Chevron

Chevron U.S.A. Products Company
2410 Camino Ramon
San Ramon, CA 94583

Marketing Department
Phone 510 842 9500

October 4, 1993

Ms. Jennifer Eberle
Alameda County Health Care Services
Department of Environmental Health
80 Swan Way, Room 200
Oakland, CA 94621

Re: Chevron Service Station #9-0121
3026 Lakeshore Avenue, Oakland, CA

Dear Ms. Eberle:

Enclosed is the Remedial Feasibility Study (RFS) dated October 4, 1993, prepared by our consultant Pacific Environmental Group, Inc. for the above referenced site. The RFS evaluated applicable alternatives to select an appropriate long-term remedial strategy for the site.

Several remedial technologies were identified and three alternatives were extensively evaluated considering effectiveness, feasibility, and relative costs of applicable alternative methods for cleanup. The results of the RFS indicate that alternative points of compliance is the most appropriate remedial option. Alternative points of compliance provides an institutional control which is easy to implement and provides the maximum benefit to people of the state.

We would appreciate your review and formal concurrence with the results of the RFS prior to implementing alternative points of compliance.

If you have any questions or comments, please do not hesitate to contact me at (510) 842-8134.

Sincerely,
CHEVRON U.S.A. PRODUCTS COMPANY

Mark A. Miller
Site Assessment and Remediation Engineer

Enclosure

cc: Mr. Rich Hiett, RWQCB - Bay Area
Mr. S.A. Willer
File (9-0121 RFS2)

Remedial Feasibility Study

Chevron Service Station 9-0121
3026 Lakeshore Boulevard
Oakland, California

OCT 1993

Prepared for

Chevron U.S.A. Products Company

October 4, 1993

Prepared by

Pacific Environmental Group, Inc.
2025 Gateway Place, Suite 440
San Jose, California 95110

Project 325-44.01

PACIFIC ENVIRONMENTAL GROUP, INC.

CONTENTS

CONTENTS

TABLES AND FIGURES

PROFESSIONAL CERTIFICATION

Remedial Feasibility Study

Chevron Service Station 9-0121

3026 Lakeshore Avenue

Oakland, California

October 3, 1993

Pacific Environmental Group, Inc. (PACIFIC) has prepared this Remedial Feasibility Study for Chevron U.S.A. Products Company (Chevron). This report concerns the feasibility of remedial alternatives for implementation at Chevron Service Station 9-0121.

On behalf of Chevron U.S.A. Products Company, I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gathered and evaluated the information submitted. Based on my inquiry of the person or persons who managed the system, or those persons directly responsible for gathering the information, the information is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

R. L. Giattino
Project Engineer

Steven E. Krcik
Senior Geologist
RG 4976

REGISTERED GEOLOGIST · STEVEN E. KRCIK · No. 4976 · Exp 6/94 · STATE OF CALIFORNIA

EXECUTIVE SUMMARY

This remedial feasibility study (RFS) was completed to lay the ground work for instituting a long term strategy for remediation at Chevron Service Station 9-0121. Preparation of this RFS was accomplished considering all investigative and remedial data generated to date, as well as State Water Control Board Resolutions 68-16, 88-63, and 92-49.

A review of all pertinent data was completed and summarized in a conceptual site model. The model served as a basis for generating remedial objectives and associated response actions. It was determined that the primary source of petroleum hydrocarbon residuals beneath the site was the underground storage tanks, which have since been removed or repaired. A majority of the secondary source of petroleum hydrocarbon residuals appears to be saturated soil and groundwater impacted with weathered gasoline and diesel fuel. This secondary source appears to exist as a static plume defined by on-site Monitoring Wells MW-1 through MW-4. The compounds of concern that distinguish the source area are the constituents of gasoline, including benzene, toluene, ethylbenzene, and xylenes.

Several interim remedial actions were described as part of the site conceptual model. These actions were intended to address the secondary source and included, soil excavation, batch separate-phase hydrocarbon/groundwater removal, and installation of a subsurface physical barrier.

Subsequent to preparing the site conceptual model, site-specific public health and safety goals and water quality goals were developed. Site water quality goals were identified as Marine Effluent Discharge Limitations (MEDL's) for shallow water discharge. The public health and safety goal focused on eliminating the potential for a hazardous environment to develop in an adjacent off-site basement.

Predicated on the need to achieve the site-specific public health and safety goal and water quality goals, groundwater-based remedial objectives were established. Appropriate response actions were identified and associated technologies were combined into remedial alternatives. Three alternatives were evaluated: (1) No Action/Discontinue

Action (Alternative 1), (2) Natural Attenuation/Alternate Points Of Compliance (Alternative 2), and (3) Groundwater Extraction (Alternative 3).

Technical, institutional, environmental safety, and economic criteria were used to evaluate the alternatives. It was determined that the natural attenuation/alternate points of compliance alternative (Alternative 2) was the most feasible for long term application. Elements of Alternative 2 are:

- o Groundwater monitoring.
- o Preparation of a contingency plan that includes institutional controls.
- o Preparation of a plan to manage the potential for risk associated with the basement environment of the adjacent site.

The recommendation was based on the probability that implementation of Alternative 3 would provide little incremental benefit to the existing situation, increase exposure and injury risk, and require substantial resources. In addition, Alternative 2 minimizes the likelihood of imposing a burden on the people of the state with the expense of remediation, when compared to Alternatives 1 and 3.

1.0 INTRODUCTION

As a result of subsurface petroleum hydrocarbon impact beneath Chevron Service Station 9-0121, Oakland, California (Figure 1), Chevron has been engaged in interim remediation since 1967. In September 1993, to further develop the remedial approach, Chevron retained Pacific Environmental Group, Inc. (PACIFIC). It was decided a feasibility study was necessary to direct development. Accordingly, the feasibility study presented herein was prepared.

1.2 Previous Investigations

Previous investigations were completed by Groundwater Technology, Inc. (GTI), beginning in 1981. Information associated with past investigation work is presented as Appendix A.

1.3 Document Format

Within this document, a conceptual site model and site water quality goals are developed (Sections 2.0 and 3.0), a public health and safety goal is established (Section 4.0) and remedial objectives are identified (Section 6.0). Within Section 6.0, technologies are screened and assembled into remedial alternatives, alternatives are evaluated and a specific alternative is recommended. An implementation schedule is proposed and is included herein as Section 7.0. Calculations, conditions, and assumptions are presented as Appendix B.

2.0 CONCEPTUAL SITE MODEL

2.1 Physical Characteristics

The site is the location of an operating service station situated in a commercial/residential area northeast of Lake Merritt. The service station has been in operation since 1956. The site is paved, with the paved surface gently sloping toward the west, in the direction of Lake Merritt. There is a slight rise in topography to the west of the site, prior to reaching Lake Merritt. Lake Merritt, a manmade lake, is located approximately 600 feet to the southwest of the site. A channel connects Lake Merritt to Oakland Inner Harbor, which is associated with San Francisco Bay. The Chancery Office Dioces of the Oakland Annex borders the southwest perimeter of the site; a storm sewer line (7 feet in diameter) is buried along the southeastern boundary of the site. The intersection of Lakeshore Avenue and MacArthur Boulevard borders the northern portion of the site.

Improvements at the site include product dispensing equipment and four underground fiberglass storage tanks. The underground storage tanks (USTs) are used to store gasoline and diesel fuel. Subsurface fiberglass lines connect product dispensers to storage tanks. A subsurface plastic barrier was installed along the southwest site perimeter as part of interim remediation.

In 1991, GTI evaluated the existence of any nearby pumping wells. No pumping wells were identified in the vicinity of the site.

2.2 Primary Source

The primary source of the petroleum hydrocarbon residuals appears to have been the USTs. A product release was documented in July 1967, and during tank replacement, a gash was observed in one of the steel tanks. Subsequent to the initial release, tank testing performed in 1980 showed that the replacement steel tanks may have been slightly leaking. These tanks were replaced, along with the lines, by the existing fiberglass storage and distribution system. In each case mentioned, hydrocarbon-impacted soils were removed from the site. In 1984, approximately 740 cubic yards were removed from beneath the site when the service station was reconstructed. More recently, in

December 1990, a hole was discovered in one of the fiberglass tanks. The hole was repaired and the tank was put back into service. Given the information provided by Chevron, it appears there are no existing primary sources of petroleum hydrocarbons at the site.

2.3 Residual Source

A majority of the petroleum hydrocarbon residual (secondary source) beneath the site is weathered gasoline and diesel fuel; constituents of concern are benzene, toluene, ethylbenzene, and xylenes (BTEX compounds). The highest concentrations of these residuals are concentrated in the central-southwestern portion of the site (Wells MW-1 and MW-2, Figure 2). As of June 1993, dissolved hydrocarbon concentrations of total petroleum hydrocarbons calculated as gasoline (TPH-g) were detected at a maximum of 7,000 parts per billion (ppb) in Well MW-1. The maximum benzene concentration was detected in Well MW-1 at 1,900 ppb.

In August 1991, borings for Wells MW-1, MW-2, MW-3, and MW-4 were installed and soil samples were collected. Petroleum hydrocarbons were detected in vadose zone soil samples collected from 2 to 9 feet below ground surface (bgs). The maximum benzene concentration (2.8 parts per million [ppm]), was detected in a soil sample from MW-2, collected at 7 feet bgs. Data suggests vertical migration of separate-phase hydrocarbons (SPH) through soil was terminated by the piezometric surface at approximately 5 feet bgs. Apparently, some lateral migration has occurred along the capillary fringe; trace levels of hydrocarbons were identified (13 ppm TPH-g) in a soil sample collected from a depth of 10 feet bgs during the installation of MW-8. Well MW-8 is located approximately 65 feet from the former primary source (USTs).

2.4 Geology/Hydrogeology

Soil beneath the site has been characterized primarily as fine silty-to-sandy clay of low permeability. Soils encountered while drilling in the southeast portion of the site were somewhat sandy, while soils located in the direction of Lake Merritt were found to be similar to Bay Mud.

Groundwater occurs at approximately 5 feet bgs and elevation data indicate seasonal fluctuations occur, probably in response to local recharge. A slight gradient tends to direct groundwater flow in a northwesterly direction; however, the storm sewer line located along the southeastern site perimeter appears to affect the general flow direction. It is possible the subsurface storm sewer line acts as a barrier, inhibiting the migration of impacted groundwater (similar to the weir system used in oil/water separators).

A pump test was performed in August 1981; no significant influence was observed and the test well ran dry after pumping for 50 minutes at 1 gallon per minute.

2.5 Interim Remediation

Several interim remedial actions have been instituted at the site since 1980, including soil excavation, batch SPH/groundwater removal, and installation of a physical barrier. Soil excavation took place during tank removal and replacement operations. Approximately 740 cubic yards of soil was removed from beneath the site at the time the service station was reconstructed in 1984. Batch SPH/groundwater extraction was accomplished using a vacuum truck to remove liquid from six on-site recovery wells. Again, the volume and composition of extracted liquid was not fully documented. The physical barrier was installed in response to the potential for migration of impacted groundwater; it was installed along the length of the southwestern site perimeter. The barrier extends to approximately 15 feet bgs.

2.6 Exposure Pathway

Since the gasoline constituents were released to shallow groundwater beneath the site, it is reasonable to expect groundwater flow to be the primary exposure pathway. Vertical migration is not expected to be a factor, considering the residual characteristics and low groundwater velocities. The exposure points would be one or both of the following locations: the basement of the adjacent site (Chancery Office Dioces of Oakland Annex); and Lake Merritt. The primary exposure route associated with the basement exposure point is inhalation. Exposure routes associated with Lake Merritt include, ingestion, inhalation, dermal adsorption, and uptake by aquatic organisms.

3.0 ENVIRONMENTAL, PUBLIC HEALTH, AND SAFETY GOALS

3.1 Site Water Quality Goals

Site-specific water quality goals are necessary to formulate remedial objectives for the site. Although petroleum hydrocarbon impact is restricted to groundwater, the location of the site relative to the San Francisco Bay requires that both ground and surface water are considered. Guidance for developing water quality goals was obtained from: the *Water Quality Control Plan, San Francisco Bay Basin Region* (RWQCB, 1991); *A Compilation of Water Quality Goals* (Marshack, 1993) the Tentative Site Cleanup Order (RWQCB, 1992), and Resolutions 68-16 and 88-63 (RWQCB, 1968/1988).

3.1.1 Beneficial Uses of Water: Groundwater

The existing and potential beneficial uses of groundwater are:

- Municipal supply
- Industrial and service supply
- Agricultural supply
- Fresh water replenishment to surface water

In general, water quality objectives for groundwater focus on protecting groundwater as a municipal supply. Although other beneficial uses may be more relevant, Resolution 88-63 specifies that all groundwater is suitable for municipal supply unless conditions preclude municipal supply use. As a result, quality objectives for groundwater include those for surface water as well as numeric objectives listed in California Administrative Code, Title 22, Chapter 15 (Tables 2, 3, 6, and 7). Since impact is existing and the water quality outside the plume boundary is questionable, the application of Resolution 68-16 is limited; therefore, development of water quality goals will begin with Resolution 88-63.

The most stringent water quality objectives for groundwater are those associated with municipal supply; however, natural levels of total dissolved solids (greater than 3,000 milligrams per liter [mg/L]) preclude use as a municipal supply (GTI, 1993). Use as a municipal supply is further invalidated when the location of the impacted groundwater body relative to Lake Merritt is considered. Significant groundwater extraction from the shallow source for municipal supply would possibly result in salt water intrusion, and further degradation of water quality. It is unlikely the residual constituents identified in groundwater will migrate vertically to any significant extent. The residual constituents' chemical characteristics, ineffectual groundwater velocity, and limited dispersion zone between the dissolved residual plume and nearest surface water are factors that significantly limit vertical migration at the site.

With regard to agricultural supply, there are several factors which make this potential use unlikely. For example, the residential use of land surrounding the site, coupled with land value and lack of clear space, create a situation where cost-effective agriculture would be difficult to achieve. Since the potential use of groundwater for agricultural supply is unlikely, the associated water quality objectives are not relevant to developing site-specific water quality goals.

The water quality objective associated with industrial supply is to maintain the existing or potential use; however, there are no specific numeric water quality objectives that achieve this objective. Each specific industrial process where groundwater is used has an associated set of water quality criteria that are specified based on the particular industrial process. At this time, shallow groundwater beneath the site is not used by industry; hence, water quality objectives for industrial supply are not relevant to developing site-specific water quality goals.

Fresh water replenishment to surface water is a beneficial use recently recognized by the Regional Water Quality Control Board (RWQCB). Numeric water quality objectives for fresh water replenishment are not yet documented; however, reasonable numeric water quality objectives coincide with Marine Effluent Discharge Limitations (MEDL's) for discharge to surface water.

Given the discussion above, the relevant beneficial use of groundwater with the most stringent numeric water quality objective is fresh water replenishment to surface water. The associated numeric water quality objectives that protect fresh water replenishment to surface water are MEDL's.

3.1.2 Beneficial Uses of Water: Surface Water

In relation to the site, the closest downgradient surface water is Lake Merritt, which is considered an estuary. The existing and potential beneficial uses are:

- o Water contact recreation
- o Non-contact water recreation

- o Wildlife habitat
- o Estuarine habitat
- o Fish spawning

To protect the beneficial uses listed, and maintain water quality, the RWQCB has identified effluent limitations to help achieve water quality objectives for surface water (Chapter 3, Basin Plan). Effluent limitations are used because the RWQCB typically regulates surface water discharges to meet water quality objectives for the receiving water. Since the intent of site-specific water quality goals is to maintain consistency with RWQCB water quality objectives, it is appropriate that site water quality goals for surface water incorporate MEDL's.

3.1.3 Water Quality Goals

Comprehensive water quality goals are meant to protect the relevant beneficial use of water identified above. The water quality goals are to be applied considering the entire site; compliance is to be achieved at the perimeter boundary. As previously described, the most relevant and stringent numeric water quality goals, for both surface and groundwater, are MEDL's. Effluent limitations for marine discharge are identified for two cases: shallow water discharge and deep water discharge. The two discharge cases are distinguished by the level of dilution associated with each discharge case. To be classified as deep water discharge, effluent must be discharged through a diffuser, and must receive a minimum initial dilution of 10:1, with generally much greater dilution. Since the surface water in question is considered an estuary, it is reasonable to assume shallow water discharge limits apply to groundwater discharge from the site.

Site-specific numeric water quality goals for the petroleum hydrocarbon constituents of concern are given below.

- o Benzene = 21 ppb; California Enclosed Bays and Estuaries Plan, human health protection, 30-day average.
- o Toluene = 300,000 ppb; California Enclosed Bays and Estuaries Plan, human health protection, 30-day average.
- o Ethylbenzene = 29,000 ppb; California Enclosed Bays and Estuaries Plan, human health protection, 30-day average.
- o Xylenes = no applicable numeric water quality goal identified.

The above water quality goals for dissolved residuals can only be achieved once SPH are removed; therefore, as an additional site water quality goal, no SPH will be allowed at the groundwater surface.

Soil concentrations must also be considered in developing numeric goals that protect beneficial water uses. Petroleum hydrocarbon concentrations in soil that do not pose a threat to site water quality goals will constitute numerical cleanup goals for soil. Acceptable soil concentrations, determined by using the method proposed in *The Designated Level Methodology for Waste Classification and Cleanup Level Determination* (Marshack, 1989), are proposed below.

- o Benzene = 0.021 milligrams per kilogram (mg/kg)
- o Toluene = 300 mg/kg
- o Ethylbenzene = 29 mg/kg

Note that acceptable soil concentrations equal water quality goals. This is because the environmental attenuation factor and leachability factor were assumed to be one. This assumption was made to establish conservative soil cleanup goals.

3.1.4 Perimeter Boundary Control

Compliance at the perimeter boundary is proposed in consideration of guidelines introduced in the Basin Plan under "Modification of Ground Water Cleanup Levels". These guidelines are paraphrased below.

1. Groundwater is located in fine-grained sediments; no significant vertical migration occurs.
2. Adequate source removal and/or isolation is undertaken.
3. Alternative or best available technologies are inappropriate or not cost effective.
4. An acceptable plan for containing and managing the risks posed by residual groundwater impact is developed.

The guidelines apply to the site because:

1. Impacted groundwater beneath the site is located primarily in Bay Mud (fine-grained material) and vertical migration is limited as previously described.

2. Adequate containment and isolation has been maintained through interim remedial actions previously described.

3. Given the site conditions, and data collected through interim remediation, it is apparent application of alternative or best available technologies may not be cost effective.

4. A contingency plan for containing and managing the risks posed by residual groundwater impact will be proposed. The discussion will focus on institutional controls, as well as a commitment to compliance.

In this subsection, site-specific water quality goals were identified to protect the most relevant beneficial groundwater use; groundwater recharge to surface water. Initially, these goals will apply to groundwater at the site perimeter.

3.2 Site-Specific Public Health and Safety Goals

According to guidance presented in Title 23, Chapter 16, Article 11 of the California Code of Regulations (CCR), any remediation approach considered must be designed to mitigate nuisance conditions and risk of fire or explosion posed by residual impact. To assure remedial objectives address the requirements of Article 11, site-specific public health and safety goals are necessary. The site-specific goal is to eliminate any threat to public health and safety associated with subsurface impact, including the potential threat posed by nuisance conditions and risk of fire or explosion.

4.0 REMEDIAL ACTION REQUIREMENTS

To identify remedial action requirements and develop remedial objectives, current site conditions are compared to those necessary to achieve the site-specific goals outlined previously. Where goals are achieved, remedial action is not required; conversely, where goals are not achieved, action may be required. In this section, remedial action requirements are specified.

As of June 11, 1993, groundwater quality within an area defined by the site perimeter did not meet site water quality goals. Dissolved benzene concentrations were detected in groundwater samples collected from Wells MW-1, MW-2, MW-3, and MW-4 at levels greater than the site water quality goal. In addition, traces of SPH have been observed as recently as March 25, 1993 in MW-2. The plume boundary, where site water quality goals are achieved, appears to almost coincide with the site perimeter boundary; accordingly, action may only be required to achieve site water quality goals within the site perimeter boundary.

A review of soil chemistry data generated as a result of soil sampling completed in June 1992, indicates that site water quality goals are not threatened. In addition, a significant volume of soil was excavated during interim remediation. As such, no soil-based action is required to achieve site water quality goals at this time.

With respect to the site public health and safety goal, there is an off-site condition which may require action. Transient conditions within a nearby basement water collection sump (see Section 2.0) may create a nuisance and possibly increase the risk of fire or explosion.

5.0 REMEDIATION

5.1 Remedial Objectives

Remedial objectives are identified to provide direction in developing remedial actions necessary to achieve the aforementioned goals. Remedial objectives also serve as a baseline for measuring achievement. Since no action is recommended in association with soil impact, only groundwater-based objectives are identified .

- o **Groundwater**: Within physical and economic constraints: (1) achieve site water quality goals at the ~~perimeter~~ plume boundary of the site, (2) eliminate hazardous conditions associated with the presence of petroleum hydrocarbon compounds in the subsurface environment, and (3) over the long term, achieve site-specific water quality goals within the perimeter plume boundary of the site.

5.2 Technology Identification and Screening

The general response actions necessary to achieve the remedial objectives are:

1. Dissolved petroleum hydrocarbon plume management.

2. Facilitate natural attenuation for the purpose of petroleum hydrocarbon mass reduction.

3. Eliminate the potential for conditions in the basement of the Chancery Office Dioces of Oakland Annex to threaten public health and safety.

5.2.1 Applied Technology

It is clear that along with natural attenuation mechanisms, installation of a physical barrier has significantly restricted impact migration. In addition, soil excavation and batch SPH/groundwater extraction has considerably reduced hydrocarbon mass beneath the site. Since the physical barrier is still in place, and the usefulness of the previously applied technologies is no longer apparent, these technologies will not be considered for further application.

5.2.2 Technology Screening

Resolution 92-49 was consulted for applicable technologies, as was available literature. Because the site is the location of an operating service station, only in-situ technologies were considered. Additionally, technologies were considered only if they could be easily integrated into the existing remediation strategy. Finally, technologies were eliminated from further consideration on the basis of technical implementability. Table 1 lists the technologies considered, along with comments regarding the screening of each technology. Technologies that passed the screening process and were found suitable for constructing alternatives were:

- o Groundwater Monitoring/Systematic Data Collection
- o Institutional Controls
- o Continuous Groundwater Extraction
- o Carbon/Resin Adsorption
- o Air/Liquid Contacting
- o Risk Management Planning

Groundwater monitoring, and institutional controls were chosen in association with Response Actions 1, 2, and 3. Groundwater monitoring will provide information necessary to manage the impact plume and demonstrate natural attenuation. Institutional controls will prevent exposure to impacted groundwater and limit the potential risks to public health and safety. Continuous groundwater extraction, carbon/resin adsorption, and air/liquid contacting were selected to address Response Action 2. Risk management planning was chosen to address Response Action 3.

5.3 Recommended Alternative

The intent of preparing a RFS is to provide the RWQCB with information identifying an applicable, cost effective, cleanup method. According to State Water Control Board Resolution 92-49, it is the responsibility of the discharger to propose a remediation strategy and obtain RWQCB concurrence. Specifically, Policy III.c. of Resolution 92-49 requires the discharger to consider effectiveness, feasibility, and relative costs of applicable alternative methods for cleanup. According to the California Code of Regulations, Title 23, Chapter 16, Article 11, at least two alternatives must be identified and evaluated for restoring or protecting beneficial water uses. In addition, each alternative must be designed to mitigate nuisance conditions and risk of fire or explosion. Alternatives considered are briefly described below.

5.3.1 Alternative 1: No Action/Discontinue Action

Facets of this alternative are: (1) abandon all groundwater monitoring wells, (2) discontinue quarterly groundwater monitoring, and (3) prepare a closure documentation report. Implementation would begin by completing all construction activities associated with terminating remedial action and discontinuing groundwater monitoring. Wells and subsurface piping would be pressure grouted, and a report documenting all closure activities would be prepared and submitted to the appropriate agencies.

5.3.2 Alternative 2: Natural Attenuation/Alternate Points of Compliance

This alternative consists of the following elements: (1) groundwater monitoring, (2) preparation and implementation of a contingency plan that includes institutional controls, and (3) preparation and implementation of a plan to manage the potential for risk associated with the basement environment of the adjacent site (risk management plan).

5.3.3 Alternative 3: Groundwater Extraction

This alternative consists of the following elements: (1) groundwater extraction using an electric submersible pump installed in the existing extraction well, (2) treatment of extracted groundwater using aqueous-phase carbon, (3) groundwater monitoring, and (4) preparation and implementation of a plan to manage the potential for risk associated with the basement environment of the adjacent site (risk management plan).

5.3.4 Alternative Evaluation

Technical, institutional, environmental protection, and economic criteria were used to evaluate the alternatives. Calculations, assumptions, and conditions used to develop comparison data for each alternative are presented as Appendix B; Tables 2 and 3 contain pertinent evaluation data and comments. Results of the evaluation process are briefly outlined below.

- o **Technical**: Considering short-term effectiveness, Alternative 3 was ranked most favorable, followed by Alternatives 2 and 1, respectively. The incremental benefit that ranked Alternative 3 above Alternative 2 was the increase in short-term effectiveness associated with the higher mass removal rate; thus, minimizing to the greatest extent the impact to water quality beneath the site. It should be noted the benefit described for the short-term may be superficial in the long-term. If, as data suggests, plume degradation is occurring naturally and migration is minimal, application of Alternative 3 will provide little benefit over that provided by Alternative 2.

Alternative 2 was ranked over Alternatives 1 and 3 considering reliability, primarily due to the increased probability of systems failure. Alternative 1 was ranked third in all technical categories because it does not provide reliable beneficial water use protection or public health and safety protection. Alternatives 2 and 3 are equally ranked overall considering all technical categories.

- **Institutional:** Alternatives 2 and 3 are consistent with Resolution 68-16, considering there are no time constraints. In addition, Alternatives 2 and 3 allow cleanup to site water quality goals and protection of public health and safety. Application of Alternatives 2 or 3 will similarly affect the community; however, extracted fluid treatment and treated fluid discharge will increase the public's perception of risk. Environmental permitting and permit compliance should be less complex for Alternative 1, followed by Alternatives 2 and 3, respectively. Considering benefit to the people of the state, Alternative 2 provides the maximum, followed by Alternatives 3 and 1, respectively. This is because using the combination of natural attenuation and alternate points of compliance (Alternative 2) provides a more efficient use of resources, while still providing a means to achieve the remedial objectives.

  Considering the maximum benefit to the people of the state, and the level of complexity concerning environmental permit compliance for Alternative 3, Alternative 2 was ranked most favorable.

- **Environmental Safety**: Alternative 3 increases the risk of exposure and injury, while Alternatives 1 and 2 may be associated with the potential for risk. The increase in risk for Alternative 3 stems from construction activities, and transporting relatively isolated hydrocarbon compounds to the surface. The potential for risk associated with Alternative 1 is linked to the need for groundwater access restrictions, which may fail to be maintained. The potential for risk associated with Alternative 2 is linked to the requirement that institutional controls and basement risk management must be maintained. The alternatives were ranked as follows: Alternative 2, followed by Alternatives 1 and 3, respectively. Alternative 2 was ranked over Alternative 1 due to the added risk associated with not addressing the basement environment.

Alternative 3 was ranked last because of the increased potential for injury and exposure.

- **Economic**: Based on economic analysis, alternatives were ranked from most economical to least economical. The most economical was Alternative 1, the least economical was Alternative 3.

Considering the data presented, PACIFIC recommends application of Alternative 2. This recommendation is based on the probability that implementation of Alternative 3 will provide little incremental benefit to the existing situation, increase exposure and injury risk, and require substantial resources. In addition, Alternative 2 minimizes the likelihood of imposing a burden on the people of the state with the expense of remediation, when compared to Alternatives 1 and 3.

6.0 IMPLEMENTATION PROCESS AND SCHEDULE

6.1 Implementation

Implementation of Alternative 2 would begin by preparing a contingency plan and risk management plan. The contingency plan would include an outline of institutional controls and a set of procedures to be implemented in the event significant problems inhibit remedial objective achievement. Preparation and implementation of the risk management plan would entail the following elements: (1) data collection, reduction, and interpretation, (2) preparation of the risk management plan, and (3) plan implementation. The risk management plan would be based on the data collection findings and would prescribe actions necessary to eliminate the potential for public health and safety risk.

Data resulting from groundwater monitoring would be used to identify the plume boundary where water quality objectives are achieved. A series of compliance points would be determined and included in an efficient groundwater monitoring plan. Beneficial water uses outside the compliance boundary would be protected and natural attenuation mechanisms would be relied upon to reduce hydrocarbon mass within the compliance boundary. Technical memoranda would be prepared and submitted at key transition events, or for approval of phased activities. For example, modifications to the groundwater monitoring program would be transmitted via technical memoranda for approval.

6.2 Implementation Schedule

A post approval implementation schedule was prepared assuming Alternative 2 is chosen for execution. Groundwater monitoring was not considered because it is an established task. Day 0 is assumed to be the regulatory approval date. The proposed schedule is shown on the following page.

Implementation Schedule

Task	Day
o Prepare and submit contingency plan with institutional controls.	45
o Prepare and submit risk management plan.	59
o Implement contingency plan and risk management plan.	75
An annual report will be submitted which contains: (1) a summary of the data collected over the past year, (2) a discussion of remedial progress made over the year, and (3) a recommendation for future activity, if needed.	

REFERENCES

Angell, Keith G., *In Situ Remedial Method: Air Sparging,* The National Environmental Journal, January/February 1992.

Ardito, Cyntha P., and Billings, Jeffery F., *Alternative Remedial Strategies: The Subsurface Volatilization and Ventilation System,* Proceedings of Petroleum Hydrocarbons and Organic Chemicals in Groundwater, Association of Groundwater Scientists and Engineers and the American Petroleum Institute 1990.

Brown, Richard A., and Jasulewicz, Frank, *Air Sparging: A New Model for Remediation*, Pollution Engineering, July 1, 1992.

Buscheck, Timothy E., and Peargin, Thomas R., *Summary of a Nation-Wide Vapor Extraction System Performance Study,* Proceedings of the Petroleum Hydrocarbons and Organic Chemicals in Groundwater: Prevention, Detection and Restoration 1991.

Chiang, C. Y., Salanitro, J.P., Chai, E.Y., Colthard, J.D., and Klein, C.L., *Aerobic Biodegradation of Benzene, Toluene, and Xylene in a Sandy Aquifer - Data Analysis and Computer Modeling.*

Environmental Protection Agency, *Underground Storage Tank Corrective Action Technologies*, 1987.

Environmental Protection Agency, *Guidance on Remedial Actions for Contaminated Groundwater at Superfund Sites*, 1988.

Groundwater Technology, Inc., *Groundwater Monitoring and Sampling Report,* July 19, 1993.

Johnson, Paul C., Kembloski, Marian W., and Colthard, James D., *Quantitative Analysis for the cleanup of Hydrocarbon-Contaminated Soils by In-Situ soil Venting*, In Groundwater, May-June 15990.

Kidd, Donald F., Miller, Randall R., *Project Life Estimation for Remediation of a Gasoline Contaminated Aquifer*, Pollution Equipment News, April 1990.

Kroopnick, Peter M., *Life-Cycle Costs for the Treatment of Hydrocarbon Vapor Extracted During Soil Venting*, Proceedings of the Petroleum Hydrocarbons and Organic Chemicals in Groundwater: Prevention, Detection and Restoration 1991.

Marley, Michael C., Hazebrouck, David J., and Walsh, Matthew T., *The Application of In Situ Air Sparging as an Innovative Soils and Groundwater Remediation Technology*, GWMR, Spring 1992.

Marshack, Jon B., *A Compilation of Water Quality Goals,* California Regional Water Quality Control Board, Central Valley Region, September 1991.

Nyer, Evan, *One Small Voice for Pump and Treat*, GWMR, Spring 1990.

Piotrowski, Michael R., *Bioremediation: Testing the Waters*, Civil Engineering, August 1990.

Sims, J.L., Suflita, J.M., and Russell, H.H., *In-Situ Bioremediation of Contaminated Ground Water*, EPA Groundwater Issue, February 1992.

Table 1
Technology Screening

Chevron Service Station 9-0121
3026 Lakeshore Avenue
Oakland, California

Technology	Retained	Comment
1. Containment/Isolation	No	Already implemented as an interim remedial action.
2. Biostimulation	No	Low permeability limits ability to distribute oxygen and nutrients.
3. Groundwater Extraction	Yes	Reduces mass, well understood. Moderately easy to implement.
4. Soil Vapor Extraction	No	Vadose zone impact minimal. Vadose zone thickness is limited.
5. Fixation	No	Limited application regarding target compounds.
6. Thermal Destruction	No	No application.
7. Sparging (in-situ)	No	See comment 6.
8. Carbon/Resin Adsorption	Yes	See comment 3.
9. Precipitation, Flocculation, and Sedimentation	No	See comment 5.
10. Filtration	No	See comment 5.
11. Chemical Treatment	No	See comment 5.
12. Air/Liquid Contacting	Yes	See comment 3.
13. Excavation	No	Previously implemented.
14. Risk Management Planning	Yes	Flexible and efficient as a means of addressing potential risks that may arise in basement.
15. Groundwater Monitoring	Yes	Appropriate for plume management and evaluation of natural attenuation.
16. Institution Controls	Yes	Can be used to maintain public health and safety.

Table 2
Technical Criteria

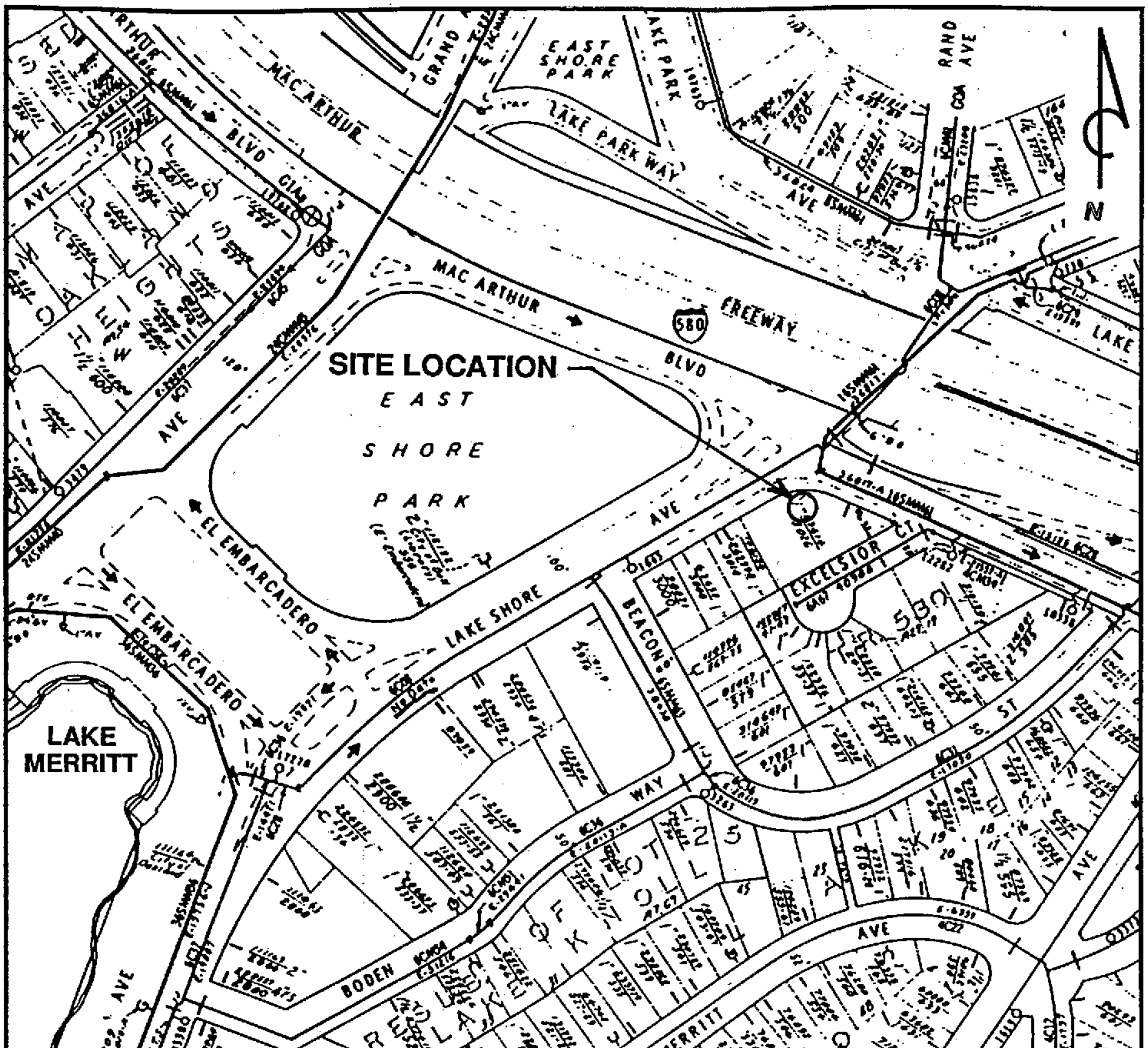
Chevron Service Station 9-0121
3026 Lakeshore Avenue
Oakland, California

Alternatives	Short-Term Effectiveness	Long-Term Effectiveness	Reliability	Implementation
1. No Action/ Discontinue Action	o Does not protect beneficial water use. o Does not enhance hydrocarbon mass attenuation. o Does not minimize impact on water quality.	o Possible groundwater use restrictions required to minimize exposure. o Does not decrease risk associated with long term residual.	o Reliable in terms of application, offers no reliability in terms of achieving remedial objectives.	o Easy to implement. o Not consistent with RWQCB policies. o Simple logistics. o Simple to permit.
2. Natural Attenuation/ Alternate Points of Compliance	o Protects beneficial water use. o Reduces hydrocarbon mass. o Water quality within the confines of the site may vary as groundwater elevation fluctuates.	o Possibility of groundwater use restrictions. o Provides a decrease in risk potential associated with long term residual. o Provides plume management.	o Reliability established by interim remedial actions. o Groundwater monitoring well established. o Moderate maintenance. o Flexibility to adjust to changing conditions.	o Compliance moderately complex. o Consistent with RWQCB policies. o Moderate ease of implementation. o Moderate logistics.
3. Groundwater Extraction	o Protects beneficial water use. o Reduces hydrocarbon mass. o Minimizes impact on water quality beneath the site.	o Slightly minimizes the possibility of groundwater use restrictions. o See Alternative 2.	o See Alternative 2. o Increased maintenance; more probability of systems failure. o Incrementally more reliable than Alternative 2 in terms of decreasing degree of impact per unit time. o High degree of technical resources required to implement and maintain.	o Permitting and compliance complex. o Consistent with RWQCB policies. o Moderate to difficult logistics. o Moderate to difficult implementation.

Table 3
Institutional, Environmental, and Economic Criteria

Chevron Service Station 9-0121
3026 Lakeshore Avenue
Oakland, California

Alternative	Institutional	Environmental Safety	Economic Present Value
1. No Action/Discontinue Action	o Does not conform to the provisions of Resolution 68-16. o Implementation of applicable provisions of Chapter 15, Division 3, Title 23 (CCR) not possible. o May not be consistent with the maximum benefit to the people of the state. o May unreasonably affect potential beneficial use of water.	o Potential for risk to increase if possible groundwater use restrictions and basement access restrictions are not maintained.	$29,000
2. Natural Attenuation/ Alterative Points of Compliance	o Complies with Basin Plan policy on modification of groundwater. cleanup levels. o Implementation of applicable provisions of Chapter 15, Division 3, Title 23 (CCR) is possible. o Consistent with the maximum benefit to the people of the state. o Does not unreasonably affect potential beneficial use of water.	o Slight risk of exposure. o See Alternative 1.	$61,470
3. Groundwater Extraction	o Does not unreasonably affect beneficial use of water.	o Increased risk of exposure and/or injury. o Enhances migration control.	$315,360

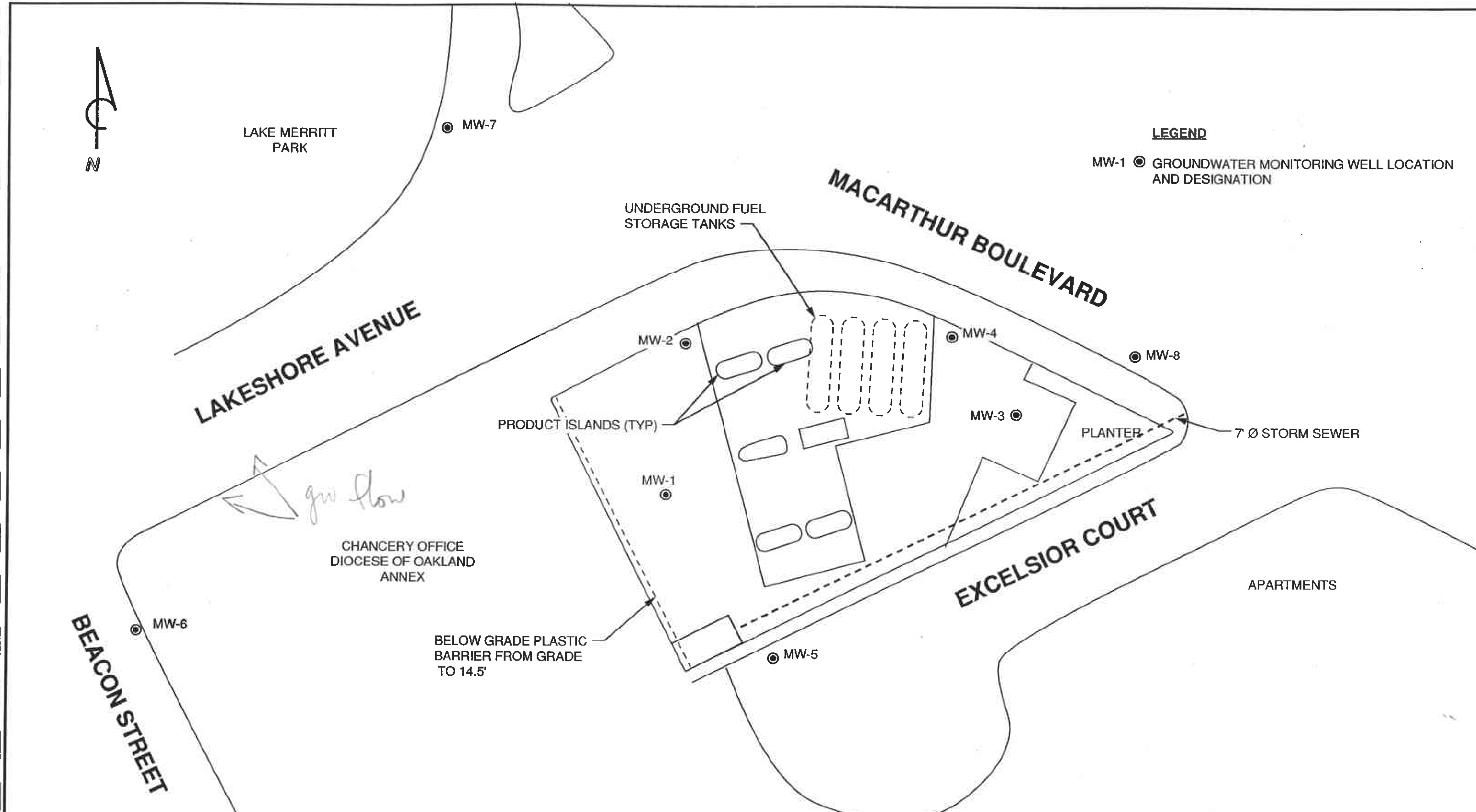


QUADRANGLE LOCATION

REFERENCES:
USGS 7.5 MIN. TOPOGRAPHIC MAP
TITLED: OAKLAND EAST, CALIFORNIA
DATED: 1959 REVISED: 1980
TITLED: OAKLAND WEST, CALIFORNIA
DATED: 1959 REVISED: 1980

SCALE IN FEET
200 0 200

PACIFIC ENVIRONMENTAL GROUP, INC.	**CHEVRON USA SERVICE STATION 9-0121** 3026 Lakeshore Avenue at MacArthur Boulevard Oakland, California	FIGURE: **1**
	SITE LOCATION MAP	PROJECT: 325-44.01



PACIFIC ENVIRONMENTAL GROUP, INC.

SCALE

0 30 60 FEET

CHEVRON USA SERVICE STATION 9-0121
3026 Lakeshore Avenue at MacArthur Boulevard
Oakland, California

SITE MAP

FIGURE: 2

PROJECT: 325-44.01

APPENDIX A

SOIL AND GROUNDWATER INVESTIGATION SUMMARY

APPENDIX A
SOIL AND GROUNDWATER INVESTIGATION SUMMARY

- In July 1967, according to service station inventory records, a 2,000 gallon inventory loss was recorded. The steel underground storage tanks (USTs) being used at the time the inventory loss was recorded were replaced by new steel tanks wrapped in asphalt. The tanks were located in the northern portion of the site. During the tank replacement a 32 inch long opening was observed in one of the fuel tanks.

- Results of a tank tightness test, performed at the site in 1980, indicated the possibility of a leak from one of the steel USTs. The steel tanks and lines were removed and replaced with new fiberglass tanks and lines. Interim remedial action was taken during removal of the tanks. Several dozen truckloads of hydrocarbon-impacted soil were removed during tank removal operations. The exact quantity of impacted soil removed is unverified. Additional remedial action was taken at this time when a 14 to 16 feet deep plastic barrier was installed on site. The barrier was installed vertically along the length of the sites' southwestern property line.

- Ten groundwater monitoring wells were installed at the site between the late 1970's and 1981. Six of the on-site monitoring wells were installed for the recovery of hydrocarbons by vacuum pumps and suction pumps (MW-A, MW-B, MW-C, MW-H, MW-I, and MW-J). A vacuum truck was reportedly used to remove product from the six wells, however, the amount and frequency of product removal was not verified (installation dates, well construction logs, and sampling information on these six wells is presently unavailable). The other four groundwater monitoring wells (MW-D, MW-E, MW-F, and MW-G) were installed by Groundwater Technology, Inc. (GTI) on July 16 and 21, 1981. These four, 8-inch diameter, on-site monitoring wells were installed to depths ranging between 14 to 21 feet below ground surface (bgs). Depth to water and separate-phase hydrocarbon (SPH) thickness measurements were taken from all ten wells in July 1981. SPH was detected in six of the on-site wells. SPH thickness ranged from 1/16 to 1/2 inches in the six wells. Depth to water measurements in the four GTI wells ranged from 4.8 to 5.2 feet bgs.

- In December 1981, a 24-inch diameter well was installed near the UST complex to be used as an extraction well for a pump and treat system. Groundwater extraction piping was installed in shallow trenches connecting the 24-inch diameter recovery well to a treatment compound. Chevron records indicate that the groundwater treatment system operated for a brief period during 1981. Records of the amount of product removed and a history of system operation were not available at the time this report was prepared.

- A pump test was performed on MW-H on August 4, 1981. Results of the test are included in a report prepared by GTI entitled "Considerations on Retrieval of Product from Groundwater". After approximately 50 minutes the well was pumped dry at a flow rate of approximately 1 gallon per minute (gpm).

- In 1984, the service station was torn down and completely rebuilt. Approximately 740 cubic yards of soil was removed in association with station reconstruction. The tanks were not replaced at this time. Two storage tanks were reportedly found beneath the sidewalk. The tanks were reported as being approximately 500 to 1,000 gallons in size. The tanks were abandoned in place with grout. The exact location of these tanks is presently unknown and no other records currently exist in relation to these tanks.

- In October 1984, Chevron received a letter from the property owner at 3014 Lakeshore Avenue stating that the tenants in that building were smelling gasoline vapors in their basement. Chevron responded by meeting the property owner at the site and visually inspecting the basement. No hydrocarbon odors or sheen were noted at that time. A letter was sent to the property owner stating that for the previous 2 years, Chevron had been monitoring odors in the basement and did not find evidence of any hydrocarbons during that time period. Notes in Chevron files indicate that monitoring was conducted daily from July 20 to August 28 and again from October 29 to April 2 (the year of this sampling was not recorded). The results of these monitoring periods did not indicate the presence of hydrocarbons in the basement of the site building.

- o In December 1990, Chevron files indicate that the regular unleaded tank at the site was taking on water due to a tank gage stick hole. The hole was repaired and the tank went back into service. our records correlate

- o GTI performed well sampling on eight of the sites' ten wells on April 10, 1991. Samples collected from the eight wells (MW-A, MW-B, MW-C, MW-D, MW-G, MW-H, MW-I and MW-J) contained detectable concentrations of total petroleum hydrocarbons calculated as gasoline (TPH-g) and benzene. Maximum concentrations of TPH-g (40,000 micrograms per liter [ug/L]) and benzene (7,600 ug/L) were detected in MW-D at approximately 5 feet bgs. Details of the soil and groundwater investigation are documented in a GTI report dated April 25, 1991. All wells at the site were abandoned in July 1991 with the exception of the 24-inch diameter recovery well. why? they still had HCs

- o GTI installed four on-site groundwater monitoring wells designated as MW-1 through MW-4 in August 1991. Soil samples collected during the installation of these wells contained TPH-g and benzene at maximum level of 660 and 1.5 parts per million (ppm), respectively. The maximum TPH-g and benzene concentrations were detected in the soil boring for [redacted] at approximately 2 feet bgs. Details of the soil and groundwater investigation are documented in a GTI report dated October 24, 1991.

- o GTI installed four off-site groundwater monitoring wells designated as MW-5, MW-6, MW-7, and MW-8 in June 1992. Soil samples collected during the installation of these wells contained non-detectable amounts of TPH-g and benzene. Details of the soil and groundwater investigation are documented in a GTI report, dated October 24, 1991.

- o Groundwater monitoring of the eight wells currently existing on and off site was initiated in August 1991. Sampling events have been performed periodically (monthly and quarterly) until June 1993. Periodically, [redacted] has been identified in Wells MW-1 and MW-2. Hydrocarbons have never been detected in groundwater samples taken from Wells MW-5 and MW-8. Benzene was detected in groundwater samples taken from Wells MW-6 and MW-7 on June 23, 1992, December 23, 1992 and June 11, 1993 (maximum concentrations of benzene - 4.7 ppb). A measurable thickness of SPH has never been observed in Wells MW-3 through MW-8. Depth to groundwater during monitoring events has ranged from 4.35 to 12.24 feet bgs and groundwater flow direction has varied from a western flow direction to a north-west direction.

- The most recent quarterly groundwater monitoring event was performed by GTI on June 11, 1993. Static groundwater was found at a depth of approximately 5 feet bgs and groundwater flow direction was to the west. Wells MW-1 through MW-8 contained TPH-g at concentrations ranging from 200 to 7,000 parts per billion (ppb). Benzene was detected in Wells MW-1 through MW-4 and MW-7 with concentrations ranging from 0.6 to 1,900 ppb. The highest concentrations of TPH-g and benzene occurred in groundwater samples collected from Well MW-1.

APPENDIX B

ALTERNATIVE ANALYSIS: CALCULATIONS, CONDITIONS, AND ASSUMPTIONS

APPENDIX B
ALTERNATIVE ANALYSIS:
ASSUMPTIONS, CONDITIONS, AND CALCULATIONS

Alternative 1: No Action/Discontinue Action

Assumptions/Conditions

1. Regulatory conditions allow pressure grouting as an acceptable method of abandonment for existing monitoring and recovery wells.
2. Current well abandonment permit fees and encroachment permit requirements apply.
3. Seven monitoring wells, one extraction well, and below-grade ground-water conveyance piping are pressure grouted in place.
4. One hundred linear feet of 4-inch diameter, Schedule 40 PVC subsurface piping to be abandoned in place.

3. Current closure report requirements apply.

4. No project life span. Single event.

Capital

o Well and piping abandonment	$19,000
o Closure Report Preparation	$10,000
ALTERNATIVE 1 TOTAL	$29,000

Alternative 2: Natural Attenuation/Alternate Points of Compliance

Assumptions/Conditions

1. Plume area is relatively stable. This assumption is valid considering the plume area configuration has not significantly changed since 1980.

2. Plume thickness is relatively stable. This assumption is based on considering vertical diffusion and groundwater elevation fluctuations as the factors influencing vertical dispersion. Vertical dispersion via groundwater velocity is considered negligible given the minimal velocity of groundwater at the site. Molecular diffusion is very slow, and as such, is considered a negligible factor. Groundwater elevation fluctuations are a strong vertical dispersion factor; however, statistical analysis of elevation data from MW-1 suggests vertical transport via elevation changes outside a narrow band (approximately 4.2 feet thick) are negligible.

3. Plume area, as delineated by Wells MW-1 through MW-4, is approximately 15,000 ft^2.

4. Plume thickness is the maximum thickness as measured by concentrations found in Borings MW-3A and MW-3B. This thickness is 8.0 feet.

5. Plume benzene concentration can be characterized as the mean of benzene concentrations identified in samples taken from Wells MW-1 through MW-4 (wells used to define the plume area). Benzene concentrations listed in Table B-1 are mean concentrations calculated from groundwater sampling results from Wells MW-1 through MW-4.

6. The effective porosity is 0.1 pore volume/total volume.

7. In analyzing field data trends, it was found concentrations are best characterized by an exponential decay function for early time series data. The function used to characterize plume decay is based on groundwater monitoring data recorded from August 1991 to June 1993 (Table B-1). It was recognized that the 2 year sampling data set (August 1991 to June 1993) provides a small time window relative to the time required for complete natural attenuation. The position of the small time window in relation to the entire natural attenuation decay trend is instrumental in projecting the natural attenuation life

span. For example, a time window associated with the period immediately following post-release subsurface stabilization will be associated with a steep decay slope. A projection of the natural attenuation life span using this decay slope will result in a gross underestimation of the true life span. The steepness of the decay slope will decrease as later time sequence data is included in the evaluation. Consequently, better approximations of natural attenuation life span can be made. The decay function associating benzene concentrations with time is given below:

$$Ct = 2337.82 * \exp(-0.00107t) \qquad \text{equation 1}$$

where:

Ct = Concentration of benzene at time t in parts per billion (ppb)

t = time in years

Calculations

- Estimated plume volume.

  Total Volume = (8.0 ft)(15,000 ft^2) = 120,000 ft^3
  Pore Volume = (120,000 ft^3)(0.1 pore vol, ft^3/total vol, ft^3) = 12,000 ft^3

- Time series average data (Table B-1) utilized for development of plume decay function.

- Estimated life span.

  Life span calculated using site-specific water goal as C(t) (equation 1) and solving for t.

  Benzene = 10.27 years
  (with estimation error factor of 30 percent)
  = 13.35 years

Cost Estimate

- Project life span is 13 years.

- Interest for present worth calculation is 8 percent, inflation was not considered.

- o Groundwater monitoring frequency will be semiannual throughout life span.

Capital

o Contingency Plan/Institutional Controls	$8,000
o Risk Management Plan	$10,000
CAPITAL SUBTOTAL	$18,000

Annual Costs

o Status Reports/Regulatory Liaison (13 year life)	$1,500/year
o Groundwater Monitoring (13 year life)	$4,000/year

Present Worth

o Groundwater Monitoring ($4,000)(7.9038)	$31,615
o Status Reports/Regulatory Liaison ($1,500)(7.9083)	$11,855
PRESENT WORTH SUBTOTAL	$43,470
ALTERNATIVE 2 TOTAL	$61,470

Alternative 3: Groundwater Extraction

Assumptions/Conditions

1. Pumping life span was estimated using a continuously stirred tank model considering benzene only. Life span of pump and treat system determined from site-specific water quality goals (when mean plume concentration equals 21 ppb benzene).
2. Assumptions/conditions 1 through 6 for Alternative 2 are valid here.
3. Estimated plume volume is 120,000 ft^3, as estimated for Alternative 2.

4. Pump and treat system incorporates three existing extraction wells and two 1,000 pound carbon units. Groundwater extraction rate is .125 gallon per minute (gpm).

5. Groundwater monitoring frequency is semiannual.

6. The estimated Life span was reduced by 40 percent (from 13 to 8 years) to account for simultaneous natural attenuation.

7. Three carbon change-outs occur over the project life span. These change-outs will be performed at project life span intervals of 2, 5, and 8 years.

8. Initial benzene concentration is 865.5 ppb (mean benzene concentration from June 11, 1993 groundwater monitoring data).

9. Pumping concentration decay estimated using continuously stirred tank model.

10. NPDES discharge is available for minimal cost per year.

Calculations

- o The estimated life span was calculated as 13 years using the following governing equation.

  Governing equation:

  $$Ct = Co\,(\exp(-t^*Q/vol)) \qquad \text{equation 1}$$

  where:

  Ct = concentration at time t (ppb)
  Co = initial concentration at t=0 (ppb)
  t = time in days
  Q = effective pumping rate (q/r) (gpd)
  r = retardation factor
  vol = wetted volume of affected aquifer (total volume * porosity) (gal)

Capital

o System Design and Remediation Permitting	$15,000
o System Construction, Installation and Permitting	$37,000
o Capital Equipment	$25,000
o Groundwater Monitoring	$4,000
o Operation and Maintenance	$22,000
o Prepare Risk Management Plan	$10,000
o Project Status, Reporting During Implementation	$6,000
CAPITAL SUBTOTAL	$119,000

Annual Costs

o Groundwater Monitoring (8 year life)	$4,000/year
o Operation and Maintenance (8 year life)	$22,000/year
o Utility Costs (8 year life)	$6,000/year

Present Worth

o Groundwater Monitoring ($4,000)(5.7466)	$22,986
o Operation and Maintenance ($22,000)(5.7466)	$126,425
o Utility Costs ($6,000)(5.7466)	$34,480
o Carbon Replacement (at 2, 5 and 8 years) ($6,000/replacement)(0.8573 + 0.6806 + 0.5403)	$12,470
PRESENT WORTH SUBTOTAL	$196,360
ALTERNATIVE 3 TOTAL	$315,360