design a plan for assessing performance and longevity of a pilot-scale demonstration of the ISRM technology.
- The second test was a treatability field-scale demonstration of ISRM. This demonstration was designed to provide the required cost and performance data for identifying requirements for constructing a full-scale barrier and to assess ISRM effectiveness for remediating chromium-contaminated groundwater, by treating a 150 foot x 50 foot area.
- A full-scale deployment at the Hanford 100-HR-3 Operable Unit is planned to begin in late '99.

Key Results

- Aqueous chromate concentrations within the reduced zone (50 feet in diameter) decreased to below detection limits (<8ppb).
- Two years after the injection of sodium dithionite reducing agent, the treatment zone remains anoxic and chromate remains below detection.
- A cost-benefit analysis showed that ISRM could save 60% of the cost of a pump-and-treat system for remediating groundwater contaminated with chromate at Hanford over a 10-year period.
- Bench-scale tests have demonstrated destruction of trichloroethylene (TCE) and perchloroethylene (PCE) by redox manipulation.
- ISRM has also been demonstrated to treat TCE contamination at a Fort Lewis, Washington DoD site in 1998 and will be demonstrated at DoD's Moffett Field, California in 2000.

Commercial Availability

- Battelle Pacific Northwest National Laboratory is currently working with commercial partners to deploy the technology.

SUMMARY continued

CONTACTS

Technical

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Management

Jim Wright, DOE EM-50, Subsurface Contaminants Focus Area Manager, (803) 725-5608.

Other

All published Innovative Technology Summary Reports are available online at http://em-50.em.doe.gov. The Technology Management System, also available through the EM-50 web site, provides information about OST programs, technologies, and problems. The OST reference number for ISRM is 15.

SECTION 2

TECHNOLOGY DESCRIPTION

Overall Process Definition

Process Descriptions

- The ISRM treatment zone is created through a three-phase process:
  - During the injection phase, a reagent is injected into the aquifer through injection/withdrawal wells at the rate and duration required to treat the desired volume of aquifer sediments. This treatment volume plus the quantity of available iron in the sediments determines the amount of reductive capacity generated in the barrier and, ultimately, the barrier's duration.
  - During the residence phase (approximately 18 hours), the reagent is allowed to react with the aquifer sediments. The reductant reacts with the iron in the sediments by the following reaction:

$$SO_2^- + Fe^{+3} + H_2O = SO_3^{-2} + Fe^{+2} + 2H^+$$

  - During the withdrawal phase, unreacted reagent, buffers, reaction products, and mobilized trace metals are withdrawn through the injection/withdrawal wells.

- Following creation of the ISRM treatment zone, contaminated groundwater flows through the permeable barrier under natural gradient conditions. No pumping or above-ground treatment is required, greatly decreasing the long-term maintenance and operation cost.
- Target contaminants are destroyed or immobilized by interactions with the reduced structural Fe in the ISRM treatment zone. Chromate is immobilized by reduction to highly insoluble chromium hydroxide or ferric-chromium hydroxide.

$$3Fe^{+2} + CrO_4^{-2} + 5H^+ = Cr(OH)_3 + 3Fe^{+3} + H_2O$$

- An ISRM treatment zone removes dissolved oxygen in the migrating groundwater by the very fast reaction:

$$4\,Fe^{+2} + O_2 + 4H^+ = 4\,Fe^{+3} + 2H_2O$$

This reaction creates a deoxygenated plume of groundwater within the treatment zone.

- If the original ISRM barrier emplacement does not meet target cleanup levels, the treatment zone's reductive capacity can be restored by repeating the emplacement process. This can be done using existing injection/withdrawal wells, so a large investment is not required.
- The redox altering reagent used in these tests was sodium dithionite ($Na_2S_2O_4$). The dithionite ion, commonly known as hydrosulfite, is a strong reductant, particularly in strongly basic solutions.
- Reduction reactions with the dithionite ion typically proceeds in two steps: dissociation of the dithionite ion to form two sulfoxyl (SO_2^-) radicals; reaction of these radicals with the oxidized species (Fe^{+3}) yields a reduced species (Fe^{+2}) and sulfite (SO_3^{-2}) or bisulfite (HSO_3^-).

A conceptual diagram of the In Situ Redox Manipulation process is shown in the figure below.

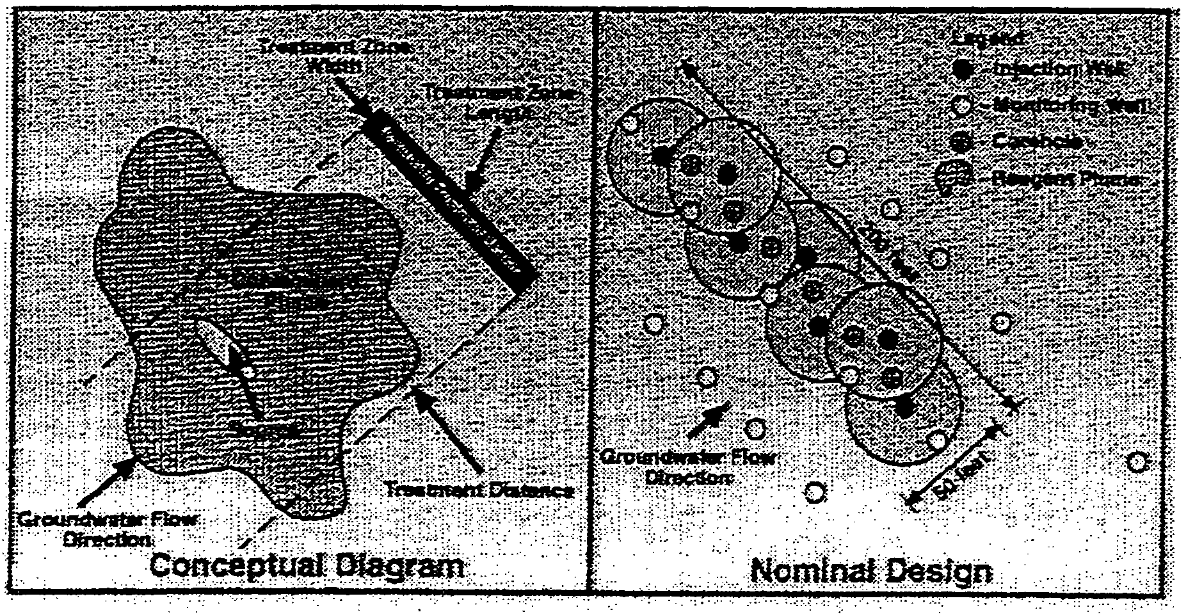

Figure 2. Conceptual Diagram and Design of ISRM barrier

System Operation

Operational parameters such as rate of injection, pressure, volume of reagent, and time of injection are determined based upon specific site characteristics and needs, such as hydraulic conductivity of the aquifer, thickness of the aquifer, spacing of injection wells, etc.

Materials and equipment to be used to deploy ISRM include the sodium dithionite reagent and the following equipment: four different types of wells, field trailers, mixing and storage tanks, pumps, and analytical equipment. The wells included: five injection/withdrawal wells, four standard monitoring wells, two multilevel monitoring wells, and three Westbay multilevel monitoring wells. Ten 20,000 gallon frac tanks were used to hold groundwater for dilution of concentrated tracer solutions and reagent for treatment zone emplacement. Two pumps were used for the bromide tracer test and dithionite injection/withdrawal test, a 0.75 horsepower pump and a 3 horsepower pump.

Manpower skills and training required include standard drilling operators for installation of the injection and monitoring wells, a field operator who is familiar with pumps, valves, piping, and handling of chemicals, and a field analytical chemistry technician.

Secondary waste generated by ISRM includes aqueous potassium/sodium sulfate at a volume of approximately 100,000 gallons per well according to the site-specific conditions required at the Hanford site.

Operational risks and concerns are equivalent to those of a pump and treat operation, but also include concerns regarding handling of chemicals, i.e. the reagent, and injection of fluids as opposed to simple extraction during a pump and treat operation.

SECTION 3

PERFORMANCE

Demonstration Plan

Performance of the technology is based upon the initial "proof-of-principle" demonstration at the Hanford Site's 100-H Area in 1995 and the Treatability Test in 1997-1998 at the 100-D Area. The 100 Area of the Hanford Site, the site of nine nuclear reactors, is located in the north-central part of the site near the Columbia River. During reactor operations, chromium was introduced to the soil and, ultimately, the groundwater in this area.

- Aqueous chromate concentrations in the reduced zones in the 100-H Area were 60 ppb and 910 ppb in the 100-D Area prior to the ISRM tests.
- Depth to the uppermost unconfined aquifer at the 100-H area is approximately 50 feet, while it is approximately 85 feet at the 100 D Area.
- The unconfined aquifer is approximately 15-20 feet thick in the 100 Area.

The objectives of the two demonstrations, one in the 100-H Area and one in the 100-D Area, were to:

- Establish feasibility of creating a reduced zone in the aquifer using ISRM, and the possibility of scaling up to full scale during both tests.
- Evaluate secondary effects of the process.
- Develop a strategy for a pilot test-scale deployment of ISRM at Hanford during the proof of principle test in 1995. The pilot test was performed in 1997 and 1998.

During the "proof-of-principle" test in the 100-H Area, operations included the following:

- 77,000 liters (20,500 gallons) of buffered sodium dithionite solution were successfully injected into the unconfined aquifer through a single 8-inch diameter injection/withdrawal well, creating a reduced zone approximately 15 m (50 ft) in diameter. The sodium dithionate reagent was allowed to react with the aquifer sediments for approximately 18 hours, and then was withdrawn. The buffer solution consisted of potassium carbonate/potassium bicarbonate at pH 11. The potassium salts also prevent dispersion of clays. During the withdrawal phase (83 hours, 4.8 injection volumes), unreacted reagent, buffer, reaction products, bromide tracer, and mobilized metals were withdrawn through the same well.
- Sixteen 2-inch-diameter monitoring wells were placed at various radial distances to assess physical and chemical conditions after the test. The monitoring wells were screened in either an upper or lower zone and they were located up and downgradient of the injection/extraction well. The site was characterized by a number of methods including hydraulic tests and a bromide tracer test to determine hydrology, geology, geochemistry and microbiology. Dithionite migration and reactivity were characterized by monitoring DO, pH, and electrical conductivity in groundwater and by directly measuring dithionite in the groundwater withdrawn from the injection well.

Results

- ISRM is able to reduce aqueous concentrations of chromate in the groundwater to less than 8 ppb in one month, versus many years of operation for a pump and treat system. The performance of ISRM is thus enhanced over that of the baseline in terms of time required to reach cleanup goals.
- Between 87% and 90% of the dithionite solution was recovered during the withdrawal phase, and most of the mobilized trace metals (Fe, Mn, Zn) were removed during this phase.
- A thin zone (1 to 4 inches) of reduced permeability occurred near the injection/withdrawal well, but this resulted in no significant adverse effects on performance.
- Within a 25-foot radial distance of the injection well, core analyses showed that 60% to 100% of the available reactive iron was reduced; this emplacement zone is estimated to have a life of 7 to 13 years, based on post-test core data.
- Two years after treatment at the 100-H Area, the treatment zone remains anoxic and hexavalent chromium remains below detection.
- Initial total chromium concentrations (as chromate) within the treatment zone ranged from 46 to 71 ppb; following the ISRM test, total chromium concentrations were near the detection limit (2 ppb).
- Other trace metals, such as arsenic and lead, mobilized by the reductant, remain below maximum allowable drinking water concentrations.

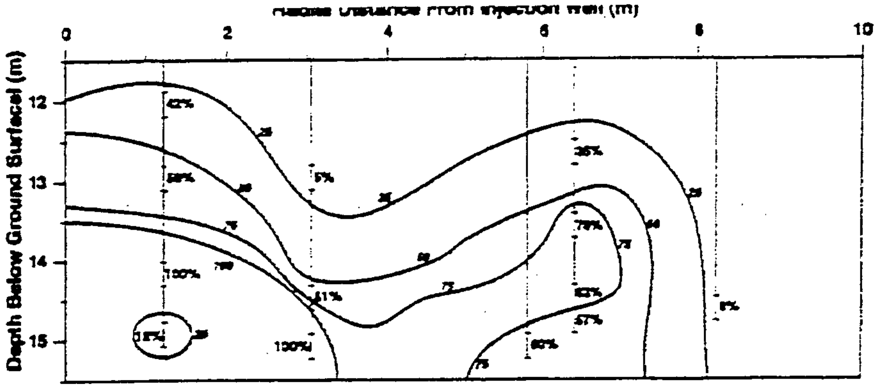

Figure 3. Contour Plot of Available Reduced Iron (%)

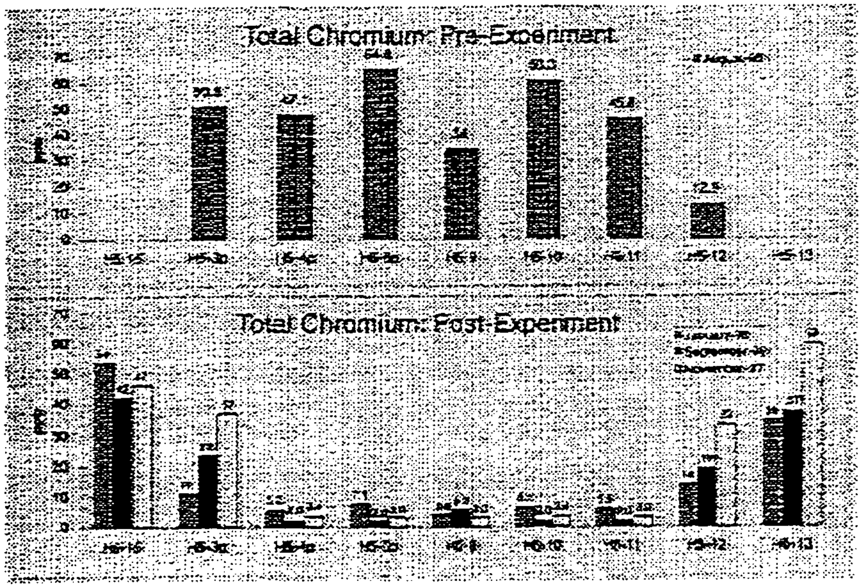

Figure 4. Total Chromium by Well Over Time

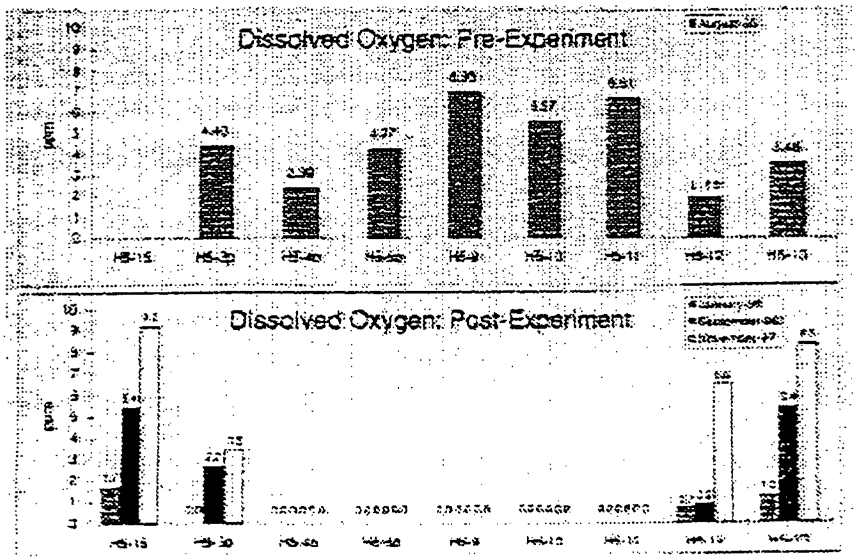

Figure 5. Dissolved Oxygen by Well Over Time

SECTION 4

TECHNOLOGY APPLICABILITY AND ALTERNATIVE TECHNOLOGIES

Competing Technologies

- The baseline against which ISRM can be compared is pump and treat. Pump and treat technology generally requires long treatment times and has high operation and maintenance requirements and costs.
- Another competing technology is the permeable reactive treatment barrier. Because ISRM technology is deployed through groundwater wells, it can be used at greater depths than conventional trench-and-fill reactive barriers which are best suited for applications less than 40 feet below the ground surface.
- For organic contaminants, other competing technologies include in well vapor stripping, air sparging, and bioremediation.

Technology Applicability

- ISRM has been demonstrated in field tests to reduce chromate concentrations in groundwater to near detection levels (2 ppb). Hexavalent chromium is reduced to the +3 state, which is not easily reoxidized.
- Bench-scale tests have shown that ISRM is also effective for treatment of dissolved trichloroethylene (TCE) and uranium in groundwater. Bench-scale or lab-scale tests are currently planned using soils from DOD sites in California and Washington State to determine applicability.
- ISRM is well suited for sand or sand and gravel aquifers, which have sufficient hydraulic conductivity to allow injection and significant migration of dithionite solution before it reacts to form sulfate, thiosulfate, and sulfite. Low permeability aquifers are not suited for ISRM.

Patents/Commercialization/Sponsors

- One patent, number 5,783,088, was issued to Battelle Pacific Northwest National Laboratory on July 21, 1998.

- Battelle Pacific Northwest National Laboratory, is currently seeking commercial partners to deploy the technology.

SECTION 5

COST

Cost Methodology

Information in this preliminary cost analysis was prepared from data provided by PNNL to Los Alamos National Laboratory (LANL), which performs independent cost analyses for the Office of Science and Technology (OST).

- The pump-and-treat technology was the baseline against which ISRM was compared.
- To develop the cost analysis comparison, the following scenario was used:
    - The objective is to prevent the migration of hexavalent chromium through a section of aquifer 200 feet long, similar to the treatment cell size used during the 1997-1998 field-scale demonstration.
    - The ISRM design requires drilling 3 coreholes, 7 injection/withdrawal wells, 4 compliance monitoring wells, and 1 performance monitoring well across the 200 foot section of aquifer to prevent the downgradient migration of chromium. The barrier width, in the direction of groundwater flow, is approximately 50 feet. Emplacement of the ISRM permeable barrier and required residence time in the aquifer to initiate conditions for the redox reactions may take only several days, but the lifetime of the treatment barrier is expected to be at least 10 years.
    - The baseline technology is a typical pump-and-treat system designed to target hexavalent chromium at a DOE site. A 200-foot section of aquifer is assumed to require a single extraction well and a single injection well. To simplify the comparison, it is assumed that compliance and performance monitoring wells are equivalent for each technology. Using a 25 gallon per minute (gpm) extraction rate, the single extraction well processes approximately 13 million gallons of groundwater per year after it is fully operational. Treated groundwater is reinjected upstream of the contaminated plume after processing by the ion exchange plant. The pump-and-treat plant is assumed to have a design life of 10 years under normal operation and maintenance conditions and to operate continuously.
    - For both technologies, the scenario assumes a 10-year project life. The scenario assumes design, construction, procurement, and construction costs occur in the first year and that both technologies become operational in the second year.
    - The scenario requires chromium to be removed to the maximum extent practicable with concentrations not to exceed 50 ppb in the pump-and-treat discharge or the monitoring samples for ISRM. The goal of the scenario is only containment of the plume, not remediation.

A more recent cost analysis comparing the full-scale (1400-ft long barrier) deployment of ISRM at Hanford to that of a planned pump and treat system was published in Soil and Groundwater Cleanup, October 1998.

- This comparison assumes the pump and treat system and the ISRM barrier operate until 2030. However, the pump and treat actually operates for only 5 years and is then followed by a monitoring program through 2030. The ISRM barrier assumed a re-injection of dithionite in 2015.

Cost Analysis

The following table includes the results of the LANL analysis.

Table 5.1. Cost Estimates for 10-Year Lifetime of a Barrier to Prevent Movement of Chromium Through Groundwater (ISRM has an economic advantage over pump and treat, primarily due to the absence of operating costs and negligible waste management costs)

Pump and Treat 10-Year Project Cost Estimates*												
Task		1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	Total
1. Characterization/Design		$400,000										$400,000
2. Procurement (i.e., reagent, IX resin)		$300,000										$300,000
3. Construction/Barrier Emplacement		$1,000,000										$1,000,000
4. Operating Costs			$650,000	$650,000	$650,000	$650,000	$650,000	$650,000	$650,000	$650,000	$650,000	$5,850,000
5. Waste Management			$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$540,000
6. Performance Monitoring			$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	$450,000
7. Project Management		$60,000	$50,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$300,000
8. Well Abandonment											$5,000	$5,000
												$8,850,000
Total		$1,750,000	$810,000	$785,000	$785,000	$785,000	$785,000	$785,000	$785,000	$785,000	$790,000	$8,850,000
Net Present Value	0.05	$1,750,000	$771,000	$712,000	$678,000	$646,000	$615,000	$586,000	$558,000	$531,000	$509,000	$7,360,000
ISRM 10-Year Project Cost Estimates**												
Task												Total
1. Characterization/Design		$560,000										$560,000
2. Procurement (i.e., reagent, IX resin)		$300,000										$300,000
3. Construction/Barrier Emplacement		$1,100,000										$1,100,000
4. Operating Costs												$0
5. Waste Management			$20,000									$20,000
6. Performance Monitoring			$260,000	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000	$660,000
7. Project Management		$50,000	$50,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$25,000	$300,000
8. Well Abandonment											$12,000	$12,000
												$2,950,000
Total		$2,010,000	$330,000	$75,000	$75,000	$75,000	$75,000	$75,000	$75,000	$75,000	$87,000	$2,950,000
Net Present Value	0.05	$2,010,000	$314,000	$68,000	$65,000	$62,000	$59,000	$56,000	$53,000	$51,000	$56,000	$2,600,000
Estimated Cost Savings over Pump and Treat ($)			$4,600,000									
Estimated Cost Savings over Pump and Treat(%)			60%									

Cost Estimates for 10-Year Lifetime of a Barrier to Prevent Movement of Chromium Through Groundwater
(ISRM has an economic advantage over pump and treat, primarily due to the absence of operating costs
and negligible waste management costs.)

COST continued

Cost Conclusions

The full-scale cost comparison (Soil and Groundwater Cleanup, 1998) shows the cost of the pump and treat system to range between $21 and $29 million, depending on the discount rate. The ISRM barrier costs range from $9 to $13 million. This amounts to projected cost savings of $12 to $16 million.

- Estimated cost savings over pump and treat are $4.6 million, a savings of 60% over a ten-year period using the LANL analysis described at the beginning of Section 5. Using the Soil and Groundwater Cleanup analysis, cost savings are estimated at $12-16 million if applied at the Hanford Site.

SECTION 6

[illegible]

Regulatory Considerations

- Under CERCLA, onsite treatability tests may be conducted without any federal, state, or local permits. Thus, no specific permits were required for the field test at Hanford. Regulatory approval was given after a "mini" dithionite injection was conducted.
- Future application of ISRM may require underground injection permits and NEPA review.
- Under CERCLA, the major ARARs pertinent to this technology are groundwater standards, Columbia River Protection Standards, cultural and ecological resource protection requirements, and water and wastewater management standards.
- Some state agencies are concerned about injection of fluids and materials that may alter the pH of the subsurface.

Safety, Risks, Benefits and Community Reaction

Worker Safety

- Health and safety issues for the ISRM technology does not present significant hazards over conventional field remediation operations.
- Reagents used in the process are easily managed using standard chemical handling procedures.

Community Safety

- ISRM does not produce any routine release of contaminants.
- No unusual or significant safety concerns are associated with the transport of equipment, samples, waste, or other materials associated with ISRM.
- Careful monitoring of field operations assures safety to workers and the public.

vironmental Impacts

- No additional impacts will be produced over those already anticipated as a result of site remediation.

Socioeconomic Impacts and Community Perception

- ISRM has a minimal economic or labor force impact.
- The general public has limited familiarity with this technology.

SECTION 7

LESSONS LEARNED

Design Issues

- The ability of the dithionite solution to penetrate far enough into the aquifer to create a continuous barrier depends on both the hydraulic conductivity of the aquifer and the iron content of the aquifer sediments. If the iron content is too low, insufficient reducing capacity will be available. If the amount of reactable iron is too high, the dithionite will be consumed before it travels far enough into the aquifer to provide reasonable coverage. therefore, accurate measurements of both of these parameters and design analysis incorporating them are crucial to the success of the project.

Implementation Considerations

- During early phases of the implementation at the first field site, oxygen was introduced into the reduced zone through the monitoring wells. This problem was corrected by blanketing the monitoring well with argon.
- To keep oxygen out of the dithionite mixing tanks, the headspaces were also blanketed with argon. At first, nitrogen was sparged through the solution, but there was sufficient oxygen as a contaminant in the nitrogen to cause problems, so this method was abandoned. In later tests, the dithionite was diluted as it was injected, so that mixing tanks were not used.

Technology Limitation/Need for Future Development

- Longer-term performance data are required to assess the need for design improvements and system optimization. This information can then be used to better quantify life-cycle costs.
- Optimization of injection concentrations, rates, and geometries should be addressed in future applications.

APPENDIX A

[illegible]

Cummings, M. A. and S.R. Booth. 1997. Cost-Effectiveness of In Situ Redox Manipulation for Remediation of Chromium-Contaminated Groundwater. LA-UR-97-165, Los Alamos National Laboratory, Los Alamos, New Mexico.

Williams, M. D. et al, 1998,. 100-D Area In Situ Redox Treatability Test for Chromate-Contaminated Groundwater FY 1998 Year-End Report. Pacific Northwest National Laboratory, Richland, Washington.

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COST AND PERFORMANCE REPORT

Pump and Treat of Contaminated Groundwater at the Odessa Chromium I Superfund Site Odessa, Texas

September 1998

EPA

Prepared by:

U.S. Environmental Protection Agency
Office of Solid Waste and Emergency Response
Technology Innovation Office

SITE INFORMATION

Identifying Information:

Odessa Chromium I Superfund Site
Operable Unit 2 (OU 2)
Odessa, Texas

CERCLIS #: TXD980867279

ROD Date for OU2: September 8, 1986

Treatment Application:

Type of Action: Remedial

Period of operation: 11/93 - Ongoing
(Monitoring and mass removal data collected through December 1996)
(Data on volume treated collected through January 1998)

Quantity of material treated during application: 125 million through January 1998

Background [1, 2, 3]

Historical Activity that Generated Contamination at the Site: Metals plating

Corresponding SIC Code: 3471, Plating of Metals

Waste Management Practice That Contributed to Contamination: Improper disposal practices

Location: Odessa, Texas

Facility Operations:

- In 1977, the Texas Natural Resources Conservation Commission (TNRCC) investigated citizen complaints of poor drinking water quality in private wells and discovered elevated levels of chromium in the groundwater. The 0.4-acre facility at 4318 Brazos Avenue was identified by EPA as the source of chromium contamination.
- Metals plating and chrome plating facilities operated at the site from 1954 to 1977, producing chromium and other metals-containing wastewater. Operations at the site ceased in 1977.
- High levels of chromium were detected in the soil and groundwater. The chromium contamination was caused by discharge of chromium-containing wastewater into unlined dirt ponds, directly to the soils, and into a septic tank drain field. Contaminants are also suspected to have migrated into the aquifer through an abandoned open well bore on the site.
- In 1984, the building, foundation, and soils contaminated with chromium were excavated and disposed. Shallow soils, down to approximately two feet, were removed. The remaining soils at the site were found to contain other heavy metals at detectable levels, but at levels that posed no apparent risk to human health and the environment.
- From 1977 until 1985, the TNRCC conducted drinking water well surveys to determine the extent of the chromium contamination.
- The Odessa I site was added to the National Priority List (NPL) in September 1984.
- The Remedial Investigation and Feasibility Study (RI/FS) was completed in 1986.

Regulatory Context:

- For the Odessa I site, EPA issued two Records of Decision (ROD): Operable Unit 1 (OU1) to address the need for an alternative drinking water supply and Operable Unit 2 (OU2) to address groundwater cleanup.
- In 1986, through the ROD for OU1, an alternate drinking water source was made available to replace water previously supplied by the contaminated wells.
- On March 18, 1988, the ROD for OU2 was approved for groundwater remediation. Further soil removal was not required by the ROD.

SITE INFORMATION (CONT.)

Background (Cont.)

- Site activities are conducted under provisions of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), as amended by the Superfund Amendments and Reauthorization Act of 1986 (SARA), § 121, and the National Contingency Plan (NCP), 40 CFR 300.

Groundwater Remedy Selection: Extraction of the groundwater and treatment of chromium through ferrous ion reduction, followed by reinjection of treated water to the aquifer, was determined to be the most appropriate remedy for groundwater based on treatability studies.

Site Logistics/Contacts

Site Lead: State

Oversight: EPA

Remedial Project Manager:
Ernest Franke
U.S. EPA Region 6
First Interstate Bank Tower
at Fountain Place
1445 Ross Avenue
12th Floor, Suite 1200
Dallas, TX 75202-2733
(214) 655-8521

*Indicates primary contact

State Contact:
Lel Medford*
Texas Natural Resources Conservation Commission
P.O. Box 13087
Austin, Texas 78711
(512) 239-2440

Treatment System Vendor:
Design and Management: IT Corporation (ITC)
Construction and Operation: WATEC

MATRIX DESCRIPTION

Matrix Identification

Type of Matrix Processed Through the Treatment System: Groundwater

Contaminant Characterization [1,2,4,9]

Primary Contaminant Group: Chromium

- The contaminant of concern is chromium. The groundwater is contaminated with the hexavalent chromium species. However, cleanup standards are set for total chromium. Likewise, laboratory analyses test for total chromium. For these reasons, chromium levels tested and regulated at the Odessa I site are for total chromium. No organic contaminants were detected in the soil or groundwater.
- During a 1985 sampling event, chromium was detected in the groundwater at levels up to 72 mg/L. During sampling events in 1993, prior to pump and treat application, chromium was detected at levels up to 4.3 mg/L.
- The chromium plume directly beneath the former on-site building was heavily concentrated in the Trinity Sands, which is the major aquifer in the region. The remnants of the Ogallala Aquifer found at

MATRIX DESCRIPTION (CONT.)

Contaminant Characterization (Cont.)

the site contain a few feet of saturated thickness at the most. The northern plume migration concurs with the north-northeasterly groundwater flow direction observed during the RI/FS.

- The initial volume of the chromium plume was estimated in the 1986 RI/FS to be 15 million gallons between 44th and 48th streets. The areal extent of the initial plume was estimated to be approximately 283,000 square feet, based on a chromium contour of 0.05 mg/L.
- The ROD required the chromium levels in the groundwater to meet the maximum contaminant level (MCL) for chromium. EPA changed the MCL from 0.05 to 0.10 mg/L in 1990.
- Figure 1 illustrates the boundaries for the chromium plume for 1994, 1995 and 1996. From 1994 and 1996, the surface area of the chromium plume has decreased from 440,000 ft^2 to 247,000 ft^2, a reduction in plume size of 44%. The areal plumes are based on a total chromium concentration contour of 0.1 mg/L.

Matrix Characteristics Affecting Treatment Costs or Performance

Hydrogeology: [4,9]

Two distinct hydrogeologic units have been identified beneath this site. Soil and sandy caliche overlie the water-bearing formations. The first water-bearing unit is encountered at approximately 30 to 45 feet below ground surface.

Unit 1	Ogallala Formation (Perched Zone)	This unit is formed of fluvial plastics consisting of fan deposits of fine to coarse grained sands, silt, clay, and occasional strings of gravel. There are only erosional remnants of this formation present in the site area, with a saturated thickness of less than 10 feet in the lower most portion. The erosional remnants of the Ogallala are hydraulically connected to the underlying Trinity Sand Aquifer, and water from the Ogallala flows into the Trinity. The Ogallalla does not exist as a continuous aquifer and thus flow direction could not be measured.
Unit 2	Trinity Sand Aquifer	This unit consists of sands and ferragiorous calcite cemented sandstones. Settled lenses of gravel, clay, and siltstone occur at irregular intervals. This unit is the primary groundwater water supply for municipal and private residences in the area. It is underlain by the Chinle Formation, which acts as an effective aquitard. Groundwater in this unit in the area of the site was observed to flow north to northeast, which concurs with the spread of the plume from the source. However, changes in water levels have altered groundwater flow direction.

The water level in the Trinity Sand Aquifer has risen over 25 feet from 1986 to 1993. The rise in the water table is attributed to the decrease of public and private wells using the aquifer and to increased precipitation during this period.

MATRIX DESCRIPTION (CONT.)

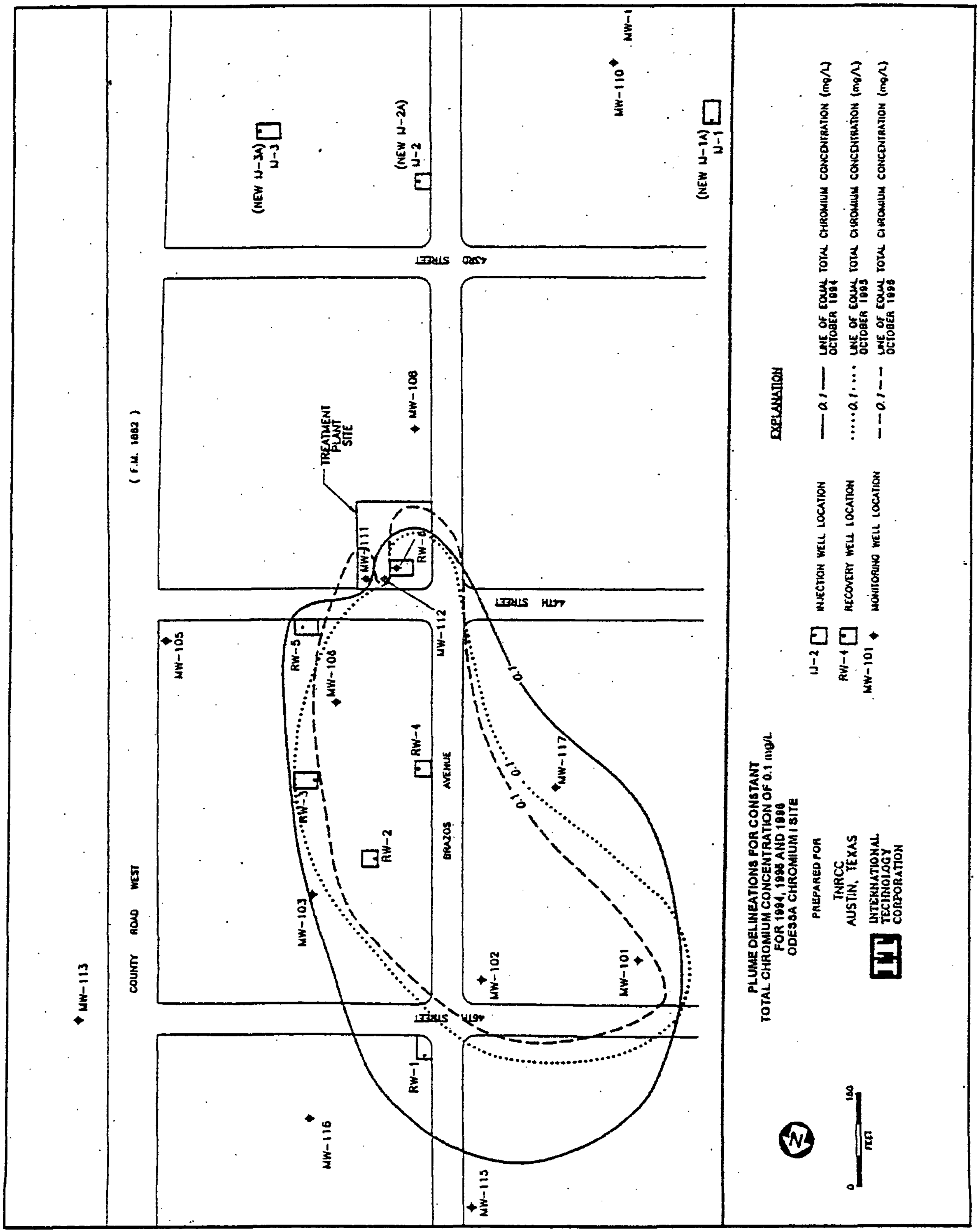


Figure 1. Chromium Concentration Contour Map, 1994 - 1996 [9]

MATRIX DESCRIPTION (CONT.)

Tables 1 and 2 include technical aquifer information and technical well data, respectively. Extraction wells are discussed in the following section.

Table 1. Technical Aquifer Information

Unit Name	Thickness (ft)	Conductivity (ft/day)	Average Flow Velocity (ft/day)	Flow Direction
Unit 1 (Ogallala)	0 - 10	1.6	0.02	Not Characterized[1]
Unit 2 (Trinity Sand)	70	1.7 - 5.1	0.03 - 0.00	North-Northeast[2]

[1] Water flows from the Ogallala to the Trinity, but the direction of flow has not been characterized.

[2] Flow observed during the 1986 remedial investigation was towards the north-northeast. However, the water table rose from 1986 to 1993 by 25 feet. Flow observed during a 1993 investigation was towards the southeast. Groundwater investigations since 1993 have shown groundwater flow direction to be northerly.

Source: [4]

TREATMENT SYSTEM DESCRIPTION

Primary Treatment Technology

Pump and treat with electrochemical precipitation of chromium using ferrous ion

Supplemental Treatment Technology

None

System Description and Operation

Table 2. Extraction Well Data

Well Name	Unit Name	Depth (ft)	Design Yield (gal/day)
RW-1/102	Trinity Sand	138	14,400
RW-2	Trinity Sand	138	14,400
RW-3	Trinity Sand	138	14,400
RW-4	Trinity Sand	138	14,400
RW-5/106	Trinity Sand	138	14,400
RW-6	Trinity Sand	138	14,400

Source: [4]

System Description [4, 5]

- The extraction system consists of six recovery wells, located in the Trinity Aquifer (Unit 2). No recovery wells were placed in the Ogallalla Formation, directly beneath the site because only erosional remnants of the Ogallalla remain in the vicinity of the Odessa I site. In addition, the groundwater in this zone flows directly into the Trinity Aquifer. A computer model was used to determine well placement and design extraction rates in the Trinity Aquifer. The modelling determined capture zone for the plume that exceeded 0.1 mg/L chromium.
- ITC used Randomwalk to model solute transport (an in-house model by Reed and Associates) and Geoflow to model groundwater flow (an in-house model by ITC).

TREATMENT SYSTEM DESCRIPTION (CONT.)

System Description and Operation (Cont.)

- The metals treatment system is designed to treat the collected groundwater at a rate of 60 gpm. Influent tanks regulate flow through the treatment system.
- Water from the extraction wells is sent to a dual-chamber reaction tank. Ferrous ion is fed into the first chamber and mixed with the contaminated well water. Ferrous ion is produced on site in an electrochemical cell. The ion reduces the hexavalent chromium to trivalent chromium, to facilitate subsequent hydroxide precipitation. In the second chamber of the reaction tank, pH is adjusted to the range of 8.5 to 8.8 to achieve minimum solubility for chromium hydroxide. Also in the second chamber, ferrous ion is oxidized by aeration to insoluble ferric ion and converted to ferric hydroxide. Both the ferric and the chromium hydroxide are mixed with a poly-electrolyte in the second chamber.
- The treated water is clarified through a flocculation and precipitation tank, where insoluble hydroxides are precipitated out. From here, the treated water is polished through a multimedia filter for reinjection. A backwash unit stores a portion of the treated water, which is used to flush the filter at least once every 24 hours. The sludge from the clarifier is disposed off site.
- Chromium concentrations in the influent and the effluent from the treatment system are monitored continuously. If the level of chromium exceeds 0.05 mg/L in the effluent, it is pumped back through the treatment system. Treated water with chromium concentrations less than 0.05 mg/L is injected through a network of six injection wells.
- A network of 14 monitoring wells placed in the Trinity Aquifer is used to monitor plume containment quarterly. The six recovery wells are monitored on a monthly basis for water quality parameters as well.

System Operation [4,5,6,7]

- Quantity of groundwater pumped from the aquifer by year is:

Year	Volume Pumped (gal)
1992	361,000*
1993	5,339,885*
1994	28,400,155
1995	30,692,836
1996	30,598,566

*The volume pumped during 1992 was during a 30-day unsuccessful trial run. The extraction system operated only for the months of November and December in 1993.

- Initial startup began in July 1992. The injection wells and the filter began to clog with iron and calcium in the first 30 days of system operation. The extraction and treatment systems were shut down for the following alterations.
  - The reactive tank was altered from a single-chamber to a two-chamber tank, separated by a baffle. The second chamber allowed for further precipitation of iron, the cause of clogging.
  - A backwash unit was added after the multi-media polishing filter to unclog the filter of iron and other precipitates. The pH of the water after the clarifier was reduced to less than 7.5.
  - Original injection wells continued to be used, but infiltration rates had slowed because of clogging. Three additional injection wells were constructed to increase the injection rate.
  - After modifications were made from May 1993 to August 1993, the system resumed operation in November 1993.
  - Backwash water is stored in the modified backwash unit and is added slowly to the influent tank. The slow addition avoids upsetting the pH balance in the influent tank.

TREATMENT SYSTEM DESCRIPTION (CONT.)

System Description and Operation (Cont.)

- Based on sampling events from 1993 to 1995, the higher chromium concentrations appeared to be migrating to the northwest. Recovery wells RW-1 and RW-5 were shut down and monitoring wells MW-102 and MW-106 were converted to recovery wells to continue pumping from areas in the plume with high chromium concentrations.
- One injection well was found to continually plug because of a local formation of silty fines. It was taken off line in May 1995. The rate of injection of treated water remained the same.
- The site has been operational 95% of the time since 1993. Downtime is primarily due to shutdowns for local brown outs and system *maintenance.*

Operating Parameters Affecting Treatment Cost or Performance

The major operating parameter affecting cost or performance for this technology is extraction rate. Table 3 presents the values measured for this and other performance parameters.

Table 3. Performance Parameters

Parameter	Value
Average Pump Rate	86,500 gpd*
Performance Standard (effluent)	0.05 mg/L total chromium
Remedial Goal (aquifer)	0.10 mg/L total chromium

Source: [2, 6]

*The average system extraction rate from January 1998 until December 1996 was estimated for this report to be 86,500 gpd or approximately 14,400 gpd per well, based on the actual 125 million gallons pumped and 95% operating rate.

Timeline

Table 4 presents a timeline for this remedial action.

Table 4. Timeline

Start Date	End Date	Activity
January 1992	July 1992	Remediation system constructed
July 1992	August 1992	System started; injection wells clogged with iron and calcium
May 1993	August 1993	Alterations made to remedial system
November 1993	—	Continuous operation of remediation system begun. Monthly monitoring of groundwater begun.
April 1995	—	Shift in plume detected. Monitoring wells MW-102 and MW-106 converted to recovery wells RW-102 and RW-106. RW-1 and RW-5 shut down
May 1995	—	Injection Well IJ-2 taken off line because of plugging

Source: [2, 4, 6, 7]

TREATMENT SYSTEM PERFORMANCE

Cleanup Goals/Standards [2]

- The cleanup goals as established by TNRCC and EPA are to remediate groundwater so that chromium levels are less than the maximum contaminant level (MCL), or the Primary Drinking Water Standard, of 0.10 mg/L. This goal is applied throughout the aquifer, as measured in all on-site monitoring wells.

Additional Information on Goals

- The original drinking water standard for chromium set by EPA was 0.05 mg/L. In 1990, EPA revised the standard to the Primary Drinking Water Standard of 0.10 mg/L.

Treatment Performance Goals [4]

- Effluent injected into the aquifer from the treatment system must have levels of chromium below 0.05 mg/L.
- As a secondary goal, the remedial system is required to create an inward gradient toward the site to contain the plume.

Performance Data Assessment [1, 3, 4, 5, 6, 7]

- Three wells have met the cleanup goal for chromium of 0.10 mg/L: RW-1, RW-3, and RW-5. The maximum concentration of chromium detected in the groundwater in January 1997 was 2.9 mg/L. Groundwater monitoring results indicate that chromium concentrations have been reduced compared to initial levels, but not to levels below the treatment goal.
- Figure 2 illustrates the changes in average chromium concentrations in the groundwater from January 1992 to January 1997 [6]. Average chromium levels were reduced by 48% during that time, from 0.98 mg/L in March 1992 to 0.54 mg/L in January 1997.
- The individual wells provided wide variations in month to month chromium concentrations for the first two years. The variation became less pronounced in 1996 with a noticeable downward trend [9].
- Concentrations of chromium in the groundwater have fluctuated in different wells. Figure 3 illustrates that chromium levels in RW-1 and RW-5 increased from 1992 to 1995. Figure 4 illustrates well-specific chromium levels that decreased from 1991 to 1997, then fluctuated during 1994. Figure 5 illustrates well-specific chromium levels that decreased from 1986 until 1997 [4,6].
- The September 1994 sampling event revealed spikes in concentrations of chromium in many wells [7]. The site contact has indicated that while no QA/QC problems were identified, the validity of the September 1994 sampling event is questionable [6].
- Other spikes in concentrations of chromium may be a result of incomplete source removal. According to the site contact, source control measures were applied only to shallow soils. Because the ROD did not specify complete removal of soil contamination, additional soil removal was not performed.
- Figure 6 presents the removal of chromium through the treatment system from December 1993 to 1996 [1,5]. During this time, a total of 1,143 pounds of chromium were removed from the groundwater [1]. Chromium mass removal was determined based on the chromium concentrations in the sludge. Data on the amount of chromium removed by the treatment system during the 30-day period in 1992 were not available.
- Figure 6 illustrates that mass flux decreased after the first year of system operation, from 1.2 pounds per day to less than 0.8 pounds per day [1].

TREATMENT SYSTEM PERFORMANCE (CONT.)

Performance Data Assessment (Cont.)

- Effluent chromium levels have met the required performance standard of 0.05 mg/L throughout treatment [6].
- Based on sampling events, plume containment has been achieved since 1995 [3,6]. The site operators determined there was a failure in plume containment during 1993 and 1995, based on a rise in chromium concentrations in some monitoring wells during this period [4]. Two monitoring wells within the area of concern were converted to recovery wells, and two recovery wells from a less contaminated area were taken off line.

Performance Data Completeness

- Data on mass flux and mass removed are reported on a monthly basis and are available for this site from the TNRCC. Annual data were used for the analyses in Figure 6.
- For the chromium concentration analyses in Figures 2 through 5, annual monitoring data were used for 1993 and 1995 through 1997. Quarterly data were used for 1994. These data were supplied in monthly reports and in the Project Status Draft Report prepared by ITC in 1995. Monitoring data are available on a quarterly basis for this site from the TNRCC.
- A geometric mean was used for average chromium concentrations detected in the groundwater, as presented in Figure 4, to represent the overall trend of chromium contamination in the groundwater at the site.
- When concentrations below detection limits were encountered, half of the detection limit was used for evaluation purposes.

Performance Data Quality

The QA/QC program used throughout the remedial action met EPA and TNRCC requirements. All monitoring was performed using EPA Method 218.1 and EPA-approved methods for pH, total suspended solids, and other water quality parameters. Except for the September 1994 data (discussed above) the vendor did not note any exceptions to the QA/QC protocols [6].

TREATMENT SYSTEM PERFORMANCE (CONT.)

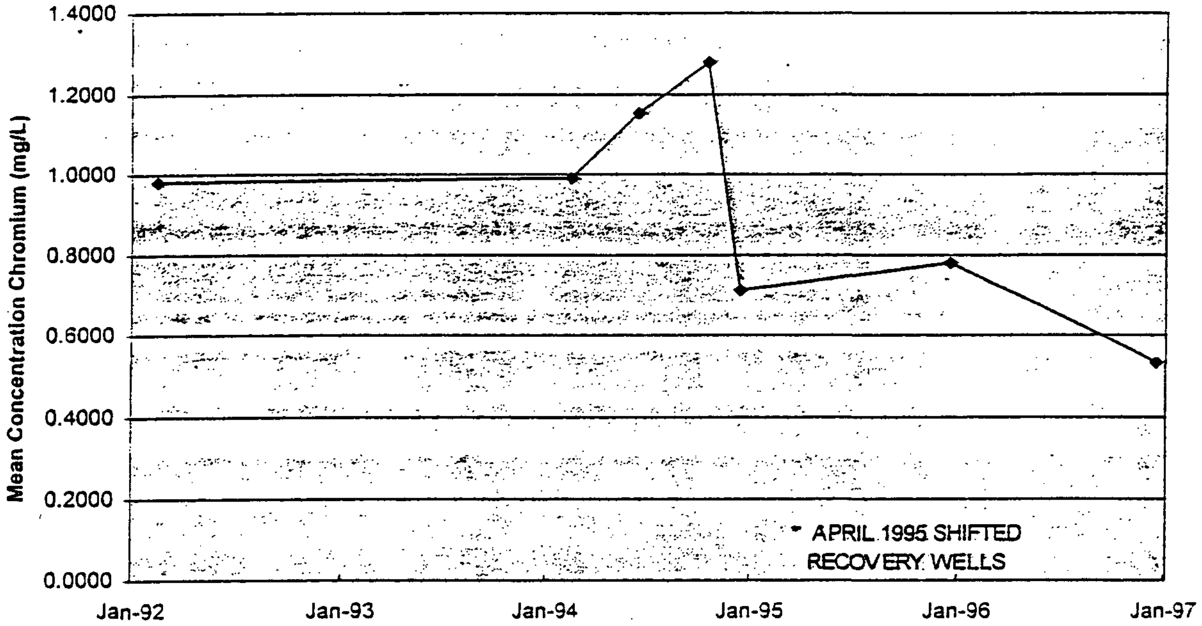


Figure 2. Average Chromium Concentrations in the Groundwater (1992 - January 1997) [4,6]

* Two monitoring wells converted to extraction wells; two other extraction wells shut down.

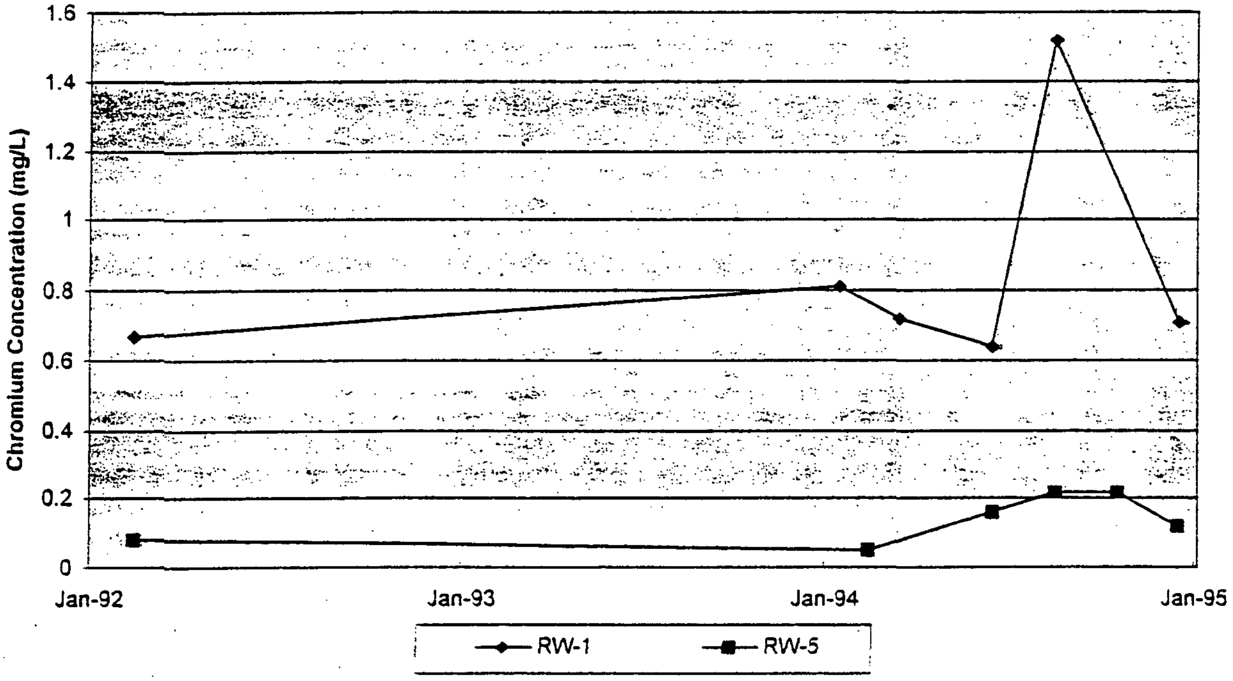
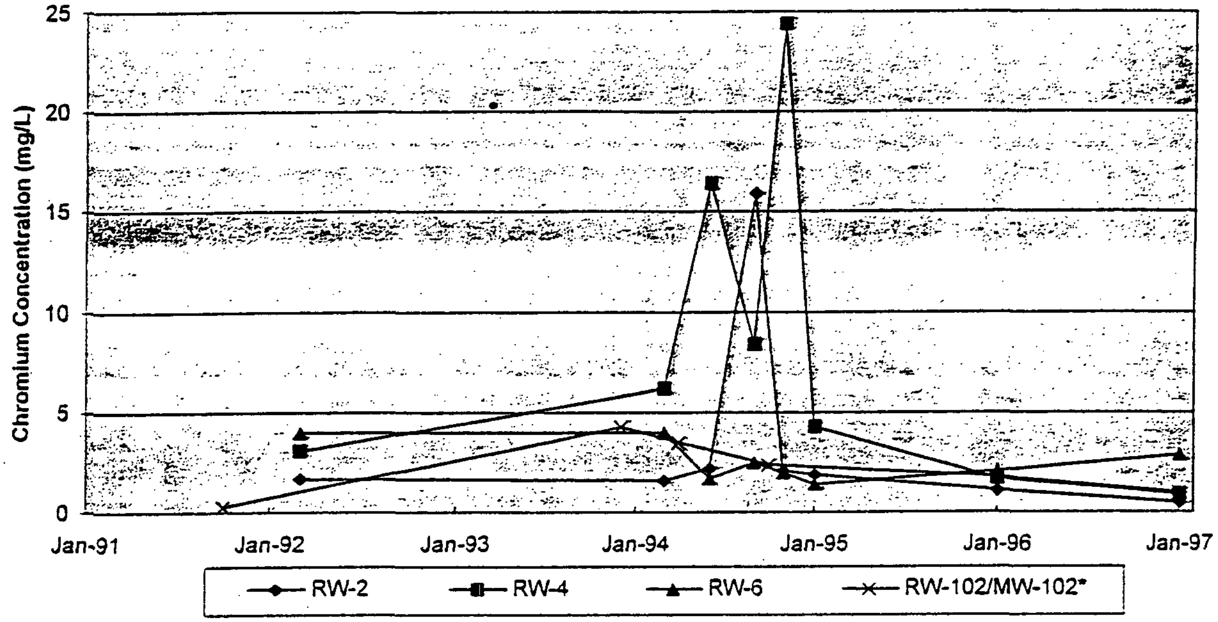


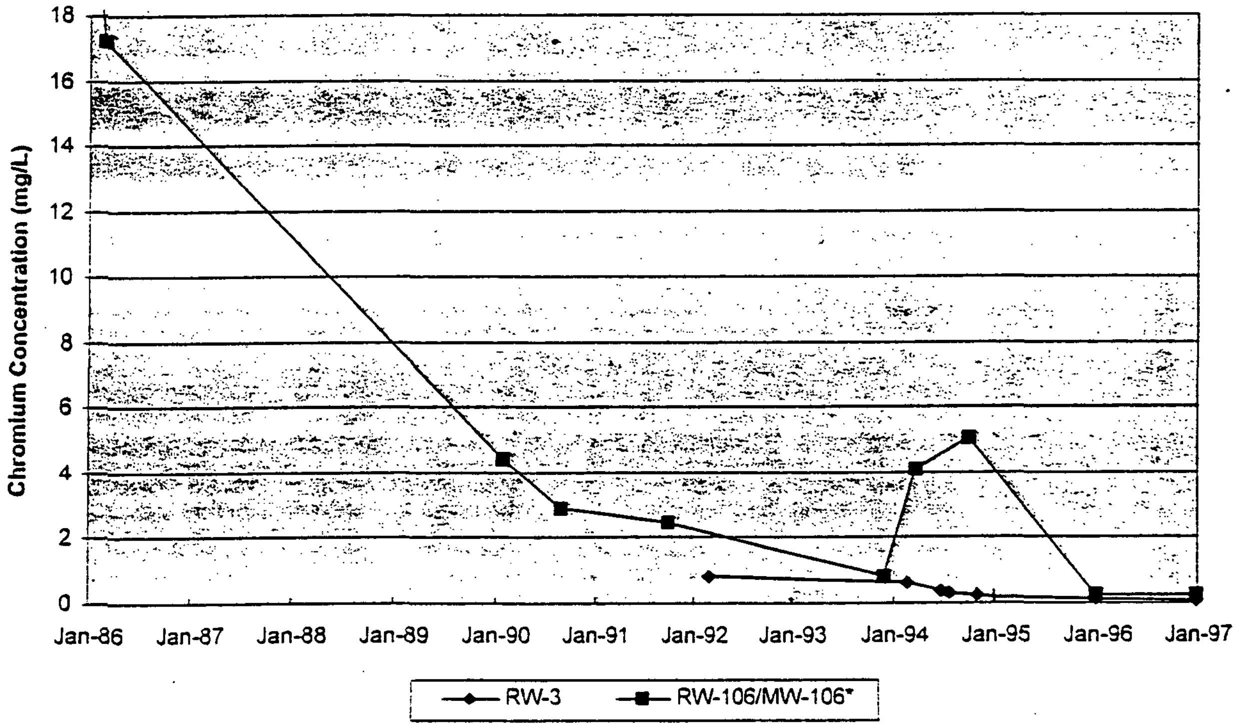
Figure 3. Chromium Concentrations in Wells RW-1 and RW-5 (1992 - 1997) [4,6]

TREATMENT SYSTEM PERFORMANCE (CONT.)



*RW-102 was MW-102 until 4/95

Figure 4. Chromium Concentrations in Wells RW-2, RW-4, RW-6, and RW-102 (1991 - 1997) [4,6]



*RW-106 was MW-106 until 4/95

Figure 5. Chromium Concentrations in Wells RW-3 and RW-106 (1986 - 1997) [4,6]

TREATMENT SYSTEM PERFORMANCE (CONT.)

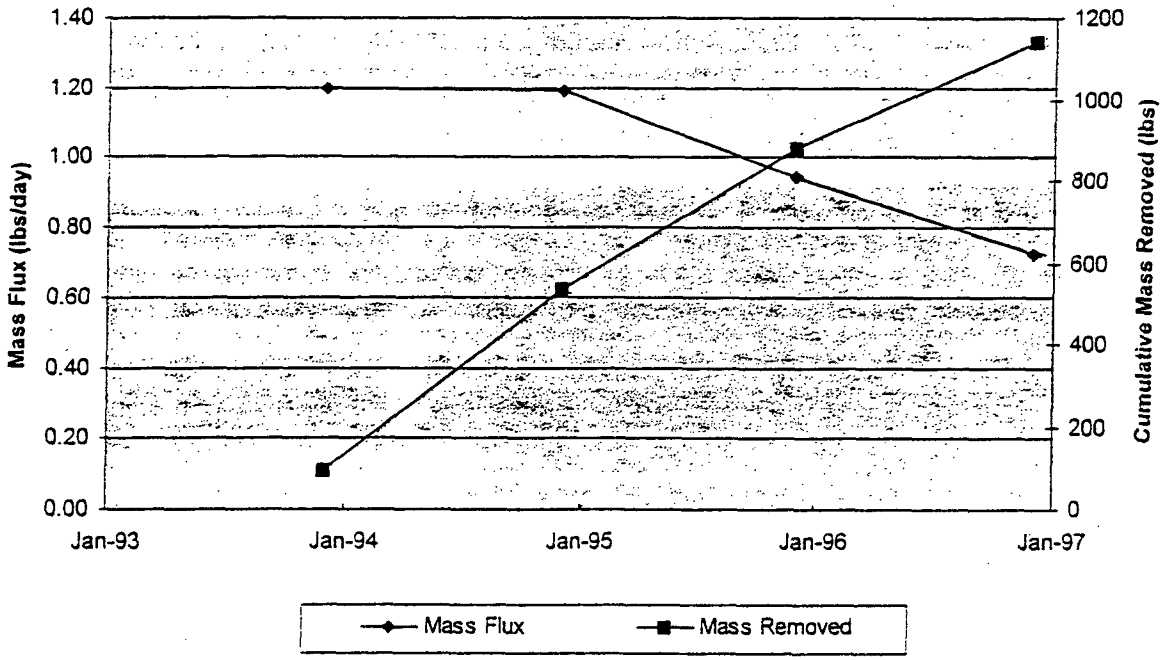


Figure 6. Mass Flux Rate and Cumulative Chromium Removal (1993 - 1996) [6]

TREATMENT SYSTEM COST

Procurement Process

TNRCC is the lead authority on this site. WATEC was awarded the construction and operations contract for the site. ITC was awarded the oversight contract for the site.

Cost Analysis

- The costs for design, construction, and operation of the P&T system at this site were split 90:10 by EPA and TNRCC, respectively.

TREATMENT SYSTEM COST (CONT.)

Capital Costs [6]

Remedial Construction	
Mobilization Work	$334,723
Monitoring Wells - Sampling/Testing Analysis	$52,761
Groundwater Collection & Control	$287,947
Installation of Treatment Plant	$944,800
Site Restoration	$13,542
Site Security	$3,298
Construction Management	$316,533
Total Remedial Construction	**$1,953,604**

Operating Costs [6]

Operation and Maintenance	$774,418
Monitoring Costs	$13,841
Total Cumulative Operating Expenses (1993-1996)	**$788,259**
1993 Operating Costs (11/93 - 12/93)	$25,772
1994 Operating Costs (1/94 - 12/94)	$202,817
1995 Operating Costs (1/95 - 12/95)	$228,705
1996 Operating Costs (1/96 - 12/96)	$330,965

Other Costs [6]

Remedial Design	
Original Bid Design	$132,180
Final Amount (redesign in 1993) (total for design)	$230,438

Cost Data Quality

Actual capital and operation and maintenance cost data are available from TNRCC for this application.

OBSERVATIONS AND LESSONS LEARNED

- Actual costs for the pump and treat application at Odessa I were approximately $2,742,000 ($1,954,000 in capital costs and $788,000 in operation and maintenance costs), which corresponds to $30 per 1,000 gallons of groundwater treated and $2,400 per pound of chromium removed. The $30 per 1,000 gallons is based on volume treated through December 1996, because cost data through 1998 were not available at the time of this report.
- The ROD specified that the ferrous ion used to reduce the chromium would be electrochemically produced, which limited the number of the on-site system vendors to two and potentially increased the cost of the treatment unit.
- The costs listed above include the system modifications performed in 1993 and in 1995. There have been no further changes to the cost for the remedial system at the site [3].
- Operating costs have increased from 1993 to 1996. The operations contract has a fixed annual cost for disposal of up to 500 lbs of chromium. Any amount of chromium beyond 500 lbs is paid on a cost plus fixed fee basis, resulting in additional annual disposal costs each year since 1993.
- While chromium levels have been reduced below the MCL in three wells, the groundwater cleanup goals have not been achieved as of December 1996. Extraction and treatment will continue until goals are achieved [3,4,6].
- Overall, average chromium concentrations decreased, but concentrations of chromium have fluctuated in some wells [4]. These variations in chromium levels are most likely a result of the increased groundwater level and further desorption of chromium from aquifer materials [3,7]. According to the site contact, because complete removal of all contaminated soils was not specified in the ROD, source control measures (i.e., soil removal) were applied to only shallow soils [4]. Deeper aquifer material may still contain high levels of chromium that can act as a source for continuing contamination [3,7]. The site contact also noted that complete source removal would have eliminated the source for a persistent plume [3].

OBSERVATIONS AND LESSONS LEARNED (CONT.)

- The plume has been contained since 1995, after containment failure from 1993 to 1995 [1]. The shift in groundwater flow observed in 1993 may have caused the containment failure [6]. By adjusting the extraction system, plume containment was achieved. This illustrates the importance of flexibility in system operation.

- There were several startup problems, including clogging of injection wells and filter by iron and calcium, that delayed full-scale operations [4]. These problems were solved through system modification, and no longer interfere with operations. The site contractor has suggested that one potential approach to identifying the problems earlier would be to increase the length of pilot operations. At this site, pilot operations were conducted in hourly increments, and the results were used to simulate full-cycle operations. Had the pilot operations been conducted for a full 24-hour cycle, it is likely that the iron and calcium fouling problems that led to clogging would have been identified [4].

- Full-scale operations were delayed by iron encrustation in the injection wells and in the filter. Setting effluent standards for iron in the future could prevent such delays.

- ITC also has concluded that the continuous chromium monitors on the influent were not useful because they could not detect chromium levels above 1.0 mg/L. They did not operate until wells were well on the way to being clean. Monthly tracking was found to be helpful for monitoring site cleanup, but continuous data were not useful [4].

- During system operation, system operators determined that backwash from the filter system should be equalized and added slowly to the influent tank to avoid large changes in the influent chemistry [4]. During early system operations, backwash water was introduced directly into the influent tank. The differences between the pH levels in the backwash and the influent reduced the effectiveness of the reaction tank. The backwash storage unit allows gradual addition of backwash to the influent. This has alleviated the earlier problems in the reaction tank [4].

REFERENCES

1. Record of Decision, USEPA, Odessa Chromium #1, OU2, March 18, 1988.
2. Record of Decision, USEPA, Odessa Chromium I, OU1, September 8, 1986.
3. Correspondence with Mr. Lel Medford, TNRCC.
4. Project Status Draft Report, ITC, January 1995.
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6. Odessa Chromium I Monthly Reports, ITC. December 1993/January 1994, January 1995, January 1996, January 1997.
7. Lessons Learned, ITC, January 1997.
8. Groundwater Regions of the United States. Heath, Ralph. U.S. Geological Survey Water Supply Paper 2242. 1984.
9. TNRCC comment on draft report, dated 3/11/98.

Analysis Preparation

This case study was prepared for the U.S. Environmental Protection Agency's Office of Solid Waste and Emergency Response, Technology Innovation Office. Assistance was provided by Eastern Research Group, Inc. and Tetra Tech EM Inc. under EPA Contract No. 68-W4-0004.

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COST AND PERFORMANCE REPORT

Pump and Treat of Contaminated Groundwater at the Odessa Chromium IIS Superfund Site Odessa, Texas

September 1998

EPA

Prepared by:

U.S. Environmental Protection Agency
Office of Solid Waste and Emergency Response
Technology Innovation Office

SITE INFORMATION

Identifying Information:

Odessa Chromium IIS Superfund Site
Operable Unit 2 (OU 2)
Odessa, Texas

CERCLIS #: TXD980697114

ROD Date: March 18, 1988

Treatment Application:

Type of Action: Remedial

Period of Operation: 11/93 - Ongoing
(Performance data collected through December 1996)
(Data on volume treated collected through December 1997)

Quantity of Material Treated During Application: 121 million gallons

Background

Historical Activity that Generated Contamination at the Site: Radiator repair

Corresponding SIC Code: 7538

Waste Management Practice That Contributed to Contamination: Unlined wastewater-holding ponds and waste drum burial

Location: Odessa, Ector County, Texas

Facility Operations: [1, 2, 3]

- The site is located in a mixed residential, commercial, industrial area. The Basin Radiator & Supply formerly located in the 5300 block of Andrews Highway operated from 1960 to the early 1970s. Wastewater containing chromium was discharged to unlined ponds, and waste radiator sludge containing chromium corrosion inhibitors was buried on the site. Also located in the 5300 block of Andrews Highway was Wooley Tool and Manufacturing which had a chromium plating operation.

- In 1977, the Texas Natural Resource Conservation Commission (TNRCC) discovered elevated levels of chromium in the groundwater during investigations in response to citizen complaints of contaminated well water.

- The TNRCC concluded that the two facilities were the source of chromium in the groundwater: Wooley Tool and Manufacturing and Basin Radiator & Supply. The former became known as the Odessa II North site and the latter as the Odessa II South(S) site. The Odessa IIS site is the subject of this report.

- In 1978, the TNRCC removed drums, on-site buildings, and contaminated soils from the site.

- In 1986, the Remedial Investigation/Feasibility Study (RI/FS) was completed. On June 10, 1986, Odessa IIS was placed on the National Priorities List (NPL).

Regulatory Context:

- For the Odessa IIS site, the EPA issued two Records of Decision (ROD). In 1986, the ROD for Operable Unit 1 (OU1) was signed to provide an alternative drinking water supply.

- On March 18, 1988, the ROD for OU2 was approved for groundwater remediation at Odessa IIS. Source control was not required by the ROD.

- Site activities are conducted under provisions of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), as amended by the Superfund Amendments and Reauthorization Act of 1986 (SARA) §121, and the National Contingency Plan (NCP), 40 CFR 300.

SITE INFORMATION (CONT.)

Background (Cont.)

Groundwater Remedy Selection:
Groundwater extraction followed by treatment to remove chromium contamination and injection of the treated water back to the aquifer was determined by the FS to be the most appropriate methodology for site remediation. The results of a pilot study confirmed the basic approach.

Site Logistics/Contacts

Site Lead: State

Oversight: EPA

Remedial Project Manager:
Ernest Franke
U.S. EPA Region 6
First Interstate Bank Tower at Fountain Place
1445 Ross Avenue
12th Floor, Suite 1200
Dallas, TX 75202-2733
(214) 655-8521

*Indicates primary site contact

State Contact:
Lel Medford*
Texas Natural Resources Conservation Commission (TNRCC)
P.O. Box 13087
Austin, Texas 78711
(512) 239-2440

Treatment System Vendor:
Design and Management: IT Corporation (ITC)
Construction and Operation: WATEC

MATRIX DESCRIPTION

Matrix Identification

Type of Matrix Processed Through the Treatment System: Groundwater

Contaminant Characterization [1, 3]

Primary Contaminant Groups: Chromium

- The contaminant of concern is chromium. Hexavalent chromium is the species of concern in the groundwater because under the aquifer conditions it is the only species that is soluble and can affect the drinking water. The ROD stipulates a clean-up standard based on total chromium since the Maximum Contaminant Limit (MCL) was set for total chromium, instead of an individual species.

- Two hydraulically connected chromium plumes have been identified and are referred to as the Perched Zone plume and the Trinity Aquifer plume.

- The maximum concentration of chromium in the groundwater in the Trinity Aquifer, detected during a 1985 sampling event, was 2.8 mg/L. The maximum chromium concentration in the Perched Zone groundwater, detected in 1986, was greater than 50 mg/L.

MATRIX DESCRIPTION (CONT.)

Contaminant Characterization [1, 3] (Cont.)

- The initial volume of the chromium plume in the Perched Zone was estimated in the 1986 RI/FS at 980,000 gallons. The areal extent of the initial plume was estimated to be approximately 105,000 square feet.
- The initial volume of the chromium plume in the Trinity Aquifer was estimated in the 1986 RI/FS at 79,000,000 gallons. The areal extent of the initial plume was estimated to be approximately 585,000 square feet.
- The ROD required the site to be cleaned to meet the MCL for chromium. In 1990, EPA changed the MCL from 0.05 mg/L to 0.10 mg/L in 1990 by EPA. The plume size estimates were originally calculated based on the 0.05 mg/L contour.
- Figures 1 and 2 delineate the 0.1 mg/L chromium contours in the Perched Zone and Trinity Aquifer, respectively, as observed during a September 1994 (nine months after beginning treatment) sampling event.
- In the Project Status Draft Report, the plume volumes in the Perched Zone and Trinity Aquifer were calculated based on the revised 0.1 mg/L clean-up goal and data that were nine years more current than the original RI data. A significant change in the aquifer water level and the chromium concentration had occurred between 1985 and 1994 because of lower water withdrawal rates in the area.
- The Perched Zone plume was found to be 61,270 square feet in area and 690,000 gallons in volume, compared to the 1986 plume estimate of 105,000 square feet in area and 980,000 gallons in volume. The Trinity Aquifer plume was found to be 210,385 square feet in area and 44,000,000 gallons in volume, compared to the 1986 estimate of 585,000 square feet and 79,000,000 gallons. The plume reductions are in part because of lowered levels of chromium but also because of the less stringent standard.

Matrix Characteristics Affecting Treatment Costs or Performance

Hydrogeology: [1, 3]

Two distinct hydrogeologic units have been identified beneath this site. Soil and sandy caliche overlie the water-bearing formations. The first water-bearing unit is encountered at approximately 30 to 45 feet below ground surface.

Unit 1	Ogallala Formation (Perched Zone)	This unit is formed of fluvial plastics consisting of fan deposits of fine to coarse grained sands, silt, clay, and occasional strings of gravel. A few miles to the south, the Ogallala has been removed by erosion. It is present in some parts of the site with a saturated thickness of approximately 5 to 15 feet, and is referred to as the Perched Zone. It is hydraulically connected and discharges to the underlying Trinity Sand Formation under natural conditions. The Ogallalla does not exist as a continuous aquifer and thus flow direction could not be measured.
Unit 2	Trinity Sand Aquifer	This unit consists of sands and ferragiorous calcite cemented sandstones. Settled lenses of gravel, clay, and siltstone occur at irregular intervals. This unit is the primary groundwater supply for municipal and private residences in the area. It is underlain by the Chinle Formation, which acts as an aquitard. Groundwater flow in this unit has been observed to flow north to northeast; however, changes in water levels have altered groundwater flow direction.

MATRIX DESCRIPTION (CONT.)

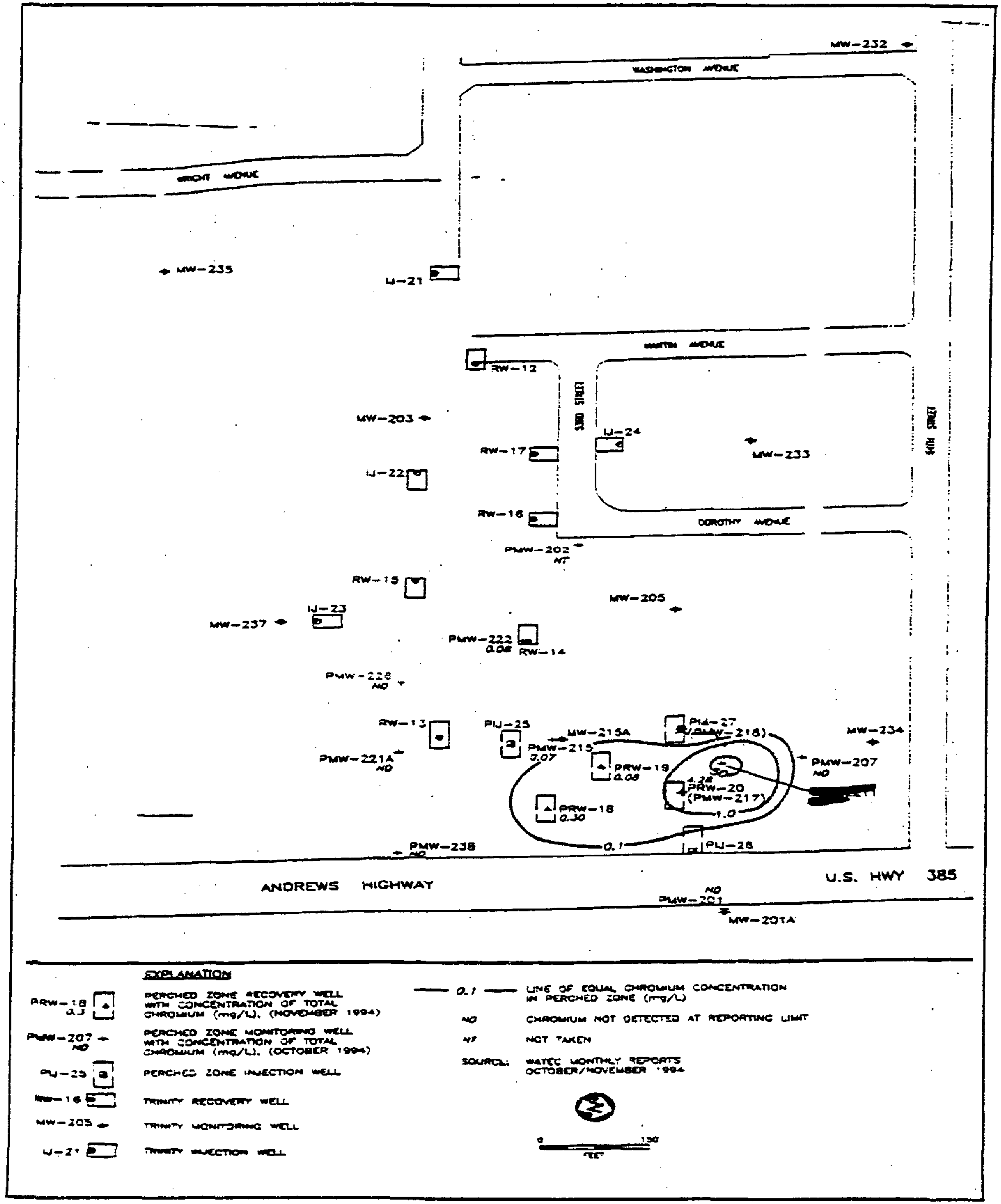

Figure 1. Perched Aquifer Chromium Contour Map (1994, Best Copy Available) [3]

MATRIX DESCRIPTION (CONT.)

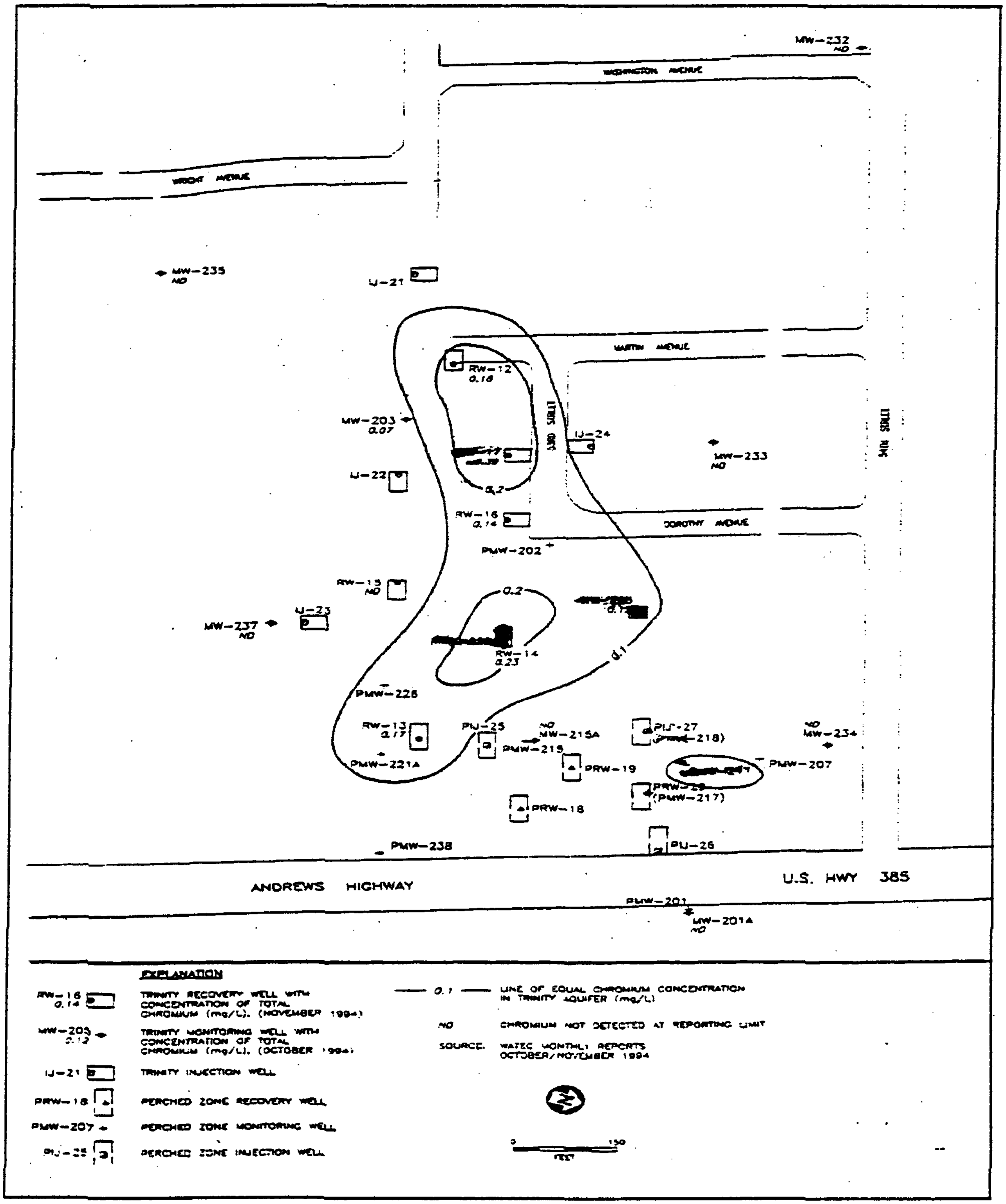

Figure 2. Trinity Aquifer Chromium Contour Map (1994, Best Copy Available) [3]

MATRIX DESCRIPTION (CONT.)

Matrix Characteristics Affecting Treatment Costs or Performance (Cont.)

The water level in the Trinity Aquifer has risen over 25 feet from 1986 to 1993. The rise in the water table is attributed to the decrease of public and private wells in the aquifer and to increased precipitation during this period.

Tables 1 and 2 present technical aquifer information and extraction well data, respectively.

Table 1. Technical Aquifer Information

Unit Name	Thickness (ft)	Conductivity (ft/day)	Average Flow Velocity (ft/day)	Flow Direction
Unit 1	5 - 15	1.6	0.0190	Not Characterized
Unit 2	70	1.7 - 5.1	0.0262 - 0.0782	North-Northeast[1]

[1] Flow observed during the 1986 remedial investigation was towards the north-northeast. However, the water table rose from 1986 to 1993 by 25 feet and could have resulted in a change in groundwater flow direction.

Source: [1, 3]

TREATMENT SYSTEM DESCRIPTION

Primary Treatment Technology

Pump and treat (P&T) with electrochemical precipitation of chromium using ferrous ion

Supplemental Treatment Technology

Solids removed by flocculation and filtration

System Description and Operation

Table 2. Extraction Well Data

Well Name	Unit Name	Depth (ft)	Design Yield (gal/day)
PRW18	Ogallala Formation	70	4,070
PRW19	Ogallala Formation	70	4,070
PRW20	Ogallala Formation	70	4,070
PRW28	Ogallala Formation	70	4,070
RW12	Trinity Aquifer	165	21,600
RW13	Trinity Aquifer	165	21,600
RW14	Trinity Aquifer	165	21,600
RW15	Trinity Aquifer	165	21,600
RW16	Trinity Aquifer	165	21,600
RW17	Trinity Aquifer	165	21,600

Source: [1,3,4]

TREATMENT SYSTEM DESCRIPTION (CONT.)

System Description and Operation (Cont.)

System Description [3, 5, 8]

- The extraction system consists of six recovery wells in the Trinity Aquifer and four recovery wells in the Ogallala Formation. ITC used Random Walk to model solute transport (an in-house model by Reed & Associates) and Geoflow to model groundwater flow (an in-house model by IT). Model results were used to determine well placement based on projected pumping rates.

- The metals treatment system is designed to treat the collected groundwater at a rate of 60 to 90 gpm. An influent tank regulates flow through the treatment system.

- Water from the extraction wells is sent to a dual chamber reaction tank (initially single chamber), into which ferrous ion is fed and mixed with the contaminated well water. Ferrous ion is produced on site in an electrochemical cell. The ion reduces the hexavalent chromium to trivalent chromium to facilitate subsequent hydroxide precipitation. In the second chamber of the reaction tank, pH is adjusted in the range of 8.5 to 8.8 to achieve minimum solubility for chromium hydroxide. Also, in the second chamber, excess ferrous ion is oxidized by aeration to insoluble ferric ion and converted to ferric hydroxide. The ferric and chromium hydroxide precipitate is mixed with a polyelectrolyte in the second chamber to aid settling.

- The treated water is clarified through a flocculation and precipitation tank. From here, the treated water is polished through a multimedia and cartridge filter for reinjection. The multimedia filters are backwashed with treated water based on pressure drop and the cartridge filters are replaced when a specified pressure differential is exceeded. The sludge from the clarifier and the cartridge filters are disposed off site as nonhazardous waste.

- Chromium concentrations in the influent to and the effluent from the system are monitored continuously. If the level of chromium exceeds 0.05 mg/L in the effluent, the effluent is recycled through the treatment system. Treated water with chromium concentrations less than 0.05 mg/L is injected through a network of six injection wells in the Trinity Aquifer and three injection wells in the Ogallala Formation.

- The recovery wells are monitored on a monthly basis for water quality parameters. A network of wells is used to monitor plume containment on a semiannual basis: 10 monitoring wells and the recovery wells in the Trinity Aquifer, and two monitoring wells and the recovery wells in the Ogallala Formation.

System Operation [3, 4, 5, 8]

- Quantity of groundwater pumped from aquifer by year:

Year	Volume Pumped (gal)
11/93-12/93	4,269,133
1994	29,660,519
1995	29,118,867
1996	31,257,749
1997	26,320,000

- Initial startup began in July 1992; however, the multimedia polishing filter and injection wells began to clog with iron and calcium in the first 30 days and treated water could not be reinjected. The extraction and treatment systems were shut down and the following alterations were made:
  - The reaction tank was altered from a single-chamber to a two-chamber tank, separated by a baffle. The second chamber allowed for precipitation of the excess iron, the main clogging problem.
  - A tank was added to receive backwash from the multimedia filters. The backwash tank acted as an equalization tank to prevent shock change to the system influent tank when the filters

TREATMENT SYSTEM DESCRIPTION (CONT.)

System Description and Operation (Cont.)

were backwashed. The pH of the treated water was set to between 7.0 and 7.5 pH beyond the clarifier to prevent precipitation of calcium carbonate.

- Two additional injection wells were constructed to allow for higher reinjection rates.
- Backwash water is stored in the modified backwash unit and is slowly added to the influent tank. The slow addition avoids upsetting the pH balance in the influent.
- Modifications were completed in August 1993, and the extraction and treatment systems became operational in November 1993.

- In September 1996, a low-flow test was performed in case future extraction would be from the Ogallala Formation only, because the Ogallala Formation was being remediated more slowly than the Trinity Aquifer. The treatment system was tested for ability to operate at 20 gpm, and was successful at low flow rates.
- In March 1997, an additional recovery well was installed in the Ogallala Formation to expedite cleanup of the suspected source area. The additional well expanded the extraction network to a total of four recovery wells in the Ogallala Formation.
- Since November 1993, the site has been operational 95% of the time. Downtime is primarily due to shutdowns for local brown-outs and routine system maintenance.
- On December 12, 1997 the Odessa IIS plant was shut down for major modification. All of the Trinity Aquifer wells had met the clean-up criterion set by the ROD as did all but two of the Ogallala Formation wells. Since the remaining two perched zone wells produced less than two gpm total flow, it became inefficient to operate a 60 gpm plant for such a small flow. Modifications were made to collect the water from the two remaining Ogallala Formation wells in the influent and effluent tanks at the plant. These tanks are periodically discharged to a tank truck for transport to an off-site treatment plant.
- The equipment that was not needed in the modified plant was either disposed off site or disconnected and stored on site for future use. All of the Trinity Aquifer recovery wells with the exception of RW14 were plugged, as were Ogallala Formation wells PRW18 and PRW19. RW14 supplies injection water to two Ogallala Formation injection wells to aid in pushing contaminated water toward the Ogallala Formation recovery wells.

Operating Parameters Affecting Treatment Cost or Performance

The operating parameter affecting cost or performance for this technology is the extraction rate. Table 3 presents the average pump rate and other performance parameters.

Table 3. Performance Parameters

Parameter	Value
Average Pump Rate	84,200 gpd*
Performance Standard (effluent)	0.05 mg/L total chromium
Remedial Goal (aquifer)	0.10 mg/L total chromium

*The average system extraction rate from November 1993 until December 1996 was approximately 84,200 gpd, based on a total volume of 94 million gallons extracted and a 95% operation rate.
Source: [3, 4]

TREATMENT SYSTEM DESCRIPTION (CONT.)

Timeline

Table 4 presents a timeline for this application.

Table 4. Timeline

Start Date	End Date	Activity
January 1992	July 1992	Remediation system constructed
July 1992	August 1992	Trial run conducted and injection wells clogged with iron and calcium
August 1992	May 1993	Redesign and pilot studies performed
May 1993	August 1993	Alterations made to remedial system
November 1993	---	Continuous operation of remediation system begun. Monthly monitoring of groundwater began
September 1996	—	Treatment system tested for effectiveness during low flow
March 1997	—	Recovery Well PRW-28 constructed in Perched Zone
December 1997	—	Plant shut down and modified for collection of Perched Zone water only.

Source: [1-4]

TREATMENT SYSTEM PERFORMANCE

Cleanup Goals/Standards [1]

The cleanup goals as established by the EPA and TNRCC are to lower the chromium levels in the groundwater to less than the maximum contaminant level (MCL), or Primary Drinking Water Standard, of 0.10 mg/L. This goal is applied throughout the aquifer, as measured in all on-site monitoring wells.

Additional Information on Goals

The original drinking water standard for chromium set by EPA was 0.05 mg/L. In 1990, EPA revised the standard to the primary drinking water standard of 0.10 mg/L.

Treatment Performance Goals [3]

- Effluent injected into the aquifer from the treatment system must have levels of chromium below 0.10 mg/L.
- As a secondary goal, the remedial system is designed to create an inward hydraulic gradient toward the site to contain the plumes.

Performance Data Assessment [3, 4, 6]

- Based on monthly sampling events, cleanup goals have been achieved in the Trinity Aquifer but not in the Ogallala Formation [1,5]. Groundwater monitoring results from the January 1997 sampling event indicate that chromium concentrations in the Ogallala Formation have been reduced, but not to levels below treatment goals. However, in the Trinity Aquifer, chromium levels detected in the 1997 sampling event were all found to be below the MCL [6].
- Based on sampling results, the site operators have concluded that the plume has been contained in both aquifers [4,6].
- Figure 3 illustrates the decline in average chromium concentrations in the groundwater over time for the Trinity Aquifer. The average chromium levels in the groundwater have decreased in this unit.

TREATMENT SYSTEM PERFORMANCE (CONT.)

Performance Data Assessment (Cont.)

- Figure 3 also shows a spiking of the average chromium concentrations in the Ogallala Formation in 1995. ITC has attributed this spike to desorption of chromium from the previously unsaturated zone that was affected by increased precipitation from 1986 to 1996[5]. Since then, concentrations have again dropped.
- The average concentration of chromium detected in the groundwater in the Ogallala Formation in January 1997 was 0.18 mg/L, while the maximum concentration found during the same sampling event was 0.88 mg/L, a level exceeding the MCL [4].
- Effluent chromium levels have met the required performance standard of 0.10 mg/L; thus, reinjection of effluent has been possible throughout system operation [4].
- From 1993 to December 1996, the P&T system removed a total of 131 pounds of chromium from the groundwater, as shown in Figure 4. Figure 4 illustrates the decline in contaminant removal rate for the P&T system during the first three years of full-scale system operation (1993-1996). The chromium removal rate decreased from 0.18 pounds per day in December 1993 to 0.05 pounds per day in 1996 [4].

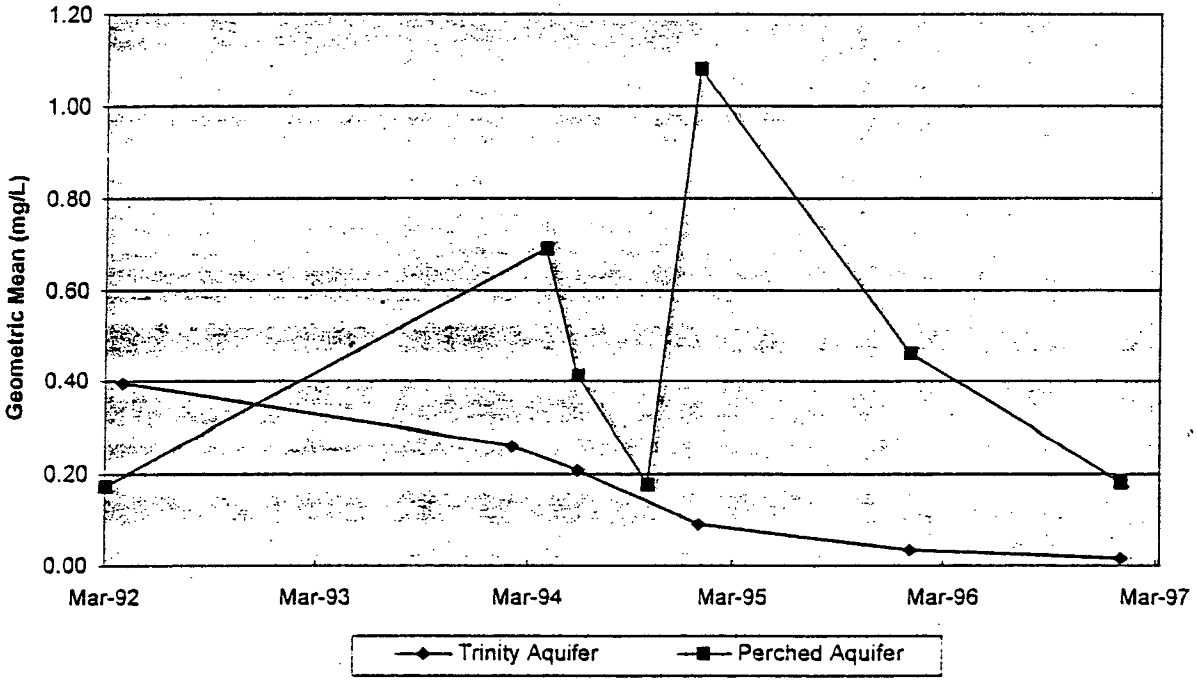

Figure 3. Average Chromium Concentrations from March 1992 - January 1997 [3,4]

TREATMENT SYSTEM PERFORMANCE (CONT.)

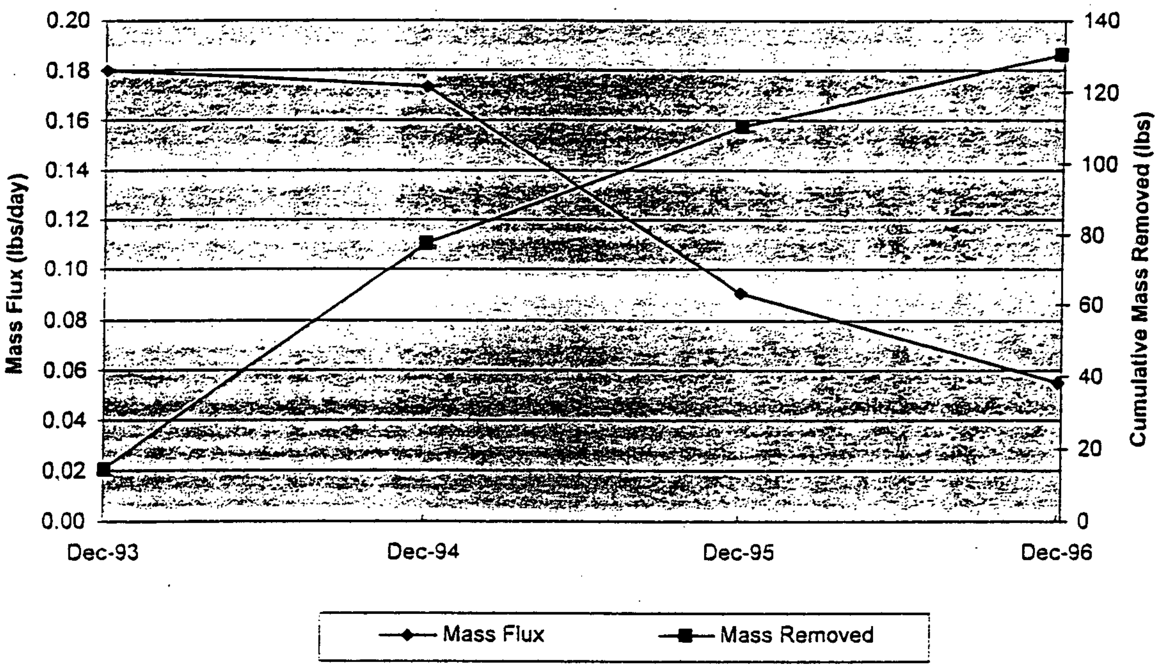

Figure 4. Mass Flux Rate and Cumulative Chromium Removal (1993 - 1996) [3,4]

Performance Data Completeness

- Data on mass flux and mass removed are reported on a monthly basis, and are available from the TNRCC. Annual monitoring data were used for Figure 3.
- Annual data on chromium mass removed were provided by the TNRCC and were used for Figure 4 analyses.
- A geometric mean was used for average chromium concentrations detected in the groundwater in Figure 4 to show the overall trend of chromium levels in the groundwater on an annual basis.
- When concentrations below detection limits were encountered, half of the detection limit was used for evaluation purposes.

Performance Data Quality

The QA/QC program used throughout the remedial action met the EPA and the TNRCC requirements. All monitoring was performed using EPA Method 218.1 and EPA-approved methods for pH, total suspended solids, and other water quality parameters. The vendor did not note any exceptions to the QA/QC protocols [4].

TREATMENT SYSTEM COST

Procurement Process

The TNRCC is the lead authority on this site. WATEC was awarded the construction and operations contract for the site. ITC was awarded the oversight contract for the site.

Cost Analysis

- The costs for design, construction, and operation of the treatment system at this site were split 90:10 by the EPA and the TNRCC, respectively.

Capital Costs [6]

Remedial Construction	
Mobilization Work	$334,723
Monitoring Wells - Sampling/Testing Analysis	$43,500
Groundwater Collection & Control	$330,944
Installation of Treatment Plant	$884,962
Site Restoration	$13,542
Site Security	$3,298
Construction Management	$316,533
Total Remedial Construction	**$1,927,502**

Operating Costs [6]

Operation and Maintenance 1993-1996	$524,766
Monitoring: Sampling and Analysis 1993-1996	$35,466
Total 1993-1996 Operating Costs	**$560,232**
1993 Operating Costs (11/93-12/93)	$ 13,060
1994 Operating Costs (1/94-12/94)	$146,260
1995 Operating Costs (1/95-12/95)	$232,416
1996 Operating Costs (1/96-12/96)	$168,506

Other Costs [6]

Engineering Design	$417,452
Oversight	$48,154
EPA Oversight	$113,978

Cost Data Quality

- The costs listed above include the system modifications performed in 1993 and in 1995. There were no other changes to the cost of the remedial system for this site greater than 10% of the total cost [6].
- Actual capital and operations and maintenance cost data are available from the TNRCC for this application.

OBSERVATIONS AND LESSONS LEARNED

- Actual costs for the P&T application at Odessa IIS were approximately $2,487,700 ($1,927,500 in capital costs and $560,200 in operations and maintenance costs), which corresponds to $26 per 1,000 gallons of groundwater treated and $19,000 per pound of chromium removed.
- The ROD specified that the ferrous ion used to reduce the chromium would be electrochemically produced. This requirement limited the on-site system to two vendors and potentially increased the cost of the treatment unit.
- Average concentrations of chromium in the Ogallala Formation spiked between 1993 and 1995. The increase may be a result of aquifer recharge through chromium-containing soil. ITC has determined the chromium in the Ogallala Formation is the source for chromium in the Trinity Aquifer. Because the Ogallala Formation is hydraulically connected to the Trinity Aquifer, water within the Ogallala Formation

OBSERVATIONS AND LESSONS LEARNED (CONT.)

is expected to continue to move downward over time, adding additional contaminated water to the Trinity Aquifer [3]. Continued extraction from the Ogallala Formation will help prevent downward migration of the plume to the Trinity Aquifer.

- Chromium levels in the Trinity Aquifer have been reduced to below the MCL. Extraction and monitoring of groundwater in the Trinity Aquifer will continue to ensure that concentrations remain stable. If levels of chromium remain below the MCL, extraction from this unit will be discontinued and increased pumping from the Ogallala Formation will begin [6].

- There were several startup problems, including clogging of injection wells and encrustation of the multimedia polishing filter by iron and calcium carbonate that delayed full-scale operations. These problems were accommodated through system modification, and no longer interfere with operations. ITC has suggested that one potential approach to identifying problems earlier would be to increase the length of pilot operations. At this site, pilot tests were conducted in hourly increments, and the results were used to simulate full-cycle operations. Had the pilot operations been conducted for a full 24-hour cycle, it is likely that the iron fouling problems that led to clogging could have been identified [2].

- Full-scale operations were delayed by iron and calcium encrustation in injection wells and the filter. Future effluent standards set for iron could prevent such delays.

- ITC found monthly monitoring of chromium levels in influent wells helpful. However, this was not the case for continuous monitoring. The continuous chromium monitors installed at this site could not detect levels above 1.0 mg/L [2].

- During system operation, ITC determined that backwash from the filter system should be equalized and added slowly to the influent tank to avoid large changes in the influent chemistry. During early system operations, backwash water was introduced directly into the influent tank. The differences between the pH levels in the backwash and the influent reduced the effectiveness of the reaction tank. The backwash storage unit allowed gradual addition of backwash to the influent. Addition of an equalization tank alleviated the earlier problems in the reaction tank [2].

REFERENCES

1. Record of Decision. USEPA, Odessa Chromium IIS, March 18, 1988.
2. Lessons Learned. IT Corporation, January 1997.
3. Project Status Draft Report. ITC, January 1995.
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5. Odessa Chromium I & IIS Superfund Sites Treatment System. Waste Abatement Technology, Inc. No date listed.
6. Correspondence with Mr. Lel Medford, TNRCC. February 12, March 5, March 11, March 14, June 4, July 29, and December 5, 1997.
7. Groundwater Regions of the United States. Heath, Ralph. U.S. Geological Survey Supply Paper 2242. 1984.
8. TNRCC comment on draft report, dated May 8, 1998.

Analysis Preparation

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APPENDIX C

HYDRODYNAMICS OF REAGENT INJECTION SYSTEMS

APPENDIX C

HYDRODYNAMICS OF REAGENT INJECTION SYSTEMS

There are three common methods for the injection of reagents into an impacted water-bearing zone:

1. Passive injection of reagents using gravity can be utilized. The natural groundwater flow and dispersion serve to mix the reagents in the surrounding water-bearing unit.

    - This is practical at sites where there is adequate groundwater velocity (0.5 feet per day or greater) and acceptable life expectancy of the active reagent in the water bearing unit geologic matrix.

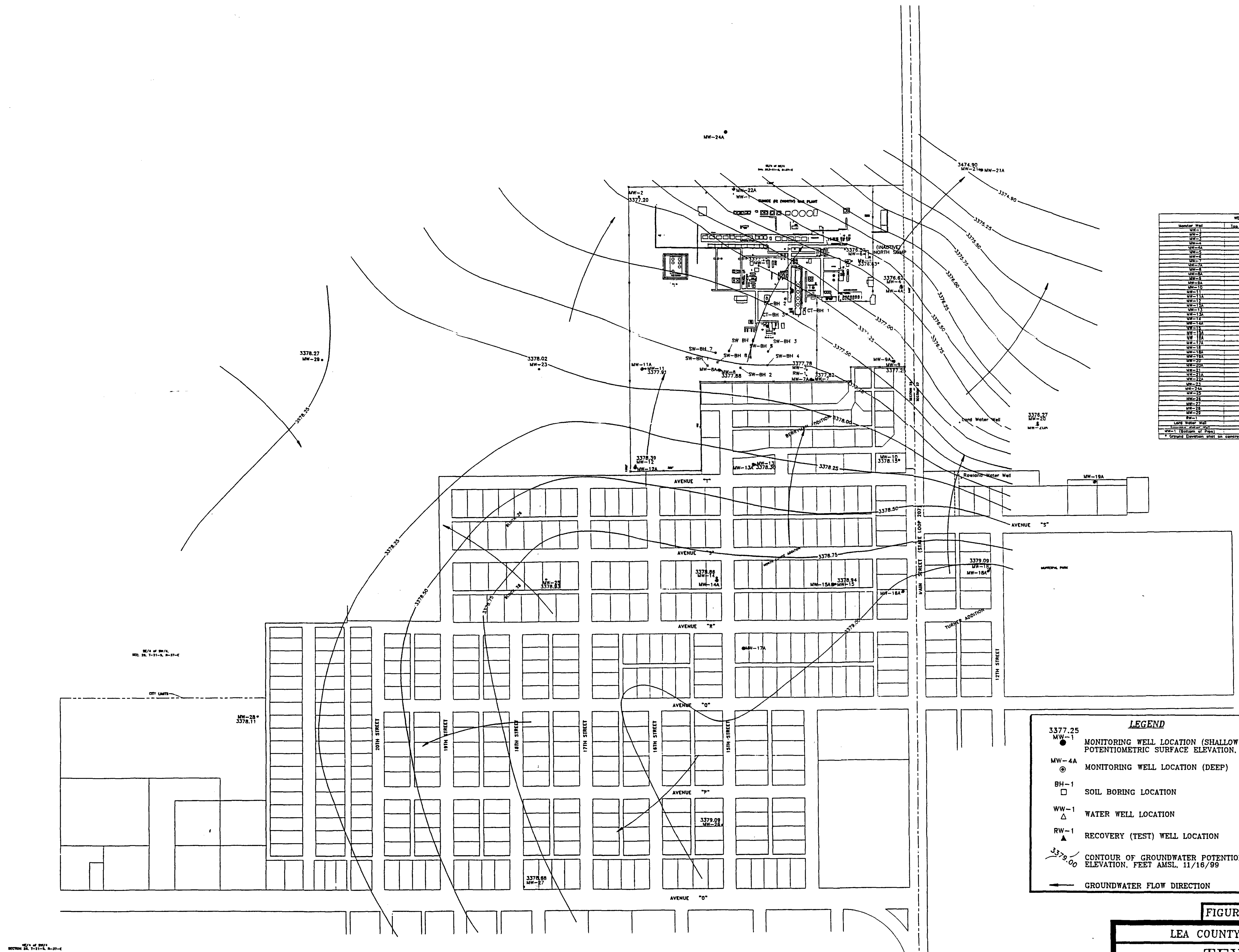
2. Pressure injection can be utilized to inject the reagent into the formation. In this case, the solutions will follow preferential hydraulic pathways during injection and then the native groundwater flow and diffusion will serve to further mix the injected reagents. Injection pressures must be kept low enough to prevent hydrofracturing. Typical injection pressures are in the 20 to 40 PSI range.

    - This approach can have significant impact when applied to geologic units with high contrast of hydraulic conductivity. ARCADIS has had instances where injected fluids have immediately reached radial distances of 100 yards with injection pressures of less than 15 PSI.

3. Lastly, a pressure injection system coupled with a groundwater recovery system to accentuate the local hydraulic gradient can be used. At Texaco Eunice, it may be possible that the recovered groundwater can be beneficially used for plant process and cooling tower makeup water in lieu of fresh uncontaminated groundwater currently being used. This approach utilizing pressure injection coupled with groundwater recovery can be appropriate in low groundwater velocity situations and when the extracted groundwater can be re-injected.

    - This approach would have the disadvantage of requiring recovery and treatment of groundwater if the water could not be re-used. However, it would offer more hydraulic control than could be obtained with a passive or pressure injection system alone.

The selection of the most appropriate injection approach is a function of the site geology, the groundwater hydrodynamics, the subsurface geochemistry, the specific remediation goals, target contaminants, and the overall cost. The injection approach will be determined following pilot testing activities and incorporated into full scale system design.



WELL DATA		
Monitor Well	Top of Casing Elevation	*Ground Elevation
MW-1	3428.57	3428.79
MW-2	3432.17	3432.29
MW-3	3428.27	3426.10
MW-4	3423.38	3423.59
MW-4A	3423.57	3423.59
MW-5	3424.77	3425.49
MW-6	3425.26	3425.09
MW-7	3428.39	3426.28
MW-7A	3428.13	3426.28
MW-8	3430.13	3427.90
MW-8A	3430.01	3427.90
MW-9	3427.63	3425.09
MW-9A	3427.48	3425.09
MW-10	3419.42	3419.77
MW-11	3431.49	3429.07
MW-11A	3431.77	3429.28
MW-12	3429.51	3427.69
MW-12A	3429.92	3427.42
MW-13	3424.11	3424.40
MW-13A	3424.25	3424.39
MW-14	3424.08	3424.31
MW-14A	3423.90	3424.50
MW-15	3420.40	3420.55
MW-15A	3420.55	3420.85
MW-16A	3418.84	3418.99
MW-17A	3424.38	3424.48
MW-18	3417.15	3417.39
MW-18A	3416.86	3417.04
MW-19A	3414.74	3414.95
MW-20	3420.85	3418.50
MW-20A	3421.14	3418.50
MW-21	3422.72	3420.41
MW-21A	3422.94	3420.41
MW-22A	3431.13	3428.50
MW-23	3436.44	3433.99
MW-24A	3430.77	3428.98
MW-25	3432.89	3432.89
MW-26	3432.04	3432.52
MW-27	3443.33	3443.72
MW-28	3451.63	3450.02
MW-29	3446.89	3444.76
RW-1	3428.32	3425.73
Lord Water Well	3419.97	3418.47
Rowland Water Well	3419.43	3418.47
WW-1 (Bottom of Pipe)	3429.65	3428.78
* Ground Elevation shot on concrete pad (if available)		

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DEC 13 2000

ENVIRONMENTAL BUREAU
OIL CONSERVATION DIVISION

LEGEND

3377.25 MW-1 ●	MONITORING WELL LOCATION (SHALLOW),AND GROUNDWATER POTENTIOMETRIC SURFACE ELEVATION, FEET AMSL, 11/16/99
MW-4A ⊙	MONITORING WELL LOCATION (DEEP)
BH-1 ☐	SOIL BORING LOCATION
WW-1 △	WATER WELL LOCATION
RW-1 ▲	RECOVERY (TEST) WELL LOCATION
3379.00	CONTOUR OF GROUNDWATER POTENTIOMETRIC SURFACE ELEVATION, FEET AMSL, 11/16/99
←	GROUNDWATER FLOW DIRECTION

NOTE:
CT: COOLING TOWER AREA
SW: SOUTHWEST AREA
*: GROUNDWATER POTENTIOMETRIC SURFACE ELEVATION CORRECTED FOR PSH

Elevations shown are based on Monitor Wells 7, 8, and 9 as shown in letter by Ronald J. Eidson of West Engineering Co. September 3, 1997.

GRAPHIC SCALE IN FEET
0 200 400 600
Original Plotted at Scale: 1"=200'

DATE: 01/11/00
DWN. BY: JDA
FILE: C:\787\NORTH\GPS-S-12-99

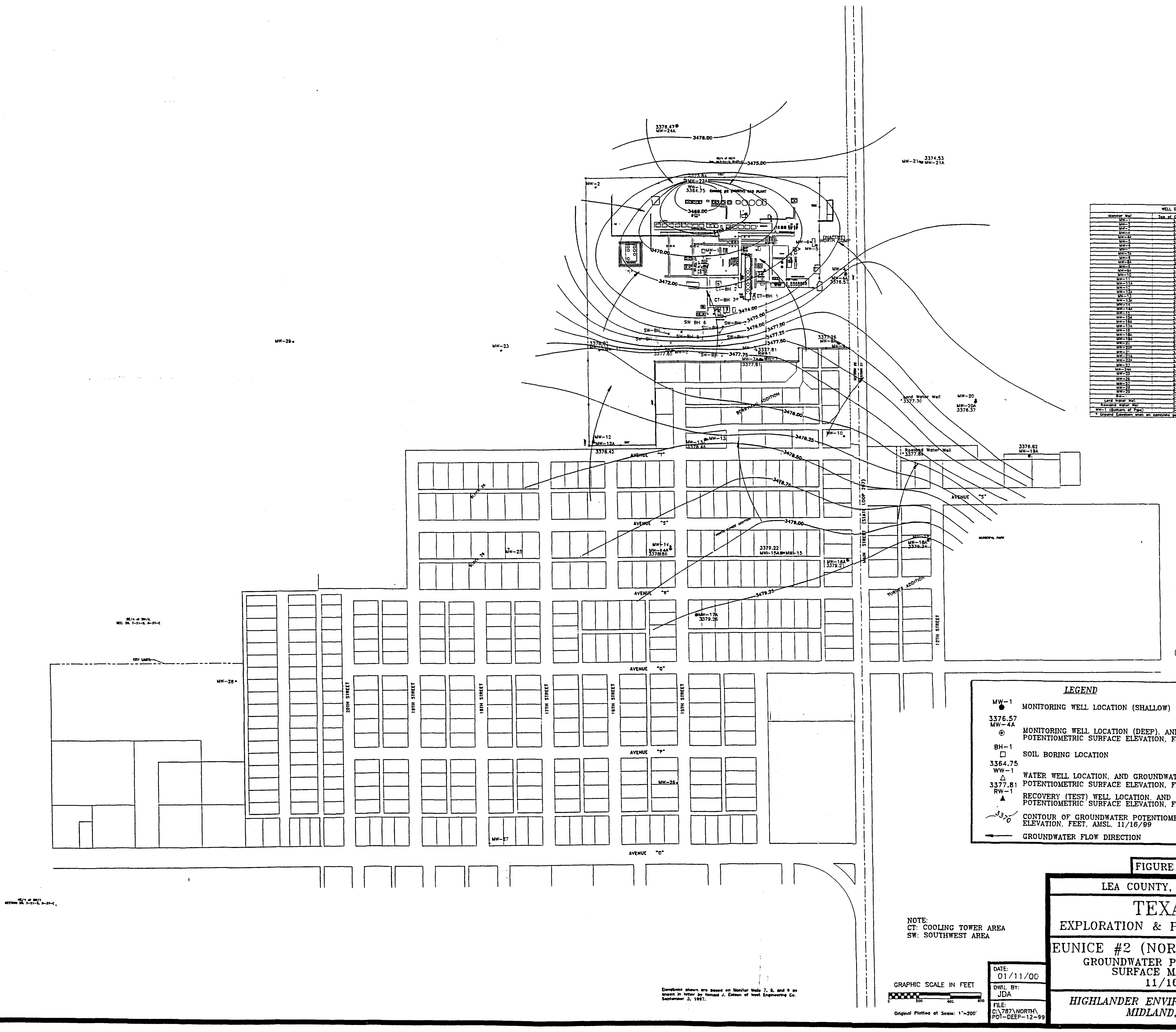
FIGURE NO. 5

LEA COUNTY, NEW MEXICO

TEXACO
EXPLORATION & PRODUCTION INC.

EUNICE #2 (NORTH) GAS PLANT
GROUNDWATER POTENTIOMETRIC
SURFACE MAP (SHALLLOW), 11/16/99

HIGHLANDER ENVIRONMENTAL CORP.
MIDLAND, TEXAS



Elevations shown are based on Monitor Wells 7, 8, and 9 as shown in letter by Ronald J. Eidson of West Engineering Co. September 3, 1997.

NOTE:
CT: COOLING TOWER AREA
SW: SOUTHWEST AREA

WELL DATA

Monitor Well	Top of Casing Elevation	*Ground Elevation
MW-1	3428.57	3428.79
MW-2	3432.17	3432.29
MW-3	3428.27	3426.10
MW-4	3423.38	3423.59
MW-4A	3423.57	3423.59
MW-5	3424.77	3425.49
MW-6	3425.26	3425.09
MW-7	3428.39	3426.28
MW-7A	3428.13	3426.28
MW-8	3430.13	3427.90
MW-8A	3430.01	3427.90
MW-9	3427.63	3425.09
MW-9A	3427.48	3425.09
MW-10	3419.42	3419.77
MW-11	3431.49	3429.07
MW-11A	3431.77	3429.28
MW-12	3429.51	3427.69
MW-12A	3429.82	3427.42
MW-13	3424.11	3424.40
MW-13A	3424.25	3424.39
MW-14	3424.08	3424.37
MW-14A	3423.90	3424.50
MW-15	3420.40	3420.55
MW-15A	3420.55	3420.65
MW-16A	3419.92	3419.99
MW-17A	3424.38	3424.48
MW-18	3417.15	3417.39
MW-18A	3416.86	3417.04
MW-19A	3414.74	3414.95
MW-20	3420.85	3418.50
MW-20A	3421.14	3418.59
MW-21	3422.72	3420.41
MW-21A	3422.94	3420.41
MW-22A	3431.13	3428.50
MW-23	3436.44	3433.89
MW-24A	3430.77	3428.98
MW-25	3432.69	3432.85
MW-26	3432.04	3432.52
MW-27	3443.33	3443.72
MW-28	3451.83	3450.02
MW-29	3448.89	3444.76
RW-1	3428.32	3425.73
Lord Water Well	3419.97	3419.47
Rowland Water Well	3419.47	3418.47
WW-1 (Bottom of Pipe)	3429.95	3428.76

* Ground Elevation shot on concrete pad (if available)

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DEC 18 2000
ENVIRONMENTAL BUREAU
OIL CONSERVATION DIVISION

LEGEND

MW-1 ●	MONITORING WELL LOCATION (SHALLOW)
3376.57 MW-4A ⊙	MONITORING WELL LOCATION (DEEP), AND GROUNDWATER POTENTIOMETRIC SURFACE ELEVATION, FEET AMSL, 11/16/99
BH-1 ☐	SOIL BORING LOCATION
3364.75 WW-1 △	WATER WELL LOCATION, AND GROUNDWATER POTENTIOMETRIC SURFACE ELEVATION, FEET AMSL, 11/16/99
3377.81 RW-1 ▲	RECOVERY (TEST) WELL LOCATION, AND GROUNDWATER POTENTIOMETRIC SURFACE ELEVATION, FEET AMSL, 11/16/99
3370	CONTOUR OF GROUNDWATER POTENTIOMETRIC SURFACE ELEVATION, FEET, AMSL, 11/16/99
←	GROUNDWATER FLOW DIRECTION

FIGURE NO. 6

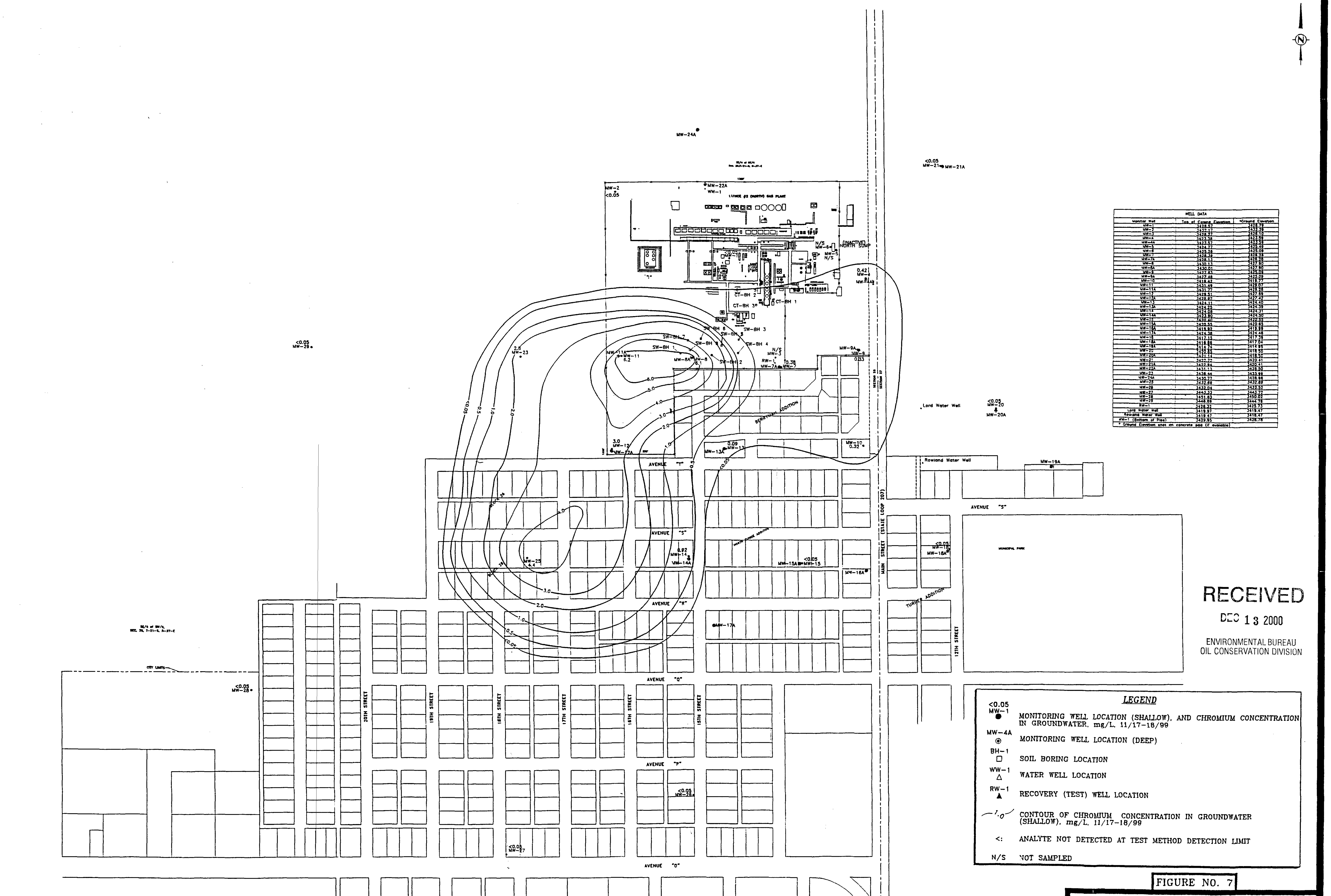
LEA COUNTY, NEW MEXICO

TEXACO
EXPLORATION & PRODUCTION INC.

EUNICE #2 (NORTH) GAS PLANT
GROUNDWATER POTENTIOMETRIC
SURFACE MAP (DEEP)
11/16/99

DATE:
01/11/00
DWN. BY:
JDA
FILE:
C:\787\NORTH\POT-DEEP-12-99

HIGHLANDER ENVIRONMENTAL CORP.
MIDLAND, TEXAS



WELL DATA		
Monitor Well	Top of Casing Elevation	*Ground Elevation
MW-1	3428.57	3428.79
MW-2	3432.17	3432.29
MW-3	3428.27	3426.10
MW-4	3423.38	3423.59
MW-4A	3423.57	3423.59
MW-5	3424.77	3425.49
MW-6	3425.28	3425.09
MW-7	3428.39	3426.28
MW-7A	3428.13	3426.28
MW-8	3430.13	3427.90
MW-8A	3430.01	3427.90
MW-9	3427.63	3425.09
MW-9A	3427.48	3425.09
MW-10	3419.42	3419.77
MW-11	3431.49	3429.07
MW-11A	3431.77	3429.28
MW-12	3429.51	3427.69
MW-12A	3429.92	3427.42
MW-13	3424.11	3424.40
MW-13A	3424.25	3424.39
MW-14	3424.08	3424.31
MW-14A	3423.90	3424.50
MW-15	3420.40	3420.55
MW-15A	3420.55	3420.65
MW-16A	3419.92	3419.99
MW-17A	3424.38	3424.48
MW-18	3417.15	3417.39
MW-18A	3418.86	3417.04
MW-19A	3414.74	3414.85
MW-20	3420.85	3418.50
MW-20A	3421.14	3418.50
MW-21	3422.72	3420.41
MW-21A	3422.94	3420.41
MW-22A	3431.13	3428.50
MW-23	3438.44	3433.99
MW-24A	3430.77	3428.98
MW-25	3432.69	3432.89
MW-26	3432.04	3432.52
MW-27	3443.33	3443.72
MW-28	3451.63	3450.02
MW-29	3446.69	3444.76
RW-1	3428.32	3425.73
Lord Water Well	3419.97	3419.47
Rowland Water Well	3419.47	3418.47
WW-1 (Bottom of Pipe)	3429.95	3428.78

* Ground Elevation shot on concrete pad (if available)

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DEC 13 2000

ENVIRONMENTAL BUREAU
OIL CONSERVATION DIVISION

LEGEND

<0.05 MW-1 ●	MONITORING WELL LOCATION (SHALLOW), AND CHROMIUM CONCENTRATION IN GROUNDWATER, mg/L, 11/17-18/99
MW-4A ◉	MONITORING WELL LOCATION (DEEP)
BH-1 ☐	SOIL BORING LOCATION
WW-1 △	WATER WELL LOCATION
RW-1 ▲	RECOVERY (TEST) WELL LOCATION
1.0	CONTOUR OF CHROMIUM CONCENTRATION IN GROUNDWATER (SHALLOW), mg/L, 11/17-18/99
<:	ANALYTE NOT DETECTED AT TEST METHOD DETECTION LIMIT
N/S	NOT SAMPLED

NOTE:
CT: COOLING TOWER AREA
SW: SOUTHWEST AREA

Elevations shown are based on Monitor Wells 7, 8, and 9 as shown in letter by Ronald J. Eidson of West Engineering Co. September 3, 1997.

GRAPHIC SCALE IN FEET
0 200 400 600
Original Plotted at Scale: 1"=200'

FIGURE NO. 7

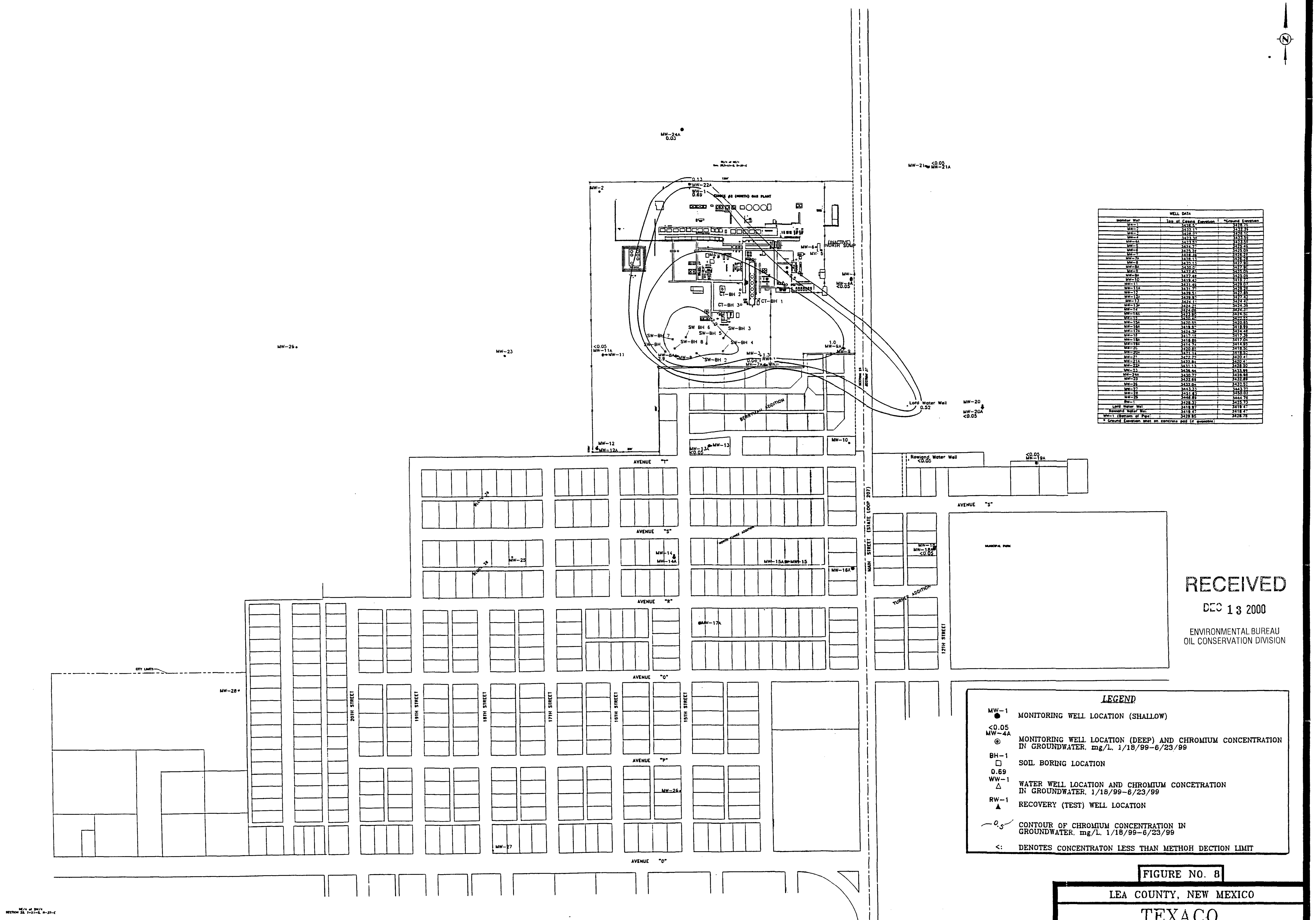
LEA COUNTY, NEW MEXICO

TEXACO
EXPLORATION & PRODUCTION INC.

EUNICE #2 (NORTH) GAS PLANT
ISOPLETH MAP OF CHROMIUM
CONCENTRATION IN GROUNDWATER
(SHALLOW), 11/17-18/99

DATE: 6/30/99
DWN BY: JCA
FILE: C:\787\BASE

HIGHLANDER ENVIRONMENTAL CORP.
MIDLAND, TEXAS



Elevations shown are based on Monitor Wells 7, 8, and 9 as shown in letter by Ronald J. Eidson of West Engineering Co. September 3, 1997.

WELL DATA		
Monitor Well	Top of Casing Elevation	*Ground Elevation
MW-1	3428.57	3428.75
MW-2	3432.17	3432.25
MW-3	3428.27	3426.10
MW-4	3423.38	3423.55
MW-4A	3423.57	3423.55
MW-5	3424.77	3425.49
MW-6	3425.26	3425.09
MW-7	3428.38	3426.28
MW-7A	3428.13	3426.28
MW-8	3430.13	3427.90
MW-8A	3430.03	3427.90
MW-9	3427.63	3425.09
MW-9A	3427.48	3425.09
MW-10	3419.42	3419.77
MW-11	3431.45	3429.07
MW-11A	3431.77	3429.28
MW-12	3429.51	3427.69
MW-12A	3429.92	3427.42
MW-13	3424.17	3424.40
MW-13A	3424.25	3424.35
MW-14	3424.06	3424.31
MW-14A	3423.90	3424.50
MW-15	3420.40	[illegible]
MW-15A	3420.55	3420.65
MW-16A	3419.92	3419.99
MW-17A	3424.38	3424.48
MW-18	3417.15	3417.39
MW-18A	3416.86	3417.04
MW-19A	3414.74	3414.95
MW-20	3420.85	3418.50
MW-20A	3421.14	3418.52
MW-21	3422.72	3420.41
MW-21A	3422.94	3420.41
MW-22A	3431.13	3428.50
MW-23	3436.44	3433.89
MW-24A	3430.77	3428.98
MW-25	3432.69	3432.89
MW-26	3432.04	3432.57
MW-27	3443.33	3443.72
MW-28	3451.63	3450.02
MW-29	3446.89	3444.76
RW-1	3428.32	3425.73
Lord Water Well	3419.97	3419.47
Rowland Water Well	3419.47	3418.47
WW-1 (Bottom of Pipe)	3429.95	3428.76

* Ground Elevation shot on concrete pad (if available)

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DEC 13 2000
ENVIRONMENTAL BUREAU
OIL CONSERVATION DIVISION

LEGEND

MW-1 ●	MONITORING WELL LOCATION (SHALLOW)
<0.05 MW-4A ⊙	MONITORING WELL LOCATION (DEEP) AND CHROMIUM CONCENTRATION IN GROUNDWATER. mg/L. 1/18/99-6/23/99
BH-1 □	SOIL BORING LOCATION
0.69 WW-1 △	WATER WELL LOCATION AND CHROMIUM CONCETRATION IN GROUNDWATER. 1/18/99-6/23/99
RW-1 ▲	RECOVERY (TEST) WELL LOCATION
0.5	CONTOUR OF CHROMIUM CONCENTRATION IN GROUNDWATER. mg/L. 1/18/99-6/23/99
<	DENOTES CONCENTRATON LESS THAN METHOH DECTION LIMIT

NOTE:
CT: COOLING TOWER AREA
SW: SOUTHWEST AREA

GRAPHIC SCALE IN FEET
0 200 400 800
Original Plotted at Scale: 1"=200'

FIGURE NO. 8

LEA COUNTY, NEW MEXICO

TEXACO
EXPLORATION & PRODUCTION INC.

EUNICE #2 (NORTH) GAS PLANT

ISOPLETH MAP OF CHROMIUM CONCENTRATION IN GROUNDWATER (DEEP) 1/18/99-6/23/99

DATE: 12/20/99
DWN. BY: JDA
FILE: C:787\NORTH\ ICCGD-12-99

HIGHLANDER ENVIRONMENTAL CORP.
MIDLAND, TEXAS

Highlander Environmental Corp.

Midland, Texas

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DEC 2 1 1998

Environmental Bureau
Oil Conservation Division

December 17, 1998

Mr. William C. Olson, Hydrogeologist
New Mexico Oil Conservation Division
Environmental Bureau
2040 S. Pacheco
Santa Fe, New Mexico 87505

Re: Work Plan for Delineation of Groundwater Contaminate Plume, Texaco Exploration and Production, Inc., Former Eunice # 2 (North) Gas Plant, Eunice, New Mexico

Dear Mr. Olson:

Highlander Environmental Corp. (Highlander) has been retained by Texaco Exploration and Production, Inc. (Texaco) to prepare a work plan for delineation of groundwater contamination at its former Eunice # 2 (North) Gas Plant (Site), located in Eunice, New Mexico. Figure 1 presents a Site location and topographic map. The New Mexico Oil Conservation Division (NMOCD), in a letter dated October 9, 1998, required the work plan following its review of the report prepared by Highlander titled, " Addendum Final Investigation Report, Texaco Exploration and Production, Inc., Eunice # 2 (North) Gas Plant, Lea County, New Mexico, January 1998" and submittal of additional information pertaining to soil and groundwater investigations at the Site (July 14, 1998). Specifically, the NMOCD is requiring Texaco to delineate the limits of benzene, toluene, ethylbenzene, and xylene (BTEX) and lead in groundwater (shallow) north and east of the Site, and chromium, chloride and total dissolved solids (TDS) in groundwater (deep) north, south and east of the Site. The results of previous investigations have indicated that chromium is present in groundwater from two (2) water wells (Lord Water Well and Rowland Water Well), located southeast of the Site. Elevated chloride was also reported in groundwater from the Rowland Water Well, however, it is believed that the chloride impact at this well is due to potassium chloride, which is warehoused at the location. Correspondence from the NMOCD is presented in Appendix A.

On December 1, 1998, a meeting was conducted between personnel of the NMOCD, Texaco and Highlander to discuss current conditions at the Site, and additional investigations needed to delineate the extent of groundwater contamination. Based on the meeting, Texaco agreed to install seven (7) additional groundwater monitoring wells, including three (3) deep monitoring wells and four (4) shallow monitoring wells, and collect groundwater samples for laboratory tests from a representative number of monitoring wells (shallow and deep) to evaluate current plume conditions. It is also Texaco's intent to conduct a pumping test, which will provide data necessary to determine placement of groundwater recovery wells for abatement purposes. A discussion of the proposed activities is presented below.

Monitoring Well Drilling and Installations Details

Texaco will install seven (7) additional monitoring wells, including three (3) deep and four (4) shallow wells, to delineate the extent of BTEX, lead, chromium, chloride and TDS in groundwater. The shallow wells will be drilled to depths of approximately 65 feet below ground surface (BGS) and the deep wells will be drilled to depths of approximately 110 feet BGS. Two (2) wells (MW-20 and MW-20A) will be installed southeast of the Site, approximately 350 feet east of the Lord water well. A shallow well (MW-20) and a deep well (MW-20A) will be installed at this location to evaluate the eastern limit of chromium, chloride and TDS in groundwater. Two (2) wells will also be installed approximately 500 feet north and east of the northeast corner of the Site. A shallow well (MW-21) and a deep well (MW-21A) will be installed at this location to evaluate the north and east extent of BTEX, lead, chromium, chloride and TDS in groundwater. A deep well (MW-22A) will be installed adjacent to the north boundary of the Site, approximately 40 -to 50 feet north of water well WW-1, to evaluate the northern limit of chromium, chloride and TDS in groundwater. At well locations MW-11A and MW-15A, a shallow well will be installed adjacent to the existing deep well to delineate the western and southern limit of chromium, chloride and TDS in groundwater. Figure 2 presents a Site drawing and proposed monitor well locations.

The wells will be drilled the wells using a truck-mounted water rotary drill rig. Samples of drill cuttings will be collected every ten feet and at changes in lithology. The drill cuttings will be visually examined for lithology and a borehole sample log will be prepared for each boring. The wells will be constructed of 4-inch diameter, screw threaded, schedule 40 PVC casing and 0.020 inch factory slotted screen. The well screen for the shallow wells will be approximately twenty (20) feet in length, and will be placed in the borings with approximately 5 feet of screen above groundwater and 15 feet below groundwater. The deep wells will be completed with approximately ten (10) feet of screen placed at the bottom of the borehole, immediately above the top of the Triassic-age redbed (shale). The annulus between the well screen and borehole will be surrounded by graded (20-40) silica sand, which will be placed to a depth approximately two (2) feet above the screen. A seal consisting of bentonite pellets, approximately 2 feet thick will be placed above the sand and hydrated. The remaining borehole annulus will be filled to approximately 2 feet BGS with cement-bentonite grout. Each well will be secured with a locking water-tight cap, and either above-grade or at-grade well covers, anchored concrete pads measuring approximately 3 x 3 feet. The wells will be surveyed for ground surface and top-of-casing elevation by a State of New Mexico licensed land surveyor. The drilling rig and all down-hole equipment (i.e., drill rods, bits, etc.) will be thoroughly washed between boreholes using a high pressure hot water washer. The drill cuttings will be placed on the ground adjacent to the boreholes.

Following installation, the wells will be developed using a rig bailer and groundwater displaced during development will be contained in a portable tank, transferred to the Eunice #2 (North) Gas Plant and discharged into the wastewater and oil sump. The bailer will be thoroughly decontaminated between wells by washing with a high pressure washer.

Groundwater Sampling Details

After the wells have stabilized, Highlander personnel will obtain depth-to-groundwater and hydrocarbon product (PSH) thickness measurements on all monitoring wells and water wells at the Site, for preparation of groundwater potentiometric surface maps (shallow and deep). Select wells will be purged, by pumping with an electric stainless steel submersible pump, in preparation of groundwater sample collection. The wells selected for groundwater sampling will include MW-1, MW-2, MW-4, MW-4A, MW-7, MW-7A, MW-8, MW-8A, MW-9, MW-9A, MW-10, MW-11, MW-11A, MW-13, MW-13A, MW-15, MW-15A, MW-18A, MW-19A, MW-20, MW-20A , MW-21, MW-21A, MW-22A, WW-1, Lord Water well and Rowland Water Well. Table 1 presents a listing of wells and analytical parameters. However, if PSH is observed on the groundwater at any of the above-mentioned wells, no groundwater samples will be collected from that well. A minimum of three (3) casing volumes of groundwater will be removed from each well. The purged groundwater will be contained in a portable tank, transferred to the Eunice #2 (North) Gas Plant and discharged to the wastewater and oil sump. The submersible pump and discharge hose will be thoroughly decontaminated between wells using a laboratory-grade detergent and potable water wash, followed by rinsing with potable water. Groundwater samples for BTEX analysis will be collected using dedicated disposable polyethylene well bailers and line, however, all remaining samples will be collected at the discharge hose from the submersible pump. Groundwater samples collected for dissolved metals analysis will be filtered in the field. The samples will be carefully transferred to appropriately labeled and preserved sample containers, which will be provided by the analytical laboratory (Trace Analysis, Inc., Lubbock, Texas). The samples will be hand delivered to a laboratory representative and transferred to the laboratory under chain-of-custody control. The samples for dissolved metals analysis will be analyzed by the laboratory using appropriate EPA methodology and detection limits consistent with New Mexico Water Quality Control Commission (WQCC) human heath standards. Notification will also be provided to the NMOCD at least 24-hours in advance of initiating field activities and prior to groundwater sampling activities to allow it the opportunity to witness field activities and split groundwater samples.

Pumping Well Installation and Testing

Highlander personnel will conduct a pumping test to define the hydraulic parameters of the unconfined aquifer. The pumping test will be conducted by installing a test (recovery) well or utilizing an existing well (MW-7A, etc.). If a test well is installed, the well may be located near the North Sump and will be constructed with 6 inch PVC well casing and screen. The well will be drilled to the top of the Triassic-age redbed (shale) and the well screen will be placed from the bottom of the borehole to approximately 3 feet above the groundwater surface (approximately 45 feet BGS). The annulus between the well screen and borehole will be surrounded by graded (20-40) silica sand, which will be placed to a depth approximately two (2) feet above the screen. A seal consisting of bentonite pellets, approximately 2 feet thick will be placed above the sand and hydrated. The remaining borehole annulus will be filled to approximately 2 feet BGS with cement-bentonite grout. The well will be secured with a locking water-tight cap, and temporary well covers until a permanent cover is installed. The well will be developed using a rig bailer and groundwater displaced during development will be contained in a portable tank, transferred to the Eunice #2 (North) Gas Plant and discharged into the wastewater and oil sump. The bailer will be thoroughly decontaminated prior to use by washing with a high pressure washer.

The well will be pumped at a constant rate for a period of twenty-four (24) hours, followed by a recovery period of about 4 hours. The pumping rate will be determined prior to conducting the pumping test by conducting a short-term step drawdown test, or if a monitor well is used, the pump rate will be determined during purging of the well for groundwater sample collection. During the pumping test, drawdown will be recorded in nearby wells using pressure transducers, dataloggers or water level indicators. Drawdown and recovery measurements will be collected using a logarithmic frequency. The pumping and recovery test data will be evaluated using applicable methods, depending on observed drawdown (i.e., Theis Method, Neuman Straight Line Method, etc.). The pumping test data will be used to calculate the aquifer's hydraulic conductivity, model the aquifer, and select locations for groundwater recovery wells.

Following completion of the plume delineation activities, Highlander will prepare a report summarizing the investigation results. The report will include shallow and deep groundwater potentiometric surface maps, as well as isopleth maps for dissolved chromium, chloride and TDS for the shallow and deep portions of the aquifer. The report will also include data tables summarizing field and laboratory measurements and a narrative of investigation activities, results and conclusions.

Highlander has scheduled field activities beginning Tuesday, January 5, 1999. Highlander anticipates that drilling and well installation to be completed by January 15, 1999, barring weather delays and unforeseen conditions. Please call if you have questions.

Sincerely,
Highlander Environmental Corp.

Mark J. Larson
Senior Project Manager

Encl.

cc: Mr. Bob Foote, Texaco
Mr. Wayne Price, OCD- Hobbs Office

FIGURES

FIGURES

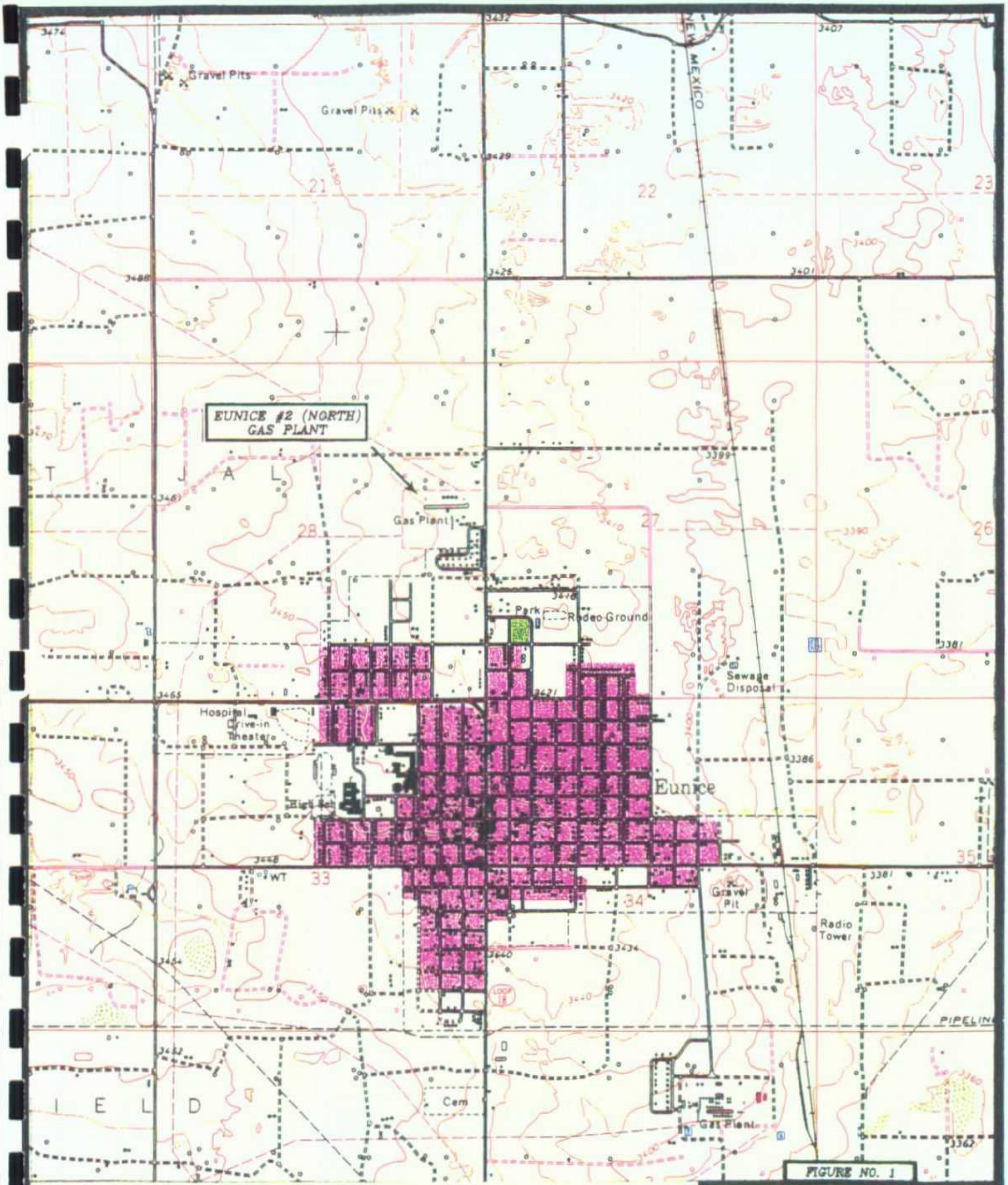


FIGURE NO. 1

LEA COUNTY, NEW MEXCIO

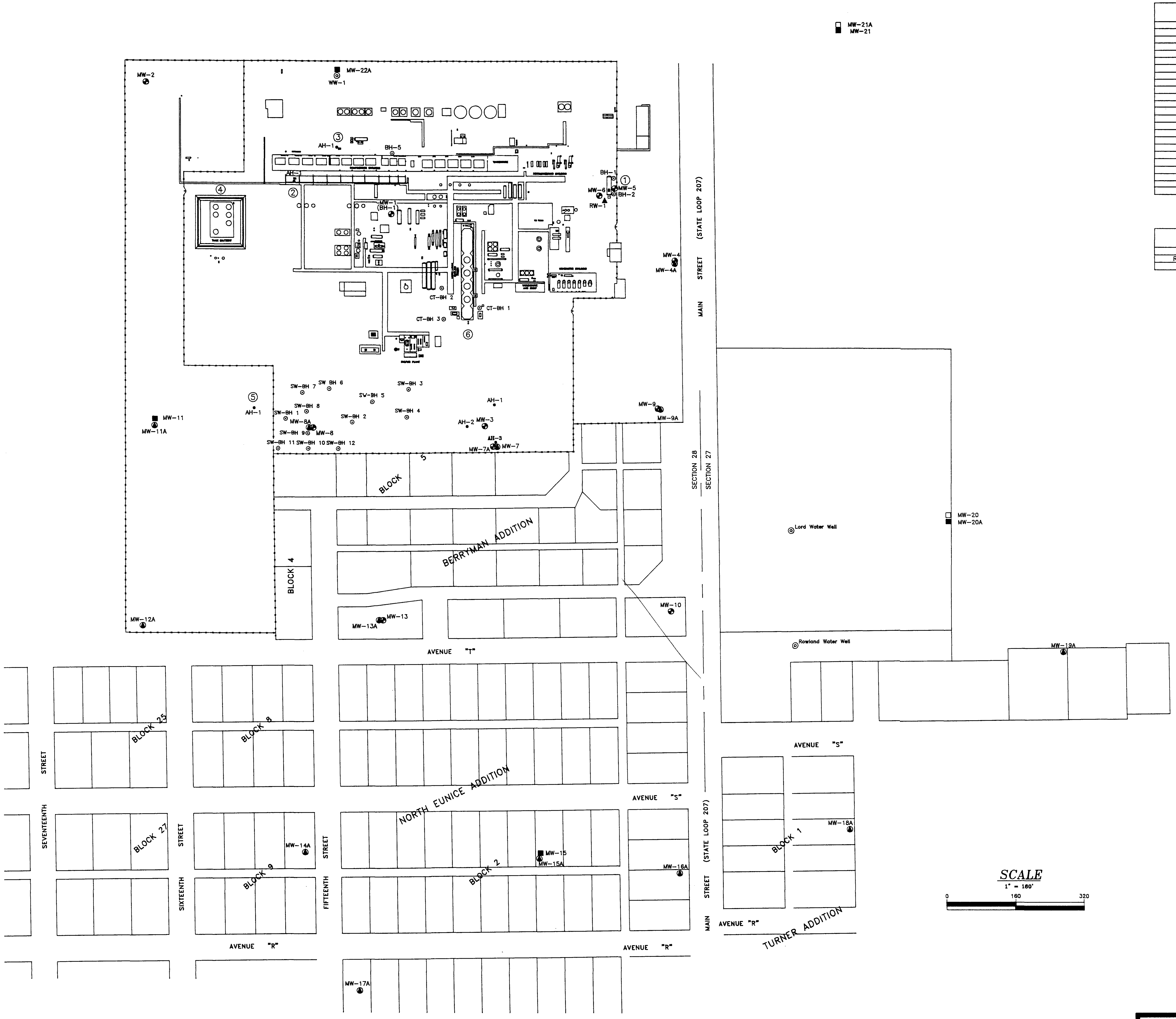
TEXACO
EXPLORATION & PRODUCTION

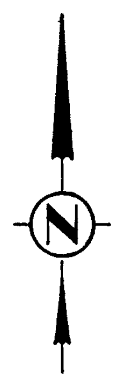
TOPOGRAPHIC
MAP

HIGHLANDER ENVIRONMENTAL
MIDLAND, TEXAS

TAKEN FROM U.S.G.S.
RATTLESNAKE CANYON, NM
7.5' QUADRANGLE

SCALE: 1" = 2,000'





Monitor Well Number	Top of Casing Elevation, Feet AMLS	Ground Elevation, Feet AMLS
MW-1	3428.57	3428.79
MW-2	3432.17	3432.29
MW-3	3428.27	3426.10
MW-4	3423.38	3423.59
MW-4A	3423.57	3423.59
MW-5	3424.77	3425.49
MW-6	3425.26	3425.09
MW-7	3428.39	3426.28
MW-7A	3428.13	3426.28
MW-8	3430.13	3427.90
MW-8A	3430.01	3427.90
MW-9	3427.63	3425.09
MW-9A	3427.48	3425.09
MW-10	3419.42	3419.77
MW-11A	3431.77	3429.28
MW-12A	3429.92	3427.42
MW-13	3424.11	3424.35
MW-13A	3424.25	3424.39
MW-14A	3423.90	3424.05
MW-15A	3420.55	3420.65
MW-16A	3419.92	3419.99
MW-17A	3424.38	3424.48
MW-18A	3416.86	3417.04
MW-19A	3414.74	3414.95

Water Well Number	Datum Eelevation, Feet AMLS	Ground Elevation, Feet AMLS
Lord Water Well	3419.97	3419.47
Rowland Water Well	3419.47	3418.47
W.W. #1	3429.95	3428.78

LEGEND

BH-1 ◉	BOREHOLE LOCATION
MW-1 ●	MONITOR WELL LOCATION (SHALLOW)
MW-4A ●	MONITOR WELL LOCATION (DEEP)
■	PROPOSED MONITOR WELL LOCATION (SHALLOW)
□	PROPOSED MONITOR WELL LOCATION (DEEP)
▲	PROPOSED RECOVERY WELL LOCATION

FIGURE NO. 2

LEA COUNTY, NEW MEXICO

TEXACO
EXPLORATION & PRODUCTION, INC.

EUNICE #2 (NORTH) GAS PLANT
PROPOSED WELL LOCATION

HIGHLANDER ENVIRONMENTAL
MIDLAND, TEXAS

DATE: 12/8/98
DWN. BY: JDA
FILE: C:\787\PRO_WELL-LOC

TABLES

Table 1: **Summary of Analytical Parameters for Groundwater Samples, Texaco Exploration and Production, Inc., Eunice #2 (North) Gas Plant, Eunice, New Mexico**

Well	BTEX	Dissolved Metals	Major Anions and Cations	TDS
MW-1	X	X	X	X
MW-2			X	X
MW-3				
MW-4	X	X	X	X
MW-4A	X	X	X	X
MW-5	PSH	PSH	PSH	PSH
MW-6	PSH	PSH	PSH	PSH
MW-7		X	X	X
MW-7A		X	X	X
MW-8		X	X	X
MW-8A		X	X	X
MW-9		X	X	X
MW-9A		X	X	X
MW-10		X	X	X
MW-11		X	X	X
MW-11A		X	X	X
MW-12A				
MW-13		X	X	X
MW-13A		X	X	X
MW-14A				
MW-15		X	X	X
MW-15A		X	X	X
MW-16A				
MW-17A				
MW-18A		X	X	X
MW-19A		X	X	X
MW-20		X	X	X
MW-20A		X	X	X
MW-21	X	X	X	X
MW-21A	X	X	X	X
MW-22A		X	X	X
WW-1		X	X	X
Lord Water Well		X	X	X
Rowland Water Well		X	X	X

Notes:

1. Includes arsenic, barium, cadmium, chromium, lead, mercury, selinium and silver.
2. Includes calcium, magnesium, sodium, potassium, bicarbonate, sulfates and chlorides.
3. PSH: Separated hydrocarbons in well.

APPENDIX A

APPENDIX A

OCD Correspondence
October 9, 1998

STATE OF NEW MEXICO
ENERGY, MINERALS AND NATURAL RESOURCES DEPARTMENT
OIL CONSERVATION DIVISION
2040 S. PACHECO
SANTA FE, NEW MEXICO 87505
(505) 827-7131

October 9, 1998

CERTIFIED MAIL
RETURN RECEIPT NO. Z-274-520-567

Mr. Robert Foote
Texaco Exploration and Production, Inc.
P.O. Box 2100
Denver, Colorado 80201

RE: SOIL AND GROUND WATER INVESTIGATIONS
TEXACO EUNICE NORTH GAS PLANT

Dear Mr. Foote:

The New Mexico Oil Conservation Division (OCD) has completed a review of Texaco Exploration and Production, Inc.'s (TEPI) July 14, 1998 "SUBMITTAL OF ADDITIONAL INFORMATION PERTAINING TO SOIL AND GROUNDWATER INVESTIGATION, FORMER TEXACO EXPLORATION AND PRODUCTION, INC., EUNICE #2 (NORTH) GAS PLANT, LEA COUNTY, NEW MEXICO" and January 30, 1998 "ADDENDUM FINAL INVESTIGATION REPORT, TEXACO EXPLORATION AND PRODUCTION, INC., EUNICE # 2 (NORTH) GAS PLANT, LEA COUNTY, NEW MEXICO, JANUARY 1998" which was submitted on behalf of TEPI by their consultant Highlander Environmental Corp. These documents contain the results of TEPI's investigation of the extent soil and ground water contamination at TEPI's Eunice North Gas Plant in Lea County, New Mexico.

The OCD has the following comments regarding the above referenced report:

1. The extent of ground water contamination has not been completely defined in the following areas:
    a. Shallow Zone Ground Water
        i. The north and east limits of the benzene, toluene, ethylbenzene, toluene (BTEX) and lead contamination.
        ii. The areal extent of chromium, chloride and total dissolved solids (TDS).
    b. Deep Zone Ground Water
        i. The northern extent of chromium.
        ii. The north, south and eastern extent of chloride and TDS.

2. The chloride and TDS values for water well WW-1 on the July 14, 1998 chloride and TDS ispoleth maps do not match the data presented in Table 6 of the January 30, 1998 report.

3. The July 14, 1998 chloride and TDS ispoleth maps list data for monitor well MW-9. However, no data is listed for this well in Table 6 of the January 30, 1998 report.

4. The 13 mg/l chloride value observed in monitor well MW-8A does not seem to correlate with the high TDS seen this well. All other site monitor wells with high TDS also have high chloride concentrations. This well will need to be resampled during a future sampling event.

5. The laboratory detection limits for cadmium, lead and selenium listed in the January 30, 1998 report are higher than the New Mexico Water Quality Control Commission standards for these constituents. The monitor wells will need to be reanalyzed with lower detection limits during a future sampling event.

Based upon the OCD's review of these documents, the OCD requires that TEPI submit a work plan to complete the definition of the extent of contamination at the TEPI Eunice North Gas Plant. The work plan will be submitted to the OCD Santa Fe Office by December 11, 1998 with a copy provided to the OCD Hobbs District Office.

If you have any questions, please call me at (505) 827-7154.

Sincerely,

William C. Olson
Hydrologist
Environmental Bureau

xc: Wayne Price, OCD Hobbs District Office
Mark Larson, Highlander Environmental Corp.
Robert Lord
Bob Patterson, Rowland Trucking Co.

Texaco Exploration
and Production Inc

500 North Loraine
Midland TX 79701

P O Box 3109
Midland TX 79702

RECEIVED
23 1996
DIVISION

April 18, 1996

Mr. Chris E. Eustice
Geologist, Environmental Bureau
New Mexico Oil Conservation Division
2040 S. Pacheco
Santa Fe, New Mexico 87505

Re: Monitor Well Work Plan
Texaco North Eunice Gas Plant
Lea County, New Mexico

Dear Chris,

As requested, please find enclosed Texaco Exploration and Production, Inc.'s proposed work plan for the installation of one monitor well in association with the soil assessment activities that have been previously conducted at the North Eunice Gas Plant, Lea County, New Mexico. This plan was prepared by Highlander Environmental, Midland, Texas, at the request of Texaco.

You will recall that the assessment activities were initiated at the request of the NMOCD District I office in Hobbs. It was their desire that Texaco investigate the vertical and horizontal extent of the hydrocarbon impact on the soil on the north and south sides of the plant compressor building. As explained in the proposed work plan, due to the presence of overhead, surface and underground lines, Texaco has completed, to the best of its ability, the soil assessment phase of this investigation.

Texaco respectfully requests an expeditious review of this proposal in as much as we are prepared to begin this work immediately upon receipt of your approval. Upon completion of the installation of this monitor well and the receipt of all analytical data, a formal report summarizing the assessment activities will be submitted to you for review.

Please contact me at (915) 688-4804 should you have questions or desire additional information related to this proposal. Thank you for prompt review and assistance in this matter.

Robert W Browning

Robert W. Browning
EH&S Professional - Environmental
Texaco Exploration & Production

RWB/

Enclosure

cc w/o enclosure: Terry Frazier

cc w/ enclosure: Charlie Adkison - Rodney Bailey

Jerry Sexton
District Supervisor
NMOCD - District I
Hobbs, New Mexico

Highlander Environmental Corp.

Midland, Texas

April 17, 1996

Robert W. Browning
Texaco Exploration and Production, Inc.
500 North Loraine Street
P.O. Box 3109
Midland, Texas 79702-3109

Re: **Work Plan for Texaco North Eunice Gas Plant, Eddy County, New Mexico**

Proposed Activity : Installation of one monitor well at the Texaco North Eunice Gas Plant.

Goal Proposed Activity

Highlander Environmental has completed a soil assessment at the Texaco North Eunice Gas Plant. Hand borings were installed on the north and south sides of the compressor building to define the extents of hydrocarbon impact. Hand borings were installed due to the overhead, surface, and under ground piping located around the compressor building which limited access to any type of drilling rig. The results of the soil investigation showed one of the areas had contamination extending to a depth of 15.0 feet below surface. Hand borings could not be advanced deeper due to a dense caliche layer encountered at 15.0 feet below surface.

A water level measurement was collected from a water well located north of the compressor building and measured 53.55' below ground level. The top impacted soils around the compressor building are proposed to be removed. In order to attempt to leave the deeper impacted soil in place, a monitor well is proposed to confirm the ground water has not been impacted. Due to the drilling accessibility next to the compressor building, one down gradient monitor well will be installed at the site approximately 50' south of the compressor building.

Monitor Well Installation and Completion

A monitor well will installed using an air rotary rig to assess the ground water down gradient of the compressor building. The monitor well will be installed down gradient to a total depth of approximately 68 feet below surface. Two soil samples will be collected from the monitor well during the borehole construction. The monitor well will be completed with 4 inch schedule 40 flush joint PVC casing and 20.0 feet of 0.035 mill slotted screen. The completion will include extending the screen 5' above the top of the water table as to account for the seasonal fluctuation and 15' below the water table. The annulus will be gravel packed from the bottom of the well with 10-20 brady gravel. A bentonite plug will be set at 2-3 feet above the screen and the casing grouted to surface with 5% bentonite added to the grout. The monitor well will be completed with an above grade completion. The monitor well will be completed as per the OCD guidelines.

The monitor well will be properly developed and purged prior to sampling. All the drill cuttings will be placed on plastic.

Sampling Procedure

During the drilling of the monitor well, discrete soil samples will be collected at five foot depth intervals to evaluate the subsurface conditions. All the samples will be collected with a splitspoon or core barrel sampler.

Each soil sample collected will be immediately sealed in clean, glass sample jar with zero head space and immediately placed in a cooler and chilled. All samples collected for potential laboratory analysis will be preserved according to EPA standards and, will be analyzed within the holding requirements. The soil samples will be analyzed for Total Petroleum Hydrocarbon (TPH) by method EPA 418.1 and Benzene, Toluene, Ethylbenzene and Xylene (BTEX) by method SW-846, 5030/8050. A portion of the sample will be field screened for organic vapor to provide support data to determine which samples will be selected for analysis. The soil samples will be properly logged by our geologist for lithologic description.

Prior to water sampling, a static ground water level will be measured from the well. A disposable bailer will be lowered in the well to check the presence of phase separated hydrocarbon (PSH). The monitor well will be purged by removing 3 casing volumes from the well. After purging, the wells will be sampled for Total Petroleum Hydrocarbon (TPH) by method EPA 418.1 and Benzene, Toluene, Ethylbenzene and Xylene (BTEX) by method SW-846, 5030/8050. The groundwater samples will be placed into a laboratory prepared bottles with zero headspace and placed into a cooler and chilled. All samples will be analyzed within the standard holding times.

Reporting of Activities

A final report of the soil and ground water assessment will be submitted to the Oil Conservation Division for review after the completion of the monitor well and sample analysis received.

Waste Management

The soil drill cuttings will be place on plastic and covered onsite. The purge ground water will be placed into drums and left onsite. The disposal of the drill cuttings and purged water will be determined after evaluating the soil sample results.

Attachment

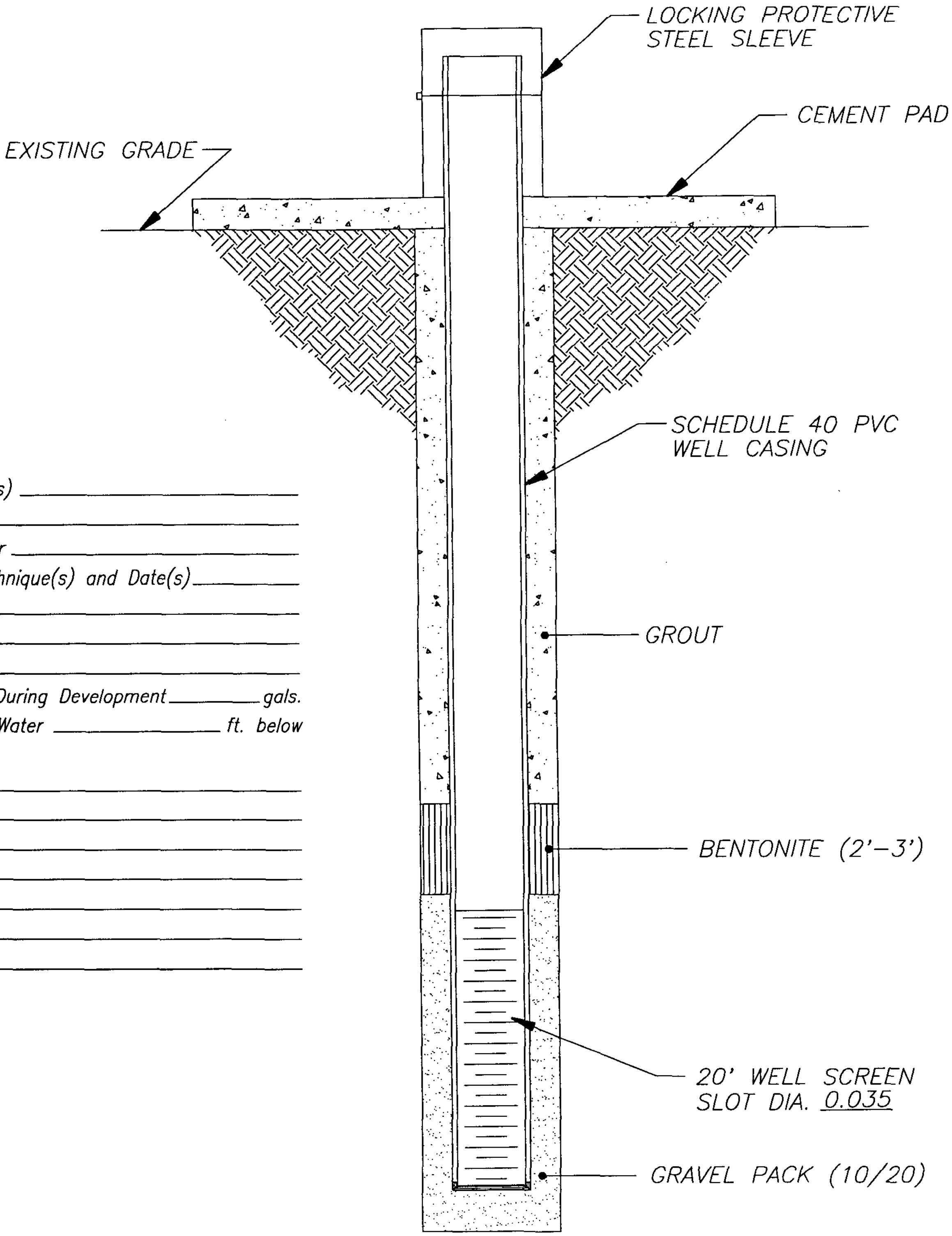
Typical monitor well construction

If you have any questions or need additional information please call.

Very truly yours,

Ike Tavarez
Geologist

TYPICAL
WELL CONSTRUCTION LOG



Installation Date(s) ____________________

Drilling Method ____________________

Drilling Contractor ____________________

Development Technique(s) and Date(s) ________

____

____

____

Water Removed During Development ________ *gals.*

Static Depth to Water ____________ *ft. below Ground Level*

Well Purpose ____________________

____

Remarks ____________________

____

____

____

____

DATE:

Highlander Environmental

CLIENT:

PROJECT:

LOCATION:

WELL NO.

MW