1R - 187

REPORTS

DATE:

7/6/1998

Ocean Energy

July 6, 1998

Mr. Chris Williams
State of New Mexico, Energy, Minerals
And Natural Resources Department
Oil Conservation Division
1000 West Broadway
Hobbs, New Mexico 88240

RE: Carlisle State Com #1
K-10-T16S-R35E
Lea County

Dear Mr. Williams;

Enclosed for your review is the revised protocol to replace the previous remediation plan for the subject well. Ocean Energy has retained Whole Earth Environmental, Inc. to implement the plan on our behalf. Mike Griffin of Whole Earth will be your primary contact as our representative.

If you have any questions or need additional information, I can be reached at (303) 573-4721. Thank you for your time and help in this matter.

Sincerely,

Scott M. Webb
Regulatory Coordinator

JUL 1998
RECEIVED
Hobbs
OCD

Ocean Energy, Inc. 410 Building 410 17th Street, Suite 1400 Denver, Colorado 80202 (303) 573-5100

Executive Summary

This protocol contains the relevant data required to request an alternative, risk based closure as described within paragraphs IV and V(A) of the NMOCD *Unlined Surface Impoundment Closure Guidelines.* Our basis of proof that the planned criteria pollutant concentrations within the pits will pose no future threat to the Ogallala Aquifer is based on the results of a modeling program designed by the American Petroleum Institute and intended for use specifically on oilfield exploration and production wastes. The modeled data will be supported by the construction of a monitoring well situated immediately down gradient from each pit and a third well located approximately 700' southeast of the centerline of the two pit monitoring wells.

Based on the earlier analytical results of the reserve pit contents, it appears certain that the reserve pits may be mixed and blended with the previously excavated materials to a concentration that does not exceed model parameters. In-situ remediation of the reserve pit contents (rather than disposal) will result in significant cost savings to Ocean Engineering while presenting no threat the environment.

Site Profile

Location

The site is located approximately 4 miles due west of Lovington, New Mexico and approximately ½ mile south of US Hwy. 82. The legal description of the site is Section 10, Township 16 South, Range 35 East. The site covers approximately 29.2 acres including the existing land farms and spread zones. The overall dimensions of the project are approximately 600' north to south by 2,100 feet east to west.

Description of Spill

The soil contamination resulted from the uncontrolled release of hydrocarbons in the form of light-end condensates released during a drilling upset that occurred on March 20th, 1998. The well discharged fluids for a period of approximately six days (156 hrs.) until ignited on March 26th. It is impossible to accurately estimate the volume of hydrocarbons soaked into the soil due to the extreme volatility of the fluids (aeration) and the necessity of pumping large amounts of fresh and brine water (approximately 3,000 bbls. each) onto the site to control the fire. It is additionally presumed that significant volumes of free condensates were consumed in the fire. Stained soils were found at a distance of ¼ mile to the north of the wellhead(1).

Ownership / Land Use

The land is owned by the State of New Mexico. The surface rights are leased to Mr. Jerry Carlisle of P.O. Box. 324, Lovington, New Mexico 88264. Mr. Carlisle owned a 4% royalty interest in the Carlisle State COM # 1 and retains a similar interest in the replacement well, Carlisle State COM # 2 presently being drilled on the same location. The State of New Mexico retains ownership of all surface and ground waters within the State.

The primary land use is for the grazing of cattle though significant oil and gas production exists within the immediate area.

Topography / Morphology

The climate is described as a semi-arid area having an average annual precipitation of 12-16" and a Class A pan evaporation of 105-110"(2). The year to date precipitation total for the area is less than 1" resulting in a near drought condition.

The soil conditions range from sandy topsoils at a depth of approximately 4-6" followed by aggregated caliche to a depth of 10-12' atop a dense caliche bed extending to the clays atop the upper vadose zone of the Ogallala at a depth of approximately 50' bgl(3).

The surrounding terrain is quite flat. There are no surface water sources within one mile of the site. The depth to groundwater is estimated at 50' based on measurements taken at a private windmill immediately adjacent to the site and well boring records filed with the OCD for a site located approximately one mile due west(4). Though the actual groundwater gradient and flow direction will be accurately fixed by the installation of three monitoring wells at the site, it appears (based on the two measurement points) to be extremely gradual averaging 10' to the mile.

Remediation History
At the time of the drilling upset, Callaway Safety immediately erected two unlined surface impoundments west and east of the wellhead to contain both condensates and water. An unknown amount of the condensate was additionally contained within the reserve pit located due east of the wellhead(1). Fluids from each of these catchments were removed by vacuum truck and sent to sales or disposal facilities.

Additional pits at the site include a flare pit and a mud make-up area currently being remediated by Callaway Safety.

Present Condition
The site presently contains four pits described as the West Pit, East and West Reserve Pits and the East Pit. The soils excavated from the East and West Pits were spread in an east / west line centered to the north of the wellhead. The contaminant concentrations within these spread zones are nominal averaging <200 ppm TPH, <50 ppm BTEX and <200 ppm total soluble chlorides(5). They presently pose little to no short-term threat to the environment or human health. A scaled plat map and photographs of the site are contained within this section.

References

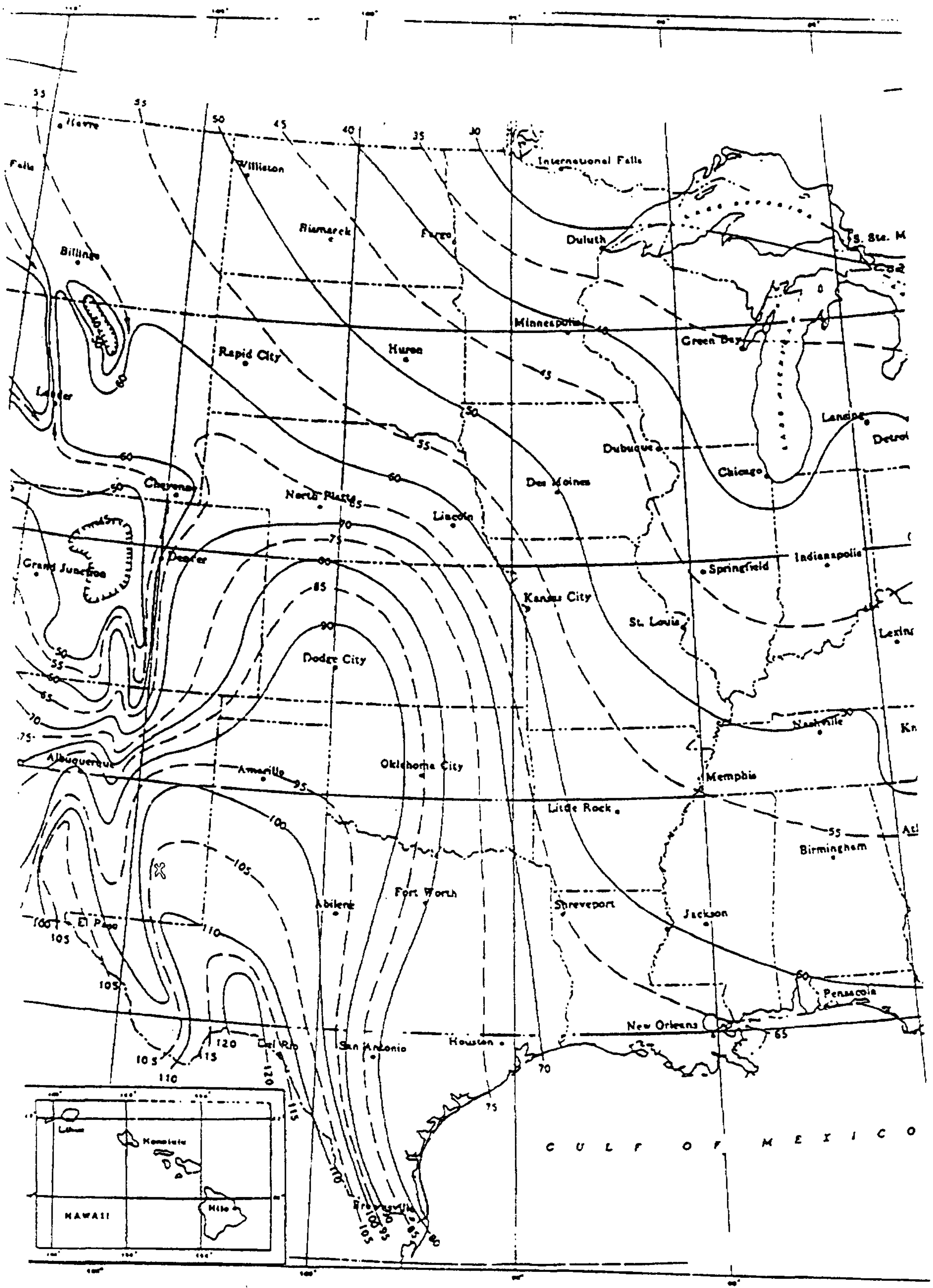
1. Callaway Safety *UMC Carlisle State COM # 1 Site Assessment Work Plan* April, 1998.

2. U.S.G.S Precipitation / Evaporation maps (enclosed).

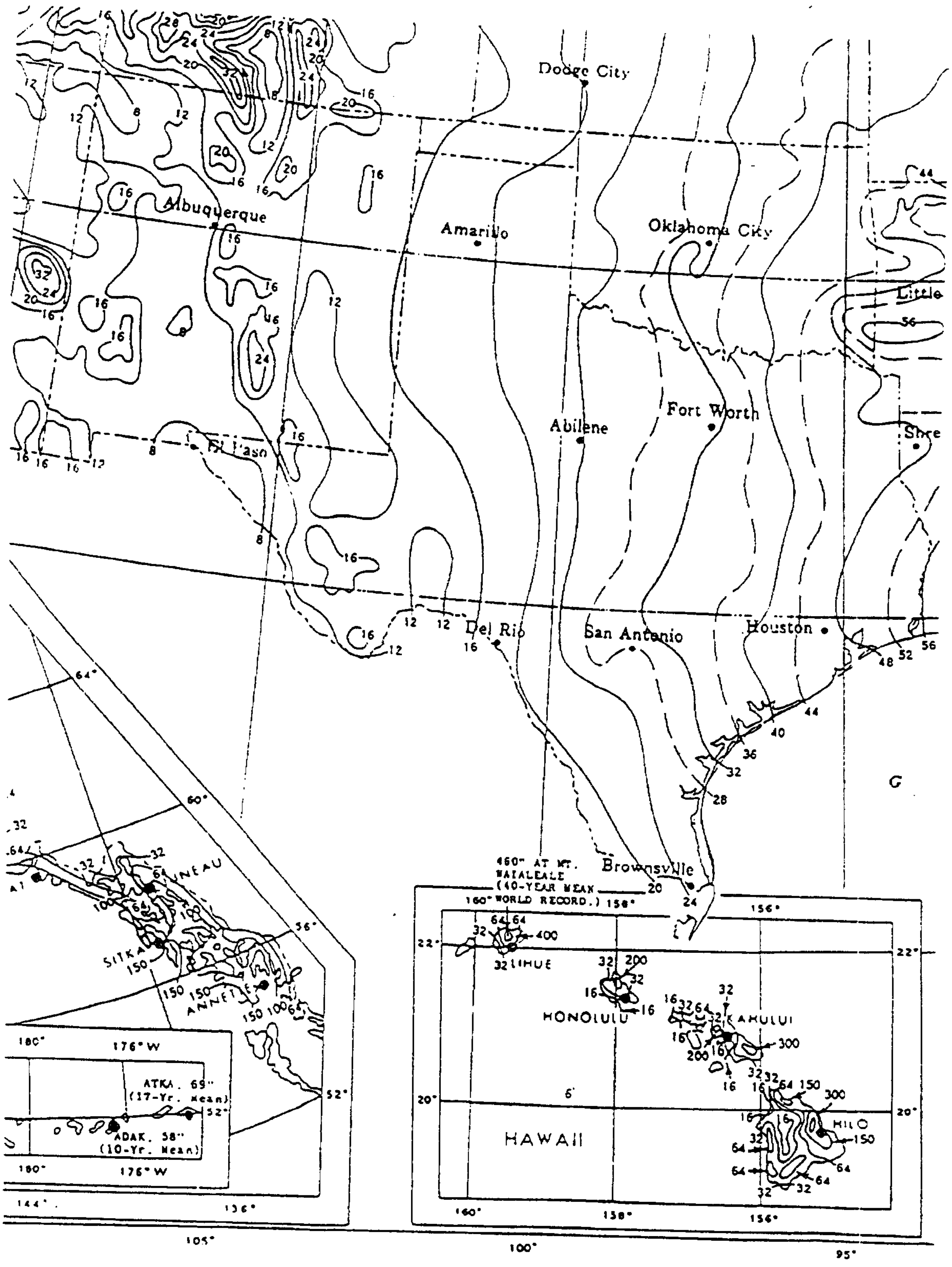
3. KEI Job No. 710016 *Subsurface Investigation Report* September 16, 1997 (excerpts enclosed).

4. KEI Job No. 710016 *Subsurface Investigation Report* September 16, 1997 (well boring logs enclosed).

5. Whole Earth Environmental *Field Sampling Results* (enclosed).



Central USA Mean Annual Class A Pan Evaporation Map



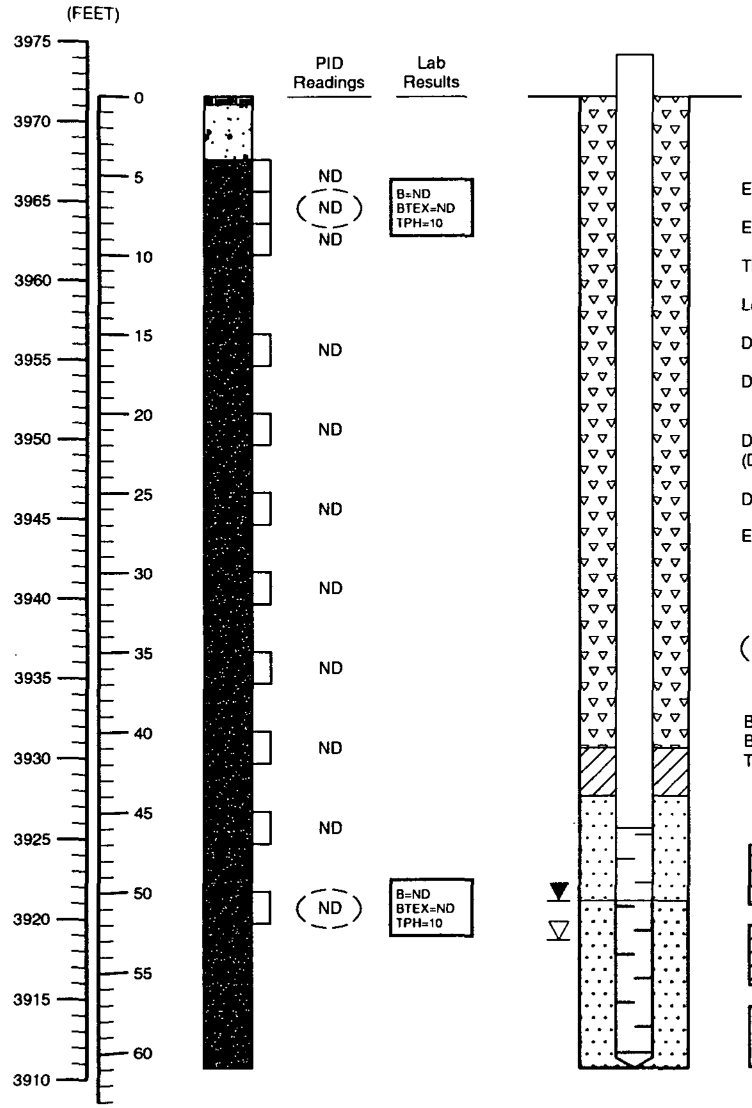
Central Southwest USA Normal Annual Total Precipitation Map

TABLE III

SUMMARY OF GROUND WATER MONITORING
TEXAS - NEW MEXICO PIPE LINE COMPANY
TNM-97-04
LOVINGTON, NEW MEXICO

WELL NO.	DATE MEASURED	PVC ELEVATION (feet)	DEPTH TO WATER (feet)	GROUND WATER ELEVATION		PSH THICKNESS (feet)
				Actual	Corrected	
MW-1	06/18/97	3,974.19	53.15	3921.04	—	—
	07/29/97	3,974.19	53.05	3921.14	—	—
MW-2	06/18/97	3,974.65	53.24	3921.41	—	—
	07/29/97	3,974.65	53.14	3921.51	—	—
MW-3	06/18/97	3,974.63	60.08	3914.55	3921.94	8.69
	06/23/97	3,974.63	60.08	3914.55	3921.96	8.72
	06/23/97	3,974.63	53.30	3921.33	3921.56	0.27
	06/23/97	3,974.63	53.78	3920.85	3921.71	1.01
	06/25/97	3,974.63	59.85	3914.78	3921.99	8.48
	06/25/97	3,974.63	55.50	3919.13	3921.72	3.05
	06/25/97	3,974.63	56.34	3918.29	3921.78	4.10
	06/25/97	3,974.63	53.29	3921.34	—	—
	06/27/97	3,974.63	59.99	3914.64	3921.96	8.61
	06/27/97	3,974.63	56.68	3917.95	3921.60	4.29
	07/01/97	3,974.63	59.99	3914.64	3921.96	8.61
	07/03/97	3,974.63	60.04	3914.59	3921.98	8.69
	07/03/97	3,974.63	55.22	3919.41	3921.75	2.75
	07/29/97	3,974.63	60.03	3914.60	3921.96	8.66
	07/29/97	3,974.63	54.47	3920.16	3921.90	2.05
MW-4	06/18/97	3,974.55	52.96	3921.59	—	—
	07/29/97	3,974.55	52.92	3921.63	—	—
MW-5	06/18/97	3,974.31	60.85	3913.46	3922.41	10.53
	06/23/97	3,974.31	58.09	3916.22	3922.08	6.89
	06/23/97	3,974.31	56.57	3917.74	3922.38	5.46
	06/23/97	3,974.31	59.18	3915.13	3921.32	7.28
	06/23/97	3,974.31	59.74	3914.57	3922.08	8.83
	06/23/97	3,974.31	54.91	3919.40	3921.88	2.92
	06/25/97	3,974.31	60.47	3913.84	3922.02	9.62
	06/25/97	3,974.31	58.47	3915.84	3921.99	7.24
	06/25/97	3,974.31	59.49	3914.82	3922.01	8.46
	06/25/97	3,974.31	53.42	3920.89	3921.94	1.23
	06/25/97	3,974.31	55.95	3918.36	3921.90	4.16
	06/25/97	3,974.31	58.50	3915.81	3922.02	7.30
	06/25/97	3,974.31	52.46	3921.85	3921.87	0.02
	06/25/97	3,974.31	51.81	3922.50	3922.50	0.00
	06/27/97	3,974.31	60.46	3913.85	3922.06	9.66
	06/27/97	3,974.31	57.47	3916.84	3922.00	6.07
	07/01/97	3,974.31	60.45	3913.86	3922.01	9.59
	07/01/97	3,974.31	56.40	3917.91	3921.94	4.74
	07/03/97	3,974.31	60.41	3913.90	3922.01	9.54
	07/03/97	3,974.31	57.53	3916.78	3921.98	6.12
	07/29/97	3,974.31	60.19	3914.12	3922.02	9.29
	07/29/97	3,974.31	57.69	3916.62	3920.97	5.12

MONITORING WELL MW-1



Monitoring Well Details (MW-1)

Elev of Ground Surface	3971.60 ft
Elev Top of PVC Well	3974.19 ft
Thickness of Bentonite Seal	3.0 ft
Length of PVC Well Screen	15.0 ft
Depth of PVC Well	61.0 ft
Depth of Exploratory Hole	61.0 ft
Depth to Ground Water (During drilling)	53.0 ft
Depth to Ground Water	50.56 ft
Elev of Ground Water	3921.04 ft

( ) Indicates sample selected for laboratory analysis.

B = Benzene Concentration (mg/kg)
BTEX = Total BTEX Concentration (mg/kg)
TPH = Total Petroleum Hydrocarbon Concentration (mg/kg)

▽	Concrete Surface Seal
▨	Bentonite Pellet Seal
⁚	Sand Pack

LEGEND

▩	Top Soil
⁘	Rock, very hard, tan to white.
■	Sand (SM), fine to medium grained, moist, tan to brown, intermixed with stone.
⊐	Indicates sample interval. Sample was obtained by hydraulically pushing a split spoon sampler.
▽	Indicates the ground water level measured during drilling.
▼	Indicates the ground water level measured on June 18, 1997.
PID	Head-space readings in ppm obtained with a photo-ionization detector.
ND	Indicates the constituent was not detected.
NS	Indicates the sample was not obtained.

NOTES

1. The monitoring well was installed on June 3, 1997 using air rotary techniques.
2. The well was constructed with 2 inch ID, 0.010 inch factory slotted, threaded joint, Schedule 40 PVC pipe.
3. The well is protected with a stick-up steel cover and a locked compression cap.
4. The lines between material types shown on the profile log represent approximate boundaries. Actual transitions may be gradual.
5. The depths indicated are referenced from the ground surface.

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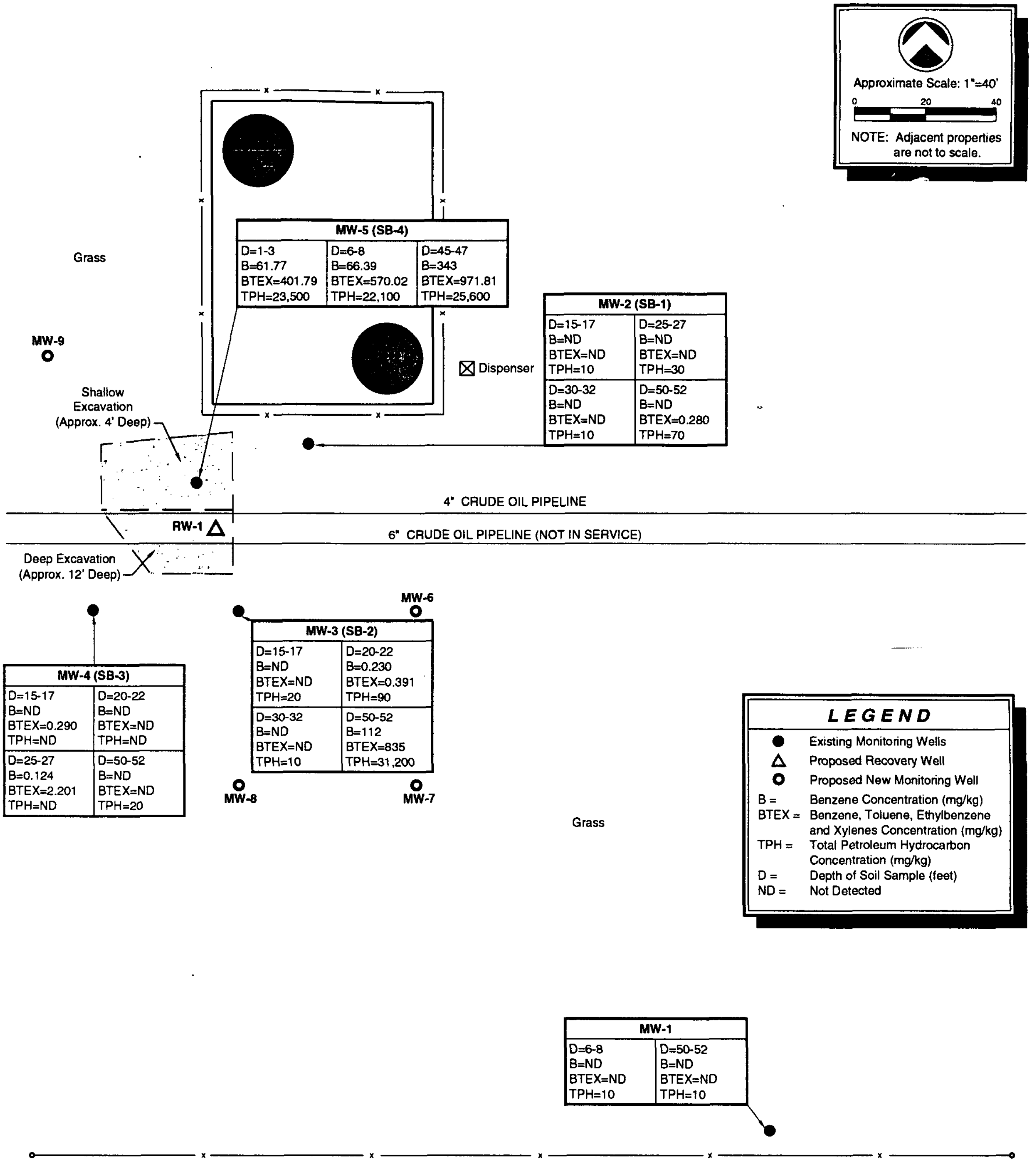
LOG AND DETAILS OF MONITORING WELL MW-1

TEXAS - NEW MEXICO PIPE LINE COMPANY **TNM-97-04** **LOVINGTON, NEW MEXICO**

710016

APPENDIX A



MW-5 (SB-4)

D=1-3 B=61.77 BTEX=401.79 TPH=23,500	D=6-8 B=66.39 BTEX=570.02 TPH=22,100	D=45-47 B=343 BTEX=971.81 TPH=25,600

MW-2 (SB-1)

D=15-17 B=ND BTEX=ND TPH=10	D=25-27 B=ND BTEX=ND TPH=30
D=30-32 B=ND BTEX=ND TPH=10	D=50-52 B=ND BTEX=0.280 TPH=70

MW-4 (SB-3)

D=15-17 B=ND BTEX=0.290 TPH=ND	D=20-22 B=ND BTEX=ND TPH=ND
D=25-27 B=0.124 BTEX=2.201 TPH=ND	D=50-52 B=ND BTEX=ND TPH=20

MW-3 (SB-2)

D=15-17 B=ND BTEX=ND TPH=20	D=20-22 B=0.230 BTEX=0.391 TPH=90
D=30-32 B=ND BTEX=ND TPH=10	D=50-52 B=112 BTEX=835 TPH=31,200

MW-1

D=6-8 B=ND BTEX=ND TPH=10	D=50-52 B=ND BTEX=ND TPH=10

LEGEND

●	Existing Monitoring Wells
△	Proposed Recovery Well
○	Proposed New Monitoring Well
B =	Benzene Concentration (mg/kg)
BTEX =	Benzene, Toluene, Ethylbenzene and Xylenes Concentration (mg/kg)
TPH =	Total Petroleum Hydrocarbon Concentration (mg/kg)
D =	Depth of Soil Sample (feet)
ND =	Not Detected

NOTE:
Soil samples were obtained June 3 through 5, 1997.

09/17/97-RM G:\(7118FIG3)

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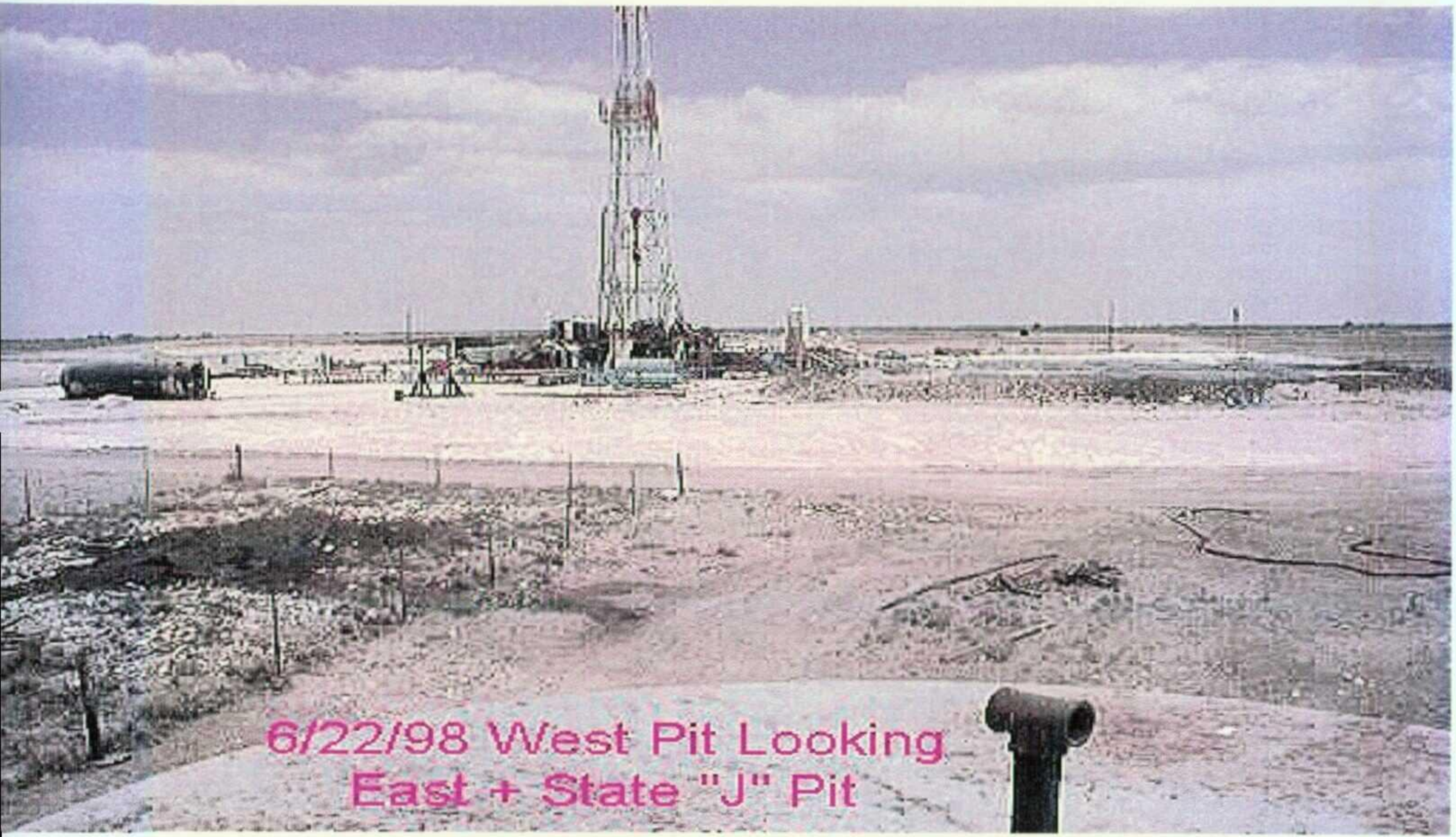
SOIL CONCENTRATION MAP

TEXAS - NEW MEXICO PIPE LINE COMPANY **TNM-97-04** **LOVINGTON, NEW MEXICO**

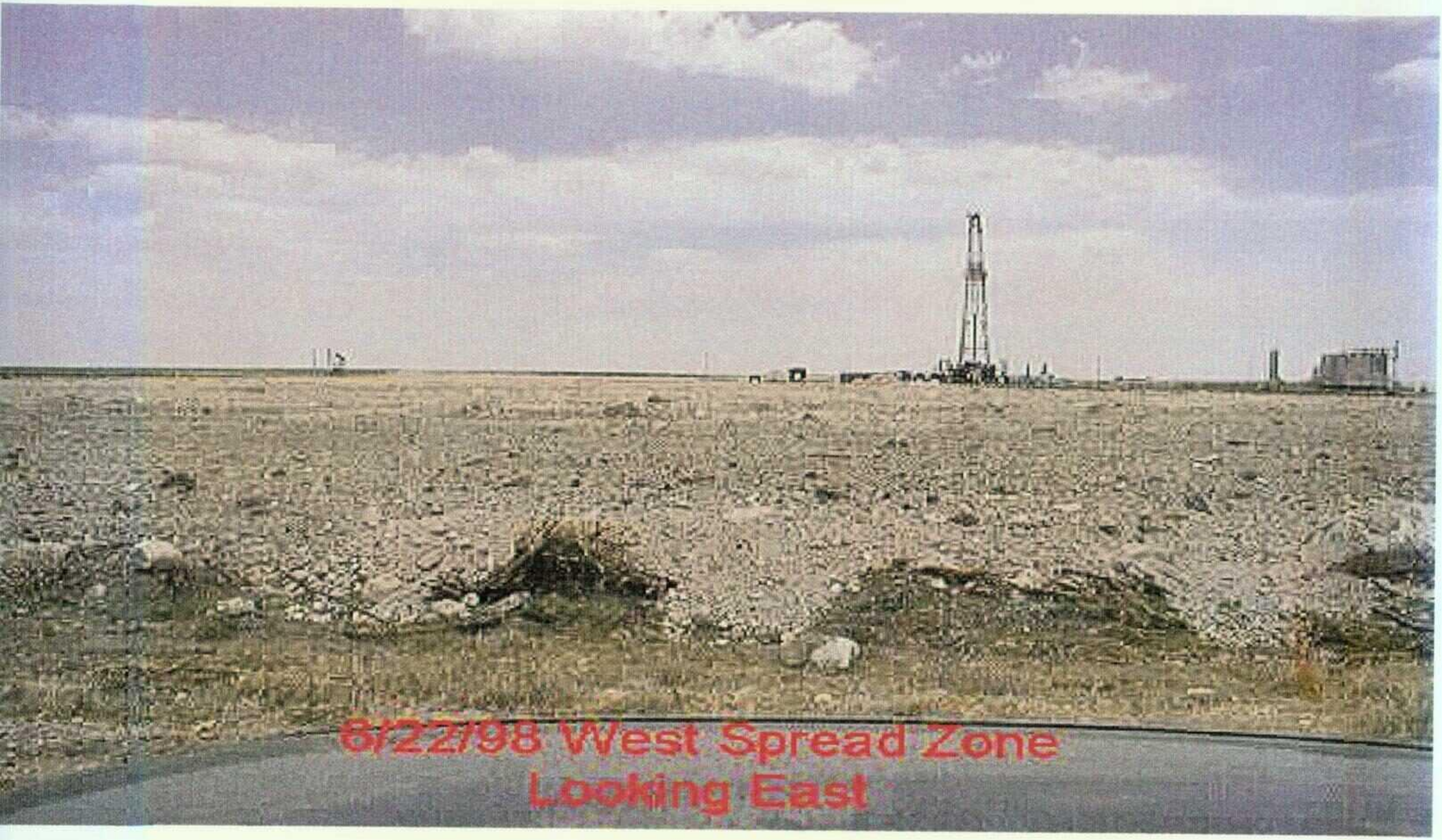
710016

FIG 3

6/22/98 West Reserve Pit
Looking Northeast



6/22/98 West Pit Looking East + State "J" Pit



6/22/98 West Spread Zone
Looking East

6/22/98 East Reserve Pit
Looking Northwest

6/22/98 East Pit
Boulder Pile

6/22/98 Additional Soils

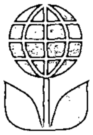

6/22/98 West Pit
Looking North

6/22/98 East Pit
Looking North

6/22/98 East Pit
Looking North


June 22, 1998 Flare Pit
Looking East


6/22/98 East Spread Zone
Looking West



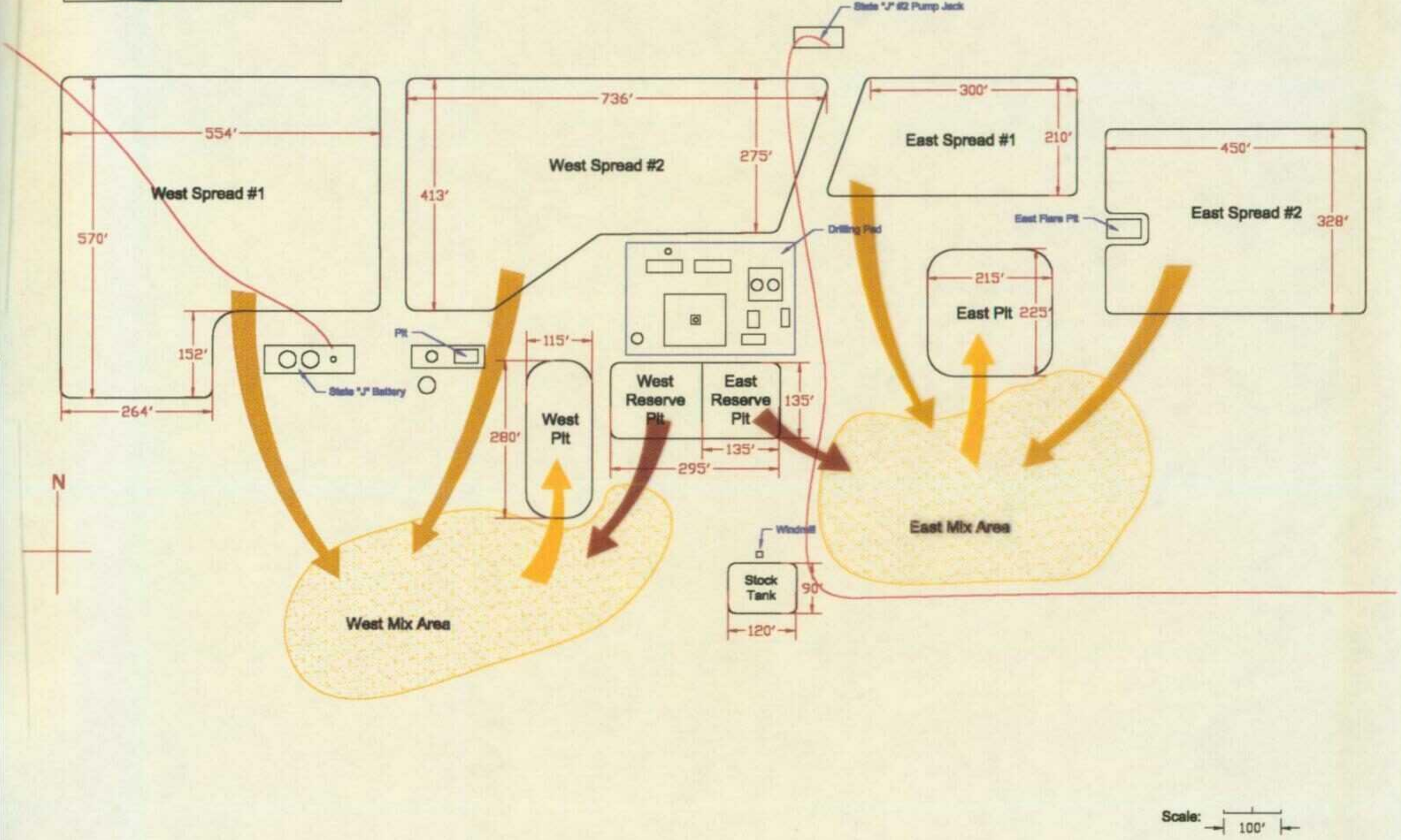
Protocol

This section contains the detailed remediation protocol planned for the project.

Ocean Energy

UMC CARLISLE STATE COM #1

Plat Map



Pit Remediation Protocol
Ocean Energy Corporation
Carlisle State COM # 1
Pits Requiring Modeling

1.0 Purpose

This protocol is provide a detailed outline of the steps to be employed in the remediation and final closure of the Ocean Energy pits using risk assessment modeling.

2.0 Scope

This protocol is site specific for the Carlisle State COM # 1 emergency disposal pits.

3.0 Preliminary

Prior to any field operations, Whole Earth Environmental shall conduct the following activities:

3.1 Client Review

3.1.1 Whole Earth shall meet with cognizant personnel within Ocean Energy to review this protocol and make any requested modifications or alterations prior to submittal to the State of New Mexico Oil Conservation Division.

3.1.2 Changes to this protocol will be documented and submitted for final review by Ocean Energy prior to submittal to the Oil Conservation Division.

3.2 Oil Conservation Division Review

3.2.1 Upon client approval, this protocol and associated modeling results will be submitted to the New Mexico Oil Conservation Division for review and comment. Recommended changes will be reviewed by the client prior to implementation.

3.2.2 Any recommended changes effecting costs will require a revised quotation to be issued to the client for approval prior to the commencement of any on-site remediation activity.

4.0 Safety

4.1 Prior to work on the site, Whole Earth shall obtain the location and phone numbers of the nearest emergency medical treatment facility. We will review all safety-related issues with the appropriate Ocean Energy personnel, sub-contractors and exchange phone numbers.

4.2 A tailgate safety meeting shall be held and documented each day. All sub-contractors must attend and sign the daily log-in sheet.

4.3 Anyone allowed on to location must be wearing sleeved shirts, steel-toed boots, and long pants. Each vehicle must be equipped with two-way communication capabilities.

4.4 Prior to any excavation, the area shall be surveyed with a line finder. If lines are discovered within the area to be excavated, they shall be marked with pin flags on either side of the line at maximum five-foot intervals. The area will be photographed prior to any excavation or fluid removal.

4.5 Each pit area will be swept with a Ludlam 2350 to determine if NORM is present in concentrations greater than 40μr / hr.

5.0 Fluid Removal

Prior to any excavation, the pit fluids including liquids contained within the reserve pits shall be removed by vacuum truck and transported to the Gandy Crossroads recycling facility. A ~~shipping manifest and an O.C.D. Form C-117-A shall be prepared for each waste load.~~ Truck to liquid disposal well

6.0 Monitor Wells

6.1 Atkins Engineering Associates, Inc. will drill develop and case three monitoring wells. The first will be in the approximate southeast corner of the east pit excavation, the second at the southeast corner of the west pit. The third well will be situated at a point due south of the center of the east / west line drawn between the two previous locations at a distance equal to the distance separating the two previous wells so as to form an equilateral triangle. The third well may be cased and completed within in a 4" diameter PVC pipe to allow for future conversion to a source well. Whole Earth will obtain soil samples at each five-foot incremental depth following our procedure QP-77. Whole earth will additionally field screen for TPH and BTEX in accordance with QP-06 and QP-19. Calibration, record retention, and instrument reporting accuracy procedures for these field screen tests are contained in QP-25 and QP-55. If the Whole Earth screen testing reveals BTEX or chloride concentrations within the first two wells in excess of NMWQCC standards, the holes will be left uncased until laboratory confirmation is obtained. Should the criteria pollutant concentrations be confirmed to be higher than NMWQCC standards Whole Earth will obtain the necessary additional information required to model the effects of natural attenuation using the USAF Bio Screen program. If the Bio Screen model reveals contamination potential to any off-site source well, the monitoring wells may be converted to recovery wells by completing within 4" casing. All confirmation samples will be analyzed by Environmental Labs of Texas for BTEX and DRO using EPA Methods 8020, 5030 and 8015m for TPH, BTEX and chlorides.

6.2 All monitoring or recovery wells will be drilled to a minimum depth of ten feet below the top of the water table, developed, fitted with a slotted screen, grouted to surface and fitted with a locking cap mechanism for security. \ MUST BE MIN 15' SCREEN

7.0 Modeling

7.1 Whole Earth will model the migration potential of the plume on VADSAT to determine the maximum concentrations of criteria pollutants allowed within the excavation consistent with a 100 year, zero percentage probability of the plume impacting ground water. ?

8.0 West Pit Preliminary Compaction

8.1 In order to achieve sufficient separation between the bottom of the west pit and the top of the Ogallala, the pit will be filled in with fresh soils obtained from the area immediately to the southwest of the pit to a maximum distance of 20 bgl. The soils filling the excavation will be field tested as they are deposited for BTEX, TPH and chloride. Concentrations shall not exceed 10, 100 and 500 ppm respectively. Once filled to a sufficient depth, the bottom will be compacted using D-6 or larger bulldozers.

9.0 Remediation

9.1 Prior to any contaminated soils being re-deposited within the excavations, the Hobbs office of the OCD will be notified. The OCD may either witness, or collect split samples with Whole Earth. The bottom of the pit and all four side walls will be tested for TPH and Benzene concentrations using WEQP-06 and WEQP-19. The samples will be collected and analyzed as described in 6.1 of this protocol. Acceptable criteria pollutant concentrations shall be <100 ppm TPH, <10 ppm benzene, <50 ppm ttl. BTEX and < 500 ppm soluble chlorides.

9.2 Using a trackhoe and D-6 bulldozer, the west reserve pit will be breached at the southwest corner and spread over the newly excavated area immediately southwest of the west pit. ***Extreme care must be taken to insure that no unmixed fluids or solids from the reserve pit be allowed into the western emergency pit. Temporary berms shall be erected around the eastern and southern sides of the pit.*** Once dried to a working consistency, the reserve pit solids will be tested extensively to determine average criteria pollutant concentrations, mixed and blended with the soils contained within the western spread zones and freshly excavated soils as necessary to achieve of <1,000 ppm TPH, 10 ppm benzene, 50 ppm ttl. BTEX and 500 ppm soluble chloride concentrations. The materials will then be re-deposited with the pit in approximately 30 yd^3 increments. The pit bottom will be tested in a minimum of four locations for each 3' lift.

9.3 As drilling and completion operations allow, the eastern reserve pit will be similarly mixed and blended with the soils contained within the eastern spread zone and deposited into the east emergency containment pit.

10. Site Restoration

10.1 The top two feet of the excavation shall be covered in remediated materials having a maximum TPH concentration of <100 ppm and benzene concentrations of <2 ppm. The area will be seeded with a mixture of local grasses. If the sodium chloride concentrations with the spread material exceed a sodium adsorption ratio greater than 12, additional remediation to include treatment with gypsum and / or calcium nitrate may be required.

11.0 Documentation & Reporting

11.1 At the conclusion of the pit remediation project, Whole Earth will prepare a closure report to include the following minimum information:

- A plat map of the location showing the exact location of the pit, the dimensions prior to excavation and the actual excavated dimensions.
- Photographs of the pit prior to excavation, at the point of maximum excavation and after final closure

- Field Sampling Report to include the side wall and pit bottom TPH and BTEX concentrations after excavation.
- Field Sampling Report to include TPH and BTEX concentrations of all remediated materials deposited into the pit deposited into the pit.
- Daily calibration records of each testing instrument
- Shipping manifests and OCD Form C-117-A
- Risk assessment model and supporting documentation
- M.S.D.S. of any amendment materials
- Construction of monitor or recovery wells

Procedures

This section contains copies of the detailed testing and sampling procedures planned for the project.

QP-06 Rev. C

WHOLE EARTH ENVIRONMENTAL
QUALITY PROCEDURE

Procedure for Conducting Field TPH Analysis

Completed By:
Approved By:
Effective Date: 02/15/97

1.0 Purpose

To define the procedure to be used in conducting total percentage hydrocarbon testing in accordance with EPA Method 418.1 (modified) using the "MEGA" TPH Analyzer.

2.0 Scope

This procedure is to be used for field testing and on site remediation information.

3.0 Procedure

3.1 The G.A.C. "MEGA" TPH analyzer is an instrument that measures concentrations of aliphatic hydrocarbons by means of infra-red spectrometry. It is manufactured to our specifications and can accurately measure concentrations from two parts per million through 100,000 parts per million. The unit is factory calibrated however minor calibration adjustments may be made in the field. Quality Procedure 25 defines the field calibration methods to be employed.

3.2 Prior to taking the machine into the field, insert a 500 ppm and 5,000 ppm calibration standard into the sample port of the machine. Zero out the Range dial until the instrument records the exact standard reading.

3.3 Once in the field, insert a large and small cuvette filled with clean Freon 113 into the sample port of the machine. Use the range dial to zero in the reading. If the machine does not zero, do not attempt to adjust the span dial. Immediately implement Quality Procedure 25 .

3.4 Place a 100 g. weight standard on the field scale to insure accuracy. Zero out the scale as necessary.

3.5 Tare a clean 100 ml. sample vial with the Teflon cap removed. Add 10 g. (+/- .01 g), of sample soil into the vial taking care to remove rocks or vegetable matter from the sample to be tested. If the sample is wet, add up to 5 g. silica gel or anhydrous sodium sulfate to the sample after weighing.

3.6 Dispense 10 ml. Freon 113 into the sample vial.

3.7 Cap the vial and shake for five minutes.

3.8 Carefully decant the liquid contents of the vial into a filter/desiccant cartridge and affix the cartridge cap. Recap the sample vial and set aside.

3.9 Insert the metal tip of the pressure syringe into the cap opening and slowly pressurize. **WARNING: APPLY ONLY ENOUGH PRESSURE ON THE SYRINGE TO EFFECT FLOW THROUGH THE FILTERS. TOO MUCH PRESSURE MAY CAUSE THE CAP TO SEPARATE FROM THE BODY OF THE CARTRIDGE.** Once flow is established through the cartridge direct the flow into the 5 cm. cuvette until the cuvette is full. Reverse the pressure on the syringe and remove the syringe tip from the cartridge cap. Set the cartridge aside in vertical position.

3.10 The cuvette has two clear and two frosted sides. Hold the cuvette by the frosted sides and carefully insert into the sample port of the machine. Read the right hand digital read-out of the instrument. If the reading is less than 1,000 ppm. the results shall be recorded in the field Soil Analysis Report. If the result is higher than 1,000 ppm, continue with the dilution procedure.

4.0 Dilution Procedure

4.1 When initial readings are greater than 1,000 ppm using the 5 cm. cuvette, pour the contents of the 5 cm. cuvette into a 1 cm. cuvette. Insert the 1. cm cuvette into the metal holder and insert into the test port of the instrument.

4.1 Read the left hand digital read-out of the machine. If the results are less than 10,000 ppm, record the results into the field Soil Analysis Report. If greater than 10,000 ppm, continue the dilution process. Concentrations >10,000 ppm are to be used for field screen purposes only.

4.2 Pour the contents of the small cuvette into a graduated glass pipette. Add 10 ml. pure Freon 113 into the pipette. Shake the contents and pour into the 1cm. cuvette. Repeat step 4.2. adding two zeros to the end of the displayed number. If the reported result is greater than 100,000 ppm. the accuracy of further readings through additional dilutions is extremely questionable. Do not use for reporting purposes.

4.4 *Pour all sample Freon into the recycling container.*

5.0 Split Samples

5.1 Each tenth test sample shall be a split sample. Decant approximately one half of the extraction solvent through a filter cartridge and insert into the instrument to obtain a concentration reading. Clean and rinse the cuvette and decant the remainder of the fluid to obtain a second concentration reading from the same sample. If the second reading varies by more than 1% from the original, it will be necessary to completely recalibrate the instrument.

QP-12

WHOLE EARTH ENVIRONMENTAL
QUALITY PROCEDURE

Procedure for Soil Sample Preparation: Moisture Weight Percentage

Completed By: Approved By: Effective Date: / /

1.0 Purpose

This procedure outlines the methods to be employed in preparing samples to be tested for electrical conductivity and cation exchange capacities.

2.0 Scope

This procedure shall be followed when preparing any electrical conductivity, (EC), or cation exchange capacity, (CEC), testing.

3.0 Procedure

3.1 Field collection of all soil samples shall be in plastic containers. Samples may be stored for a maximum of five days prior to processing.

3.2 Homogenize sample thoroughly. Test for hydrophobic characteristics as follows:

a. examine for visible globs of oil or grease
b. press soil sample to determine if it compresses into a damp mass
c. test to determine if the sample stains filter paper

If the sample exhibits hydrophobic characteristics, prepare in accordance with 3.3.2 below. Otherwise, prepare in accordance with 3.3.1.

3.3.1 Weigh 120 +/- 0.1g sample into tared crucible and dry at 105^{0} C for 1 hour. Cool and reweigh. Repeat until weight difference is less than 1% value.

3.3.2 Weigh 120 +/- 0.1 g sample into tared crucible and dry in oven at 250^0 C for one hour. Cool and heat with propane torch until sample just begins to smoke. Maintain gradual heating until smoke dissipates (approximately 1/2 hour). **DO NOT ALLOW THE SAMPLE TO CATCH FIRE OR EXCEED 390^0 C.** Cool and reweigh. Grind to pass 2mm sieve.

3.4 Report percent moisture to three significant figures as follows:

Moisture % = [(W - D)/D] X 100
W = wet sample weight
D = dry sample weight

3.5 References

Diagnosis and Improvement of Saline and Alkali Soils; U.S. Salinity Laboratory Staff, Agriculture Handbook No. 60; 1954

Deuel & Holliday, Soil Remediation for the Petroleum Extraction Industry; Houston, Tx. 1993.

QP-13

WHOLE EARTH ENVIRONMENTAL
QUALITY PROCEDURE

Procedure for Preparing a Paste Extraction

Completed By: Approved By: Effective Date: / /

1.0 Purpose

This procedure defines the methods to be employed in preparing a paste extraction to be analyzed for conductivity and exchangeable cations.

2.0 Scope

This procedure shall be used in all electrical Conductivity (EC) and Cation Exchange Capacity (CEC) tests.

3.0 Procedure

3.1 All samples shall be prepared in accordance with QP-12.

3.2 Weigh 100 +/- 0.1g soil sample into tared sample reservoir of filter assembly. Add deionized reagent water to fill pores, stirring gently with plastic stirrer to achieve saturation. The solid/water mixture is consolidated occasionally by tapping the container on the workbench. At saturation the surface of the mixture glistens and flows slightly when tipped. Let stand for one hour. The mixture should not stiffen or puddle; add more sample or water as required and allow to stand for one additional hour.

3.3 Analyze paste extract directly for EC and pH.

3.4 Connect filter assembly to vacuum assembly and filter extract until air begins to pass through filter. Analyze directly for Na, Ca, Mg, K.

QP-14

WHOLE EARTH ENVIRONMENTAL
QUALITY PROCEDURE

Procedure for Conducting Sodium Adsorption Ratio (SAR) Testing

Completed By: Approved By: Effective Date: / /

1.0 Purpose

This procedure defines the methods to be employed when conducting sodium adsorption ratio testing from paste extract samples.

2.0 Scope

This procedure shall be used in all SAR's obtained from sample paste extracts.

3.0 Procedure

3.1 All samples shall be prepared in accordance with QP-12 and 13.

3.2 Calibration of the equipment shall be performed daily. Calibrate using a 5 point series of standards. The range of standards must include a blank, and should span the range of expected concentrations of the samples. The following concentrations are appropriate:

Low Range: 0, 1.0, 3.0, 5.0, 10.0 ppm
High Range: 0, 10.0, 20.0, 50.0, 100 ppm

With the instrument on, inject standard mixture with 10 µL syringe and start data collection. Store calibration data under the date of generation for use in subsequent analyses.

3.3 Calibrate instrument in accordance with 3.2. Dilute aqueous extract volumetrically so that sample concentrations fall within the working range of the instrument. Enter sample I.D. and operator name into data collection system. Inject 10 µL sample and start data collection.

3.4 Report cation concentrations to three significant digits. Milliequivilents conversions are automatically performed in the calculation for SAR as follows:

$$\text{soluble cations (meq/100g)} = \left(\left\{\frac{[Na]}{23.0} + \frac{[Ca]}{20.0} + \frac{[Mg]}{12.2} + \frac{[K]}{39.1}\right\} \text{ X SP}\right) / 1000$$

$$\text{SAR} = \frac{[Na]}{23.0} / \left(0.5\left\{\frac{[Ca]}{20.0} + \frac{[Mg]}{12.2}\right\}\right)^{-1/2}$$

Where [ ] = concentration in ppm

QP-15

WHOLE EARTH ENVIRONMENTAL
QUALITY PROCEDURE

Procedure for Determining Distribution of Exchangeable Cations

Completed By: Approved By: Effective Date: / /

1.0 Purpose

This procedure defines the methods to be employed when determining the distribution of cations adsorbed on the solid phase.

2.0 Scope

This procedure shall be used in all exchangeable cation distribution testing.

3.0 Procedure

3.1 All samples shall be prepared in accordance with QP-12 and 13.

3.2 Calibration of the equipment shall be performed daily. Calibrate using a 5 point series of standards. The range of standards must include a blank, and should span the range of expected concentrations of the samples. The following concentrations are appropriate:

Low Range: 0, 1.0, 3.0, 5.0, 10.0 ppm
High Range: 0, 10.0, 20.0, 50.0, 100 ppm

With the instrument on, inject standard mixture with 10 µL syringe and start data collection. Store calibration data under the date of generation for use in subsequent analyses.

3.3 Weigh 5 +/- 0.01g sample into fritted extraction tube. Add 20 mL ammonium acetate, cap and shake for 5 minutes. Connect tube into filtration apparatus and collect extract. Repeat three times. Enter sample I.D. and operator name in data collection system. Inject 10 µL into 100mL container of deionized water and shake. Extract 10 µL of dilute sample and inject into sampling port of the ion Chromatograph.

3.4 Report cation concentrations to three significant digits. Milliequivilents conversions are automatically performed in the calculation for SAR as follows:

$$\text{extractable cations} = \left(\left\{\frac{\text{Na]}}{23.0} + \frac{[\text{Ca}]}{20.0} + \frac{[\text{Mg}]}{12.2} + \frac{[\text{K}]}{39.1}\right\} \text{ X } 10\right) / W$$

soluble cations = (SC X SP) / 1000

EC = extractable cations - soluble cations

Where [ ] = concentration in ppm
W = sample weight, grams

3.5 References:

Methods for Chemical analysis of Water and Wastes; USEPA; EMSL, Cincinnati, OH 1979

Deuel and Holliday, Soil Remediation for the Petroleum Extraction Industry; Houston, Tx., 1993

QP-16

WHOLE EARTH ENVIRONMENTAL
QUALITY PROCEDURE

Procedure for Determining Cation Exchange Capacity (CEC)

Completed By: Approved By: Effective Date: / /

1.0 Purpose

This procedure defines the methods to be employed when determining the cation exchange capacity of soils.

2.0 Scope

This procedure shall be used in all CEC testing.

3.0 Procedure

3.1 All samples shall be prepared in accordance with QP-12 and 13.

3.2 Calibration of the equipment shall be performed daily. Calibrate using a 5 point series of standards. The range of standards must include a blank, and should span the range of expected concentrations of the samples. The following concentrations are appropriate:

Low Range: 0, 1.0, 3.0, 5.0, 10.0 ppm
High Range: 0, 10.0, 20.0, 50.0, 100 ppm

With the instrument on, inject standard mixture with 10 µL syringe and start data collection. Store calibration data under the date of generation for use in subsequent analyses.

3.3 Weigh 5 +/- 0.01g sample into fritted extraction tube. Add 30 mL sodium acetate, cap and shake for 5 minutes. Connect tube into filtration apparatus and discard extract. Repeat three times. Rinse sample with 30 mL iso-propyl alcohol, shaken and filtered as above. Add 30 mL ammonium acetate, shake and collect filtrate as in above.Inject 10 µL into 100mL container of deionized water and shake. Extract 10 µL of dilute sample and inject into sampling port of the ion Chromatograph.

3.4 Report cation concentrations to three significant digits. Milliequivilents conversions are automatically performed in the calculation for SAR as follows:

CEC = 10 [Na] / 23.0 W

Where [ ] = concentration in ppm
W = sample weight, grams

3.5 References:

Methods for Chemical analysis of Water and Wastes; USEPA; EMSL, Cincinnati, OH 1979

Deuel and Holliday, Soil Remediation for the Petroleum Extraction Industry; Houston, Tx., 1993

QP-19

WHOLE EARTH ENVIRONMENTAL
QUALITY PROCEDURE

Sampling and Testing Protocol
BTEX Speciation in Soil

Completed By:	Approved By:	Effective Date: / /

1.0 Purpose

This procedure is to be used to determine the concentrations of Benzene, Toluene, Ethyl-Benzene and Xylene (BTEX) in soils.

2.0 Scope

This procedure is to be used as the standard field measurement for soil BTEX concentrations. It is not to be used as a substitute for full spectrographic speciation of organic compounds.

3.0 Procedure

3.1 Sample Collection and Preparation

3.1.1 Collect at least 500 g. of soil from the sample collection point. Take care to insure that the sample is representative of the general background to include visible concentrations of hydrocarbons and soil types. If necessary, prepare a composite sample of soils obtained at several points in the sample area. Take care to insure that no loose vegetation, rocks or liquids are included in the sample(s).

3.1.2 The soil sample(s) shall be immediately inserted into a one quart or larger polyethylene freezer bag and sealed. When sealed, the bag should contain a nearly equal space between the soil sample and trapped air.

3.1.3 The sealed samples shall be allowed to set for a minimum of five minutes at a minimum temperature of 70°F.

3.1.4 The sealed sample bag should be massaged to break up any clods, and to provide the soil sample with as much exposed surface area as practically possible.

3.2 Sampling Procedure

3.2.1 The instrument to be used in conducting VOC concentration testing shall be a Photovac Ion-chromatograph with BTEX Module. Prior to use the instrument shall be zeroed out in accordance with QP-55.

3.2.2 Carefully open one end of the collection bag and insert the probe tip into the bag taking care that the probe tip not touch the soil sample or the side walls of the bag. If VOC analysis was conducted on the sample prior to BTEX analysis, care should be taken to insure that a sufficient air volume exists in the bag to provide accurate results. **If the available air space within the bag is insufficient to run a full analysis, the sample shall be discarded.**

3.2.3 Set the instrument to retain the highest result reading value. Record the reading onto the Field Analytical Report Form and additionally enter the location code into the instrument data logger.

4.0 After testing, the soil samples shall be returned to the sampling location, and the bags collected for off-site disposal. **IN NO CASE SHALL THE SAME BAG BE USED TWICE. EACH SAMPLE CONTAINER MUST BE DISCARDED AFTER EACH USE.**

QP-25

WHOLE EARTH ENVIRONMENTAL
QUALITY PROCEDURE

Procedure for Instrument Calibration and Quality Assurance Analysis for General Analysis "MEGA" TPH Analyzer

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Completed By: Approved By: Effective Date: / /

1.0 Purpose

This procedure outlines the methods to be employed in calibrating the GAC MEGA TPH analyzer and for determining and reporting of accuracy curves.

2.0 Scope

This procedure shall be followed each day that the instrument is used.

3.0 Procedure

3.1 Turn the instrument on and allow to warm up with no cuvette in the receptacle. The instrument will take between five and ten minutes to come to equilibrium as can be determined by the concentration display readings moving a maximum of 5 ppm on the low scale. If the instrument continues to display erratic readings greater than 5 ppm, remove the cover and check both the mirrors and chopper to insure cleanliness.

3.2 All TPH standards shall be purchased form Environmental Resources Corporation and as a condition of their manufacture subject to independent certification by third party laboratories. Each standard is received with a calibration certificate.

3.3 Insert the low range (100 ppm) calibration standard into the receiving port and note the result on the right hand digital display. If the displayed reading is less than 98 ppm or greater than 102 ppm, remove the circuit board cover panel and zero out the instrument in accordance with QP-26.

(Note: Except in New Mexico, set the span to read 105% of actual standard).

3.4 Repeat the process with the mid range (500 ppm) calibration standard. If the displayed reading is less than 490 ppm or greater than 510 ppm zero out the span as described in QP-26.

3.5 Repeat the process again with the 1,000 and 5,000 ppm calibration standards.

3.6 Pour clean Freon 113 into a filter cartridge and extract into 10 ml cuvette. Insert the cuvette into the receiving port and zero out the instrument reading using the far right adjustment knob on the instrument. Repeat using the 1 ml cuvette and the left hand zero dial.

4.0 Determining & Reporting Instrument Accuracy

4.1 After making the fine adjustment with the zero dials reinsert each calibration standard into the instrument and note the concentration values. ***If any concentration value exceeds 2% of the standard set point, repeat all steps in section 3.0 of this Procedure.*** Note the actual concentration values displayed by the instrument after each calibration standard.

4.2 The four calibration standards shall be used in reporting span deviation as follows:

Standards Range			
100 ppm	**500 ppm**	**1,000 ppm**	**5,000 ppm**
0-250 ppm	251-750 ppm	751-2,500 ppm	2,501-10,000 ppm

4.3 Divide the actual instrument reading value of each calibration sample by the concentration shown on the standard (e.g.. 501 ppm instrument reading / 500 ppm standard = 1.002%). These readings shall be reported for each test performed.

5.0 Re-calibration

5.1 If any sample exceeds the concentration of 1,000 ppm on the 10 ml cuvette or 10,000 ppm on the 1 ml cuvette, the cuvette must be thoroughly rinsed with clean Freon and the instrument re-zeroed in accordance with 3.6 of this procedure.

QP-55

WHOLE EARTH ENVIRONMENTAL
QUALITY PROCEDURE

Procedure for Instrument Calibration and Quality Assurance Analysis for Photovac Gas Chromatograph

Completed By: Approved By: Effective Date: / /

1.0 Purpose

This procedure outlines the methods to be employed in calibrating the Photovac analyzer in the BTEX mode and for determining and reporting of accuracy curves.

2.0 Scope

This procedure shall be followed each day that the instrument is used.

3.0 Procedure

Start-up

3.1 Turn the instrument on and press the Battery button. A battery status report will appear on the screen. If the charge level is less than 8.0, either charge the battery or insert a fresh battery pack.

3.2 Open carrier gas valve on right side of instrument. The instrument is now tuning the lamp. If any "boot" problems occur during warm-up, the "chck" symbol will appear on the screen. Pressing TUTOR will prompt the instrument to provide details. The instrument will not progress beyond the start-up mode until all prompts are cleared.

3.3 The next screen display will be "purj" and will last approximately ten minutes. The instrument is purging the column.

Calibrate

3.4 Connect the regulator to cylinder of calibration gas. Connect calibration adapter and tee assembly to both the regulator and instrument. **DO NOT FORCE ANY CONNECTION!**

3.5 Inspect the open end of the tee vent to insure unobstructed flow.

3.6 Enter CAL on the key pad. The instrument will query "benzene?". Following the prompts and using the key pad, set the concentrations to those defined on the calibration gas bottle. Follow the same procedure for toluene, ethyl-benzene and xylene. After each compound, the instrument will read that the next analysis will be a calibration.

3.7 Press ENTER on key pad. The instrument will calibrate itself for the concentrations specified.

Confirmation Sample

3.8 After each calibration, run the calibration gas through the instrument once again. The display readings should be **exactly** those of the concentrations displayed on the calibration gas bottle. If they are not, the instrument needs factory calibration; do not use.

4.0 Re-calibration

4.1 The instrument is designed with software that prompts you to recalibrate each day, each thirty minutes of use, and after running a sample with high concentrations of one or more of the detected compounds.

5.0 Reporting Instrument Accuracy

5.1 The instrument accuracy as certified by the factory is 15% within one decade of instrument set point. Lower detection limits are 0.1 ppm for benzene and 1.0 ppm for toluene, ethylbenzene and xylene.

5.2 These standards and detection limits must be shown on all reports in which the instrument is used.

WHOLE EARTH ENVIRONMENTAL
QUALITY PROCEDURE

Procedure for Obtaining Water Samples (Cased Wells) Using One Liter Bailer

Completed By: Approved By: Effective Date: / /

1.0 Purpose

This procedure outlines the methods to be employed in obtaining water samples from cased monitoring wells.

2.0 Scope

This procedure shall be used for developed, cased water monitoring wells. It is not to be used for standing water samples such as ponds or streams.

3.0 Preliminary

3.1 Obtain sterile sampling containers from the testing laboratory designated to conduct analyses of the water. The shipment should include a Certificate of Compliance from the manufacturer of the collection bottle or vial and a Serial Number for the lot of containers. Retain this Certificate for future documentation purposes.

3.2 The following table shall be used to select the appropriate sampling container, preservative method and holding times for the various elements and compounds to be analyzed.

Compound to be Analyzed	Sample Container Size	Sample Container Description	Cap Requirements	Preservative	Maximum Hold Time
BTEX	40 ml.	VOA Container	Teflon Lined	HCl	7 days
TPH	1 liter	clear glass	Teflon Lined	HCl	28 days
PAH	1 liter	clear glass	Teflon Lined	Ice	7 days
Cation / Anion	1 liter	clear glass	Teflon Lined	None	48 Hrs.
Metals	1 liter	HD polyethylene	Any Plastic	Ice / HNO_3	28 Days
TDS	300 ml.	clear glass	Any Plastic	Ice	7 Days

4.0 Chain of Custody

4.1 Prepare a Sample Plan. The plan will list the well identification and the individual tests to be performed at that location. The sampler will check the list against the available inventory of appropriate sample collection bottles to insure against shortage.

4.2 Transfer the data to the Laboratory Chain of Custody Form. Complete all sections of the form except those that relate to the time of delivery of the samples to the laboratory.

4.3 Pre-label the sample collection jars. Include all requested information except time of collection. (Use a fine point Sharpie to insure that the ink remains on the label). Affix the labels to the jars.

5.0 Bailing Procedure

5.1 Identify the well from the site schematics. Place pre-labeled jar(s) next to the well. Remove the bolts from the well cover and place the cover with the bolts nearby. Remove the plastic cap from the well bore by first lifting the metal lever and then unscrewing the entire assembly.

5.2 The well may be equipped with an individual 1 liter bailing tube. If so, use the tube to bail a volume of water from the well bore equal to 10 liters for each 5' of well bore in the water table. (This assumes a 2" dia. Well bore).

5.3 Take care to insure that the bailing device and string do not become cross-contaminated. A clean pair of rubber gloves should be used when handling either the retrieval string or bailer. The retrieval string should not be allowed to come into contact with the ground.

6.0 Sampling Procedure

6.1 Once the well has been bailed in accordance with 5.2 of this procedure, a sample may be decanted into the appropriate sample collection jar directly from the bailer. The collection jar should be filled to the brim. Once the jar is sealed, turn the jar over to detect any bubbles that may be present. Add additional water to remove all bubbles from the sample container.

6.2 Note the time of collection on the sample collection jar with a fine Sharpie.

6.3 Place the sample directly on ice for transport to the laboratory. The preceding table shows the maximum hold times between collection and testing for the various analyses.

6.4 Complete the Chain of Custody form to include the collection times for each sample. Deliver all samples to the laboratory.

7.0 Documentation

7.1 The testing laboratory shall provide the following minimum information:

A. Client, Project and sample name.
B. Signed copy of the original Chain of Custody Form including data on the time the sample was received by the lab.
C. Results of the requested analyses
D. Test Methods employed
E. Quality Control methods and results

QP-77

WHOLE EARTH ENVIRONMENTAL
QUALITY PROCEDURE

Procedure for Obtaining Soil Samples for Transportation to a Laboratory

Completed By: Approved By: Effective Date: / /

1.0 Purpose

This procedure outlines the methods to be employed when obtaining soil samples to be taken to a laboratory for analysis.

2.0 Scope

This procedure shall be used for developed, cased water monitoring wells. It is not to be used for standing water samples such as ponds or streams.

3.0 Preliminary

3.1 Obtain sterile sampling containers from the testing laboratory designated to conduct analyses of the soil. The shipment should include a Certificate of Compliance from the manufacturer of the collection bottle or vial and a Serial Number for the lot of containers. Retain this Certificate for future documentation purposes.

3.2 If collecting TPH, BTEX, RCRA 8 metals, cation / anions or O&G, the sample jar may be a clear 4 oz. container with Teflon lid. If collecting PAH's, use an amber 4 oz. container with Teflon lid.

4.0 Chain of Custody

4.1 Prepare a Sample Plan. The plan will list the number, location and designation of each planned sample and the individual tests to be performed on the sample. The sampler will check the list against the available inventory of appropriate sample collection bottles to insure against shortage.

4.2 Transfer the data to the Laboratory Chain of Custody Form. Complete all sections of the form except those that relate to the time of delivery of the samples to the laboratory.

4.3 Pre-label the sample collection jars. Include all requested information except time of collection. (Use a fine point Sharpie to insure that the ink remains on the label). Affix the labels to the jars.

5.0 Sampling Procedure

5.1 Go to the sampling point with the sample container. If not analyzing for ions or metals, use a trowel to obtain the soil. Do not touch the soil with your bare hands. Use new latex gloves with each sample to help minimize any cross-contamination.

5.2 Pack the soil tightly into the container leaving the top slightly domed. Screw the lid down tightly. Enter the time of collection onto the sample collection jar label.

5.3 Place the sample directly on ice for transport to the laboratory.

5.4 Complete the Chain of Custody form to include the collection times for each sample. Deliver all samples to the laboratory.

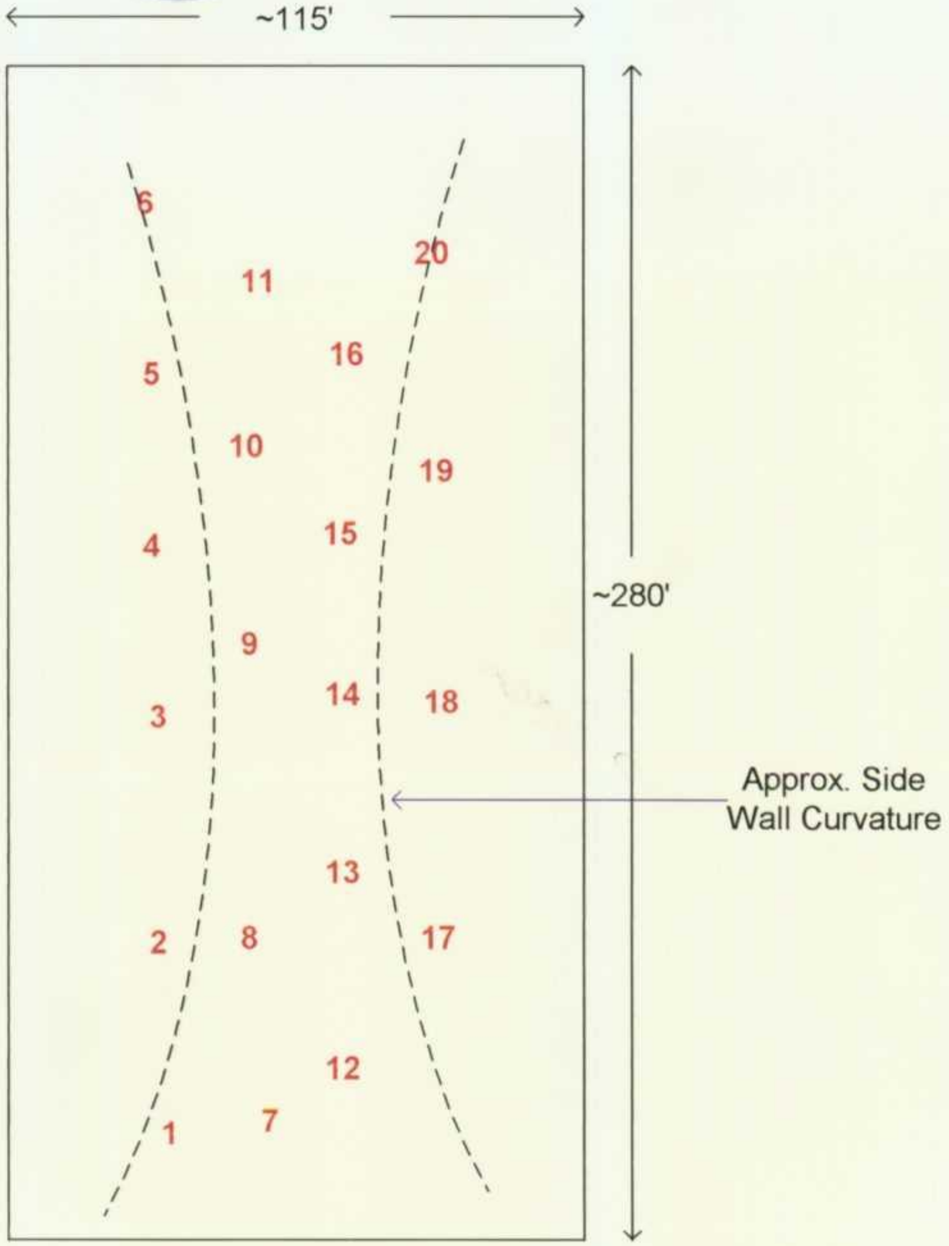
7.0 Documentation

7.1 The testing laboratory shall provide the following minimum information:

A. Client, Project and sample name.
B. Signed copy of the original Chain of Custody Form including data on the time the sample was received by the lab.
C. Results of the requested analyses
D. Test Methods employed
E. Quality Control methods and results

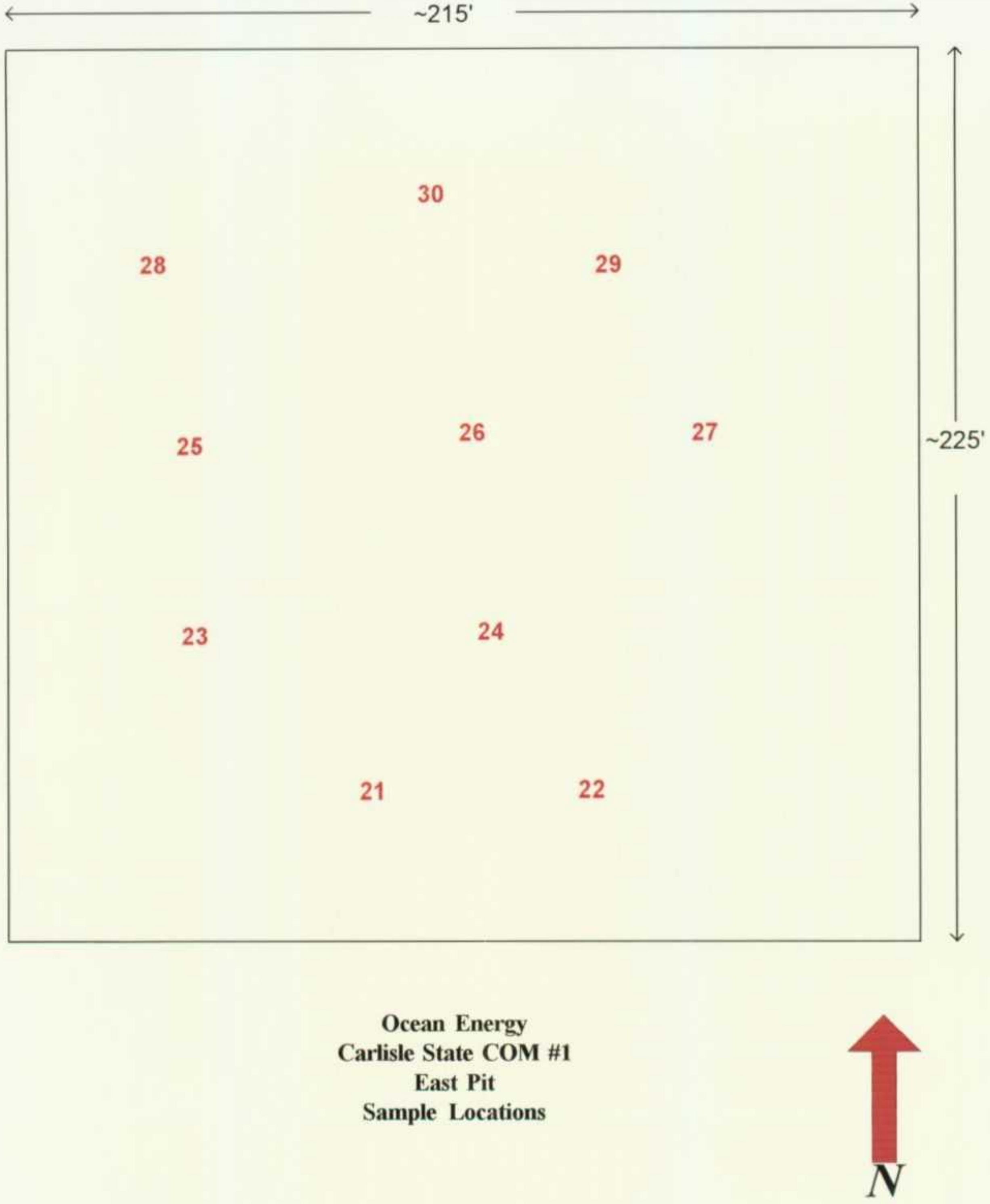
Analyses

This section contains copies of the laboratory analyses and chain of custody forms for the site testing performed by Callaway Safety and copies of the Whole Earth field testing results.



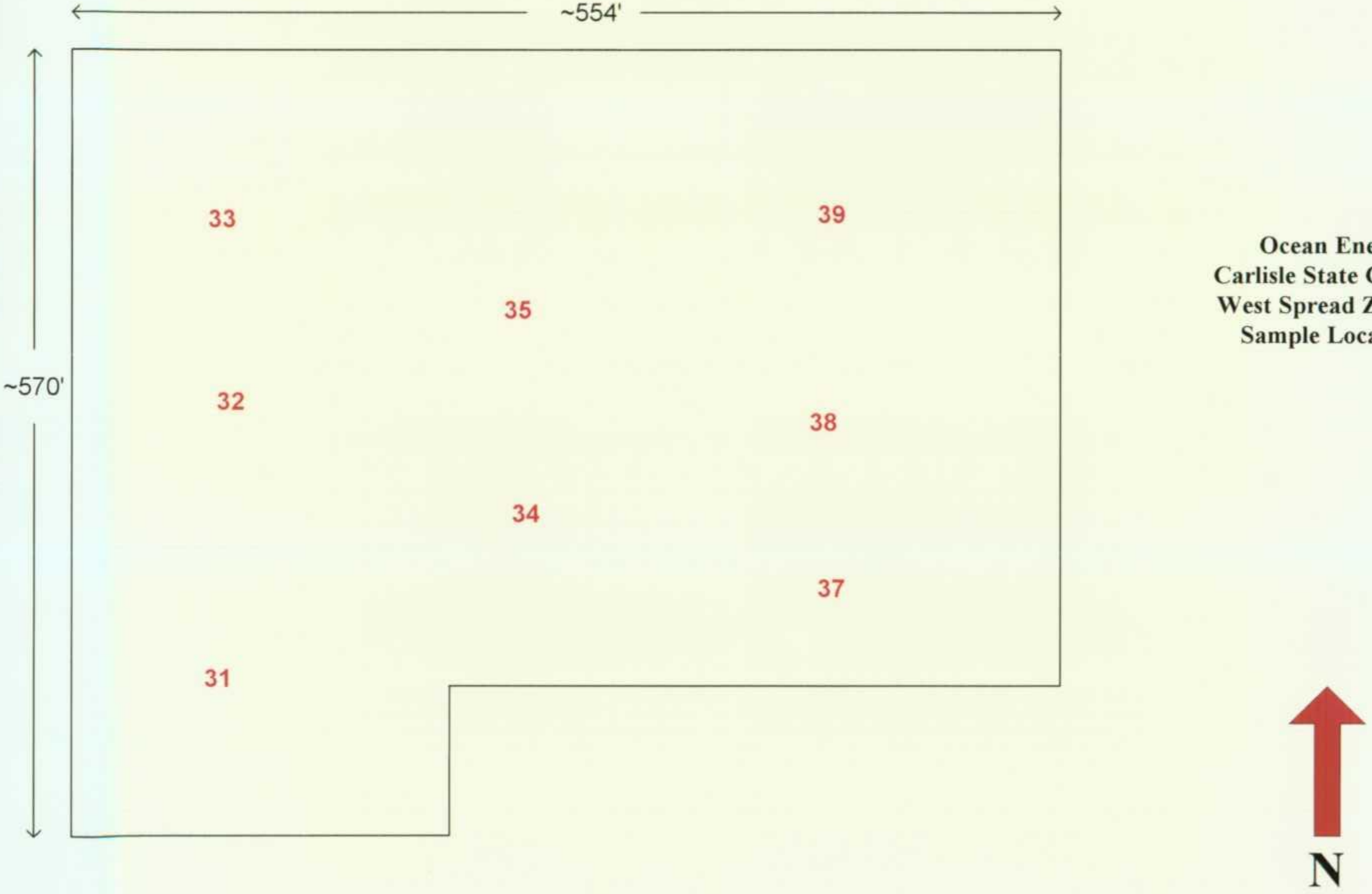
Ocean Energy
Carlisle State COM #1
West Pit
Sample Locations

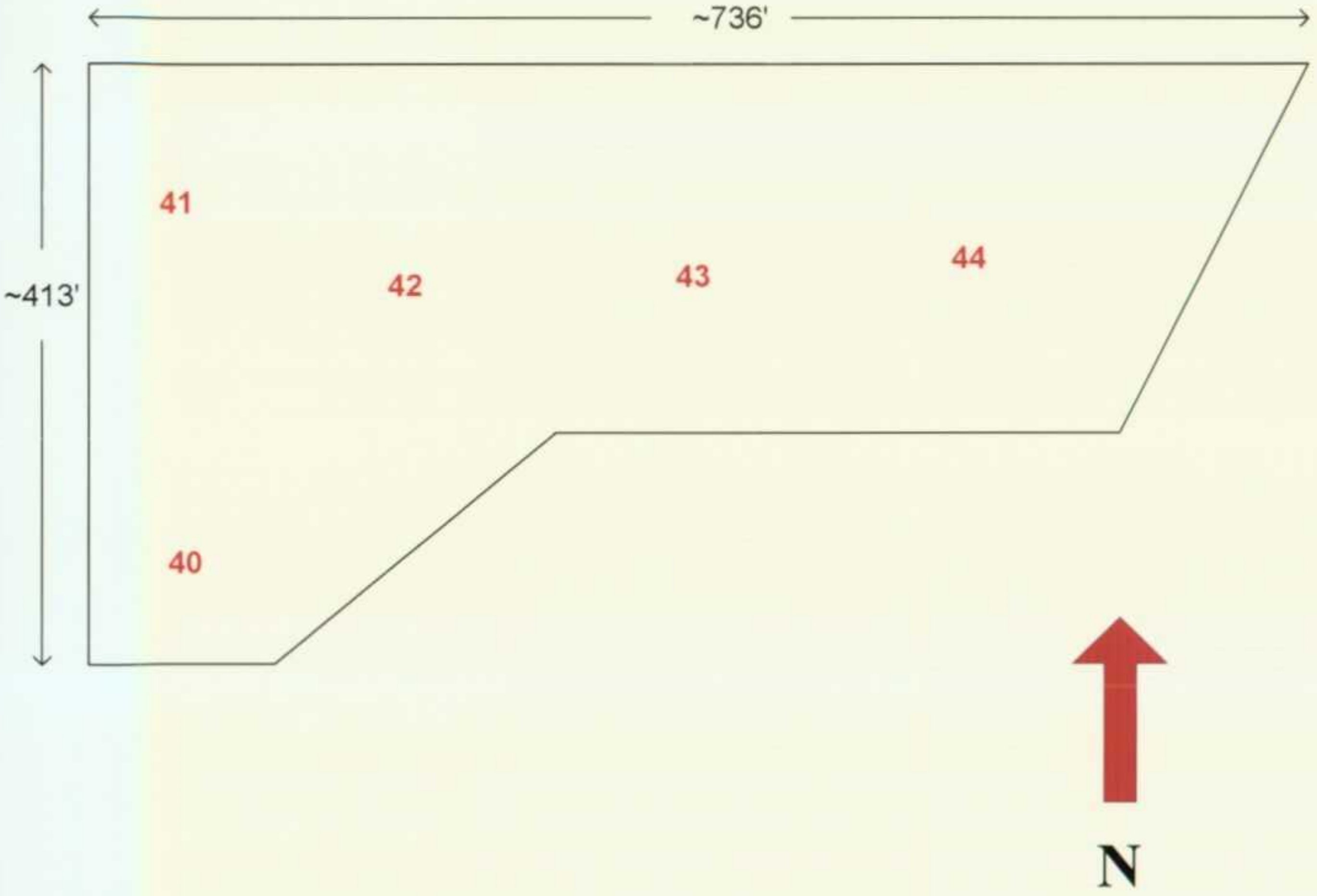
Ocean Energy



Ocean Energy
Carlisle State COM #1
East Pit
Sample Locations

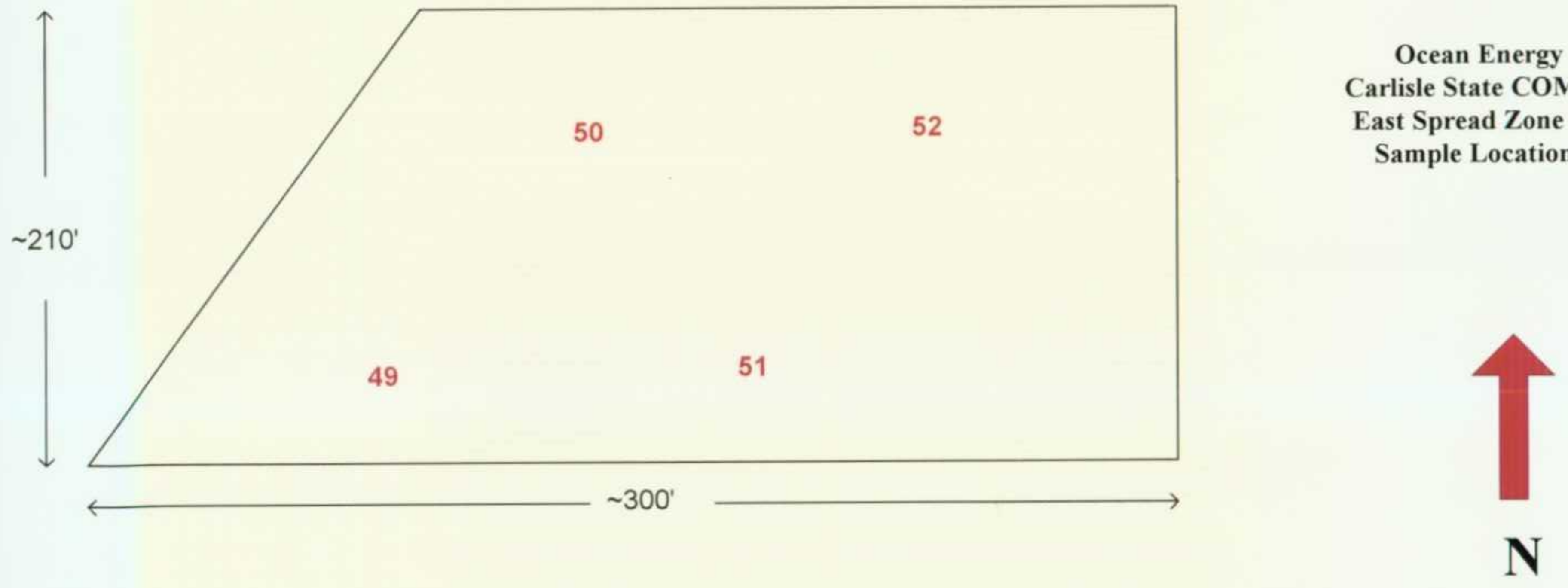
Ocean Energy
Carlisle State COM #1
West Spread Zone # 1
Sample Locations





Ocean Energy
Carlisle State COM #1
West Spread Zone # 2
Sample Locations

Ocean Energy
Carlisle State COM #1
East Spread Zone # 1
Sample Locations



Ocean Energy
Carlisle State COM #1
East Spread Zone # 2
Sample Locations

N

Ocean Energy

Carlisle State COM # 1
Field Sampling Results

Sample No.	Location	TPH	BTEX	Chlorides	
1	West Pit	83	N / D		
2	West Pit	247		77	
3	West Pit	N / D			
4	West Pit	42			
5	West Pit	74			
6	West Pit	N / D			
7	West Pit	104			
8	West Pit	63			
9	West Pit	N / D	12	63	
10	West Pit	41	7	24	
11	West Pit	107			
12	West Pit	N / D			
13	West Pit	22			
14	West Pit	41	N / D		
15	West Pit	73	N / D	18	
16	West Pit	88			
17	West Pit	N / D			
18	West Pit	251*		92	*Stain
19	West Pit	107			
20	West Pit	8			
Average		*55*	*3.8*	*54.8*	

Sample No.	Location	TPH	BTEX	Chlorides	
21	East Pit	471*	43		*Stain
22	East Pit	35		174	
23	East Pit	N / D			
24	East Pit	104	7		
25	East Pit	26		87	
26	East Pit	51	N / D	44	
27	East Pit	202*	11	97	*Stain
28	East Pit	N / D			
29	East Pit	77			
30	East Pit	12	3	227	
Average		97.8	12.8	125.8	

Sample No.	Location	TPH	BTEX	Chlorides
31	West Spread	10	▨	▨
32	West Spread	387	47	59
33	West Spread	N / D	▨	▨
34	West Spread	201	12	▨
35	West Spread	66	▨	▨
36	West Spread	*Sample not acceptable*		
37	West Spread	N / D	▨	▨
38	West Spread	109	5.2	▨
39	West Spread	N / D	▨	▨
40	West Spread	63	N / D	44
41	West Spread	N / D	▨	▨
42	West Spread	297	33	73
43	West Spread	374	18	121
44	West Spread	N / D	▨	▨
Average	▨	115.9	23.0	59.4

Sample No.	Location	TPH	BTEX	Chlorides
45	East Spread	563	58	▨
46	East Spread	211	▨	▨
47	East Spread	336	13	▨
48	East Spread	308	▨	197
49	East Spread	102	7	▨
50	East Spread	17	N / D	124
51	East Spread	140	▨	▨
52	East Spread	246	▨	▨
53	East Spread	298	▨	▨
54	East Spread	12	N / D	71
55	East Spread	*Sample not acceptable*		
56	East Spread	43	▨	▨
57	East Spread	1,230*	▨	377
Average	▨	*189.7*	*15.6*	*192.3*

*Stain

Sample No.	Location	TPH	BTEX	Chlorides
58	West Pile	14,680	63	▨

Note: All concentrations reported in mg / kg (ppm)

▨ **Denotes sample not run**

Whole Earth Environmental
Field Test
Analytical Results

Facility Name	Carlisle St. COM # 1	**Date of Collection**	6/22/98
Pit Type	Emergency Overflow	**Date of Analysis**	6/22/98
Client	Ocean Energy	**Analysist**	M. Griffin
TPH Analyzer S/N	01152	**VOC Analyzer S/N**	N/A
Chromatograph S/N	3714	**E.C. Analyzer S/N**	3659251

Analysis: TPH (418.1)
Analysis: BTEX
Analysis: Chlorides
Analysis:

Sample Location: (Described further on plat map)

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7
T.P.H$^{(1)}$	83	247	ND	42	74	ND	104
E.C$^{(2)}$	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Chlorides	N/A	77	N/A	N/A	N/A	N/A	N/A
BTEX	ND	N/A	N/A	N/A	N/A	N/A	N/A

Notes: 1. Results shown in mg / L (ppm)
2. Results Shown in mmhos / cm

Technician:

Whole Earth Environmental
Field Test
Analytical Results

Facility Name	Carlisle St. COM # 1	**Date of Collection**	6/22/98
Pit Type	Emergency Overflow	**Date of Analysis**	6/22/98
Client	Ocean Energy	**Analysist**	M. Griffin
TPH Analyzer S/N	01152	**VOC Analyzer S/N**	N/A
Chromatograph S/N	3714	**E.C. Analyzer S/N**	3659251

Analysis: TPH (418.1)
Analysis: BTEX
Analysis: Chlorides
Analysis:

Sample Location: (Described further on plat map)

	Sample 8	Sample 9	Sample 10	Sample 11	Sample 12	Sample 13	Sample 14
T.P.H(1)	63	ND	41	107	ND	22	41
E.C(2)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Chlorides	N/A	63	24	N/A	N/A	N/A	N/A
BTEX	N/A	12	7	N/A	N/A	N/A	ND

Notes:
1. Results shown in mg / L (ppm)
2. Results Shown in mmhos / cm

Technician: M. Griff

Whole Earth Environmental
Field Test
Analytical Results

Facility Name	Carlisle St. COM # 1	**Date of Collection**	6/22/98
Pit Type	Emergency Overflow	**Date of Analysis**	6/22/98
Client	Ocean Energy	**Analysist**	M. Griffin
TPH Analyzer S/N	01152	**VOC Analyzer S/N**	N/A
Chromatograph S/N	3714	**E.C. Analyzer S/N**	3659251

Analysis: TPH (418.1)
Analysis: BTEX
Analysis: Chlorides
Analysis:

Sample Location: (Described further on plat map)

	Sample 15	Sample 16	Sample 17	Sample 18	Sample 19	Sample 20	Sample 21
T.P.H(1)	73	88	ND	251	107	8	471
E.C(2)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Chlorides	18	N/A	N/A	92	N/A	N/A	N/A
BTEX	ND	N/A	N/A	N/A	N/A	N/A	43

Notes: 1. Results shown in mg / L (ppm)
2. Results Shown in mmhos / cm

Technician: M. Giff

Whole Earth Environmental
Field Test
Analytical Results

Facility Name	Carlisle St. COM # 1	**Date of Collection**	6/22/98
Pit Type	Emergency Overflow	**Date of Analysis**	6/22/98
Client	Ocean Energy	**Analysist**	M. Griffin
TPH Analyzer S/N	01152	**VOC Analyzer S/N**	N/A
Chromatograph S/N	3714	**E.C. Analyzer S/N**	3659251

Analysis: TPH (418.1)
Analysis: BTEX
Analysis: Chlorides
Analysis:

Sample Location: (Described further on plat map)

	Sample 22	Sample 23	Sample 24	Sample 25	Sample 26	Sample 27	Sample 28
T.P.H(1)	35	ND	104	26	51	202	ND
E.C(2)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Chlorides	174	N/A	N/A	87	44	97	N/A
BTEX	N/A	N/A	7	N/A	ND	11	N/A

Notes: 1. Results shown in mg / L (ppm)
2. Results Shown in mmhos / cm

Technician: M. Griff

Whole Earth Environmental
Field Test
Analytical Results

Facility Name	Carlisle St. COM # 1	Date of Collection	6/22/98
Pit Type	Emergency Overflow	Date of Analysis	6/22/98
Client	Ocean Energy	Analysist	M. Griffin
TPH Analyzer S/N	01152	VOC Analyzer S/N	N/A
Chromatograph S/N	3714	E.C. Analyzer S/N	3659251

Analysis: TPH (418.1)
Analysis: BTEX
Analysis: Chlorides
Analysis:

Sample Location: (Described further on plat map)

	Sample 29	Sample 30	Sample 31	Sample 32	Sample 33	Sample 34	Sample 35
T.P.H(1)	77	12	10	387	ND	201	66
E.C(2)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Chlorides	N/A	227	N/A	59	N/A	N/A	N/A
BTEX	N/A	3	N/A	47	N/A	12	N/A

Notes:
1. Results shown in mg / L (ppm)
2. Results Shown in mmhos / cm

Technician: M. Griff.

Whole Earth Environmental
Field Test
Analytical Results

Facility Name	Carlisle St. COM # 1	Date of Collection	6/22/98
Pit Type	Emergency Overflow	Date of Analysis	6/22/98
Client	Ocean Energy	Analysist	M. Griffin
TPH Analyzer S/N	01152	VOC Analyzer S/N	N/A
Chromatograph S/N	3714	E.C. Analyzer S/N	3659251

Analysis: TPH (418.1)
Analysis: BTEX
Analysis: Chlorides
Analysis:

Sample Location: (Described further on plat map)

	Sample 36	Sample 37	Sample 38	Sample 39	Sample 40	Sample 41	Sample 42
T.P.H(1)	N/A	ND	109	ND	63	ND	297
E.C(2)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Chlorides	N/A	N/A	N/A	N/A	44	N/A	73
BTEX	N/A	N/A	502	N/A	ND	N/A	33

Notes: 1. Results shown in mg / L (ppm)
2. Results Shown in mmhos / cm

Technician: M. Griff.

Whole Earth Environmental
Field Test
Analytical Results

Facility Name	Carlisle St. COM # 1	Date of Collection	6/22/98
Pit Type	Emergency Overflow	Date of Analysis	6/22/98
Client	Ocean Energy	Analysist	M. Griffin
TPH Analyzer S/N	01152	VOC Analyzer S/N	N/A
Chromatograph S/N	3714	E.C. Analyzer S/N	3659251

Analysis: TPH (418.1)
Analysis: BTEX
Analysis: Chlorides
Analysis:

Sample Location: (Described further on plat map)

	Sample 43	Sample 44	Sample 45	Sample 46	Sample 47	Sample 48	Sample 49
T.P.H(1)	374	ND	563	211	336	308	102
E.C(2)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Chlorides	121	N/A	N/A	N/A	N/A	197	N/A
BTEX	18	N/A	58	N/A	13	N/A	7

Notes:
1. Results shown in mg / L (ppm)
2. Results Shown in mmhos / cm

Technician: M. Griff

Whole Earth Environmental
Field Test
Analytical Results

Facility Name	Carlisle St. COM # 1	**Date of Collection**	6/22/98
Pit Type	Emergency Overflow	**Date of Analysis**	6/22/98
Client	Ocean Energy	**Analysist**	M. Griffin
TPH Analyzer S/N	01152	**VOC Analyzer S/N**	N/A
Chromatograph S/N	3714	**E.C. Analyzer S/N**	3659251

Analysis: TPH (418.1)
Analysis: BTEX
Analysis: Chlorides
Analysis:

Sample Location: (Described further on plat map)

	Sample 50	Sample 51	Sample 52	Sample 53	Sample 54	Sample 55	Sample 56
T.P.H(1)	17	140	246	298	12	N/A	43
E.C(2)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Chlorides	124	N/A	N/A	N/A	71	N/A	N/A
BTEX	ND	N/A	N/A	N/A	ND	N/A	N/A

Notes:
1. Results shown in mg / L (ppm)
2. Results Shown in mmhos / cm

Technician: M. Griffin

Whole Earth Environmental
Field Test
Analytical Results

Facility Name	Carlisle St. COM # 1	**Date of Collection**	6/22/98
Pit Type	Emergency Overflow	**Date of Analysis**	6/22/98
Client	Ocean Energy	**Analysisist**	M. Griffin
TPH Analyzer S/N	01152	**VOC Analyzer S/N**	N/A
Chromatograph S/N	3714	**E.C. Analyzer S/N**	3659251

Analysis: TPH (418.1)
Analysis: BTEX
Analysis: Chlorides
Analysis:

Sample Location: (Described further on plat map)

	Sample 57						
T.P.H$^{(1)}$	14,680	N/A	N/A	N/A	N/A	N/A	N/A
E.C$^{(2)}$	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Chlorides	N/A	N/A	N/A	N/A	N/A	N/A	N/A
BTEX	63	N/A	N/A	N/A	N/A	N/A	N/A

Notes:
1. Results shown in mg / L (ppm)
2. Results Shown in mmhos / cm

Technician: M. Griff

UMC Carlisle State Com #1 Water and Soil Data

Sample ID	Location Description	Medium	Lab ID	Parameter	Value	Units	EPA method	Sample Date	Analytical Date
GW6998A2	Carlisle #1 Windmill	GW	H3680-1	P-Alkalinity	0.000	mg/L	2320B	6/9/98	6/11/98
GW6998A2	Carlisle #1 Windmill	GW	H3680-1	T-Alkalinity	168.000	mg/L	2320B	6/9/98	6/11/98
GW6998A2	Carlisle #1 Windmill	GW	H3680-1	Hardness	280.000	mg/L	130.2	6/9/98	6/11/98
GW6998A2	Carlisle #1 Windmill	GW	H3680-1	Chloride	53.000	mg/L	325.3	6/9/98	6/11/98
GW6998A2	Carlisle #1 Windmill	GW	H3680-1	Sulfates	83.000	mg/L	375.4	6/9/98	6/11/98
GW6998A2	Carlisle #1 Windmill	GW	H3680-1	pH	6.160	s.u.	150.1	6/9/98	6/11/98
GW6998A2	Carlisle #1 Windmill	GW	H3680-1	Hydroxides	0.000	mg/L	2320B	6/9/98	6/11/98
GW6998A2	Carlisle #1 Windmill	GW	H3680-1	Carbonates	0.000	mg/L	2320B	6/9/98	6/11/98
GW6998A2	Carlisle #1 Windmill	GW	H3680-1	Bicarbonates	205.000	mg/L	2320B	6/9/98	6/11/98
GW6998A2	Carlisle #1 Windmill	GW	H3680-1	Conductivity	754.000	umhos/cm	120.1	6/9/98	6/11/98
GW6998A2	Carlisle #1 Windmill	GW	H3680-1	TDS	386.000	mg/L	160.1	6/9/98	6/12/98
GW6998A2	Carlisle #1 Windmill	GW	H3680-1	TPH	<1.0	mg/L	8015M	6/9/98	6/10/98
GW6998A2	Carlisle #1 Windmill	GW	H3680-1	Benzene	<.002	mg/L	8260	6/9/98	6/9/98
GW6998A2	Carlisle #1 Windmill	GW	H3680-1	Toluene	<.002	mg/L	8260	6/9/98	6/9/98
GW6998A2	Carlisle #1 Windmill	GW	H3680-1	Ethyl Benzene	<.002	mg/L	8260	6/9/98	6/9/98
GW6998A2	Carlisle #1 Windmill	GW	H3680-1	Xylenes - Total	<.002	mg/L	8260	6/9/98	6/9/98
S52998CLFW1BL	Caliche Lfarm West Baseline	Soil	H3667-2	P-Alkalinity	0.000	mg/Kg	2320B	5/29/98	6/1/98
S52998CLFW1BL	Caliche Lfarm West Baseline	Soil	H3667-2	T-Alkalinity	928.000	mg/Kg	2320B	5/29/98	6/1/98
S52998CLFW1BL	Caliche Lfarm West Baseline	Soil	H3667-2	Hardness	4240.000	mg/Kg	130.2	5/29/98	6/1/98
S52998CLFW1BL	Caliche Lfarm West Baseline	Soil	H3667-2	Chloride	166.000	mg/Kg	325.3	5/29/98	6/1/98
S52998CLFW1BL	Caliche Lfarm West Baseline	Soil	H3667-2	Sulfates	122.000	mg/Kg	375.4	5/29/98	6/1/98
S52998CLFW1BL	Caliche Lfarm West Baseline	Soil	H3667-2	pH	7.230	s.u.	150.1	5/29/98	6/2/98
S52998CLFW1BL	Caliche Lfarm West Baseline	Soil	H3667-2	Hydroxides	0.000	mg/Kg	2320B	5/29/98	6/1/98
S52998CLFW1BL	Caliche Lfarm West Baseline	Soil	H3667-2	Carbonates	0.000	mg/Kg	2320B	5/29/98	6/1/98
S52998CLFW1BL	Caliche Lfarm West Baseline	Soil	H3667-2	Bicarbonates	1132.000	mg/Kg	2320B	5/29/98	6/1/98
S52998CLFW1BL	Caliche Lfarm West Baseline	Soil	H3667-2	Conductivity	5390.000	umhos/cm	120.1	5/29/98	6/2/98
S52998CLFW1BL	Caliche Lfarm West Baseline	Soil	H3667-2	TPH	15.900	mg/Kg	8015M	5/29/98	5/29/98
S52998CLFW1BL	Caliche Lfarm West Baseline	Soil	H3667-2	Benzene	<.002	mg/Kg	8260	5/29/98	5/29/98
S52998CLFW1BL	Caliche Lfarm West Baseline	Soil	H3667-2	Toluene	0.004	mg/Kg	8260	5/29/98	5/29/98
S52998CLFW1BL	Caliche Lfarm West Baseline	Soil	H3667-2	Ethyl Benzene	0.005	mg/Kg	8260	5/29/98	5/29/98
S52998CLFW1BL	Caliche Lfarm West Baseline	Soil	H3667-2	Xylenes - Total	0.070	mg/Kg	8260	5/29/98	5/29/98
S52998HSP	Halliburton South Pit	Soil	H3667-1	TPH	282.000	mg/Kg	8015M	5/29/98	5/29/98
S52998HSP	Halliburton South Pit	Soil	H3667-1	Benzene	<.002	mg/Kg	8260	5/29/98	5/29/98
S52998HSP	Halliburton South Pit	Soil	H3667-1	Toluene	0.003	mg/Kg	8260	5/29/98	5/29/98
S52998HSP	Halliburton South Pit	Soil	H3667-1	Ethyl Benzene	<.002	mg/Kg	8260	5/29/98	5/29/98
S52998HSP	Halliburton South Pit	Soil	H3667-1	Xylenes - Total	<.006	mg/Kg	8260	5/29/98	5/29/98
SW41698EP	East Pit Water	SW	H3580-1	Benzene	0.002	mg/L	8021B	4/16/98	4/16/98
SW41698EP	East Pit Water	SW	H3580-1	Toluene	0.036	mg/L	8021B	4/16/98	4/16/98
SW41698EP	East Pit Water	SW	H3580-1	Ethyl Benzene	<.002	mg/L	8021B	4/16/98	4/16/98
SW41698EP	East Pit Water	SW	H3580-1	Xylenes - Total	0.113	mg/L	8021B	4/16/98	4/16/98
SW41698EP	East Pit Water	SW	H3580-1	TDS	7910.000	mg/L	160.1	4/16/98	4/16/98

UMC Carlisle State Com #1 Water and Soil Data

Sample ID	Location Description	Medium	Lab ID	Parameter	Value	Units	EPA method	Sample Date	Analytical Date
SW41698EP	East Pit Water	SW	H3580-1	Chloride	3900.000	mg/L	325.3	4/16/98	4/16/98
S42898DRP	Drilling Reserve Pit Sediment	Soil	3612-1	TPH	28200.000	mg/Kg	418.1	4/28/98	4/29/98
S42898DRP	Drilling Reserve Pit Sediment	Soil	3612-1	Benzene	21.300	mg/Kg	8260	4/28/98	4/28/98
S42898DRP	Drilling Reserve Pit Sediment	Soil	3612-1	Toluene	396.000	mg/Kg	8260	4/28/98	4/28/98
S42898DRP	Drilling Reserve Pit Sediment	Soil	3612-1	Ethyl Benzene	95.000	mg/Kg	8260	4/28/98	4/28/98
S42898DRP	Drilling Reserve Pit Sediment	Soil	3612-1	Xylenes - Total	990.000	mg/Kg	8260	4/28/98	4/28/98
S42898DRP	Drilling Reserve Pit Sediment	Soil	3612-1	Chloride	38800.000	mg/Kg	325.3	4/28/98	4/30/98
S42898LFBL	East Landfarm Baseline	Soil	3612-2	TPH	<10.0	mg/Kg	418.1	4/28/98	4/29/98
S42898LFBL	East Landfarm Baseline	Soil	3612-2	Benzene	0.057	mg/Kg	8260	4/28/98	4/28/98
S42898LFBL	East Landfarm Baseline	Soil	3612-2	Toluene	0.577	mg/Kg	8260	4/28/98	4/28/98
S42898LFBL	East Landfarm Baseline	Soil	3612-2	Ethyl Benzene	0.207	mg/Kg	8260	4/28/98	4/28/98
S42898LFBL	East Landfarm Baseline	Soil	3612-2	Xylenes - Total	2.380	mg/Kg	8260	4/28/98	4/28/98
S42898LFBL	East Landfarm Baseline	Soil	3612-2	Chloride	107.000	mg/Kg	325.3	4/28/98	4/30/98
S42998HSP	Halliburton South Pit	Soil	H3615-1	TPH	2010.000	mg/Kg	418.1	4/29/98	5/1/98
S42998HSP	Halliburton South Pit	Soil	H3615-1	Benzene	0.011	mg/Kg	8260	4/29/98	5/1/98
S42998HSP	Halliburton South Pit	Soil	H3615-1	Toluene	0.259	mg/Kg	8260	4/29/98	5/1/98
S42998HSP	Halliburton South Pit	Soil	H3615-1	Ethyl Benzene	0.099	mg/Kg	8260	4/29/98	5/1/98
S42998HSP	Halliburton South Pit	Soil	H3615-1	Xylenes - Total	0.641	mg/Kg	8260	4/29/98	5/1/98
S42998HSP	Halliburton South Pit	Soil	H3615-1	Chloride	11300.000	mg/Kg	325.3	4/29/98	4/30/98
S42998HNP	Halliburton North Pit	Soil	H3615-2	TPH	123.000	mg/Kg	418.1	4/29/98	5/1/98
S42998HNP	Halliburton North Pit	Soil	H3615-2	Benzene	<,002	mg/Kg	8260	4/29/98	5/1/98
S42998HNP	Halliburton North Pit	Soil	H3615-2	Toluene	0.006	mg/Kg	8260	4/29/98	5/1/98
S42998HNP	Halliburton North Pit	Soil	H3615-2	Ethyl Benzene	0.003	mg/Kg	8260	4/29/98	5/1/98
S42998HNP	Halliburton North Pit	Soil	H3615-2	Xylenes - Total	0.032	mg/Kg	8260	4/29/98	5/1/98
S42998HNP	Halliburton North Pit	Soil	H3615-2	Chloride	2800.000	mg/Kg	325.3	4/29/98	4/30/98
S51198HSP	Halliburton South Pit	Soil	H3636-1	TPH	5160.000	mg/Kg	418.1	5/11/98	5/12/98
S51198HSP	Halliburton South Pit	Soil	H3636-1	Benzene	0.003	mg/Kg	8260	5/11/98	5/12/98
S51198HSP	Halliburton South Pit	Soil	H3636-1	Toluene	0.009	mg/Kg	8260	5/11/98	5/12/98
S51198HSP	Halliburton South Pit	Soil	H3636-1	Ethyl Benzene	0.007	mg/Kg	8260	5/11/98	5/12/98
S51198HSP	Halliburton South Pit	Soil	H3636-1	Xylenes - Total	0.044	mg/Kg	8260	5/11/98	5/12/98
S51198HSP	Halliburton South Pit	Soil	H3636-1	Chloride	1778.000	mg/Kg	325.3	5/11/98	5/11/98
S51198EFP	East Flare Pit	Soil	H3636-2	TPH	58.000	mg/Kg	418.1	5/11/98	5/12/98
S51198EFP	East Flare Pit	Soil	H3636-2	Benzene	<.002	mg/Kg	8260	5/11/98	5/12/98
S51198EFP	East Flare Pit	Soil	H3636-2	Toluene	0.003	mg/Kg	8260	5/11/98	5/12/98
S51198EFP	East Flare Pit	Soil	H3636-2	Ethyl Benzene	<.002	mg/Kg	8260	5/11/98	5/12/98
S51198EFP	East Flare Pit	Soil	H3636-2	Xylenes - Total	0.100	mg/Kg	8260	5/11/98	5/12/98
S51198EFP	East Flare Pit	Soil	H3636-2	Chloride	4742.000	mg/Kg	325.3	5/11/98	5/11/98
S5598CLFNEBL	Caliche Lfarm NE Baseline	Soil	3626-1	TPH	747.000	mg/Kg	418.1	5/5/98	5/6/98
S5598CLFNEBL	Caliche Lfarm NE Baseline	Soil	3626-1	Benzene	<.001	mg/Kg	8260	5/5/98	5/5/98
S5598CLFNEBL	Caliche Lfarm NE Baseline	Soil	3626-1	Toluene	<.001	mg/Kg	8260	5/5/98	5/5/98
S5598CLFNEBL	Caliche Lfarm NE Baseline	Soil	3626-1	Ethyl Benzene	<.001	mg/Kg	8260	5/5/98	5/5/98

UMC Carlisle State Com #1 Water and Soil Data

Sample ID	Location Description	Medium	Lab ID	Parameter	Value	Units	EPA method	Sample Date	Analytical Date
S5598CLFNEBL	Caliche Lfarm NE Baseline	Soil	3626-1	Xylenes - Total	<.003	mg/Kg	8260	5/5/98	5/5/98
S5598CLFNEBL	Caliche Lfarm NE Baseline	Soil	3626-1	Chloride	107.000	mg/Kg	325.3	5/5/98	5/5/98
S5598CLFNWBL	Caliche Lfarm NW Baseline	Soil	3626-2	TPH	<10	mg/Kg	418.1	5/5/98	5/6/98
S5598CLFNWBL	Caliche Lfarm NW Baseline	Soil	3626-2	Benzene	<.001	mg/Kg	8260	5/5/98	5/5/98
S5598CLFNWBL	Caliche Lfarm NW Baseline	Soil	3626-2	Toluene	<.001	mg/Kg	8260	5/5/98	5/5/98
S5598CLFNWBL	Caliche Lfarm NW Baseline	Soil	3626-2	Ethyl Benzene	<.001	mg/Kg	8260	5/5/98	5/5/98
S5598CLFNWBL	Caliche Lfarm NW Baseline	Soil	3626-2	Xylenes - Total	<.003	mg/Kg	8260	5/5/98	5/5/98
S5598CLFNWBL	Caliche Lfarm NW Baseline	Soil	3626-2	Chloride	47.000	mg/Kg	325.3	5/5/98	5/6/98
S5598CLFNEBL	Caliche Lfarm NE Baseline	Soil	3626-1	P-Alkalinity	0.000	mg/Kg	2320B	5/5/98	5/6/98
S5598CLFNEBL	Caliche Lfarm NE Baseline	Soil	3626-1	T-Alkalinity	144.000	mg/Kg	2320B	5/5/98	5/6/98
S5598CLFNEBL	Caliche Lfarm NE Baseline	Soil	3626-1	Hardness	176.000	mg/Kg	130.2	5/5/98	5/6/98
S5598CLFNEBL	Caliche Lfarm NE Baseline	Soil	3626-1	Sulfates	12.000	mg/Kg	375.4	5/5/98	5/6/98
S5598CLFNEBL	Caliche Lfarm NE Baseline	Soil	3626-1	pH	7.680	s.u.	150.1	5/5/98	5/6/98
S5598CLFNEBL	Caliche Lfarm NE Baseline	Soil	3626-1	Hydroxides	0.000	mg/Kg	2320B	5/5/98	5/6/98
S5598CLFNEBL	Caliche Lfarm NE Baseline	Soil	3626-1	Carbonates	0.000	mg/Kg	2320B	5/5/98	5/6/98
S5598CLFNEBL	Caliche Lfarm NE Baseline	Soil	3626-1	Bicarbonates	176.000	mg/Kg	2320B	5/5/98	5/6/98
S5598CLFNEBL	Caliche Lfarm NE Baseline	Soil	3626-1	Conductivity	117.000	umhos/cm	120.1	5/5/98	5/6/98
S5598CLFNWBL	Caliche Lfarm NW Baseline	Soil	H3626-2	P-Alkalinity	0.000	mg/Kg	2320B	5/5/98	5/6/98
S5598CLFNWBL	Caliche Lfarm NW Baseline	Soil	H3626-2	T-Alkalinity	208.000	mg/Kg	2320B	5/5/98	5/6/98
S5598CLFNWBL	Caliche Lfarm NW Baseline	Soil	H3626-2	Hardness	208.000	mg/Kg	130.2	5/5/98	5/6/98
S5598CLFNWBL	Caliche Lfarm NW Baseline	Soil	H3626-2	Sulfates	40.000	mg/Kg	375.4	5/5/98	5/6/98
S5598CLFNWBL	Caliche Lfarm NW Baseline	Soil	H3626-2	pH	8.190	s.u.	150.1	5/5/98	5/6/98
S5598CLFNWBL	Caliche Lfarm NW Baseline	Soil	H3626-2	Hydroxides	0.000	mg/Kg	2320B	5/5/98	5/6/98
S5598CLFNWBL	Caliche Lfarm NW Baseline	Soil	H3626-2	Carbonates	0.000	mg/Kg	2320B	5/5/98	5/6/98
S5598CLFNWBL	Caliche Lfarm NW Baseline	Soil	H3626-2	Bicarbonates	254.000	mg/Kg	2320B	5/5/98	5/6/98
S5598CLFNWBL	Caliche Lfarm NW Baseline	Soil	H3626-2	Conductivity	139.000	umhos/cm	120.1	5/5/98	5/6/98
S42498LFBL	East Landfarm Baseline	Soil	H3626-3	P-Alkalinity	0.000	mg/Kg	2320B	4/24/98	5/6/98
S42498LFBL	East Landfarm Baseline	Soil	H3626-3	T-Alkalinity	191.000	mg/Kg	2320B	4/24/98	5/6/98
S42498LFBL	East Landfarm Baseline	Soil	H3626-3	Hardness	128.000	mg/Kg	130.2	4/24/98	5/6/98
S42498LFBL	East Landfarm Baseline	Soil	H3626-3	Sulfates	56.000	mg/Kg	375.4	4/24/98	5/6/98
S42498LFBL	East Landfarm Baseline	Soil	H3626-3	pH	7.820	s.u.	150.1	4/24/98	5/6/98
S42498LFBL	East Landfarm Baseline	Soil	H3626-3	Hydroxides	0.000	mg/Kg	2320B	4/24/98	5/6/98
S42498LFBL	East Landfarm Baseline	Soil	H3626-3	Carbonates	0.000	mg/Kg	2320B	4/24/98	5/6/98
S42498LFBL	East Landfarm Baseline	Soil	H3626-3	Bicarbonates	234.000	mg/Kg	2320B	4/24/98	5/6/98
S42498LFBL	East Landfarm Baseline	Soil	H3626-3	Conductivity	88.000	umhos/cm	120.1	4/24/98	5/6/98
S42498LFBL	East Landfarm Baseline	Soil	H3626-3	Chloride	36.000	mg/Kg	325.3	4/24/98	5/6/98
GW98331A1	Osborn Well	GW	H3550-1	Benzene	<.002	mg/L	8021B	3/31/98	4/1/98
GW98331A1	Osborn Well	GW	H3550-1	Toluene	<.002	mg/L	8021B	3/31/98	4/1/98
GW98331A1	Osborn Well	GW	H3550-1	Ethyl Benzene	<.002	mg/L	8021B	3/31/98	4/1/98
GW98331A1	Osborn Well	GW	H3550-1	Xylenes - Total	<.006	mg/L	8021B	3/31/98	4/1/98
GW98331A1	Osborn Well	GW	H3550-1	TDS	375.000	mg/L	160.1	3/31/98	4/1/98

UMC Carlisle State Com #1 Water and Soil Data

Sample ID	Location Description	Medium	Lab ID	Parameter	Value	Units	EPA method	Sample Date	Analytical Date
GW98331A1	Osborn Well	GW	H3550-1	Chloride	48.000	mg/L	325.3	3/31/98	4/1/98
GW98331A2	Carlsile #1 Windmill	GW	H3550-2	Benzene	<.002	mg/L	8021B	3/31/98	4/1/98
GW98331A2	Carlsile #1 Windmill	GW	H3550-2	Toluene	<.002	mg/L	8021B	3/31/98	4/1/98
GW98331A2	Carlsile #1 Windmill	GW	H3550-2	Ethyl Benzene	<.002	mg/L	8021B	3/31/98	4/1/98
GW98331A2	Carlsile #1 Windmill	GW	H3550-2	Xylenes - Total	<.006	mg/L	8021B	3/31/98	4/1/98
GW98331A2	Carlsile #1 Windmill	GW	H3550-2	TDS	428.000	mg/L	160.1	3/31/98	4/1/98
GW98331A2	Carlsile #1 Windmill	GW	H3550-2	Chloride	64.000	mg/L	325.3	3/31/98	4/1/98
GW9841A3	Carlisle Irrigation Well	GW	H3550-3	Benzene	<.002	mg/L	8021B	4/1/98	4/1/98
GW9841A3	Carlisle Irrigation Well	GW	H3550-3	Toluene	<.002	mg/L	8021B	4/1/98	4/1/98
GW9841A3	Carlisle Irrigation Well	GW	H3550-3	Ethyl Benzene	<.002	mg/L	8021B	4/1/98	4/1/98
GW9841A3	Carlisle Irrigation Well	GW	H3550-3	Xylenes - Total	<.006	mg/L	8021B	4/1/98	4/1/98
GW9841A3	Carlisle Irrigation Well	GW	H3550-3	TDS	360.000	mg/L	160.1	4/1/98	4/1/98
GW9841A3	Carlisle Irrigation Well	GW	H3550-3	Chloride	68.000	mg/L	325.3	4/1/98	4/1/98
GW98331A4	Carlisle Residence	GW	H3550-4	Benzene	<.002	mg/L	8021B	3/31/98	4/1/98
GW98331A4	Carlisle Residence	GW	H3550-4	Toluene	<.002	mg/L	8021B	3/31/98	4/1/98
GW98331A4	Carlisle Residence	GW	H3550-4	Ethyl Benzene	<.002	mg/L	8021B	3/31/98	4/1/98
GW98331A4	Carlisle Residence	GW	H3550-4	Xylenes - Total	<.006	mg/L	8021B	3/31/98	4/1/98
GW98331A4	Carlisle Residence	GW	H3550-4	TDS	511.000	mg/L	160.1	3/31/98	4/1/98
GW98331A4	Carlisle Residence	GW	H3550-4	Chloride	52.000	mg/L	325.3	3/31/98	4/1/98
S51998EPNR12	East Pit 12' Interval	Soil	H3653-1	TPH	33010.000	mg/Kg	418.1	5/19/98	5/19/98
S51998EPNR12	East Pit 12' Interval	Soil	H3653-1	Benzene	0.167	mg/Kg	8260	5/19/98	5/20/98
S51998EPNR12	East Pit 12' Interval	Soil	H3653-1	Toluene	35.000	mg/Kg	8260	5/19/98	5/20/98
S51998EPNR12	East Pit 12' Interval	Soil	H3653-1	Ethyl Benzene	17.700	mg/Kg	8260	5/19/98	5/20/98
S51998EPNR12	East Pit 12' Interval	Soil	H3653-1	Xylenes - Total	197.000	mg/Kg	8260	5/19/98	5/20/98
S51998EPNR16	East Pit 16' Interval	Soil	H3653-2	TPH	1884.000	mg/Kg	418.1	5/19/98	5/19/98
S51998EPNR16	East Pit 16' Interval	Soil	H3653-2	Benzene	0.003	mg/Kg	8260	5/19/98	5/20/98
S51998EPNR16	East Pit 16' Interval	Soil	H3653-2	Toluene	0.435	mg/Kg	8260	5/19/98	5/20/98
S51998EPNR16	East Pit 16' Interval	Soil	H3653-2	Ethyl Benzene	0.499	mg/Kg	8260	5/19/98	5/20/98
S51998EPNR16	East Pit 16' Interval	Soil	H3653-2	Xylenes - Total	6.000	mg/Kg	8260	5/19/98	5/20/98
S52898WPB37	West Pit Bottom 37' Interval	Soil	H3664-1	TPH	<10	mg/Kg	418.1	5/28/98	5/28/98
S52898WPEW32	West Pit East Wall 32' Interval	Soil	H3664-2	TPH	<10	mg/Kg	418.1	5/28/98	5/28/98

Modeling

The enclosed contaminant migration models were produced using VADSAT release 3.5. The program was prepared under contract for the API by Environmental Systems and Technologies. It is formally titled: *"A Vadose and Saturated Zone Transport Model for Assessing the Effects on Groundwater Quality from Subsurface Petroleum Hydrocarbon Releases and Petroleum Production Waste Management Practices".*

The first set of graphs, (West Pit Hydrocarbon Model 1A) predicates a 1,000 ppm TPH pit concentration extending from the surface to a depth of 45' bgl and terminating five feet from the water table. It calculates the first impact on the table in approximately twenty years at a non-recordable concentration gradually diminishing over time.

The second set, (West Pit Hydrocarbon Model # 1) describes the same pit with a vertical separation between the pit and water table of thirty feet. It shows no hydrocarbon migration to the table at all.

The third set, (East Pit Hydrocarbon Model # 1) was run with the same concentrations and separation as West Pit #1. It does show connectivity to the table in about one hundred years but at a concentration too small to be recorded.

The final sets show the chloride concentrations at the water table based on a 500 ppm soluble chloride concentration and thirty foot separation. Both sets show connectivity in approximately forty years with chloride concentrations well below WQCC standards.

The entry data is shown in spreadsheet form immediately before each model set.

Modeling Data Entry
Carlisle State Com # 1
West Pit
Hydrocarbon Model # 1A

Control Data	Entry	U / M
Deterministic	Yes	
Monte Carlo	No	
Evaporation of Chemicals	Yes	
Adsorbed Phase Biodecay	Yes	
Low Permeability Layer Below Contamination	Not Present	

Source Data		
Waste Zone Thickness	13.84	meters
Waste Zone Area	3,048	Sq. meters
Ratio of Length to Width	2.43:1	
Soil Thickness Above Waste Zone	0.1524	meters
Contaminant Concentration in Soil / Waste Zone	10	ppm (benzene)
Hydrocarbon Concentration in Soil / Waste Zone	1,000	ppm

Chemical Data	
Benzene	Yes

Unsaturated Zone		
Biodecay Cooefficient	0.001	1 / day
Organic Carbon Fraction	1.00E-06	
Soil Database	Sandy Clay	
Hydrological Database	Sedimentary	
Unsaturated Zone Thickness	1.53	meter
Soil Database	Sandy Clay	
van Genuchten n	1.09	(Default)
Residual Water Content	0.01001	
Unsaturated Zone Dispersivity	0	Internally

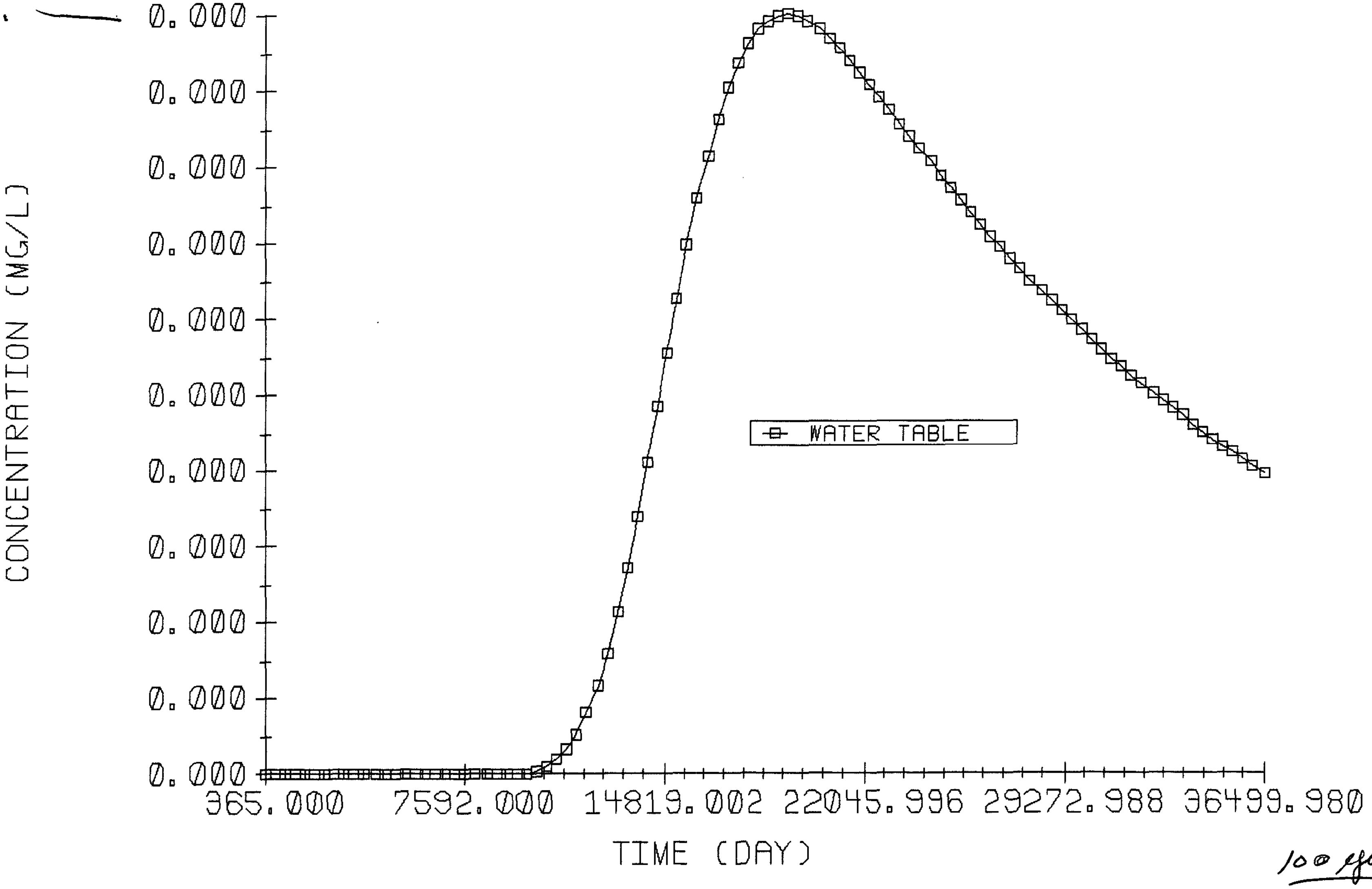
Saturated Zone		
Biodecay Cooefficient	0.001	1 / day
Aquifer Porosity	0.2	(Default)
Organic Carbon Fraction	0	Internally
Longitudinal Dispersivity	0	Internally
Ratio of Long. / Trans. Dispersivities	3	
Ratio of Trans. / Vert. Dispersivities	87	Default
Hydrological Database	Sedimentary	
Aquifer Thickness	10	meters
Aquifer Gradient	0.023	
Saturated Hydraulic Conductivity	0.13	meters / day

Net Infiltration Rate	0.00001	ft. / day

(feet)

WEST PIT WATER 1K 5 SEPARATION

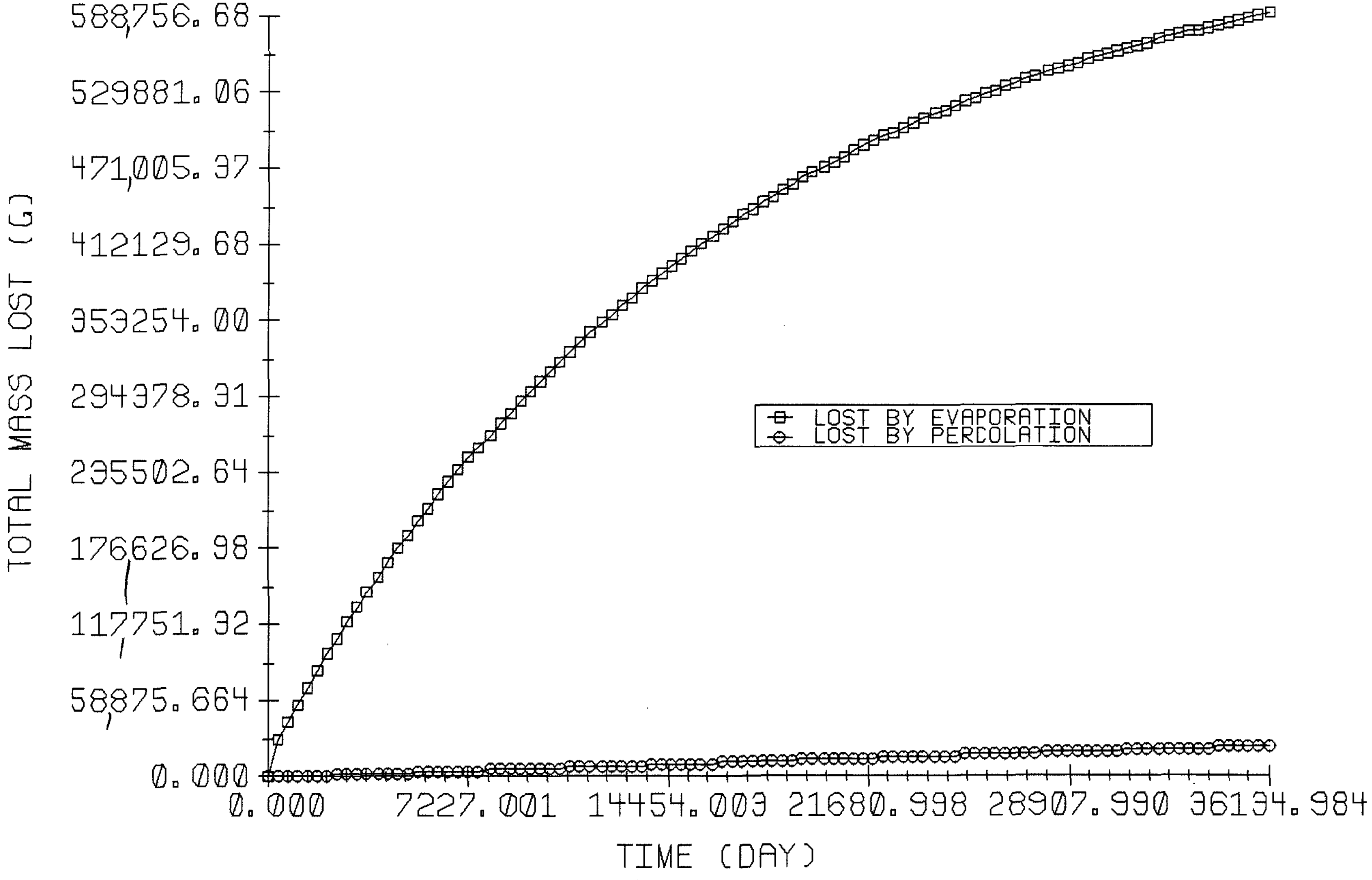
7.



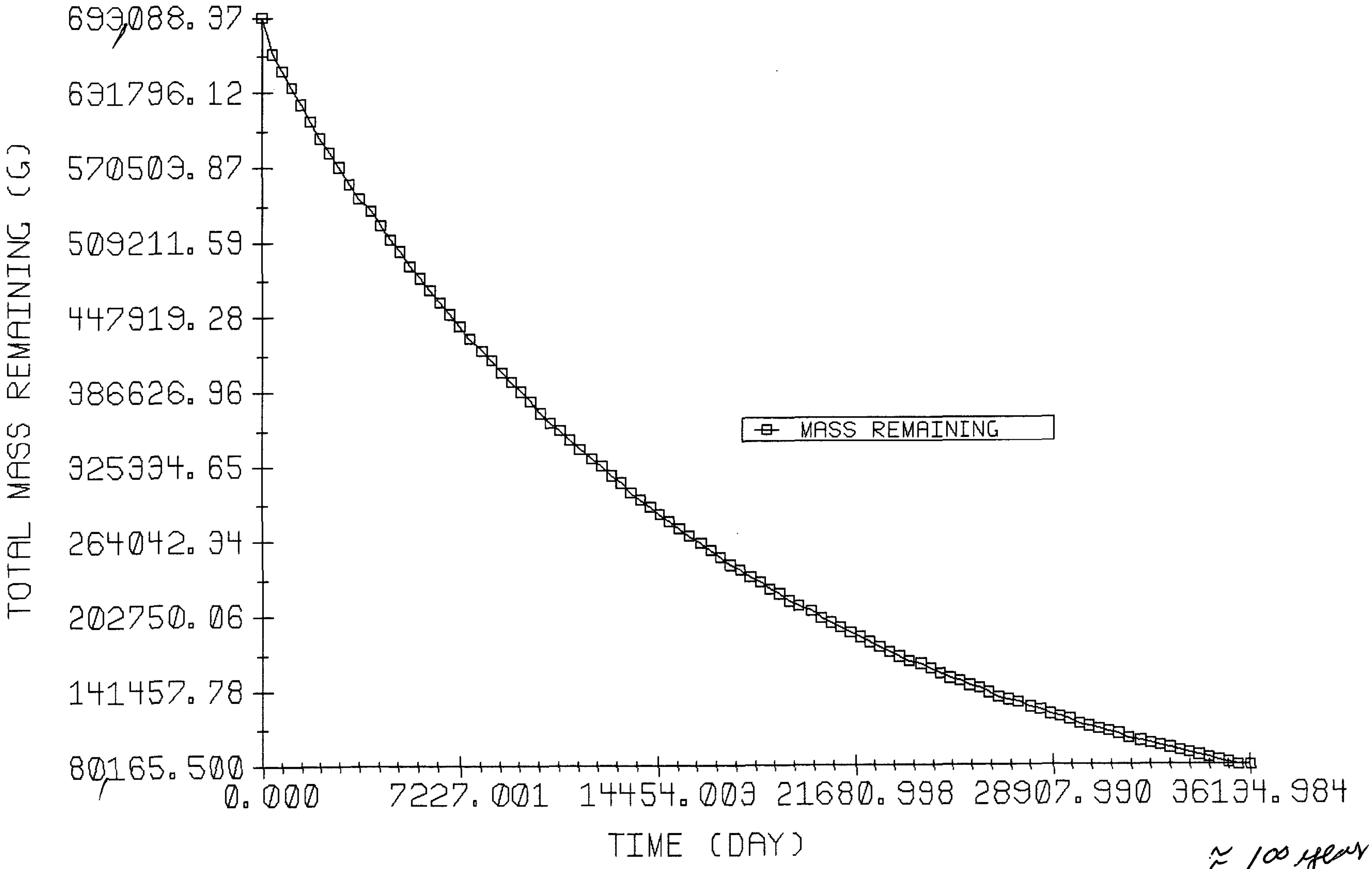
100 years

TPH

WEST PIT MASS LOST 1K 5 SEPARATION



WEST PIT MASS REM. 1K 5 SEPARATION



≈ 100 years

Modeling Data Entry
Carlisle State Com # 1
West Pit
Hydrocarbon Model # 1

Control Data	Entry	U / M
Deterministic	Yes	
Monte Carlo	No	
Evaporation of Chemicals	Yes	
Adsorbed Phase Biodecay	Yes	
Low Permeability Layer Below Contamination	Not Present	

Source Data		
Waste Zone Thickness	6.096	meters
Waste Zone Area	3,048	Sq. meters
Ratio of Length to Width	2.43:1	
Soil Thickness Above Waste Zone	0.1524	meters
Contaminant Concentration in Soil / Waste Zone	10	ppm (benzene)
Hydrocarbon Concentration in Soil / Waste Zone	1,000	ppm

Chemical Data	
Benzene	Yes

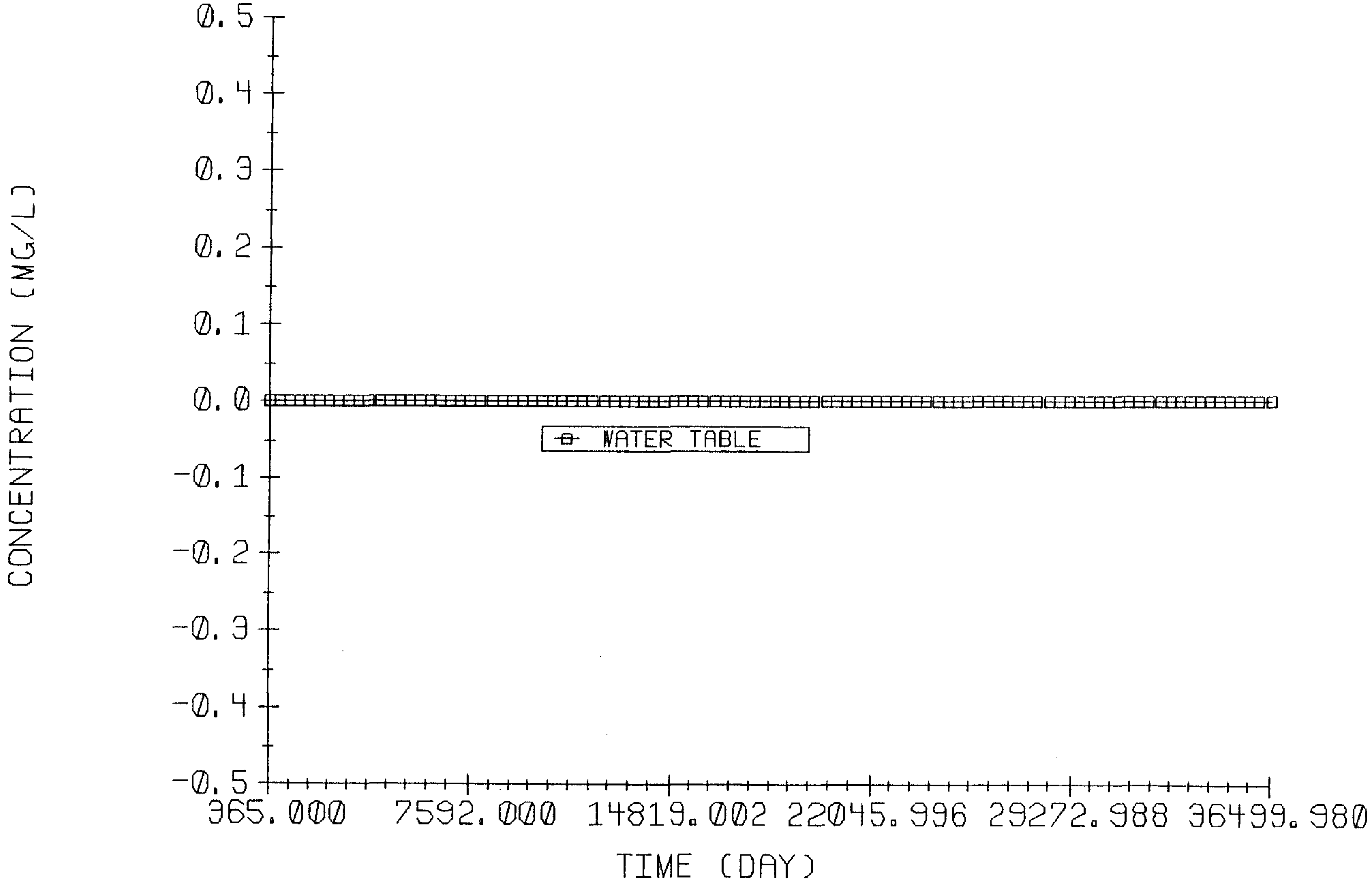
Unsaturated Zone		
Biodecay Cooefficient	0.001	1 / day
Organic Carbon Fraction	1.00E-06	
Soil Database	Sandy Clay	
Hydrological Database	Sedimentary	
Unsaturated Zone Thickness	9.23	meter
Soil Database	Sandy Clay	
van Genuchten n	1.09	(Default)
Residual Water Content	0.01001	
Unsaturated Zone Dispersivity	0	Internally

Saturated Zone		
Biodecay Cooefficient	0.001	1 / day
Aquifer Porosity	0.2	(Default)
Organic Carbon Fraction	0	Internally
Longitudinal Dispersivity	0	Internally
Ratio of Long. / Trans. Dispersivities	3	
Ratio of Trans. / Vert. Dispersivities	87	Default
Hydrological Database	Sedimentary	
Aquifer Thickness	10	meters
Aquifer Gradient	0.023	
Saturated Hydraulic Conductivity	0.13	meters / day

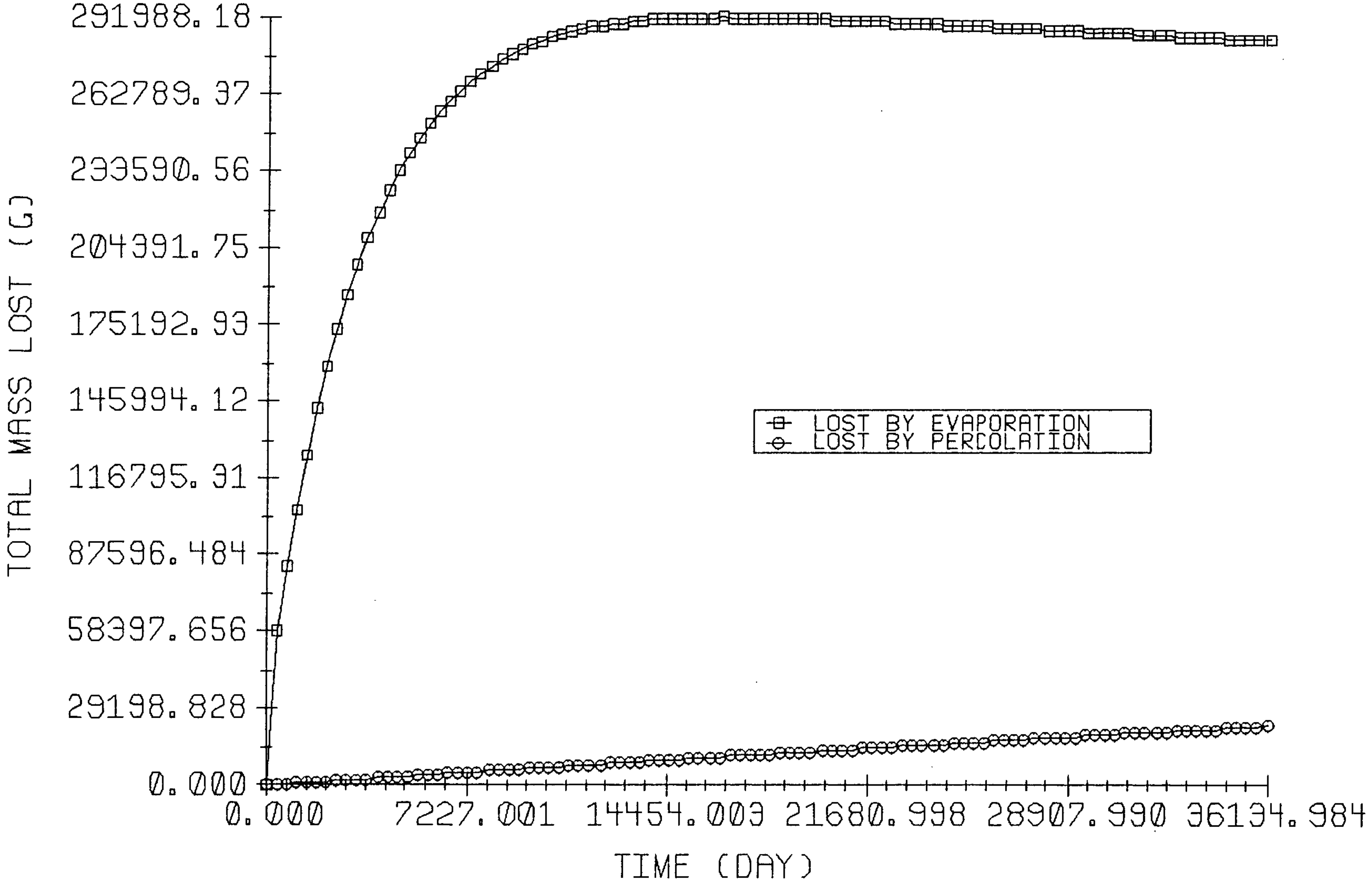
Net Infiltration Rate	0.00001	ft. / day

Feet

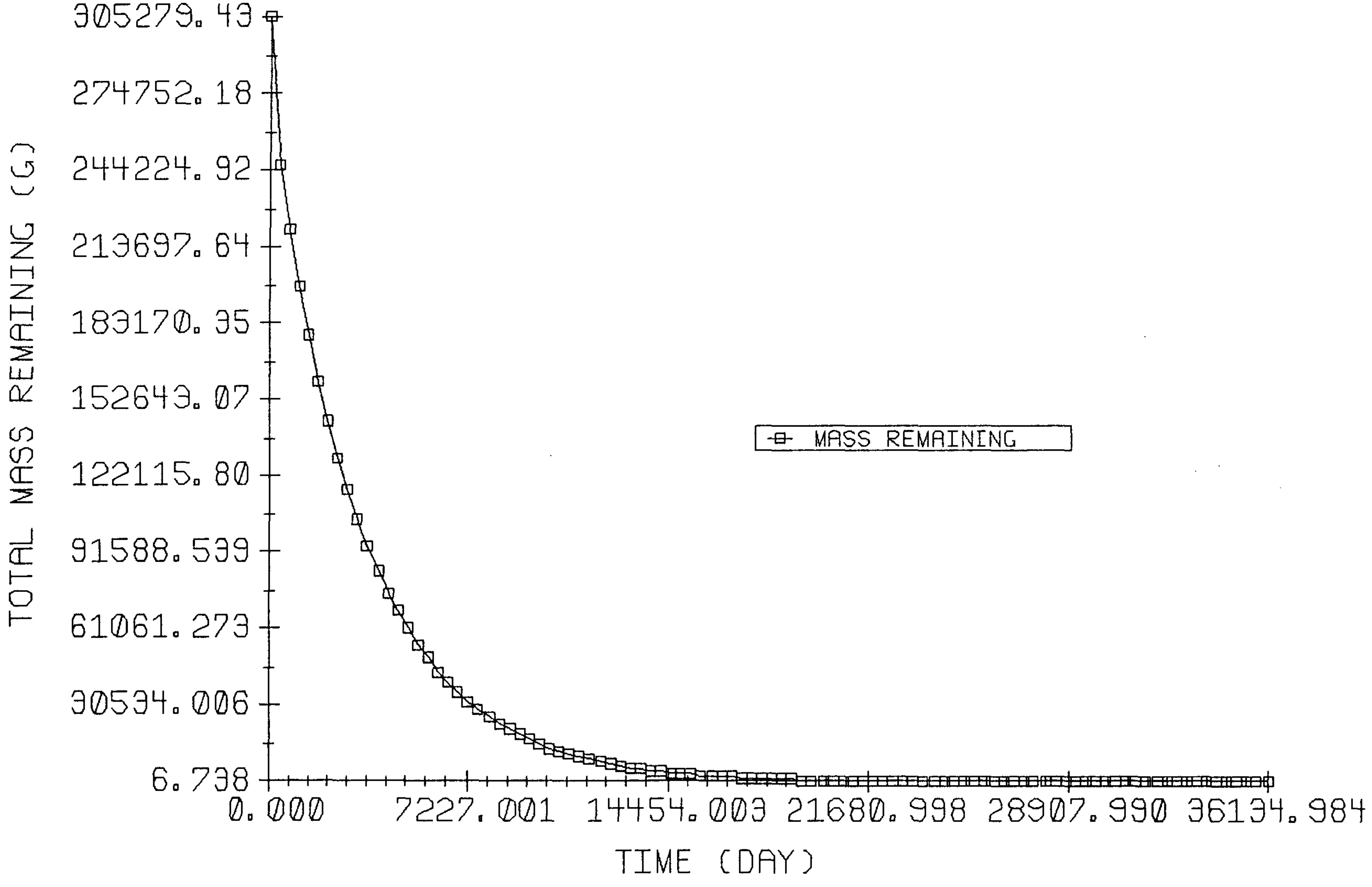
WEST PIT WATER 1K 30 SEPARATION



WEST PIT MASS LOST 1K 30 SEPARATION



WEST PIT MASS REM. 1K 30 SEPARATION



Modeling Data Entry
Carlisle State Com # 1
East Pit
Hydrocarbon Model # 1

Control Data	Entry	U / M
Deterministic	Yes	
Monte Carlo	No	
Evaporation of Chemicals	Yes	
Adsorbed Phase Biodecay	Yes	
Low Permeability Layer Below Contamination	Not Present	

Source Data		
Waste Zone Thickness	6.096	meters
Waste Zone Area	4,432	Sq. meters
Ratio of Length to Width	1:1	
Soil Thickness Above Waste Zone	0.1524	meters
Contaminant Concentration in Soil / Waste Zone	10	ppm (benzene)
Hydrocarbon Concentration in Soil / Waste Zone	1,000	ppm

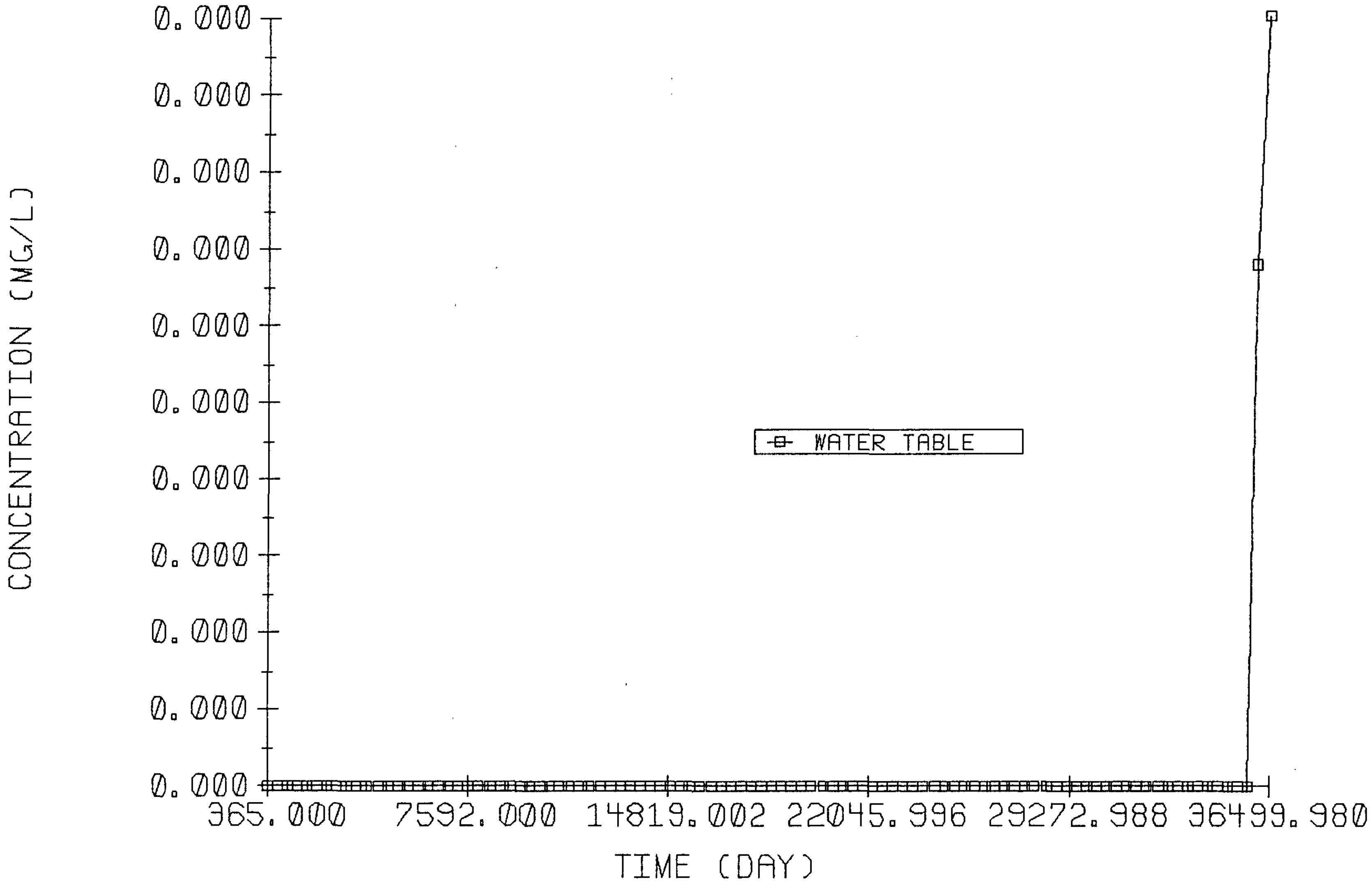
Chemical Data	
Benzene	Yes

Unsaturated Zone		
Biodecay Cooefficient	0.001	1 / day
Organic Carbon Fraction	1.00E-06	
Soil Database	Sandy Clay	
Hydrological Database	Sedimentary	
Unsaturated Zone Thickness	9.23	meter
Soil Database	Sandy Clay	
van Genuchten n	1.09	(Default)
Residual Water Content	0.01001	
Unsaturated Zone Dispersivity	0	Internally

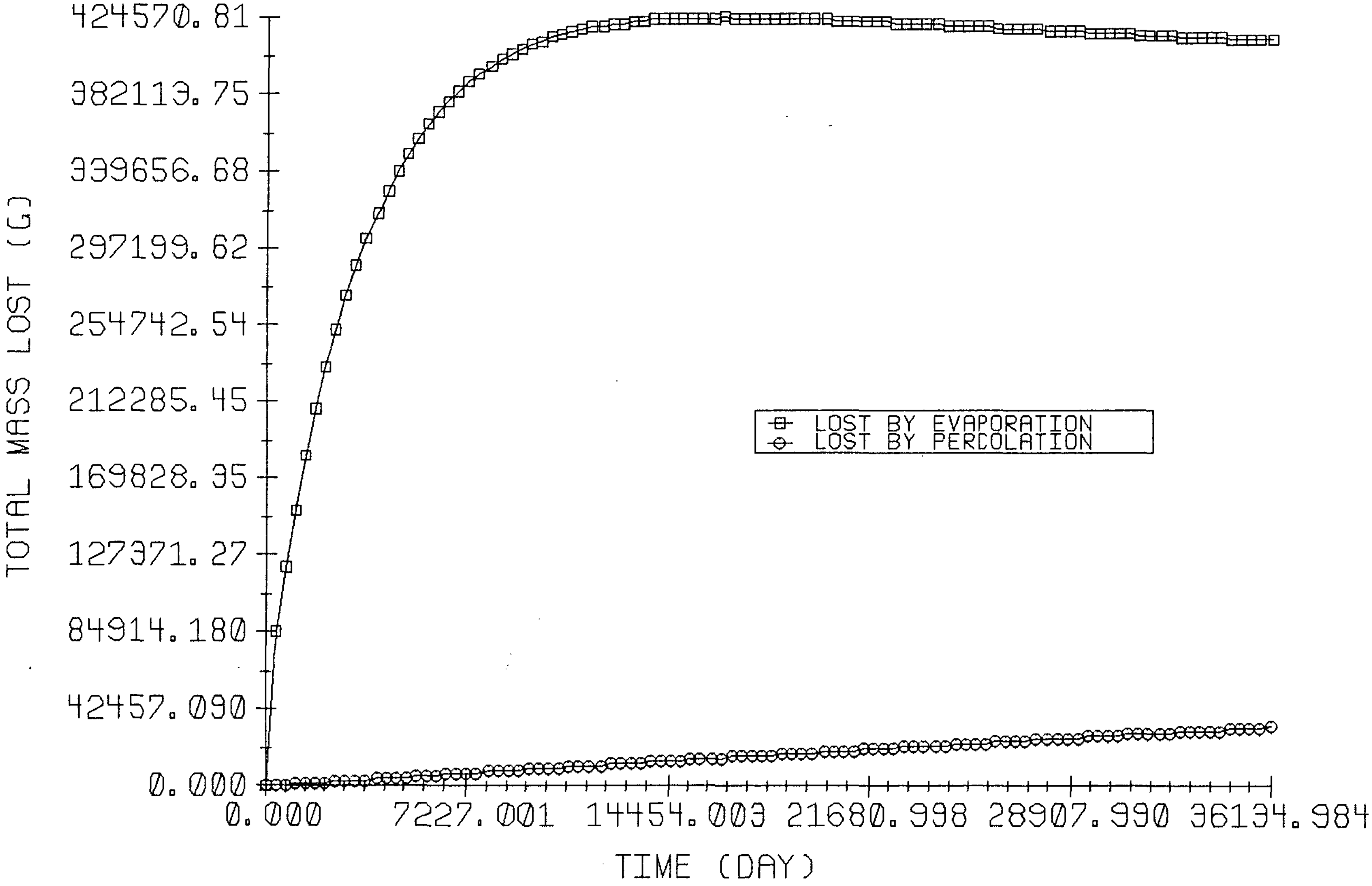
Saturated Zone		
Biodecay Cooefficient	0.001	1 / day
Aquifer Porosity	0.2	(Default)
Organic Carbon Fraction	0	Internally
Longitudinal Dispersivity	0	Internally
Ratio of Long. / Trans. Dispersivities	3	
Ratio of Trans. / Vert. Dispersivities	87	Default
Hydrological Database	Sedimentary	
Aquifer Thickness	10	meters
Aquifer Gradient	0.023	
Saturated Hydraulic Conductivity	0.13	meters / day

Net Infiltration Rate	0.00001	ft. / day

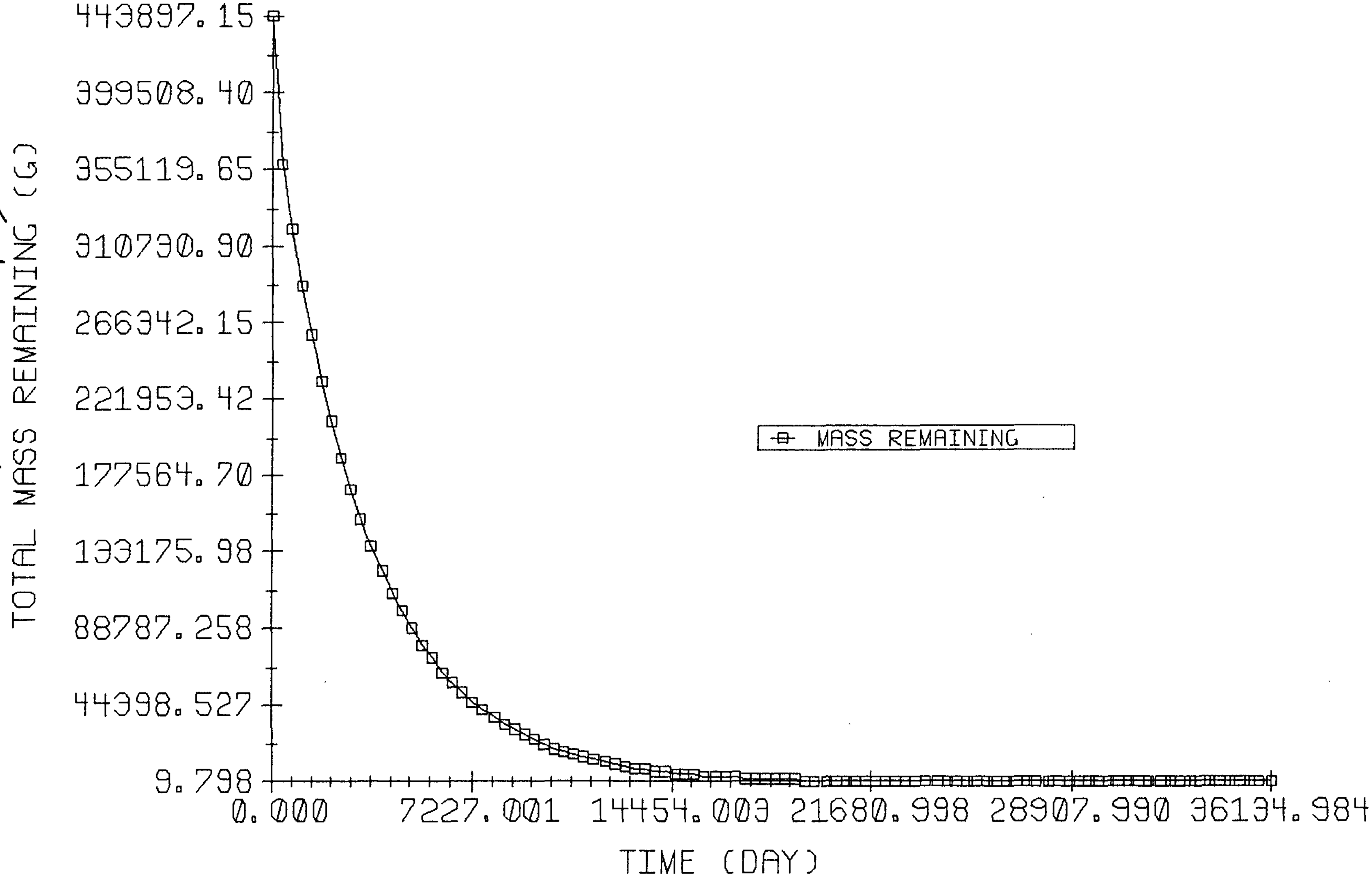
EAST PIT WATER 1K 30 SEPARATION



EAST PIT MASS LOST 1K 30 SEPARATION



EAST PIT MASS REM. 1K 30 SEPARATION



How CALCULATE TOTAL MASS?

Modeling Data Entry
Carlisle State COM # 1
West Pit
NaCl

Control Data	Entry	U / M
Deterministic	Yes	
Monte Carlo	No	
Low Permeability Layer Below Contamination	No	

Source Data		
Waste Zone Thickness	6.096	meters
Waste Zone Area	3,048	sq. meters
Ratio of Length to Width	2.43: 1	
Soil Thickness Above Waste Zone	0.1524	meter
Soluable Concentration in Soil / Waste Zone	500	ppm

Chemical Data	
NaCl	Yes

Unsaturated Zone		
Biodecay Cooefficient	0.001	1 / day
Soil Database	Sandy Clay	
Hydrological Database	Sedimentary	
Unsaturated Zone Thickness	9.23	Meters
Soil Database	Sandy Clay	
van Genuchten n	1.09	(Default)
Residual Water Content	0.01001	
Unsaturated Zone Dispersivity	0	Internally

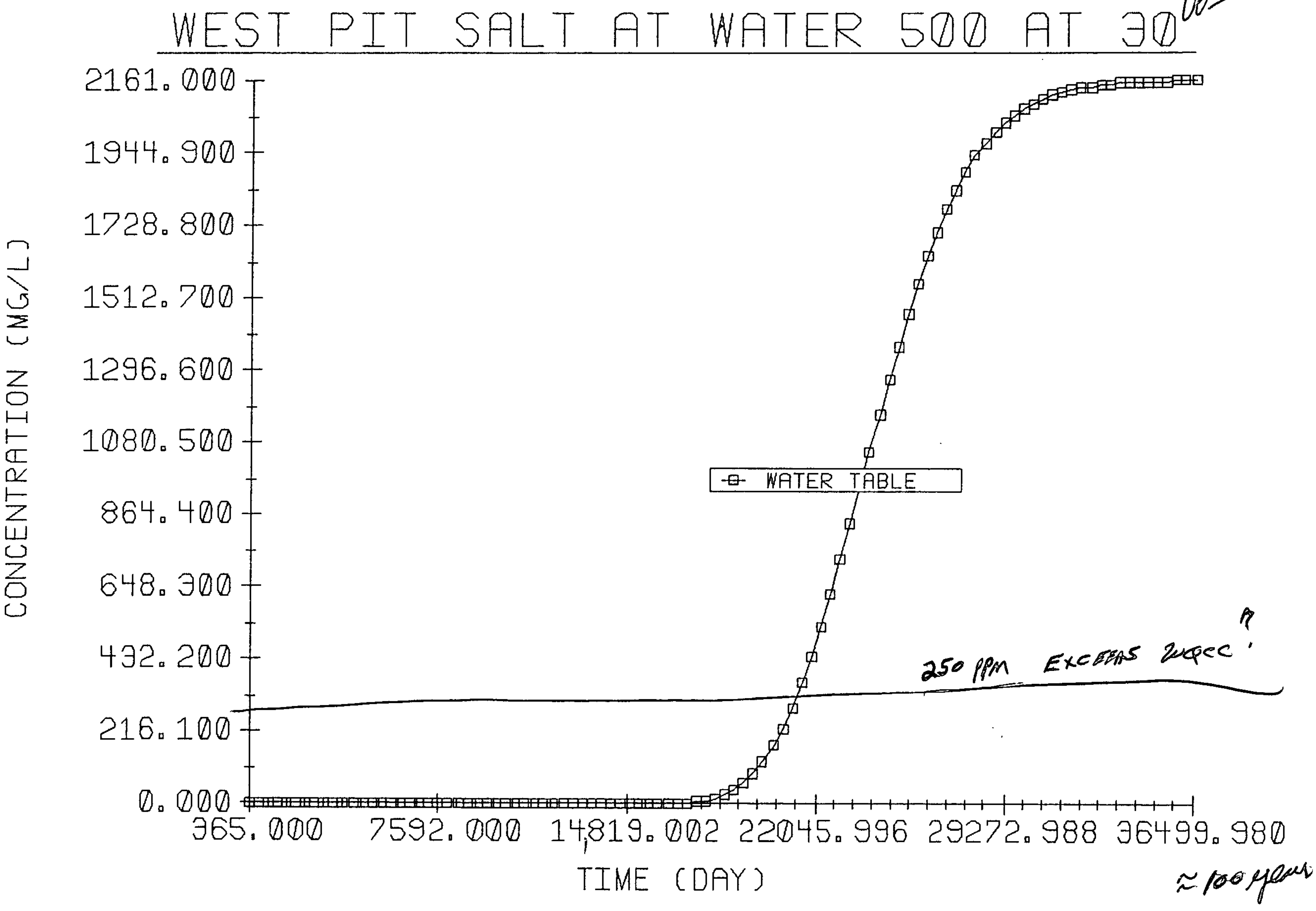
?

? %?

Saturated Zone		
Aquifer Porosity	0.2	(Default)
Longitudinal Dispersivity	0	Internally
Ratio of Long. / Trans. Dispersivities	3	
Ratio of Trans. / Vert. Dispersivities	87	
Hydrological Database	Sedimentary	
Aquifer Thickness	10	meters
Aquifer Gradient	0.023	
Saturated Hydraulic Conductivity	0.13	meters / day

Net Infiltration Rate	0.00001	ft. / day

?


WEST PIT SALT AT WATER 500 AT 30
CONCENTRATION (MG/L)
2161.000
1944.900
1728.800
1512.700
1296.600
1080.500
864.400
648.300
432.200
216.100
0.000
WATER TABLE
365.000
7592.000
14819.002
22045.996
29272.988
36499.980
TIME (DAY)
250 PPM EXCEEDS 2ndec ?
≈ 100 years

Modeling Data Entry
Carlisle State COM # 1
East Pit
NaCl

Control Data	Entry	U / M
Deterministic	Yes	
Monte Carlo	No	
Low Permeability Layer Below Contamination	No	

Source Data		
Waste Zone Thickness	6.096	meters
Waste Zone Area	4,432	sq. meters
Ratio of Length to Width	1:1	
Soil Thickness Above Waste Zone	0.1524	meter
Soluable Concentration in Soil / Waste Zone	500	ppm

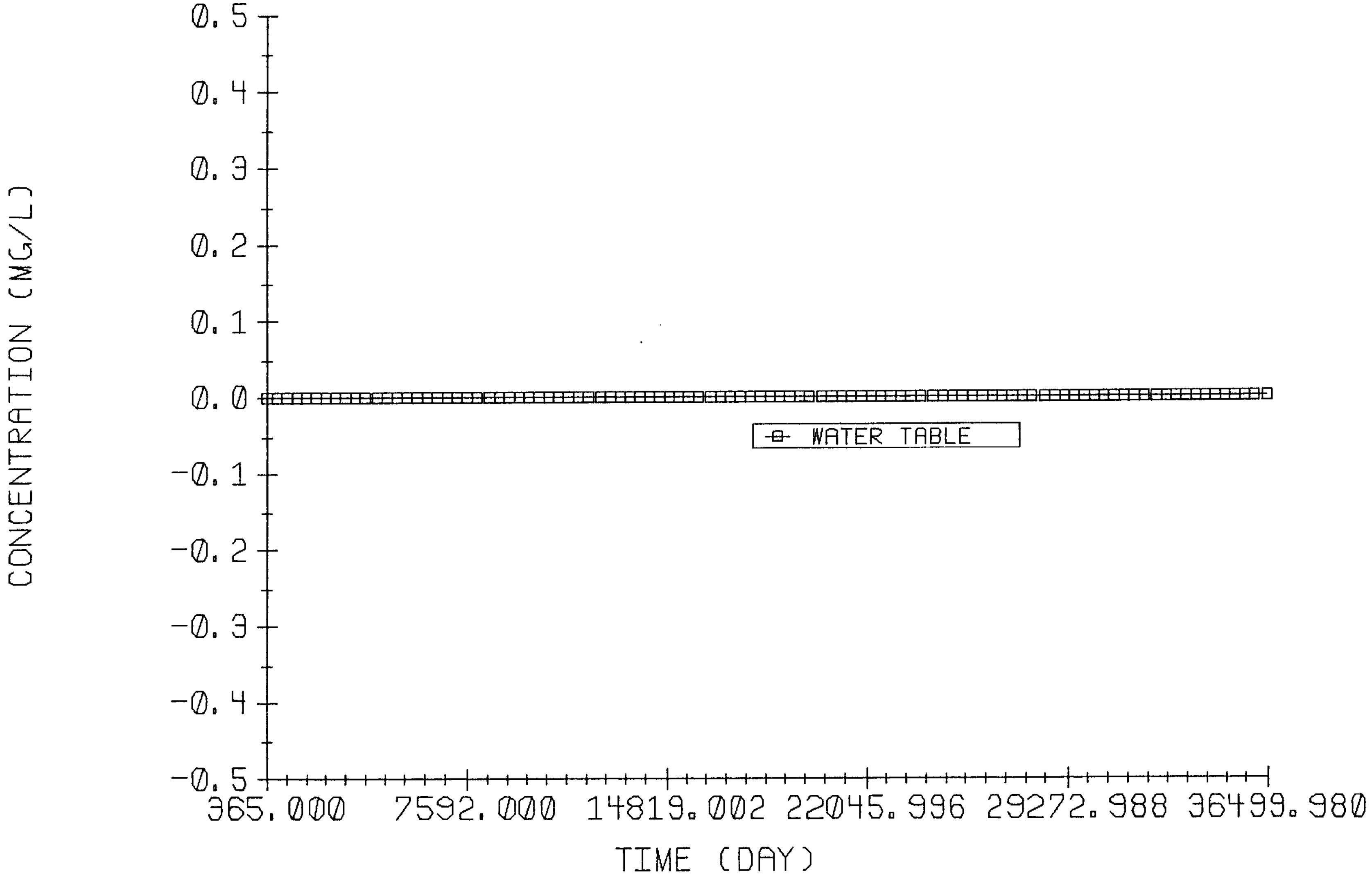
Chemical Data	
NaCl	Yes

Unsaturated Zone		
Organic Carbon Fraction	1.00E-06	
Soil Database	Sandy Clay	
Hydrological Database	Sedimentary	
Unsaturated Zone Thickness	9.23	Meters
Soil Database	Sandy Clay	
van Genuchten n	1.09	(Default)
Residual Water Content	0.01001	
Unsaturated Zone Dispersivity	0	Internally

Saturated Zone		
Aquifer Porosity	0.2	(Default)
Longitudinal Dispersivity	0	Internally
Ratio of Long. / Trans. Dispersivities	3	
Ratio of Trans. / Vert. Dispersivities	87	
Hydrological Database	Sedimentary	
Aquifer Thickness	10	meters
Aquifer Gradient	0.023	
Saturated Hydraulic Conductivity	0.13	meters / day

Net Infiltration Rate	0.00001	ft. / day

EAST PIT SALT AT WATER 500 AT 30



3. Description of VADSAT

The VADSAT model consists of three modules: 1) a source model which considers the release of chemicals from a contaminated soil zone, 2) an unsaturated or vadose zone model which considers transport of chemicals vertically through the unsaturated zone to the water table, and 3) a saturated zone model which simulates three dimensional transport of dissolved chemicals in the groundwater. These three submodels are linked and executed once for deterministic simulations or repeatedly for Monte Carlo simulations. A description of the three submodels and of the Monte Carlo analysis will be given in this chapter.

3.1 Source Submodel

Waste constituents are assumed to occur within a specified interval which may start at or below the ground surface and extend to some depth above or below the water table. The areal extent of the contaminated soil zone, which is subsequently referred to as the "waste zone", is described as a rectangular region in plan view. The waste zone may be engineered (e.g. landspreading or burial) or it may represent a region of residual organic liquid saturation following a spill or leak. Two types of chemical species are considered: (1) inorganic salts and (2) organic species in an oily waste or any nonaqueous liquid phase (denser or lighter than water). Since salts and oily waste will behave differently, a different source submodel is used for each. The two locations of the waste zones considered are: 1) source above the water table, and 2) source below the water table.

3.1.1 Source Above the Water Table

Source for salts

The assumption used in modeling inorganic species (salts) is that the concentration of the species that passes through the waste zone is constant and equal to an equilibrium solubility-controlled value. Under this assumption, the waste zone acts as a constant strength source of contamination for a period of time, t_o [T], after which the concentration of leachate is zero. The duration of the source is given by

$$t_o = \frac{M_t}{q_u C_S^o} \tag{3.1}$$

where M_t is the total mass of the species in the waste zone per unit area [M L^{-2}], q_u is the net recharge rate [L T^{-1}] and C_S^o is the dissolved concentration of the species [ML^{-3}]. The total species mass per area in the water zone is given by

$$M_t = \rho_b L_w F_s \tag{3.2a}$$

where ρ_b is the waste zone dry bulk density [M L^{-3}], L_w is the thickness of the waste zone [L], and F_s is the mass of salts in the waste zone per mass of total solids [M M^{-1}]. Soil bulk density is computed from soil porosity by

$$\rho_b = \rho_s(1 - \phi) \tag{3.2b}$$

where ρ_s is the particle density, which is assumed to be 2.65 g cm^{-3} and ϕ is the waste zone porosity, assumed to be the same as that of the unsaturated zone porosity, ϕ_u. Assuming all of the salts are dissolved, the mass fraction of salts is related to the dissolved concentration by

$$F_s = \frac{\phi C_s^o}{\rho_b} \tag{3.3}$$

Data requirements for the inorganic source model are C_s^o, M_t, L_w, ϕ_u and q_u.

Nonaqueous liquid

Depletion of organic species, such as benzene or other potential contaminants in a nonaqueous liquid (e.g., crude oil, residual hydrocarbon, oily waste, solvent, etc.) over time is assumed to occur due to combined effects of water percolating through the waste zone and to evaporation of volatile components from the soil surface. A molar balance for compound i may be written as

$$\frac{dm_i}{dt} = -\frac{J_i^w}{W_i} - \frac{J_i^v}{W_i} \tag{3.4}$$

where m_i is the number of moles of i per unit area in the hydrocarbon [moles L^{-2}], W_i is the molecular weight of i [M moles^{-1}], J_i^w is the rate of mass depletion per area due to percolating water [ML^{-2} T^{-1}], J_i^v is the rate of mass depletion per area due to volatilization

[M L^{-2} T^{-1}] and t is time. The aqueous loss is assumed to be purely convective and is given by

$$J_i^w = q_u C_i^w \tag{3.5}$$

where q_u is the net recharge rate [L T^{-1}] and C_i^w is the aqueous concentration of i [M L^{-3}], which is related to the composition of the hydrocarbon by

$$C_i^w = x_i S_i \tag{3.6}$$

where S_i is the aqueous solubility of pure component i [M L^{-3}], and x_i is the mole fraction of i in the hydrocarbon [moles moles^{-1}]. The mole fraction may be written as

$$x_i = \frac{m_i W_H}{\rho_b L_w F_H} \tag{3.7}$$

where m_i is the moles of species i per area [moles L^{-2}], m_H is the total moles of hydrocarbon per unit area [moles L^{-2}], W_H is average molecular weight of hydrocarbon [M mole^{-1}], ρ_b is the bulk density of the waste zone [M L^{-3}], L_w is the thickness of the waste zone [L], and F_H is the mass of hydrocarbon per mass of solids in the waste zone [M M^{-1}].

The diffusive vapor loss rate at the soil surface is computed assuming a linear concentration drop from the waste zone to the soil surface as

$$J_i^v = D_i^v \frac{C_i^v}{L_d} \tag{3.8}$$

where D_i^v is the gas phase diffusion coefficient for i in the porous medium [L^2 T^{-1}], C_i^v is the vapor concentration in the waste zone [M L^{-3}], and L_d is the diffusion path length [L], which is taken as $L_c + L_w/2$, where L_c is the waste cover thickness. For land-spread waste, $L_c = 0$. The effective diffusion coefficient is estimated from the free gas diffusion coefficient, D_i^{vo}, using the Millington-Quirk (1961) model as

$$D_i^v = (\phi - \theta)^{10/3} \phi^{-2} D_i^{vo} \tag{3.9}$$

where ϕ and θ are the porosity and volumetric water content of the cover, respectively, which are assumed to be the same as in the underlying soil. In the case of lined pits, a fine grained liner is assumed to restrict contaminant loss from the waste zone which is liquid saturated. The gas phase concentration in the waste zone is related to the aqueous concentration via Henry's law as

$$C_i^v = H_i C_i^w \tag{3.10}$$

where H_i is the dimensionless Henry's constant for species i. Combining (3.4) - (3.10) yields

$$\frac{dm_i}{dt} = -\beta_i m_i \tag{3.11}$$

where β_i is a waste zone depletion coefficient given by

$$\beta_i = \frac{q_u W_H S_i}{\rho_b L_w F_H W_i} + \frac{D_i^v H_i W_H S_i}{\rho_b L_d L_w F_H W_i} \tag{3.12}$$

The first term in (3.12) represents aqueous losses from the waste zone and the second term describes vapor losses. Assuming that F_H does not change significantly with time, i.e. that the waste consists primarily of low solubility components, (3.11) may be solved analytically to obtain

$$m_i = m_i^o \, exp(-\beta_i t) \tag{3.13}$$

where m_i^o is the initial moles of i per area. Output information on the time for source depletion is computed based on the operational definition of source depletion at the time when $m_i / m_i^o = 0.01$, hence $t_o = 4.6/\beta_i$. The aqueous concentration will likewise decrease exponentially with time according to

$$C_i = C_i^w \, exp(-\beta_i t) \tag{3.14}$$

where C_i^w is the initial aqueous concentration of species i given by

$$C_i^w = \frac{f_i^o \, W_H \rho_i S_i}{W_i \rho_H} \tag{3.15}$$

where f_i^o is the initial volume fraction of component i in the hydrocarbon, ρ_i is the density of component i, and ρ_H is the average density of hydrocarbon.

Data requirements for the organic source submodel are S_i, H_i, W_i, ρ_i, D_i^{vo}, f_i^o, W_H, ρ_H, F_H, L_w, L_c, ρ_b, ϕ and θ. The compound solubility, Si, density, ρ_i, molecular weight, Wi, Henry's constant, Hi, free air diffusion coefficient, D_i^{vo}, and the initial volume fraction in the waste, f_i^o, are compound specific input parameters. Soil bulk density, ρ_b, Soil water content in the cover above the waste zone (if present) is assumed to be the same as that in underlying soil, the estimation of which is described later.

3.1.2 Source Below the Water Table

For the analysis in this section, the waste zone is assumed to be located below the water table. The mass loading rate to groundwater is computed for the inorganic and organic waste types directly, and transport in the unsaturated zone is not considered.

Source for salts

As discussed in section 3.1.1, the waste zone is assumed to act as a constant strength source of contamination for a period of time, t_o [T], after which the concentration of leachate is zero. Assuming horizontal groundwater flow through the waste zone, the duration of the source is given by

$$t_o = \frac{M_T}{q_s L_w B C_S^o} \tag{3.16}$$

where M_T is the total mass of the species in the waste zone [M], q_s is the Darcy velocity in the x direction [L T^{-1}] and B is the width of the waste zone [L] perpendicular to the groundwater flow. The total species mass is given by

$$M_T = \rho_b L_w B A F_s \tag{3.17}$$

where ρ_b is the waste zone dry bulk density [M L^{-3}], L_w is the thickness of the waste zone [L], A is the length of the waste zone [L], and M_T is the total species mass in the waste zone [M]. The mass loading rate [MT^{-1}] into the groundwater is

$$M_o = q_s B L_w C_S^o \ . \tag{3.18}$$

Nonaqueous liquid

Assuming horizontal flow through the waste zone, a mass balance equation for the total mass of a species in a hydrocarbon phase of the waste zone can be written as

$$\frac{dM_T}{dt} = -q_s B L_w C_T \tag{3.19a}$$

$$\frac{dM_T}{dt} = -q_s M_T / A\theta \qquad (3.19b)$$

$$\frac{dM_T}{dt} = -\beta M_T \qquad (3.19c)$$

where C_T is the aqueous phase concentration of a soluble species [ML^{-3}] in the waste zone at time t, and β is a depletion coefficient for the waste zone below the water table given by

$$\beta = q_s / A\theta \qquad (3.20)$$

The aqueous phase concentration will decrease exponentially with time according to

$$C_T = C_i^w \, exp(-\beta t) \qquad (3.21)$$

where C_i^w is given by (3.15). The mass loading rate [MT^{-1}] into the groundwater at time *t* is

$$M_o = q_s B L_w C_T. \qquad (3.22)$$

3.2 Unsaturated Zone Transport Submodel

Transport in the unsaturated zone is modeled from the bottom of the waste zone to the water table assuming negligible horizontal spreading. Linear adsorption and first order decay reactions are considered for reactive chemicals. The governing equation for one dimensional transport in the unsaturated zone may be written

$$R_{ui}\frac{\partial C_i}{\partial t} = D_u \frac{\partial^2 C_i}{\partial x^2} - V_u \frac{\partial C_i}{\partial x} - \mu_{u_i} C_i \qquad (3.23)$$

where C_i is the concentration of component *i* in the aqueous phase [ML^{-3}], D_u is the dispersion coefficient in the unsaturated zone [L^2T^{-1}], V_u is the pore water velocity in the unsaturated zone [LT^{-1}], μ_{u_i} is a first-order decay coefficient for component *i* in the unsaturated zone [T^{-1}], *x* is distance [L], *t* is time [T] and R_{ui} is the retardation factor (explained later).

3.2.1 Solution for Inorganic Transport

Salts are modeled as nonadsorbing conservative solutes with $R_{u_i} = 1$ and $\mu_{u_i} = 0$. The relevant initial and boundary conditions for (3.23) to obtain flux concentrations (*Parker and van Genuchten*, 1984) for salt transport are

$$C_i(x, 0) = 0 \tag{3.24a}$$

$$C_i(0, t) = C_S^o \qquad 0 < t \leq t_o \tag{3.24b}$$

$$C_i(0, t) = 0 \qquad t > t_o \tag{3.24c}$$

$$\frac{\partial C_i}{\partial x}(\infty, t) = 0 \tag{3.24d}$$

The solution is given by *van Genuchten and Alves* (1982) as

$$C_i(x, t) = C_S^o\, E(x, t) \qquad 0 < t \leq t_o \tag{3.25a}$$

$$= C_S^o\, [E(x, t) - E(x, t - t_o)] \qquad t > t_o \tag{3.25b}$$

where

$$E(x, t) = \frac{1}{2} erfc\left[\frac{x - V_u t}{2(D_u t)^{1/2}}\right] + \frac{1}{2} exp\left[\frac{V_u x}{D_u}\right] erfc\left[\frac{x + V_u t}{2(D_u t)^{1/2}}\right] \tag{3.25c}$$

Since the unsaturated zone solution gives the flux concentration, the mass flux of contaminant entering the groundwater may be computed as

$$M_i(t) = q_u A C(L_u, t) \tag{3.26}$$

where $M_i\,(t)$ is the mass flux at the water table as a function of time [MT^{-1}], q_u is the unsaturated zone Darcy velocity (net recharge rate), A is the source area [L^2], and $C(L_u, t)$ is the concentration computed from (3.25) at a distance $x = L_u$ where the latter is the distance from the bottom of the waste zone to the water table.

3.2.2 Solution for Organic Chemical Transport

For the case of organic contaminant transport, the relevant initial and boundary conditions for (3.23) are

$$C_i(x, 0) = 0 \tag{3.27a}$$

$$C_i(0, t) = C_i^o\, exp(-\beta_i t) \tag{3.27b}$$

$$\frac{\partial C_i}{\partial x}(\infty, t) = 0 \tag{3.27c}$$

The solution is given by *van Genuchten and Alves* (1982) as

$$C_i(x, t) = C_i^o \, exp(-\beta_i t) B(x, t) \tag{3.28a}$$

where

$$B(x, t) = \frac{1}{2} exp\left[\frac{(V_u - w)x}{2D_u}\right]\left(erfc\left[\frac{R_{u_i}x - wt}{2\left[D_u R_{u_i} t\right]^{1/2}}\right]\right)$$

$$+ \frac{1}{2} exp\left[\frac{(V_u + w)x}{2D_u}\right] erfc\left[\frac{R_{u_i}x + wt}{2\left[D_u R_{u_i} t\right]^{1/2}}\right] \tag{3.28b}$$

and

$$w = V_u\left[1 + \frac{4D_u R_{u_i}}{V_u^2}[\mu_{u_i} - \beta_i]\right]^{1/2} \tag{3.28c}$$

The chemical flux at the water table is computed from the flux concentration, water flux and source area in the same manner as in the salt model.

3.2.3 Unsaturated Zone Pore Water Velocity

The actual flow behavior in the vadose zone can be quite complicated when one considers the effects of spatial heterogeneity and transient boundary conditions. However, in the present analysis, we are concerned with simulating the average conditions over long term periods. In light of this objective, it was decided to simplify the flow calculations, utilizing a unit hydraulic gradient approximation. This approach has been proven to work reasonably well even in moderately heterogeneous soils under steady flow conditions (*Yeh*, 1989). The major simplification obtained from this assumption is that the pressure head in the soil profile is constant, as is the moisture content. Darcy's equation for the unit gradient case may be written as

$$q_u = k_r K_{su} \tag{3.29}$$

where K_{su} is the saturated hydraulic conductivity of the unsaturated zone [L T^{-1}], k_r is the relative permeability [L^0], and q_u is the net recharge rate [L T^{-1}]. The relative permeability will depend on the volumetric water content, θ, in a manner described by the *Brooks-Corey* (1964) model as

$$k_r = \left[\frac{\theta - \theta_r}{\phi_u - \theta_r}\right]^{\gamma} \tag{3.30}$$

where ϕ_u is the porosity in the unsaturated zone, θ_r is an "irreducible" water content and γ is a pore size distribution parameter. Owing to the availability of a large database on statistical distributions of van Genuchten model parameters (*Carsel and Parrish*, 1988), we relate the Brooks-Corey exponent to the van Genuchten parameter n following *Lenhard et al.* (1989) as

$$\gamma = 3 + \frac{2}{(n-1)(1-0.5^{n/(n-1)})} \tag{3.31}$$

Using (3.29 and 3.30), we calculate the water content, which is used in turn to estimate the pore water velocity, V_u, as

$$V_u = \frac{q_u}{\theta} \tag{3.32}$$

If $q_u > K_{su}$ for a given set of parameters, the flux q_u is set equal to K_{su} assuming the excess flow will be diverted to runoff, and ϕ is equal to the unsaturated zone porosity, ϕ_u. If a soil layer of low permeability occurs above the waste zone, the analysis proceeds as above, except that the maximum water flux is set equal to the saturated hydraulic conductivity of the low permeability zone, $K_{sw}[LT^{-1}]$, rather than that of the soil.

3.2.4 Adsorption and Decay of Organics

The retardation factor for organic species is computed from

$$R_{u_i} = 1 + \frac{\rho_b f_{oc} k_{oc_i}}{\theta} \tag{3.33}$$

where f_{oc} is the ratio of soil organic carbon to total dry soil mass [M M^{-1}] and k_{oc} is the organic carbon normalized partition coefficient [L^3 M^{-1}]. The model requires f_{oc} and k_{oc_i} to be input.

Considering decay of organic species that may occur in the dissolved or absorbed state, the decay coefficient may be defined by

$$\mu_{u_i} = \mu_{uw}\theta + F\mu_{uw}\rho_b f_{oc} k_{oc_i} \tag{3.34}$$

where μ_{uw} is the decay coefficient for aqueous phase species and F is a factor that relates aqueous phase decay to adsorbed phase decay. VADSAT restricts the user to either specify $F = 0$ (no solid phase decay) or $F = 1$ (solid and dissolved phase decay coefficients are equal).

The decay of organic species is a complex process that may often be satisfactorily approximated as an apparent first-order reaction. Field observations of transport from which apparent first order decay coefficients may be inferred are not available in great numbers. *Chiang et al.* (1989) modeled the transport and attenuation of BTX in an aquifer in Michigan. Based on a mass balance analysis of field data over time, an apparent first order decay coefficient for benzene of approximately 0.01 day^{-1} was calculated. Data from a controlled field experiment by *Barker et al.* (1987) indicates a rate constant for benzene of about 0.008 day^{-1}. The California Office of Underground Storage Tanks recommends using 0.002 day^{-1} as a conservative value for benzene decay.

3.2.5 Dispersion in the Unsaturated Zone

The dispersion coefficient in the unsaturated zone is regarded as a linear function of the pore water velocity, V_u, as

$$D_u = \alpha_L V_u \tag{3.35}$$

where α_L is the unsaturated zone dispersivity $[L]$. The latter may be treated as a function of the distance from the source to the water table. Based on data from *Gelhar et al.* (1985) on field measurements of dispersion in the unsaturated zone, the following bilinear model was obtained to describe the scale-dependent dispersivity

$$ln\alpha_L = -4.933 + 3.811 ln\, x \qquad x \leq 2m \tag{3.36a}$$

$$ln\alpha_L = -2.727 + 0.584 ln\, x \qquad x > 2m \tag{3.36b}$$

where x is the distance from the source to the observation location (i.e., the water table). Variability in $ln\,\alpha_L$ is approximately normally distributed with a standard deviation of 1.18 for $x \leq 2m$ and of 0.34 for $x > 2m$.

3.3 Saturated Zone Transport Submodel

3.3.1 Horizontal Plane Source Transport Model

Leaching of chemicals from the unsaturated zone will result in an areally distributed horizontal plane source at the water table. Treating the source as a point source or as a partially penetrating vertical plane source, as employed in certain models, will yield a less accurate representation of the chemical distribution, particularly at locations near the source. Furthermore, due to limited vertical mixing near a chemical source, consideration must generally be given to groundwater transport in three dimensions. An analytical three-dimensional, horizontal plane source solute transport model (HPS) developed by *Galya* (1987) is used to simulate transient saturated zone transport. The model considers three-dimensional convective-dispersive transport with linear adsorption and first-order decay in a one-dimensional planar regional groundwater flow field. For a uniform velocity field, chemical transport in an aquifer with uniform hydrogeologic properties can be described by

$$R_{s_i}\frac{\partial C_i}{\partial t} = D_x\frac{\partial^2 C_i}{\partial x^2} + D_y\frac{\partial^2 C_i}{\partial y^2} + D_z\frac{\partial^2 C_i}{\partial z^2} - \frac{q_s \partial C_i}{\phi_s \partial x} - \mu_{s_i} C_i + \frac{Q_i(x, y, z)}{\phi_s} \tag{3.37}$$

where C_i is the aqueous concentration of species i in the aquifer; q_s is the Darcy velocity in the saturated zone in the down-gradient (x) direction; t is time; D_x, D_y and D_z are dispersion coefficients in the x, y and z directions, respectively; R_{s_i} is the retardation factor for species i in the saturated zone; ϕ_s is the saturated zone porosity, μ_{s_i} is a first-order decay coefficient for mass loss in the saturated zone; and Q_i is a source term for contaminant $[MT^{-1}L^{-3}]$ which is nonzero over a finite rectangular area at the water table and zero elsewhere. Initial and boundary conditions are stipulated by

$$C_i = 0 \quad for \quad t = 0 \tag{3.38a}$$

$$C_i = 0 \quad for \quad x, y = \pm\infty \tag{3.38b}$$

$$D_z\frac{\partial C_i}{\partial z} = 0 \quad for \quad z = 0 \tag{3.38c}$$

$$D_z\frac{\partial C_i}{\partial z} = 0 \quad for \quad z = H \tag{3.38d}$$

where H is the aquifer thickness and $z = 0$ represents the water table. The solution of (3.37) is obtained by the superposition of Green's function for x, y and z directions. The primitive form of the solution is given by

$$C_i = \frac{1}{\phi_s R_{s_i}} X_o(x,t) Y_o(y,t) Z_o(z,t) T_i(t) \tag{3.39}$$

where X_o, Y_o and Z_o are the Green's function solutions to the convection-dispersion equation in x, y and z directions, and T_i is a first-order decay function. Time convolution yields a solution for the concentration of the chemical at any point in space and time due to an arbitrary time-dependent mass loading rate $M_i(t)$ as

$$C_i(x,y,z,t) = \frac{1}{\phi_s R_{s_i}} \int_0^t M_i(\tau) X_o(x, t-\tau) Y_o(y, t-\tau) Z_o(z, t-\tau) T_i(t-\tau) d\tau \tag{3.40}$$

where τ is a dummy variable for integration and $M_i(t)$ is given from the unsaturated zone model. The derivation of Green's functions for the x, y and z directions is described by *Galya* (1987).

3.3.2 Saturated Zone Model Parameters

Dispersion coefficients in the saturated zone are described by expressions of the form

$$D_x = \alpha_x q_s / \phi_s \tag{3.41a}$$

$$D_y = \alpha_y q_s / \phi_s \tag{3.41b}$$

$$D_z = \alpha_z q_s / \phi_s \tag{3.41c}$$

where α_x, α_y and α_z are dispersivities in the x, y and z directions. Dispersivities in the saturated zone may be estimated from the database of *Gelhar et al.* (1985). The longitudinal dispersivity, α_x, is observed to be a function of distance from the source which may be described by the empirical expression

$$ln\alpha_x = -3.795 + 1.774 ln\ x - 0.093 (ln\ x)^2 \tag{3.42}$$

where x is the distance from the source in the direction of the flow field. Variability in $ln\alpha_x$ is assumed to be normally distributed with a standard deviation of 1.58 as determined from the results of *Gelhar et al.* (1985). Transverse dispersivities, α_y and α_z, are described by

$$\alpha_y = \frac{\alpha_x}{\tau_1} \tag{3.43a}$$

$$\alpha_z = \frac{\alpha_y}{\tau_2} \tag{3.43b}$$

where τ_1 and τ_2 are taken as lognormally distributed random variables. Field data indicate the dispersion ratio τ_1 has a mean of 3 with a standard deviation of 1, while τ_2 has a mean value of 87 with a standard deviation of 31 (*API*, 1987).

To ensure that the saturated zone concentration below the source does not exceed the concentration leaving the unsaturated zone, the vertical dispersivity is subjected to the following constraint for an unsaturated zone source

$$\alpha_z \geq \frac{q_u^2 L}{q_s^2} \tag{3.44a}$$

and for a source below the water table, the constraint is

$$\alpha_z \geq \frac{L_w^2}{L} \tag{3.44b}$$

where L_w is the waste zone thickness below the water table, q_u is the unsaturated zone Darcy velocity, q_s is the saturated zone Darcy velocity, and L is the length of the source parallel to the flow direction. A message is printed in the output file when the vertical dispersivity is adjusted by (3.44).

Additional aquifer properties required by the model are aquifer thickness, H, aquifer porosity, ϕ_s, aquifer organic carbon content, f_{oc_s}, and aquifer Darcy velocity in the direction of the regional gradient, q_s. Component-specific properties for organic species transport are the organic carbon normalized partition coefficient, k_{oc_i}, and the first order decay coefficient in the saturated zone. The retardation factor is computed from (3.33) in the same manner as for the unsaturated zone, except that the water content in the saturated zone is replaced by the saturated zone porosity.

To convert from mass fluxes per area from the unsaturated zone model to total mass fluxes and to define the source distribution in space, the user must specify the source area, A, and the ratio of source length in the direction of flow to the width, $S_R = L/W$. Distributions of A and S_R are regarded as log-normal.

3.3.3 Evaluation of Maximum Concentration at Receptor

In order to provide a conservative assessment of the effects of contaminant leaching on groundwater, it is of interest to determine the peak concentration at receptor locations in the saturated zone. If the time elapsed from placement of waste in the unsaturated zone to the time of peak concentration at the receptor is t_{max}, then it is necessary to compute the receptor concentration at this time only. However, since the source is transient in nature, even though the saturated zone solution may only be needed for t_{max}, the concentration exiting the unsaturated zone must be known as a function of time from $t = 0$ to t_{max} to define the temporal source function for the saturated zone model. For the purpose of estimating the duration of the unsaturated zone analysis, a conservative (i.e., high) first estimate of t_{max} is taken as the mean travel time through the unsaturated and saturated zones times a factor to account for tailing due to dispersion. For the case of salts, which are not adsorbed, we define this estimate by

$$t_1 = \frac{4L_s\phi_s}{q_s} + \frac{4L_u\phi_u}{q_u} \qquad (3.45a)$$

where L_u and L_s are travel distances in unsaturated and saturated zones, respectively, and other terms are as previously defined. For the case of oily wastes, a similar procedure is used, except that retardation is considered so that

$$t_1 = \frac{4L_s\phi_s R_{s_i}}{q_s} + \frac{4L_u\phi_u R_{u_i}}{q_u} \qquad (3.45b)$$

The duration of the unsaturated zone analyses may be reduced in some instances. If the source is depleted by time $t_2 < t_{max}$, then the unsaturated zone solution need only be computed for the interval $t = 0$ to t_2. For the case of salt transport, which has a pulse-type input function at the source, the duration of nonzero effluent concentrations from the unsaturated zone may be estimated as the duration of the pulse plus the travel time through the unsaturated zone times a factor to account for dispersion. The computational procedure for salts is

$$t_2 = t_o + \frac{4L_u\phi_u}{q_u} \qquad (3.46a)$$

where t_o is the duration of the pulse at the source defined by (3.1). For organic chemical transport, a similar procedure is employed, but with the duration of the exponentially decaying source taken as the time when the source mass has decreased by a factor e^{-6}. The expression for an oily waste source is

$$t_2 = \frac{6}{\beta_i} + \frac{4L_u\phi_u R_{u_i}}{q_u} \qquad (3.46b)$$

where β_i is the source decay parameter for species i given by (3.12). The final time for the unsaturated zone analyses is taken to be $t_u = minimum\ (t_1, t_2)$ where t_1 and t_2 are computed from the appropriate expressions for salts or oily waste.

Concentrations leaving the unsaturated zone are computed over the time period t_u in 300 equal intervals. Concentrations obtained from the model at times $t = (t_u /300, 2\ t_u /300, ..\ t_u)$ are stored in an array and subsequently scanned by a search algorithm to determine the time, t_u , at which the concentration at the water table reaches a maximum. The effluent concentration is taken to be zero for $t > t_u$

An improved estimate is next made of the time, t_{Rmax}, at which the maximum concentration occurs at a receptor in the saturated zone as

$$t_{Rmax} = t_u + t_s \tag{3.47}$$

where t_s is the time for the peak concentration to propagate from the point of entry into the groundwater to the receptor. An estimate of t_s is made by computing the time required to propagate a *dirac* pulse in the direction of flow. The solution to the one dimensional convection-dispersion equation for a dirac pulse is

$$C_i(x, t) = \frac{x^2}{V_R t(4\pi D_R t)^{1/2}} exp \frac{-(x - V_R t)^2}{4 D_R t} \tag{3.48a}$$

where $D_R = D_x / R_{si}$ and $V_R = q_s / \phi_s R_{si}$. For a given set of x, D_R and V_R values, the time corresponding to the maximum for the dirac solution may be obtained by setting $\partial C_i / (\partial t) = 0$, which yields

$$exp\left(\frac{-(x - V_R t)^2}{4 D_R t}\right)\left(\frac{-3 V_R^2 x^2 t^2 + (2 V_R x^3 - 6 D_R x^2) t + x^4}{8 D_R V_R t^3 (\pi D_R t)^{1/2}}\right) = 0$$

(3.48b)

For (3.48b) to hold, it is sufficient that

$$-3 V_R^2 x^2 t^2 + (2 V_R x^3 - 6 D_R x^2) t + x^4 = 0 \ , \tag{3.49}$$

which is a quadratic polynomial in t for given x, D_R and V_R.The positive root of this polynomial yields an estimate of t_s. This value is employed in (3.47) to obtain an approximation of the actual time, t_{max}, at which the receptor concentration reaches a maximum.

Due to the gradual release characteristics of organic contaminants from oily wastes, the peaks are generally rather broad and receptor concentrations computed at the estimated time t_{Rmax} generally yield accurate values for the peak receptor concentration. For the case of salt migration, the peak is usually narrower, so the concentration computed at t_{Rmax} may underestimate the actual peak. Therefore, in the latter case, the peak concentration is refined using a search algorithm starting from the value at t_{Rmax}. The golden ratio algorithm (*Forsythe et al.*, 1977) is employed to find the peak receptor concentration by progressively bisectioning the initial time interval, (i.e., by calculating and comparing the concentrations corresponding to times at the beginning and at the end of each time interval until the last two consecutive concentrations differ by a specified tolerance). Upon satisfying the convergence criteria, t_{max} as taken at the midpoint of the final time interval.

The highest 70-year exposure level at a receptor location is computed as the average concentration over a period from 35 years before to 35 years after the peak concentration. Using a three-point trapezoid rule integration, the 70-year exposure concentration, C_{70}, is computed as

$$C_{70} = \frac{1}{4}C(t_{max} - 35) + \frac{1}{2}C(t_{max}) + \frac{1}{4}C(t_{max} + 35) \qquad (3.50)$$

where $C(t)$ denotes the computed receptor concentration at time t in years.

Verification of the correctness and accuracy of the computer model VADSAT, which implements the coupled source zone, vadose zone and saturated zone submodels was performed by comparing results with other analytical solutions for special cases and by performing sensitivity analyses.

3.4 Monte Carlo Method

The screening model described in the preceding sections contains a number of parameters which are subject to variability from location to location due to heterogeneous waste, soil and aquifer characteristics and variations in climate. As a result of the uncertain nature of model input parameters, predictions are also uncertain and may be characterized by a probability distribution. The most general manner of determining the nature of prediction uncertainty, given the distribution of input parameters, is to use Monte Carlo simulation methods.

The Monte Carlo method involves execution of the model for many realizations of parameter sets from their statistical distributions to obtain the distribution of possible model outcomes. The method requires a knowledge of the probability distribution functions of the random input parameters. Monte Carlo methods are well documented and have been applied extensively to groundwater contamination problems. Applications of the Monte Carlo method have been discussed by *Wagner and Gorelick* (1987), *Smith and Freeze* (1979), and *Warren and Price* (1961) among others.

A Monte Carlo analysis of the screening model described in the preceding chapter was implemented in VADSAT. A random number generation algorithm described by *Press et al.* (1986) was used to generate realizations of random input parameters according to their specified probability distribution functions. Distributions of all input parameters are assumed to be independent. Histograms and statistical moments (mean and variance) of the model output (e.g, maximum concentration at a receptor location) are computed from the results. Input parameters in VADSAT which are regarded as random variables are listed in Tables 4.5 and 4.6 along with their distribution types for transport of salts or hydrocarbon species. Depending on the nature of the parameter, the distribution type is assumed to be log-normal or uniform. Regardless of the distribution type, all distributions are specified in terms of the mean and standard deviation of the original variable. Note that several parameters that are often characterized by normal distributions are regarded here as log-normal. In practice, normal distributions with a low variance are closely approximated by a log-normal distribution when the appropriate variance transformation described below is used. The log-normal distribution has the advantage that it handles cases with high variance more accurately than the normal distribution.

For variables characterized by a range from X_{min} to X_{max} (e.g., 95 percent lower and upper confidence limits), the mean and standard deviation may be estimated by

$$m = \frac{X_{max} + X_{min}}{2} \tag{3.51a}$$

$$\sigma = \frac{X_{max} - X_{min}}{\sqrt{12}} \tag{3.51b}$$

which may be employed to compute the required input parameters for VADSAT from the known range. Equation (3.51) is exact for uniformly distributed variables.

For log-normally distributed variables, the following conversion formulas are used internally by the program to determine the mean and variance of log-transformed variables as

$$m_{ln} = ln(m) - \frac{\sigma_{ln}^2}{2} \tag{3.52a}$$

$$\sigma_{ln}^2 = ln\left[\frac{\sigma^2}{m^2} + 1\right] \tag{3.52b}$$

where m_{ln} and σ_{ln}^2 are the mean and variance of the log-transformed variable and m and σ^2 are the mean and variance of the original random variable. The user directly inputes m and σ, whereas m_{ln} and σ_{ln}^2 are used internally by the program to generate the random variables for the transformed normal distribution $N(m_{ln},\sigma_{ln}^2)$. Log-normal distributions are truncated at 3σ or $3\sigma_{ln}$.

Verification of the Monte Carlo analysis implemented in VADSAT was performed by comparing statistical distributions of model output with independently computed distributions based on a first-order error analysis.

4. Guidelines for Parameter Estimation

This chapter is intended to help VADSAT users define values for various model input parameters. Efforts have been made to either tabulate typical values for these parameters or provide guidelines for users to determine site-specific values. The information in this chapter is divided into two sections.

Section 4.1 tabulates various input parameters along with their distribution types. (A description of the format in the VADSAT data files is given in Appendix B.) Section 4.2 describes various databases linked to the VADSAT pre-processor that can be accessed to obtain typical parameter values for a site. These databases should be used when site specific estimates cannot be obtained due to high cost, time, and/or other technical limitations or when only an order of magnitude accuracy in results is sufficient and the user finds it justifiable to use typical values for input parameters available in the literature.

All of the VADSAT parameters were defined earlier in Chapter 3. Additional information is provided in this Chapter for a few of the parameters that are crucial to obtain accurate results and which are difficult to estimate. These are the organic carbon fraction, biodegradation rate coefficient, net infiltration rate, soil texture, saturated hydraulic conductivity and groundwater hydraulic gradient. Suggestions on how to make an educated judgement of the values for these parameters are summarized in Section 4.2.

4.1 VADSAT input parameters

4.1.1 Distribution of random variables in VADSAT

Input parameters in VADSAT which are regarded as random variables are listed in Tables 4.1 and 4.2 along with their distribution types for transport of salts or hydrocarbon species. Depending on the nature of the parameter and available databases (*Gelhar et al.*, 1985: *Marsek et al.*, 1987: *Carsel and Parrish*, 1988: *Newell et al.*, 1989), the distribution type is assumed to be normal, lognormal or uniform and specified in terms of the mean and standard deviation of the (untransformed) input parameters.

Table 4.1. Random Variables for VADSAT for Salt Transport.

Random Variable	Distribution Type
Salt Source	
Source Area (A)	log-normal
Ratio of source length to width (S_R)	log-normal
Waste zone thickness (L_w)	uniform
Mass fraction of species in soil (F_s)	log-normal
Aqueous concentration in waste (C_S)	log-normal
Net recharge rate (q_u)	uniform
Unsaturated Zone	
Porosity (ϕ_u)	log-normal
Depth to water table (L_u)	log-normal
Residual water content (θ_r)	log-normal
Pore size distribution parameter (n)	log-normal
Saturated conductivity (K_{su})	log-normal
Longitudinal dispersivity (α_L)	log-normal
Saturated Zone	
Saturated zone thickness (H)	log-normal
Porosity (ϕ_s)	log-normal
Hydraulic gradient (i)	log-normal
Hydraulic conductivity (K_s)	log-normal
Longitudinal dispersivity (α_x)	log-normal
X-Y dispersivity ratio (α_x / α_y)	log-normal
Y-Z dispersivity ratio (α_y / α_z)	log-normal

Table 4.2. Random Variables for VADSAT for Organic Transport.

Random Variable	Distribution Type
Hydrocarbon Source	
Source area (A)	log-normal
Ratio of source length to width (S_R)	log-normal
Waste zone thickness (L_w)	uniform
Cover thickness (L_c)	uniform
Vol. fraction species in hydrocarbon (f^o)	log-normal
Mass fraction hydrocarbon in soil (F_H)	log-normal
Henry's constant (H_i)	log-normal
Diffusion coefficient in air (D_i^{vo})	log-normal
Net recharge rate (q_u)	uniform
Unsaturated zone	
Depth to water table (L_u)	log-normal
Porosity (ϕ_u)	log-normal
Residual water content (θ_r)	log-normal
Pore size distribution parameter (n)	log-normal
Organic carbon fraction (f_{oc})	log-normal
Partition coefficient (k_{oc})	log-normal
Aqueous decay coefficient (μ_u)	log-normal
Saturated conductivity (K_{su})	log-normal
Dispersivity (α_L)	log-normal
Saturated Zone	
Saturated zone thickness (H)	log-normal
Porosity (ϕ_s)	log-normal
Organic carbon fraction (f_{oc})	log-normal
Partition coefficient (k_{oc})	log-normal
Aqueous decay coefficient (μ_s)	log-normal
Hydraulic conductivity (K_s)	log-normal
Hydraulic gradient (i)	log-normal
Longitudinal dispersivity (α_x)	log-normal
X-Y dispersivity ratio (α_x/α_y)	log-normal
Y-Z dispersivity ratio (α_y/α_z)	log-normal

4.2 VADSAT Database

The VADSAT pre-processor includes databases for waste source geometry, species chemical properties, and physical properties for the unsaturated and saturated zones. The objective of this Section is 1) to summarize the basis of VADSAT parameter databases and 2) to describe techniques for determining sensitive parameters that are not readily available in literature. Typical values for various parameters are listed under different categories including Source and Chemical Parameters, Unsaturated Zone Parameters, and Saturated Zone Parameters.

4.2.1 Source and Chemical Parameters

The statistics of waste zone parameters were obtained from *Bedient et al.* (1989). Table 4.3 gives the mean waste zone thickness and area, and the length to width ratio for exploration and production (E&P) waste pits in the continental U.S. The corresponding standard deviations for these parameters are also given in Table 4.3. In case of the land spreading, the user should enter the site specific values for thickness of the waste zone, waste area, and the length to width ratio.

The physical and chemical properties of various species, including molecular weight, density, solubility, Henry's coefficient, organic carbon fraction, and diffusion coefficient are given in Table 4.4. These properties have been compiled from *A.D Little* (1994), *Lide* (1992), *Montgomery and Welkom* (1990), *Lyman et al.* (1990), *Karickhoff et al.* (1979), and *Kayal and Connell* (1990).

Table 4.3. Waste Zone Geometry Database

	Thickness (m)		Area (m^2)		Ratio of L/W	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Alluvial basins	2	1	643	1931	1.26	2.06
Glaciated central region	2	1	534	983	1.87	2.50
High plains	2	1	1237	1134	1.06	0.68
Colorado plateau & Wyoming basin	3	1	1374	974	1.31	0.82
Non-glaciated central region	2	1	996	1397	1.46	1.40
Atlantic & Gulf coastal plains	2	1	2788	6444	1.09	1.46
National	2	1	1442	3613	1.24	1.72

Table 4.4. Chemical Property Database

Species	MW (g/mol)	Density (g/cm^3)	Solubility (g/m^3)	Henry's Coeff. (dimensionless)	Species Diffusion Coeff. (m^2/d)	k_{oc} (cm^3/g)
benzene	78.1	0.876	1790	0.23	0.77	83
ethylbenzene	106.2	0.867	135	0.27	0.64	309
toluene	92.1	0.867	759	0.26	0.69	832
xylene	106.2	0.869	199.3	0.313	0.64	776
1,2,4-trimethyl benene	120.2	0.876	51.9	0.253	0.59	2750
1-ethyl 2-methyl benzene	120.2	0.881	74.6	0.215	0.59	2750
napthalene	128.2	1.150	30.6	0.0562	0.61	1450
2-methylnapthalene	142.2	1.006	25.6	0.0203	0.57	7940
acenapthene	154.2	1.024	3.93	0.0042	0.57	5130
2,6-dimethylnapthalene	156.2	1.011	2.00	0.0065	0.53	12600
flourene	166.2	1.203	1.84	0.0036	0.54	9330
phenanthrene	178.2	0.98	1.18	0.0014	0.52	22900
pyrene	202.3	1.271	0.135	0.000347	0.50	933300
chrysene	228.3	1.274	0.002	0.00018	0.46	1840000
benzo (a) antracene	228.3	1.27	0.14	0.000168	0.46	1730000
benzo (a) pyrene	252.3	1.35	0.00154	0.000170	0.44	503000
cyclopentane	70.1	0.746	160.0	7.50	0.82	617
n-pentane	72.2	0.626	40.8	48.8	0.73	2570
cyclohexane	84.2	0.779	57.5	7.50	0.73	1700
2,3-dimethylbutane	86.2	0.662	19.1	57.0	0.66	4370
n-hexane	86.2	0.660	12.3	57.1	0.66	617
methylcyclohexane	98.2	0.769	16.0	15.3	0.66	407
2,2dimethylpentane	100.2	0.674	4.40	129.0	0.61	776
n-heptane	100.2	0.684	3.06	80.6	0.61	28200
n-hexadecane	226.4	0.773	0.0000521	157.0	0.39	6150

Estimation of Net Infiltration Rate

This is the net recharge rate to groundwater. A large fraction of the precipitation in an area is lost as runoff, evapotranspiration, interception and interflow in the vadose zone. The difference between the total precipitation and these losses is the net recharge to the groundwater that can be estimated either using computer models (like HELP) or by monitoring deep drainage in the vadose zone. Net infiltration rate for most hydrogeological settings varies from 1 to 10 inches/year.

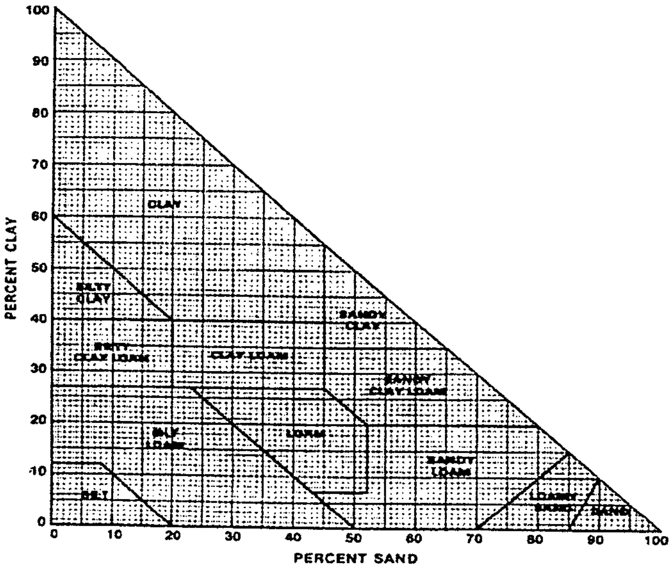
4.2.2 Unsaturated Zone Parameters

The unsaturated zone parameters required for VADSAT simulations are: hydraulic conductivity, van-Genuchten n, residual water content, and porosity. Distributions of the van Genuchten pore size distribution parameter, n, residual water content, θ_r, and unsaturated zone porosity, ϕ_u, were obtained from a study by *Carsel and Parrish* (1988). Data from 5,700 core samples from soils throughout the United States were divided into groups based on USDA grain size class and statistically analyzed. These data enable characterization of statistical distributions of n, θ_r and ϕ_u for each grain size class. In addition, nationwide means were computed as the weighted averages of grain size class means from Carsel and Parrish and nationwide standard deviations were computed as the sum of: 1) the mean of the class standard deviations and, 2) the standard deviation of the class means. This data is compiled in the "soils" database which is accessible from within the VADSAT pre-processor. Statistical distributions of hydraulic conductivity, groundwater seepage velocity, saturated thickness and depth to groundwater for various "hydrogeologic environments" have been reported by *Newell et al.* (1989).This data is accessible from the "hydrogeologic" database within the VADSAT pre-processor.

VADSAT requires data for vertical hydraulic conductivity of the unsaturated zone. However, the *API* (1989) database includes only horizontal conductivity of the aquifer. We assume that the coefficient of variation of hydraulic conductivity for different hydrogeological environments is the same for the unsaturated and saturated zones, but that the mean unsaturated and saturated zones conductivities for each class differ by a constant factor, defined as the mean anisotropy factor. *ES&T* (1992) compared the national mean unsaturated zone conductivity from the database of *Carsel and Parrish* (1988) with the mean value from the *API* (1989) database and an anisotropy factor of 0.13 was obtained. The unsaturated zone conductivity statistics computed based on this analysis are given in

Table 4.5 and are included in the "soils" database in VADSAT. Other soil physical properties, including van-Genuchten *n*, residual water content, and porosity for various textural classes were obtained from *Carsel and Parrish* (1988) and are given in Table 4.5. Figure 1 is a soil texture diagram that can be used to classify soils based on the texture class defined below.

Figure 1



Soil Texture Class

The proportion of different size soil particles in a porous media defines its texture. A textural classification chart for the 12 classes, shown in Figure 19, has been developed by the U.S. Department of Agriculture. Typical soil physical properties have been given in Table 4.5 for various soil textural classes.

Table 4.5. Soil Property Database.

Soil Type	Porosity (fraction)		van Gen. n (dimensionless)		Residual W.C. (fraction)		Sat. Conductivity (m/d)	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Clay	0.38	0.09	1.09	0.09	0.068	0.034	0.048	0.101
Clay loam	0.41	0.09	1.31	0.09	0.095	0.010	0.062	0.168
Loam	0.43	0.10	1.56	0.11	0.078	0.013	0.250	0.437
Loamy sand	0.41	0.09	2.28	0.27	0.057	0.015	3.502	2.726
Silt	0.46	0.11	1.37	0.05	0.034	0.010	0.060	0.079
Silt loam	0.45	0.08	1.41	0.12	0.067	0.015	0.108	0.295
Silty clay	0.36	0.07	1.09	0.06	0.070	0.023	0.005	0.026
Silty clay loam	0.43	0.07	1.23	0.06	0.089	0.009	0.017	0.046
Sand	0.43	0.06	2.68	0.29	0.045	0.010	7.128	3.744
Sandy clay	0.38	0.05	1.23	0.10	0.100	0.013	0.029	0.067
Sandy clay loam	0.39	0.07	1.48	0.13	0.100	0.006	0.314	0.658
Sandy loam	0.41	0.09	1.89	0.17	0.065	0.017	1.061	1.351

Estimation of Organic Carbon Fraction

The transport velocity of a species in soil and groundwater in relation to the water flow velocity is controlled by retardation due to adsorption on the solid matrix. The distribution coefficient (Chapter 3) defining sorption of a species is often assumed to be directly proportional to the soil organic carbon fraction, f_{oc}, which varies significantly for different soil types and aquifer materials. The f_{oc} is generally higher in the top few feet of the soil due to decomposition of organic matter from native plant material.

The organic content of various soils are listed in Table 4.6. The following steps outline how to use the information.

Buried Pit Wastes - The pit bottom is usually greater than 100 cm (1 meter) below ground surface. Pick the mean or a value within the range of the unsaturated zone subsurface organic carbon content, 0.0065 +/- 0.0011, and use the associated standard deviation of 0.0040 (Note, the standard deviation listed for the desert soils is also that of deep subsurface soils. It is used as the standard deviation for buried waste scenarios because the wastes do not interact with any surface soils.)

Land or Roadspread Oily Wastes - The waste organics are incorporated into the surface soil and will be influenced by its organic content. Determine which soil type is most appropriate from those listed. Choose organic carbon means or values from the ranges given for each layer of the selected soil type. Calculate a weighted average for organic carbon content from the zone of waste incorporation to the water table as

$$\frac{\sum_{i=1}^{N} T_i OC_i}{\sum_{i=1}^{N} T_i} \tag{4.1}$$

where T_i is the thickness of a soil layer i (m); OC_i is the corresponding organic carbon content for layer i; and N is the number of layers with different organic carbon contents (*API, 1994*).

A standard deviation is given for each soil type which is the combined standard deviation for all the layers. The standard deviation is used with the weighted mean for Monte Carlo modeling.

Table 4.6. Unsaturated Zone Organic Carbon Fraction.

Organic matter in soils and subsoil sediments	Mean	+/- 95% confidence interval	Standard deviation (all layers)
Desert soils, limited vegetation cover, evaporation >> precipitation (Aridisol, Serozems, Solonets)			
Surface soil and unsaturated zone subsurface	0.0065	0.0011	0.0040
Semiarid grasslands-steppe, chaparral and scrub forest; evapotranspiration > precipitation, (Aridosol, Alfisol, Chestnut soils)			
Near Surface, 0-20cm	0.0166	0.0023	0.0016
Near Surface, 20-60cm	0.0096	0.0018	
Unsaturated zone subsurface, > 60cm	0.0065	0.0011	
Prarie, meadow, valley bottom grasslands or under sparse forest; deep organic-rich soils (Molisols, Chernozems, Rendizinas)			
Near surface, 0-20 cm	0.0637	0.0065	0.0059
Near surface, 20-60 cm	0.0353	0.0071	
Near surface,60-100 cm	0.0164	0.0062	
Broadleaf forest soils of temperate humid regions (Alfisol, Gray forest soils)			
Near surface, 0-20 cm	0.0427	0.0062	0.0035
Near surface, 20-100 cm	0.0143	0.0029	
Unsaturated zone subsurface>60 cm	0.0065	0.0011	
Coniferous forest, savanna, or rainforest soils of humid regions; acidic forest litter causes leaching of organic carbon from root zone (Spodosol, Podzols)			
Near surface, 0-20 cm	0.0316	0.0094	0.0048
Near surface, 20-100 cm	0.0034	0.0007	
Unsaturated zone subsurface> 100 cm	0.0065	0.0011	
Warm to hot, humid, sub-tropical hardwood/pine woods and tropics; high degree of mineral weathering and leaching; precipitation > evapotranspiration (Ultisol, Oxisol, Krasnozems, Laterites, and Red/Yellow Podzols)			
Near surface, 0-20 cm	0.0407	0.0123	0.0068
Near surface, 20-100 cm	0.0150	0.0048	
Unsaturated zone subsurface> 100 cm	0.0065	0.0011	
Soils with accumulated organic matter; poorly drained bog and swamp areas; slow decay under anaerobic conditions; organic layer from 40 cm to meters thick (Histosol, Peat, Muck)			
Surface zone, thickness of organic layer	0.7762	0.0615	0.0314
Mineral soil below organic layer	0.0065	0.0011	
Humid soils frozen much of the year (Alfisol, Mollisol, Ultisol)			
Near surface, 0-20 cm	0.1928	0.0540	0.0305
Near surface, 20-60 cm	0.0441	0.0255	
Near surface, 60-100cm	0.0092	0.0010	
Unsaturated zone subsurface > 100cm	0.0065	0.0011	

Estimation of Biodegradation Rate Coefficient

Biodegradation in soil and groundwater is a complex biological phenomenon. The rate of biodegradation depends upon the availability of microorganisms adapted to the subsurface environment, an optimum supply of an electron acceptor (oxygen, nitrate, sulfate or ferric ions), electron donors (contaminant), and water and nutrients to assure continuous reproduction of the biomass. In VADSAT, decay is modeled as a first order phenomenon. A typical range for the first order biodegradation rate coefficient for hydrocarbon species is 0.00005 to 0.01 day^{-1}. For readily biodegradable hydrocarbon species like benzene, the rate coefficient can vary between 0.0005 to 0.01 day^{-1}, while for more persistent hydrocarbons and PCBs, the rate may range from 0.00005 to 0.001 day^{-1}. The coefficient of variation in the biodegradation rate can range from 100 to 1000 percent, or higher.

4.2.3 Saturated Zone Parameters

Table 4.7 lists information on the saturated zone organic carbon content provided by *API* (1994). Table 4.8 provides information reported in *Bedient et al.* (1989) and *API* (1989) on the mean saturated hydraulic conductivity, hydraulic gradient, aquifer thickness and unsaturated zone thickness for various hydrogeological environments. The regional groundwater gradient data was obtained from *API (*1989). The corresponding standard deviation for these parameters is also given in Table 4.8. The information in Table 4.8 disregarded the obvious outliers in data sets reported in *Bedient et al.* (1989) and *API* (1989).

Saturated Zone Organic Carbon Content

Due to decreases in plant matter with depth, f_{oc} generally decreases exponentially with depth (*Brady*, 1990, *Zhang et al*, 1993). Aquifers generally have a low f_{oc} compared to the topsoil.

Organic carbon contents of various aquifer sediments have been measured to assess their capacity to adsorb dissolved organic contaminants from groundwater. Table 4.7 summarizes measured organic carbon contents of 24 aquifer sediments and gives an organic carbon range for 3 others (*API, 1994)*

Table 4.7. Saturated Zone Organic Carbon Fraction

Aquifer Name	Aquifer Texture	Organic Carbon Fraction
Tirstrup 1	c. sand-2%, f. sand-94%, silt-2%, clay-3%	0.00048
Tirstrup 2	c. sand--18%, f. sand-79%, silt- 0%, clay-2%	0.00035
Finderup 2	c. sand--34%, f. sand-63%, silt- 2%, clay-0%	0.00213
Tylstrup	c. sand-42%, f. sand-52%, silt-2%, clay-4%	0.00159
Barksdale	sand-52.3%, silt-41.5%, clay-6.2%	0.00030
Allerod 2	c. sand-54%, f.sand-42%,, silt-4%, clay-0%	0.00048
Vasby	c. sand-63%, f. sand-34%, silt-2%, clay-1%	0.00012
Gunderup 2	c. sand-74%, f. sand-22%, silt-4%, clay-0%	0.00021
Finderup 1	c. sand-77%, f. sand-18%, silt-1%, clay-1%	0.00006
Vejen 2	c. sand-77%, f.sand-21%, silt-0%, clay-3%	0.00032
Allerod 1	c. sand-78%, f. sand-17%, silt-3%, clay-2%	0.00071
155-21- cm	sand-83.7%, silt-6.8%, clay-9.5%	0.00039
Rabis	c. sand-84%, f. sand- 15%, silt-0%, clay-1%	0.00016
Brande 2	c. sand-87%, f. sand-10%, silt-2%, clay-1%	0.00020
Vorbasse 1	c. sand-88%, f. sand-11%, silt-0%, clay 1%	0.00006
Vejen 1	c. sand-90%, f. sand-8%, silt-1%, clay-1%	0.00029
Vorbasse 3	c. sand-90%, f.sand-8%, silt-2%, clay-1%	0.00122
Lula	sand-91%, silt 5.6%, clay-3.4%	0.00020
Borris	c. sand-92%, f. sand-6%, silt-2%, clay-0%	0.00020
Gunderup 1	c. sand-93%, f. sand-6%, silt-0%, clay-1%	0.00009
Herborg	c. sand-93%, f. sand-5%, silt-2%, clay-0%	0.00213
Vorbasse 2	c. sand-93%, f. sand-5%, silt-2%, clay-0%	0.00007
Brande 1	c. sand-94%, f. sand-3%, silt-2%, clay-1%	0.00010
350-450 m	black sands	0.00730
Borden		<0.0005
Tinker		<0.0005
Columbus		<0.0005

Note: f = fine, c = course

Table 4.8. Hydrogeologic Database.

Hydrogeologic Environment	Saturated Conductivity (m/d)		Hydraulic Gradient (ft/ft)		Saturated Zone Thickness (m)		Unsaturated Zone Thickness (m)	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Alluvial Basins, Valley & Fans	0.9	1.97	0.026	0.048	20.9	42.6	16.7	21.3
Bedded Sedimentary Rock	0.13	0.30	0.023	0.027	40.4	78.2	17.4	33.4
Coastal Beaches	1.07	2.79	0.018	0.036	38.8	79.9	2.3	1.9
Outwash	1.83	4.85	0.005	0.077	26.1	27.0	8.9	10.2
Sand and Gravel	1.03	2.97	0.027	0.068	23.4	70.5	10.3	18.3
River Valley with Overbank	1.03	2.39	0.005	0.005	9.6	7.6	6.8	7.4
River Valley without Overbank	1.24	2.58	0.017	0.045	26.1	54.4	10.0	13.6
Till and Till over Outwash	0.08	0.18	0.068	0.121	12.0	12.2	6.2	8.7
Till over Sedimentary Rock	0.12	0.25	0.016	0.016	9.7	12.8	8.41	9.0
Unconsolidated & Semi-consolidated	1.21	4.95	0.013	0.022	11.0	12.2	7.5	8.4
All Groups	0.86	2.90	0.021	0.046	21.8	50.6	9.5	18.6

Estimation of Hydraulic Conductivity

Hydraulic conductivity is a critical parameter that can significantly influence modeling results. Efforts should be made to reduce uncertainty in the estimation of hydraulic conductivity. Several techniques, including pump tests, slug tests, auger hole, cavity methods, exfiltration tests, and double ring infiltrometer tests can be used to estimate the hydraulic conductivity in the field. Representative values of various hydrogeologic environments are given in Table 4.8.

Estimation of Groundwater Hydraulic Gradient

Regional groundwater gradient is an important parameter because of its direct influence on the Darcy velocity. A network of monitoring wells can be used to observe water piezometric heads in space and time. The observations can be interpolated in space to generate piezometric/water table surface at specified time. The hydraulic gradient in any spatial direction is the slope of the water table surface in that direction. Sometimes for screening studies, monitoring well data is not available. The hydraulic gradient of unconfined aquifers for such cases may be assumed to be approximately parallel to the ground surface.

5. References

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REPORTS

DATE:

6/24/1998

cc: CW
50

NEW MEXICO OIL CONSERVATION COMMISSION
FIELD TRIP REPORT

INSPECTION	CLASSIFICATION	FACILITY	HOURS	QUARTER HOURS

Name WAYNE PRICE Date 6/24/98 Miles ______ District I
Time of Departure 7 AM Time of Return 4 PM Car No. G 047

In the space below indicate the purpose of the trip and the duties performed, listing wells or leases visited and any action taken.

Signature Wayne Price

MMC - K-10-16-35

SITE VISIT REQUESTED BY NMG&F

BILL HAYS, MIKE MASSEY

TOOK PICTURES -

Mileage		Per Diem		Hours	
UIC		UIC		UIC	
RFA		RFA		RFA	
Other		Other		Other	

TYPE INSPECTION PERFORMED

H = Housekeeping
P = Plugging
C = Plugging Cleanup
T = Well Test
R = Repair/Workover
F = Waterflow
M = Mishap or Spill
W = Water Contamination
O = Other

INSPECTION CLASSIFICATION

U = Underground Injection Control - Any inspection of or related to injection project, facility, or well or resulting from injection into any well. (SWD, 2ndry injection and production wells, water flows or pressure tests, surface injection equipment, plugging, etc.)
R = Inspections relating to Reclamation Fund Activity
O = Other - Inspections not related to injection or The Reclamation Fund
E = Indicates some form of enforcement action taken in the field (show immediately below the letter U, R or O)

NATURE OF SPECIFIC WELL OR FACILITY INSPECTED

D = Drilling
P = Production
I = Injection
C = Combined prod. inj. operations
S = SWD
U = Underground Storage
G = General Operation
F = Facility or location
M = Meeting
O = Other

NMOCD: ID#. 276485 By: W Price
Date/Time: June 24, 1998
Site/Co. UMC Blow-out area
Location: K-10-16-35
Subject: Visit with NMG&F

1R - 187

REPORTS

DATE:

4/16/1998

UMC Petroleum Corporation

April 16, 1998

Mr. Wayne Price
New Mexico, Energy, Minerals
& Natural Resources Department
Oil Conservation Division
1000 West Broadway
Hobbs, New Mexico 88240

RE: Carlisle State Com #1
Site Assessment Work Plan

Dear Mr. Price;

UMC Petroleum Corporation grants Calloway Safety Equipment Company, Inc., their personnel and or representatives, full authority to submit and administer any and all legal or procedural documentation on behalf of UMC Petroleum Corporation in the remedial effort of the Carlisle State Com #1 well and location. Calloway Safety Equipment Company recently submitted a Preliminary Site Assessment Work Plan to your office for consideration and approval on our behalf. UMC is in full agreement with the stipulations and information contained in the work plan.

We are awaiting your approval of the plan to begin working on the remedial project as soon as possible. If you have any questions or need additional information, I can be reached in Denver at (303) 573-4721. Thank you for your time and help in this matter.

Sincerely,

Scott M. Webb
Regulatory Coordinator

APR 1998
Received
Hobbs
OCD

CC: Calloway Equipment Company, Inc.

410 Building 410 17th Street, Suite 1400 Denver, Colorado 80202 (303) 573-5100
A Subsidiary of United Meridian Corporation

CALLAWAY SAFETY EQUIPMENT CO., INC.
3229 INDUSTRIAL DRIVE ••• HOBBS, NEW MEXICO 88240
TELEPHONE: (505) 392-2973 • FAX: (505) 392-4990 • E-MAIL: CALLSAFE@GTE.NET

April 15, 1998

Mr. Chris Williams
New Mexico Department of Energy, Mineral, and Natural Resources
Oil Conservation Division, Hobbs Field Office
P.O. Box 1980
1000 West Broadway
Hobbs, New Mexico 88240

Subject: Site Assessment Work Plan for the UMC Petroleum Corporation well: Carlisle State Com #1

Mr. Williams,

UMC has contracted with Callaway Safety Equipment Company, Inc. (CSE) to provide environmental services at the above referenced well location. Attached is the proposed Site Assessment Work Plan developed by CSE for UMC and is being submitted to you for review and approval. To establish baseline/background reference concentrations of Benzene, Toluene, Ethylbenzene, and Xylene (total), ground water analytical results and the request for analyses/chain of custody form from area water wells is attached.

Currently, down hole work at the well has been suspended for two weeks until equipment becomes available and will allow some excavation and sampling to be initiated and possibly minimize ground water contamination.

Your response may be directed to UMC or CSE. Please call either Sam Callaway or myself at 392-2973 if there are any questions. Thank you for your assistance.

Sincerely,

Pat McCasland

Pat McCasland
CSE SAFETY AND ENVIRONMENTAL DIRECTOR

CC: WAYNE PRICE, NMOCD
SCOTT WEBB, UMC DENVER

APR 1998
Received
Hobbs
OCD

Site Assessment Work Plan

for the

UMC Petroleum Corporation Well:

Carlisle State Com #1

N.M.P.M.
S10 T16S R35E
1650' FSL & 1980' FWL
Lea County New Mexico

TABLE OF CONTENTS

1 UMC-Carlisle State Com #1: Site Assessment Work Plan

1.1 Event Description

1.1.1 March 20, 1998

At 3:30 AM on Friday March 20, 1998, during drilling of the UMC Petroleum Corporation Carlisle State Com #1 well at an estimated depth of 12,100 feet, a highly pressurized and uncontrollable flow of natural gas and natural gas liquids was encountered. The estimated volume was ~ 8 to 15 mmcf per day of sweet gas, i.e., 0.0 ppm H_2S concentration. Although H_2S was not a concern, initial responders were concerned that explosive levels of natural gas could migrate to nearby residences and possibly the City of Lovington, New Mexico located four miles east of the well. Consequently, residents within one mile of the well were evacuated, the site secured, the Lea County Sheriff Department, New Mexico State Police, Lovington Police and Fire Department, and the Local Emergency Planning Committee were notified, and the Incident Command System activated. The resulting plume of gas was monitored for Volatile Organic Contaminants (VOCS) with Photoionization Detectors (PIDs) and the Lower Explosive Limit (LEL) with LEL monitors. All instruments were routinely calibrated every 6 to 12 hours.

1.1.2 March 26, 1998

Plume monitoring ceased when, on March 26, 1998, during preparations to move the drilling rig from over the well bore, ignition occurred. There were no injuries.

1.1.3 April 3, 1998

On April 3, 1998 at approximately 8:20 A.M., the well fire was extinguished with dynamite. The plume of natural gas that developed was monitored for VOC and Benzene with no hazardous concentrations detected. (See attached Benzene monitoring report) Shortly after Noon, a 15-ton well head was installed on the casing and secured. At 5:15 P.M. the well flow was diverted to the previously constructed flare pit 600 feet NW of the well and ignited. Plume monitoring for VOCs and Benzene was terminated.

1.1.4 Current Activities

Work continues to complete the well, i.e., retrieve drill string and install casing. Approximately 3 mmcf of the well flow is being sold to Warren Petroleum with the balance being flared.

1.2 Site Description

The legal description is: N.M.P.M., S10 T16S R35E, 1650' FSL & 1980' FWL, Lea County New Mexico and is approximately four miles due west of the City of Lovington. The property is State lease land with the surface rights leased to Mr. Jerry Carlisle for grazing livestock and subsurface rights to UMC and Yates Petroleum.

1.2.1 Primary Usage's

Primary use of the land is for grazing livestock and local access roads to oil and gas production equipment.

1.2.2 Ecology

The area is host to small nomadic bands of Pronghorn Antelope (Antelocapra americana), the desert cottontail rabbit (Sylivagus audiboni), Blacktailed Jackrabbit (Lepus californicus), Coyote (Canas latrans), and many small rodents typical of the upper Chihuahuan Desert. Desert grasses cover the area with interspersions of mesquite and cholla cactus. Approximately 200 feet due south of the well is a pond fed by a windmill operated pump set 70 feet below the surface and according the Mr. Carlisle is capable of producing two gallons per minute.

1.2.3 Geology

Three feet of dark brown clay matrix overlays an extensive layer of caliche. The caliche is inconsistently fractured with the fractures filled with the overlaying clay. The caliche caps the Ogallala Formation that constitutes the major fresh water aquifer at this site.

1.3 Source Term

1.3.1 Volume Estimate

Prior to ignition, the release of natural gas and natural gas liquids persisted for approximately 156 hours. Assuming a flow volume of 8 to 15 mmcf per 24 hours, the release volume is estimated to be 52 mmcf to 97.5 mmcf.

1.3.2 Natural Gas Liquid

The gaseous phase of the release dissipated rapidly, however, when not dispersed by air currents, the liquid phase was atomized to some extent and remained airborne and detectable for up to 6 miles (verbal communication with NMOCD). Nevertheless, sufficient quantities of the liquid phase, i.e., condensate, accumulated on the location near the well bore and drained or drained away with the recirculating water into a newly excavated pit 350 feet east of the well. This pit acted as a water monitor supply reserve and recirculating pit for the water monitors used to spray the well discharge in an effort to diminished ignition risk and plume formation. The condensate darken the soil and pasture due north of the well bore radiating at 45° to 90° for approximately .25 miles. It must be noted that after ignition the pits and the area around the well bore burned vigorously for three hours, consuming the condensate and volatilizing much of the soil contamination.

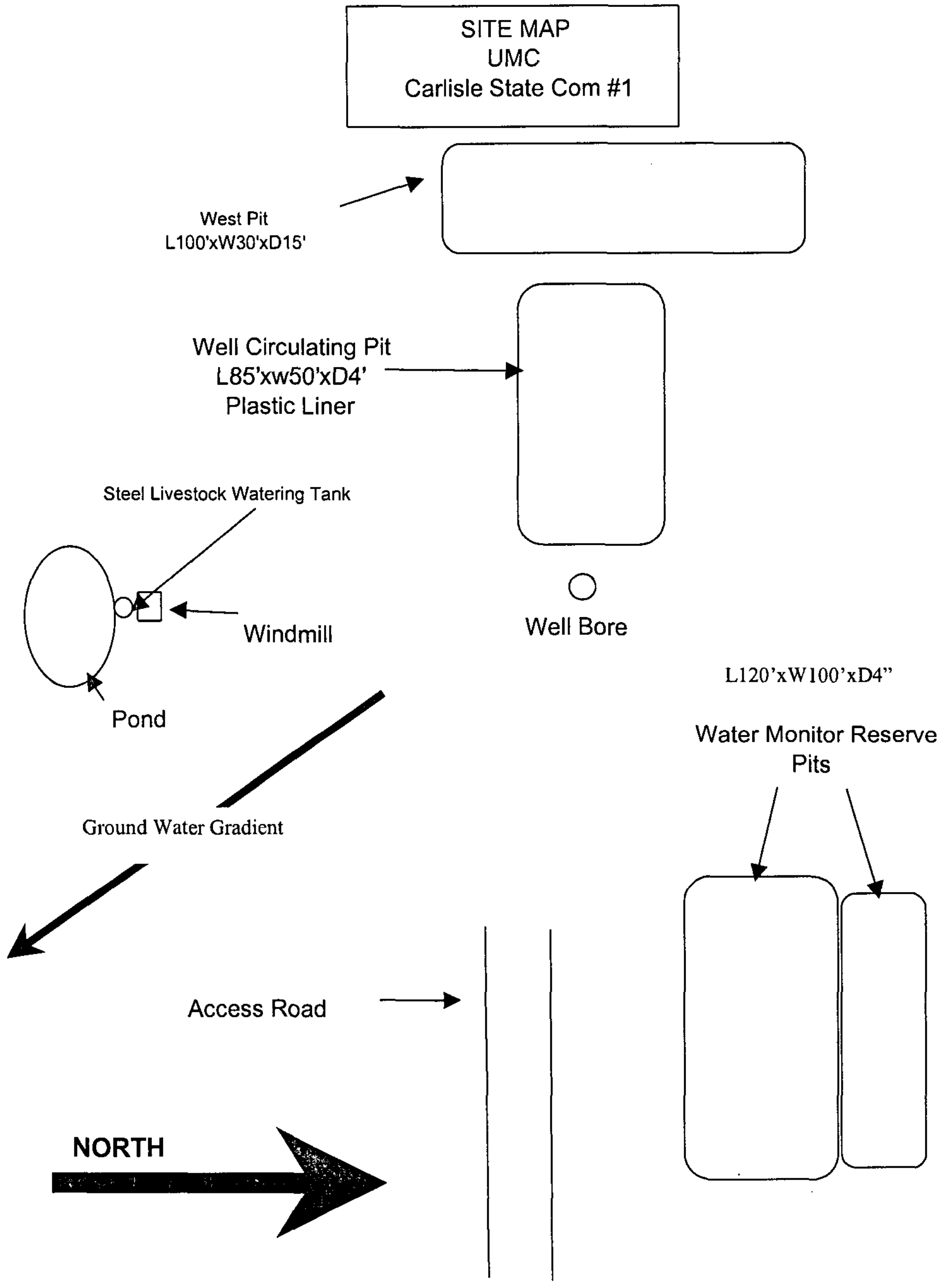
1.3.3 Brine Water

The well has not produced appreciable amounts of brine water, however, 3000 barrels of brine water was used in an unsuccessful attempt to kill the well and is considered to be a contaminant. It should be noted that this volume was diluted with at least an order of magnitude greater quantity of fresh water used to spray the well.

1.3.4 Benzene, Ethlybenzene, Toluene, and Xylenes (BTEX)

These are known hazardous constituents of natural gas, and are partially soluble in water. These VOCs are considered indicators of produced hydrocarbon contamination of the groundwater. The highest ambient Benzene concentration detected during plume monitoring 200 feet from the well bore was .3 ppm.

1.4 Site Map


SITE MAP
UMC
Carlisle State Com #1
West Pit
L100'xW30'xD15'
Well Circulating Pit
L85'xw50'xD4'
Plastic Liner
Steel Livestock Watering Tank
Windmill
Pond
Well Bore
L120'xW100'xD4"
Water Monitor Reserve Pits
Ground Water Gradient
Access Road
NORTH

1.5 General Site Characteristics

These parameters will be evaluated and used to determine potential domestic and environmental risks, need for remedial action, and level of cleanup required at the site.

1.5.1 Depth to Ground Water

This vertical distance begins at the lowermost contaminants and extends to the seasonal high water elevation of the ground water.

1.5.2 Well Protection Area

This is the horizontal distance to the nearest water source. The windmill well is located 200' south of the well bore.

1.5.3 Distance to Nearest Surface Water Body

The nearest surface water body is located 220' south of the well bore and during the release of unburned natural gas, condensate inundated the L40'xW20' dirt pond.

1.6 Soil/Waste Characteristics

These parameters will be determined visually and with PID field measurements. To demonstrate effective cleanup, confirmatory analyses will be performed on strategically located soil samples.

1.6.1 Highly Contaminated/Saturated Soils

The excavated pits exhibit gross staining and will likely be the locations with contamination nearest the ground water table.

1.6.2 Unsaturated Contaminated Soils

Soils within a .25 mile radius of the well are unsaturated and may be contaminated.

1.6.2.1 Soil Ranking Criteria

This ranking system establishes risk based cleanup thresholds for Benzene ppm, BTEX ppm, and Total Petroleum Hydrocarbon (TPH) ppm.

1.6.2.1.1 Depth to Ground Water

It is likely that contamination is <50 feet from the uppermost seasonal water table and results in a Ranking Score of 20.

1.6.2.1.2 Wellhead Protection Area

The well bore is <1,000 feet from a water source, i.e., windmill due south, and results in a Ranking Score of 20.

1.6.2.1.3 Distance to Surface Water Body

The pond south of the well bore is between the 200 – 1,000 horizontal feet and results in a Ranking Score of 10.

1.6.2.2 Soil Remediation Thresholds: >19 Ranking Score

The sum of the ranking criteria is 50 and therefore the following remediation action levels apply to this location.

Soil Remediation/Cleanup Thresholds	
Benzene*	10.0 ppm
BTEX*	50.0 ppm
TPH**	100.0 ppm

*A field soil vapor headspace measurement (Section V.B.1) of 100 ppm may be substituted for a laboratory analysis of the Benzene and BTEX concentration limits.

**The contaminant concentration for TPH is the concentration above Background levels.

1.6.2.3 Ground Water Thresholds

Ground water requires remediation if it exhibits concentrations of dissolved phase VOC or other dissolved constituents in excess of the natural background water quality. Section 3103 of the New Mexico Water Quality Control Commission (WQCC) ground water standards will apply if the background concentrations are nominal and are as follows.

Parameter	mg/L or ppm
Benzene	0.01
Toluene	0.75
Ethylbenzene	0.75
Xylenes (Total)	0.62
Chloride (Cl^-)	250.0
Total Dissolved Solids (TDS)	1000.0

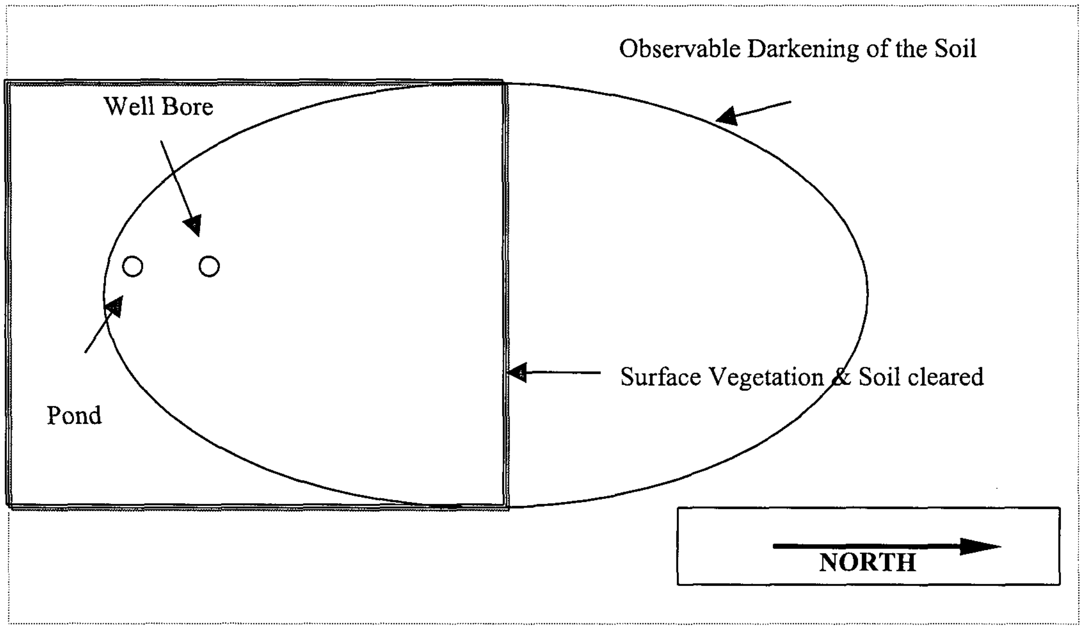
1.7 Preliminary Site Investigation

The progress of the release was visually monitored during the unignited phases with the following environmental observations noted.

1.7.1 Soil Contamination

Soil within a 300-foot radius of the well bore received noticeable fall-out of condensate and fresh water. Prevailing winds maintained the plume direction generally northward with plume fall-out noticeable to .25 mile within a 45° to 90° arc relative to the well bore.

1.7.1.1 Observable Surface Contamination

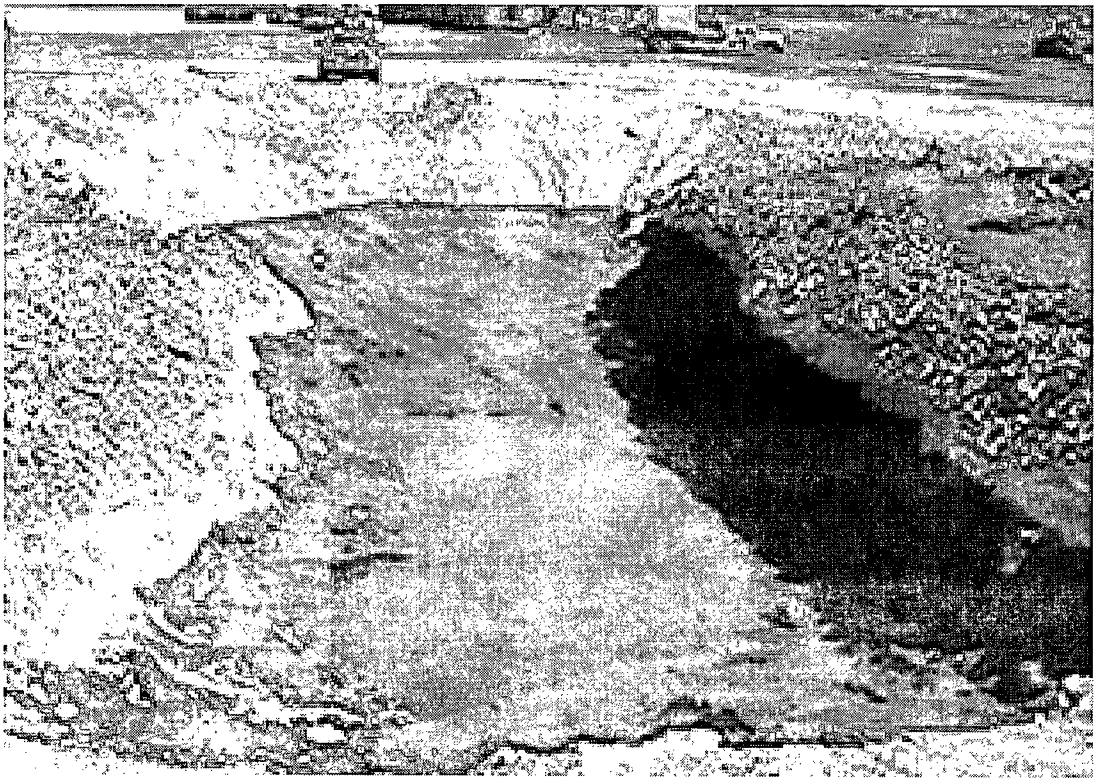


1.7.1.2 Pit Soil Contamination

The excavated pits received a mixture of water from the spraying activities and condensate from the well. There are three pits on location.

1.7.1.2.1 West Pit

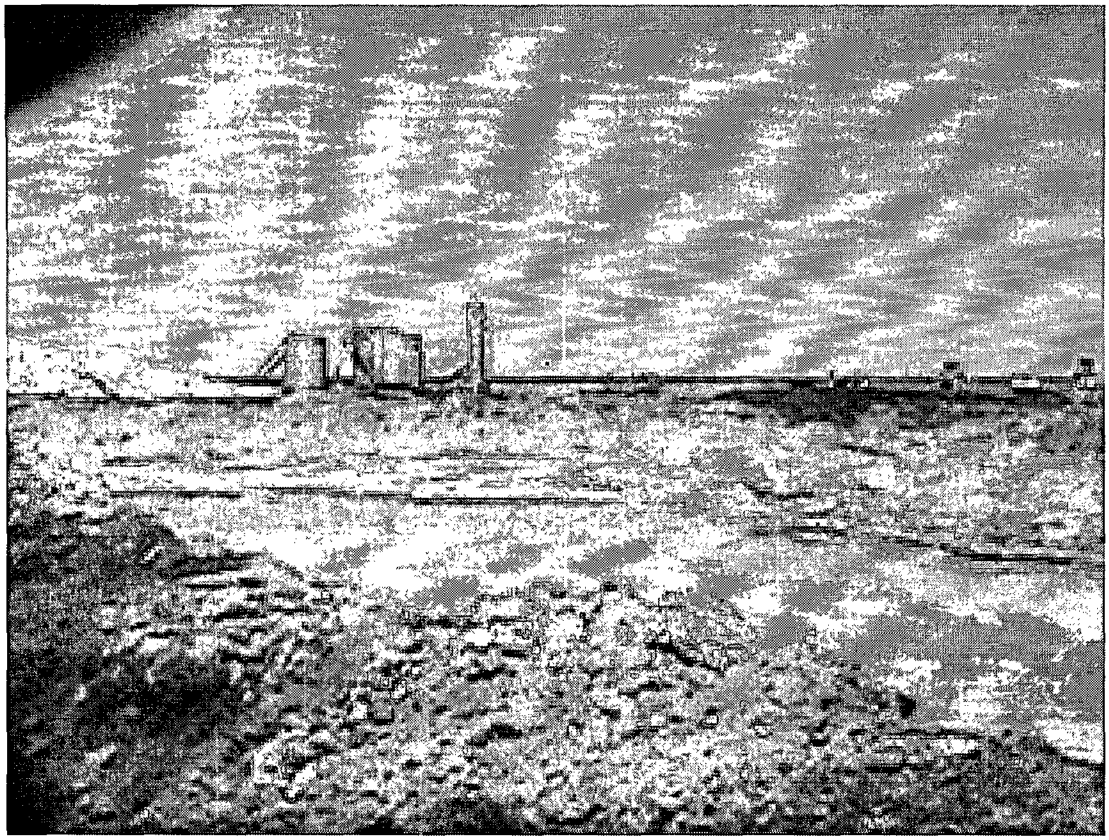
The pit is L100'x W30'x D15' and received water and condensate. The liquids were removed by truck and sold as usable product.



West Pit (looking North)

1.7.1.2.2 Drilling Rig Reserve Pit

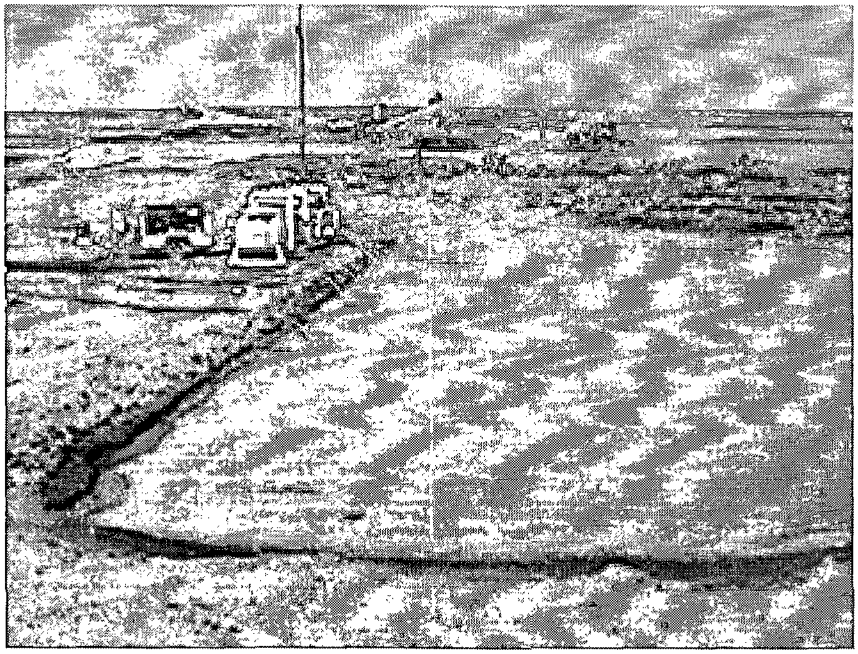
This pit is L85' x W50' x D4' and has a plastic liner. In addition to the drilling fluids being used during drilling operation, this pit also received water and condensate and burned vigorously for 3 hours after the well ignited. The pit has not been evacuated of fluids or sediment.



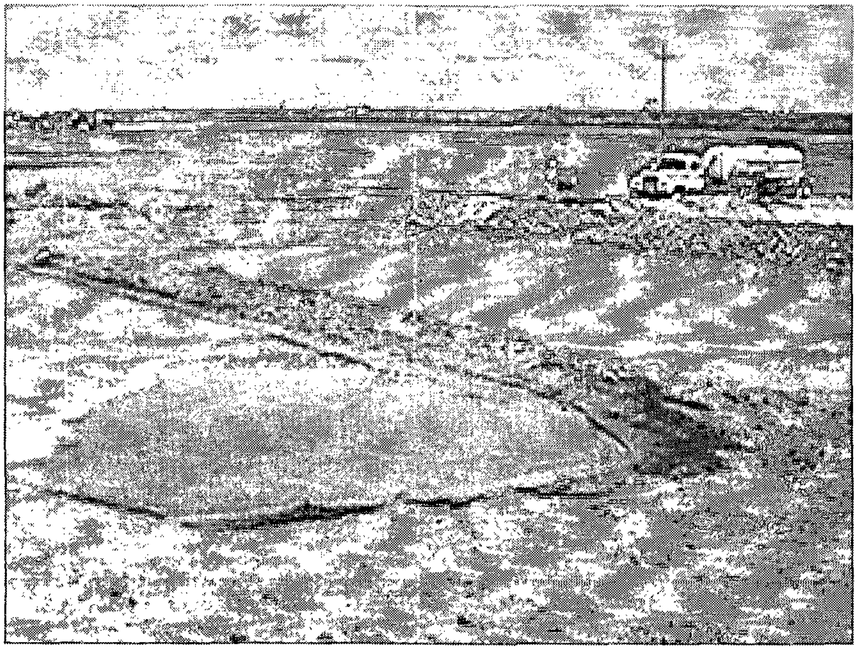
Drilling Rig Reserve Pit (looking NW)

1.7.1.2.3 East Monitor Reserve Pits

These pits received run-off from the well, i.e., fresh water and condensate, and also served as the water monitor pump supply.



East Water Monitor Reserve Pits (looking West)



East Water Monitor Reserve Pits (looking NW)

1.7.2 Ground Water Contamination

Given the potential for ground water contamination resulting from the release and excavations, the following water wells were sampled and analyzed for BTEX contamination and background levels. The results are summarized in the following matrix. Clean 40-ml septum (zero headspace) vials were obtained from Cardinal Laboratories, Inc. in Hobbs, New Mexico. Samples were analyzed using "BTEX-EPA-SW846-8020." Quality Control data was submitted with the analytical report and is attached to this report.

Preliminary Site Investigation
Ground Water Analytical Results

Sample ID-Location	Date		TDS	Cl^-	Benzene	Toluene	Ethyl Benzene	Total Xylene
	Sample	Analyzed	mg/L	mg/L	ppm	ppm	ppm	ppm
A1: Windmill .75 mile NW (upgradient) of well bore (9-16S-35E) Well Depth = unknown Baseline/Background Sample Location	3-31-98	4-1-98	375	48	<.002	<.002	<.002	<.002
A-2: Windmill 200' South of Carlisle #1 well bore (10-16S-35E) Well Depth = 60'	3-31-98	4-1-98	428	64	<.002	<.002	<.002	<.002
A-3: Carlisle Residence Well ~ 1.0 miles South of well bore (10-16S-35E) Well Depth = 72'	4-1-98	4-1-98	360	68	<.002	<.002	<.002	<.002
A-4: Carlisle Irrigation Well ~ .75 mile South of well bore (10-16S-35E) Well Depth = 70'	3-31-98	4-1-98	511	52	<.002	<.002	<.002	<.002

1.8 Site Investigation and Remediation Plan

The different environmental media which have been contaminated by the released condensate will be restored to BTEX risk concentration levels discussed previously and are based on the risk ranking system. This phase of the Site Assessment Work Plan is also investigatory, in that, the depth to ground water will be determined and the extent of Surface Soil Contamination determined.

1.8.1 Pits Remediation

Remaining liquids will be disposed of properly and stained soil excavated. Samples of the walls and bottom of the excavation will be taken and analyzed for BTEX and TPH. If analytical results are > the soil cleanup thresholds, further excavation will be done until the soil results are < or = the threshold levels.

1.8.2 Landfarm and Site Reclamation

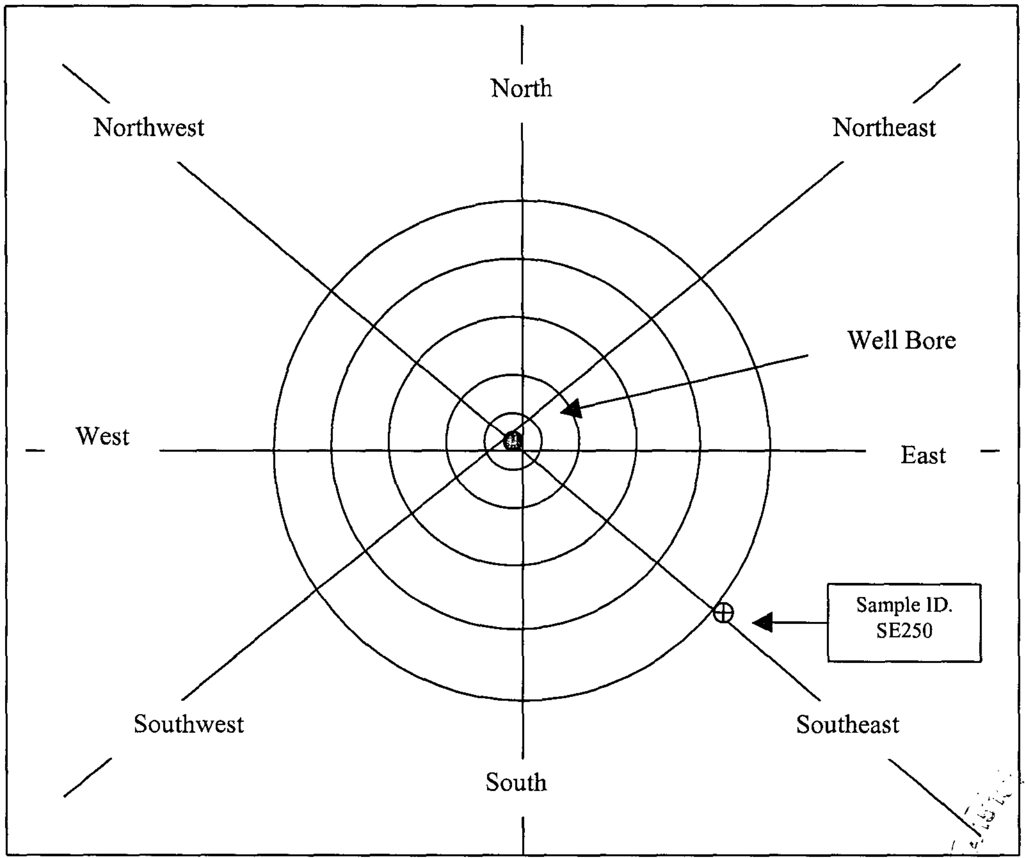
A landfarm will be established and the excavated soil spread in a 6" lift and contained within a bermed area. The lift will be watered and tilled monthly to enhance aerobic biodegradation. To further enhance microbial activity and hasten remediation of the soil, organic material will be tilled in, i.e., straw or hay. It is also contemplated to develop two areas within the landfarm for different matrixes, i.e., one for caliche and one for soil. BTEX and TPH analysis will be performed monthly.

When levels have been reduced to <= the threshold value, the soil will be place back into the excavated pits or spread and recontoured. After remediation is complete, the pastureland will be reseeded with native vegetation.

1.8.3 Surface Soil Contamination Investigation

A comprehensive field survey of the site will be conducted. VOC measurements will be made with a calibrated PID. Sample locations will be established at 50' intervals along the Cardinal and Intermediate Compass Radians. At each sample location the depth to uncontaminated soil will be determined visually and core samples taken at six-inch vertical intervals. These samples will be placed in a plastic bag, it's temperature raised to 70°F, and the head space gas sampled and analyzed with the PID. If contamination is encountered the extent of downward contamination must be observed and noted.

Example of the Soil Sampling Grid:



1.8.4 Ground Water Monitoring

The windmill ~ 200' south of the well bore is down gradient from the pits west of the well bore and will serve as the ground water monitoring location. Initially, BTEX and TPH were undetectable. Samples will be analyzed monthly for 6 months and should be sufficient time for a contaminant plume to migrate to the well. Ground water remediation is not indicated at this time nor is installation of monitoring wells. The TDS, Chloride, and BTEX data presented earlier in this report shall constitute the ground water parameter baseline/background levels.

1.9 Quality Assurance / Quality Control

To ensure that the information used in making the environmental management decisions is reliable, the following protocols will be followed.

1.9.1 Field Sampling and Sample Handling

All samples will be placed in certifiably clean containers obtained from the contracting analytical laboratory. All samples will be properly labeled with the following information:

- Sample date
- Sample time
- Matrix
- Unique Sample Identification Number
- Sampler
- Parameter
- Preservative added
- Preservation method

1.9.2 Sample QA/QC

A duplicate sample will be analyzed every ten samples for all field and laboratory tests. Acceptable relative percent difference will be +/- 20%.

1.9.3 Field Instruments

All analytical instruments used in the field will be calibrated prior to each sampling day activities and verified every two hours of running time.

1.9.4 Analytical Laboratory QA/QC

Quality control data will be submitted by the laboratory to ensure credibility of the laboratory data.

1.10 Plan Implementation

This plan will be implemented after all down hole operations are completed and approval has been issued by the NMOCD.

CARDINAL LABORATORIES, INC.

2111 Beechwood, Abilene, TX 79603 (915) 673-7001 Fax (915) 673-7020
101 East Marland, Hobbs, NM 88240 (505) 393-2326 Fax (505) 393-2476

CHAIN-OF-CUSTODY AND ANALYSIS REQUEST

H3550

Page 1 of 1

Company Name: Callaway Safety / UMC
Project Manager: Pat McCasland
Address: 3229 Industrial Drive
City: Hobbs State: NM Zip: 88240
Phone #: 505 392 2923
Fax #: 505 392 4990
Project #: Carlilse St Com #1 Project Owner: UMC
P[illegible]ct Name:
Project Location: 4 miles west of Lovington, NM

BILL TO PO #:
Company:
Attn:
Address:
City:
State: Zip:
Phone #:
Fax #:

FOR LAB USE ONLY				MATRIX						PRES.			SAMPLING		ANALYSIS REQUEST		
LAB I.D.	Sample I.D.	(G)RAB OR (C)OMP.	# CONTAINERS	GROUNDWATER	WASTEWATER	SOIL	OIL	SLUDGE	OTHER :	ACID:	ICE / COOL	OTHER :	DATE	TIME	Chloride	TDS	BTEX
H3550-1	GW98331A1	G	3	✓							✓		3-31-98	1420	✓	✓	✓
H3550-2	GW98331A2	G	3	✓							✓		3-31-98	1420	✓	✓	✓
H3550-3	GW9841A3	G	3	✓							✓		4-1-98	1030	✓	✓	✓
H3550-4	GW98331A4	G	3	✓							✓		3-31-98	1510	✓	✓	✓

PLEASE NOTE: Liability and Damages. Cardinal's liability and client's exclusive remedy for any claim arising whether based in contract or tort, shall be limited to the amount paid by the client for the analyses. All claims including those for negligence and any other cause whatsoever shall be deemed waived unless made in writing and received by Cardinal within 30 days after completion of the applicable service. In no event shall Cardinal be liable for incidental or consequental damages, including without limitation, business interruptions, loss of use, or loss of profits incurred by client, its subsidaries, affiliates or successors arising out of or related to the performance of services hereunder by Cardinal, regardless of whether such claim is based upon any of the above stated reasons or otherwise.

Terms and Conditions: Interest will be charged on all accounts more than 30 days past due at the rate of 24% per annum from the original date of invoice, and all costs of collections, including attorney's fees.

Sampler Relinquished: Pat McCasland
Date: 4-1-98
Time: 1200
Received By:

Relinquished By:
Date: 4/1/98
Time: 12:02
Received By: (Lab Staff)

Delivered By: (Circle One)
Sampler - UPS - Bus - Other:

Sample Condition
Cool ☒ Yes ☐ No
Intact ☒ Yes ☐ No

CHECKED BY: (Initials)

Phone Result ☐ Yes ☐ No Additional Fax #:
Fax Result: ☐ Yes ☐ No
REMARKS:

† Cardinal cannot accept verbal changes. Please fax written changes to 915-673-7020.

CARDINAL
LABORATORIES

PHONE (915) 673-7001 • 2111 BEECHWOOD • ABILENE, TX 79603
PHONE (505) 393-2326 • 101 E. MARLAND • HOBBS, NM 88240

ANALYTICAL RESULTS FOR
CALLAWAY SAFETY/UMC
ATTN: PAT McCASLAND
3229 INDUSTRIAL DR.
HOBBS, NM 88240
FAX TO: 505-392-4990

Receiving Date: 04/01/98
Reporting Date: 04/02/98
Project Owner: UMC
Project Name: CARLISLE ST. COM #1
Project Location: 4 MILES WEST OF LOVINGTON, NM

Sampling Date: 03/31/98
Sample Type: GROUNDWATER
Sample Condition: COOL & INTACT
Sample Received By: GP
Analyzed By: BC/AH

LAB NUMBER	SAMPLE ID	TDS (mg/L)	Cl (mg/L)	BENZENE (mg/L)	TOLUENE (mg/L)	ETHYL BENZENE (mg/L)	TOTAL XYLENES (mg/L)
ANALYSIS DATE:		04/01/98	04/01/98	04/01/98	04/01/98	04/01/98	04/01/98
H3550-1	GW98331A1	375	48	<0.002	<0.002	<0.002	<0.006
H3550-2	GW98331A2	428	64	<0.002	<0.002	<0.002	<0.006
H3550-3	GW9841A3	360	68	<0.002	<0.002	<0.002	<0.006
H3550-4	GW98331A4	511	52	<0.002	<0.002	<0.002	<0.006
Quality Control		NR	468	0.092	0.092	0.092	0.281
True Value QC		NR	500	0.100	0.100	0.100	0.300
% Accuracy		NR	93.6	91.5	92.2	92.3	93.6
Relative Percent Difference		0.3	3.4	9.2	3.4	2.9	2.9

METHODS: TDS-EPA 600/4-79-020, 160.1;Cl-EPA 600/4-79-020 325.3 BTEX-EPA SW-846-8020

Burgess J. A. Cooke, Ph.D.

4/2/98
Date

4/8/98

UMC - Carlisle State Com #1


7

1R - 187

REPORTS

DATE:
4/1998

Site Assessment Work Plan

for the

UMC Petroleum Corporation Well:

Carlisle State Com #1

N.M.P.M.
S10 T16S R35E
1650' FSL & 1980' FWL
Lea County New Mexico

TABLE OF CONTENTS

1 UMC-Carlisle State Com #1: Site Assessment Work Plan

1.1 Event Description

1.1.1 March 20, 1998

At 3:30 AM on Friday March 20, 1998, during drilling of the UMC Petroleum Corporation Carlisle State Com #1 well at an estimated depth of 12,100 feet, a highly pressurized and uncontrollable flow of natural gas and natural gas liquids was encountered. The estimated volume was ~ 8 to 15 mmcf per day of sweet gas, i.e., 0.0 ppm H_2S concentration. Although H_2S was not a concern, initial responders were concerned that explosive levels of natural gas could migrate to nearby residences and possibly the City of Lovington, New Mexico located four miles east of the well. Consequently, residents within one mile of the well were evacuated, the site secured, the Lea County Sheriff Department, New Mexico State Police, Lovington Police and Fire Department, and the Local Emergency Planning Committee were notified, and the Incident Command System activated. The resulting plume of gas was monitored for Volatile Organic Contaminants (VOCS) with Photoionization Detectors (PIDs) and the Lower Explosive Limit (LEL) with LEL monitors. All instruments were routinely calibrated every 6 to 12 hours.

1.1.2 March 26, 1998

Plume monitoring ceased when, on March 26, 1998, during preparations to move the drilling rig from over the well bore, ignition occurred. There were no injuries.

1.1.3 April 3, 1998

On April 3, 1998 at approximately 8:20 A.M., the well fire was extinguished with dynamite. The plume of natural gas that developed was monitored for VOC and Benzene with no hazardous concentrations detected. (See attached Benzene monitoring report) Shortly after Noon, a 15-ton well head was installed on the casing and secured. At 5:15 P.M. the well flow was diverted to the previously constructed flare pit 600 feet NW of the well and ignited. Plume monitoring for VOCs and Benzene was terminated.

1.1.4 Current Activities

Work continues to complete the well, i.e., retrieve drill string and install casing. Approximately 3 mmcf of the well flow is being sold to Warren Petroleum with the balance being flared.

1.2 Site Description

The legal description is: N.M.P.M., S10 T16S R35E, 1650' FSL & 1980' FWL, Lea County New Mexico and is approximately four miles due west of the City of Lovington. The property is State lease land with the surface rights leased to Mr. Jerry Carlisle for grazing livestock and subsurface rights to UMC and Yates Petroleum.

1.2.1 Primary Usage's

Primary use of the land is for grazing livestock and local access roads to oil and gas production equipment.

1.2.2 Ecology

The area is host to small nomadic bands of Pronghorn Antelope (Antelocapra americana), the desert cottontail rabbit (Sylivagus audiboni), Blacktailed Jackrabbit (Lepus californicus), Coyote (Canas latrans), and many small rodents typical of the upper Chihuahuan Desert. Desert grasses cover the area with interspersions of mesquite and cholla cactus. Approximately 200 feet due south of the well is a pond fed by a windmill operated pump set 70 feet below the surface and according the Mr. Carlisle is capable of producing two gallons per minute.

1.2.3 Geology

Three feet of dark brown clay matrix overlays an extensive layer of caliche. The caliche is inconsistently fractured with the fractures filled with the overlaying clay. The caliche caps the Ogallala Formation that constitutes the major fresh water aquifer at this site.

1.3 Source Term

1.3.1 Volume Estimate

Prior to ignition, the release of natural gas and natural gas liquids persisted for approximately 156 hours. Assuming a flow volume of 8 to 15 mmcf per 24 hours, the release volume is estimated to be 52 mmcf to 97.5 mmcf.

1.3.2 Natural Gas Liquid

The gaseous phase of the release dissipated rapidly, however, when not dispersed by air currents, the liquid phase was atomized to some extent and remained airborne and detectable for up to 6 miles (verbal communication with NMOCD). Nevertheless, sufficient quantities of the liquid phase, i.e., condensate, accumulated on the location near the well bore and drained or drained away with the recirculating water into a newly excavated pit 350 feet east of the well. This pit acted as a water monitor supply reserve and recirculating pit for the water monitors used to spray the well discharge in an effort to diminished ignition risk and plume formation. The condensate darken the soil and pasture due north of the well bore radiating at 45° to 90° for approximately .25 miles. It must be noted that after ignition the pits and the area around the well bore burned vigorously for three hours, consuming the condensate and volatilizing much of the soil contamination.

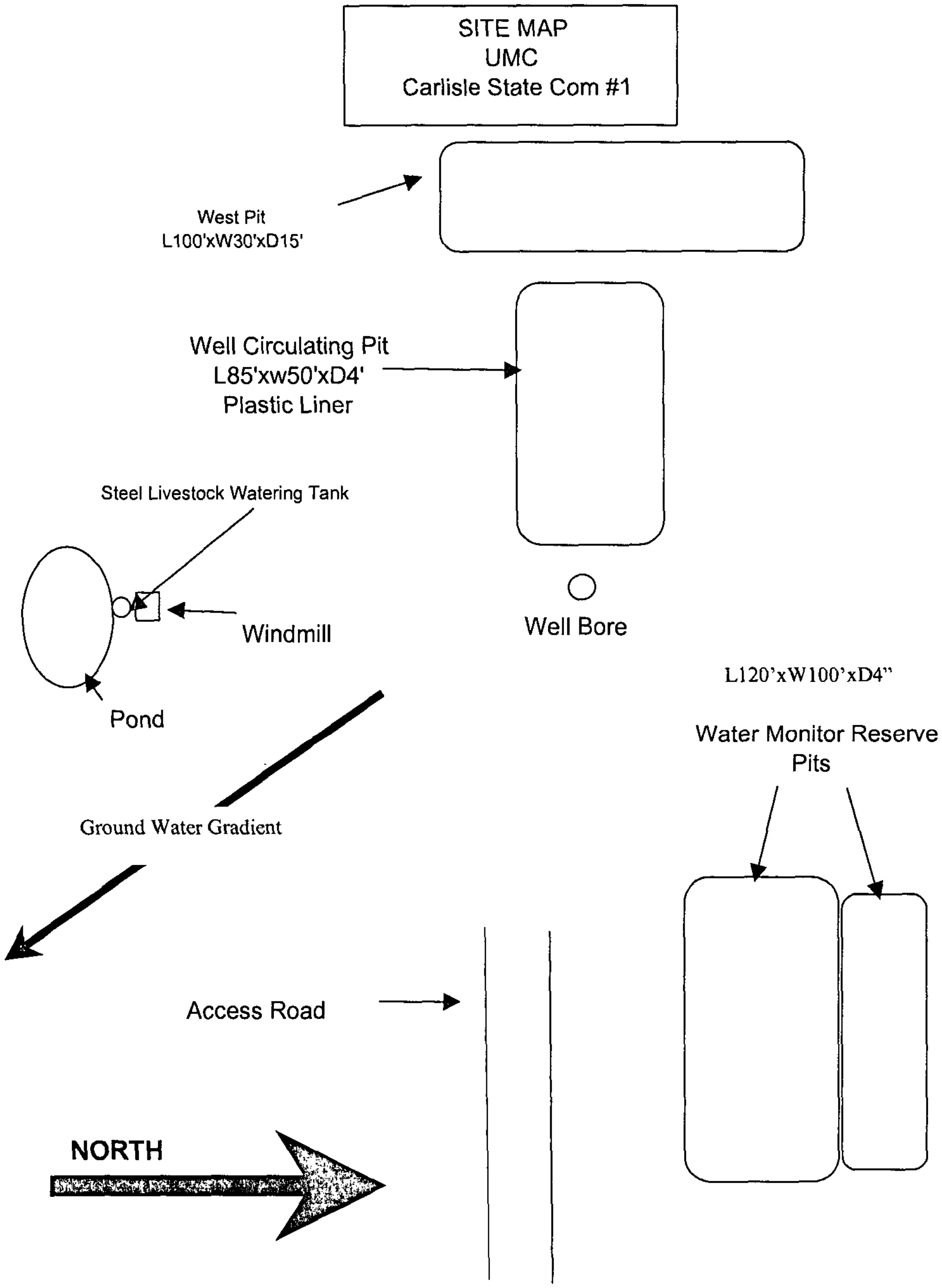
1.3.3 Brine Water

The well has not produced appreciable amounts of brine water, however, 3000 barrels of brine water was used in an unsuccessful attempt to kill the well and is considered to be a contaminant. It should be noted that this volume was diluted with at least an order of magnitude greater quantity of fresh water used to spray the well.

1.3.4 Benzene, Ethlybenzene, Toluene, and Xylenes (BTEX)

These are known hazardous constituents of natural gas, and are partially soluble in water. These VOCs are considered indicators of produced hydrocarbon contamination of the groundwater. The highest ambient Benzene concentration detected during plume monitoring 200 feet from the well bore was .3 ppm.

1.4 Site Map


SITE MAP
UMC
Carlisle State Com #1
West Pit
L100'xW30'xD15'
Well Circulating Pit
L85'xw50'xD4'
Plastic Liner
Steel Livestock Watering Tank
Windmill
Well Bore
Pond
L120'xW100'xD4"
Water Monitor Reserve Pits
Ground Water Gradient
Access Road
NORTH

1.5 General Site Characteristics

These parameters will be evaluated and used to determine potential domestic and environmental risks, need for remedial action, and level of cleanup required at the site.

1.5.1 Depth to Ground Water

This vertical distance begins at the lowermost contaminants and extends to the seasonal high water elevation of the ground water.

1.5.2 Well Protection Area

This is the horizontal distance to the nearest water source. The windmill well is located 200' south of the well bore.

1.5.3 Distance to Nearest Surface Water Body

The nearest surface water body is located 220' south of the well bore and during the release of unburned natural gas, condensate inundated the L40'xW20' dirt pond.

1.6 Soil/Waste Characteristics

These parameters will be determined visually and with PID field measurements. To demonstrate effective cleanup, confirmatory analyses will be performed on strategically located soil samples.

1.6.1 Highly Contaminated/Saturated Soils

The excavated pits exhibit gross staining and will likely be the locations with contamination nearest the ground water table.

1.6.2 Unsaturated Contaminated Soils

Soils within a .25 mile radius of the well are unsaturated and may be contaminated.

1.6.2.1 Soil Ranking Criteria

This ranking system establishes risk based cleanup thresholds for Benzene ppm, BTEX ppm, and Total Petroleum Hydrocarbon (TPH) ppm.

1.6.2.1.1 Depth to Ground Water

It is likely that contamination is <50 feet from the uppermost seasonal water table and results in a Ranking Score of 20.

1.6.2.1.2 Wellhead Protection Area

The well bore is <1,000 feet from a water source, i.e., windmill due south, and results in a Ranking Score of 20.

1.6.2.1.3 Distance to Surface Water Body

The pond south of the well bore is between the 200 – 1,000 horizontal feet and results in a Ranking Score of 10.

1.6.2.2 Soil Remediation Thresholds: >19 Ranking Score

The sum of the ranking criteria is 50 and therefore the following remediation action levels apply to this location.

Soil Remediation/Cleanup Thresholds	
Benzene*	10.0 ppm
BTEX*	50.0 ppm
TPH**	100.0 ppm

*A field soil vapor headspace measurement (Section V.B.1) of 100 ppm may be substituted for a laboratory analysis of the Benzene and BTEX concentration limits.

**The contaminant concentration for TPH is the concentration above Background levels.

1.6.2.3 Ground Water Thresholds

Ground water requires remediation if it exhibits concentrations of dissolved phase VOC or other dissolved constituents in excess of the natural background water quality. Section 3103 of the New Mexico Water Quality Control Commission (WQCC) ground water standards will apply if the background concentrations are nominal and are as follows.

Parameter	mg/L or ppm
Benzene	0.01
Toluene	0.75
Ethylbenzene	0.75
Xylenes (Total)	0.62
Chloride (Cl^-)	250.0
Total Dissolved Solids (TDS)	1000.0

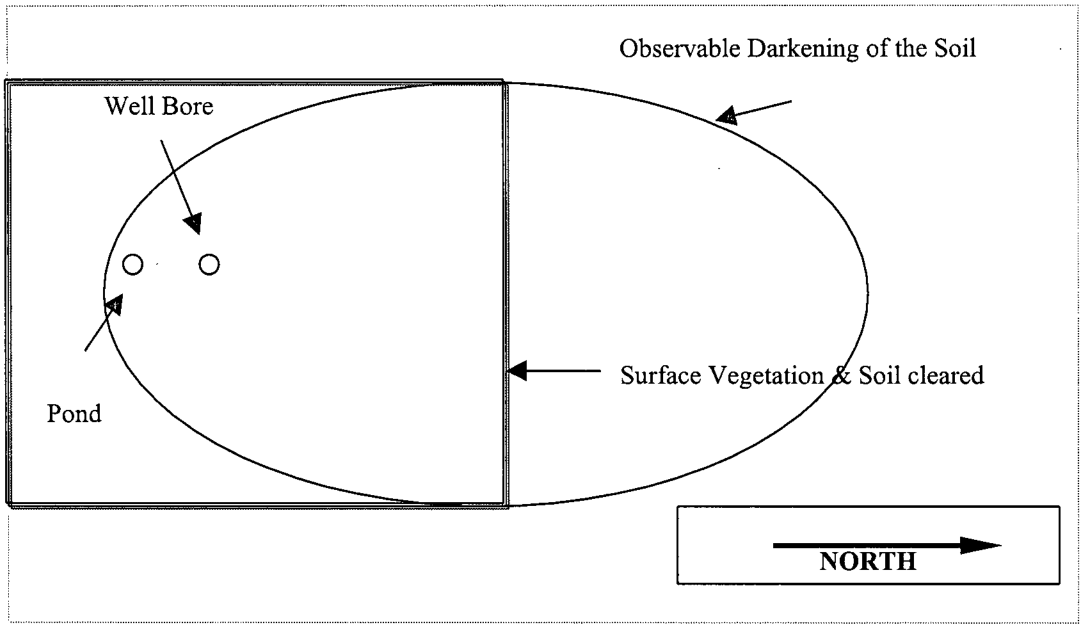
1.7 Preliminary Site Investigation

The progress of the release was visually monitored during the unignited phases with the following environmental observations noted.

1.7.1 Soil Contamination

Soil within a 300-foot radius of the well bore received noticeable fall-out of condensate and fresh water. Prevailing winds maintained the plume direction generally northward with plume fall-out noticeable to .25 mile within a 45° to 90° arc relative to the well bore.

1.7.1.1 Observable Surface Contamination

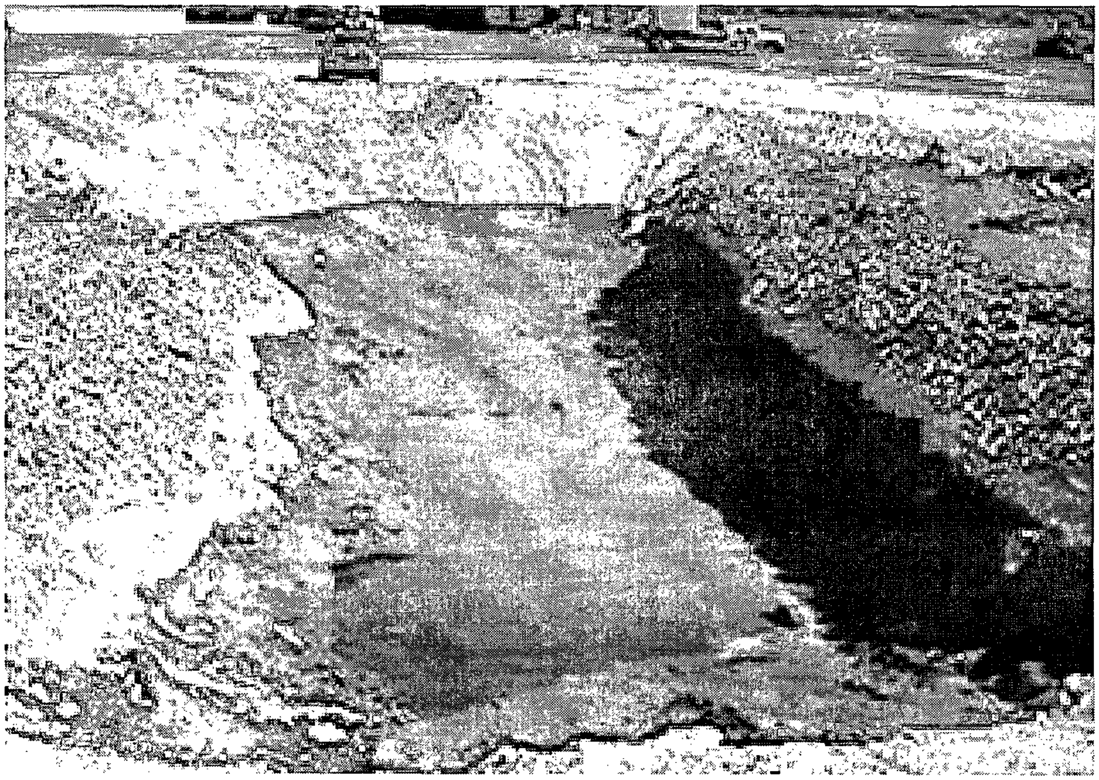


1.7.1.2 Pit Soil Contamination

The excavated pits received a mixture of water from the spraying activities and condensate from the well. There are three pits on location.

1.7.1.2.1 West Pit

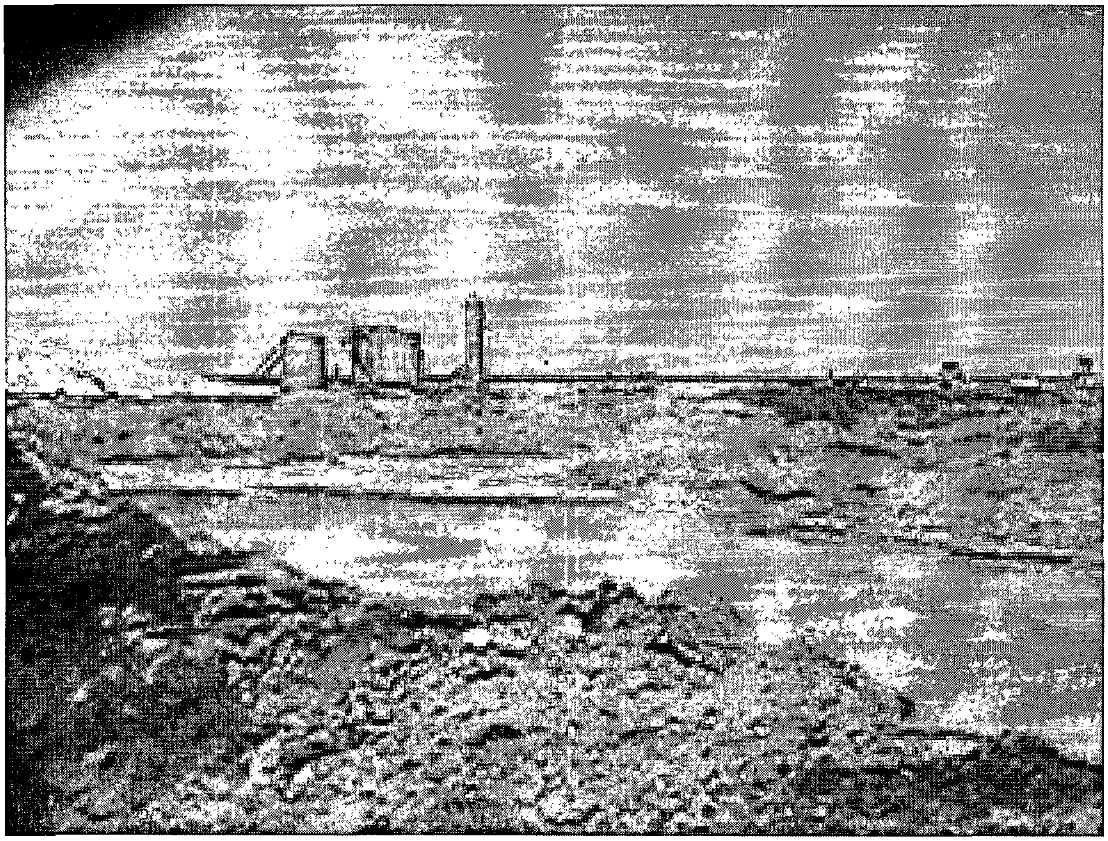
The pit is L100'x W30'x D15' and received water and condensate. The liquids were removed by truck and sold as usable product.



West Pit (looking North)

1.7.1.2.2 Drilling Rig Reserve Pit

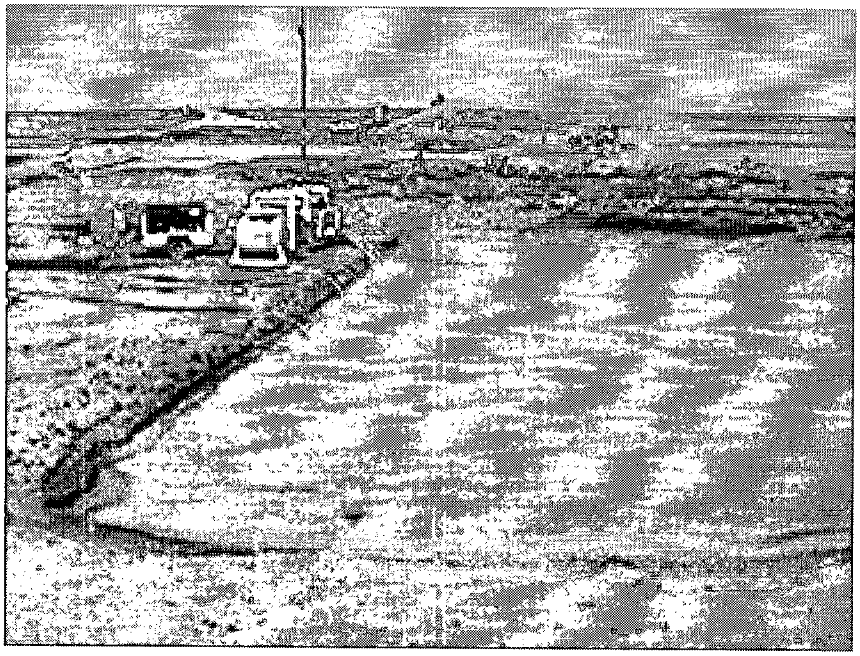
This pit is L85' x W50' x D4' and has a plastic liner. In addition to the drilling fluids being used during drilling operation, this pit also received water and condensate and burned vigorously for 3 hours after the well ignited. The pit has not been evacuated of fluids or sediment.



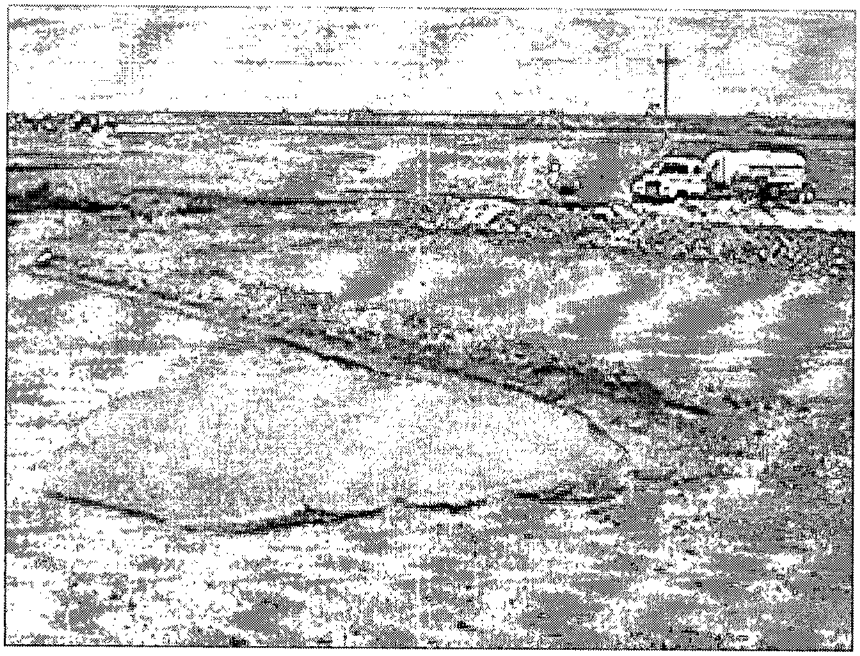
Drilling Rig Reserve Pit (looking NW)

1.7.1.2.3 East Monitor Reserve Pits

These pits received run-off from the well, i.e., fresh water and condensate, and also served as the water monitor pump supply.



East Water Monitor Reserve Pits (looking West)



East Water Monitor Reserve Pits (looking NW)

1.7.2 Ground Water Contamination

Given the potential for ground water contamination resulting from the release and excavations, the following water wells were sampled and analyzed for BTEX contamination and background levels. The results are summarized in the following matrix. Clean 40-ml septum (zero headspace) vials were obtained from Cardinal Laboratories, Inc. in Hobbs, New Mexico. Samples were analyzed using "BTEX-EPA-SW846-8020." Quality Control data was submitted with the analytical report and is attached to this report.

Preliminary Site Investigation
Ground Water Analytical Results

Sample ID-Location	Date		TDS	Cl^-	Benzene	Toluene	Ethyl Benzene	Total Xylene
	Sample	Analyzed	mg/L	mg/L	ppm	ppm	ppm	ppm
A1: Windmill .75 mile NW (upgradient) of well bore (9-16S-35E) Well Depth = unknown Baseline/Background Sample Location	3-31-98	4-1-98	375	48	<.002	<.002	<.002	<.002
A-2: Windmill 200' South of Carlisle #1 well bore (10-16S-35E) Well Depth = 60'	3-31-98	4-1-98	428	64	<.002	<.002	<.002	<.002
A-3: Carlisle Residence Well ~ 1.0 miles South of well bore (10-16S-35E) Well Depth = 72'	4-1-98	4-1-98	360	68	<.002	<.002	<.002	<.002
A-4: Carlisle Irrigation Well ~ .75 mile South of well bore (10-16S-35E) Well Depth = 70'	3-31-98	4-1-98	511	52	<.002	<.002	<.002	<.002

1.8 Site Investigation and Remediation Plan

The different environmental media which have been contaminated by the released condensate will be restored to BTEX risk concentration levels discussed previously and are based on the risk ranking system. This phase of the Site Assessment Work Plan is also investigatory, in that, the depth to ground water will be determined and the extent of Surface Soil Contamination determined.

1.8.1 Pits Remediation

Remaining liquids will be disposed of properly and stained soil excavated. Samples of the walls and bottom of the excavation will be taken and analyzed for BTEX and TPH. If analytical results are > the soil cleanup thresholds, further excavation will be done until the soil results are < or = the threshold levels.

1.8.2 Landfarm and Site Reclamation

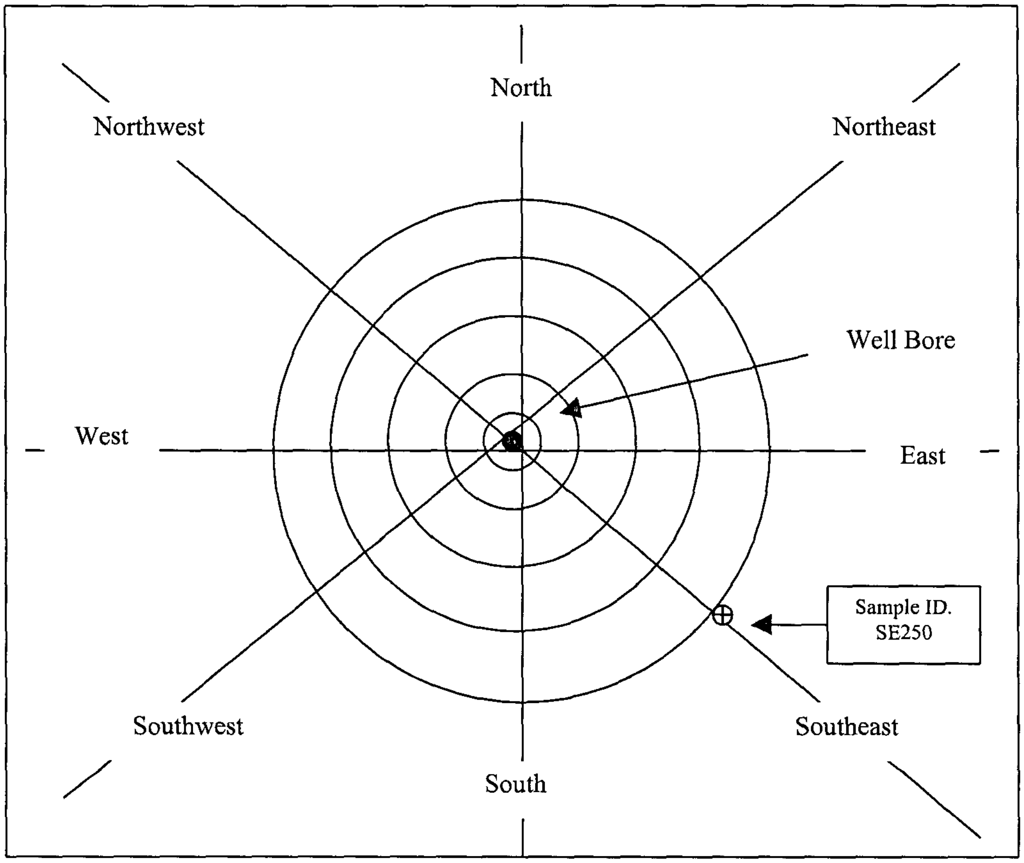
A landfarm will be established and the excavated soil spread in a 6" lift and contained within a bermed area. The lift will be watered and tilled monthly to enhance aerobic biodegradation. To further enhance microbial activity and hasten remediation of the soil, organic material will be tilled in, i.e., straw or hay. It is also contemplated to develop two areas within the landfarm for different matrixes, i.e., one for caliche and one for soil. BTEX and TPH analysis will be performed monthly.

When levels have been reduced to <= the threshold value, the soil will be place back into the excavated pits or spread and recontoured. After remediation is complete, the pastureland will be reseeded with native vegetation.

1.8.3 Surface Soil Contamination Investigation

A comprehensive field survey of the site will be conducted. VOC measurements will be made with a calibrated PID. Sample locations will be established at 50' intervals along the Cardinal and Intermediate Compass Radians. At each sample location the depth to uncontaminated soil will be determined visually and core samples taken at six-inch vertical intervals. These samples will be placed in a plastic bag, it's temperature raised to 70°F, and the head space gas sampled and analyzed with the PID. If contamination is encountered the extent of downward contamination must be observed and noted.

Example of the Soil Sampling Grid:



1.8.4 Ground Water Monitoring

The windmill ~ 200' south of the well bore is down gradient from the pits west of the well bore and will serve as the ground water monitoring location. Initially, BTEX and TPH were undetectable. Samples will be analyzed monthly for 6 months and should be sufficient time for a contaminant plume to migrate to the well. Ground water remediation is not indicated at this time nor is installation of monitoring wells. The TDS, Chloride, and BTEX data presented earlier in this report shall constitute the ground water parameter baseline/background levels.

1.9 Quality Assurance / Quality Control

To ensure that the information used in making the environmental management decisions is reliable, the following protocols will be followed.

1.9.1 Field Sampling and Sample Handling

All samples will be placed in certifiably clean containers obtained from the contracting analytical laboratory. All samples will be properly labeled with the following information:

- Sample date
- Sample time
- Matrix
- Unique Sample Identification Number
- Sampler
- Parameter
- Preservative added
- Preservation method

1.9.2 Sample QA/QC

A duplicate sample will be analyzed every ten samples for all field and laboratory tests. Acceptable relative percent difference will be +/- 20%.

1.9.3 Field Instruments

All analytical instruments used in the field will be calibrated prior to each sampling day activities and verified every two hours of running time.

1.9.4 Analytical Laboratory QA/QC

Quality control data will be submitted by the laboratory to ensure credibility of the laboratory data.

1.10 Plan Implementation

This plan will be implemented after all down hole operations are completed and approval has been issued by the NMOCD.

CARDINAL LABORATORIES, INC.

2111 Beechwood, Abilene, TX 79603 (915) 673-7001 Fax (915) 673-7020
101 East Marland, Hobbs, NM 88240 (505) 393-2326 Fax (505) 393-2476

CHAIN-OF-CUSTODY AND ANALYSIS REQUEST

H3550

Page 1 of 1

Company Name: Callaway Safety / UMC
Project Manager: Pat McCasland
Address: 3229 Industrial Drive
City: Hobbs State: NM Zip: 88240
Phone #: 505 392 2973
Fax #: 505 392 4990
Project #: Carlilse St Com #1 Project Owner: UMC
P[illegible]t Name:
Project Location: 4 miles west of Lovington, NM

BILL TO PO #:
Company:
Attn:
Address:
City:
State: Zip:
Phone #:
Fax #:

FOR LAB USE ONLY				MATRIX						PRES.			SAMPLING		ANALYSIS REQUEST		
LAB I.D.	Sample I.D.	(G)RAB OR (C)OMP.	# CONTAINERS	GROUNDWATER	WASTEWATER	SOIL	OIL	SLUDGE	OTHER :	ACID:	ICE / COOL	OTHER :	DATE	TIME	Chloride	TDS	BTEX
H3550-1	GW98331A1	G	3	✓							✓		3-31-98	1420	✓	✓	✓
H3550-2	GW98331A2	G	3	✓							✓		3-31-98	1420	✓	✓	✓
H3550-3	GW9841A3	G	3	✓							✓		4-1-98	1030	✓	✓	✓
H3550-4	GW98331A4	G	3	✓							✓		3-31-98	1510	✓	✓	✓

PLEASE NOTE: Liability and Damages. Cardinal's liability and client's exclusive remedy for any claim arising whether based in contract or tort, shall be limited to the amount paid by the client for the analyses. All claims including those for negligence and any other cause whatsoever shall be deemed waived unless made in writing and received by Cardinal within 30 days after completion of the applicable service. In no event shall Cardinal be liable for incidental or consequental damages, including without limitation, business interruptions, loss of use, or loss of profits incurred by client, its subsidiaries, affiliates or successors arising out of or related to the performance of services hereunder by Cardinal, regardless of whether such claim is based upon any of the above stated reasons or otherwise.

Terms and Conditions: Interest will be charged on all accounts more than 30 days past due at the rate of 24% per annum from the original date of invoice, and all costs of collections, including attorney's fees.

Sampler Relinquished:
Date: 4-1-98
Time: 1200
Received By:

Relinquished By:
Date: 4/1/98
Time: 12:02
Received By: (Lab Staff)

Delivered By: (Circle One)
Sampler - UPS - Bus - Other:

Sample Condition
Cool: ☒ Yes ☐ No
Intact: ☒ Yes ☐ No

CHECKED BY: (Initials)

Phone Result ☐ Yes ☐ No Additional Fax #:
Fax Result: ☐ Yes ☐ No
REMARKS:

† Cardinal cannot accept verbal changes. Please fax written changes to 915-673-7020.

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PHONE (915) 673-7001 • 2111 BEECHWOOD • ABILENE, TX 79603
PHONE (505) 393-2326 • 101 E. MARLAND • HOBBS, NM 88240

ANALYTICAL RESULTS FOR
CALLAWAY SAFETY/UMC
ATTN: PAT McCASLAND
3229 INDUSTRIAL DR.
HOBBS, NM 88240
FAX TO: 505-392-4990

Receiving Date: 04/01/98
Reporting Date: 04/02/98
Project Owner: UMC
Project Name: CARLISLE ST. COM #1
Project Location: 4 MILES WEST OF LOVINGTON, NM

Sampling Date: 03/31/98
Sample Type: GROUNDWATER
Sample Condition: COOL & INTACT
Sample Received By: GP
Analyzed By: BC/AH

LAB NUMBER	SAMPLE ID	TDS (mg/L)	Cl (mg/L)	BENZENE (mg/L)	TOLUENE (mg/L)	ETHYL BENZENE (mg/L)	TOTAL XYLENES (mg/L)
ANALYSIS DATE:		04/01/98	04/01/98	04/01/98	04/01/98	04/01/98	04/01/98
H3550-1	GW98331A1	375	48	<0.002	<0.002	<0.002	<0.006
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Burgess J.A. Cooke

Burgess J. A. Cooke. Ph.D.

4/2/98

Date