

**PHASE II SITE ASSESSMENT
CITY OF KENAI MAINTENANCE SHOP
KENAI, ALASKA**

Prepared For:

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RECEIVED

JUN 06 1995

Department of
Environmental Conservation
KDO

June, 1995
Project # 94133

Northern Test Lab

June 2, 1995

94133

Rachel Clark
City of Kenai
210 Fildalgo
Kenai AK 99611

Subject: Kenai Maintenance Shop Phase II Site Assessment
ADEC Spill # 94-23-01-101-02

Ms. Clark:

This Phase II Site Assessment report is presented based upon further field investigation at the City Maintenance Shop. The work has been performed in general accordance with NTL protocol and ASTM standards. We have made recommendations for additional work at the site.

We appreciate the opportunity to have performed this work for you.

Please call if you have any questions.



Peter Campbell
Environmental Scientist

Attachments



Kenai\mainshop\kmsp2.011

PHASE II SITE ASSESSMENT

CITY OF KENAI MAINTENANCE SHOP

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CITY OF KENAI MAINTENANCE SHOP

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SUMMARY

The City of Kenai, in response to a request from the Alaska Department of Environmental Conservation (ADEC), retained Northern Test Lab (NTL) to conduct a Phase I and Phase II Site Assessment of the City Maintenance Shop in Kenai, Alaska after petroleum products were discovered at the old Carver Drilling Company (currently the Kenai Airport Fuel Service Tesoro Gas Station).

The site had been used as a military facility prior to 1963 when the property was deeded to the City of Kenai. The military facility consisted of barracks, mess hall, and fuel storage. The City has used the property for maintenance and storage for all City equipment.

During the course of the investigation several potential sources of contamination were identified. The Phase II investigation was designed to pursue information gathered in the Phase I investigation with a drilling and sampling program. Significant levels of contamination were confirmed in what has been known as the drum disposal area, and the old road oil pit. Diesel range organics were discovered in all seven monitor wells, and chlorinated solvents were identified in four of the wells and one of the soil borings. Gasoline range organics were identified in one of the wells and three of the soil borings. No contamination was detected in three of the borings.

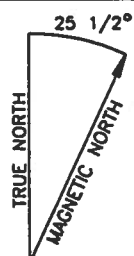
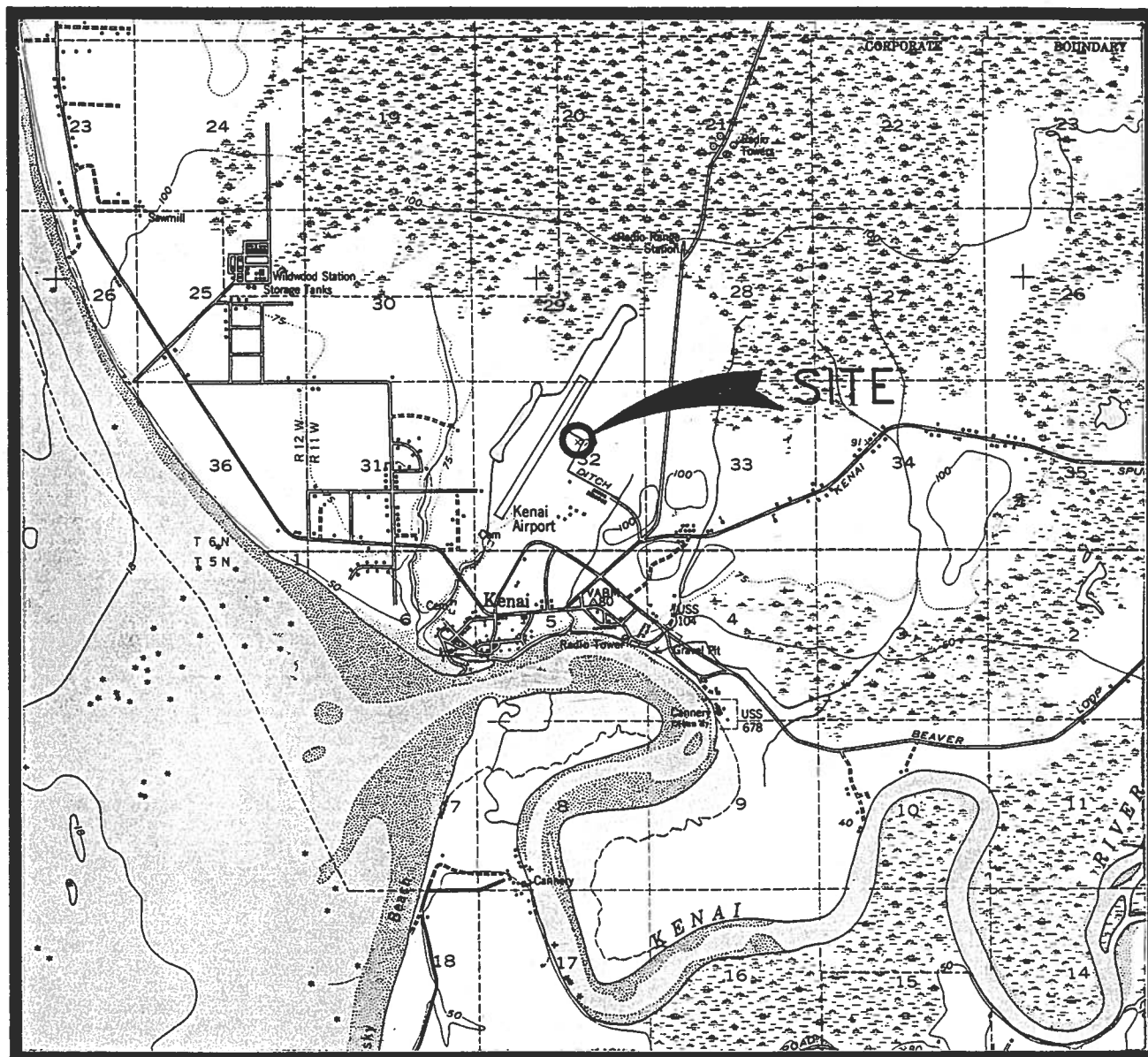
We have recommended resampling the monitor wells prior to conducting any further work. Then excavating the grossly contaminated areas, and again resampling the wells. After further information is gathered, re-evaluate the data. Additional wells have been recommended to define the type and extent of contamination present.

1. INTRODUCTION

1.1 Background

The City Maintenance Shop is located near the corner of Airport Way and Willow Street approximately 700 feet east of the Kenai Airport Terminal. Legal description: FBO Subdivision, Tract A; 10.96 acres in Section 32, T6N, R11W, Kenai, Alaska; 60° 34' North Latitude and 151° 14' West Longitude. See Figure 1. Street and airport equipment are stored, repaired, and maintained at the facility.

The property had been part of a military facility since the 1940s. No known use occurred prior to military development of the site. The City acquired the property from the Federal Aviation Administration in 1963. The Maintenance Shop was constructed prior to 1980. Four underground



APPROXIMATE
MEAN
DECLINATION,
1951

TOPOGRAPHIC SITE LOCATION MAP
CITY OF KENAI MAINTENANCE SHOP
ENVIRONMENTAL SITE ASSESSMENT REPORT
FBO SUB. TRACT A, 10.96 ACRES, SEC. 32, T6N, R11W SM
ADAPTED FROM USGS 1951 15' TOPOGRAPHIC QUADRANGLE
KENAI (C-4), ALASKA

0 5280' 10560'

Northern Test Lab

storage tanks were removed from the site in 1988. No spills or releases have been reported to ADEC from the Maintenance Shop, however, ADEC has assigned Spill #94-23-01-101-02 to the site as a result of an investigation on an adjoining parcel.

During a routine property transaction site assessment for the Kenny Carver Drilling Company property, diesel contamination was discovered in test pits on that property which is southwest of and adjacent to the Maintenance Shop property.

A Phase I Site Assessment was performed by NTL in 1994. Our historical research has included review of aerial photographs, site plans, surveys, and geologic and soils maps. Groundwater use in the immediate vicinity and within a two mile radius was reviewed and State and Federal records of waste disposal sites close to the site were also reviewed. Results were reported to the City in a March 1995 report.

The Phase I investigation by NTL identified eight potential areas of subsurface contamination. Several of the potential sources of contamination originated with the military uses of the property, and included the on site disposal of waste products left by the military.

1.2 Scope of Work

The City of Kenai requested that NTL conduct a Phase I Site Assessment to identify the likelihood of soil and groundwater contamination and the nature of potential sources, and prepare a report based on the findings. This Phase II assessment was subsequently authorized as a drilling investigation to qualify data gathered in the Phase I investigation.

This work covers the site investigation specified by the City to accomplish the following objectives:

- Determine if site soil or groundwater contamination is present
- Determine sources of contamination associated with past uses
- Determine if any additional site investigation is necessary
- Report the Phase II findings to the client.

2. INVESTIGATION METHODS

This environmental site assessment has been implemented in two phases. The Phase II investigation followed the recommendations made in the Phase I report. Phase II includes subsurface investigation and analytical sampling. This phase of the investigation involved drilling six soil borings and seven monitor wells on and adjacent to the City Maintenance Shop property.

2.1 Drilling Investigation

On March 29, 1995 Hughes Drilling and NTL arrived on site to begin the drilling investigation. The site had been previously marked for utility locates. Soil borings were located to determine soil conditions, primarily at the soil/water interface, in the areas of known or reported problems. Monitor wells were located on the probable downgradient side of known or suspected problems to monitor groundwater quality. Two monitor wells were located in the probable up-gradient direction to determine water quality coming onto the property. Soil samples from each borehole were collected at five-foot intervals with a two-foot split spoon sampler driven by a 340 pound hammer. Blow counts were recorded and the soil type logged. The soils were screened with an organic vapor monitor (OVM) and contained in appropriate sample jars. The soils exhibiting the greatest observable contamination, or the sample at the soil water interface in the case of a clean hole, were then submitted to the laboratory for analysis. Cuttings from the borings were contained in fifty-five gallon drums for storage on site, currently in the north storage yard.

Soil borings were backfilled with bentonite chips to seal the borehole. In areas of foot traffic the last half foot was covered with sand and gravel. Wells were set so that the 10 foot screen straddled the water table, five feet above and below the water. The borehole was sand packed to approximately 1 foot above the screen. Bentonite grout was added to the borehole from the top of the sand to the surface. The well casing was secured with either a flush mount or surface locking protective casing. The security casing was cemented with concrete and locked. Individual well and soil boring details are presented in Appendix A: Drillers Logs.

The wells were allowed to stabilize for a few days prior to development and sampling. The static water levels were measured, and a minimum of three casing volumes were purged from the well. The purge water was then measured for temperature, conductivity, pH, and dissolved oxygen. The well was continually purged until the water stabilized within approximately 10% of the noted parameters. Water samples were collected with disposable bailers. The water samples were sent to Commercial Testing and Engineering in Anchorage under Chain-of-Custody.

The water wells were surveyed by Swan surveying, and the well and boring locations were plotted on a base map provided by Swan Surveying and digitized by NTL (Figure 2).

2.2.1 Soil Borings

The drill rig was positioned in the reported drum disposal area. Soil boring SB1 was advanced to the water table, and to a total depth of 11.5'. No drums were contacted because the soil boring was located on the southern side of the geophysical anomaly. OVM readings of 22.6 ppm were

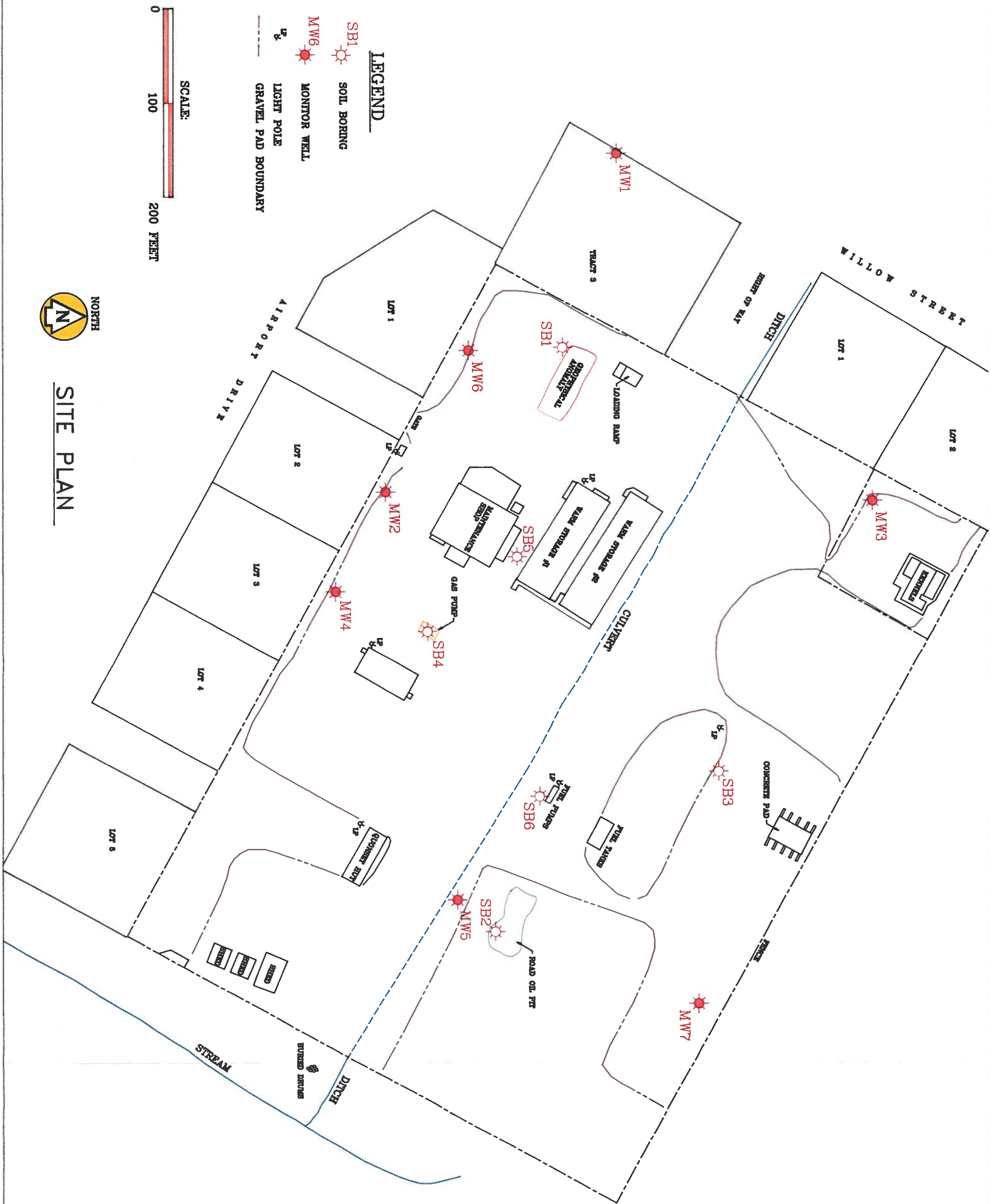


FIGURE 2

SITE LOCATION MAP

Northern Test Lab
CITY OF KENAI MAINTENANCE SHOP

DATE 5/24/88
DRAWN TS
CHECKED PC
SCALE 1"=100
PROJ. NO. 84133

encountered in the first split spoon, which increased to 279 ppm in the second spoon. A soil sample from the second spoon was collected for laboratory analysis. The results are presented in Table 1. Complete sample results are presented in Appendix B: Laboratory Sample Results.

TABLE 1: SB1 SOIL SAMPLE RESULTS

SAMPLE NO.	LOCATION	PARAMETERS	ANALYTIC RESULTS	OVM READING
KMS-01-02-9.5	SB1 9.5-11.5'	EPA 8100	9300 ppm DRO	279 ppm
		SM17 9215D	LT 235 col/gm HETEROTROPHIC PLATE COUNT	
KMS-02-02-9.5	SB1 9.5-11.5'	EPA 8015	113 ppm VPH	
		EPA 8020	0.054 ppm TOLUENE 1.77 ppm ETHYL BENZENE 1.741 ppm T-XYLENE	
		EPA 8010	0.069 ppm 1,4 DICHLOROBENZENE 0.159 ppm 1,2 DICHLOROBENZENE	

Soil boring SB2 was drilled in the road oil pit identified in the aerial photographs from the Phase I investigation. The first split spoon sample retrieved a foot thick layer of black, oil-soaked material at 5 to 6' below ground level (BGL). The soils had an oily odor and OVM readings of 359 ppm. This probably was the road oil pit bottom. The second sample at 9.5' had OVM reading of 151 ppm, and was water saturated. A sheen was noted on the sampler and in the water of the sample. The 9.5 foot sample was collected for analysis. Sample results from this boring are presented in Table 2.

TABLE 2: SB2 SOIL SAMPLE RESULTS

SAMPLE NO.	LOCATION	PARAMETERS	ANALYTIC RESULTS	OVM READING
KM2-01-02-9.5	SB2 9.5-11.5'	EPA 8100	1190 ppm DRO	151 ppm
		EPA 8080	ND PCB	
KM2-02-02-9.5	SB2 9.5-11.5'	EPA 8015	127 ppm VPH	
		EPA 8020	0.087 ppm BENZENE 0.511 ppm TOLUENE 1.06 ppm ETHYL BENZENE 3.93 ppm T-XYLENE	
		EPA 8010	ND SOLVENTS	

Soil boring 3 (SB3) was drilled in the north storage yard at a location specified by the City. A Maintenance Shop employee reported, subsequent to the Phase I investigation, that the City had at one time disposed of oil in a dump site in this area. We drilled at the specified location but could find no apparent trace of oil. The first split spoon had no indication of oil, either in OVM readings, odor or staining. The second sample had an OVM reading of 3.1 ppm and no other indicators. The laboratory sample results indicated no detectable contamination. Sample summaries are presented in Table 3.

TABLE 3: SB3 SOIL SAMPLE RESULTS

SAMPLE NO.	LOCATION	PARAMETERS	ANALYTIC RESULTS	OVM READING
KM3-01-02-9.5	SB3 9.5-11.5'	EPA 8100	ND DRO	3.1 ppm
KM3-02-02-9.5	SB3 9.5-11.5'	EPA 8015	ND VPH	
		EPA 8020	ND BTEX	

Soil boring SB4 was drilled in the old (1980) pump island area identified in the Phase I investigation. The first split spoon retrieved what was apparently backfill from the pump island excavation. OVM readings of 4.7 ppm were observed in the first sample. The second sample from the soil water interface, collected from 9.5 feet, had 590 ppm on the OVM. A sample from this interval was analyzed at the laboratory; results are presented in Table 4.

TABLE 4: SB4 SOIL SAMPLE RESULTS

SAMPLE NO.	LOCATION	PARAMETERS	ANALYTIC RESULTS	OVM READING
KM4-01-02-9.5	SB4 9.5-11.5'	EPA 8100	8.37 ppm DRO	570 ppm
		SM17 9215D	LT 219 col/gm HETEROTROPHIC PLATE COUNT	
KM4-02-02-9.5	SB4 9.5-11.5'	EPA 8015	142 ppm VPH	
		EPA 8020	0.257 ppm BENZENE 0.123 ppm TOLUENE 0.685 ppm ETHYL BENZENE 2.585 ppm T-XYLENE	

Soil boring SB5 was drilled between the Maintenance Shop and Warm Storage Building 1. This area was of concern because it was a drum storage area prior to construction of the annex on the north

side of the shop. No contamination was observed during drilling, and none was detected in the laboratory results. Laboratory results are presented in Table 5.

TABLE 5: SB5 SOIL SAMPLE RESULTS

SAMPLE NO.	LOCATION	PARAMETERS	ANALYTIC RESULTS	OVM READING
KM5-02-02-9.5	SB5 9.5-11.5'	EPA 8015	ND VPH	1.5 ppm
		EPA 8020	ND BTEX	
		EPA 8010	ND SOLVENTS	

Soil boring SB6 was drilled adjacent to the existing pump island to investigate the possibility of fuel contamination. The boring was placed on the probable downgradient side of the island, and within the radius of the hose, to best find contamination if present, at the same time avoiding electrical and fuel lines. No contamination was detected in either of the soil samples or in the samples submitted to the laboratory for analysis. Sample results are presented in Table 6.

TABLE 6: SB6 SOIL SAMPLE RESULTS

SAMPLE NO.	LOCATION	PARAMETERS	ANALYTIC RESULTS	OVM READING
KM6-01-02-9.5	SB6 9.5-11.5'	EPA 8100	ND DRO	ND
KM6-02-02-9.5	SB6 9.5-11.5'	EPA 8015	ND VPH	
		EPA 8020	ND BTEX	

2.2.2 Monitor Well Drilling

Monitor well MW1 was drilled in the southwest corner of the airport long term parking overflow lot. This well was located to determine any long term effects from fuel storage in this area during the 1950s. The well was drilled to 15', with no field observable contamination encountered. Laboratory samples indicated a trace (0.225 ppm) of diesel range contamination in the water. Water sample results for MW1 are presented in Table 13.

Monitor well MW2 was located 60' south of the shop to determine water quality downgradient from the floor-drain drain field. No contamination was detected with the OVM, and no odors were noted in the soils. Soil sampling data are presented in Table 7.

TABLE 7: MW2 SOIL SAMPLE RESULTS

SAMPLE NO.	LOCATION	PARAMETERS	ANALYTIC RESULTS	OVM READING
KMW2-01-02-9.5	MW2 9.5-11.5'	EPA 8100	ND DRO	ND
KMW2-02-02-9.5	MW2 9.5-11.5'	EPA 8015	ND VPH	
		EPA 8020	ND BTEX	
		EPA 8010	ND SOLVENTS	

MW 3 was located southeast of the animal shelter as an upgradient monitor well. No contamination was detected with the OVM, and no odors were noted in the soils. Soil sampling data are presented in Table 8.

TABLE 8: MW3 SOIL SAMPLE RESULTS

SAMPLE NO.	LOCATION	PARAMETERS	ANALYTIC RESULTS	OVM READING
KMW3-01-02-9.5	MW3 9.5-11.5'	EPA 8100	ND DRO	ND
KMW3-02-02-9.5	MW3 9.5-11.5'	EPA 8015	ND VPH	
		EPA 8020	ND BTEX	
		EPA 8010	ND SOLVENTS	

Monitor well MW4 was drilled along the fence line southwest of the water/sewer office. This location was chosen to check groundwater quality downgradient from the old pump island. Soil sample results are presented in Table 9. No detectable concentrations were noted with the OVM and soil samples came back clean.

TABLE 9: MW4 SOIL SAMPLE RESULTS

SAMPLE NO.	LOCATION	PARAMETERS	ANALYTIC RESULTS	OVM READING
KMW4-01-02-9.5	MW4 9.5-11.5'	EPA 8080	ND PCB	ND
KMW4-02-02-9.5	MW4 9.5-11.5'	EPA 8015	ND VPH	
		EPA 8020	ND BTEX	

Monitor well MW5 was drilled downgradient from the road oil pit. No contamination was detected in field screening with the OVM. The soils in this sample were not analyzed for petroleum hydrocarbons, but were checked for biological activity. The heterotrophic plate count is a method of determining biological activity on petroleum contaminated soils.

TABLE 10: MW5 SOIL SAMPLE RESULTS

SAMPLE NO.	LOCATION	PARAMETERS	ANALYTIC RESULTS	OVM READING
KMW5-01-02-9.5	MW5 9.5-11.5'	SM17 9215D	15500 col/gm HETEROTROPHIC PLATE COUNT	ND

Monitor well MW6 was drilled south of the reported drum disposal area (geophysical anomaly). The soil sample from 4.5 to 6.5 feet had no odor and no OVM detectable concentrations in the soil. The sample from the 9.5 to 11.5 foot interval, which straddled the water table had a strong petroleum odor and OVM readings of 335 ppm. The 9.5 foot sample was analyzed at the laboratory, with results presented in Table 11.

TABLE 11: MW6 SOIL SAMPLE RESULTS

SAMPLE NO.	LOCATION	PARAMETERS	ANALYTIC RESULTS	OVM READING
KMW6-01-02-9.5	MW6 9.5-11.5'	EPA 8100	7490 ppm DRO	335 ppm
KMW6-02-02-9.5	MW6 9.5-11.5'	EPA 8015	475 ppm VPH	
		EPA 8020	7.04 ppm ETHYLBENZENE 6.65 ppm T-XYLENE	

Monitor well MW7 was positioned to be an upgradient well, monitoring groundwater quality moving onto the site. No OVM detectable concentrations were noted in the drilling process. Soil samples were collected from the soil water interface at the 9.5' interval. Sample results are presented in Table 12.

TABLE 12: MW7 SOIL SAMPLE RESULTS

SAMPLE NO.	LOCATION	PARAMETERS	ANALYTIC RESULTS	OVM READING
MW7-02-02-9.5	MW7 9.5-11.5'	EPA 8015	ND VPH	ND
		EPA 8020	ND BTEX	
MW7-04-02-9.5	MW7 9.5-11.5'	EPA 8015	ND VPH	
		EPA 8020	ND BTEX	

A soil sample was collected from this borehole and a gradation was completed on the sample. The sample was collected from the auger flights, and based on our experience is not representative of the native Kenai Sands. This material is a very fine sand with 24% silt, characteristic of the surficial soils and fill in the area. The Kenai sands typically have about 3% silt and are coarser. The gradation results are presented in Appendix B.

2.2 Monitor Well Sampling

A synoptic water level survey was conducted on April 3, 1995. All of the wells were measured for the depth to the water table from the top of casing. This data was compiled with the survey data to generate an elevation table presented in Appendix C: Elevational Data. The groundwater elevation data has been used to generate a water table contour map presented as Figure 3.

The monitor wells were sampled on April 3rd and 4th, 1995. Three times the casing volume of water was removed from each well. The purged water was checked for temperature, pH, conductivity, and dissolved oxygen. The data has been tabulated along with the well sample results in Tables 13 through 19.

TABLE 13: MW1 WATER SAMPLE RESULTS

TIME	TEMPERATURE	pH	CONDUCTIVITY	TEMPERATURE	DISSOLVED OXYGEN	TEMPERATURE
17:07	4.0	8.28	83.7	4.2	38	4.8
17:15	4.2	9.15	58.6	4.1	33	3.9
17:20	3.9	8.52	64.1	3.9	37	4.3

SAMPLE NO.	LOCATION	PARAMETERS	ANALYTIC RESULTS
KMW1-01-05	MW1	EPA 8100	0.225 ppm DRO
KMW1-02-05	MW1	EPA 601	ND
		EPA 602	ND

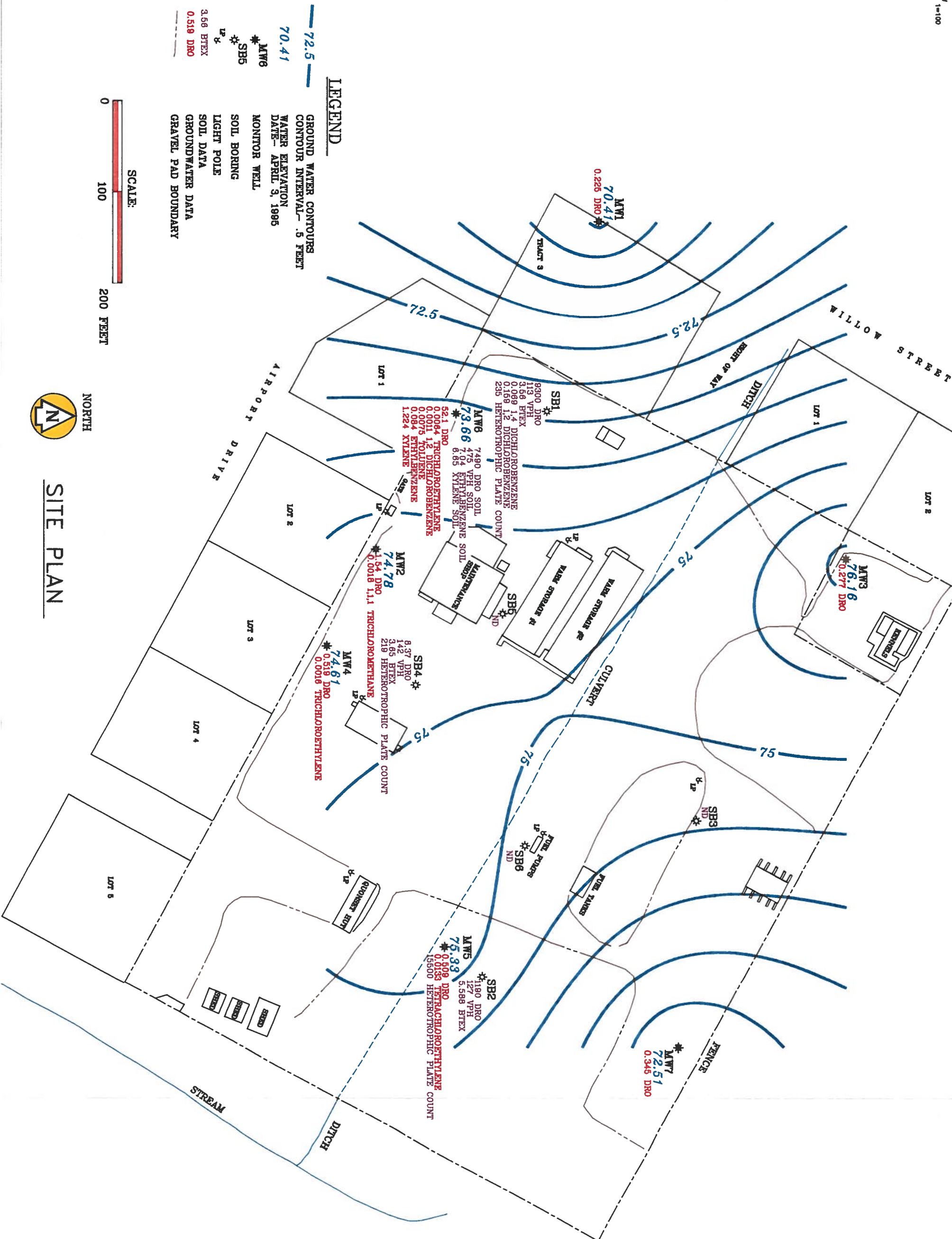


TABLE 14: MW2 WATER SAMPLE RESULTS

TIME	TEMPERATURE	pH	CONDUCTIVITY	TEMPERATURE	DISSOLVED OXYGEN	TEMPERATURE
11:20	6.3	8.04	168.4	5.3	25	6.3
11:30	4.8	6.7	162.8	5.6	25	5.6
11:37	5.1	6.86	169.1	4.8	25	5.8
SAMPLE NO.	LOCATION	PARAMETERS	ANALYTIC RESULTS			
KMW2-01-08	MW2	EPA 8100	1.54 ppm DRO			
KMW2-02-08	MW2	EPA 601	0.0018 ppm 1,1,1 TRICHLOROETHANE			
		EPA 602	ND			

TABLE 15: MW3 WATER SAMPLE RESULTS

TIME	TEMPERATURE	pH	CONDUCTIVITY	TEMPERATURE	DISSOLVED OXYGEN	TEMPERATURE
16:15	2.6	8.5	86.9	2.8	43	4.2
16:25	2.4	8.46	83.6	2.6	39	3.3
SAMPLE NO.	LOCATION	PARAMETERS	ANALYTIC RESULTS			
KMW3-01-04	MW3	EPA 8100	0.277 ppm DRO			
KMW3-02-04	MW3	EPA 601	ND			
		EPA 602	ND			

TABLE 16: MW4 WATER SAMPLE RESULTS

TIME	TEMPERATURE	pH	CONDUCTIVITY	TEMPERATURE	DISSOLVED OXYGEN	TEMPERATURE
10:35	4.2	7.11	249	5.2	23	5.3
10:40	4.0	7.49	250	5.2	25	4.8
SAMPLE NO.	LOCATION	PARAMETERS	ANALYTIC RESULTS			
KMW4-01-07	MW4	EPA 8100	0.519 ppm DRO			
		EPA 8080	ND			
KMW4-02-07	MW4	EPA 601	0.0016 ppm TRICHLOROETHYLENE			
		EPA 602	ND			

TABLE 17: MW5 WATER SAMPLE RESULTS

TIME	TEMPERATURE	pH	CONDUCTIVITY	TEMPERATURE	DISSOLVED OXYGEN	TEMPERATURE
9:40	7.2	8.57	152.2	5.3	20	10.7
9:45	4.0	8.32	147.3	3.7	24	4.7
SAMPLE NO.	LOCATION	PARAMETERS	ANALYTIC RESULTS			
KMW5-01-06	MW5	EPA 8100	0.509 ppm DRO			
KMW5-02-06	MW5	EPA 601	0.0133 ppm TETRACHLOROETHYLENE			
		EPA 602	ND			

TABLE 18: MW6 WATER SAMPLE RESULTS

TIME	TEMPERATURE	pH	CONDUCTIVITY	TEMPERATURE	DISSOLVED OXYGEN	TEMPERATURE
13:20	6.7	7.14	419	7.12	20	7.9
13:25	6.2	7.15	398	5.3	23	7.1
SAMPLE NO.	LOCATION	PARAMETERS	ANALYTIC RESULTS			
KMW6-01-09	MW6	EPA 8100	52.1 ppm DRO			
KMW6-02-09	MW6	EPA 601	0.0064 ppm TRICHLOROETHYLENE 0.0011 ppm 1,2 DICHLOROBENZENE			
		EPA 602	0.0075 ppm TOLUENE 0.084 ppm ETHYLBENZENE 1.224 ppm T-XYLENE			

TABLE 19: MW7 WATER SAMPLE RESULTS

TIME	TEMPERATURE	pH	CONDUCTIVITY	TEMPERATURE	DISSOLVED OXYGEN	TEMPERATURE
15:14	3.9	7.57	282	5.6	38	5.9
15:18	3.2	8.84	49.3	4.5	31	3.7
15:22	3.0	8.86	45.3	4.2	36	4.7
SAMPLE NO.	LOCATION	PARAMETERS	ANALYTIC RESULTS			
KMW7-01-03	MW7	EPA 8100	0.345 ppm DRO			
KMW7-02-03	MW7	EPA 601	ND			
		EPA 602	ND			

TABLE 20: TRIP BLANK WATER SAMPLE RESULTS

SAMPLE NO.	LOCATION	PARAMETERS	ANALYTIC RESULTS
TRIP BLANK		EPA 601	ND
TRIP BLANK		EPA 602	ND

Soil and water sampling data have been compiled and presented on Figure 3.

3. ADDITIONAL INFORMATION GATHERED

During a routine utility locate, a former City employee stopped at the site and stated that the Quonset hut was the City electrical shop, and that transformer oils may have been dumped on the site. He indicated a potential area of dumping south of the Quonset hut. This information had not been considered in the design of the Phase II investigation.

An oil dumping area was also identified by a City employee in the north storage yard. Used oils were apparently dumped into a pit on a regular basis in the 1970s. The oiled material was apparently excavated in the 1980s. No trace of this site was found in our investigation, but this may be a source of undefined contamination.

It appears that the land to the north of the maintenance shop property, which was a borrow pit identified in the Phase I investigation, may have been filled with debris. This was reportedly filled with military construction materials, machinery, and other types of waste material.

Five buried drums were observed outside of the fence on the east side of the site, south of the ditch. The City has confirmed that the drums are on the Maintenance Shop property, and have visually inspected the drums, which bear Fort Richardson, aircraft fuel labels. The drum contents have not been inspected to determine if they are empty or full.

4. DATA INTERPRETATION

SB1 which was drilled in the drum storage area, exhibited elevated gasoline and diesel range organics, as did MW6, slightly to the southeast. This represents a significant area of contamination of both the soil and groundwater. The groundwater flow patterns in this area, according to our interpretation of the flow based on the data, should be carrying the contamination to MW1, which

has not been observed. It is possible that groundwater flow more southerly, and the chlorinated solvents present in MW6 are being carried from the floor drain sump, and away from MW1.

Chlorinated solvents were detected in four of the monitor well samples. Two of the wells, MW6 and MW5, have concentrations above the maximum contaminant level (MCL). See Appendix D: Maximum Contaminant Levels. The potential contamination sources at MW6 have been discussed, and the source at MW5 has not been explained. No chlorinated solvents were detected in the road oil pit. Chlorinated solvents are heavier than water, and tend to settle in the water table. If pure product is present, it can pool at the bottom of the aquifer, with dilute concentrations bleeding off. It may be that this is material dissolved in the soil, with no pure product source. Because our wells are shallow, and screened at the soil-water interface, we have no significant knowledge of the deeper lithologies or chemical concentrations.

The microbial enumeration test (heterotrophic plate count) is a measure of biological activity in the soil and water. It is interesting to note that in samples with higher diesel range organics, (SB1 & SB4) the plate counts are significantly lower than in MW5, where the diesel range organics are apparently lower.

Diesel range organics were detected in all seven of the monitor wells, including the upgradient wells, and in four of the six soil borings. Diesel range organics were not detected in the trip blanks. It appears from this single round of sampling that groundwater contamination is wide spread from an unidentified source or sources. Some low level diesel range detects (<0.3 ppm) can be attributed to biogenic interference; that is, the product of biological decay can show up in the EPA 8100 method. This interference, if present can be eliminated by doing a methanol extraction on the sample. However, based on our understanding of the site and surrounding uses, it is likely that a source of contamination exists off site, leading to at least some of the widespread contamination.

The areas of very high diesel range contamination can be attributed to sources identified in the Phase I investigation. The drum disposal area, the floor drain sump, the 1980s pump island and the road oil pit, all appear to be sources of contamination. The drum disposal area appears to have the greatest concentration of contamination. Based on information gathered in our Phase I investigation, this material was left over from the military base, and buried by the City.

4.1 Potential Impacts

4.1.1 Groundwater

Groundwater has apparently been impacted in two primary areas, the drum disposal area, which includes the shop, and the abandoned road oil pit. Contaminated groundwater is apparently moving off site in the southwest portion of the property, and possibly to the northeast. The adjoining property to the southeast, a Tesoro gas station, has apparently been impacted by contamination migrating off this site.

4.1.2 Surface water

The ditch running through the site, is mostly contained in a culvert. There have been reports of sheens and odors emanating from the stream in the past, but our limited inspections have not revealed any direct contamination from the groundwater to the surface water.

During spring breakup, fuel spilled to the ground in the area of the pump island was observed flowing across the ground with the meltwater. This water was ponding north of the ditch.

The above-ground tank area has had a valve installed on the berm drain pipe to cut off the flow of water from inside the berm to the ground. Recent inspection revealed the valve in the open position. This defeats the purpose of the valve and berm.

4.1.3 Air

The subsurface contamination observed at the site has not been exposed to the air. No air emissions have been documented from the subsurface contamination.

4.1.4 Direct Contact With Materials

Contamination observed at the property, as the focus of this site assessment, is subsurface. Monitor wells are locked and the property is secured with a chain link fence, controlling access. Two, fifty-five gallon drums with drill cuttings and development water remain on site. The drums are sealed and labeled, and have been placed in the north storage yard on pallets.

4.1.5 Fire and Explosion

The storm drains adjoining the property have been checked for explosive levels; none were found. Discharges to surface water are not at an explosive level. Buildings in the area have been constructed on slab, with no basements to collect vapors. No fire or explosive hazards were observed during the subsurface investigation.

4.2 Estimates of Contamination

We have identified two primary areas of soil contamination on site, the drum disposal area, and the old road oil pit. The drum disposal area has been approximately located with a geophysical survey. Estimates of the volume of contaminated soil are based on the size of the geophysical anomaly, and the soils contamination extending from two feet below ground surface to the water table. We estimate approximately 1000 cubic yards of contaminated soil and drums. Assuming a product smear zone of approximately 3 feet at the soil/water interface, another 5,000 to 10,000 cubic yards of soil could be contaminated. Because the drums have been buried for approximately 30 years, the potential for a significant groundwater plume is likely. The length of a plume has not been determined.

The road oil pit in the northeast side of the property has been calculated to contain approximately 650 cubic yards of contaminated material based on the size of the pit determined from aerial photos. The pit measured 70 feet by 40 feet with an assumed thickness of 6 feet. No estimates of plume migration have been made due to lack of empirical data.

Secondary sources of contamination include the old pump island, the shop floor drain, possible off-site sources, and some source of diesel range product that has shown up in all of the monitor wells. The old pump island area soil samples exceeded the Level B cleanup standards for gasoline at 142 ppm VPH. Monitor wells MW2 and MW4 both exhibited diesel range contamination above action levels, along with trace amounts of chlorinated hydrocarbons.

4.3 Matrix Score

The following table presents the matrix score used by ADEC to determine required cleanup levels for soils at UST sites. The table has been completed to address conditions at the site. The cleanup level for diesel fuel in groundwater has been set at the detection level of 0.5 ppm EPH. The complete matrix score guidelines are presented in Appendix E.

TABLE 21: KENAI MAINTENANCE SHOP MATRIX SCORE

DEPTH TO SUBSURFACE WATER: 5 to 15 FEET	8
MEAN ANNUAL PRECIPITATION: 15-25 INCHES	3
SOIL TYPE: CLEAN COARSE-GRAINED SOILS	10
POTENTIAL RECEPTORS: NO KNOWN WELL WITHIN 1 MILE	4
VOLUME OF CONTAMINATED SOIL: > 500 CUBIC YARDS	10
TOTAL MATRIX SCORE:	35

With a matrix score of 35 for soil remaining in the ground, the site would be a Level B clean up. See Table 22. The matrix score applies to soils contamination. Because groundwater contamination has occurred, guidelines state that remediation may be required to reach background levels.

TABLE 22: CLEANUP LEVELS

MATRIX SCORE	CLEANUP LEVEL IN mg/kg (ppm)			
	DIESEL (EPH)	GASOLINE/UNKNOWN		
	DIESEL RANGE PETROLEUM HYDROCARBONS	GASOLINE RANGE PETROLEUM HYDROCARBONS	BENZENE	BTEX
LEVEL A >40	100	50	0.1	10
LEVEL B 27-40	200	100	0.5	15
LEVEL C 21-26	1000	500	0.5	50
LEVEL D <20	2000	1000	0.5	100

5. GEOLOGY & HYDROGEOLOGY

According to the USGS Professional Paper 443, Geology of the Kenai Lowlands, the area is in "the Cook Inlet Lowland physiographic region that occupies a structural trough, underlain by rocks of Tertiary age and mantled by [unconsolidated] Quaternary deposits of varying thickness." Further, deposits in the "area consist of proglacial-lake-bottom sediments underlying terraced and channeled surfaces between major morainal belts in [the] lowlands..." The site lies north of the Kenai River, and east of Cook Inlet. The general area is characterized by proglacial lake deposits, windblown sands and silts, swamps, and poorly integrated drainage patterns.

The USDA Soil Survey of the Kenai-Kasilof Area, Alaska refers to the native soils in the area as part of the "Soldatna series of well-drained soils developed in a moderately deep to deep mantle of wind-

laid silty material over a thick deposit of gravelly sand or coarse sand." Soils encountered in the boreholes were generally surficial sands and gravels with some silt at the surface, underlain by medium sand with minor gravel at depth.

We estimated groundwater depth at approximately 9 to 9.5' BGL on site. While drilling we encountered groundwater as shallow as 6.7 feet BGL in MW5 near the ditch, and averaging approximately 10' BGL. Potable water for the area is provided by municipal wells which are located several miles from the site. Based on our knowledge of the site conditions, and monitor well data from adjoining properties, we expected a uniform groundwater flow pattern from the north-northwest to the south-southeast. The data mapped out significantly different. The ditch running across the property may be acting as a groundwater divide, but we do not have enough elevational data to confirm or explain this apparent anomaly.

The ditches and streams were filled with snow, making surveying the water levels impossible at the time. The surface water should be tied into the survey during the next synoptic water level survey. With this single round of elevational data from the monitor wells, our confidence in the data is low, primarily due to the time of year. Much of the ground was frozen at the time of the investigation, with significant surface water flow from snow melt. The influence of this snow melt on groundwater flow is unknown.

The medium to coarse sands encountered at the site are estimated to have an estimated porosity of 25 to 40%. The surficial material encountered on site, which had a larger partition of silt could range from 25 to 50% porosity.

Typical hydraulic conductivity for fine to coarse sand ranges from 10^{-1} to 10^4 gallons per day per square foot (Driscoll). The thickness of this aquifer has not been determined to calculate the actual conductivity. The groundwater contours presented on Figure 3 depict a groundwater gradient from 0.65 to 1.25%. Other sites in the area, (Haliburton property, Kenai Airport UST) have gradients approximating 0.27%.

6. CONCLUSIONS & RECOMMENDATIONS

Of the eight potential sources of contamination were identified in the Phase I investigation, four appear to be sources of significant contamination, with two additional area of potential problems. The previously identified areas include:

- 1960s Drum disposal area
- 1975 Road oil storage pit
- 1980s Pump island
- Shop floor drain seepage bed

The additional areas of concern are the possible PCB disposal areas and potential deeper contamination from chlorinated solvents.

Petroleum storage and vehicle maintenance have been conducted at the site for many years. Military and subsequent City operations appear to have contributed to likely subsurface contamination.

We recommend excavating grossly contaminated areas to stop continuing sources of groundwater contamination. After the source has been eliminated, reevaluating the conditions. Health risks appear to be low, as contamination is subsurface, and no potable water uses are in the area. After a thorough evaluation of contaminant migration and extent, a risk assessment could be conducted as part of a remedial action feasibility study.

Current practices appear to minimize active contribution to the floor drain problem. However, water flushed into the floor drain through vehicle washing and snow melt can continue to flush contaminants out of the soils for extended periods of time, causing long-term problems in monitor well sampling. The City may wish to decommission the floor drain system, and connect it to the City sewer.

The fuel pump island and the above ground tanks could be modified to minimize liabilities and surface water runoff problems. The pump island could have a concrete pad installed to minimize infiltration and contain spills in the short term. A roof covering the island would minimize the amount of precipitation mixing with any spilled gasoline.

A roof covering the tanks, surrounded with a partial wall would minimize the amount of water contained in the tank berm. If no roof is installed, a policy of keeping the valve closed until the water contained in the berm can be verified as clean should be instituted. The manner that the tanks are managed now offers no secondary containment.

The City should conduct at least one additional round of monitor well sampling to check groundwater flow directions and groundwater quality. Basing decisions on one round of sampling could lead to erroneous judgements.

Two of the flush mount wells, MW-2 and MW-4 have had the security casings jacked out of the ground by frost, or the ground settled around the wells. The wells have been repaired but need to be resurveyed. The stream and ditch should be added to the survey map. Because of the likelihood of extensive environmental work, a new topographic survey for the shop and surrounding property would be very useful.

6.1 Recommended Additional Drilling Locations

Figure 4 presents additional proposed drilling locations. Three monitor wells, PMW1, PMW2, and PMW3, are proposed to determine the characteristics of the aquifer at depth, and to check for deeper chlorinated solvent contamination.

The southeast part of the property requires further investigation. The potential of PCB contamination necessitates further investigation. We recommend some research into potential dumping and further subsurface investigation with a backhoe. Two additional wells have been proposed to evaluate the shallow groundwater flow patterns and conditions in the southeast part of the property.

We have placed wells in a pattern to detect contamination coming from known sources. The locations are not ideal placement for observing groundwater conditions on site. After static water levels and chemical concentrations have been evaluated over several sampling events, additional drilling locations may be identified.

Because contamination has been detected coming onto the site, and exiting the site, the City should consider expanding the investigation off site. Environmental regulations will require defining the nature and extent of contamination. The City should consider placing wells north of the Shop to determine off site conditions, and also track contamination moving off site to the south.

6.2 Remediation Areas

The layer of oil-soaked material found in the old road oil pit should be remediated to eliminate it as a source of further groundwater contamination. Because this is a heavy oil, mixed with other components, many forms of remediation may have a limited effect. Our recommendation is to excavate the grossly contaminated material, sample the perimeter of the excavation zone to determine if cleanup goals have been met, and proceed with further remediation if necessary.

The drum disposal area represents a significant source of contamination. We recommend removal of the buried drums to remove the source of contamination. Because of some of the compounds present in the initial sampling, special caution should be used in the removal of the material. The

City should develop a complete work plan to address procedures and health and safety issues. Groundwater contamination at the soil-water interface appears to exceed cleanup standards for an undefined distance. After the source of the contamination is removed, the City should assess the extent of the contamination both on and off site, and then analyze the best form of action.

If conditions warrant, after further monitoring, the City may conduct a risk assessment to determine what further action is necessary. Based on the information at hand, some remediation will be necessary. The City may wish to undertake a Remedial Investigation Feasibility Study (RIFS) to thoroughly understand the nature of the site, and explore remedial alternatives.

In summary, the City should consider accomplishing the following tasks:

- Resample the monitor wells
- Conduct a current topographic survey of the site
- Excavate grossly contaminated soils
- Investigate the deeper parts of the aquifer for solvent contamination
- Sample soils and water near the old electric shop
- Investigate conditions off site
- Conduct a remedial action feasibility study

6.3 Cost Estimates

Excavation and disposal of drums at the drum area will require the development of a work plan, physical removal of the drums, disposal, excavation sampling, and reporting. The costs could be as high as \$200,000., actual costs may vary considerably. Background data for determining costs are presented in Appendix F.

Because a groundwater plume is associated with the drum area, some form of water remediation will probably be necessary. Defining the extent of the plume, and determining the nature of the contaminants will be the first problem. Once a better understanding of the problem is achieved, a method of remediation can be chosen. It appears that the drum disposal area includes diesel, gas, and solvent contamination which can be treated by pump and treat, bioremediation, or vapor extraction. Groundwater cleanup costs can range from \$0.05 to \$2.00 per gallon depending on the compounds treated and the method used. Costs for groundwater cleanup, if required, could exceed \$1,000,000.

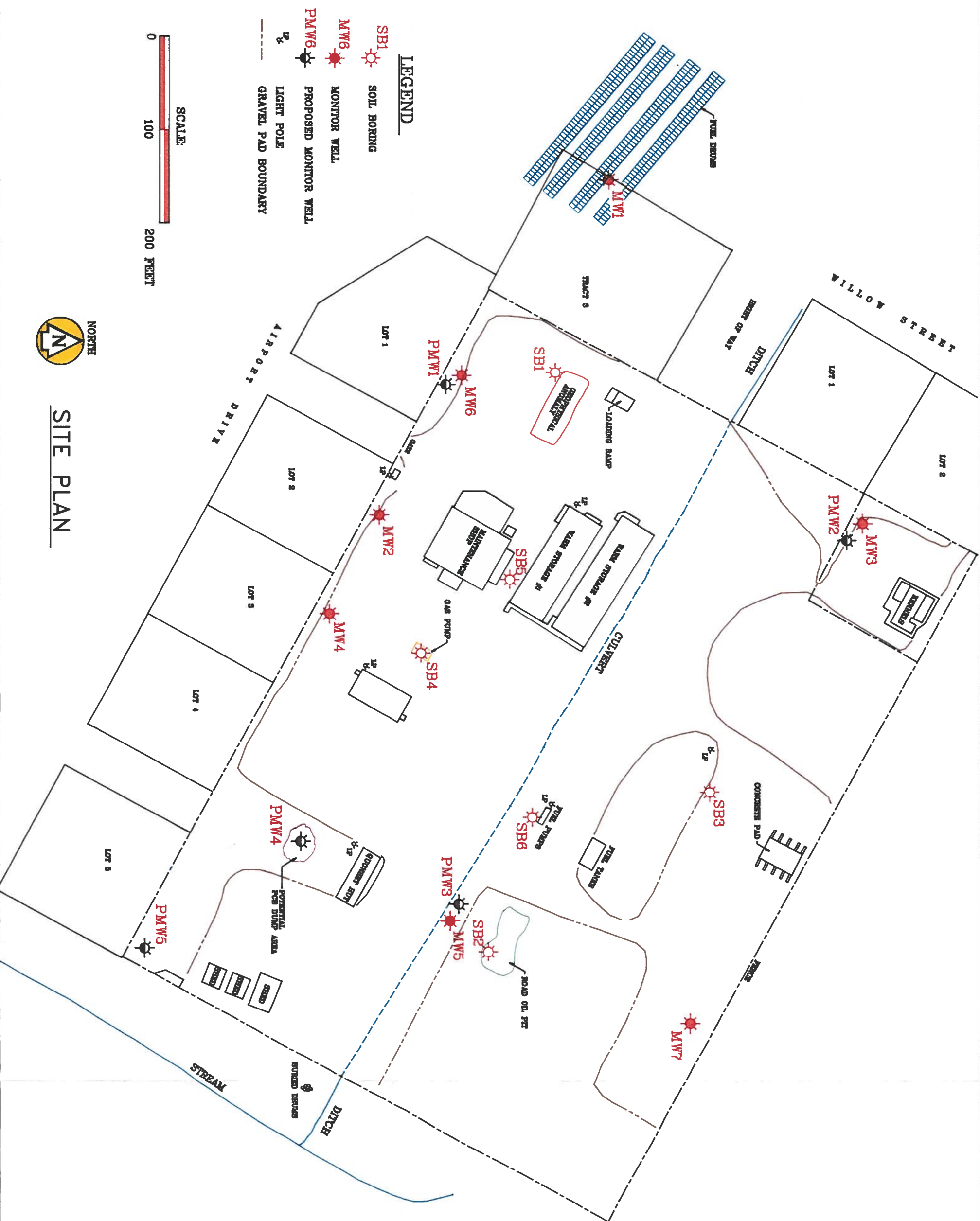
The road oil pit remediation will require the development of a work plan, removal of the contaminated soil, soil disposal, excavation sampling, and reporting. The costs could be as high as \$100,000 with possible groundwater contamination expenses.

The shop floor drain is another potential problem, along with the old pump island. If each of these four areas are treated individually the costs could be exorbitant, but a system could be designed to treat the areas as a single unit. If the source of the contamination is removed, a method of treating contaminated water and soil in place (in situ) could be designed. This could include a pump and treat system like carbon adsorption, air-stripping, or biological treatment. With the information available at this point, in situ bioremediation could be a viable treatment alternative. Costs for typical treatment systems vary from \$500,000 to \$1,000,000. We have included an overview of remediation alternatives compiled by the National Ground Water Association (NGWA) in Appendix F for reference.

7. CLOSURE

This Phase II investigation was conducted according to NTL standard procedures to evaluate site environmental conditions. This report was prepared solely for the City of Kenai to determine current environmental conditions at the Kenai Maintenance Shop site and is presented based on our understanding of the site history and information collected during our investigation. The information and data supplied by others which have been considered in this report are from sources believed to be reliable, but no responsibility is assumed for their accuracy. Any use of this report, or conclusions drawn, by third parties is at their own risk.

Due to the variable nature of site soils and geology, the limited investigation, and the lack of a complete record of previous site activities, subsurface conditions may vary from the information presented in this report. Special risks occur whenever professional consulting services are applied to determine the composition of a site's subsurface or the existence of contamination. This investigation is limited and does not eliminate all uncertainties, but we have applied good professional practice to reduce uncertainties to a reasonable level and believe our investigation fairly represents the site.



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APPENDIX A

Drill Logs



NORTHERN TEST LAB

PROJECT: Kenai Maintenance Shop	BORING NO. SB1
LOCATION: EAST OF SHOP BURIED DRUM AREA	DATE DRILLED: 3/29/95
DRILLING METHOD: Hollow Stem Auger	CASING TYPE/DIA. NA
DEPTH DRILLED: 11.5'	TOTAL CASING: NA
GROUND ELEVATION: NA	T.O.C. ELEVATION: NA
GROUT TYPE/QUANTITY: 1 BAG CHIPS 20 GALLONS GROUT	SCREEN TYPE/ LENGTH: NA
GROUT INTERVAL: 0 - 11.5'	SCREENED INTERVAL: NA
SAND PACK TYPE/INTERVAL NA	STATIC WATER LEVEL/DATE: NA
DEPTH TO WATER WHILE DRILLING: 10'	LOGGED BY: PETE CAMPBELL
WATER LEVEL ELEVATION: NA	DRILLER: JIM HARRINGTON - HUGHES DRILLING

[illegible]

NORTHERN TEST LAB

PROJECT: Kenai Maintenance Shop	BORING NO. SB2
LOCATION: ROAD OIL PIT EAST OF FUEL PUMPS	DATE DRILLED: 3/29/95
DRILLING METHOD: Hollow Stem Auger	CASING TYPE/DIA. NA
DEPTH DRILLED: 11'	TOTAL CASING: NA
GROUND ELEVATION: NA	T.O.C. ELEVATION: NA
GROUT TYPE/QUANTITY: 1 BAG CHIPS 20 GALLONS GROUT	SCREEN TYPE/ LENGTH: NA
GROUT INTERVAL: 0 - 11'	SCREENED INTERVAL: NA
SAND PACK TYPE/INTERVAL: NA	STATIC WATER LEVEL/DATE: NA
DEPTH TO WATER WHILE DRILLING: 10'	LOGGED BY: PETE CAMPBELL
WATER LEVEL ELEVATION: NA	DRILLER: JIM HARRINGTON - HUGHES DRILLING

[illegible]

NORTHERN TEST LAB

PROJECT: Kenai Maintenance Shop	BORING NO. SB3
LOCATION: NORTH STORAGE YARD	DATE DRILLED: 3/29/95
DRILLING METHOD: Hollow Stem Auger	CASING TYPE/DIA. NA
DEPTH DRILLED: 11.5'	TOTAL CASING: NA
GROUND ELEVATION: NA	T.O.C. ELEVATION: NA
GROUT TYPE/QUANTITY: 1 BAG CHIPS 20 GALLONS GROUT	SCREEN TYPE/ LENGTH: NA
GROUT INTERVAL: 0-11.5'	SCREENED INTERVAL: NA
SAND PACK TYPE/INTERVAL: NA	STATIC WATER LEVEL/DATE: NA
DEPTH TO WATER WHILE DRILLING: 10'	LOGGED BY: PETE CAMPBELL
WATER LEVEL ELEVATION: NA	DRILLER: JIM HARRINGTON - HUGHES DRILLING

[illegible]

NORTHERN TEST LAB

PROJECT: Kenai Maintenance Shop	BORING NO. SB4
LOCATION: OLD PUMP ISLAND EXCAVATION	DATE DRILLED: 3/29/95
DRILLING METHOD: Hollow Stem Auger	CASING TYPE/DIA. NA
DEPTH DRILLED: 11.5'	TOTAL CASING: NA
GROUND ELEVATION: NA	T.O.C. ELEVATION: NA
GROUT TYPE/QUANTITY: 1 BAG CHIPS 20 GALLONS GROUT	SCREEN TYPE/ LENGTH: NA
GROUT INTERVAL: 0.11.5'	SCREENED INTERVAL: NA
SAND PACK TYPE/INTERVAL: NA	STATIC WATER LEVEL/DATE: NA
DEPTH TO WATER WHILE DRILLING: 11'	LOGGED BY: PETE CAMPBELL
WATER LEVEL ELEVATION: NA	DRILLER; JIM HARRINGTON - HUGHES DRILLING

[illegible]

NORTHERN TEST LAB

PROJECT: Kenai Maintenance Shop	BORING NO. SB5
LOCATION: 5' NORTH OF SHOP AT WARM STORAGE #1	DATE DRILLED: 3/29/95
DRILLING METHOD: Hollow Stem Auger	CASING TYPE/DIA. NA
DEPTH DRILLED: 11.5'	TOTAL CASING: NA
GROUND ELEVATION: NA	T.O.C. ELEVATION: NA
GROUT TYPE/QUANTITY: 1 BAG CHIPS 20 GALLONS GROUT	SCREEN TYPE/ LENGTH: NA
GROUT INTERVAL: 0-11.5'	SCREENED INTERVAL: NA
SAND PACK TYPE/INTERVAL: NA	STATIC WATER LEVEL/DATE: NA
DEPTH TO WATER WHILE DRILLING: 11.5'	LOGGED BY: PETE CAMPBELL
WATER LEVEL ELEVATION: NA	DRILLER: JIM HARRINGTON - HUGHES DRILLING

[illegible]

NORTHERN TEST LAB

PROJECT: Kenai Maintenance Shop	BORING NO. SB6
LOCATION: PUMP ISLAND	DATE DRILLED: 3/29/95
DRILLING METHOD: Hollow Stem Auger	CASING TYPE/DIA. NA
DEPTH DRILLED: 11.5'	TOTAL CASING: NA
GROUND ELEVATION: NA	T.O.C. ELEVATION: NA
GROUT TYPE/QUANTITY: 1 BAG CHIPS 20 GALLONS GROUT	SCREEN TYPE/ LENGTH: NA
GROUT INTERVAL: 0-11.5'	SCREENED INTERVAL: NA
SAND PACK TYPE/INTERVAL: NA	STATIC WATER LEVEL/DATE: NA
DEPTH TO WATER WHILE DRILLING: 11.5'	LOGGED BY: PETE CAMPBELL
WATER LEVEL ELEVATION: NA	DRILLER: JIM HARRINGTON - HUGHES DRILLING

[illegible]

NORTHERN TEST LAB

PROJECT: KENAI MAINTENANCE SHOP	WELL NO. MW1
LOCATION: SW CORNER AIRPORT LONG TERM PARKING OVERFLOW LOT	DATE DRILLED: 3/29/95
DRILLING METHOD: HOLLOW STEM AUGER	CASING TYPE/DIA. PVC 2"
DEPTH DRILLED: 14.7'	TOTAL CASING: 3.64'
GROUND ELEVATION: NA	T.O.C. ELEVATION: 79.20'
GROUT TYPE/QUANTITY: BENTONITE 1 50# BAG	SCREEN TYPE/ LENGTH: 20 SLOT PVC 10'
GROUT INTERVAL: 0.5 - 3.5'	SCREENED INTERVAL: 4 - 14'
SAND PACK TYPE/INTERVAL 4-50# BAGS 10/20SAND FROM 3.5 - 14.7'	STATIC WATER LEVEL/DATE: 8.79' BGL 4/3/95
DEPTH TO WATER WHILE DRILLING: 10'	LOGGED BY: PETE CAMPBELL
WATER LEVEL ELEVATION: 70.41 4/3/95	DRILLER: JIM HARRINGTON - HUGHES DRILLING

[illegible]

NORTHERN TEST LAB

PROJECT: KENAI MAINTENANCE SHOP	WELL NO. MW2
LOCATION: 60' SOUTH OF SHOP	DATE DRILLED: 3/30/95
DRILLING METHOD: HOLLOW STEM AUGER	CASING TYPE/DIA. PVC 2"
DEPTH DRILLED: 14.7'	TOTAL CASING: 4.1
GROUND ELEVATION: NA	T.O.C. ELEVATION: 85.70
GROUT TYPE/QUANTITY: BENTONITE 1 50# BAG	SCREEN TYPE/ LENGTH: 20 SLOT PVC 10'
GROUT INTERVAL: 0.5 - 5.2'	SCREENED INTERVAL: 4.8 - 14.8' BGL
SAND PACK TYPE/INTERVAL 5-50# BAGS 10/20SAND FROM 4 - 14.7'	STATIC WATER LEVEL/DATE: 10.92' BGL 4/3/95
DEPTH TO WATER WHILE DRILLING: 10'	LOGGED BY: PETE CAMPBELL
WATER LEVEL ELEVATION: 74.78' 4/3/95	DRILLER: JIM HARRINGTON - HUGHES DRILLING

[illegible]

NORTHERN TEST LAB

PROJECT: KENAI MAINTENANCE SHOP	WELL NO. MW3
LOCATION: 60' SOUTH WEST OF ANIMAL SHELTER	DATE DRILLED: 3/30/95
DRILLING METHOD: HOLLOW STEM AUGER	CASING TYPE/DIA. PVC 2"
DEPTH DRILLED: 14.7'	TOTAL CASING: 7.2
GROUND ELEVATION: NA	T.O.C. ELEVATION: 86.10'
GROUT TYPE/QUANTITY: BENTONITE 1 50# BAG	SCREEN TYPE/ LENGTH: 20 SLOT PVC 10'
GROUT INTERVAL: 0.5 - 3.5'	SCREENED INTERVAL: 4.7-14.7
SAND PACK TYPE/INTERVAL 4-50# BAGS 10/20SAND FROM 3.5 - 14.7'	STATIC WATER LEVEL/DATE: 9.94' BGL 4/3/95
DEPTH TO WATER WHILE DRILLING: 11'	LOGGED BY: PETE CAMPBELL
WATER LEVEL ELEVATION: 76.16 4/3/95	DRILLER: JIM HARRINGTON - HUGHES DRILLING

[illegible]

NORTHERN TEST LAB

PROJECT: KENAI MAINTENANCE SHOP	WELL NO. MW4
LOCATION: SOUTH WEST OF WATER SEWER PLANT	DATE DRILLED: 3/30/95
DRILLING METHOD: HOLLOW STEM AUGER	CASING TYPE/DIA. PVC 2"
DEPTH DRILLED: 15'	TOTAL CASING: 4.4'
GROUND ELEVATION: NA	T.O.C. ELEVATION: 85.00
GROUT TYPE/QUANTITY: BENTONITE 1 50# BAG	SCREEN TYPE/ LENGTH: 20 SLOT PVC 10'
GROUT INTERVAL: 0.5 - 3.5'	SCREENED INTERVAL: 4.8-14.8'
SAND PACK TYPE/INTERVAL 5-50# BAGS 10/20SAND FROM 3.5 - 15'	STATIC WATER LEVEL/DATE: 10.39 4/3/95
DEPTH TO WATER WHILE DRILLING: 11'	LOGGED BY: PETE CAMPBELL
WATER LEVEL ELEVATION: 74.61 4/3/95	DRILLER: JIM HARRINGTON - HUGHES DRILLING

[illegible]

NORTHERN TEST LAB

PROJECT: KENAI MAINTENANCE SHOP	WELL NO. MW5
LOCATION: NORTH OF TIRE STORAGE QUONSET	DATE DRILLED: 3/30/95
DRILLING METHOD: HOLLOW STEM AUGER	CASING TYPE/DIA. PVC 2"
DEPTH DRILLED: 15'	TOTAL CASING: 4.7'
GROUND ELEVATION: NA	T.O.C. ELEVATION: 82.03
GROUT TYPE/QUANTITY: BENTONITE 1 50# BAG	SCREEN TYPE/ LENGTH: 20 SLOT PVC 10'
GROUT INTERVAL: 0.5 - 3.8'	SCREENED INTERVAL: 4.9 - 14.9'
SAND PACK TYPE/INTERVAL 5-50# BAGS 10/20SAND FROM 3.8 - 15'	STATIC WATER LEVEL/DATE: 6.70 4/3/95
DEPTH TO WATER WHILE DRILLING: 11'	LOGGED BY: PETE CAMPBELL
WATER LEVEL ELEVATION: 75.33	DRILLER: JIM HARRINGTON - HUGHES DRILLING

[illegible]

NORTHERN TEST LAB

PROJECT: KENAI MAINTENANCE SHOP	WELL NO. MW6
LOCATION: NORTH OF TESORO, SOUTH OF DRUM DISPOSAL AREA	DATE DRILLED: 3/31/95
DRILLING METHOD: HOLLOW STEM AUGER	CASING TYPE/DIA. PVC 2"
DEPTH DRILLED: 15'	TOTAL CASING: 8'
GROUND ELEVATION: NA	T.O.C. ELEVATION: 83.07
GROUT TYPE/QUANTITY: BENTONITE 1 50# BAG	SCREEN TYPE/ LENGTH: 20 SLOT PVC 10'
GROUT INTERVAL: 0.5 - 3.8'	SCREENED INTERVAL: 4.9 - 14.9
SAND PACK TYPE/INTERVAL 5-50# BAGS 10/20SAND FROM 3.8 - 15'	STATIC WATER LEVEL/DATE: 9.41' 4/3/95
DEPTH TO WATER WHILE DRILLING: 10'	LOGGED BY: PETE CAMPBELL
WATER LEVEL ELEVATION: 73.66'	DRILLER: JIM HARRINGTON - HUGHES DRILLING

[illegible]

APPENDIX C

Elevational Data



PROJECT KENAI MAINTENANCE SHOP

[illegible]

APPENDIX D

Maximum Contaminant Levels

DRINKING WATER MAXIMUM CONTAMINANT CONCENTRATION LEVELS (MCLs)

PRIMARY

CONTAMINANT	MCL
Inorganic Chemical Contaminants	
Arsenic	0.050 mg/L
Barium	1.0 mg/L
Cadmium	0.010 mg/L
Chromium	0.050 mg/L
Fluoride	4.000 mg/L
Lead	0.050 mg/L
Mercury	0.002 mg/L
Nitrate (as Nitrogen)	10.0 mg/L
Selenium	0.010 mg/L
Silver	0.050 mg/L
Organic Chemical Contaminants	
Pesticides	
Endrin	0.0002 mg/L
Lindane	0.004 mg/L
Methoxychlor	0.100 mg/L
Toxaphene	0.005 mg/L
2,4-D	0.100 mg/L
2,4,5-TP Silvex	0.010 mg/L
Volatile Organic Chemical (VOCs)	
1,1-Dichloroethylene	0.007 mg/L
1,1,1-Trichloroethane	0.200 mg/L
1,2-Dichloroethane	0.005 mg/L
Benzene	0.005 mg/L
Carbon Tetrachloride	0.005 mg/L
1,4-Dichlorobenzene	0.075 mg/L
Trichloroethylene	0.005 mg/L

CONTAMINANT	MCL
Vinyl Chloride	0.002 mg/L
Total Trihalomethanes (TTHMs)	
Total Trihalomethanes	0.1 mg/L
Physical Contaminants	
Turbidity	1.49 or 5.0 NTU*
Radioactive Contaminants	
Natural Radioactivity	
Gross Alpha	15.0 pCi/l
Combined Radium-226 and 228	5.0 pCi/l
Manmade Radioactivity	
Gross Beta	50.0 pCi/l
Strontium-90	8.0 pCi/l
Tritium	20,000.0 pCi/l

* 1.49 Nephelometric Turbidity Unit (NTU) as a monthly average of samples required, or 5.0 NTU as an average or two consecutive days. Exceeding either measure is a violation of this paragraph.

SECONDARY

CONTAMINANT	MCL
Chloride	250 mg/L
Color	15 Units
Copper	1 mg/L
Corrosivity	Noncorrosive
Fluoride	2.0 mg/L
Foaming Agents	0.5 mg/L
Iron	0.3 mg/L
Manganese	0.05 mg/L
Odor	3 threshold odor #
pH	6.5 - 8.5 su
Sodium	250 mg/L
Sulfate	250 mg/L
Total Dissolved Solids	500 mg/L
Zinc	5 mg/L

National Primary Drinking Water Standards

United States Environmental Protection Agency

Effective Date: January 1, 1993

Contaminants	Health Effects	MCL ¹	Sources
Organic Chemicals			
Acrylamide	probable cancer, nervous system	TT ²	flocculents in sewage/waste-water treatment
Alachlor	probable cancer	0.002	herbicide on corn and soy-beans; under review for cancellation
Aldicarb	nervous system	0.003	insecticide on cotton, potatoes; restricted in many areas due to groundwater contamination.
Aldicarb sulfone	nervous system	0.002	degraded from aldicarb by plants
Aldicarb sulfoxide	nervous system	0.004	degraded from aldicarb by plants
Atrazine	reproductive and cardiac	0.003	widely used herbicide on corn and on non-crop land
Benzene	cancer	0.005	fuel(leaking tanks); solvent commonly used in manufacture of industrial chemicals, pharmaceuticals, pesticides, paints and plastics
Carbofuran	nervous system	0.04	soil fumigant/insecticide on corn/cotton; restricted in some areas
Carbon Tetrachloride	possible cancer	0.005	commonly used in cleaning agents, industrial wastes from manufacture of coolants
2,4-D	liver, kidney, nervous system	0.07	herbicide for wheat, corn, rangelands
Dibromochloropropane (DBCP)	probable cancer	0.0002	soil fumigant on soybeans, cotton; cancelled in 1977
Dichlorobenzene o- ²	nervous system, lung, liver, kidney	0.6	industrial solvent; chemical manufacturing
Dichloroethane (1,2-)	possible cancer	0.005	used in manufacture of insecticides, gasoline

Contaminants	Health Effects	MCL ¹	Sources
Dichloroethylene (1,1-)	liver/kidney effects	0.007	used in manufacture of plastics, dyes, perfumes, paints, SOCs (Synthetic Organic Chemicals)
Dichloroethylene (cis-1,2-)	nervous system, liver, circulatory	0.07	industrial extraction solvent
Dichloroethylene (trans-1,2)	nervous system, liver, circulatory	0.1	industrial extraction solvent
Dichloropropane (1,2-)	probable cancer, liver, lungs, kidney	0.005	soil fumigant; industrial solvent
Endrin ³	nervous system/kidney effects	0.0002	insecticide used on cotton, small grains, orchards (cancelled)
Epichlorohydrin	probable cancer, liver, kidney, lungs	TT ²	epoxy resins and coatings, flocculents used in treatment
Ethylbenzene	kidney, liver, nervous system	0.7	present in gasoline and insecticides; chemical manufacturing
Ethylene dibromide (EDB)	probable cancer	0.00005	gasoline additive; soil fumigant, solvent cancelled in 1984; limited uses continue
Heptachlor	probable cancer	0.0004	insecticide on corn; cancelled in 1983 for all but termite control
Heptachlor epoxide	probable cancer	0.0002	soil and water organisms convert heptachlor to the epoxide
Lindane	nervous system, liver, kidney	0.0002	insecticide for seed/lumber/livestock pest control; most uses restricted in 1983
Methoxychlor	nervous system, liver, kidney	0.04	insecticide on alfalfa, livestock
Monochlorobenzene	kidney, liver, nervous system	0.1	pesticide manufacturing; metal cleaner, industrial solvent
Pentachlorophenol	probable cancer, liver, kidney	0.001	wood preservative and herbicide; non-wood uses banned in 1987
Polychlorinated biphenyls (PCBs)	probable cancer	0.0005	electrical transformers, plasticizers; banned in 1979
Styrene	liver, nervous, system	0.1	plastic manufacturing; resins used in water treatment equipment

Contaminants	Health Effects	MCL¹	Sources
Tetrachloroethylene	probable cancer	0.005	dry cleaning/industrial solvent
Toluene	kidney, nervous system, lung	1	chemical manufacturing gasoline additive; industrial solvent
Toxaphene	probable cancer	0.003	insecticide/herbicide for cotton, soybeans; cancelled in 1982
2-4-5-TP (Silvex)	nervous system, liver, kidney	0.05	herbicide on range-lands, sugar cane, golf courses; cancelled in 1983
Trichloroethane (1,1,1)	nervous system problems	0.2	used in manufacture of food wrappings, synthetic fibers
Trichloroethylene (TCE)	possible cancer	0.005	waste from disposal of dry cleaning materials and manufacturing of pesticides, paints, waxes and varnishes, paint stripper, metal degreaser
Vinyl chloride	cancer risk	0.002	polyvinyl chloride pipes and solvents used to join them; industrial waste from manufacture of plastic and synthetic rubber.
Xylenes	liver, kidney, nervous system	10	paint/ink solvent; gasoline refining by-product; component of detergents
Inorganic Chemicals			
Arsenic ⁴	dermal and nervous system toxicity effects	0.05	geological, pesticide residues, industrial waste and smelter operations
Asbestos	benign tumors	7 MFL ⁵	natural mineral deposits; also in Asbestos/Cement pipe
Barium	circulatory system	2	natural mineral deposits oil/gas drilling operations; paint and other industrial uses
Cadmium	kidney	0.005	natural mineral deposits; metal finishing; corrosion product plumbing
Chromium	liver/kidney, skin and digestive system	0.1	natural mineral deposits; metal finishing, textile, tanning and leather industries

Contaminants	Health Effects	MCL ¹	Sources
Copper	stomach and intestinal distress; Wilson's disease	TT ²	corrosion of interior household and building pipes
Fluoride	skeletal damage	4	geological; additive to drinking water; toothpaste; foods processed with fluorinated water
Lead	central and peripheral nervous system damage; kidney; highly toxic to infants and pregnant women	TT ²	corrosion of lead solder and brass faucets and fixtures; corrosion of lead service lines
Mercury	kidney, nervous system	0.002	industrial/chemical manufacturing; fungi cide; natural mineral deposits
Nitrate	methemoglobinemia "blue baby syndrome"	10	fertilizers, feedlots, sewage; naturally in soil, mineral deposits
Nitrite	methemoglobinemia "blue baby syndrome"	1	unstable, rapidly converted to nitrate; prohibited in working metal fluids
Total (Nitrate and Nitrite)	Not applicable	10	Not applicable
Selenium	nervous system	0.05	natural mineral deposits; by-product of copper mining/ smelting
Radionuclides			
Beta particle and photon activity	cancer	4mrem/yr ⁶	radioactive waste, uranium deposits, nuclear facilities
Gross alpha particle activity	cancer	15 pCi/L ⁷	radioactive waste, uranium deposits, geological/natural
Radium 226/228	bone cancer	5 pCi/L ⁷	radioactive waste, geological/natural
Microbiological			
Giardia Lamblia	stomach cramps, intestinal distress (Gardiasis)	TT ²	human and animal fecal matter
Legionella	Legionnaires' disease (pneumonia), Pontiac Fever	TT ²	water aerosols such as vegetable misters
Total Coliforms	Not necessarily disease-causing themselves, coliforms can be indicators of organisms that can cause gastroenteric infections, dysentery, hepatitis, typhoid fever, cholera, and other. Also, coliforms interfere with disinfection.	See note ⁵	human and animal fecal matter

Contaminants	Health Effects	MCL ¹	Sources
Turbidity	interferes with disinfection	0.5-1.0 NTU (nephelometric turbidity unit)	erosion, runoff, discharges
Viruses	gastroenteritis (intestinal distress)	TT ²	human and animal fecal matter
Other substances			
Sodium	possible increase in blood pressure in susceptible individuals	none (20mg/l report level) ⁹	geological, road salting

¹ In milligrams per liter, unless otherwise noted

² TT = Treatment technique requirement in effect

³ Phase V proposes changing MCL for Endrin to 0.002

⁴ MCL for arsenic currently under review

⁵ Million fibers per liter, with fiber length > 10 microns

⁶ "Rem" means the unit of dose equivalent from ionizing radiation to the total body of any internal organ or organ system. A "millirem (mrem)" 1/1000 of a rem.

⁷ "Pecocurie (pCi)" means the quantity of radioactive material producing 2.22 nuclear transformations per minute.

⁸ For larger systems (40 or more samples per month) no more than 5.0% of the samples can be positive. For small systems no more than one sample can be positive.

⁹ Monitoring is required and data is reported to health officials to protect individuals on highly restricted sodium diets.

National Secondary Drinking Water Standards*

United States Environmental Protection Agency

Effective Date: January 1, 1993

Contaminants	Suggested Levels	Contaminant Effects
Aluminum	0.05-0.2 mg/l	Discoloration of water
Chloride	250 mg/l	Taste; corrosion of pipes
Color	15 color units	Aesthetic
Corrosivity	non-corrosive	Aesthetic and health related (corrosive water can leach pipe materials, such as lead, into drinking water)
Fluoride	2.0 mg/l	Dental fluorosis (a brownish discoloration of the teeth)
Foaming Agents	0.5 mg/l	Aesthetic
Iron	0.3 mg/l	Taste; staining of laundry
Manganese	0.05 mg/l	Tate; staining of laundry
Odor	3 threshold odor number	Aesthetic
pH	6.5 - 8.5	Water is too corrosive
Silver	0.1 mg/l	Argyria (discoloration of the skin)
Sulfate	250 mg/l	Taste; laxative effects
Total dissolved solids (TDS)	500 mg/l	Taste and possible relation between low hardness and cardiovascular disease; also an indicator of corrosivity (related to lead levels in water); can damage plumbing and limit effectiveness of soaps and detergents
Zinc	5 mg/l	Taste

Secondary Drinking Standards are unenforceable federal guidelines regarding the taste, odor, color (and certain other non-aesthetic effects) of drinking water. EPA recommends them to the States as reasonable goals, but federal law does not require water systems to comply with them. States may, however, adopt their own enforceable regulations governing these concerns. To be safe, check your State's drinking water rules.

APPENDIX E

Matrix Score



- o Soil categories using the Unified Soil Classification system are felt to be suitable for characterizing hydraulic conductivity and absorption. The responsible party has the option of proposing other methods for determining hydraulic conductivity which would allow fitting soils into the given categories. Soil types using the Unified Soil Classification system are further defined as follows:

<u>Soil Type</u>	<u>Unified Soil Classifications</u>
Clean coarse-grained	GW, GP, SW, SP
Coarse-grained with fines	GM, GC, SM, SC, GP-GC, SP-SM, GW-GM, SW-SM, SW-SC
Fine grained with high organic carbon	ML, CL, MH, CH
Fine grained with low organic carbon	OL, OH, Pt

- o The responsible party has the option to demonstrate that otherwise coarse-grained soils have an organic carbon content that might enable a lower point classification.

4. Potential Receptors

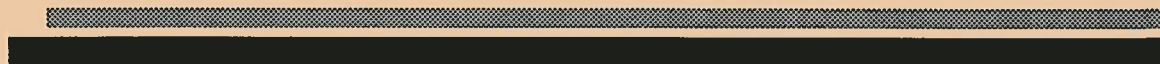
- o The responsible party has the option to demonstrate that well proximity, in relation to such factors as the groundwater gradient or hydrologic barriers, can justify the next more liberal category.
- o The term "non-potable" means an aquifer unusable for drinking water due to water quality conditions such as excessive salinity.

5. Volume of Contaminated Soil

- o The volume to be considered is that amount of soil containing a concentration greater than the most restrictive matrix value for the given constituent.

APPENDIX F

Cost Estimates





Kenai Maintenance Shop Remediation Cost Estimate

Drum Storage Area Remediation Cost Estimates

Work Plan	\$ 5,000	
Excavation of Drums	20,000	
Disposal of drums and soil (1000 cy)	140,000	
Sampling	12,000	
Reporting	<u>12,000</u>	
Estimated Total		\$ 189,000

Groundwater Treatment Drum Area

Work Plan	\$ 6,000	
Monitor Well Installation	50,000	
Sampling	30,000	
Report	15,000	
System Design	40,000 - 60,000	
Hardware and Installation	140,000 - 300,000	
Operation & Maintenance		
\$4000 month/18 months	72,000	
Operational Sampling		
\$2000 month/18 months	36,000	
Report	20,000	
Decommission	<u>20,000</u>	
Estimated Total		\$ 429,000 - 609,000

Road Oil Pit Soil Remediation Cost Estimates

Work Plan	\$ 3,000	
Excavation of Contaminated Material	10,000	
Disposal of soil (600 cy)	84,000	
Sampling	10,000	
Reporting	<u>8,000</u>	
Estimated Total		\$ 115,000

Road Oil Pit Groundwater Treatment

Work Plan	\$ 7,000	
Monitor Well Installation & Recovery Well	35,000	
Sampling	15,000	
Report	15,000	
System Design	40,000 - 60,000	
Hardware and Installation	140,000 - 300,000	
Operation and Maintenance		
\$4000 month x 18 months	72,000	
Operational Sampling		
\$2000 month x 18 months	36,000	
Report	15,000	
Decommission	<u>20,000</u>	
Estimated Total		\$ 395,000 - 575,000



Floor Drain Crib Abandonment Cost Estimates

Work Plan	\$ 5,000	
Excavation of Contaminated Material	10,000	
Disposal of Soil (600 cy)	84,000	
Sampling	8,000	
Reporting	<u>8,000</u>	
Estimated Total		\$ 115,000

Floor Drain Recycler

Hardware	\$120,000	
Installation	30,000	
Maintenance		
\$100/month x 18 months	<u>18,000</u>	
Estimated Total		\$ 168,000

Alternative - City Sewer System with Lift Station**Groundwater Treatment Floor Drain**

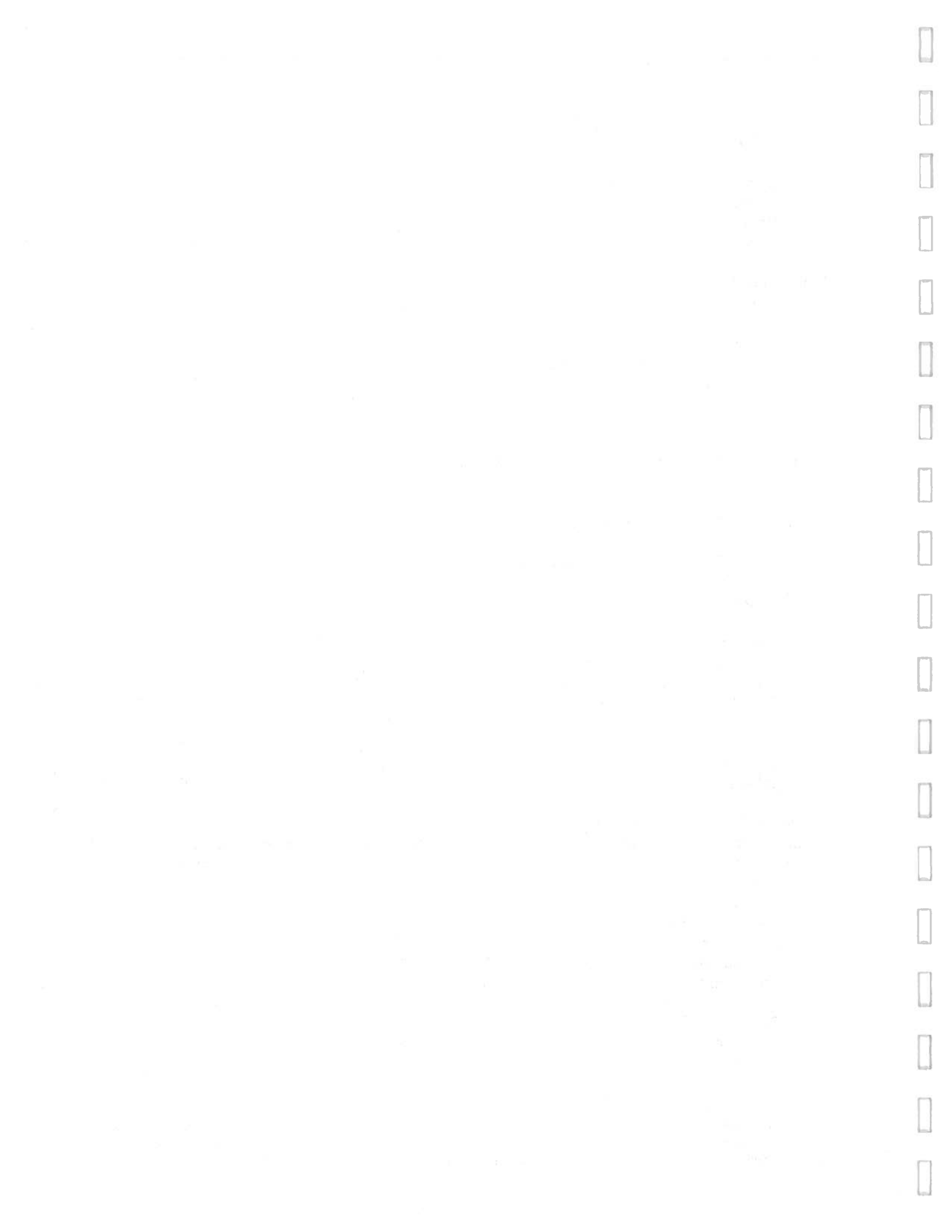
Work Plan	\$ 15,000	
Deep Monitor Well & Recovery Well Install.	65,000	
Sampling	40,000	
Report	15,000	
System Design	40,000 - 60,000	
Hardware & Installation	140,000 - 300,000	
Operation & Maintenance		
\$4000 month x 18 months	72,000	
Operational Sampling		
\$2000 month x 18 months	36,000	
Report	20,000	
Decommission	<u>20,000</u>	
Estimated Total		\$463,000-643,000

Integrated System Remediation

Assumptions: Extensive petroleum groundwater contamination in the drum area, road oil pit, deep groundwater contamination with chlorinated solvents. No PCB contamination from electrical shop

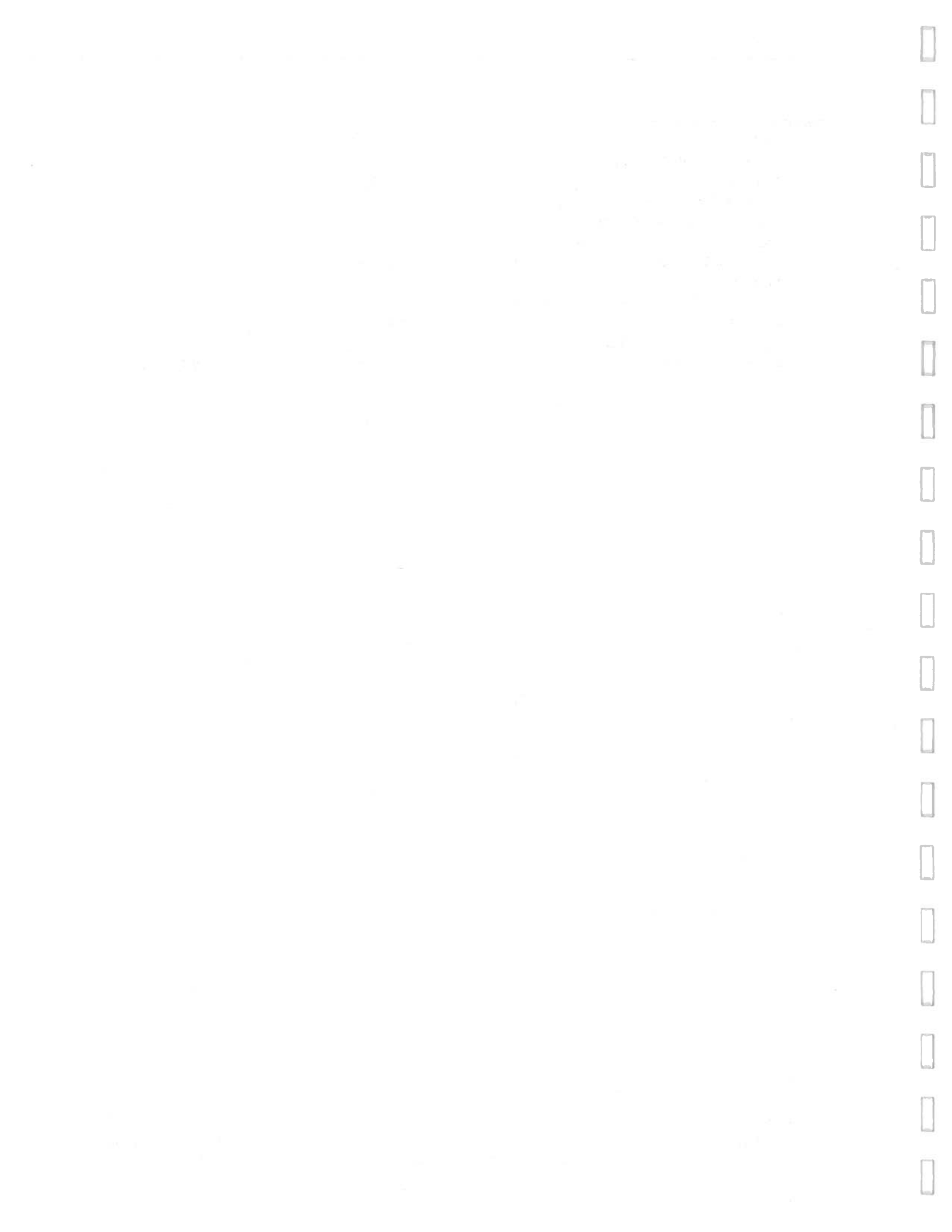
Contaminated Soil Removal

Work Plan	\$ 20,000	
Excavation of Contaminated Material	40,000	
Treatment of Soil on Site (Bioremediation)		
2000 cy	120,000	
Sampling	16,000	
Reporting	<u>40,000</u>	
Estimated Total		\$ 236,000



Groundwater Treatment

Drilling Investigation	\$150,000	
Monitor Well Sampling	60,000	
Remedial Action Feasibility Study	80,000	
System Design	60,000	
Hardware & Installation	600,000	
Operation & Maintenance		
\$4000 month x 18 months	72,000	
Operational Sampling		
\$2000 month x 18 months	36,000	
Report	40,000	
System Decommission	<u>60,000</u>	
Estimated Total		\$1,158,000



INTRODUCTION

Groundwater contamination by organic chemicals is a complex multi-phase problem. Organic contaminants in the subsurface can be present as multiple phases: immiscible product (free phase), residually saturated soil (adsorbed phase), and contaminated groundwater (dissolved phase). All phases must be addressed to control groundwater quality. Free product, material which exists as a mobile, discrete phase in the subsurface, is the source of both contaminated soil and groundwater. If free product is not removed, it will continue to dissolve into the groundwater. The residually saturated soil, if untreated, is also a continuing source of groundwater contamination. Contaminated groundwater is the end result of subsurface contamination. Because of the mobility of groundwater and the low solubility of many chemicals, it is the easier phase to treat. However, unless the soil is also remediated, groundwater will be continually recontaminated.

There are basically three approaches that have been developed for treating subsurface contamination:

Containment - preventing the problem from spreading,

Removal - removing the gross contamination, and

In Situ Treatment - transforming the contaminant in place to an innocuous form.

The simplest approach to groundwater contamination is to contain the spread of the plume. Containment may be achieved either physically, through the use of slurry walls or grout curtains, or hydrogeologically, with an array of pumping and injection wells. However, since containment is ultimately only a "stop-gap" measure, eliminating continued degradation of groundwater quality requires the removal of contamination in both the soil and groundwater.

The next level of treatment beyond containment is to physically remove the contamination. Some common methods of removal are soil excavation, free product recovery, soil vapor extraction, air sparging, and groundwater pumping. All of these technologies have their limitations.

Excavation and soil vapor extraction are generally effective in treating soils above the water table. Excavation, however, is severely constrained by depth and by physical construction on the site; contamination may underlie buildings and streets, making the affected soils inaccessible to excavation. Soil vapor extraction is limited to unsaturated soils.



GROUNDWATER
TECHNOLOGY

Free product recovery of mobile, free-phase liquids is often an important first step in the treatment of subsurface contamination. It is, however, incomplete as it does not adequately address either contaminated soil or groundwater.

Pumping groundwater can be an effective means of controlling downgradient groundwater quality by preventing continued migration of dissolved contaminants; however, removal of contaminated groundwater requires surface treatment prior to discharge. Additionally, pumping strategies do not solve groundwater problems as they do not address the problem of soil contamination. If pumping is discontinued, contamination in the soil will continue to leach and thus will recontaminate the groundwater. Consequently, pumping contaminated groundwater is at best a long term containment process with questionable effectiveness for remediating soils.

Air sparging, the injection of air below the water table, is proving to be an effective means of treating contaminated soils and groundwater in the saturated zone. Without proper design and controls, however, air sparging can spread contamination instead of removing it.

An alternative to temporary containment or simple physical removal of contaminants is to neutralize the materials in place through the use of chemical or biological treatment methods. Readily oxidizable contaminants can be treated with common chemical oxidizers; however, these reactive compounds are more the exception than the rule. A wide range of organic contaminants can be biodegraded by heterotrophic microorganisms. Biological mineralization of organics by microorganisms results in the ultimate conversion of the contaminant to carbon dioxide and water, thereby eliminating the impact of the contamination on aquifer water quality.

BASIS OF REMEDIAL DESIGN

Successful and cost-effective aquifer restoration requires an understanding of the mobility, reactivity and distribution of the contaminants. For example, highly mobile contaminants may be extracted while less mobile, highly reactive materials can be degraded by in situ treatment. Since most instances of groundwater contamination involves a mixture of contaminants, an effective remediation program will consist of a systematic application of various treatment technologies. In evaluating remedial options one needs to consider their ability to effectively remove or destroy the contaminant. The more mass a process removes per unit time, and the more completely it deals with all aspects of contamination, the more effective it will be.



**GROUNDWATER
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Selecting a remedial process is a logical process. Remedial design is based on the properties of the contaminant and its phase and spatial distribution in the subsurface. The more completely these factors are understood the more facile and effective the remedial design.

The phase and spatial distribution of a contaminant is a function of its transport properties. How the contaminant moves through and is distributed in soil and water is a function of its density, physical state, volatility and solubility. For example, the lower the solubility of the contaminant the more it will be present as adsorbed phase or free phase material. The higher the solubility, the more it partitions into the dissolved phase. Simply viewed, the spread of a contaminant and its entrance into a groundwater system is a balance of these two mechanisms - dissolution and sorption. Consequently, these two factors have a particularly strong impact on the phase distribution of a contaminant. Increasing contaminant solubility drives the phase distribution towards the groundwater; increasing sorptivity, towards the soil.

The spatial location of the contaminant phases needs to be understood in relation to the phase distribution. This consists of the contaminant location relative to the water table and/or any lithological changes. An immiscible but volatile organic adsorbed to the soil will respond very differently if it is above or below the water table. The goal of a site investigation should be a geological cross section(s) upon which is overlain the contaminant phase distribution.

Once a contaminant has migrated into the subsurface, its persistence in the environment is also a function of these chemical properties as well as its chemical and/or biological reactivity. The long term contamination of a unit volume of the subsurface is ultimately a balance of the transport and reactive processes dictated by the nature of the contaminant and its interaction with the environment. The transport and reactivity of a contaminant is impacted by hydrogeological factors such as permeability, porosity and water saturation.

Treatment of the contaminant is, therefore, understanding where the contaminant is and which properties/processes can be effectively manipulated to remove the mass of contamination. A remedial process should key on the transport/reactivity of the contaminant and be effective for the phase of contamination and the hydrogeological matrix that is being treated.

PHASE DISTRIBUTION OF CONTAMINANTS

The goal of a remedial system is to remove mass. Mass distribution varies widely between the different phases. Consequently understanding phase distribution is important. The distribution of a



chemical into different phases is a function of its physical and chemical properties, and the hydrogeological and geochemical characteristics of the formation.

Tables I to III illustrate the variability of phase distribution. Phase distribution can be assessed by two means: the areal extent of contamination or the volume of the subsurface impacted by a phase, and the severity of contamination or the amount of the contaminant within a phase, measured as either total weight or concentration.

Table I represents the phase distribution of a gasoline spill in a sand and gravel aquifer. In this case both the solubility of the contaminant and the sorptive properties of the formation are low. Consequently, most of the contaminant (91%) is present as free phase material. However, because of the low concentration and high mobility of groundwater, the areal extent of groundwater contamination is greater than the other phases. If the focus of remediation is only the groundwater, the strategy would be a simple extraction and treatment of a low level contaminant. This, however, addresses only a small fraction of the total problem.

Table I. Phase Distribution of Gasoline in Sand and Gravel

Phase	Extent of Contamination			Mass Distribution	
	Volume	% of		Conc.	% of
	cu. yd	Total	lb	ppm	Total
Free Phase	780	5.3	126,800 ¹	—	90.9
Adsorbed (soil)	2,670	18.3	11,500	2000	8.2
Dissolved (water)	11,120	76.3	390	15	0.3

¹ Actual value recovered from site.

Table II illustrates the distribution of a spill in a fractured bedrock environment. In this case sorption is more significant. In a fractured bedrock system there is appreciable physical retention of gasoline in the formation due to flow into secondary fractures. Consequently the amount of material recovered as free phase is smaller and the adsorbed phase is greater than in a sand aquifer. The primary extent of contamination is, however, still in the dissolved phase.

Table II. Phase Distribution of Gasoline in
Fractured Bedrock

Phase	Extent of Contamination			Mass Distribution	
	Volume	% of		Conc.	% of
	<u>cu. yd</u>	<u>Total</u>	<u>lb</u>	<u>ppm</u>	<u>Total</u>
Free Phase	44	0.5	12,390 ¹	—	72.8
Adsorbed (soil)	1,630	18.9	4,600	2400	26.9
Dissolved (water)	6,960	80.6	70	25	0.2

¹ Actual value recovered from site.

Table III shows the phase distribution of a mixed chemical spill in a sand environment. In this case a number of the components are highly soluble. The source of contamination was a disposal pit in which a mixture of chemicals was dumped over a period of several years. Because of the high solubility of some of the contaminants, there is, as expected, a significant increase in the amount of material in the groundwater. Surprisingly, the distribution areally through the soil is also increased. The reason for this increase in soil contamination is the more active transport engendered by the increased solubility of the contaminant. The contaminant dissolves and re-sorbs as it is carried down-gradient by the groundwater. This case illustrates the impact of solubility on phase distribution and groundwater contamination. With soluble contaminants, transport through the subsurface is facilitated.

Table III. Phase Distribution of Mixed Chemical Spill¹
in Sand and Gravel

Phase	Extent of Contamination			Mass Distribution	
	Volume	% of		Conc.	% of
	<u>cu. yd</u>	<u>Total</u>	<u>lb</u>	<u>ppm</u>	<u>Total</u>
Free Phase	3,340	1.1	51,480 ¹	—	42.3
Adsorbed (soil)	144,500	45.9	48,000	300	39.4
Dissolved (water)	166,960	53.0	22,200	100	18.2

¹ Contaminants: Alcohols, esters, hydrocarbons (aromatic and aliphatic).



GROUNDWATER
TECHNOLOGY

REMEDIAL PROCESSES

Conceptually, there are two ways that one can eliminate a contaminant from the subsurface. The first is to use the mechanisms of transport. In such cases, the focus is on enhancing the movement of the contamination from the subsurface. The second approach is to focus on the factors that impact persistence such as chemical or biological transformation.

Remedial processes can, thus, be divided into two categories- extraction processes and reaction processes. With extraction processes, the type of the process depends both on the nature of the contaminant and on the phase in which it exists. Reaction processes depend much more on the nature of the contaminant, that is, whether it is chemically or biologically reactive. The nature of the contaminant, particularly whether it is an organic or an inorganic substance, impacts the utility of extraction or reaction processes.

With organics, remediation can be either an extractive process or a reactive (destructive) process. With organics the contaminant can be completely transformed chemically or biologically to carbon dioxide and thus "leave" the system. The properties of significance for organics are volatility, solubility, density, adsorbivity, and reactivity- biological, and chemical. Volatility is a function of vapor pressure and is a measure of ventability. Solubility is a measure of the potential for water flushing and of the potential for air stripping. Density is an indicator of whether free phase material will be a "floaters" or a "sinker" and thus what type of recovery system is appropriate. Adsorbivity is a measure of how difficult extractive processes will be. Reactivity is an indicator of the potential for biological or chemical treatment.

With inorganics transformations are much more limited. Metals can only be transformed to a higher or lower oxidation state; ions such as ammonia or sulfate can be biologically decomposed to gaseous products and thus be removed. As a result of the limited transformation processes available, inorganics, for the most part, can only be remediated by extractive processes. Oxidative/reductive processes do not eliminate the inorganic, they only change the solubility. Also most inorganics lack volatility and are very limited with respect to biological transformations. The properties of significance for inorganics are solubility, adsorbivity and complexation/chelation. All of these properties are strongly dependent on the oxidation state of the inorganic. Solubility can be manipulated to remove the inorganic by water extraction, or it can be manipulated to tie up the inorganic by precipitation. Complexation/chelation are methods of manipulating solubility to improve extraction. With inorganics, adsorbivity is a much more complex process than with



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organics due to the formation of chemical bonds with soils. As a result, extractive processes need to take into account the soil properties.

The primary extraction processes are soil vapor extraction, air sparging, water extraction, and free phase recovery. Soil vapor extraction is a process for removing volatile organic contaminants adsorbed in unsaturated soils. It is based on volatilization through induced air flow - either from vacuum or air injection. Air sparging is a means of extending volatile removal to saturated soils. The injection of air under pressure creates a transient air filled porosity, which promotes the volatilization and removal of organic compounds. With water extraction, the systems involve both the collection system - trenches, wells, with/without injection, as well as treatment systems for the extracted material. When water extraction is used to treat adsorbed phase contamination the extraction involves enhancing changes in the solubility or desorption of the contaminant. The reagents used and the systems involved are very different depending on whether the contaminant is organic or inorganic. Finally, free phase recovery depends on whether the contaminant is a LNAPL - light non aqueous phase liquid, or a DNAPL - dense non aqueous phase liquid. Free phase recovery involves the collection of the organic and its removal from the subsurface.

Reactive systems are primarily biological or chemical in nature. Biological systems vary with the nature of the contaminant. Current technology can be classified as petroleum hydrocarbon based, or chlorinated based. Also the biological systems vary with application, whether it is on-site or in situ.

Chemical treatment is limited for organics. However with the organic compounds that are directly chemically oxidizable, chemical treatment is an effective process. With inorganics, the main use of chemical treatment is to affect the solubility of the contaminant to either promote extraction or to prevent leaching.

REMEDIAL PROCESSES

The following is an overview of several basic remedial processes. An understanding of the performance and the limitations of the technology is a basic requirement to proper utilization. The processes covered are free phase recovery, groundwater recovery, venting, and bioreclamation.



Free Phase Recovery

When sufficient immiscible phase liquids have been lost in the subsurface to exceed the ability of the soil to retain the liquid (residual saturation), immiscible, non-aqueous phase liquids (NAPL) can result. If the non-aqueous phase liquid is less dense than water it will appear as a "floaters" or LNAPL, being found on the top of the water table. If, on the other hand, the non-aqueous phase liquid is denser than water it will appear as a "sinker" or DNAPL.

Recovery of NAPLs is basically a gravity driven process. The basic principle of design is to create a drainage point to which the NAPL migrates. With a LNAPL, this is accomplished by depressing the water table and collecting the LNAPL as pictured in Figure 1. With DNAPL recovery the drainage gradient is created by pumping both water and DNAPL. Both LNAPL and DNAPL recovery can be accomplished by total fluids recovery or by differential pumping. With total fluids recovery water and NAPL must be separated by equipment such as an oil water separator.

Ground Water Recovery

Treating dissolved phase contaminants consists of two functions. The first function is groundwater capture. This entails a rigorous understanding of the hydrogeological system. A discussion of hydrogeology is beyond the scope of this paper. The second function in groundwater recovery is treatment of the extracted groundwater.

Groundwater treatment parallels the types of processes discussed above. There are basically two types of groundwater treatment systems. The first type are extractive processes. The second type of processes are reactive processes.

With extractive processes the contaminant is removed from the water stream without being destroyed. The two most common systems are carbon adsorption and air stripping (Figures 2 & 3). Both processes work best with very low solubility materials. Carbon adsorption is best used for treating low volatile organics such as high molecular weight polynuclear aromatics and pesticides. With such materials a pound of carbon will adsorb ~.1-.15 lb of organic. Air stripping is best applied to volatile organics. It is based on Henry's Law, which describes the partitioning of an organic between the vapor phase and the dissolved phase. Compounds having a dimensionless Henry's Law constant of >1 are amenable to air stripping. Air stripping is accomplished by passing air through contaminated groundwater. This typically entails counter current air-water flow over a high surface area support.



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Reactive processes directly destroy the contaminant in the water stream. There are two approaches, biological and chemical (Figures 4 & 5).

Biological water treatment is primarily an aerobic system. Reactors are either fixed film or activated sludge types. With fixed film reactors the bacteria are attached to a high surface area rigid support and the contaminated water flows over the bio film. With activated sludge type reactors the bacteria are dispersed and suspended in the contaminated water stream. Bioreactors are used to treat any degradable, soluble organic material.

Chemical water treatment utilizes advanced oxidation processes such as UV/Ozone, UV/H₂O₂, or Ozone/H₂O₂. All of these systems rely on the production of active free radicals such as the hydroxyl radical, OH[•] which is a strong oxidant. These systems are particularly useful in treating chlorinated organics.

Soil Vapor Extraction

Venting is the removal of volatile organic materials from unsaturated soils by induced air flow as pictured in Figure 6. The keys to a successful design are 1) knowing where the contaminant is, and 2) being able to induce air flow preferentially through that area. The rate of extraction of the VOC and therefore the venting efficiency, is a function of how well these two items are defined and acted upon. The goal of design is to develop a flow-controlled system. This minimizes dilution of the vent stream by clean air and minimizes diffusion controlled limitations on the rate of removal. In cases of extreme geological heterogeneity venting may not be an effective technology.

In defining where the contaminant is, the focus is on adsorbed phase or free phase material. Venting is generally not an efficient method for remediating dissolved phase contamination.

To direct air flow through the areas of soil contamination requires understanding the air flow dynamics of the site. This entails determining the area of influence of an extraction well - horizontal and vertical; the achievable flow rates or vacuum levels; and the relationship between vapor recovery and air movement. Critical to understanding the air flow dynamics of a venting system is a proper geological characterization of the site, since mass flux during venting is a function of permeability.

A key component of venting is treating the contaminated air stream. The two most efficient systems are on site regenerable carbon and thermal treatment. Thermal treatment can be either by direct



fume incineration or by catalytic oxidation. Generally catalytic oxidation is the most cost effective process.

Air Sparging

Air sparging, simply viewed, is the injection of air under pressure below the water table. This creates a transient air filled porosity by displacing water in the soil matrix (Figure 7). The minimum pressure that is required to displace water in an air sparging system is that which is needed to overcome the resistance of the soil matrix to air flow. This resistance to flow is a function of the height of the water column that needs to be displaced and of the flow restriction (air/water permeability) of the soil matrix. When this "break-out" pressure is achieved, air enters the soil matrix, travels horizontally and vertically through the soil matrix, displacing water, and eventually exits into the vadose zone.

Air sparging, pressurized air injection, is a relatively new treatment technology for addressing contamination below the water table. By displacing water in the soil matrix and creating a transient air filled porosity, air sparging provides two benefits. First it can enhance the physical removal of organics by direct volatile (vapor phase) extraction. Second air sparging enhances biodegradation by increased oxygen transfer to the groundwater.

With direct extraction, air is injected under pressure below the water table. The air bubbles which form, traverse horizontally and vertically through the soil column creating transient air filled regimes in the saturated zone. Volatile compounds that are exposed to this sparged air environment "evaporate" into the gas phase and are carried by the air stream into the vadose zone where they can be captured by a vent system. The extractability of an adsorbed phase contaminant by an air sparge system is, as with soil vapor extraction (SVE), determined by the vapor pressure of the contaminant.

Given good air-to-water contact, the air sparging can also be used in groundwater treatment. Its applicability is determined by the stripability of the dissolved VOC contaminants being treated by the air sparger system. The degree of stripability is indicated by the Henry's Law constant, K_H ($\text{atm} \cdot \text{m}^3 \cdot \text{mole}^{-1}$). A K_H of $> 10^5$ indicates a stripable volatile constituent. Table IV lists the Henry's constant for several volatile constituents.



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Table IV
Henry's Constant for Selected VOCs

<u>Constituent</u>	<u>Henry's Constant, K_1 (atm-m³-mole⁻¹)</u>
Benzene	5.6×10^{-3}
Toluene	6.3×10^{-3}
Xylene	5.7×10^{-3}
Tetrachloroethylene	1.5×10^{-2}
Trichloroethylene	9.9×10^{-3}
Trans-1,2-Dichloroethene	9.4×10^{-3}
Acetone	6.8×10^{-6}
Phenanthrene	2.5×10^{-5}
2,4,5 - Trichlorophenol	6.8×10^{-6}

The first six are strippable, as indicated by their Henry's constant being greater than 10^{-5} (atm-m³-mole⁻¹); the latter three are not.

Another benefit of air sparging is that it is an effective means of supplying oxygen to the saturated zone. This benefit leads to the third application of air sparging, enhancing aerobic bioremediation. Air sparging results in more efficient aeration. This is the result of several factors. First, there is better penetration of air into the contaminated saturated zone. Under normal conditions air contact is only at the surface of the aquifer; with air sparging the contact is distributed over the entire sparged interval. Second, because air sparging creates air filled porosity in the soil matrix, the diffusive path length of air (oxygen) into the water is considerably shortened compared to normal groundwater conditions. Under normal conditions the distance between the air and water phases can be on the order of meters; with air sparging, the distance will be, at most, only several times greater than a soil pore, i.e., a few millimeters. Third, the "turbulence" caused by air sparging enhances the dissolution and distribution of oxygen into the water phase. Since biodegradation is critically dependent on oxygen supply, the efficient aeration engendered by air sparging will enhance bioremediation. For air sparging to be effective in stimulating enhanced bioremediation, the contaminant must be biodegradable under highly aerobic conditions.

In Situ Enhanced Bioremediation

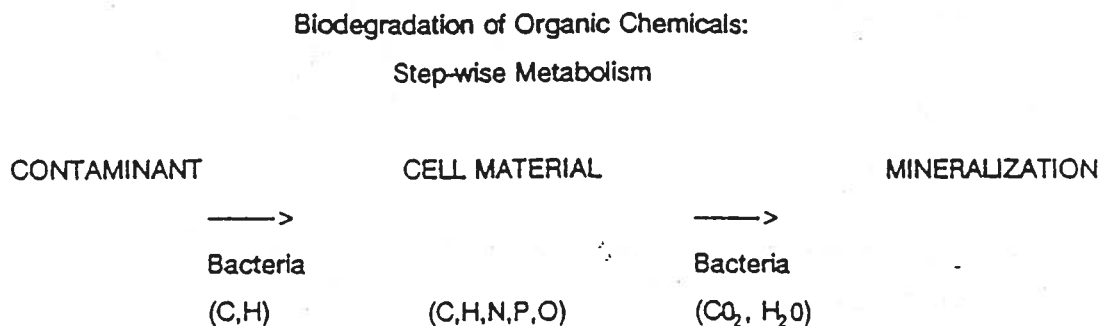
Bioreclamation, in situ aerobic biological treatment, is one of the most versatile remediation processes, dealing with a wide range of organic compounds in a number of different



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hydrogeological conditions. In situ enhanced bioreclamation is a proven method for remediating groundwater aquifers contaminated with petroleum hydrocarbons and many organic chemicals. It is simply the use of common aerobic soil bacteria to degrade organic contaminants. It involves the stimulation of indigenous bacteria through the addition of essential nutrients. The bacteria used in the process are already there.

The process can be simply viewed as a step-wise degradation as pictured below:



Bacteria which can feed directly on the contaminant use it to grow, producing primarily cell material. Looking at this first step we can see what is required for stimulation. The contaminant is primarily carbon and hydrogen; cell consists of carbon, hydrogen, nitrogen, phosphorus, and oxygen (with minute amounts of minerals). The key to accelerating this natural degradation process is to add sufficient nitrogen phosphorous, and oxygen to balance the available carbon and hydrogen (the contaminant). This process is already occurring in nature but is very slow because the bacteria quickly expend the naturally occurring nutrients. Once the specific degraders convert the contaminant to cell material they die and serve as a readily utilizable food source for other bacteria. The end result of the overall process is the conversion of the contaminant into carbon dioxide and water.

The key to in situ bioreclamation is getting the nutrients to the contaminated area, as shown in Figure 8. The first stage in this process is to hydrogeologically create a reaction vessel by pumping and injecting groundwater. This accomplishes two things. First, the treatment area is confined; the contaminant and nutrients are enhanced. Since normal groundwater flow ranges from 10 to 200 feet per year, it could take years for nutrients to traverse even a small site. By increasing the gradient through pumping (draw-down) and injection (mounding), transport times can be reduced from years to days or hours. Since the nutrients limit the process, the more quickly they can be added, the faster the remediation. Compared to the rate of nutrient transport the biological processes are essentially instantaneous.

In situ bioreclamation is a versatile groundwater treatment tool. However, this form of remediation is not general panacea, and has some definite limitations. In some cases the selection of surface treatment over in-situ treatment is appropriate. If contamination is primarily in the groundwater, or containment of the contamination is the sole priority, or if the source of contaminant cannot be readily defined and the point of impact is the groundwater, a pump and treat strategy may be the most appropriate solution. Additionally, if the contaminants of concern are not biodegradable or readily oxidizable to a less harmful form, extraction and surface treatment may be the only option. It is also a site specific process and its applicability depends on local site microbiology, hydrogeology, and chemistry. To be successful, the contaminant must be biodegradable, the hydrogeology must allow for the controlled and timely transport of nutrients, and the soil and water chemistry must be compatible with the introduction of nutrients and must also allow for the stimulation of the subsurface microbial community.

CHOOSING A REMEDIAL SYSTEM

As previously discussed, the choice of a particular treatment process is determined by an understanding of the mechanisms of contaminant movement and reaction. The volatility, solubility and sorptive properties of the contaminant determine how easily it moves through the subsurface. The reactivity of a contaminant either chemically or biologically and its ultimate fate determine whether an in situ treatment process can be used or whether containment or physical removal is more appropriate. The most effective remediation strategy is one that is based on these two aspects of transport and reactivity. The choice of a remediation process depends on the matching of available technology with an understanding of contaminant transport and reaction. The mechanism which ties this all together is the Selection Matrix. This consists of a two-by-two matrix of reactivity and transport:



CONTAMINANT MOVEMENT

	HIGH	LOW
HIGH	QUADRANT 2 Soil Vapor Extraction Extraction	QUADRANT 3 Bioremediation Air Sparging
LOW	QUADRANT 1 Free Phase Recovery Pump & Treat	QUADRANT 4 Physical Containment

For each of the quadrants the most effective remedial processes are identified. One uses the matrix by locating the contaminant in the appropriate quadrant, based on its properties and its spatial/phase distribution and then choosing from the listed remedial processes. The choice of a particular process is a function of mass-removal rate and/or cost.

Contaminants and remedial processes vary within the different quadrants. High transport contaminants can be treated by extractive processes; high reactive contaminants, by biological/chemical processes. The remedial processes within a quadrant are dictated by the appropriate transport/reactivity factors, solely. The placement of a contaminant within a quadrant, on the other hand, is a function not only of the properties of the contaminant but also its spatial location in the subsurface.

Quadrant 1 covers high transport, low reactivity situations. These include volatile chlorinated solvents in the vadose zone, soluble inorganics, and free phase material. All of these have limited reactivity. Chlorinated solvents are chemically and biologically quite stable but have fairly high vapor pressures and solubilities, which means that they can be vented or extracted. Inorganics generally can only be removed by extraction. Free phase material, while being in many cases inherently biodegradable, is too much of a "load" on biological systems and is, therefore, quite recalcitrant. It can, however, be removed by direct extraction.

Quadrant 2 covers high transport, high reactive situations. In these cases one has maximum flexibility in choosing a remedial process. Included in this quadrant are volatile petroleum hydrocarbons in the vadose zone, soluble or miscible organics in the saturated zone, and low level dissolved organics (no adsorbed phase). Since most petroleum hydrocarbons (PHC) are biodegradable, volatile PHC's such as gasoline, can be either vented or biodegraded in the vadose zone. With soluble organics, there is little or no adsorbed phase if the material has entered the water table. As a result these contaminants can be extracted or biodegraded. The same is generally true if the subsurface contamination is simply low level dissolved organics with limited or no adsorbed phase.

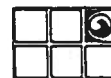
Quadrant 3 covers low transport, high reactive situations such as any petroleum hydrocarbon or low solubility organic in the saturated zone, or low volatility PHC's in the vadose zone. In such cases biodegradation or chemical treatment is an effective means of remediation. If the contaminant is volatile than air sparging can be used.

Quadrant 4 covers low transport, low reactive situations such as most high molecular weight organics, many complex pesticides, and insoluble inorganics. With these materials there is little phase differentiation, as most of the contaminant will be adsorbed. There is also little impact due to limited spacial distribution and mobility. The best course in these situations is to use containment as the remedial process.

While remedial processes are governed by the transport and reactivity of the contaminant(s), another strategy is to move a contaminant from one quadrant to another by changing the transport or reactivity. For example a soluble metal such as chromium VI can be transformed into an unreactive, insoluble Chromium III. A complex contaminant such as coal tars can be biostabilized by removing the lighter, more soluble fractions, leaving the insoluble non-degradable high molecular weight polynuclear aromatics.

CONCLUSION

While groundwater contamination is a complex and difficult-to-treat problem, it is possible to develop a methodology that makes managing the problem more understandable. It is applicable to any remediation option: containment, removal, or in situ treatment. The key to this methodology is to properly define the problem, characterizing both the hydrogeology of the site and the nature of the contamination, identifying possible receptors, and defining the nature and magnitude of potential impacts.



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The purpose of this methodology is to determine for a given site what needs to be done and what can be done. The process of selecting a remedial system involves characterization of the site and definition of the properties of the contaminant(s).

The characteristics of the site determine what method of remediation is applicable, how difficult it will be to apply a given method, and how long it will take to remediate the site. The aquifer characteristics, heterogeneity and permeability, determine how difficult it is to apply a process. The hydrogeology determines the ease of transport and thus how readily the contaminant can be extracted or destroyed by the addition of chemicals or nutrients. The focus of transport in destroying a contaminant is to contact the contaminant with the reactive agents.

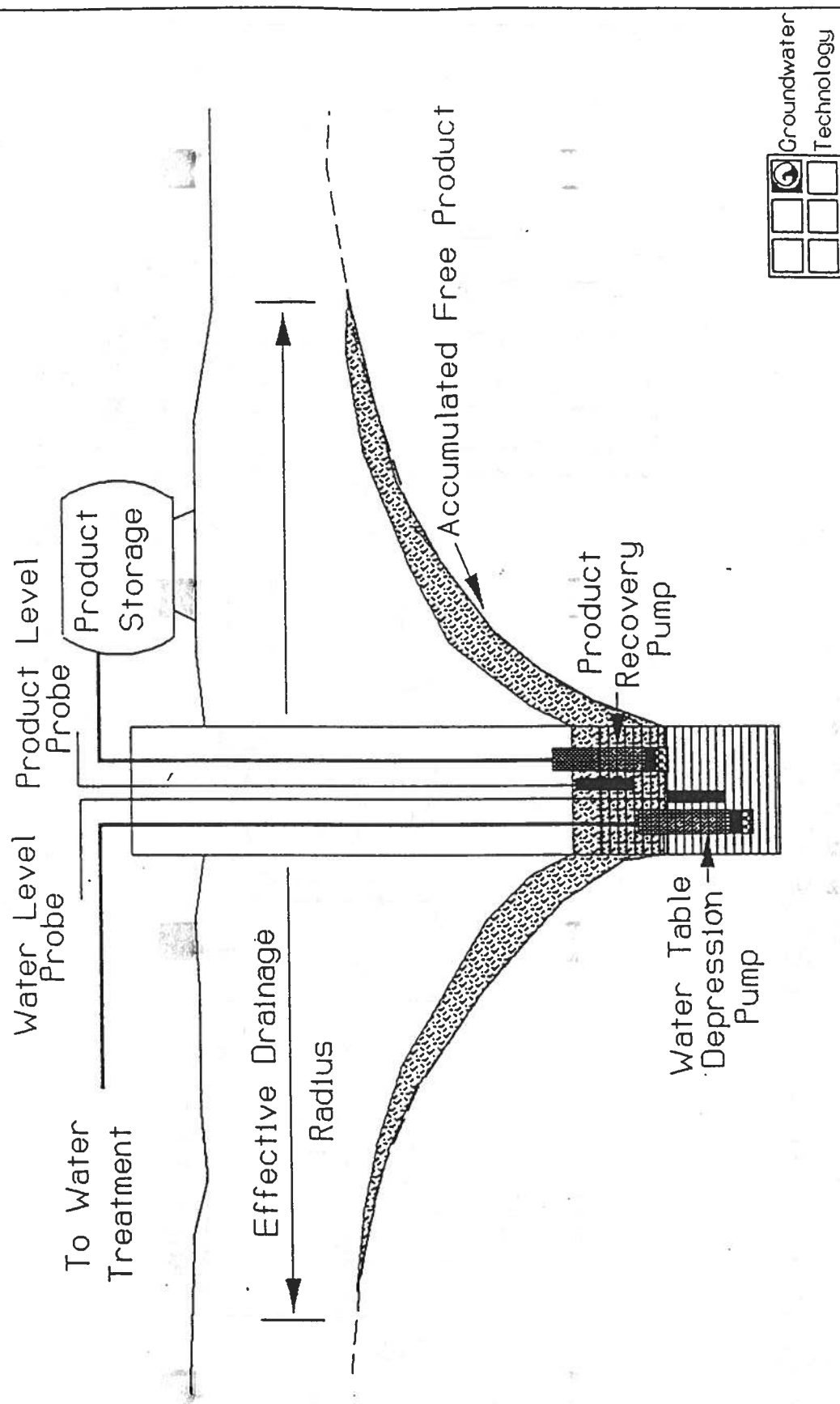
The contaminant itself primarily impacts what process can be used for remediation. Processes are selected by determining both the reactivity and phase distribution of the contaminant. Successful remediation processes are based on a transport or reactive property of the contaminant(s). If a material is biologically recalcitrant, it cannot be treated with bioreclamation. If a contaminant is not volatile, it cannot be vented.

By understanding how a contaminant was transported and is distributed in the subsurface and what affects its persistence (reactivity), one can choose an effective remediation strategy. The most effective remediation strategy is one that is based on these two aspects of transport and reactivity. The choice of a remediation process thus depends on the matching of available technology with a thorough understanding of contaminant transport and reaction.



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Fig. 1 Schematic of Free Product Recovery System



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Fig. 2 Schematic of Carbon System
For Groundwater Treatment

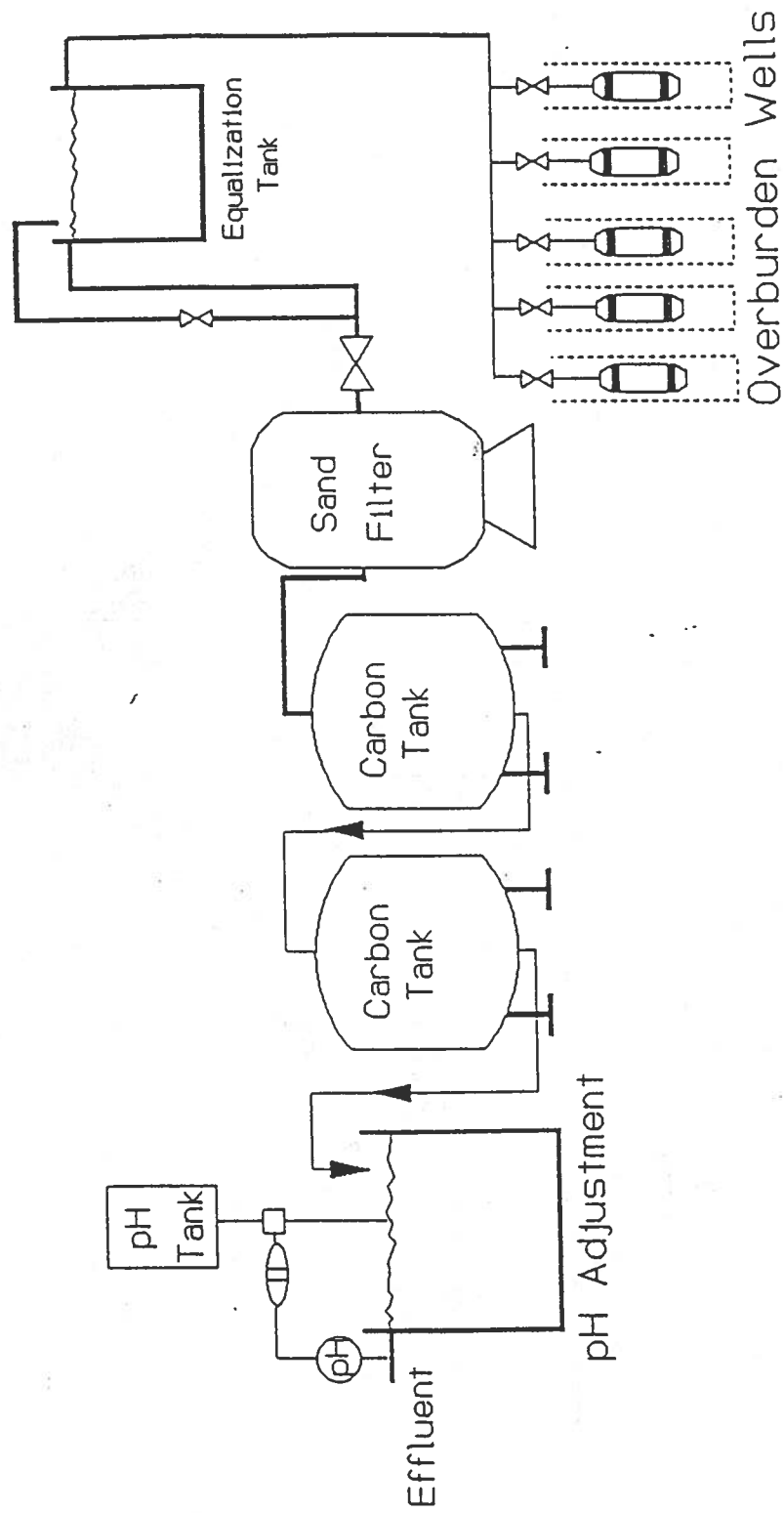


Fig 3. Schematic of Air Stripper/Carbon System
For Groundwater Treatment

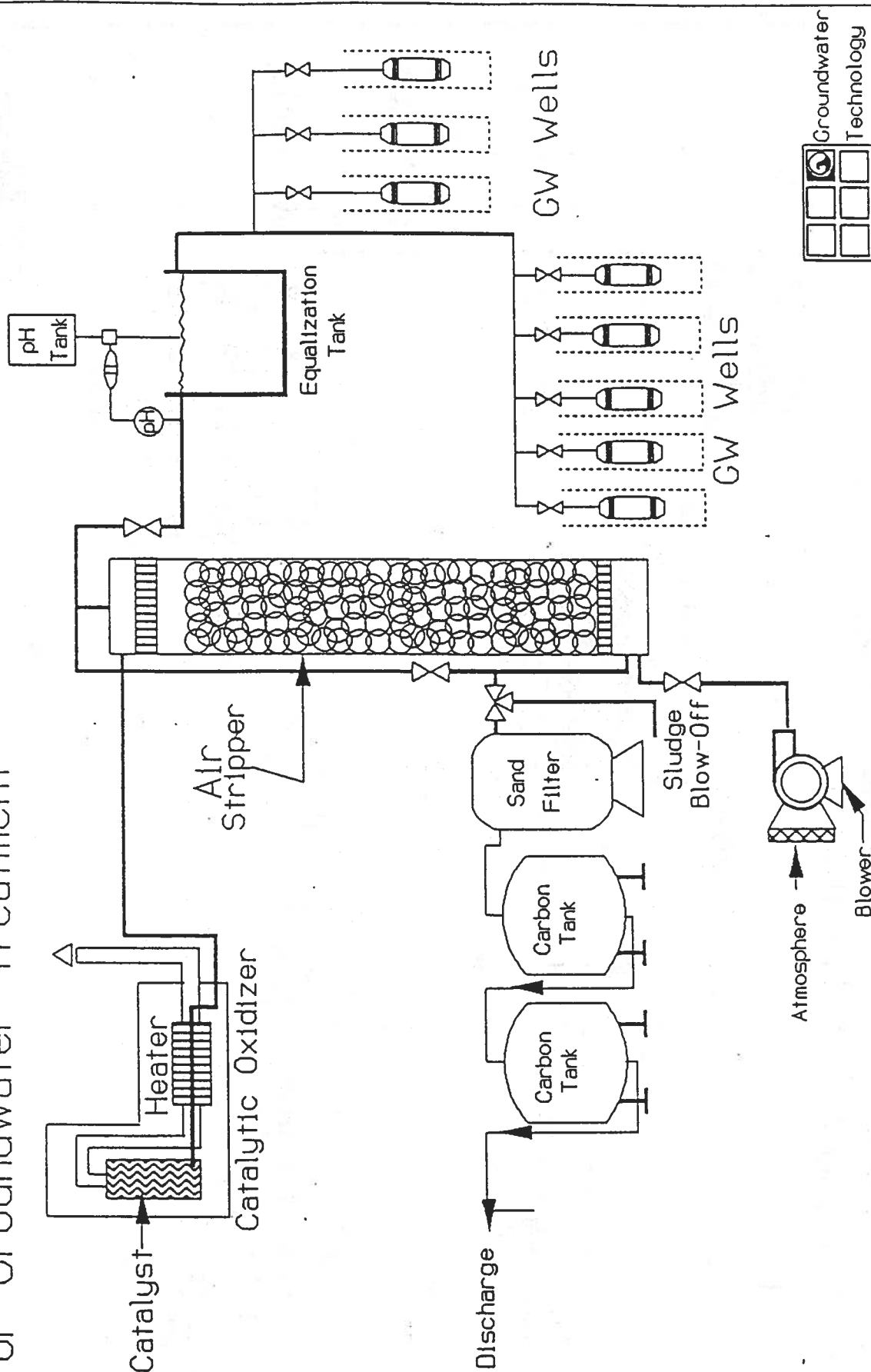


Fig. 4 Schematic of Bioreactor System
For Groundwater Treatment

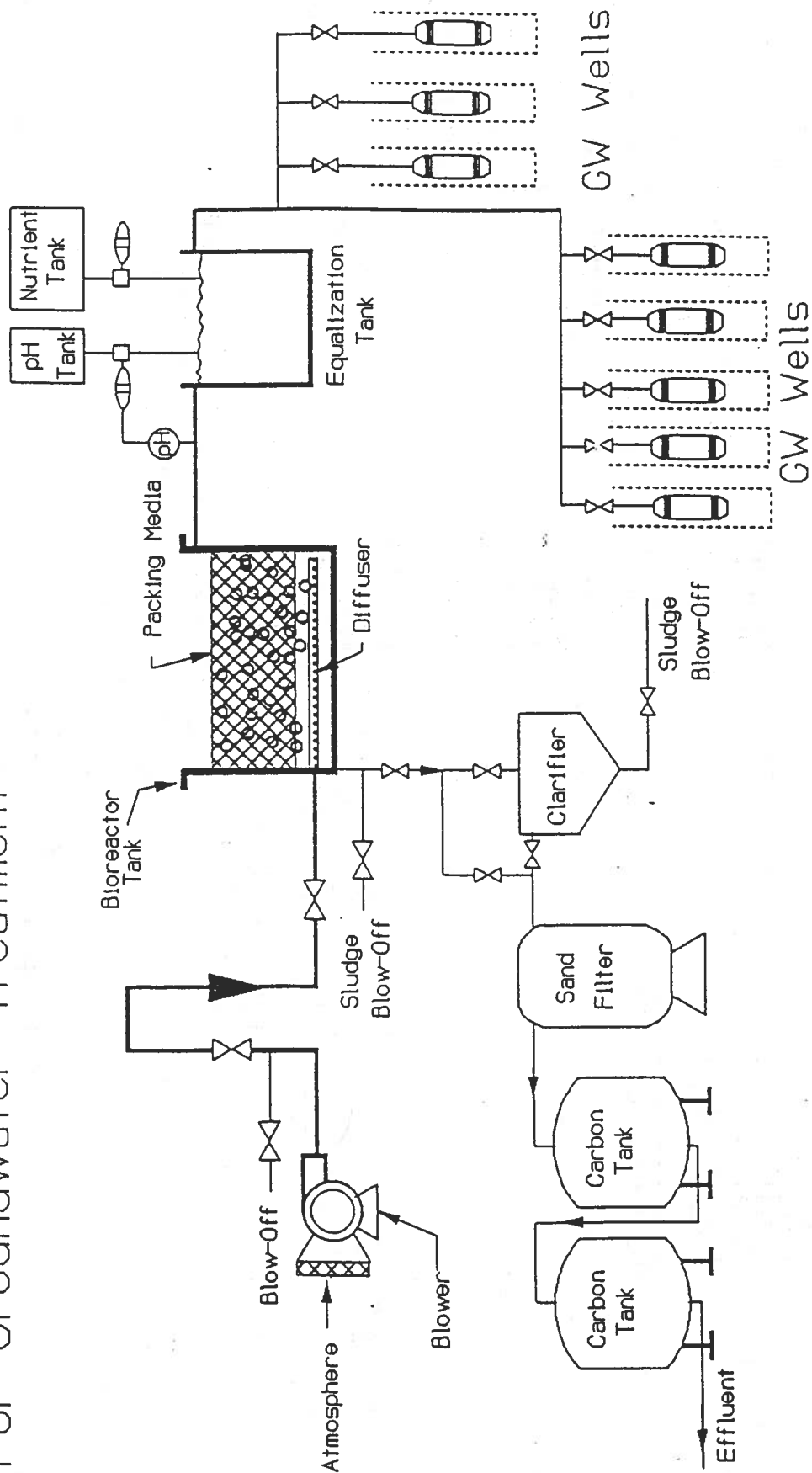


Fig. 5 Schematic of AOP System (UV/H₂O₂)
For Groundwater Treatment

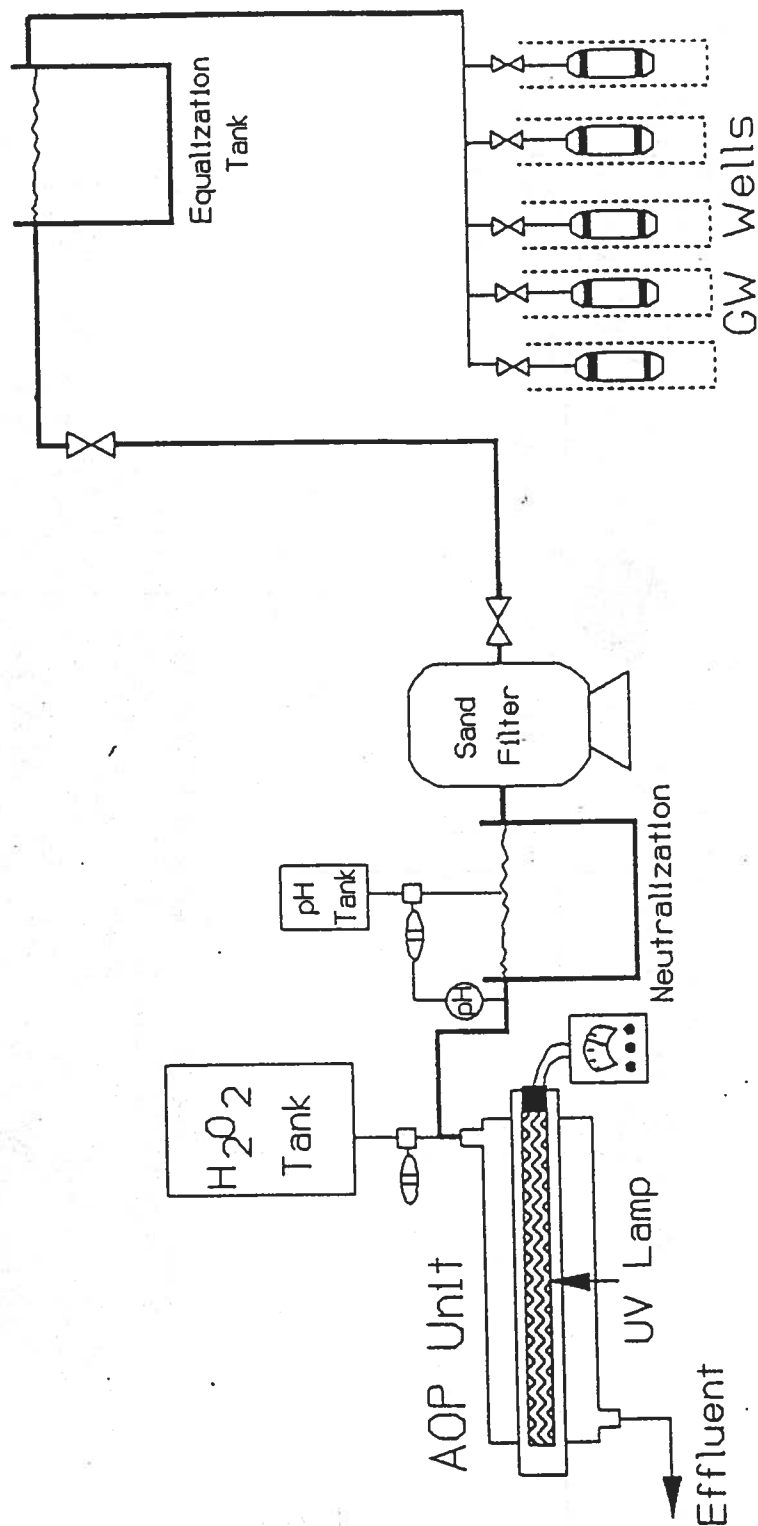


Fig. 6 Schematic of Soil Vapor Extraction System

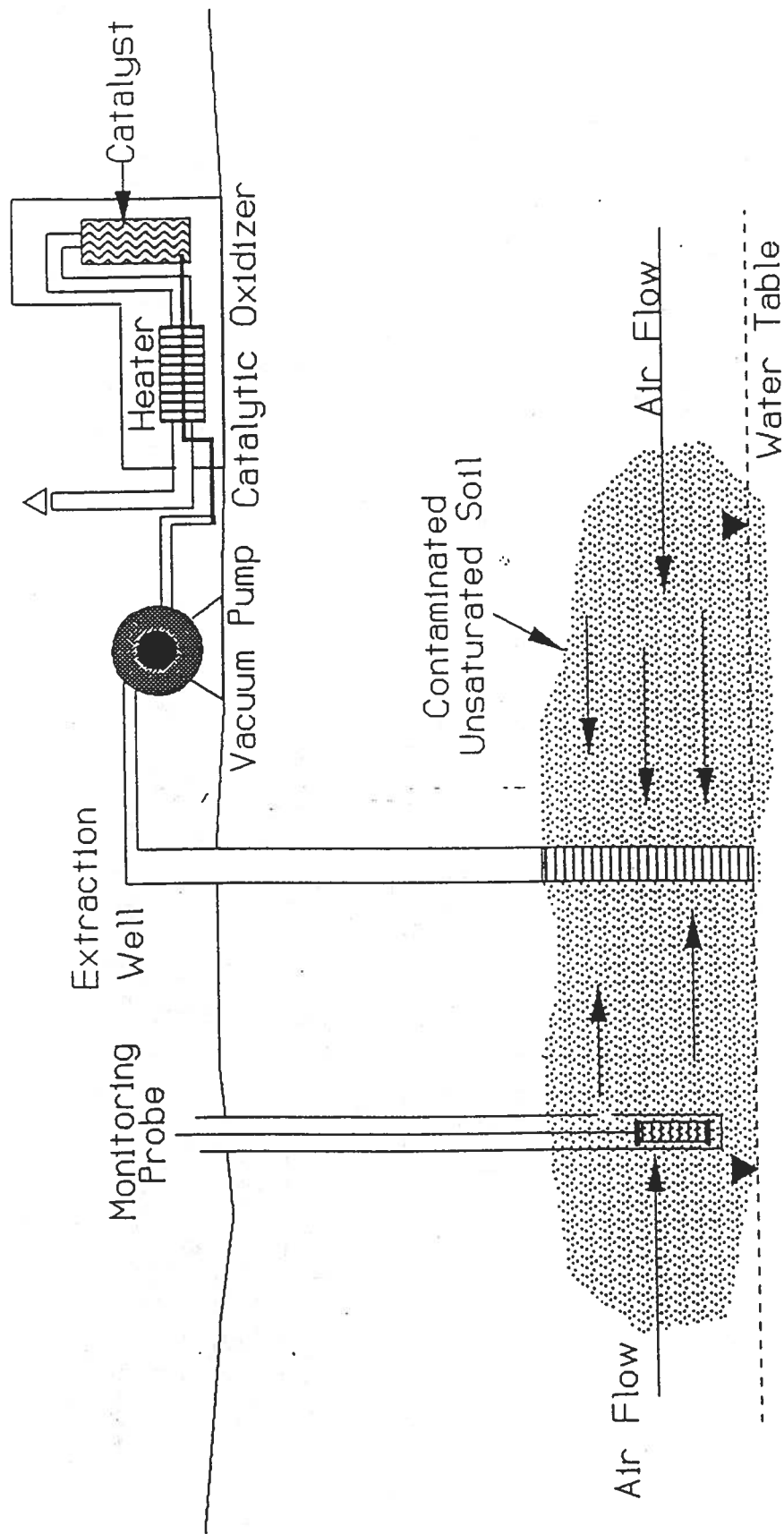


Figure 7: Diagram of Air Sparging System

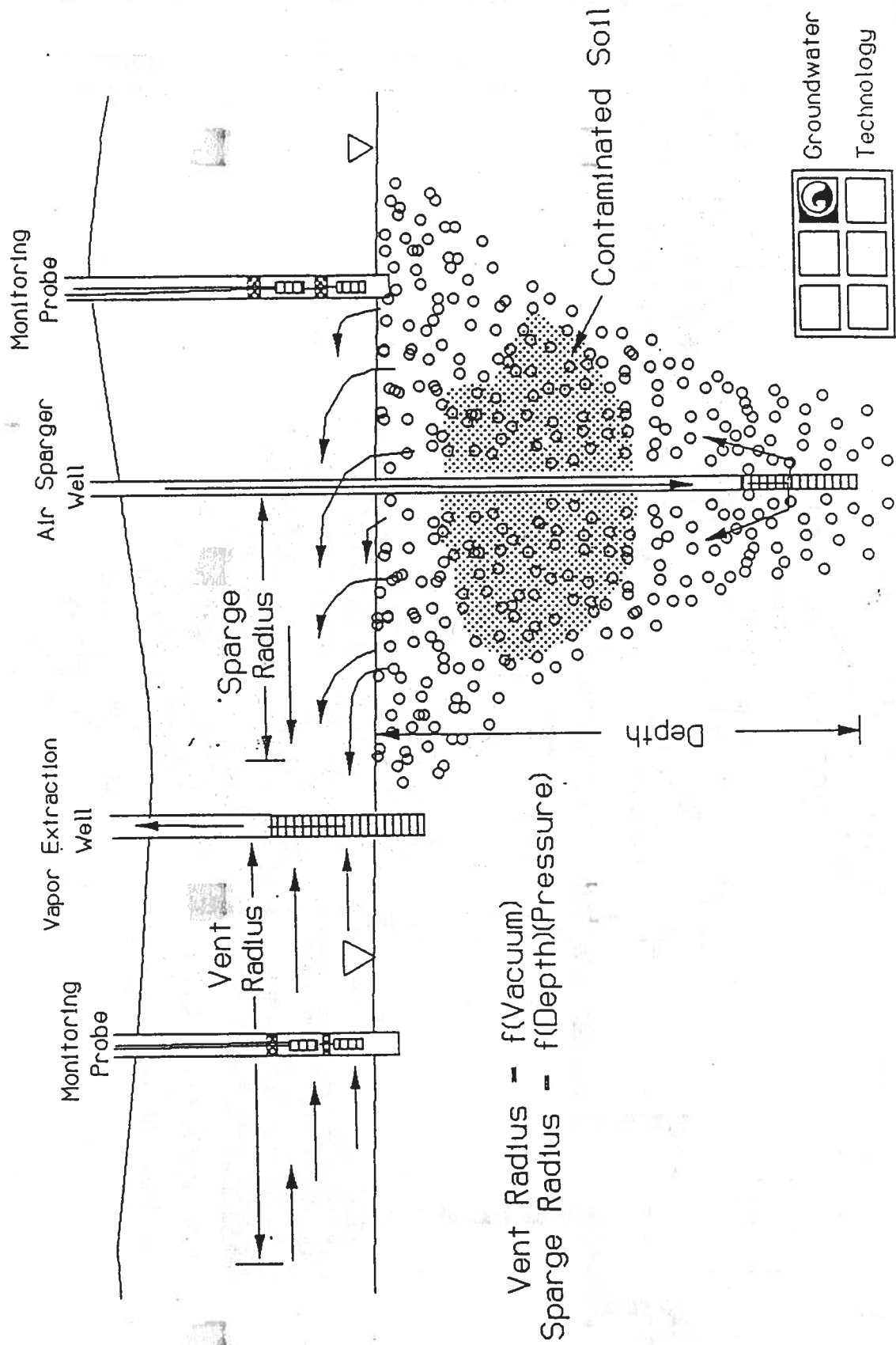
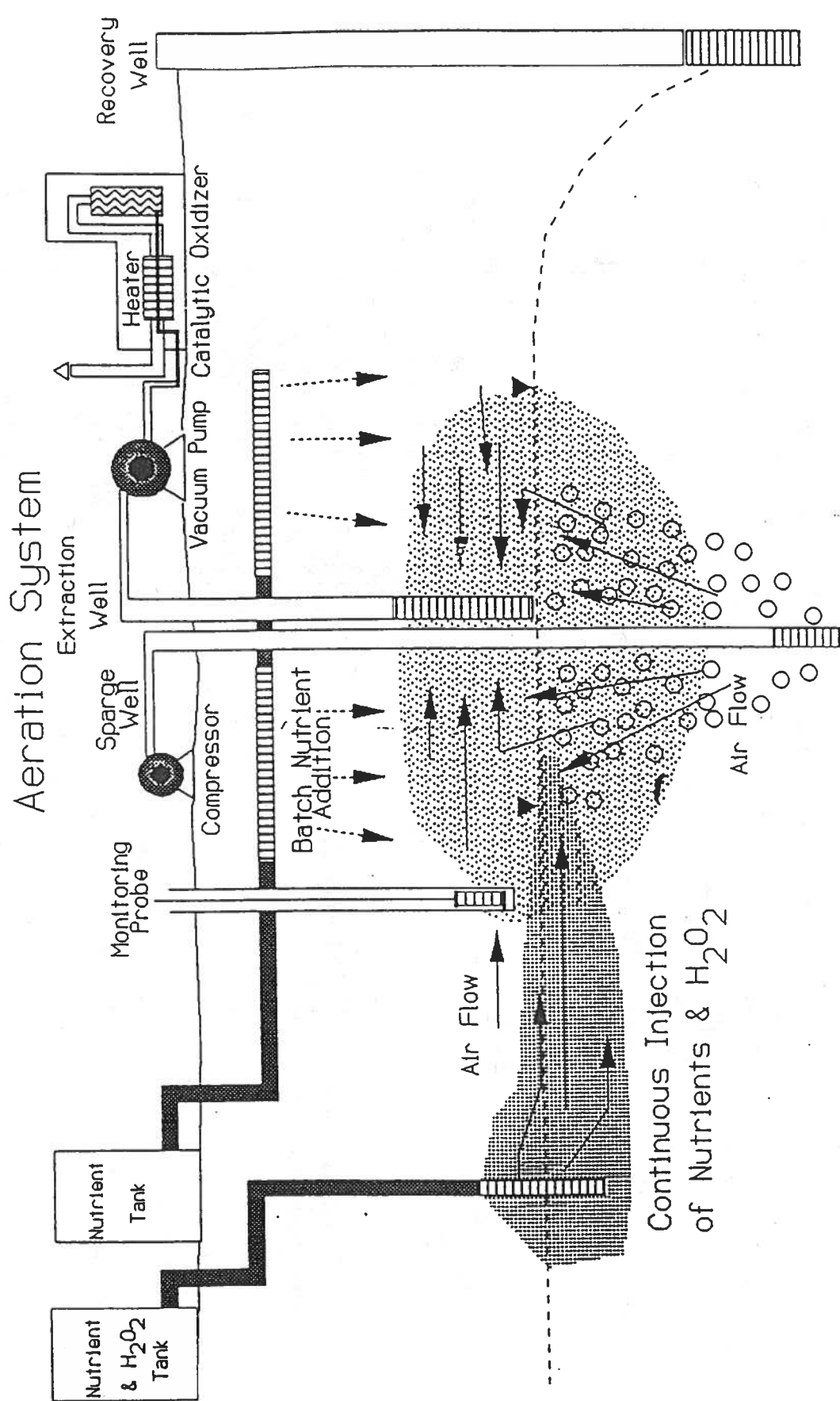


Fig. 8 Schematic of Bioremediation System



Overview Of Remedial Technology

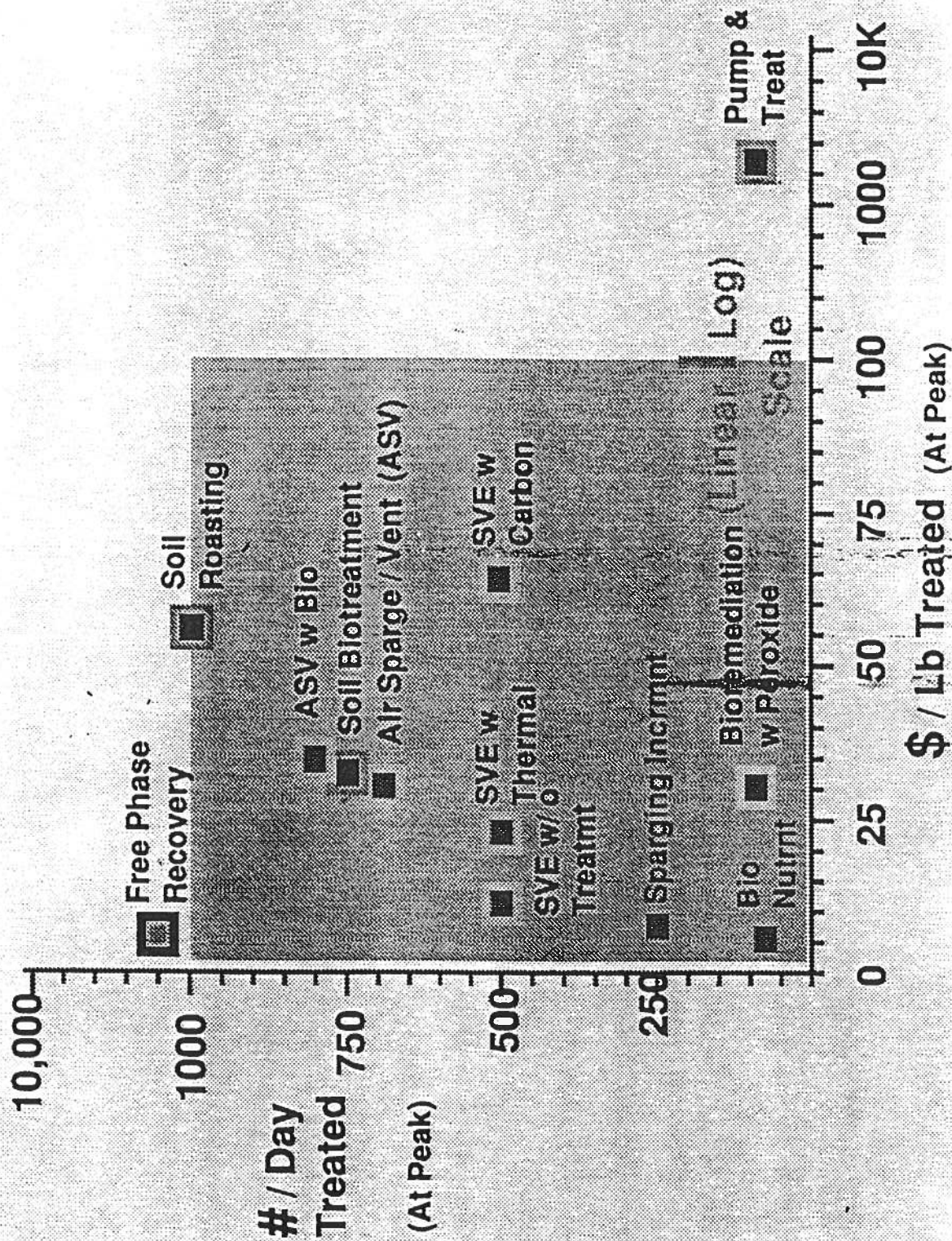


TABLE 2
SUITABILITY OF TREATMENT PROCESSES

EFFECTIVENESS

<u>PROCESS</u>	<u>VOLATILE ORGANICS</u>	<u>NON-VOLATILE ORGANICS</u>	<u>INORGANICS</u>
Ambient Air Stripping	Inadequate Removal	Not Suitable	Not Suitable
Steam or Pre-heated Air Stripping	Effective Removal Technique	Not Suitable	Not Suitable
Carbon Adsorption	Inadequate Removal	Effective Removal Technique	Not Suitable
U V-Ozone	Not Suitable Due to High Concentration	Not Suitable Due to High Concentration	May oxidize and precipitate some metals
Biological	Effective Removal Technique	Effective Removal Technique	Not Suitable
Wet Oxidation	Not Suitable Due to Low Concentration	Not Suitable Due to Low Concentration	Not Suitable
Reverse Osmosis	Inadequate Treatment	Not Applicable	Effective but Difficult Operation
Chemical Precipitation	Not Applicable	Not Applicable	Effective Removal Technique
Electrodialysis	Not Applicable	Not Applicable	Inefficient Operation/Inadequate Removal
Ion Exchange	Not Applicable	Not Applicable	Inappropriate Technology - Difficult Operation



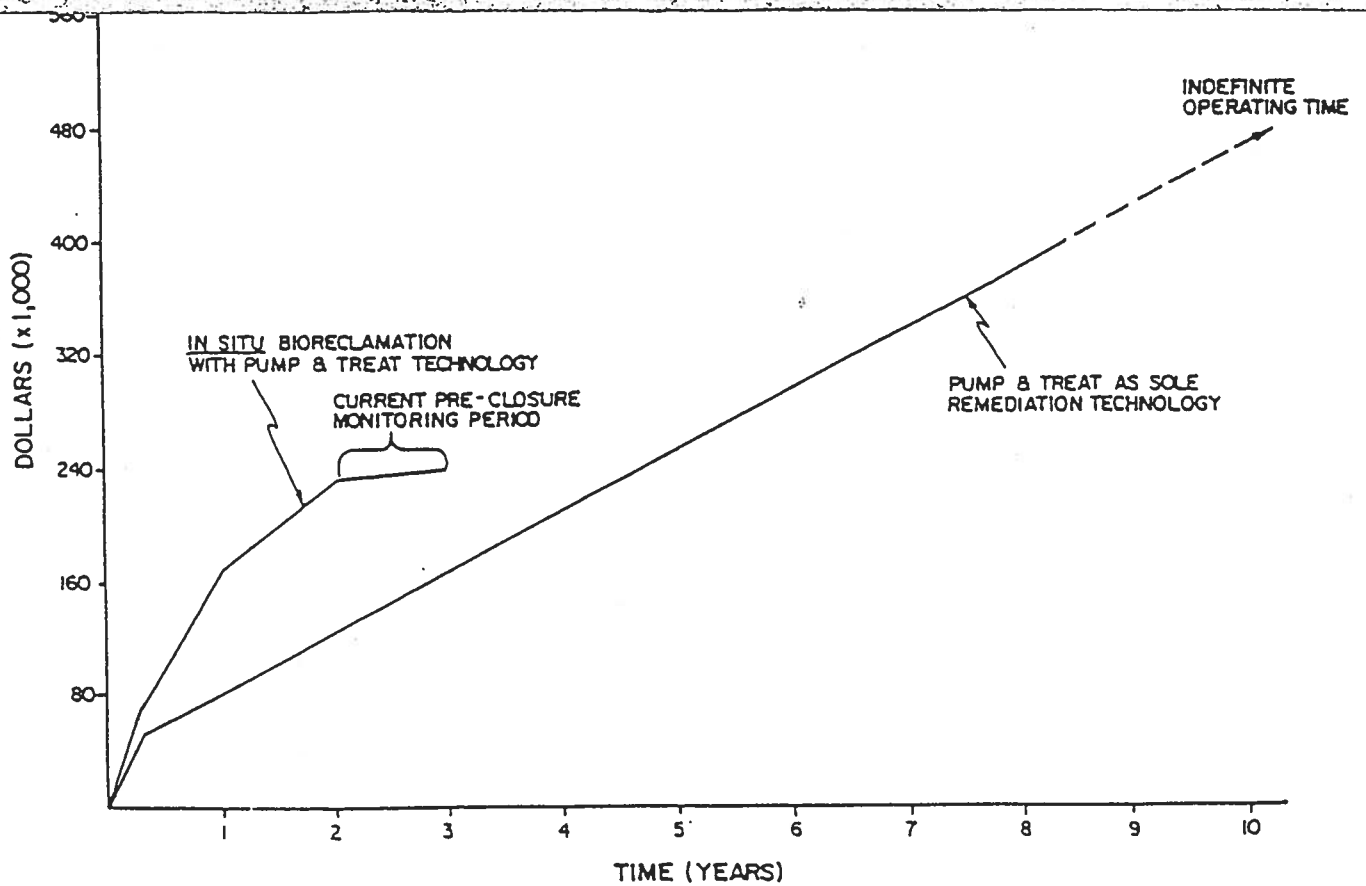


Figure 6. Cost comparison: In situ bioreclamation vs. simple pump-and-treat.



Cost/Performance Comparison for Various Oxygen Systems
High Degree of Contamination

System	Costs			Lbs/Day Oxygen	Performance		Time of Treatment	\$ /Lb oxygen Used
	Capital	Operation	Maintenance		% Site Treated	Utilization Efficiency %		
Air Sparging	\$35,000	\$800/month	\$1200/month	6	41	70	858 days	\$25.80
Water Injection	\$77,000	\$1200/month	\$1000/month	8	75	50	1580 days	\$28.62
Venting System	\$88,500	\$1500/month	\$1000/month	4000	60	5	132 days	\$ 3.82
Peroxide System	\$60,000	\$10,000/month	\$1500/month	190	100	15	330 days	\$18.60
Nitrate System	\$120,000	\$6500/month	\$1000/month	211	100	12.5	335 days	\$22.06

TABLE 1

COMMON AERATION TECHNOLOGIES

Device	Typical Configuration	Removal*	Cost (\$/1000 gal)	References
Slat Tray Aerator	Redwood slat trays in boxlike structure 10 to 18 feet tall. Countercurrent air/water flow.	60-80%	\$0.05	3,16
Diffused Air	Water storage basin with air diffusers. Up to 20 minute contact times common.	>90%	\$0.40-\$2.00	2,18,19,20
Spray Aeration	Spray nozzles in open or closed system. Fine droplets provide air/water contact.	50%-90%	N/A	21
Cascade Aerator	Exposed system of stacked trays, relies on natural draft.	50%	\$0.05	2,19
Packed Column	Cylindrical tower with plastic media. Countercurrent air/water flows.	90-99.9%	\$0.05-0.25	2,16,17,18,20
Rotary Stripper	Rotating packed bed. Relies on centrifugal force to form thin liquid films and high turbulence.	>90%	N/A	15,22

*Removal of Trichloroethylene

N/A - Not Available



Soil Treatment Options

	Soil Washing	Biotreatment	Thermal Treat
Capital	\$250-500K	\$10-50 / Ton	\$250-500K
Max Capacity	10-20 Ton / Hr	Unlimited	40-50m Ton / Hr
Min Capacity	500 Ton	None	500 Ton
O&M Captive	\$60-80 / Ton	\$25-70 / Ton	\$50-75 / Ton
O&M Subcont	\$75-90 / Ton	\$30-80 / Ton	\$80-100 / Ton
Problems	Water Treatmnt "New Technlgy"	Heavy Ends Clayey Soils	Clayey Soils Permitting
Advntges	Throughput	Proven / Flexible	Throughput

