Feasibility Study of Industrial Asphalt Facility

Pleasanton, California
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1.0 Executive Summary

A feasibility study (FS) was conducted for Industrial Asphalt, Inc., located at 52 El Charro Road, Pleasanton, Alameda County, California. The FS was initiated after the discovery of floating free product during the removal of Underground Storage Tanks (USTs). This report presents the results of our analyses and recommendations for the remediation of the facility.

The following steps have been taken to arrive at the appropriate remedial action:

- A review of the remedial investigation (RI) completed by Kleinfelder, Inc. on December 28, 1990 was conducted. This report was used as the primary source of site specific data.
- The fate and migration of the petroleum hydrocarbons, benzene and PCBs were examined. Based on this study, as well as the site characteristics, current and future risks associated with the contaminants were determined.
- Potentially applicable technologies were screened to determine technologies which were technically, financially and legally feasible for remediation of the site.
- Feasible technologies were combined into remediation alternatives. These alternatives were evaluated and ranked according to their estimated cost, feasibility of implementation, ability to meet the remedial objectives, and likelihood of public acceptance.
- The alternative which ranked highest was choosen as the recommended remedial response.

The following conclusions were reached during the course of this study:

- The groundwater within the contaminated region must be protected as a state resource and, in its present state, the groundwater does not currently meet reequired health-based standards.

- The remedial objectives are:
    - To minimize the migration of the petroleum hydrocarbons and PCBs.
    - To reduce the concentration of total petroleum hydrocarbon, benzene and PCB to 0.1 mg/l, 0.3 μg/l and 0.0046 μg/l, respectively, in the ground water.

The recommended remediation alternative consists of the following:

- An extraction well system to control further migration of the contaminant plume is required to reduce petroleum hydrocarbons and benzene concentrations.
- Extracted water will be treate using a UV/hydrogen peroxide oxidation system.
- Excavation and landfill disposal of the remaining PCB laden soil after Industrial Asphalt removes its plant operations prior to reclamation by the state of California.

2.0 Site Conditions

2.1 Site Location/Description

Industrial Asphalt (IA) is located at 52 El Charro Road, Pleasanton, Alameda County, California. The facility is situated in the Livermore Valley, approximately two miles south of Interstate 580. The facility, which is leased from the Jamieson Company, occupies a 177 acre parcel leased from the Jamieson Company, and is permitted for gravel quarry operations through December 31, 2030. Figure 1 is the location of the Industrial Asphalt facility.

The Livermore Valley is surrounded by hilly to mountainous terrain. The topography of the IA facility is approximately level, with a slight downward slope from the southwest corner to the northeast corner of the site. The approximate elevations range from 376 to 380 feet above mean sea level. The facility is paved. Extensive pit mining operations surround the site, and the nearest urban residential areas are located approximately one mile west in the city of Pleasanton.

Asphalt for industrial, commercial, and residential purposes is manufactured at the site by combining mixtures of gravel and heavy hydrocarbon oil to produce the asphalt product. There are currently no known underground storage tanks at the IA facility. There are no reported underground pipelines or other potential subsurface sources of petrochemicals or chlorinated solvents onsite. Liquid chemicals and wastes on site, which are potential sources of subsurface contamination, are carefully managed above ground in drums and tanks. Waste oil is drummed and shipped for disposal offsite. Figure 2 is a map of the Industrial Asphalt plant.

2.2 Hydrogeology

The subsurface in the Livermore Valley is composed of alluvial deposits with depths varying between less than 100 feet to approximately 400 feet below ground surface. Water-bearing zones in the alluvium are composed of gravel, sand and clay, and are moderately permeable. There are confining beds of silty clays varying depths throughout the valley. The regional groundwater flow in the Livermore Valley groundwater basin is generally northwest.

There are several production wells used for water supply in gravel pit operations within a one-mile radius of the IA facility. The screened intervals of these supply wells are at varying depths between 100 and 350 feet below ground surface. The nearest municipal supply wells are located approximately two miles east of IA. The closest domestic water supply well is at the Jamieson quarry located 900 feet to the northeast.

Soil stratigraphy beneath IA resembles an alluvial fan deposit, with interfingered beds containing varying amounts of clay, silt, sand, and gravel. Fine-grained material, such as silty clay and silt, is found to varying depths up to 60 feet below ground surface. Unconsolidated silty-clayey gravel deposits are found below the fine-grained material to depths of 130 feet below ground surface.

Within the silty-clayey deposits are discontinuous water-bearing zones of silty-sandy gravel, typically found at 90 to 110 feet below ground surface. At 120 feet below ground surface, a deeper water-bearing zone is found. No information is available for conditions deeper than 130 feet.

As mentioned previously, the regional horizontal groundwater flow generally is to the northeast. However, groundwater flow beneath the site has occurred in both the northeasterly and southwesterly direction, and fluctuates greatly due to nearby surface water and groundwater activities.

2.3 Site History & Investigations

Industrial Asphalt (IA) is a California based company that has been at the site since 1963. Asphalt for industrial, commercial, and residential purposes is manufactured by combining gravel mined on site and heavy hydrocarbons which are trucked to the facility. Following mixing, the hot asphalt is loaded into trucks and delivered to construction sites.

From 1963 to 1986, IA maintained six asphalt and two diesel underground storage tanks at the facility. The diesel fuel purchased during 1983 and 1984 was used as a fuel oil in the batch plant. Following 1984, the plant began utilizing natural gas due to lower costs. In 1985, a leaking fill pipe serving the diesel tanks was identified and repaired.

Upon removal of two diesel tanks (6,700 and 4,920 gallon capacities) in February 1987, diesel product was observed in the bottom of the excavation. Chemical analysis of the free product indicated the presence of total petroleum hydrocarbons (TPH) at a concentration of 340,000 mg/kg and polychlorinated biphenyls (PCBs) at a concentration of 12 mg/kg. Approximately 5,000 gallons of a mixture of diesel product and water was recovered and disposed of at a Class I disposal facility. Figure 3 shows the location of the cavity of the former Underground Storage Tank (UST).

In March of 1987, IA hired a consultant (Kleinfelder, Inc.) to initiate environmental investigations of the subsurface. Six soil borings were completed in and around the area of the two diesel tanks. Analyses of soil samples collected from borings 45 feet below grade indicated TPH and PCBs as high as 4,600 mg/kg and 0.073 mg/kg, respectively.

In September 1987, the four remaining underground asphalt tanks were removed. Approximately 700 cubic yards of soil were excavated and subsequently incorporated in the asphalt produced at the facility. The excavation was backfilled with clean fill and covered with concrete. Between the summer of 1987 and February 1990, 16 monitoring wells were installed at various locations on site. Figure 4 presents the location of these wells.

2.4 Current Conditions

Analyses of groundwater and soil samples indicated that presently the diesel fuel contamination extends 90 feet to the north and south of the UST cavity and approximately 450 feet west and 260 feet east of the cavity. PCB contamination is confined to 50 feet north and south of the UST cavity and 25 feet east and 140 feet west of the cavity. Figures 5,6,7, and 8 presents the contours of the approximate range of contamination for the diesel fuel and PCBs in the soil and groundwater. Table 1 lists the results of the most recent groundwater sampling done in April 1991.

2.5 Future Plans for the Site

Industrial Asphalt is currently leasing the site from the State of California. In the year 2030, the state will reclaim the land, and the land is currently planned to be used as a recreational park. Industial Asphalt plans to mine the land for its asphalt operations prior to the state's reclamation. This would require them to move in approximately 30 years.

3.0 Health Risk Assessment

A screening-level baseline assessment of the offsite risk to human health from contaminants which might be found in the subsurface of the site was performed. The assessment was comprised of several discrete tasks: Determination of chemicals of concern, assessment of exposure pathways, quantification of exposure concentrations through a ground water plume modeling technique, and estimation of daily dose and risk associated with exposure. In the following sections, a description of the methods are presented.

Prior to our analysis, another consultant performed a similar assessment. The results of the assessment were reported in the Industrial Asphalt's Remedial Investigation Report published December 28, 1990 by Kleinfelder Incorporated.

3.1 Chemicals of Concern

Diesel oil is composed of a complex mixture of hydrocarbons. Table x describes the typical composition of diesel fuel. From this list, benzene and naphthalene are the chemicals most likely to pose adverse health effects following chronic exposure. These two chemicals were chosen because of their serious adverse health effects, their high water solubility and low optimal water partitioning coefficient, K_{ow}, relative to the other compounds found in diesel. High solubility and low K_{ow} indicate that these contaminants are relatively mobile in the subsurface ground water. Benzene is classified by EPA as a class A carcinogen and naphthalene is identified as non-carcinogenic human toxicant.

Table 3 indicates that there are three other compounds which may have also warranted investigation. Ethyl benzene, toluene, and xylene which are constituents of diesel have significantly higher water solubility and similar, or lower, K_{ow} values than naphthalene. The chronic non-carcinogenic risk from these compounds is two orders of magnitude lower than that of naphthalene. As such, their exclusion from this screening level risk assessment is warranted.

PCBs are not a typical component of diesel fuel. No history of activities on site indicate the source of the PCB contamination. However, PCBs have been found in the soil, ground water and free product samples taken from the site. Because this group of compounds are rated as a class B2 carcinogen, PCBs are also considered in the baseline risk assessment.

Although benzene was listed as a typical constituent of diesel, this compound is volatile and may not be a significant fraction of the weathered product currently found in the subsurface. During 1991, quarterly well water sampling indicated benzene concentration above the detection limit ($0.5\,\mu g\,/\,l$) in only four of the 13 wells tested on site. Sampling for naphthalene in the ground water has not been performed on site. As stated above, PCBs have been found consistently in the ground water at several wells on site.

3.2 Exposure Pathways

Several exposure pathways for the three contaminants of concern were examined but we concluded that exposure through ingestion and inhalation of contaminants in the ground water at the closest well to the site presented the only significant risk.

Other pathways which were considered negligible due to the nature of the site and contaminants included inhalation of compounds volatilized from subsurface soils, and ingestion of contaminated food products or soil. Environmental damage due to surface water contamination is not considered likely.

3.3 Prediction of Migration at Nearest Current Domestic Well

The previous calculation of the groundwater concentration profile of benzene, naphthalene and PCBs was made by assuming that the estimated volume of diesel currently remaining in the subsurface was instantly released. The amount of benzene and naphthalene released was estimated using the average weight fraction of these compounds found in the pure fuel, 50 ppm and 1300 ppm, respectively. In addition, the PCB concentration in the free product was predicted using the measured concentration of 50 ppm found in free product during past excavations. A ground water transport model was applied to predict the concentration of the contaminants as a function of time, at the nearest domestic water supply, the Jamieson well 14A2, which is 900 feet from the spill. This well is used to supply water for industrial uses and as potable water for employees.

The total volume of free product spilled was assumed to be 20 m^3 based on the aerial averaged concentration of contamination (32 mg/l TPH) throughout the site and the aerial extent of contamination (84000 ft^2). The one-dimensional model was based on a confined line source of contamination (aquifer thickness of 20 ft) advected by a constant flow of water in a homogeneous media. A first order approximation of dispersion and retardation through adsorption was also included. The model included conservative estimates for parameters included in the governing equation to provide a worst case scenario for the risk at the Jamieson well. The concentration of contaminates at the Jamieson well were time weight averaged over seventy years for use in the health risk assessment.

The model predicted a 70 year average concentration of benzene and naphthalene in the water at the Jamieson well of 0.00020 mg/l and 0.0051 mg/l, respectively. Due to their high affinity for soil organic fraction, PCBs are relatively immobile in the subsurface and were not predicted to reach the drinking water well.

The conservative nature of the model used may be illustrated by comparing sampling data to the predicted results. Although predicted to reach the drinking water well, benzene was not found in the Jamieson well water during four consecutive quarterly samplings during 1991 (detection limit 0.5 $\mu g / l$). PCBs have never been detected in this well. No data is available on naphthalene testing at the Jamieson well.

3.4 Risk Characterization

The daily dosage of benzene and naphthalene received by persons consuming the contaminated water from the Jamieson Well was determined using the following equation (EPA, 1989),

Intake (mg/kg-day) = CW x IR x EF x ED/ (BW x AT)

Where:

CW = Contaminant concentration in water, 0.0002 mg/l
IR = Ingestion rate, 2 l/day (EPA, 1989)
EF = Exposure frequency, 365 days/year
ED = Exposure duration, 70 years
BW = Body weight, 70 kg
AT = Averaging time, 365 days for 70 years

Using these data, the daily intake of benzene through ingestion was calculated as 5.7 x 10^{-6} mg/(kg body weight x day).

The risk associated with a worker breathing the volatilized contaminant while washing was also calculated. The daily intake was calculated using the following equation:

Intake (mg/kg-day) = CA x IR x ET x EF x ED/(BW x AT)

Where:

CA = Contaminant concentration in air, 0.0047 mg/m^3

(See Appendix B for calculation of CA)

IR = Inhalation rate, 30 m^3/day

ET = Exposure time, 0.01 (15 min/day or 1% of day)

EF = 50 weeks x 5 days/week

ED = 70 years

BW = 70 kg

AT = 365 days for 70 years

The average daily intake of benzene through inhalation was calculated as 1.4×10^{-5} mg/kg-day. The following equation may be used to calculate the risk associated with the exposure:

Risk = 1 - exp(-CDI x SF)

Where:

CDI = Chronic daily intake, 2×10^{-5} mg/kg-day

SF = Cancer slope factor, 0.029 kg-day/mg

The risk associated with inhalation of benzene vapors and ingestion of contaminated water is calculated as 5.8×10^{-7}. It should be noted that the risk calculated by our group was performed using very conservative exposure parameters and that the carcinogen, benzene, has not been found (detection limit 0.5 μg/l) in the drinking water well used in this analysis.

The non-carcinogenic health risk was calculated using a Department of Health Services (DHS) appraisal method (DHS, 1986). An Applied Action Level (AAL) set by DHS as a health-based criteria was used to compared with the average naphthalene drinking water concentration. If the AAL is less than the drinking water concentration, the receptor is at significant risk. The AAL for naphthalene is 0.02 mg/l. The estimated 70 year average naphthalene concentration in the Jamieson well water was 0.26 of the AAL and, as such, was determined to pose no significant risk.

3.5 Clean Up Goals

The original baseline assessment indicated that the health risk due to offsite migration of the contaminants is not significant. Due to the results of this analysis, it was originally concluded that no further remedial actions at the Industrial Asphalt site were warranted. The Alameda County Department of Environmental Health (DEH) responded to this determination by maintaining that the waters directly beneath the Industrial Asphalt site are waters of the State within an aquifer used for water supply and must be restored to drinking water standards. DEH required that Industrial Asphalt reduce the groundwater contaminant concentration to below the maximum contamination levels (MCLs) and to below levels which could result in a 1 per million cancer risk. DEH noted that this level of cleanup would require both ground water and subsurface soil remediation.

Using EPA guidelines, the PCB and benzene concentrations which would individually cause a 1 in a million risk were estimated. These calculations are presented in Appendix A. The concentrations of benzene and PCBs which will individually cause a one per million risk are listed in Table 4. Because the total health risk is calculated as the sum of the individual risks, the concentrations listed in Table 4 can not be considered the clean up levels. Either the benzene concentration or the PCB concentration in the ground water must be brought well below these levels to reach the one in a million cancer risk goal for the site.

Table 4 also lists peak contaminant concentrations found in the past two years. The number of wells with benzene contamination above the one per million risk is unknown because the detection limit (0.5 micrograms/l) was higher than the target value. The field sampling indicates that the current benzene and PCB concentrations in the ground water exceed the one in a million cancer risk goal and that the TPH level exceeds the secondary MCL. This analysis indicates that site cleanup is required.

4.0 Regulatory Overview

In order to evaluate remedial technologies and final cleanup goals, the anticipated regulatory actions will be analyzed. This section describes regulations that may govern the necessary cleanup goals and appropriate remediation technologies at the site.

4.1 Remediated Soil Concentrations

The San Francisco Bay Regional Water Quality Control Board (RWQCB) has the authority to establish cleanup goals for soil. For sites where little is known about the behavior of chemicals in the soil, typical cleanup concentrations are:

- 1 ppm (mg/kg) for volatile organic compounds
- 10 ppm (mg/kg) for base-neutral organic chemicals (most components of diesel fuel are considered base-neutral organic chemicals)

These concentrations are based upon levels at which no water quality impact is expected. Even though these levels have been established, the RWQCB prefers to establish cleanup goals based on site specific data. This may then require an assessment of leachability, and attenuation of pollutants in the soil may be required.

4.2 Remediated Ground Water Concentrations

On December 17, 1986 the RWQCB created a Water Quality Control Plan for the San Francisco Bay Region. The main purpose of this plan is to establish water quality objectives and potential uses for contiguous and ground water in the South San Francisco Bay. The underlying and adjacent water at the IA site has been classified as the following:

Municipal and Domestic Water
Agricultural Water
Industrial Service Water
Industrial Process Water

In addition, this plan states that "It shall be prohibited to discharge all conservative toxic and deleterious substances above those levels which can be achieved by a program acceptable to the Board, to waters of the Basin." The Board also cites a policy form the

State Water Resources Control Board Resolution 68-16 regarding a non degradation policy. This policy states:

"Whenever the existing quality of water is better than the quality established in policies as of the date on which such policies become effective, such existing high quality will be maintained until it has been demonstrated to the State that any change will be consistent with maximum benefit to the people of the State, will not unreasonably affect present and anticipated beneficial use of such water, and will not result in water quality less than that prescribed in the policies."

These policies are the basis for any ground water cleanup level that will be required by the RWQCB.

4.3 Hazardous Material Identification

In order to determine if the soil at the site is deemed as a Hazardous Material the following regulations apply:

State Based Criteria - The California Code of Regulations (Title 22) classifies hazardous materials based upon the TTLC (Total Threshold Limit Concentration) and the STLC (Soluble Threshold Limit Concentration) criteria, which have been established by the California Department of Health Services (DHS). A solid is automatically considered a hazardous material if the concentration of any pollutant within the material is larger than the listed TTLC. A solid may also be considered a hazardous material if it produces an extract, from a waste extraction test, that produces a soluble concentration that exceeds the STLC.

Federal Based Criteria - The Code of Federal Regulations (Part 261 of 40 CFR) identifies hazardous materials based on the Toxicity Characteristic and Leachate Procedure (TCLP) program established by the EPA. A hazardous classification by the TCLP program results in the solid being subject to the regulations of Subtitle C of the Resource Conservation and Recovery Act (RCRA).

PCBs are uniquely addressed by the California Code of Regulations (Title 22, Division 4, Chapter 30) and the Federal Toxic Substance Control Act (40 CFR, Part 761, Subparts C and D). According to these regulations, a material is considered hazardous if its concentrations are larger than 50 ppm for a solid and more than 5 ppm for a liquid.

4.4 Health-Based Criteria

Presently the Alameda County Department of Environmental Health has the authority to require that the ground water cleanup concentration should be below the Maximum Contaminant Levels and levels that could result in a one-in-a-million cancer risk.

Maximum Contaminant Levels (MCLs) have been established by the EPA and the California DHS for certain chemicals and water quality characteristics. Primary MCLs are based on health, economic, and technological factors related to the ability to measure and detect these concentrations in water. Secondary MCLs are based on aesthetic criteria such as taste and odor of water. MCLs are typically used by the RWQCB as standards for ground water treatment system discharges in NPDES and WDR permits.

Risk is calculated using the EPA formula described in Section 3. The chronic daily dose is calculated by determining the amount of intake of pollutant from several different routes of exposure. This dosage is then averaged over a 70 year period. The slope factor is a carcinogenic extrapolation from low-dose animal tests to human cancer risks.

If a given chemical is not considered as a carcinogen then the health risk level will correspond to a chemical level referred to as the reference dose (RfD). RfDs have been established by the EPA based on laboratory animal or human epidemiological studies.
In addition to the MCLs and the one-in-a-million risk the DHS has established AALs (Applied Action Levels) for certain chemicals. AALs are used to asses the potential risks of chemicals based on their health effect, the media of exposure, and the receptor.

4.5 Disposal of Treated Water

The RWQCB is required to permit any discharges whether they be to surface or subsurface waters. Usually, RWQCBs require Waste Discharge Requirement (WDR) permits for subsurface disposal and a National Pollution Discharge Elimination System (NPDES) permit for disposal to a surface water or a storm sewer.

WDR permits are required in order to "ensure reasonable protection of beneficial uses (of water) and the prevention of nuisances". In addition to this definition, the RWQCB requires a WDR permit for soil that cannot be remediated. Usually, any WDR permit that is issued also stipulates that long term ground water monitoring is required.

The NPDES permit program is a national program that is intended to eliminate point source pollution from industrial, municipal, commercial, and agricultural discharges. The RWQCB use this program to establish pollutant discharge limits. NPDES permits are evaluated on a case-by-case basis . Where effluent limitations or regulations have not been established for a particular discharger, effluent limits will be established using available and economically feasible abatement technology.

If treated ground water is to be injected into the subsurface, the Underground Injection Control Program will come into effect. Ground water recharge wells qualify as Class V injection wells an would be subject to construction and permitting criteria described in 40 CFR Parts 144-146.

5.0 Feasibility Study

Remediation technologies were reviewed to determine the most effective method to meet the cleanup goals. This analysis was conducted by determining all technologies which were potentially applicable for the site. These technologies were screened for any outstanding characteristics which clearly indicated that the technology was not technically, financially or legally feasible. The site specific costs and constraints associated with the technologies which passed the screening analysis were reviewed in detail. A system was developed so that the alternatives could be consistently compared using a ranking system. This system weighted the feasibility, the ability to meet the remedial objectives, the potential for public acceptance, the likelihood of receiving regulatory approval and cost of each technology. The highest ranked remediation technology is recommended as the treatment technology for the site.

5.1 Screening of Remedial Alternatives

Table 5 lists all technologies which were considered in the screening analysis. These technologies fall into the following categories: administrative actions, containment, in situ treatment, and ex situ treatment. The following subsections describe each of these technologies and any outstanding characteristics which indicate that the technology is not feasible for the site.

5.1.1 Administrative Actions

The "no action" alternative consists of performing no remediation at the site. Restricted access to the site or to the ground water which may limit potential exposure to the contaminants could be included in this alternative. Because DEH has required that the groundwater be restored to drinking water standards, this alternative is not feasible.

5.1.2. In Situ Technologies

The following technologies were considered as in situ treatments at the site. In situ treatment if preferred if feasible to due the limited public exposure during remediation.

5.1.2.1 Bioremediation

It is presently known that microorganisms are capable of degrading certain organic compounds in the subsurface. Biological degradation of benzene and diesel constituents has been demonstrated in numerous laboratory studies and in industrial waste treatment processes. PCBs which were commonly considered non-degradable have been demonstrated to readily degrade PCBs in the laboratory. Biological degradation as an in situ treatment technology is theoretically feasible although it has not been proven to a large extent. The feasibility of an in situ biological process is based on the biodegradability, environmental factors, and site hydrology. In order to establish degradation an oxygen source and nutrients are required in the subsurface.

There are several drawbacks to this treatment technology that make this impractical at the IA site. Firstly, this treatment can not readily be applied for the removal of PCBs because this compound is typically bound tightly to the soil. Once this occurs in situ bioremediation is very difficult. Another drawback of this treatment is that traditionally it is very hard to alter conditions in the ground. Even if we could alter the underground conditions for most in situ processes we know that "sandy soils are far more amenable to in situ treatment than clayey soils" (e.g the Industrial Asphalt site) (Freeman, 1989). The heterogeneity of the subsurface may limit the ability of transferring the required nutrients to the microbial community. The organisms which have been isolated for the treatment of PCBs have not been readily adaptable to the subsurface climate. Finally, this treatment technology still has not be tried to a large extent. All of these factors coupled together eliminate biological in situ degradation from the list of possible remediation technologies.

5.1.2.2 In Situ Heating

In situ heating has been proposed as a method to destroy or remove organic contaminants in the subsurface through thermal decomposition, vaporization, and distillation. Heating can either be supplied through steam injection or radio frequency (RF) heating. The use of RF heating works in conjunction with steam. The advantages of this system is the fact that only a gas or vapor recovery system is required on the surface. Unfortunately, although this method appears very promising for sites contaminated with organics, more research is necessary to verify its effectiveness in situ.

5.1.2.3 In Situ Solidification

In situ solidification is a method where cement is mixed with the soil as an auger drills into the subsurface. The cement stabilizes and solidifies the soil and contaminants. Because the plume of contaminants extends beneath the IA facility, angular drilling would need to be employed to stabilize the entire plume. There is unacceptable risk of structural failure of the foundation which could occur while drilling beneath the operating facility. Secondly, the technical feasibility of drilling in this fashion is not assured.

Alternatively, in situ solidification should be performed following temporary or permanent dismantling of the facility. High costs would be associated with the removal. In light of the aforementioned difficulties in implementing this technology, in situ solidification will not be considered.

5.1.2.4 In Situ Vitrification

This remediation technology would glassify the contaminated soil through the use of electric current or electro-magnetic energy introduced into the ground. This is a prohibitively expensive method of remediation relative to other possible options and, as such, is considered infeasible.

5.1.2.5 Steam Injection

Steam injection is considered as a possible in situ treatment technology for the site. In this process, steam is injected into the ground above or below the saturated zone at the outer edge of the plume through a screened interval in one or more wells . The steam is extracted through a second set of wells which may lie in the center of the contaminated area. As the injected steam progresses toward an extraction well, a condensation front forms where volatilized compounds and thermally desorbed contaminants accumulate and are driven towards the well. The addition of heat to the soil greatly enhances mass transfer resulting from beneficial changes in vapor pressure, diffusion, viscosity and Henry's constants. This technology is feasible for the removal of TPH and benzene but is not is a feasible option for PCB contaminated soil due to its high gravity.

5.1.2.6 Soil Vapor Extraction

Soil vapor extraction wells can be efficiently used to remove volatile organic compounds from the unsaturated subsurface. The PCBs and the majority of constituents in diesel fuel are not volatile enough for this remediation method to be appropriate. Further, the majority of the contamination lies beneath the vadose zone. Soil vapor extraction is not a feasible remediation alternative for the Industrial Asphalt site.

5.1.3 Containment Technologies

Containment of a contaminated site is any method by which migration of the pollutants are prevented. Although containment does not explicitly achieve the remediation goals goals because the contamination is not reduced, a properly implemented containment technology may allow the water resources in the region surrounding the spill to be used without risk. Containment will not reduce the risk associated with use of the water obtained within the contaminated region. Proper containment also allows treatment of the contained area with less risk of accidental spreading of the contamination during treatment.. Physical barriers and hydrodynamic control will be considered for possible implementation at the IA site.

5.1.3.1 Physical Barrier

A barrier technology is the introduction of an impermeable barrier between uncontaminated and contaminated soil. A bentonite slurry wall was considered for this application. Because of the depth of the contaminated region, a crane and clamshell would be required to excavate a trench around the contaminated zone. A bentonite slurry is introduced into the excavated area to maintain its structural integrity. A soil/bentonite mixture is added to the slurry to provide strength and a more permanent barrier. Although other materials may be used in place of bentonite, this material is the most cost effective. It is also compatible with the contaminants.

In addition to the slurry wall, a permanent cap could be placed over the site to prevent intrusion and accumulation of rain water within the contained area. Such a cap is not considered necessary because the majority of the IA site is already cover by asphalt.

5.1.3.2 Hydrodynamic Control

Hydrodynamic control involves creating gradients in the groundwater to preferentially drive the contaminated waters away from uncontaminated zones. The use of hydrodynamic control would be most easily implemented at the Industrial Asphalt site through the use of extraction wells and also possibly injection wells. To control the plume of contamination, extraction wells are used to pulled the water one direction while the injection wells push the contaminated plume away from the uncontaminated aquifer. The use of a pump and treat system would implicitly contain the plume to some degree.

Injection wells would be beneficial in that this technology could be used as a disposal method for treated extracted ground water. The draw back of injecting water into the formation is that a large amount of water will become contaminated and the extraction pumping requirements would be increased.

This technology is similar in logistics to a pump and treat technology since any extracted water would need to be treated. The primary difference would be that the design would focus on the prevention of migration rather than the remediation of the site. This could result in lower pumping rates and possibly different well positions. The resulting cost of implementation might lower but would not in itself achieve the remediation objectives.

5.1.4 Ex Situ Treatment

Treatment of the soil or ground water following extraction from the subsurface is one of the most common treatment methods. As discussed earlier, this set of treatment technologies are not preferred due to the greater risk of public exposure to the contaminants than in situ treatment. The attractiveness of additional control over the treatment parameters may offset the potential exposure risk associated with these methods. Finally, in many instances ex situ treatment may be the only technically feasible choice for the site.

The following subsections describe alternative methods for removal of the ground water and the soil from the subsurface. The treatment technologies used to remediate the contaminated soil and water examined in this analysis are also discussed.

5.1.4.1 Soil Treatment

Presently the main pollutants of concern in the soil are PCBs and TPH. It is well known that most of the constituents of diesel are not very highly sorbed to the soil particles and may subsequently be treated in any ground water remediation technology. The only problem with the diesel contamination is that it can spread rather quickly and any soil treatment alternative must take this factor into account. The PCBs on the other hand are highly sorbed to the soil and this results in PCBs being very immobile in the subsurface. Because the PCBs are immobile conventional ground water removal will not work. This then facilitates the use of an excavation technique to remove all or part of the contaminated soil. This option is considered to be a feasible option at Industrial Asphalt. This technology consists of removing all or part of the Industrial Asphalt facility prior to excavation and using typical construction equipment to remove the contaminated soil and overburden.

Another alternative to immediate removal of the contaminated soil would be to allow the soil to remain in place for approximately 30 years. After approximately 30 years Industrial Asphalt plans on moving their site and at this time excavation may occur without any interruption in plant operation.

5.1.4.1.1 Excavation

The excavation of all or part of the contaminated soil is considered a feasible option, for the site. This technology consists of removing all or part of the IA facility prior to excavation and using typical construction equipment to remove the contaminated soil and overburden. The treatment of the excavated soil with PCBs or hydrocarbons must be considered.

5.1.4.1.2 Recycle of Contaminated Soil at the Facility

This soil treatment technique would involve using the excavated soil in the asphalt manufacturing process. This is an acceptable disposal method for soil contaminated only with the THP because these compounds are constituents of the asphalt already. It is not clear whether the PCB contaminated soil could also be recycled in the asphalt but this has been performed during past excavations . Due to the low concentrations of PCBs (less than 50 mg/kg) in the soil this method may be both appropriate and cost effective.

Prior to large scale incorporation of the soil into the asphalt, a bench scale study should be performed to ascertain the leachability of the contaminants from the asphalt product. Potentially a portion of the excavated soil may be treated in this manner while the remaining highly contaminated soil may be processed using other remediation technologies.

5.1.4.1.3 Land Disposal

The excavated soil or the most contaminated portion could be disposed of offsite. It is unclear whether it would be acceptable to dispose of the excavated soils in a non-hazardous land fill. As a worst case estimate, it is assumed that it will be necessary to send the soil to a Class I land disposal facility. The assumption that the soil may be removed and disposed of in a similar manner in thirty years may be inaccurate considering the increasingly stringent land disposal regulation.

5.1.4.1.4 Incineration

Incineration is another method that could remove the highly absorbed PCBs and TPHs from the soil. One possible incineration system that could be used is the cement kiln. Cement kilns are a versatile alternative for feed wastes of various consistency and subsequently soil would be perfect for this incineration system. Freeman has even gone so far to say that "with few exception, materials introduced into cement kilns will be oxidized and stabilized, requiring no further treatment".

5.1.4.2 Ground Water Treatment

Ground water treatment involves the pumping of the existing ground water to the surface for physical, chemical and/or biological treatment to reduce the toxicity and volume of the contaminants. Hydrodynamic containment may also be accomplished by ground water pumping by influencing gradients.

Due to the desorption qualities of PCBs, we have determined that it would be infeasible to completely remove this contaminant by ground water pumping (Appendix B). However, this does not preclude the possibility that PCBs will be present in concentrations of concern in the effluent. Therefore, it will be necessary to select the appropriate process for the treatment of all possible contaminants.

Discharge of the treated effluent will be to either a municipal sewer by means of an NPDES permit or on-site surface water in compliance with state and local regulatory agencies.

5.1.4.2.1 Extraction Wells

Extraction wells are used either to deliver groundwater to be treated or for hydrodynamic control. These wells are constructed by boring a hole down to the watertable. The inside of the well is usually then cased with a PVC tube. A submersible pump and the associated electrical wiring is then placed within the well to allow for the pressure difference that will eventually draw the water to the well.

5.1.4.2.2 Trenching

A trench filled with a permeable material could be constructed so that the water bearing zone would be intercepted. Pumps inserted into the trenches would drain leachate collected within them. A trench created from the surface presents a risk of creating permeable pathways to uncontaminated soils and currently uncontaminated water bearing zones. Without greater confidence in the continuity of the aquitard beneath the first aquifer, this risk is unacceptable, and, as a result ,this technology is not feasible.

5.1.4.2.3 Lateral Wells

The IA site is unique in that the contaminated area is beside a large pit which extends over 100 feet below surface level. Therefore, vertical profile of the contaminated site is, in essence, exposed as the steep side of the excavated gravel pit. Another possible method of draining leachate from the site would be with the use of lateral wells drilled beneath the contamination. This would allow the static head above the wells to push the leachate out. This assumes that the static head is adequate to overcome the lateral gradients. This does seem to be the case (static head 1 ft/ft vs. gradient .035 ft/ft). Unfortunately, lateral wells also have a significant risk associated with the creation of permeable paths into uncontaminated waters. The lateral wells would be technically difficult to implement, and even under ideal vertical drilling conditions, a straight well is difficult to achieve. A horizontal well could veer off enough to penetrate existing aquitards. In addition, a drill rig would be difficult to support while it drilled horizontally. Lateral wells will not be considered further as a feasible remediation alternative.

5.1.4.2.4 Solvent Extraction

As discussed earlier, PCBs are relatively immobile in the subsurface due to their affinity for organic soil matter and low water solubility. Due to these characteristics, their removal from the subsurface by groundwater pumping is limited. To increase the PCB concentration in the groundwater, organic solvents with high PCB solubility may be injected into the groundwater upgradient from the extraction wells. PCBs are quite soluble in many solvents including methanol. As the solution flows through the contaminated zone, the PCBs in the water will become more concentrated due to the solvents.

Because PCBs are more dense than water, any additional PCB that has solubilized has the potential to migrate deeper into the uncontaminated zone. Due to the potential risk of contaminating lower water bearing zones and the liabilities associated with introducing a solvent into the subsurface, this potentially powerfull remediation alternative is not feasible at this location.

5.1.4.2.5 Discharge of Pumped Water to Local Pond

The ground water could be directly discharged following removal from the subsurface. Adjacent to the site, there is a large pond which is currently used to for process water discharge. The discharge of the contaminated water to this pond would require the receipt of a NPDES permit from the Regional Water Quality Control Board. Given the quality of the water being removed from the ground, the possibility of receiving such authorization is low.

5.1.4.2.6 Bioremediation

Bioremediation would involve the ex situ treatment of groundwater using microorganisms which destroy the organic contaminants. The biological process may use a trickling filter, activated sludge system or an anaerobic digestion system. Any system which would be open to the atmosphere may require costly emission control equipment to remove any volatile organic emissions. The primary reason for disregarding this technology is that the destruction of PCBs using such systems has not been demonstrated although certain microorganisms, Nocardia, in activated sludge have been shown to concentrate PCBs.

5.1.4.2.7 Ozonation

Ozone is a relatively unstable gas consisting of three oxygen atoms per molecule and is one of the strongest oxidizing agents known. Complete oxidation of organic contaminants to nitrogen and carbon dioxide gas can be obtained with some compounds if sufficient ozone doses and reaction time are used. However, the higher capital costs of the ozone generator compared with its relative effectiveness and reliability of removing complex organic compounds in respect to other oxidation systems discussed in following sections renders this technology unattractive.

5.1.4.2.8 Granular Activated Carbon

Granular activated carbon adsorption can be used to remove a wide variety of contaminants from liquid or gaseous streams. It is most frequently used for organic compounds, although some inorganic species are also efficiently adsorbed. Carbon adsorption should be considered as a potential removal process for organic contaminants that are non polar, of low solubility, or of high molecular weight. Chlorinated aromatics, such as PCBs, and hydrocarbons are generally amenable to adsorption. This technology has been used extensively for the remediation of ground water and treatment off domestic water. Because this technology is proven and is relatively cost effective, this technology will be considered for remediation of the IA site.

5.1.4.2.9 Steam Stripping

Steam stripping consists of the distillation of volatile components from wastewater. The injection of steam into the waste stream raises the temperature and allows the less volatile components to be stripped from the water. The water enters a fractional distillation column and steam is injected at the base of the unit. Similar to a petroleum distillation column, the components with lower boiling points are preferentially evaporated. The vapors flow through a condenser, and the condensed liquids are gravity separated. This technology is applicable for diesel removal from the waste water, but PCBs which have a boiling point ranging from approximately 325-375°C, are not removed. This technology is energy intensive due to the required steam and would require pretreatment to remove suspended solids which may clog the distillation column. Air pollution control equipment may be required to mitigate uncondensed benzene vapors. Because this technology does not remove PCBs from the contaminated water, this technology is not being considered.

5.1.4.2.10 Hyperfiltration

Hyperfiltration uses a semipermeable membrane to remove 100 to 500 molecular weight compounds from water. Pressure is applied to the side containing the contaminated water, and clean water, the permeate, is pushed through the membrane. Typical membranes have pore sizes of 10 to 10,000 angstroms. This technology is not effective for removing benzene from the water but may be used in conjunction with other technologies. Studies of oily water separation has indicated that the permeate may contain up to 10 mg/L of oil (Farnand and Krug, 1989). The same study indicated that the membranes may be prone to clogging and required frequent cleaning. Specific information on the removal of PCBs using this technology were not found. Because this technology does not have a proven track record at removing the contaminants of concern, it will not be considered further.

5.1.4.2.11 Dissolved Air Floatation

Dissolved air floatation (DAF) may be used for the removal of low specific gravity compounds such as diesel from waste water. This is accomplished by introducing minute bubbles into the DAF unit. The contaminants adhere to the surface of the bubbles and are carried up as the bubbles rise to the surface. A layer of contaminants form on the top of the unit and are scraped off automatically. Due to the presence of volatiles, including benzene, emission control may be required. This treatment is not suitable for PCB removal because of their high density (specific gravity approximately 1.4).

5.1.4.2.12 Incineration

The contaminants may be oxidized using liquid injection incineration. The liquid is sprayed into a chamber where auxiliary fuel is used to heat the unit to approximately 1500°F. The hydrocarbon contaminants will be oxidized to carbon dioxide and water. The water entering the unit is vaporized into steam and leaves the unit with the carbon dioxide. Because of the very dilute nature of the waste water, there is negligible heating value associated with the contaminants. A significant amount of natural gas would be required to heat the inlet water to the operation temperature. High heating, maintenance, and installation costs are anticipated for this system. Because the PCB concentration is so low, Industrial Asphalt would not be required to meet the restrictive TSCA incineration requirements, but the public perception of this technology may make this technology infeasible.

5.1.4.2.13 UV/Hydrogen Peroxide Oxidation

Ultraviolet (UV) radiation may be used in conjunction with hydrogen peroxide to produce hydroxyl radicals to oxide organic contaminants. This technology has been proven in the field to reduce PCBs, benzene and TPH to the concentrations required on site. Because the hydroxyl radical is a stronger oxidizer than hydrogen peroxide or ozone alone, this technology has a much higher, faster removal efficiency for organic contaminants. The system is operated entirely within the liquid phase within a closed vessel so the potential for volatile hydrocarbon emissions are nonexistent. The equipment costs for this unit are comparable with other proven control technologies. Due to its cost competitiveness and high removal efficiency, this control technology will be considered further.

5.1.4.2.14 UV/Ozone Oxidation

UV radiation may be used with hydrogen peroxide and ozone to form hydroxyl radicals to destroy organic contaminants. This technology is similar to the preceding process but requires additional equipment including an ozone generator and air pollution control equipment to remove any residual ozone or volatile hydrocarbons prior to exhausting. Costs associated with this equipment are not trivial. Operating costs associated with this technology are higher than UV/ hydrogen peroxide oxidation because of the additional energy required to generate the ozone.

The removal efficiencies of this unit are comparable with the hydrogen peroxide system. This technology has been proven in EPA studies to be an efficient method of removing hydrocarbons (Lewis et al., 1990)). Because the technology is better tested than the hydrogen peroxide system, this technology deserves continued consideration even through it is clearly more expensive.

5.2 Ranking of Screened Alternatives

Technologies which passed the screening analysis were combined to form several remedial alternatives. In order to determine the alternative which best meets the remediation objectives, a methodology was developed to rank important aspects of the project. The critical parameters of concern to our client have been grouped into four categories: cost, feasibility, adherence to remediation objectives and public acceptance. All categories were weighted according to their relative importance. Out of 100 points, cost, feasibility, remediation objectives, and public acceptance have been assigned a weighting of 30, 30, 30, and 10 respectively.

Cost scoring is based on each alternative's cost relative to the other options being considered. Feasibility scores are based upon the degree to which potential problems may arise and upon the confidence that the alternative can be fully implemented. The scoring for the remediation objectives are based on the ability for a remediation technology to satisfy the requirements listed in Section 3.0. Public acceptance is based on a judgment of the perception and concern of the local community toward the clean up effort. A remediation alternative will be rated according to how strongly the public feel that their safety and property is being protected (or is being put at risk) by the use of a particular alternative.

5.2.1 Excavation Considerations

Each alternative consists of several elements. As mentioned earlier, the PCBs in the subsurface are strongly sorbed to the soil and will not be completely removed by any treatment technology except excavation. Thus, at some point, excavation of, at least , the PCB contaminate soil will be required. The current horizontal extent of contaminated soil is approximately 115,000 square feet. The plume is comprised of 85,000 cubic yards of contaminated soil and 395,000 cubic yards of overburden. At least 25,000 cubic yards of this soil is contaminated with PCBs, and a total of 138,000 cubic yards of overburden would have to be excavated to remove this soil.

The IA facility would have to be temporarily removed during excavation. During the excavation period, operations at Industrial Asphalt and at the Jamieson gravel quarry would cease. The approximate excavation period would be between 1 and 2 years. The costs for this closure have been previously estimated. If only the PCB contaminated soil is removed, we estimate that the cost of closure would be one third of the total estimated closure costs.

The cost for excavation are considered for each treatment alternative based upon the time of the excavation and the extent of excavation required using a standard price per cubic foot of soil removed. Several of the treatments will reduce the total amount of soil which requires excavation and, as such, the excavation costs associated with those alternatives are lower than the cost of excavating the entire present contaminated zone.

5.2.2 Contaminated Soil Considerations

Because each of the remediation alternatives will require the disposal of some quantity of contaminated soil, the costs associated with their disposal must be considered. Three technologies may be used for the disposal of the soil: incineration, land disposal or recycle at the facility. Recycling the asphalt at the facility is the preferred disposal technique because it is the least costly. Recycling of the asphalt at the facility has been performed during past excavations and is anticipated by IA to be an accepted method for disposal of the current contaminated soil. We suggest performing leachability tests on the asphalt soil mixtures prior to large scale disposal to assure that the PCBs are immobile in the mixture. Because the soil contaminated with only diesel contains relatively begin contaminants we anticipate that all of this soil may be incorporated in the asphalt and will not require alternative disposal.

Alternatively, incineration or disposal in a Class I landfill may be required for highly contaminated PCB soils. Because there is currently no indication that the soil is contaminated to a high enough level to require incineration , the cost estimates for the disposal of the PCB contaminated soil are based on land disposal.

5.2.3 Extraction Well Considerations

Extraction wells will be required if any pump and treat technologies are chosen as the treatment alternative for groundwater. For this reason it is important to determine the necessary costs and pump requirements that will be required if extraction wells are to be utilized.

During the drawdown tests it was determined that the maximum flow through an extraction well at the Industrial Asphalt site was 2.6 gal/min. The number of wells that will be required to treat the contaminated groundwater was also determined to be 10 pumps that require 2 horsepower (1491 W) each.

The costs were evaluated in Appendix A and as the expected extraction well cost table illustrates that for 30 years of treatment (with constant well monitoring) the total present worth will cost approximately $2,456,342.

5.2.4 Alternative 1 - Steam Injection - Slurry wall - Excavation

The steam injection process removes the most mobile compounds and reduces the mobility of the more persistent (less volatile, more strongly adsorbed) contaminants. This would meet the primary remediation objectives as listed in section 3.0. Because the treatment period only lasts a few weeks, it is the most immediate solution to the TPH and benzene contamination.

A slurry wall would be built around the PCB contaminated area and the surrounding diesel contaminated region would be injected with steam. In 30 years, the remaining PCB contaminated soil would be excavated and disposed of in a Class I landfill.

Although not a proven technology, full-scale and bench scale steam injection demonstrations have been generally successful. The possibility of increased migration of contaminants to uncontaminated regions during the injection process is a prime concern. Proper design of well locations can avoid lateral migration, while a low permeability barrier beneath the contaminated region is a current prerequisite for this technology. Because PCBs can not be remediated using this technology, the steam injection will only be applied to the TPH and benzene contaminated soil. In order to prevent the possible spread of PCBs by the steam , it would be necessary to construct a slurry wall or another similar containment technology around the PCB contaminated region.

The costs for steam injection range from $30 to $100 per cubic yard. A reasonable cost estimate for this site is $60 per cubic yard because of the location and geometry of the site, the age of the spill, and the type of contaminated soil (Kent Udell, 1992). An estimated 60,000 cubic yards of soil would be steam injected. The calculation of the cost of the slurry wall barrier, the steam injection and the excavation of the contaminated soil is presented in Table 6. The approximate cost associated with this alternative is 4.1 million dollars.

5.2.5 Alternative 2 - Slurry Wall - Ground Water Extraction - Excavation

A second alternative considered is building a slurry wall around the PBC contaminated zone. The ground water in the surrounding THP contaminated region would be extracted and treated with UV/ hydrogen peroxide oxidation. In 30 years the remaining PCB contaminated soil would be excavated and disposed of at a Class I landfill. This alternative utilizes proven technology and reduces the potential for migration of the PCBs into uncontaminated zones. Costs associated with the implementation of this alternative is 3.7 million dollars. The calculation of these costs is presented in Table 6.

5.2.6 Alternative 3 - Excavation of Entire Site

In this alternative, all of the contaminated soil would be excavated immediately. This would require a facility closure. The PCB contaminated soil would be sent to a Class I landfill and the TPH and benzene contaminated soil would be incorporated into asphalt. The cost of this alternative is estimated in Table 6 as 8.1 million dollars.

5.2.7 Alternative 4 - Granular Activated Carbon treatment of ground water-Excavation

In this alternative, the ground water will be pumped and treated using granular activated carbon. Following closure of the facility, the remaining PCB contaminated soil will be excavated and disposed of at a Class I disposal facility.

Granular activated carbon adsorption can be used to remove a wide variety of contaminants from liquid or gaseous streams. It is most frequently used for organic compounds, although some inorganic species are also efficiently adsorbed. Carbon adsorption should be considered as a potential removal process for organic contaminants that are non polar, of low solubility, or of high molecular weight. Chlorinated aromatics, such as PCBs, and hydrocarbons are generally amenable to adsorption. To assess the feasibility of adsorption for a particular application, it is necessary to perform an adsorption isotherm on the waste stream of interest.

Maintenance requirements include periodic servicing of the canisters to exchange exhausted carbon. The carbon may be slurry-pumped to and from permanently installed canisters or whole canisters may be exchanged.

The size of the GAC system is dependent on type and concentrations of chemicals in the influent. Usage rates are estimated based on adsorption isotherms, influent concentrations and flowrates.

GAC must be disposed after it is spent due to microbial fouling or saturating of adsorptive sites. For typical remediation projects, a carbon replacement service contract can be negotiated for replacing and regenerating spent GAC, thereby reducing costs of purchasing virgin carbon. However, due to the presence of PCBs in extracted groundwater, regeneration may not be possible. Therefore, spent GAC would require either offsite disposal at a Class I landfill or incineration at a permitted facility. Both of these options represent substantial costs associated with handing, transport and disposal or incineration.

A possible disposal option for spent GAC is onsite recycling in the asphalt manufacturing process. Although state and local health departments have historically approved recycling of affected soil at the IA facility, we believe that TCLP tests will determine that this is unacceptable.

A site specific approach to cost prediction for activated carbon adsorbers is difficult to construct since differences between systems will radically affect the cost. The calculations used to determine the costs associated with the ground water treatment are presented in Appendix A. The total cost of this alternative is calculated in Table 6 as 3.81 million dollars.

5.2.8 Alternative 5 - UV/Ozone Oxidation

In this alternative, the ground water will be pumped and treated using UV/ozone oxidation. Following closure of the facility, the remaining PCB contaminated soil will be excavated and disposed of at a Class I disposal facility.

The ultraviolet radiation (UV)/oxidation technology uses UV radiation, hydrogen peroxide and ozone to oxidize organic compounds in water. This technology has been demonstrated as an effective method to remove organic contaminants in wastewater (Lewis, 1990).

The influent water passes through a filter where particles which may reduce the transmission of UV radiation are removed. Hydrogen peroxide is fed into the filtered waste water. The water then flows into a reactor where UV radiation and ozone are introduced. Hydroxyl radical formation from the ozone is catalyzed by the radiation and the hydrogen peroxide. The hydroxyl radical which as a strong, rapid oxidizer attacks the organic contaminants and converts them to carbon dioxide and water.

Some of the volatile organics in the wastewater, including the benzene, would be stripped from the water as the ozone bubbles through the system. These contaminants and the residual ozone must be removed from the exhaust gas stream prior to discharge. Patented off-gas treatment systems are provided by the vendor of the UV/oxidation unit.

Studies indicate that this technology can reduce the PCB, benzene and TPH concentrations to the levels required at this site. Pilot studies may be appropriate to insure that these concentrations can be achieved.

This technology is particularly attractive because the majority of the contaminants are destroyed by oxidation. There will be some waste generation in the air pollution control equipment and in the filter. PCBs may accumulate with entrained soil in the inlet filter. Should significant amounts of PCBs be found in the filters, TSCA disposal requirements may be applicable.

The units are typically sold as a complete unit. They are skid mounted and may be placed at a convenient location at the facility. The operation of this technology on site would have no impact on Industrial Asphalt's business activities following the installation of the system. There would be periodic maintenance, monitoring and hydrogen peroxide unloading which may require supervision by facility staff.

Costs which are associated with the power requirements of the UV lamps, hydrogen peroxide feed, installation and maintenance of the unit. are calculated in Appendix A. The total cost of the alternative is calculated in Table 6 as 3.66 million dollars.

5.2.9 UV/Hydrogen Peroxide Oxidation

In this alternative, the ground water will be pumped and treated using UV/Hydrogen peroxide oxidation. Following closure of the facility, the remaining PCB contaminated soil will be excavated and disposed of at a Class I disposal facility.

This system is similar to the UV/Ozone oxidation but does not require either the ozone generator or the emission control system. Water mixed with the hydrogen peroxide enters the reactor chamber at the bottom and flows up through the unit in a serpentine fashion past a series of UV lamps. Fewer lamps are required then the ozone oxidation technique.

This technology is attractive because there are no waste streams or air emission concerns. It has been proven to remove the contaminants of concern to the levels required for the site.

Highly turbid waters have been shown to reduce the effectiveness of the system. Prior to installation, a bench scale test is performed to determine the organic matter removal efficiency. At this time, it is determined if upstream filters are required. Following the bench scale study, the vendor will provide the client with a written guarantee of the removal efficiency.

In systems treating water with high concentrations of iron, precipitation of metal hydroxides has also been shown to reduce the effectiveness of the system. The problem has been addressed by installing wipers which periodically sweep the hydroxides into the effluent water.

Costs associated with this waste water technology were estimated in Appendix A using vendor data and include the cost of subsequent removal and disposal of the remaining PCB contaminated soil. The total cost of implementing this technology is calculated in Table 6 as 3.49 million.

6.0 Recommendations and Conclusions

Based upon our screening of remedial technologies we recommend the following remedies for meeting the remedial objectives at the Industrial Asphalt facility as based on our ranking system in Table 7:

- Extraction wells should be constructed to control the migration of the contaminant plume and to remediate the petroleum hydrocarbons to drinking water standards.
- Treatment of the extracted groundwater should be performed using UV/hydrogen peroxide oxidation system.
- Excavation of the remaining contaminated soil should occur once Industrial Asphalt has dismantled their operation in 2030.

Future considerations prior to the implementation of the recommended response are:

- A ground water flow model must be created to properly achieve the remediation objectives with extraction wells

- Extraction well tests need to be performed to properly size the water treatment system and characterize the water chemistry. Filters or other influent screening prior to oxidation may be necessary.

- Leachability tests will need to be performed on soil samples to insure that proper remediation of the petroleum hydrocarbons can be achieved in the necessary time limit as well as characterizing the expected state of PCB contamination prior to excavation for proper soil disposal recommendations.

- Alternatives for the disposal of treated water need to be discussed with the property owner and the appropriate regulatory agency.

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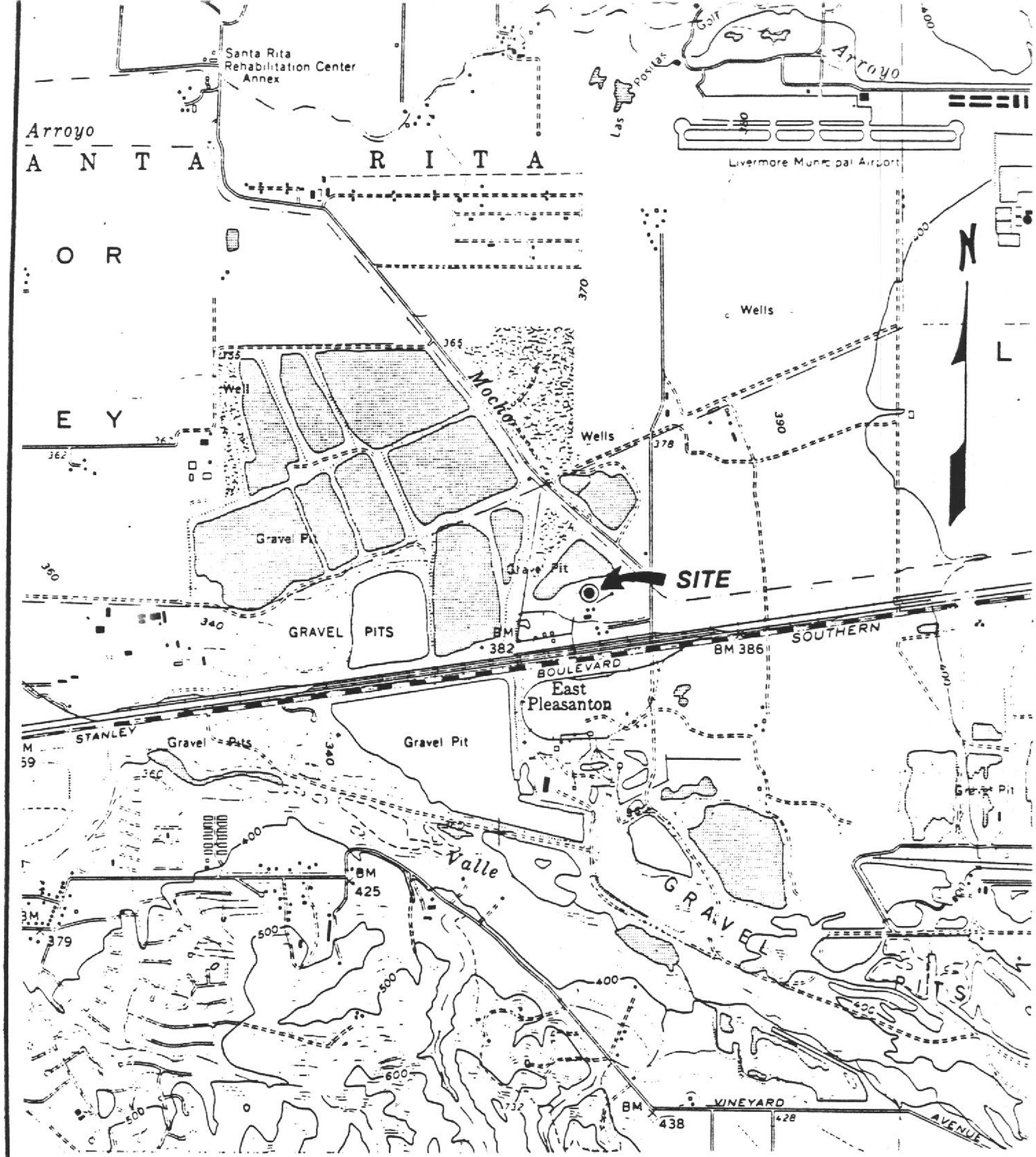

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Source: USGS 7.5 minute Livermore Quadrangle

AFTER
J.H. KLEINFELDER & ASSOCIATES
GEOTECHNICAL CONSULTANTS • MATERIALS TESTING
LAND AND WATER RESOURCES

PROJECT NO. 10-1682-01

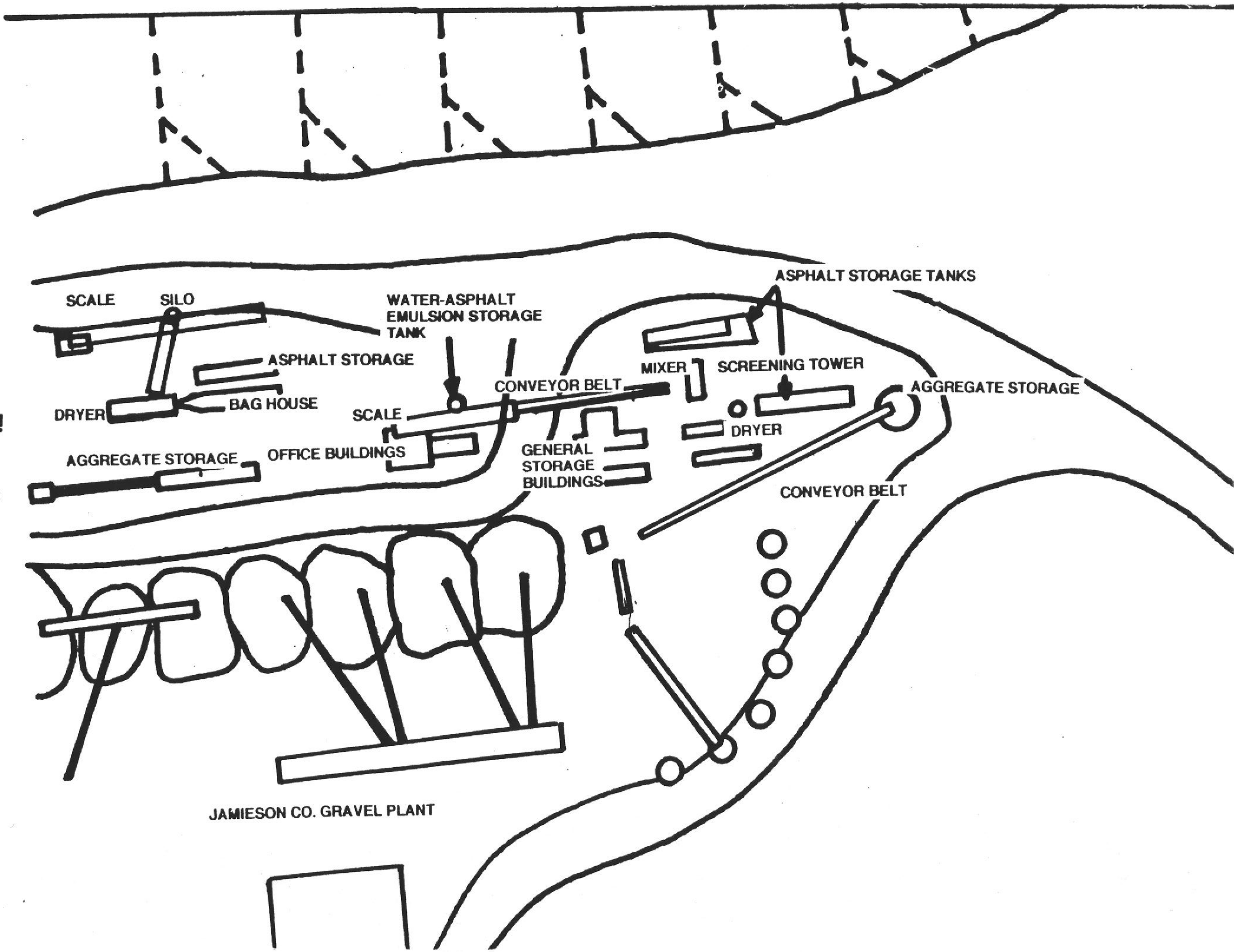
INDUSTRIAL ASPHALT
PLEASANTON, CALIFORNIA

SITE LOCATION MAP

PLATE
1

Figure 1

Figure 2



ASPHALT STORAGE TANKS
SCALE
SILO
WATER-ASPHALT EMULSION STORAGE TANK
ASPHALT STORAGE
MIXER
SCREENING TOWER
CONVEYOR BELT
AGGREGATE STORAGE
DRYER
BAG HOUSE
SCALE
DRYER
GENERAL STORAGE BUILDINGS
AGGREGATE STORAGE
OFFICE BUILDINGS
CONVEYOR BELT
JAMIESON CO. GRAVEL PLANT

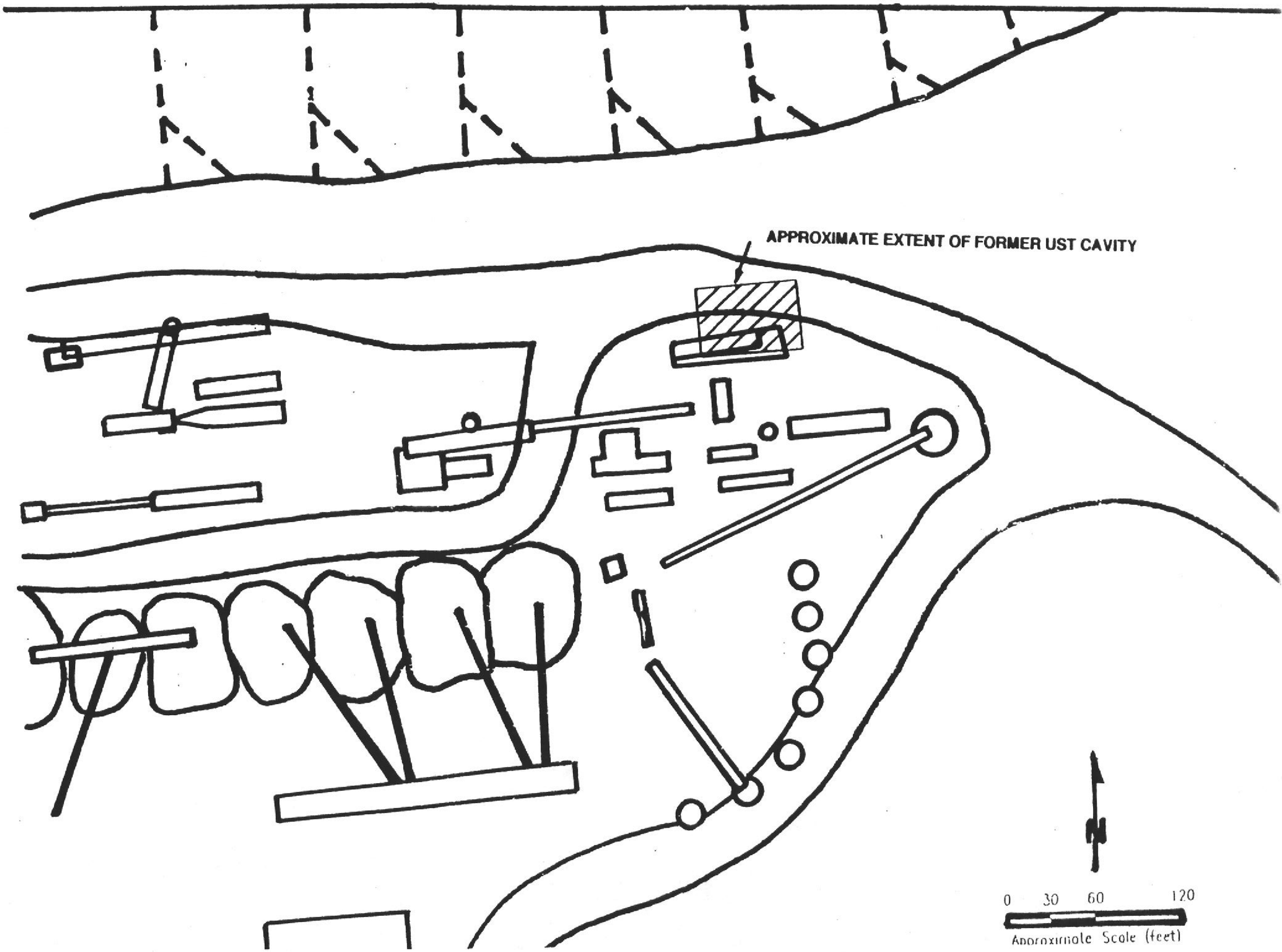
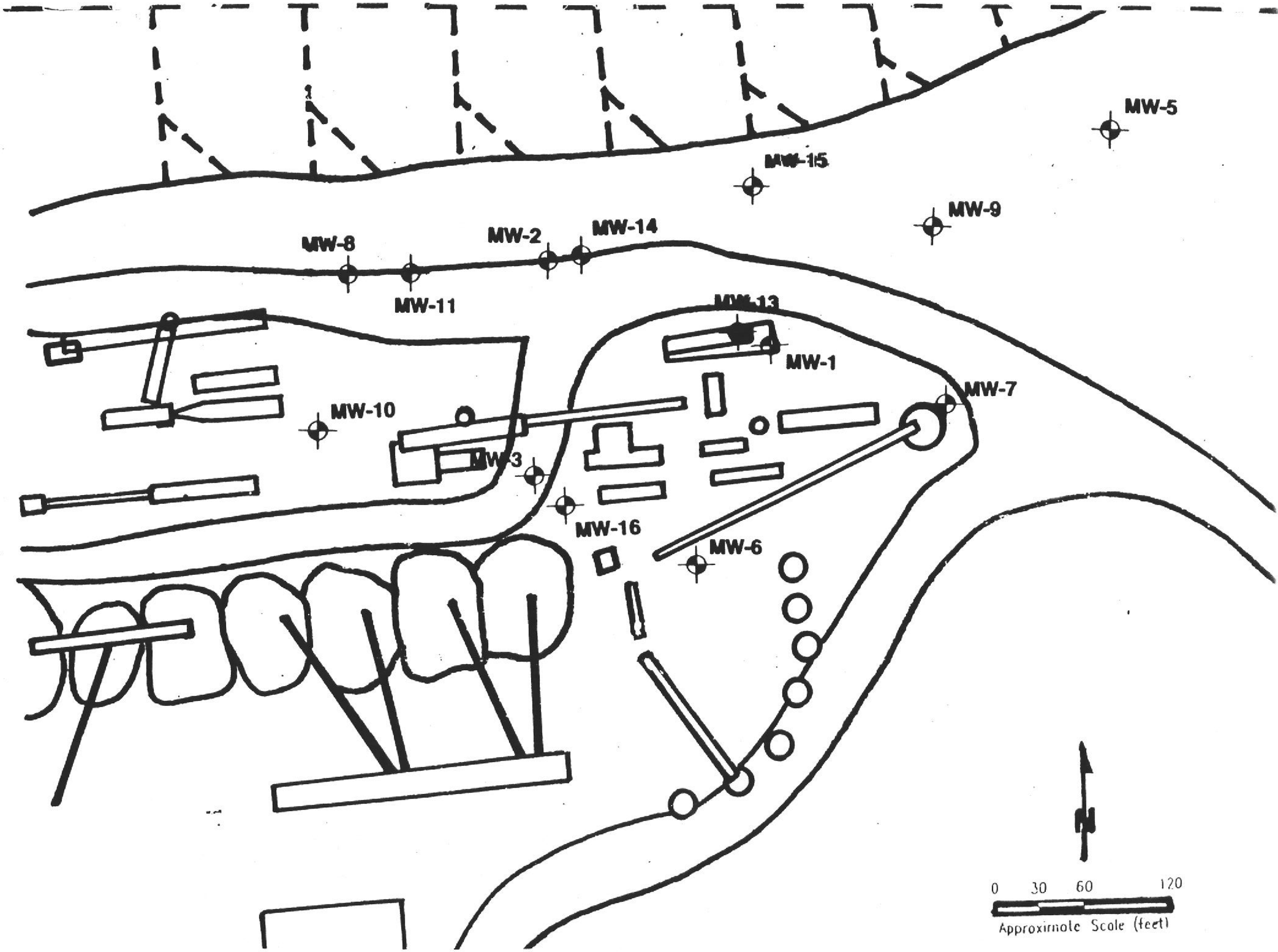

APPROXIMATE EXTENT OF FORMER UST CAVITY
N
0 30 60 120
Approximate Scale (feet)

Figure 3

Figure 4


MW-5
MW-15
MW-9
MW-8
MW-2
MW-14
MW-11
MW-13
MW-1
MW-10
MW-7
MW-3
MW-16
MW-6
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0
30
60
120
Approximate Scale (feet)

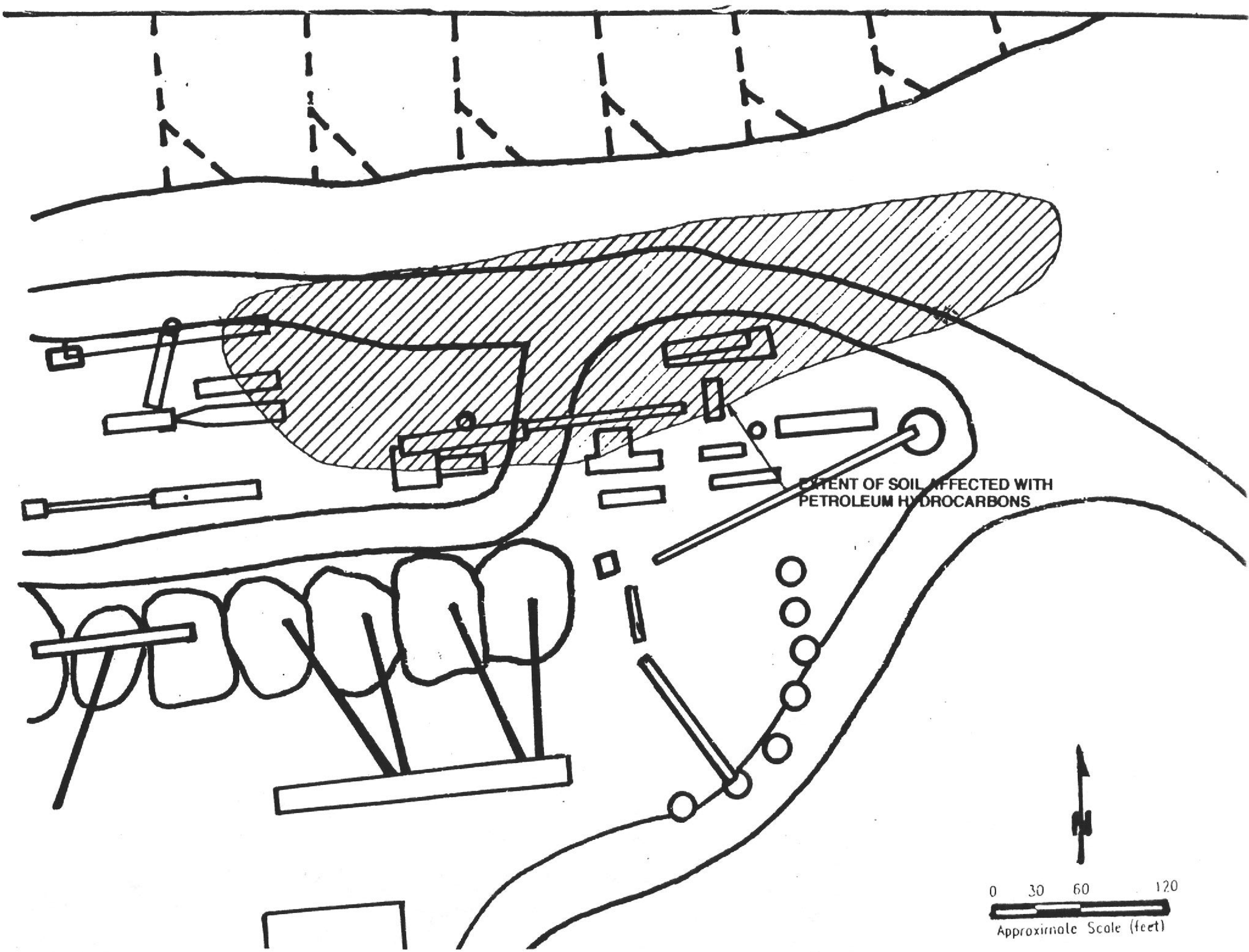
EXTENT OF SOIL AFFECTED WITH PETROLEUM HYDROCARBONS
N
0 30 60 120
Approximate Scale (feet)

Figure 5

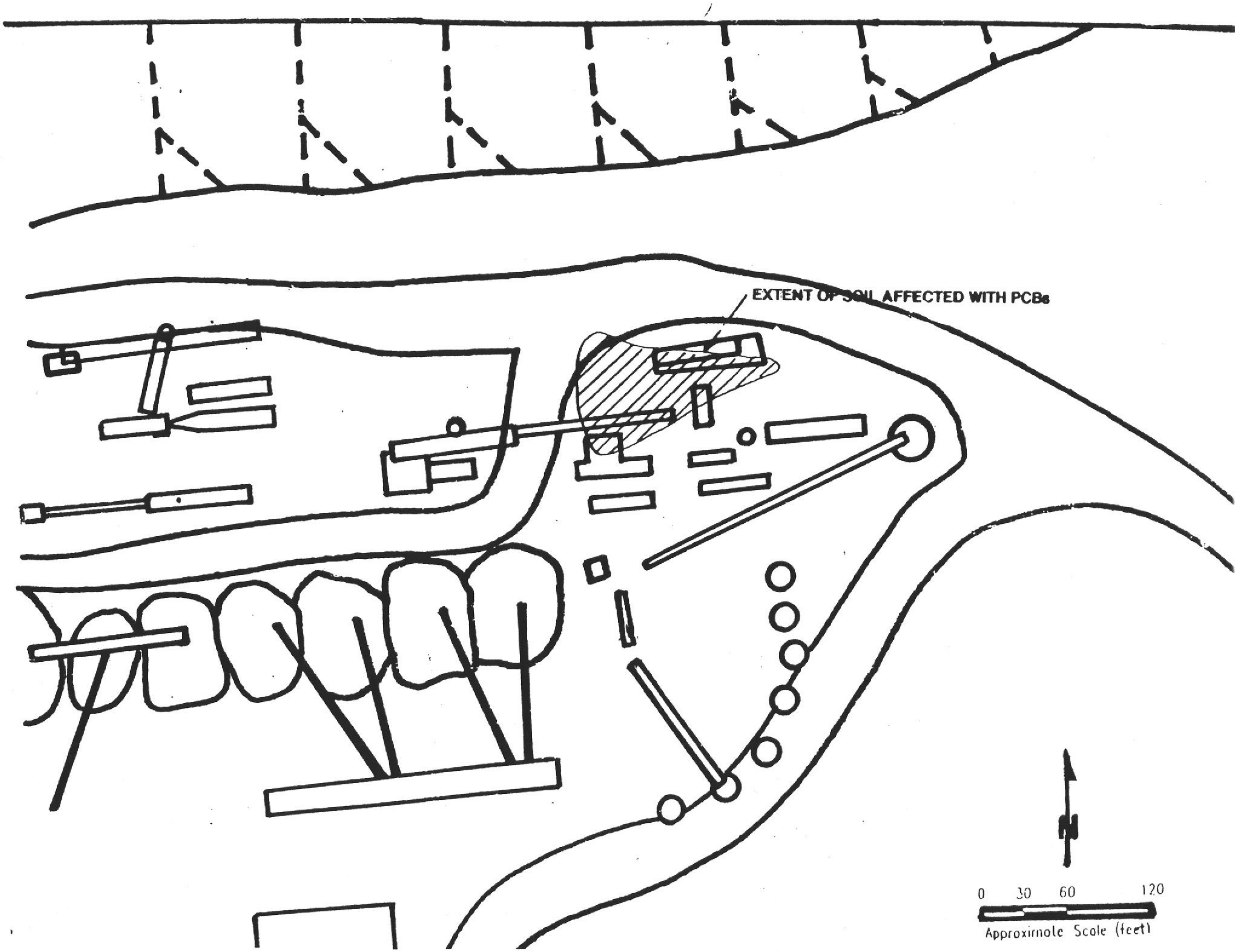
EXTENT OF SOIL AFFECTED WITH PCBs
N
0 30 60 120
Approximate Scale (feet)

Figure 6

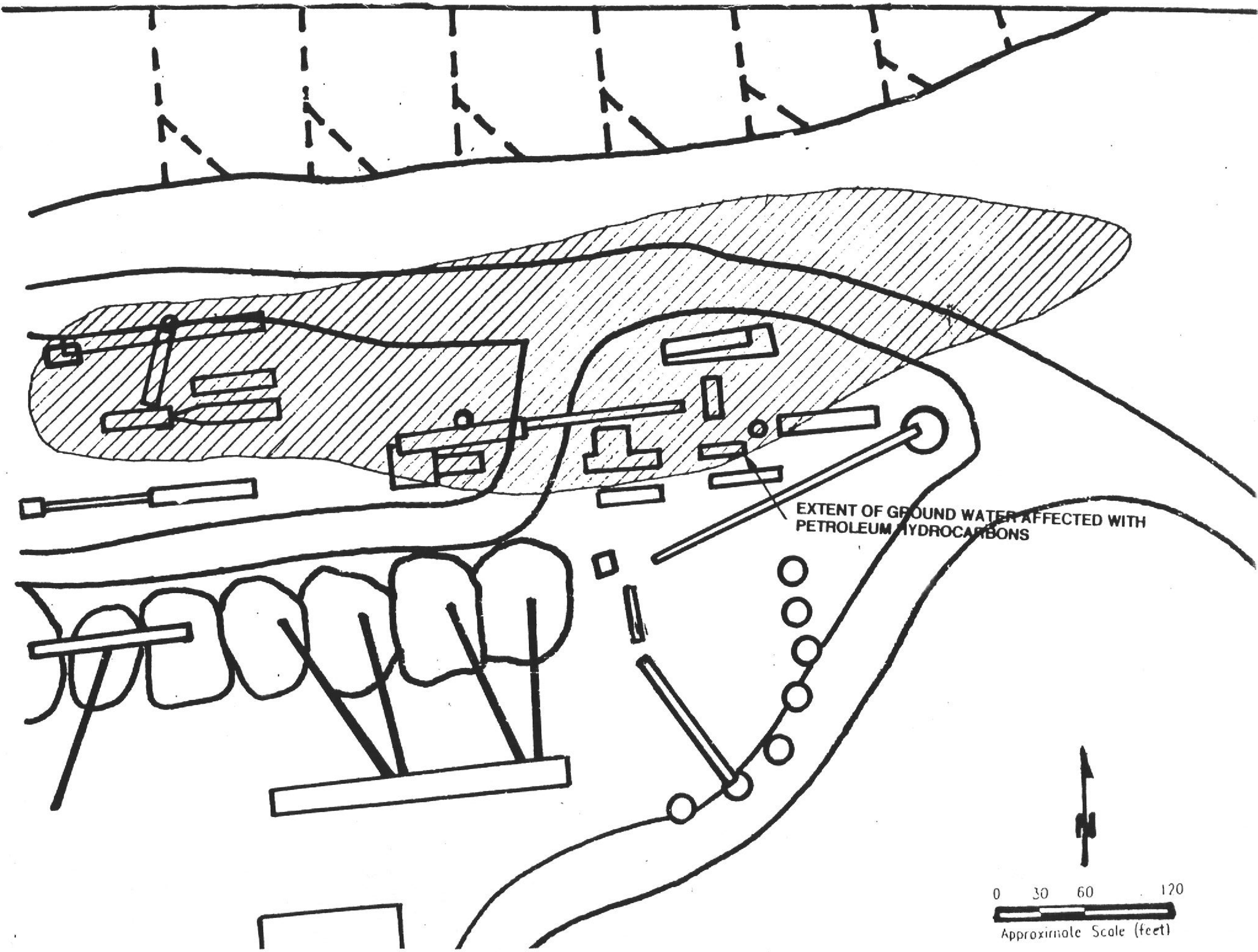
EXTENT OF GROUND WATER AFFECTED WITH PETROLEUM HYDROCARBONS
N
0 30 60 120
Approximate Scale (feet)

Figure 7

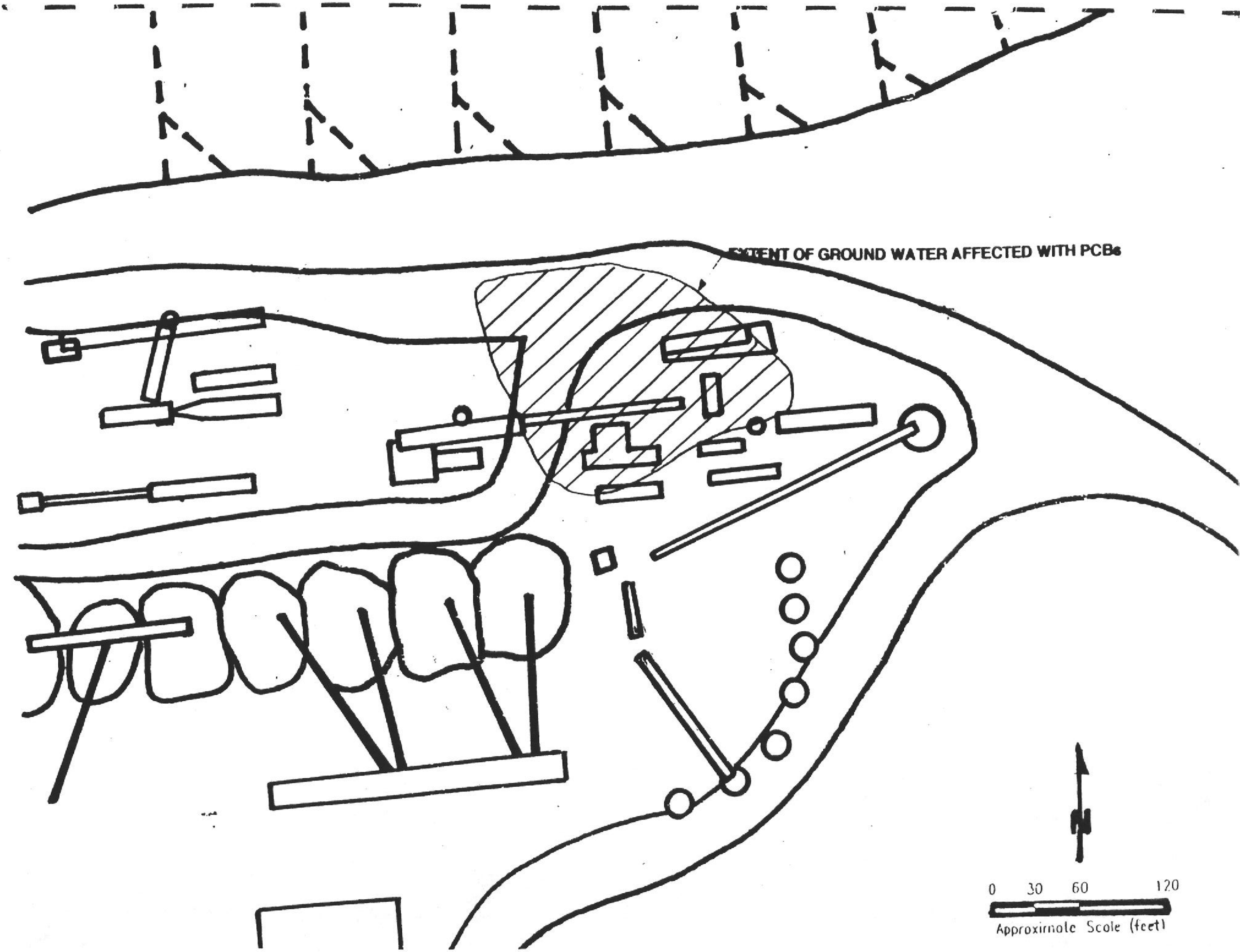
EXTENT OF GROUND WATER AFFECTED WITH PCBs
N
0
30
60
120
Approximate Scale (feet)

Figure 8

Table 1

KLEINFELDER

RESULTS OF GROUND WATER SAMPLING, APRIL 1991
INDUSTRIAL ASPHALT FACILITY

(concentrations in ppm)

Monitoring Well	Total Depth (feet)	Depth to Water$^{(1)}$ (feet)	Ground Water Elevation$^{(2)}$ (feet)	Product Thickness (feet)	TPH as Diesel$^{(3)}$	TPH as Waste Oil$^{(4)}$	PCBs$^{(5)}$	Oil & Grease$^{(10)}$	Total Hydrocarbons$^{(11)}$
MW-1	88	73.69	305.72	SHEEN	40	27	ND	91	74
MW-2	90	72.00	307.80	SHEEN	44	35	0.005	150	130
MW-3	90	72.34	306.20	SHEEN	19	14	0.0008	34	30
MW-4	95	70.71	305.55	NE	0.7	9.7	ND	11	6
MW-5	110	78.57	303.98	NE	ND	ND	ND	ND	ND
MW-6	109	NC	NA	NA	NT	NT	NT	NT	NT
MW-7	109	73.07	305.87	NE	0.5	ND	ND	1	ND
MW-8	109	72.82	305.74	NE	4.1	4.8	0.0008	15	11
MW-9	108	NC	NA	NA	NT	NT	NT	NT	NT
MW-10	111	72.02	306.02	NE	3	ND	ND	4	1
MW-11$^{(8)}$	NA	NA	NA	NA	NA	NA	NA	NA	NA
MW-13$^{(9)}$	116	73.62	306.59	SHEEN	0.7	ND	ND	ND	ND
MW-14	114.5	74.27	305.82	NE	ND	ND	ND	ND	ND
MW-15	117	73.03	305.09	NE	0.5	ND	ND	2	1
MW-16	110	73.27	306.38	NE	ND	0.5	ND	0.9	ND
14A2$^{(12)}$	UNK	UNK	UNK	UNK	ND	ND	ND	ND	ND
SG	NA	1.5	301.5$^{(7)}$	NA	NA	NA	NA	NA	NA

(1)	Below top of casing
(2)	Feet above mean sea level (USGS Datum)
(3)	Laboratory detection limits - 0.05 ppm
(4)	Laboratory detection limit - 0.1 ppm
(5)	Laboratory detection limit - 0.0005 ppm
(6)	Reading on the staff gage
(7)	Surface water elevation in the pit
(8)	Well abandoned on August 8, 1990
(9)	Extraction well
(10)	Laboratory detection limit - 0.5 ppm
(11)	Laboratory detection limit - 0.5 ppm
(12)	Jamieson Well

TPH	Total Petroleum Hydrocarbons
PCBs	Polychlorinated Biphenyls (Aroclor 1260)
NE	Not Encountered
ND	Not Detected at or above laboratory detection limits
NA	Not Applicable
SG	Staff Gage
NC	Not Acessible
NT	Not Tested
UNK	Unknown

Table 2

TYPICAL COMPOSITION OF DIESEL FUEL BY HYDROCARBON CLASSIFICATIONS

Compound	Weight Per Cent
Straight-chain Paraffins and Isoparaffins	37-43
Cycloparaffins	
mono-	23
di-	8
tri-	2
total	26-33
Aromatics (substituted benzenes and polyaromatic hydrocarbons (PAHs))	
alkybenzenes	9
indans and tetralins	5
dinaphthenobenzenes	1
alkylnapthalenes	6
biphenyls, etc.	2
fluorenes, napthalenes, etc.	1-3
tricyclic aromatics	1
benzene	47 parts per million
Total	23-28

Table 3

Chemical and Physical Properties of Constituents of Diesel Fuel and No. 2 Fuel Oil and PCBs

Chemical	CASRN	Concentration Range in No.2 Fuel Oil (ppm)(1)	Molecular Weight (grams/mole)	Water Solubility (mg/l)	Vapor Pressure (mm Hg)	Henry's Law Constant (atm-m^3/mole)	K_{oc}(4) (ml/g)	Log K_{ow}(5)
Volatile Organics								
Benzene	71-43-2	6-82	78	1.8×10^{3}	9.5×10^{1}	5.6×10^{-3}	83	2.1
Ethylbenzene	100-41-4	100-800	106	1.5×10^{2}	7.0	6.4×10^{-3}	1,100	3.2
Toluene	108-88-3	100-800	92	5.3×10^{2}	2.8×10^{1}	6.4×10^{-3}	300	2.7
Xylene(2)	1330-20-7	100-800	106	2.0×10^{2}	1.0×10^{1}	7.0×10^{-3}	240	3.3
Polycyclic Aromatic Hydrocarbons								
benzo(a)pyrene	50-32-8	0.001 - 0.6	252	1.2×10^{-3}	5.6×10^{-9}	$1.6 \times {}^{10-6}$	5,500,000	6.1
benzanthracene	56-55-3	0.01 - 1.2	228	5.7×10^{-3}	2.2×10^{-8}	1.2×10^{-6}	20,000	5.6
chrysene	218-01-9	1.4	228	1.8×10^{-3}	6.4×10^{-9}	1.0×10^{-6}	1,380,000	5.6
cresol	1319-77-3	54	108	3.1×10^{-4}	2.4×10^{-4}	1.0×10^{-6}	500	2.0
methylnaphthalene	1321-94-4	5,700 - 9,100	---	---	---	---	---	—
2-methylnaphthalene	91-57-6	6,700	142	—	---	---	—	—
naphthalene	91-20-3	2,730	128	3.0×10^{-1}	1 mm at 53°	---	---	3.3
phenanthrene	85-01-8	1,500	178	1.0	6.8×10^{-4}	1.6×10^{-4}	14,000	4.5
phenol	108-95-2	6.8	94	9.3×10^{-4}	3.4×10^{-1}	4.5×10^{-7}	14.2	1.5
quinoline	91-22-5	9.2	129	6.0×10^{-4}	1 mm at 60°	---	---	2.0
Polychlorinated Biphenyls (3)	1336-36-3	---	328	3.1×10^{-2}	7.7×10^{-5}	1.1×10^{-3}	530,000	6.0

NOTES:

CASRN Chemical Abstract Service Registry Number.
ppm Parts per million.
(1) Stone, 1990.
(2) Entries for xylenes are for mixtures of three isomers.
(3) Polychlorinated biphenyls are not a typical component of diesel or fuel oil. They are included here because they have been detected in samples of diesel fuel product collected at the Industrial Asphalt site.
(4) K_{oc} = organic carbon partitioning coefficient.
(5) K_{ow} = octanol/water partitioning coefficient.

KLEINFELDER

Table 4

Clean Up Levels and Peak Contaminant Concentrations At Industrial Asphalt

	PCB	DIESEL	BENZENE
CLEAN UP LEVEL	$0.0046\ \frac{\mu g}{l}$[A]	$0.1\ \frac{mg}{l}$[B]	$0.3\ \frac{\mu g}{l}$[C]
HIGHEST CONC. IN GROUNDWATER	$9.6\ \frac{\mu g}{l}$[E]	$400\ \frac{mg}{l}$[F]	$0.9\ \frac{\mu g}{l}$[D]
# OF WELLS ABOVE CLEANUP LEVEL	4 MW-1,2,3,8	10 MW-1,2,3,8 9,10,13-16	2 MW-2,3

A - Calculated as a one-in-a-million risk, SMCL = $0.005\frac{\mu g}{l}$

B - Maximum Contaminant Level (MCL)

C - Calculated as a one-in-a-million risk, PMCL = $1.0\frac{\mu g}{l}$

D - Based on 1991 quarterly testing

E - Based on January 1991 data

F - Based on January 1991 data, wells 1-3 100 to 440 $\frac{mg}{l}$
wells 8-10,13-16 12 to 0.1 $\frac{mg}{l}$

Table 5

Preliminary Alternative Evaluation

Remediation Technology	Acceptability	Comments
In-place Technologies		
Slurry Wall	Acceptable	
Injector Wells	Not Acceptable	Do not want to introduce more water into the contaminated zone
Extractor Wells	Acceptable	
Trenching	Not Acceptable	Prohibitively expensive.
In situ Vitrification	Not Acceptable	Prohibitively expensive.
Excavation & Treatment		
Excavation		
Removal	Acceptable	
Incineration	Acceptable	
Solidification	Acceptable	
Pump & Treat Technologies		
Bioremediation	Not Acceptable	Not proven technology for PCB removal.
UV/Ozone oxidation	Acceptable	
UV/H2O2 Oxidation	Acceptable	
GAC	Acceptable	
Ultraficltration	Not Acceptable	Not applicable for PCB removal.
Discharge w/o Treatment	Not Acceptable	Not legally feasible.
Incineration	Not Acceptable	Prohibitively expensive.
Volatilization	Not Acceptable	PCBs are unable to volatilize.
Dissolved Air Flotation	Not Acceptable	PCBs have higher specific gravity than water.
S.Critical WA Oxidation	Not Acceptable	Untimely down time due to ash plugging and uncertain acid purge schedule.
Insitu Technologies		
Bioremediation	Not Acceptable	Not suited for calcitrants and clayey soils. Still not an accepted technology.
Solidification	Not Acceptable	Poses a large risk. Future land usage poses a problem.
Soil Vapor Extraction	Not Acceptable	TPH and PCBs not volatile.
Steam Injection	Acceptable	
Thermal enhanced	Not Acceptable	Not an accepted technology (still in experimental stages).

Table 7

Alternative Scoring Evaluation

Remediation Alternative	Cost 30%	Feasibility 30%	Remedial Objects 30%	Public Acceptanc 10%	Total 100%
Alternative 1 Slurry Wall - Steam Injection - Future Excavation	15	10	30	8	63
Alternative 2 Slurry Wall - Ground Water Extraction - Future Excavation	20	10	30	8	68
Alternative 3 Excavation of Whole Site (today)	0	0	30	5	35
Alternative 4 Ground Water Extraction - GAC Treatment - Future Excavation	25	20	30	8	83
Alternative 5 Ground Water Exctraction - UV/H202 - Future Excavation	30	20	30	8	88
Alternative 6 Ground Water Exctraction - UV/Ozone - Future Excavation	27	20	30	8	85

Table 6

Combined Remediation Alternatives Cost Estimate After 30 Years With Excavated PCB Soil Landfilled									
Interest Rate for present worth calculations		10%							
				Alternative 1 Build slurry wall around PCBs Steam inject Diesel Excavate PCBs	Alternative 2 Build slurry wall around PCBs Pump and UV/H2O2 diesel Excavate PCBs	Alternative 3 Excavate all soil immediately	Alternative 4 Pump Treat with GAC Excavate PCBs	Alternative 5 Pump Treat with UV/Ozone Excavate PCBs	Alternative 6 Pump Treat with UV/H2O2 Excavate PCBs
Slurry Wall									
Slurry wall cost per lineal foot (110' deep) (a)			$1,000						
Approximate perimeter necessary to surround									
PCBs	780 ft								
Entire plume	2000 ft								
Time until implemented (years)				1	1	0	0	0	0
Lineal feet of wall				780	780	0	0	0	0
Cost of wall				$780,000	$780,000	$0	$0	$0	$0
Present worth				$709,091	$709,091	$0	$0	$0	$0
Excavation									
Excavation costs per cubic yard (b)			$10						
Landfill disposal costs per cubic yard			$100						
Cost for temporary removal of facilities			$1,700,000						
Approximate Excavation Volumes									
PCB removal	25,000 cu.yd.	(contaminated)							
	135,000 cu.yd.	(including overburden)							
Entire Site	65,000 cu.yd.	(contaminated)							
	470,000 cu.yd.	(including overburden)							
Time until implemented (years)				30	30	1	30	30	30
Excavation volume (cu.yd.)				135000	135000	470000	135000	135000	135000
Cost for excavation				$1,350,000	$1,350,000	$4,700,000	$1,350,000	$1,350,000	$1,350,000
Landfill disposal volume				25000	25000	25000	25000	25000	25000
Cost to landfill				$2,500,000	$2,500,000	$2,500,000	$2,500,000	$2,500,000	$2,500,000
Temporary facility removal (% of site)				0%	0%	100%	0%	0%	0%
Cost for Temporary facility removal				$0	$0	$1,700,000	$0	$0	$0
Present worth				$220,638	$220,638	$8,090,909	$220,638	$220,638	$220,638
Pump and Treat									
Pumping present worth for 30 years (see other calc.)		$2,458,342		$0	$2,458,342	$0	$2,458,342	$2,458,342	$2,458,342
Capital cost for treatment					$87,500		$65,000	$245,000	$87,500
Annual operation and maintenance for treatment					$28,000		$65,000	$30,000	$28,000
Duration of implementation (years)				0	30	0	30	30	30
Cost of treatment				$0	$927,500	$0	$927,500	$927,500	$927,500
Present worth				$0	$2,807,796	$0	$3,134,091	$2,984,149	$2,807,796
Steam Injection									
Steam injection cost per cubic yard (d)			$60						
Total contaminated volume		85,000 cu.yd.							
Time until implemented (years)				1	0	0	0	0	0
Steam injected volume (cu.yd.)				60000	0	0	0	0	0
Cost of steam injection				$3,570,000	$0	$0	$0	$0	$0
Present Worth				$3,245,455	$0	$0	$0	$0	$0
Total Cost				$4,175,184	$3,737,524	$8,090,909	$3,354,729	$3,204,787	$3,028,434

(a) Conversation with Wyo-Ben Inc, Billings Montana
(b) Rishel, H.L. "Costs of Remedial Response Actions at Uncontrolled Hazardous Waste Sites," 1984
(c) Conversation with Dennis Hunt, Industrial Asphalt
(d) Conversation with Kent Udell, University of California, Berkeley

Capital and Operating Cost Comparison for Ground Water Treatment Alternatives

	GAC(a)	UV Oxidation Hydrogen Peroxide(b)	UV Oxidation Ozone(a)
Capital Costs	$65,000	$87,500	$245,000
Operating Costs - Annual			
Electrical	n/a	$10,000	$10,000
GAC Replacement	$35,000	n/a	n/a
Landfill Disposal	$10,000	n/a	n/a
Operation & Maintenance	$15,000	$18,000	$20,000
Total	$65,000	$28,000	$30,000
Present Worth	**$677,749**	**$351,454**	**$527,807**

(a) Kleinfelder, Inc. 1991 Feasibility Study
(b) Norman Olson, Peroxidating Systems, Inc

Costs of UV-hydrogen peroxide system

Based on data obtained from

Norman Olson
Peroxidation Systems, Inc.
Tucson, AR 85711-3558
(602) 327-0277

unit to reduce
PCB $10 \frac{\mu g}{l} \rightarrow 4.6 \times 10^{-3} \frac{\mu g}{l}$
TPH $400 \frac{mg}{l} \rightarrow 0.1 \frac{mg}{l}$
Flowrate 20 gpm

CAPITAL COSTS OF UNIT	80K
INSTALLATION OF UNIT	7.5K
	87.5K

Annual costs

O & M PARTS (lamps, quartz tubes, etc.)	6.5K
hydrogen peroxide (at 84¢/lb)	2.2K
electrical cost (at 6¢ KW/hr)	15.5K
Maintenance labor (4 hours/month) at 80$/hr	3.8K
	28K

Present cost for 10 years of pumping

$$87.5k + 28k \frac{(1+.1)^{10}-1}{.1(1+.1)} = 493K$$

= for 20 years of pumpg

$$87.5k + 28k \frac{(1+.1)^{20}-1}{.1(1+.1)} = 1,545K$$

for 30 years of pumpg

$$87.5k + 28k \frac{[(1+.1)^{30}-1]}{.1(1+.1)} = 4,275K$$

Expected Extraction Well Costs

ITEM/DESCRIPTION	QUANTITY	UNIT	UNIT COST (a)	TOTAL COST
CAPITAL COSTS				
EXTRACTION				
Extraction Well	10	ea	$30,000	$300,000
Piping	8000	ft	$65	$520,000
Electrical Conduit, Wire and Instrumentation	8000	ft	$10	$80,000
Connection to Treatment Facility	1	ea	$5,000	$5,000
CAPITAL COSTS				$905,000
FEES AND CONTINGENCIES				
Contingency (15% of Capital Costs)		15%		$135,750
TOTAL CAPITAL REQUIREMENT				$1,040,750
OPERATIONS AND MAINTENANCE COSTS				
FIRST 5 YEARS				
EXTRACTION				
Power (10 wells @ 2 hp each)	130000	kWh/yr	$0.14	$18,200
MONITORING				
Sample Well (8 wells, quarterly)	32	ea	$200	$6,400
Water Quality Analyses	32	ea	$2,500	$80,000
Disposal of Purge Water	32	ea	$2,000	$64,000
SUBTOTAL				$168,600
FEES AND CONTINGENCIES				
Contingency (15% of Subtotal)	15%			$25,290
TOTAL ANNUAL COSTS FOR FIRST 5 YEARS				$193,890
REMAINING YEARS				
EXTRACTION				
Power (10 wells @ 2 hp each)	130000	kWh/yr	$0.14	$18,200
MONITORING				
Sample Well (5 wells, semi-annually)	10	ea	$200	$2,000
Water Quality Analyses	10	ea	$2,500	$25,000
Disposal of Purge Water	10	ea	$2,000	$20,000
SUBTOTAL				$65,200
FEES AND CONTINGENCIES				
Contingency (15% of Subtotal)	15%			$9,780
TOTAL ANNUAL COSTS FOR REMAINDER				$74,980
PRESENT WORTH				
TOTAL CAPITAL REQUIREMENT				$1,040,750
Operation and Maintenance Duration	30	yrs		
Interest Rate	10%			
PRESENT WORTH OF ANNUAL COSTS FOR FIRST 5 YEARS				$734,996
PRESENT WORTH OF ANNUAL COSTS FOR REMAINING YEARS				$680,596
TOTAL PRESENT WORTH				$2,456,342

(a) Costs taken from "Feasibility Study of Glendale Study Area - North Plume Operable Unit", James M. Montgomery Incorporated, April 1992.

Determination of benzene air concen. at drinking H_2O well.

$C_{B,w}$ = 0.00020 mg/l P_B = vapor pressure

Henry's law constant = $5.6\times10^{-3} \frac{\text{atm m}^3}{\text{mole}}$ = H_c

$C_{B,air}$ = concentration benzene in air

$H_c \cdot C_{B,w} = P_B$

$$P_B = 0.0002 \frac{\text{mg}}{\text{l}} \times \frac{5.6\times10^{-3}\,\text{atm m}^3}{\text{mole}} \times \frac{\text{mole}}{78\times10^{3}\,\text{mg}} \times \frac{10^3\,\text{l}}{\text{m}^3} = 1.44\times10^{-8}\,\text{atm}$$

$$C_{B,air} = \frac{1.44\times10^{-8}\,\text{atm}}{1\,\text{atm}} = \frac{1.44\times10^{-8}\,\text{mole Benzene}}{1\,\text{mole air total}}$$

$$1\,\text{mole air} \times \frac{8.314\,\text{m}^3\,\text{Pa}}{\text{mole}\cdot\text{K}} \times (273+20)\,\text{K} \times \frac{1}{1.01\times10^{5}\,\text{Pa}} = 2.4\times10^{2}\,\frac{\text{m}^3}{\text{mole}}$$

$$C_{B,air} = \frac{1.44\times10^{-8}\,\text{mole Benzene}}{1\,\text{mole air total}} \times \frac{\text{mole air}}{2.4\times10^{-2}\,\text{m}^3} = 6.\times10^{-7}\,\frac{\text{mole}}{\text{m}^3}$$

$$= 4.7\times10^{-2}\,\text{mg/m}^3$$

assume a 10/1 dilute before breathing

so 4.7×10^{-3} mg/m^3

Determination of $C_{B,w}$ which will give 1×10^{-6} risk

$C_{B,w}$ = Benzene water concentration

$$P_B = H_c \cdot C_{B,w} = 0.0056 \, \frac{\text{atm m}^3}{\text{mole}} \times C_{w,B} \times \frac{10^3 \, \ell}{\text{m}^3} \times \frac{\text{mole}}{78\times10^3 \, \text{mg}} = 7.18\times10^{-5} \, C_w \; \text{atm}$$

RISK = 1 − exp(−CDI × SF) SLOPE FACTOR = SF = $0.029 \, \frac{\text{kg}\cdot\text{day}}{\text{mg}}$

$$10^{-6} = 1 - \exp\left(-\text{CDI} \times 0.029 \, \frac{\text{kg day}}{\text{mg}}\right)$$

$$\text{CDI} = 3.448 \times 10^{-5} \, \frac{\text{mg}}{\text{kg}\cdot\text{day}}$$

$$\text{CDI} = \frac{C_w \times IR \times EF \times ED}{BW \times AT} + \frac{C_A \times IR \times EF \times ED}{BW \times AT}$$

$$\text{gas concen.} = C_{B,air} = \frac{7.18\times10^{-5} \cdot C_w \text{ mole}}{\text{mole}} \times \frac{\text{mole}}{2.41\times10^{-2} \, \text{m}^3} \times \frac{78\times10^3 \, \text{mg}}{\text{mole}} \times \frac{10^{-3} \, \text{m}^3}{\ell}$$

$$= 2.32\times10^{-1} \cdot C_w \cdot \frac{\text{mg}}{\ell}$$

assume a 10/1 dilution before inhalation

$$C_{B,air} = 2.32 \times 10^{-2} \, \frac{\text{mg}}{\ell} \text{ Benzene}$$

CDI for H_2O

$$= \frac{C_w \times 2 \text{ liter/day} \times 70 \text{ year} \times 365 \text{ day/yr}}{70 \text{ kg} \times 70 \text{ year} \times 365 \text{ day/yr}} = C_w \times 2.86\times10^{-2} \, \frac{\text{mg}}{\text{kg}\cdot\text{day}}$$

CDI for air

$$= \frac{C_w \times 2.32\times10^{-2} \frac{\text{mg}}{\ell} \times \frac{10^3 \, \ell}{\text{m}^3} \times 30 \frac{\text{m}^3}{\text{day}} \times \frac{12 \text{ min}}{\text{day}} \times \frac{\text{hr}}{60 \text{ min}} \times \frac{\text{day}}{24 \text{ hour}} \times \frac{365 \text{ day}}{\text{yr}} \times 70 \text{ y}}{70 \text{ kg} \times 70 \text{ years} \times 365 \text{ day/year}}$$

$$= 8.29 \times 10^{-2} \, C_w \, \frac{\text{mg}}{\text{kg}\cdot\text{day}}$$

$$3.448\times10^{-5}\,\frac{mg}{kg\cdot dy} = C_w\times 8.29\times10^{-2}\,\frac{mg}{kg\cdot dy} + C_w\times 2.86\times10^{-2}\,\frac{mg}{kg\cdot dy}$$

$$C_{,w} = 3\times10^{-4}\,\frac{mg}{l} = \underline{\underline{0.3\,\frac{\mu g}{l}}}$$

Concentration of Benzene giving 1×10^{-6} risk.

Determination of $C_{PCB,w}$ which will give 1×10^{-6} risk

assume inhalation is negli.
By similar method as above

$$10^{-6} = 1 - \exp(-CDI\times7.7)$$

SF for PCB's $= 7.7\,\frac{kg\,day}{mg}$

$$CDI = 1.3\times10^{-7}\,\frac{mg}{kg\cdot dy}$$

$$1.3\times10^{-7}\,\frac{mg}{kg\cdot dy} = \frac{C_{PCB,w}\times 2\text{ liter/day}\times 70\text{ years}\times 365\text{ days/yr}}{70\text{ kg}\times 70\text{ yr}\times 365\text{ dy/yr}}$$

$$C_{PCB,w} = 4.6\times10^{-6}\,\frac{mg}{l} - 4.6\times10^{-3}\,\frac{\mu g}{l}$$

Conc. of PCB in water to give 1×10^{-6} risk

Can PCB's or TPH be treated by pump and treat

Assume a CMFR with adsorption. Perform a mass balance within one well capture zone

$$\rho_s V_s \Delta C_s + V_w \Delta C_w = -Q C_w \Delta t$$

$$\longrightarrow \quad \frac{dC_w}{dt} = \frac{-Q}{\rho_s V_s K_d + V_w} C_w$$

where Q = flow rate for one well

V_s, V_w = Volume of soil and water zones within aquifer capture zone of one well

ρ_s = density of soil

$$C_w = C_o e^{-\Theta t}$$

C_o = initial concentration

$\Theta = Q / \rho_s V_s K_d + V_w$

From pump-drawdown test

$Q = 2 gpm = .00757 \ m^3/min$

assume porosity $= \eta = .35$

capture zone = 100 feet → 50 feet insuring proper coverage

$V_T = V_s + V_w = \pi (50 ft)^2 \, 20 ft = 1.57 \times 10^5 ft^3 = 4.45 \times 10^3 m^3$

where 20 ft = thickness of water bearing zone

$V_s = 4.45 \times 10^3 (1. - .35) = 2.89 \times 10^3 m^3$

$V_w = 4.45 \times 10^3 (.35) = 1.56 \times 10^3 m^3$

$\rho_s \cong 2 \frac{g}{cm^3} = 2000 \frac{kg}{m^3}$

Assumes linear adsorption isotherms apply from Karickhoff et. al. (1979)

$$K_d = .6\, f_{oc}\, K_{ow}$$

from physical properties data assuming ~~that~~ $f_{oc} = .001$ (typical for Bay Area Soils)

for PCB's $\log K_{ow} = 6.0$ for TPH $\log K_{ow} \cong 5.0$

this is an assumed $\overset{\text{nominal}}{\wedge}$ value since TPH consists of primarily many cycloparafins and straight chained hydrocarbons.

For PCB's $K_d = .6(.001)\,10^6 = 600\,\frac{l}{kg} = .6\,\frac{m^3}{kg}$

For TPH $K_d = .6(.001)\,10^3 = .6\,\frac{l}{kg} = 6\times10^{-4}\,m^3/kg$

solving for time $t = -\frac{1}{\theta}\ln\frac{C_w}{C_o}$

CB : $$t = \frac{-\left(2000\,\frac{kg}{m^3}\;2.89\times10^3\,m^3\;.6\,\frac{m^3}{kg} + 1.56\times10^3\,m^3\right)}{.00757\;m^3/min}\ln\left(\frac{4.6\times10^{-7}}{9.6\times10^{-6}}\right)$$

$$= 3.5\times10^7\ min = 6{,}600\ years$$

PH : $$t = \frac{-\left[(2000\;2.89\times10^3\;46\times10^{-4}) + 1.56\times10^3\right]}{.00757}\ln\frac{1\times10^{-4}}{.4}$$

$$= 5.5\times10^6\ min = 10\ years$$