EXXON COMPANY, U.S.A.

POST OFFICE BOX 4032 • CONCORD, CA 94524-2032

ENVIRONMENTAL ENGINEERING

W. Y. Wang
SENIOR ENVIRONMENTAL ENGINEER

91 OCT 16 AM 11:30

14 October, 1991

Former Exxon RAS 7-3006
720 High Street
Oakland, California

Mr. Larry Seto
Alameda County Health Agency
Division of Hazardous Materials
80 Swan Way, Suite 200
Oakland, California 94621

Dear Mr. Seto:

Attached for your review and comment is a work plan entitled **Interim Groundwater Remediation Work Plan** for the above referenced former Exxon station. The work plan, prepared by RESNA/Applied GeoSystems of Fremont, California, details the selection of utilizing an oil/water separator followed by activated carbon adsorption as the preferred method to remediate free and dissolved phase petroleum hydrocarbons in the ground water at the referenced site.

As Exxon would like to start this project in the near future, please provide me with comments regarding the work plan at your earliest convenience. Should you have any questions or require additional information, please do not contact me at (510) 246-8768.

Sincerely,

William Y. Wang

William Y. Wang

WYW:hs
0651E
Attachments

c - w/attachment:
Mr. L. Feldman - San Francisco Bay Region Water Quality Control Board
Mr. V. A. Sevier

w/o attachment:
Mr. D. J. Bertoch
Mr. P. J. Brininstool
Mr. J. R. Hastings
Mr. M. Detterman - RESNA/Applied GeoSystems, Fremont

A DIVISION OF EXXON CORPORATION

Applied GeoSystems, Inc.
A RESNA Company

RESNA
Environmental Solutions
Through Applied Science,
Engineering & Construction

42501 Albrae Street, Suite 100
Fremont, CA 94538
Phone: (415) 651-1906
Fax: (415) 651-8647

INTERIM GROUNDWATER REMEDIATION WORK PLAN
for
Exxon Station No. 7-3006
720 High Street
Oakland, California

Oct 10, 1991

AGS Job No. 87042-9RAP

Report prepared for

Exxon Company U.S.A.
P.O. Box 4032
2300 Clayton Road
Concord, California 94520

by
Applied GeoSystems

Rasmi El-Jurf
Project Engineer

John H. Turney, P.E.
Engineering Manager

October 10, 1991

CONTENTS

1.0 INTRODUCTION 1

1.1 Site Location and Description 2

1.2 Background 3

1.2.1 Excavation of USTs 3

1.2.2 Initial Soil Excavation - 1987 3

1.2.3 Soil Vapor Survey - 1987 4

1.2.4 Initial Site Investigation - 1987 to 1988 4

1.2.5 Additional Soil Excavation - 1989 4

1.2.6 Records Search - 1989 5

1.2.7 Additional Site Investigation - 1989 6

1.2.8 Additional Site Investigation - 1990 6

1.2.9 Ground-Water Monitoring, Sampling, and Product Recovery Program 7

1.2.10 Summary of Results of Previous Investigations 7

2.0 SUBSURFACE CHARACTERISTICS 9

2.1 Site Geology and Hydrogeology 9

2.2 Possible Sources of Hydrocarbons 10

2.3 Extent of Hydrocarbons in Soil 10

2.4 Extent of Hydrocarbons in Ground Water 11

3.0 EVALUATION OF REMEDIAL ALTERNATIVES 13

3.1 Selection Criteria and Cleanup Levels 13

3.1.1 Hydrocarbons in Soil 13

3.1.2 Hydrocarbons in Ground Water 14

3.2 Ground Water Remedial Alternatives 14

3.2.1 No Action Alternative 14

3.2.2 Recovery/Containment Alternatives 15

3.2.3 Treatment Alternatives 16

3.2.4 Screening Acceptable Alternative 19

3.2.4.1 Recovery/Containment 19

3.2.4.2 Treatment 20

4.0 PROPOSED TREATMENT ALTERNATIVES 21

4.1 Evaluation of Treatment Alternatives for Ground Water 21

4.1.1 Technical Evaluation 21

4.1.2 Economical Evaluation 22

4.2 Recommended Remedial Action 22

4.2.1 Remedial System Settings 22

4.2.1 Permit and Monitoring Requirements 23

Applied GeoSystems, Inc.
A RESNA Company

RESNA
Environmental Solutions
Through Applied Science,
Engineering & Construction

42501 Albrae Street, Suite 100
Fremont, CA 94538
Phone: (415) 651-1906
Fax: (415) 651-8647

INTERIM GROUNDWATER REMEDIATION WORK PLAN
for
Exxon Station No. 7-3006
720 High Street
Oakland, California

for Exxon Company, U.S.A.

1.0 INTRODUCTION

At the request of Exxon Company, U.S.A. (Exxon), RESNA, formerly Applied GeoSystems (AGS) has prepared this Interim Remediation Work Plan (RWP) to describe a proposed groundwater remedial action for the Exxon Service Station at 720 High Street in Oakland, California. The objective of the remedial action is to achieve control over the further migration of both free and dissolved hydrocarbons in the groundwater beneath the site and to recover hydrocarbons without significantly increasing the potential impact of offsite contaminants to the site.

A number of techniques are available to remediate groundwater impacted with hydrocarbons. Because groundwater remediation is site specific, available technology will be reviewed and evaluated relative to site parameters and application. This RWP describes the site, briefly summarizes previous work conducted at the site, describes the planned remedial action and scope of work, and presents the proposed schedule for this work. The planned work consists primarily of the engineering design, permitting, and construction of groundwater extraction, collection, treatment, and discharge facilities.

1.1 Site Location and Description

The site is located at 720 High Street in Oakland, California, as shown on the Site Vicinity Map, Plate 1. The station is east of State Highway 880, at the intersection of High Street and Coliseum Way, on the western edge of an alluvial fan, less than 1/2 mile northeast of a tidal canal, and 3/4 mile north of San Leandro Bay (Plate 1). The station is in a predominantly industrial area, and is bounded to the northeast by a former dry-cleaning plant and Ed's Auto Parts, to the northwest by High Street, to the southwest by Coliseum Way and Freeway 880, and to the southeast by Alameda Avenue and a vacant lot. The site is currently used as an automobile maintenance garage and contains no underground storage tanks (USTs) or dispensers. Pertinent site features are shown on Plate 2.

The earth materials at the site are Quaternary bay deposits composed of silty clay and clay, with discontinuous fluvial lenses of silty and gravelly sand. The description of earth materials encountered under the site is presented in cross-sections A-A' through D-D' on Plates 3 and 4; the reference locations of the sections are shown in Plate 2. The sections suggest that there are two permeable units beneath the site, one at 7 to 12 feet below ground surface and the other at 20 to 30 feet below ground surface. These two units appear to merge in the central part of the site. The general groundwater flow direction is to the southwest toward the tidal canal. Observations of the groundwater depth during various phases of subsurface investigations indicate that the groundwater is confined and its level does not appear to be related to tidal fluctuation. According to the California Regional Water Quality Control Board, San Francisco Bay Region, this site is located in a low-sensitivity water-use area. The groundwater in the general area of the site is not being used as a municipal water supply, although it may be in the future.

1.2 Background

The following sections describe previous phases of environmental work conducted at the site.

1.2.1 Excavation of USTs

In April 1987, four USTs (6,000-, 10,000-, 8,000-, and 1000-gallons) that stored extra-unleaded, regular unleaded, regular leaded gasoline, and waste-oil, respectively, were removed by Exxon's contractor. The gasoline USTs were located in the southeast corner of the site and the waste-oil tank was located behind the station building (Plate 2). Soil samples collected after tank removal indicated the presence of total volatile hydrocarbons in concentrations greater than 1,000 parts per million (ppm) in the gasoline UST pit (AGS Report No. 87042-1, May 13, 1987). A sample collected from soil excavated from the waste-oil UST pit contained no detectable total extractable hydrocarbons (TEH).

Removal of the product piping le~~a~~d to the exposure of a black soil layer in the trenches that appeared to contain relatively high hydrocarbon concentrations. The layer was sampled and laboratory results indicated the presence of 434 ppm of TEH.

1.2.2 Initial Soil Excavation - 1987

In May, 1987, AGS observed the over-excavation of the gasoline UST pit and product line trenches. A black soil lens that appeared to contain hydrocarbons was noticed at approximately 14 feet below the ground surface in the southwestern wall of the pit, and free-phase product was later observed seeping into the pit from this lens. The excavation indicated that this lens became larger southwest of the tank pit (AGS Report No. 87042-2, July 10, 1987).

1.2.3 Soil Vapor Survey - 1987

In June 1987, Exxon contracted with EA Engineering, Science, and Technology, Inc., of Lafayette, California, to perform a soil-vapor survey. The results of the survey indicated that the highest hydrocarbon-vapor concentrations were between the former gasoline UST pit and the southern pump islands, and extended southwest towards Coliseum Way.

1.2.4 Initial Site Investigation - 1987 to 1988

In September 1987 and May 1988, nine groundwater monitoring wells, MW-1 through MW-9 were installed (Plate 2). The wells were installed to evaluate the impact of hydrocarbons on groundwater. Soil samples from the borings for wells MW-1 through MW-9 contained up to 2,689 ppm of total petroleum hydrocarbons as gasoline (TPHg) and up to 4,261 ppm of total petroleum hydrocarbons as diesel (TPHd). Soon after the wells were installed, free-phase product was measured in wells MW-2, MW-4, and MW-5, see Table 1, in the area of the former gasoline USTs and in well MW-8 in the former area of the former product piping (AGS Report No. 87042-5, August 5, 1988).

1.2.5 Additional Soil Excavation - 1989

In May 1989, Exxon contracted with AGS to excavate additional soil from the southern part of the existing gasoline UST pit (AGS Report No. 87042-6, October 16, 1989). On July 1989, well MW-5 was properly destroyed to start excavating the southern boundary of the gasoline pit to a maximum depth of about 10 feet (just above the ground-water level). Soil with debris (bricks, lumber, etc.) was found in the southern part of the pit, and soil in this area contained the most evidence of hydrocarbons. In addition, two metal pipes were exposed in the southern wall of the excavation that appeared to be former product lines. The pipes appeared to run west toward Coliseum Way. Soil was excavated from the southern and southwestern sides of the pit as far towards Coliseum Way as possible (Plate 2).

On the northwestern side of the pit, two exploratory trenches were excavated to evaluate the extent of hydrocarbons while minimizing the volume of excavated soil (Plate 2). Moderate organic vapor meter (OVM) readings (200 to 500 ppm) were taken from the soil along both trenches. Four samples from the trenches and southern walls of the excavation were collected from just above the groundwater (9 feet below grade). The laboratory results showed 3.8 to 290 ppm TPHg. One sample from 9 feet below grade in the southern part of the pit was analyzed for TPHd and contained 4,200 ppm.

An estimated 300 cubic yards of soil were excavated and stockpiled on the site. Analytical results of six composite samples showed 63 to 330 ppm TPHg and 250 to 3,800 ppm TPHd. Exxon subsequently arranged to have the soil hauled to an appropriate disposal facility.

1.2.6 Records Search - 1989

Because soil from the southern boundary of the gasoline UST pit contained TPHd, and it was our understanding that Exxon stored no diesel fuel on the site, AGS recommended that the history of the site be investigated (AGS Report 87042-6, dated October 16, 1989). The records review revealed that the Exxon site was used as an oil-storage and distribution facility by Standard Oil Company of California (currently Chevron U.S.A) between approximately 1912 and 1934. Up to five aboveground oil-storage tanks were onsite during that period. Between 1953 and 1969, the northeastern part of the site was part of an automobile wrecking yard. The existing Exxon Station was built in 1970.

Several nearby sites were identified as potential sources of hydrocarbons. These sites include a former dry-cleaning plant and automobile wrecking yard (Ed's Auto Parts) to the northeast of the Exxon site; a former sheet-metal foundry owned by Southern Pacific Transit

Company further to the northeast of the Exxon site; two gasoline pipelines owned by Southern Pacific Pipeline to the southeast of the Exxon site; and a former oil-distribution business (Norwalk Oil Sales Company) to the east of the Exxon site (AGS Report 87042-6R, January 30, 1990).

At Exxon's request, samples of the free-phase product in two of the monitoring wells at the site were collected and analyzed by a fuel-fingerprint analysis. The results indicated that the free product from well MW-3 is diesel fuel, and free-phase product from MW-8 is predominantly diesel fuel with some gasoline (AGS Report 87042-6R, January 30, 1990).

1.2.7 Additional Site Investigation - 1989

To delineate the extent of diesel and gasoline in the soil and groundwater, AGS drilled 11 borings and installed four additional groundwater monitoring wells (MW-10 through MW-13) in November 1989. In soil analyzed from the borings, the highest concentrations of TPHd (up to 4,000 ppm) were found in the southwestern part of the site, and the highest concentrations of TPHg (3,400 ppm) were found adjacent to the excavation at Ed's Auto Parts, which is adjacent to the northeastern property line of the Exxon site (AGS Report 87042-6R, January 30, 1990).

1.2.8 Additional Site Investigation - 1990

Based on the results of previous investigations, AGS drilled 12 shallow soil borings and two deeper borings in which monitoring wells were installed. The soil borings (B-21 through B-30) were drilled to delineate the extent of diesel and gasoline hydrocarbons in the subsurface soil. Concentrations of TPHg in the collected soil samples ranged from nondetectable to 3,232 ppm; TPHd concentrations ranged from nondetectable to 2,115 ppm. Monitoring well MW-14 was installed adjacent to the excavation at Ed's Auto Parts to evaluate offsite sources of hydrocarbons. Well MW-15 was installed east of the location of the former USTs to delineate hydrocarbons in the groundwater. Low concentrations of TPHg, TPHd, and BTEX were detected in MW-14 and MW-15 (AGS Report No. 87042-9R, May 21, 1991).

1.2.9 Groundwater Monitoring, Sampling, and Product Recovery Program

AGS is currently performing monthly monitoring and quarterly sampling of wells at the site. Cumulative results of subjective evaluation of groundwater and results of groundwater analyses is included summarized in Tables 1 and 2, respectively. The general direction of groundwater flow is toward the southwest with an average gradient of 0.02. The most recent results indicate that the groundwater beneath the site continues to show elevated concentrations of TPHg and TPHd. In addition, thin layers of free-phase product were observed in wells MW-2, MW-3, MW-4, MW-12, and MW-8 (AGS Report No. 87042-9R, May 21, 1991). Free-phase product is being bailed from the wells on a monthly basis.

1.2.10 Summary of Results of Previous Investigations

Results of previous environmental investigations indicate that the subsurface at the site is impacted with petroleum hydrocarbons; namely, TPHg, TPHd, and BTEX. Both volatile and nonvolatile hydrocarbons are in the groundwater. Hydrocarbons in soil at the site had been delineated; however, hydrocarbons in groundwater are yet to be delineated offsite to the east and west of the site. Concentrations of TPHg in subsurface soil greater than 100 ppm were found at 3- to 5-foot depth interval along the western property boundary (Plate 5). At the 7-1/2- to 10-foot depth interval, those concentrations were encountered along the western property boundary, in the southwestern corner of the station, near the former location of the waste-oil tank, and at the northern property line adjacent to the excavation at Ed's Auto Parts (Plate 6). Concentrations of TPHd greater than 100 ppm at 3 to 5 feet in depth were found in the southwestern part of the site, south of the former main dispenser island (Plate 7). At 7-1/2 to 10 feet below grade, TPHd concentrations

not true

greater than 100 ppm were found in the southwestern corner of the site, adjacent to the former waste-oil UST, and at the northern property line adjacent to the excavation at Ed's Auto Parts (Plate 8).

Groundwater is encountered at the site at an average depth of 10 feet below grade. The direction of the groundwater flow is towards the southwest with a shallow gradient of 0.02. The western portion of the site is suspected to contain groundwater in unconfined condition; whereas in other parts of the site, the ground-water is believed to be confined. The highest concentrations of dissolved TPHg and TPHd were detected in groundwater from the western part of the site. Free-phase product, maximum of 3-inch since January 1991, is concentrated in the southwestern part of the site (Plates 9 and 10). No hydrocarbons were detected in the groundwater at the northern and eastern site perimeters.

Based on the results of previous and ongoing investigations, AGS recommended no additional delineation of hydrocarbons in the soil and work proceed to contain and remediate free product and dissolved hydrocarbons in the groundwater. A pump test was performed on April 1991 to help in the design of the groundwater remediation system. The pump test indicated an approximate pumping rate of 0.2 gallon per minute (gpm) to last approximately 4 hours before the well was pumped dry.

2.0 SUBSURFACE CHARACTERISTICS

The site geology and hydrogeology are discussed in Section 2.1, possible sources of hydrocarbons are discussed in Section 2.2, and the extent and magnitude of hydrocarbons in soil and groundwater are discussed in Sections 2.3 and 2.4, respectively.

2.1 Site Geology and Hydrogeology

Materials encountered during various phases of subsurface investigations were interbeded layers of silty clay, silt, clayey gravel to gravel, and clayey sand to sand. An upper 6 to 12 feet of silty clay were encountered, which is underlain by saturated clayey gravel or clayey sand that appears to vary in thickness and extent. The permeable layer is underlain by a silty clay aquitard.

The data from borings drilled to date at the site were used to construct generalized cross sections A-A' through D-D' (Plates 3 and 4). The sections suggest that there are two permeable units beneath the site, one at 7 to 12 feet below the surface and one at 20 to 30 feet below the surface. In the central part of the site, the two units appear to merge, as shown in Section D-D'. In other areas, one or both permeable units appear to pinch out, as shown in Sections A-A' and B-B'. In the northern area of the site, the shallow aquifer is separated from the deeper aquifer by a silty clay layer that varies in thickness. The southeastern portion of the site contains only the shallow aquifer which is underlain by a silty clay aquitard to a depth of approximately 35 feet.

Groundwater was initially encountered at 8 to 12 feet below grade in most of the borings. However, in the northern corner of the site (MW-8, MW-10, and MW-11), groundwater was encountered 20 to 24 feet below grade in the lower permeable unit. Water levels in the wells later stabilized at approximately 10 feet below grade, which support the assumption that the shallow aquifer is underlain by the deeper one in that portion of the site. Groundwater in both permeable units appear to be confined by a silty clay layer.

A pump test performed on well MW-8 at an approximate pumping rate of 0.2 gallon per minute (gpm) lasted approximately 4 hours before the well was pumped dry. Pumping from MW-8 influenced the water level in well MW-11, approximately 40 feet away from MW-8. However, no influence was noticed in wells MW-12 and MW-13, 30 and 25 feet from MW-8, respectively. This influence was anticipated since MW-8 and MW-11 were screened in the lower aquifer, while, MW-12 and MW-13 were screened in the shallow aquifer. The pump test did not last long enough to evaluate whether the shallow aquifer is connected or seeps to the lower aquifer.

2.2 Possible Sources of Hydrocarbons

Previous investigations indicate the vadose zone and the groundwater beneath the site are impacted by hydrocarbons. Three separate sources of hydrocarbons were identified: one or more source along the southwestern property boundary near the original tank excavation and along product pipes, the former waste-oil UST, and the former tanks at Ed's Auto Parts.

2.3 Extent of Hydrocarbons in Soil

In near-surface soil (less than 5 feet in depth), concentrations of TPHg greater than 100 ppm are found along the western property boundary and beneath the area of the former main service island (Plate 5). Concentrations of TPHd greater than 100 ppm in near-surface soil are limited to the area just southwest of the main service island, near the western property line (Plate 7).

Soil just above the groundwater table (less than 10 feet deep) with TPHg and TPHd concentrations greater than 100 ppm is predominantly in the southern and western parts of the site, except for an area adjacent to the former waste-oil UST and an area adjacent to the excavation at Ed's Auto Parts (Plates 6 and 8).

2.4 Extent of Hydrocarbons in Groundwater

Hydrocarbons have impacted the groundwater beneath the site. Both free-phase and dissolved hydrocarbons have been detected. Volatile organic compounds have been detected periodically in minor amounts.

Free-phase hydrocarbons, as shown in Plates 9 and 10, are periodically detected as sheen or a slight measurable amount in wells MW-2 through MW-4, MW-6, MW-8, and MW-12 (in the southern and western edge of the site). The free-phase hydrocarbons in well MW-3 were identified as diesel, where MW-8 floating product was identified to be predominantly diesel fuel with some gasoline. Product is only detected as a thin layer (maximum of 3 inches thick) floating on the groundwater table.

Dissolved hydrocarbons appear to be concentrated in the groundwater beneath the site in the vicinity of the southern and western portion of the site (Plates 9 and 10). Results of analyses of groundwater samples, see Table 2, indicate the northern and northeastern extent of dissolved hydrocarbons is delineated by wells MW-9 through MW-11 and MW-14. Southern and western offsite migration of hydrocarbons is suggested by wells MW-2 through MW-4 and MW-12. Delineation of hydrocarbons offsite to the south is established by well MW-1. Low levels of dissolved hydrocarbons are present in samples from MW-15, which suggests the possibility that low levels of dissolved hydrocarbons have impacted a narrow area offsite and southeast between the former UST pit and Alameda Avenue. Analytical testing of water samples from wells MW-8 and MW-12 indicates that the western migration of dissolved hydrocarbons needs to be delineated.

In conclusion, soils impacted with hydrocarbons are located in the southern and eastern portions of the site. Free-phase and dissolved hydrocarbons are found in the groundwater in the southern and western portion of the site which indicates that soils above the groundwater table are acting as a hydrocarbon source for the groundwater.

3.0 EVALUATION OF REMEDIAL ALTERNATIVES

This chapter presents discussions on selection criteria and cleanup levels, available alternatives to treat hydrocarbons in groundwater, and an initial screening to identify treatment alternatives that can be successfully applied to the site. Interim remedial measures and source control actions are not addressed, because a threat to public health and safety is not imminent and we are aware of no continuous release of hydrocarbons. Alternatives are selected and evaluated in Chapter 4.0.

3.1 Selection Criteria and Cleanup Levels

The primary remedial objective is to minimize the impact of hydrocarbons to groundwater that is considered of potential beneficial use. Criteria used to evaluate treatment alternatives are effectiveness, treatment time, future liability, and cost. Proposed cleanup levels for soil and groundwater should be consistent with the primary objective and selection criteria.

3.1.1 Hydrocarbons in Soil

As demonstrated above, the main source of hydrocarbons to groundwater is impacted soils in the capillary fringe. Although soil cleanup will be discussed in a different RWP, it should be emphasized that proper groundwater cleanup can only be accomplished with adequate soil cleanup. Hydrocarbon-impacted soil in the vadose zone is found in locations shown in Plates 5 through 8. A cleanup level for soil should be evaluated by assessing the potential impact of residual hydrocarbons in soil on the groundwater. When free-phase product is removed, groundwater should be depressed to stop further contact with impacted soil which will introduce further degradation to water quality.

3.1.2 Hydrocarbons in Groundwater

The groundwater basin plan set forth by the RWQCB asserts that the site is located in a low sensitivity area. Groundwater cleanup levels will be negotiated with regulatory agencies after adequate plume containment and floating product recovery.

3.2 Groundwater Remedial Alternatives

Remedial alternatives for groundwater include no action and active treatment. Active treatment alternatives reduce hydrocarbon concentrations or minimize the continued migration of the dissolved hydrocarbon plume. Preliminary aquifer tests indicate the saturated soils have low hydraulic conductivities, and recovery and treatment alternatives must account for this characteristic.

3.2.1 No Action Alternative

The no action response results in continued migration of hydrocarbons from soil to the ground water and continued expansion of the floating and dissolved hydrocarbon plume. A prerequisite of this alternative is delineation of the hydrocarbons in groundwater and identification of points of potential human impact. Under this alternative, groundwater monitoring would probably continue for an indefinite period of time. Continued migration of the plume is closely monitored to verify that hydrocarbons do not impact human health.

To implement the no action alternative, additional wells should be installed and an assessment of possible human health risks should be conducted. Wells need to be installed south of the site in Alameda Avenue and northeast of the site in the intersection of High Street and Coliseum Way. Additional offsite wells southeast of the site in the vacant lot may also be required. Logistical considerations preclude the likelihood of drilling at these locations. A risk assessment may be conducted, but it may not conclusively identify the risk to human health as hydrocarbons in the subsurface have not been delineated. Disadvantages of the no action response are that hydrocarbons in the subsurface are not treated, implementation of the monitoring and health risk investigations require delineation of the plume, the property owner is not released from potential future liability, and no action may jeopardize site closure.

3.2.2 Recovery/Containment Alternatives

Groundwater recovery and containment can be implemented by extraction wells, horizontal subsurface drains, or low permeability barriers. A discussion of the proposed methods is presented below.

1) Groundwater pumping from one or more extraction wells involves the active manipulation and management of groundwater to contain, divert, or remove impacted groundwater. Pumping is most effective in relatively high permeability sediments. The effectiveness of extraction in low permeability sediments may be increased by enlarging well diameter. Containment may be achieved as a result of extraction or as a result of both extraction and injection. For this site, up to six 4-foot-diameter boreholes would be drilled with a bucket auger to approximately 35 feet in depth, and 6- to 8-inch diameter wells would be installed in the boreholes.

2) Horizontal subsurface drains include any type of buried conduit (*i.e.*, perforated pipe) used to convey and collect aqueous discharges by gravity. Subsurface drains function like an infinite line of extraction wells by introducing a continuous zone of influence within which groundwater flows toward the drain. A system of drains are installed to direct water flow toward an extraction point or points. Drains are generally applicable to shallow groundwater depths. The most widespread use of drains is to intercept a contaminant plume hydraulically downgradient from a

source. For this option, approximately 180 feet of interconnected drain pipe would be installed in 4-foot-wide trenches beneath the southeastern portion of the station property. The drain pipe would be set approximately 5 feet below the groundwater surface, and would be connected to five extraction wells.

3) Low permeability barriers include a variety of methods whereby low-permeability cutoff walls or diversions are installed below grade to contain impacted groundwater or divert the flow of unaffected groundwater. The common subsurface barriers are slurry walls, grouted barriers, and sheet piling. Impacted groundwater can be either left untreated, if fully contained, or may be recovered and treated. Since hydrocarbons are suspected to have travelled offsite, this option is not feasible for containment.

3.2.3 Treatment Alternatives

Groundwater impacted by petroleum hydrocarbons can be treated on site or offsite. Onsite alternatives include the use of interim treatment units or the construction of stationary longer-term treatment systems. Interim treatment units are usually used for temporary groundwater containment or free-phase hydrocarbon recovery; while stationary systems, with some components installed underground, are used for longer-term cleanup of groundwater. The groundwater can be fully treated onsite and either reinjected to the subsurface, discharged to surface water, or discharged to a municipal wastewater treatment plant. Groundwater may also be collected and hauled to an offsite treatment facility. Offsite treatment is not cost effective for larger volumes of water because of high transportation and disposal costs.

Two major categories of technologies applicable for groundwater treatment are *in situ* and non-*in situ* (aboveground or pump-and-treat) technologies. *In situ* technologies are used when the plume of contamination is fully contained. Accordingly, this option will not be discussed any further. Non-*in situ* or pump-and-treat technologies involve groundwater recovery, aboveground treatment of water with dissolved hydrocarbons, and fluid disposal. Selection of a treatment system depends on the contaminants to be removed and may consist of a combination of several technologies to effect a solution. Because groundwater at the site contains hydrocarbons in floating and dissolved phases, a description of the applicable technologies for both phases is described below.

A) Free-Phase Recovery Stage: Free-phase hydrocarbon recovery may be accomplished aboveground using an oil/water separator or below ground using a two-pump recovery system.

1) Oil/water separation is used to remove large quantities of immiscible petroleum products from the ground-water aboveground. This method is applicable if the petroleum product and water exist as separate or emulsified phases. The separation is accomplished in three stages. The free petroleum product is allowed to rise to the top of the oil/water separator system. Next, the emulsified product particles flow with water through a coalescing plate assembly that attract product droplets together into a larger droplet that can float to the top of the system. The final stage is the movement of the separated water out of the system through a second coalescing plate. The separated product is then skimmed to a holding tank.

2) A two-pump system in the extraction well can be used for downhole separation of the free-phase hydrocarbons. The first pump is used to depress the groundwater surface to enhance migration of free-phase hydrocarbons to the recovery well. The second pump usually situated just above the product/groundwater interface skims the collected product. This method is most practical when appreciable amounts of free-phase hydrocarbons are encountered.

B) Alternatives for removal of dissolved hydrocarbons in ground water include air stripping, carbon adsorption, and biodegradation. These alternatives are discussed below.

1) Air stripping is useful for the removal of volatile organic compounds from water by transferring the dissolved hydrocarbons in the groundwater from the liquid phase into a flowing gas or vapor stream. Hydrocarbon-impacted water is pumped to the top of the air stripper tower and distributed uniformly across packing material. Water flows downward in a film layer along the packing material surfaces. Air blown into the base of the tower flows upwards, contacting the water. Volatile organics are transferred from the water to the air and carried to the top of the column. A properly designed and operated packed-tower air stripper can achieve greater than 95 percent removal of the volatile organics from water. Residuals from an air-stripping process include the treated water and the contaminated off gas, which may be either discharged to the atmosphere in low volumes, or directed through carbon filtration units.

2) Carbon adsorption is used to remove the dissolved phase of petroleum products by adsorption to activated carbon. At least two carbon filtration units are placed in series. The efficiency of removal for aqueous phase carbon is 98 percent. Activated carbon is used as a primary or secondary treatment technology.

3) Biodegradation uses enhanced biologic activity to degrade dissolved hydrocarbons in groundwater. Impacted ground water is pumped into a bioreactor and flows around a medium (typically plastic packing material) where bacteria grow on the surface of the medium. A typical bioreactor with proper maintenance can achieve a hydrocarbon destruction efficiency of greater than

85 percent. Removal of remaining hydrocarbons may be done using carbon filtration.

3.2.4 Screening Acceptable Alternative

3.2.4.1 Recovery/Containment

Site-specific hydrogeologic data suggest that groundwater pumping from existing wells may not yield sufficient water to control plume migration. An increase in the groundwater extraction rate can be achieved by installation of larger diameter boreholes. An estimate of total recovery from six 4-foot-diameter boreholes is approximately 5.3 gpm (Appendix A), and is dependant on well locations. If wells are constructed in central or northern parts of the site, they are expected to produce better than the southern and eastern potions of the site due to geological factors discussed earlier.

Estimates of the total recovery from the 180 feet of horizontal subsurface drain pipe were made using analysis for horizontal flow in a pipe using a modified Darcy's equation. The estimates of total recovery is approximately 10 gpm (see Appendix A for calculations). Considering higher construction costs along with subsurface utility lines intersecting the drains, subsurface drains do not appear to be appropriate for groundwater recovery at this site.

On the basis of preliminary data on hydraulic characteristics of the saturated zone, both subsurface drains and large diameter borehole wells recovery methods may be effective in capturing impacted groundwater. The effective recovery method would likely be installing large diameter wellbores because of the difficulty of installing the drains and associated costs.

3.2.4.2 Treatment

Free-phase hydrocarbons can be effectively removed by an oil/water separator. Downhole product separation is not considered effective for this site because floating product exists as a thin layer. Dissolved hydrocarbons can be treated using either carbon adsorption units or a bioreactor. Air stripping is not applicable for this site because diesel hydrocarbons are also dissolved in the groundwater beneath the site.

4.0 PROPOSED TREATMENT ALTERNATIVES

To reduce further degradation of the groundwater and potential liability, an active hydrocarbon-reduction response is preferred over a response of no action. An active groundwater recovery option is also considered more appropriate because of increased chance for site closure. In this section, the selected treatment alternatives for groundwater are evaluated.

4.1 Evaluation of Treatment Alternatives for Groundwater

The East Bay Municipal Utility District (EBMUD) permits discharge of water with hydrocarbons concentrations up to 5 parts per billion (ppb) benzene, 22 ppb toluene, 5 ppb ethylbenzene, and 23 ppb total xylenes. The September 1991 laboratory analysis results of water samples indicate discharge of untreated groundwater from most parts of the site to the sanitary sewer would not be allowed without adequate treatment. Treatment by the bioreactor alone will not meet the EBMUD discharge limits either (Appendix B). The applicable treatment technologies to be evaluated are: 1) oil/water separator, bioreactor, and carbon adsorption; and 2) oil/water separator with carbon adsorption.

4.1.1 Technical Evaluation

Carbon adsorption technology is the most practical method for hydrocarbon treatment at this site. Operation and maintenance (O&M) for the carbon units is usually simple and requires minimum operating parameters and no special training. In the other hand, the bioreactor requires intensive O&M, warm climate, constant TPH load, and neutral water pH. Highly trained personnel are required for O&M of the system. Problems associated with the bioreactor are fouling and sometimes odor control.

Although both systems can achieve the treatment goal for the same amount of time, carbon canisters are ready to install in days where the bioreactor will take several weeks to order and install.

4.1.2 Economical Evaluation

Since both systems will require the use of an oil/water separator, economical analysis was carried on the basis of capital cost, carbon regeneration and disposal, monthly energy consumption, and O&M. Total cost for the usage of the bioreactor for ground water treatment was estimated to be approximately $81,000 (Table 3). For the same groundwater treatment levels, activated carbon total cost was estimated to be approximately $69,000.

4.2 Recommended Remedial Action

The recommended remedial action is to contain and extract the impacted groundwater by large diameter borehole wells in the locations shown in Plate 11. Extracted groundwater would be treated with an oil/water separator for product recovery followed by activated carbon adsorption. Treated water would be discharged to the sanitary sewers. A process flow diagram for the remedial system is shown in Plate 12.

4.2.1 Remedial System Settings

Six wells, as shown in Plate 11, would be installed for groundwater containment and extraction. Locations of the wells are based on the maximum hydrocarbon concentrations in the groundwater to be extracted and contained. The containment/recovery stage will involve pumping from the proposed extraction wells. An estimated total flow of 5.3 gpm will be pumped below ground through piping to the proposed treatment system.

Floating product will be separated from the groundwater and stored in a product storage tank. Accumulated product will be periodically removed from the site. Groundwater, after treatment, will drain into the sanitary sewer.

4.2.1 Permit and Monitoring Requirements

The proposed interim remedial system and the discharge of contaminants from the site as part of site cleanup measures are regulated by a series of permits from various agencies. Some of the required permits are:

1) Discharge of groundwater: The discharge of treated water is regulated by a permit from the EBMUD.

2) Bay Area Air Quality Management District permit to operate with a product recovery tank.

3) Other permits: Permits will be required from the City of Oakland for building the treatment system. The permitting procedure will include a review by the City Planning, Inspection and Fire Departments for adequate building code enforcement.

4) In the future, a treatment permit may be required from the California Department of Toxic Substances Control. Permit by Rule regulations are being formulated at this time.

Effluent discharged from the treatment system initially will be sampled between 4 and 6 hours after startup. If system discharge effluent is within the discharge limits set by EBMUD, the system will continue to pump and treat. Otherwise, system modification will be required to meet discharge limitations. A daily sample of the system effluent will be collected for laboratory analysis for the first week of operation. Monthly samples will be then collected to assess system efficiency.

Discharge water will be collected in laboratory-cleaned 40-milliliter glass vials and 1-liter glass containers then covered with Teflon-lined lids. The sealed samples will be labeled and promptly placed in iced storage. A Chain of Custody Record will be initiated in the field and will accompany the samples to a laboratory certified in the State of California for analyses. Collected water samples will be analyzed for TPHg, TPHd, and BTEX by EPA Methods 3550/8015, 3510/8015, and 602, respectively. Samples will be analyzed at Pace Laboratory in Novato, California. Additional water samples may be required for EPA 624 and 625 and priority pollutants by EBMUD.

5.0 ESTIMATED SCHEDULE OF WORK

The planned work will be accomplished in 4 major tasks. Some of these tasks will be concurrent with others. The major tasks are: 1) engineering design, 2) permitting, 3) construction of remedial system, and 4) operations and maintenance.

Preliminary schedule for the planned work is present in Plates 13 and 14. The schedules present an average time for design and construction of a project of this size and scope. The proposed schedule assumes no delays in task completion as a result of obtaining onsite power, regulatory agencies, or permitting.

6.0 LIMITATIONS

This report was prepared solely for the use of Exxon Company U.S.A and reliance on this report by third parties shall be at such parties' sole risk. The technical information used in this RAP was collected in accordance with currently accepted general standards of environmental practice in northern California, was collected solely for the purpose of evaluating environmental conditions of the soil and ground water with respect to the extent of hydrocarbon compounds. No soil engineering or geotechnical recommendations are implied or should be inferred. Evaluation of the hydrogeological conditions at the site for the purpose of comparing remedial technologies is made from a limited number of observation points, and subsurface conditions may vary away from the observation points. Additional subsurface investigation can reduce the inherent uncertainties associated with this type of investigation.

5.0 REFERENCES

Applied GeoSystems. May 13, 1987. Letter Report for First Phase Soil Contamination Investigation, Exxon Station No. 7-3006, Oakland, California. Job No. 87042-1.

Applied GeoSystems. July 10, 1987. Report of Excavation, Aeration, and Removal of Contaminated Soil Including Soil Sampling and Analyses, Exxon Station No. 7-3006, Oakland, California. Job No. 87042-2.

Applied GeoSystems. August 5, 1988. Report of Subsurface Environmental Investigation, Exxon Station No. 7-3006, Oakland, California. Job No. 87042-5.

Applied GeoSystems. July 8, 1989. Site Safety Plan, Exxon Station No. 7-3006, 720 High Street, Oakland, California. Job No. 87042-6S.

Applied GeoSystems. October 16, 1989. Report on Subsurface Environmental Investigation, Exxon Station No. 7-3006, 720 High Street, Oakland, California. Job No. 87042-6.

Applied GeoSystems. January 30, 1990. Report on Limited Environmental Investigation, Exxon Station 7-3006, 720 High Street, Oakland, California. Job No. 87042-6R.

Applied GeoSystems. January 30, 1991. Letter Report on Ground-Water Monitoring for Fourth Quarter 1990, Exxon Station No. 7-3006, 720 High Street, Oakland, California. Job No. 87042-9.

Applied GeoSystems. May 29, 1991. Report on Supplemental Subsurface Environmental Investigation, Exxon Station No. 7-3006, 720 High Street, Oakland, California. Job No. 87042-9R.

TABLE 1
RESULTS OF SUBJECTIVE EVALUATION OF WATER SAMPLES
(page 1 of 6)

Date	Depth to Water (ft)	Floating Product (ft)	Sheen	Emulsion
MW-1				
04/25/89	7.55	NONE	NONE	NONE
04/27/89	10.16	NONE	SLIGHT	NONE
09/06/89	10.88	NONE	SLIGHT	NONE
09/22/89	11.06	NONE	NONE	NONE
11/01/89	10.82	NONE	NONE	NONE
11/15/89	11.07	NONE	NONE	NONE
12/06/89	10.33	NONE	NONE	NONE
02/20/90	8.81	NONE	NONE	NONE
04/19/90	9.33	NONE	NONE	NONE
07/03/90	8.44	NONE	NONE	NONE
07/26/90	8.99	NONE	NONE	NONE
08/20/90	9.50	NONE	NONE	NONE
09/19/90	9.99	NONE	NONE	NONE
11/27/90	10.62	NONE	NONE	NONE
01/17/91	10.31	NONE	NONE	NONE
03/26/91	7.97	NONE	NONE	NONE
05/02/91	8.88	NONE	NONE	NONE
06/20/91	9.62	NONE	NONE	NONE
09/17/91	10.40	NONE	NONE	NONE
MW-2				
04/25/89	9.27	2.16	N/A	NONE
07/19/89	10.81	1.56	N/A	NONE
07/27/89	10.18	0.13	N/A	HEAVY
09/06/89	10.89	0.09	N/A	SLIGHT
09/22/89	11.56	0.56	N/A	SLIGHT
11/01/89	10.85	0.09	N/A	NONE
11/15/89	11.05	0.07	N/A	NONE
12/06/89	10.23	0.13	N/A	NONE
02/20/90	8.86	0.29	N/A	NONE
04/19/90	9.09	0.10	N/A	NONE
07/03/90	8.75	0.05	N/A	NONE
07/26/90	8.71	0.10	N/A	NONE
08/20/90	9.25	0.02	N/A	NONE
09/19/90	9.79	0.02	N/A	NONE
11/27/90	10.40	0.07	N/A	NONE
01/17/91	10.03	0.05	N/A	NONE
03/26/91	8.98	0.08	N/A	NONE
05/02/91	8.73	0.02	N/A	NONE
06/20/91	9.11	0.02	N/A	NONE
09/17/91	10.11	0.02	N/A	NONE

TABLE 1
RESULTS OF SUBJECTIVE EVALUATION OF WATER SAMPLES
(page 2 of 6)

Date	Depth to Water (ft)	Floating Product (ft)	Sheen	Emulsion
MW-3				
04/25/89	7.57	0.08	N/A	NONE
07/19/89	10.33	0.66	N/A	NONE
07/27/89		covered by soil		
09/06/89	11.22	0.07	N/A	SLIGHT
09/22/89	11.38	0.28	N/A	SLIGHT
11/01/89	10.90	0.01	N/A	NONE
11/15/89	11.18	0.11	N/A	NONE
12/06/89	10.29	NONE	SLIGHT	NONE
02/20/90	8.73	0.04	N/A	NONE
04/19/90	9.20	0.09	N/A	NONE
07/03/90	8.50	0.03	N/A	NONE
07/26/90	8.58	0.04	N/A	NONE
08/20/90	9.21	0.01	N/A	NONE
09/19/90	10.02	0.35	N/A	NONE
11/27/90	10.72	0.42	N/A	NONE
01/17/91	10.05	0.10	N/A	NONE
03/26/91	7.65	0.10	N/A	NONE
05/02/91	8.54	0.03	N/A	NONE
06/20/91	8.89	0.03	N/A	NONE
09/17/91	10.32	0.22	N/A	NONE
MW-4				
04/25/89	7.26	0.16	N/A	NONE
07/19/89	10.32	0.72	N/A	NONE
07/27/89		covered by soil		
09/06/89	11.40	0.07	N/A	SLIGHT
09/22/89	11.64	0.19	N/A	SLIGHT
11/01/89	11.00	NONE	SLIGHT	NONE
11/15/89	11.18	0.10	N/A	NONE
12/06/89	10.25	NONE	SLIGHT	NONE
02/20/90	8.40	NONE	N/A	NONE
04/19/90	9.04	0.03	N/A	NONE
07/03/90	8.00	---	N/A	MODERATE
07/26/90	8.57	0.04	N/A	NONE
08/20/90	9.08	0.01	N/A	NONE
09/19/90	9.76	0.03	N/A	NONE
11/27/90	10.83	0.09	N/A	NONE
01/17/91	9.96	0.20	N/A	NONE
03/26/91	6.20	0.09	N/A	NONE
05/02/91	7.50	0.04	N/A	NONE
06/20/91	7.79	0.04	N/A	NONE
09/17/91	10.02	0.10	N/A	NONE

TABLE 1
RESULTS OF SUBJECTIVE EVALUATION OF WATER SAMPLES
(page 3 of 6)

Date	Depth to Water (ft)	Floating Product (ft)	Sheen	Emulsion
MW-5				
04/25/89	8.06	0.32	NONE	NONE
07/18/89		well destroyed		
MW-6				
04/25/89	8.02	NONE	NONE	NONE
09/06/89	13.64	0.08	N/A	SLIGHT
09/22/89	13.79	0.07	N/A	SLIGHT
11/01/89	12.78	NONE	SLIGHT	NONE
11/15/89	12.91	NONE	SLIGHT	NONE
12/06/89	11.84	NONE	NONE	NONE
02/20/90	9.08	NONE	NONE	NONE
04/19/90	9.72	NONE	NONE	NONE
07/03/90	8.00	NONE	NONE	NONE
07/26/90	8.70	NONE	NONE	NONE
08/20/90	9.62	NONE	NONE	NONE
09/19/90	10.25	NONE	MODERATE	NONE
11/27/90	10.82	NONE	SLIGHT	NONE
01/17/91	9.93	NONE	NONE	NONE
03/26/91	8.45	NONE	NONE	NONE
05/02/91	8.90	NONE	NONE	NONE
06/20/91	9.47	NONE	SLIGHT	NONE
09/17/91	10.21	NONE	SLIGHT	NONE
MW-7				
04/25/89	8.66	NONE	NONE	NONE
09/06/89	11.72	NONE	SLIGHT	NONE
09/22/89	11.89	NONE	NONE	NONE
12/06/89	10.46	NONE	NONE	NONE
02/20/90	8.44	NONE	NONE	NONE
04/19/90	9.54	NONE	NONE	NONE
07/03/90	7.45	NONE	NONE	NONE
07/26/90	8.08	NONE	NONE	NONE
08/20/90	8.82	NONE	NONE	NONE
09/19/90	9.01	NONE	NONE	NONE
11/27/90	9.54	NONE	NONE	NONE
01/17/91	8.50	NONE	NONE	NONE
03/26/91	5.92	NONE	NONE	NONE
05/02/91	7.72	NONE	NONE	NONE
06/20/91	8.19	NONE	NONE	NONE
09/17/91	8.77	NONE	NONE	NONE

TABLE 1
RESULTS OF SUBJECTIVE EVALUATION OF WATER SAMPLES
(page 4 of 6)

Date	Depth to Water (ft)	Floating Product (ft)	Sheen	Emulsion
MW-8				
04/25/89	8.31	0.66	N/A	NONE
07/19/89	10.97	1.25	N/A	NONE
07/27/89	10.34	0.08	N/A	HEAVY
09/06/89	11.09	0.17	N/A	SLIGHT
09/22/89	11.58	0.36	N/A	SLIGHT
11/01/89	11.03	NONE	NONE	NONE
11/15/89	11.25	0.01	N/A	NONE
12/06/89	10.30	NONE	SLIGHT	NONE
02/20/90	8.00	0.01	N/A	NONE
04/19/90	8.50	NONE	NONE	NONE
07/03/90	7.55	NONE	NONE	NONE
07/26/90	7.86	NONE	NONE	NONE
08/20/90	8.92	NONE	NONE	NONE
09/19/90	9.55	NONE	NONE	NONE
11/27/90	10.29	0.01	N/A	NONE
01/17/91	9.97	NONE	HEAVY	NONE
03/26/91	8.45	NONE	MODERATE	NONE
05/02/91	8.85	NONE	LIGHT	NONE
06/20/91	9.45	NONE	SLIGHT	NONE
09/17/91	10.11	NONE	SLIGHT	NONE
MW-9				
04/25/89	8.25	NONE	NONE	NONE
09/06/89		covered by soil		
09/22/89		covered by soil		
12/06/89	10.12	NONE	NONE	NONE
02/20/90	9.38	NONE	NONE	NONE
04/19/90	9.40	NONE	NONE	NONE
07/03/90	8.79	NONE	NONE	NONE
07/26/90	8.70	NONE	NONE	NONE
08/20/90	9.09	NONE	NONE	NONE
09/19/90	9.52	NONE	NONE	NONE
11/27/90	9.89	NONE	NONE	NONE
01/17/91		covered by soil		
03/26/91		covered by soil		
05/02/91	9.10	NONE	NONE	NONE
06/20/91	8.76	NONE	NONE	NONE
09/17/91	9.57	NONE	NONE	NONE

TABLE 1
RESULTS OF SUBJECTIVE EVALUATION OF WATER SAMPLES
(page 5 of 6)

Date	Depth to Water (ft)	Floating Product (ft)	Sheen	Emulsion
MW-10				
12/06/89	10.46	NONE	NONE	NONE
02/20/90	8.12	NONE	NONE	NONE
04/19/90	8.54	NONE	NONE	NONE
07/03/90	7.88	NONE	NONE	NONE
07/26/90	8.19	NONE	NONE	NONE
08/20/90	10.33	NONE	NONE	NONE
09/19/90	9.49	NONE	NONE	NONE
11/27/90	9.89	NONE	NONE	NONE
01/17/91	9.19	NONE	NONE	NONE
03/26/91	7.48	NONE	NONE	NONE
05/02/91	8.16	NONE	NONE	NONE
06/20/91	8.75	NONE	NONE	NONE
09/17/91	9.72	NONE	NONE	NONE
MW-11				
12/06/89	10.62	NONE	NONE	NONE
02/20/90	9.20	NONE	NONE	NONE
04/19/90	9.80	NONE	NONE	NONE
07/03/90	8.90	NONE	NONE	NONE
07/26/90	9.36	NONE	NONE	NONE
08/20/90	9.90	NONE	NONE	NONE
09/19/90	10.39	NONE	NONE	NONE
11/27/90	10.97	NONE	NONE	NONE
01/17/91	10.76	NONE	NONE	NONE
03/26/91	8.80	NONE	NONE	NONE
05/02/91	9.38	NONE	NONE	NONE
06/20/91	10.16	NONE	NONE	NONE
09/17/91	10.80	NONE	NONE	NONE
MW-12				
12/06/89	8.00	NONE	NONE	NONE
02/20/90	6.33	NONE	NONE	NONE
04/19/90	7.18	NONE	NONE	NONE
07/03/90	7.41	NONE	NONE	NONE
07/26/90	6.54	NONE	NONE	NONE
08/20/90	7.23	NONE	NONE	NONE
09/19/90	7.77	NONE	NONE	NONE
11/27/90	8.15	NONE	NONE	NONE
01/17/91	8.06	NONE	NONE	NONE
03/26/91	7.21	NONE	NONE	NONE
05/02/91	7.60	NONE	SLIGHT	NONE
06/20/91	8.02	NONE	SLIGHT	NONE
09/17/91	8.20	NONE	SLIGHT	NONE

TABLE 1
RESULTS OF SUBJECTIVE EVALUATION OF WATER SAMPLES
(page 6 of 6)

Date	Depth to Water (ft)	Floating Product (ft)	Sheen	Emulsion
MW-13				
12/06/89	9.35	NONE	NONE	NONE
02/20/90	7.73	NONE	NONE	NONE
04/19/90	8.68	NONE	NONE	NONE
07/03/90	8.00	NONE	NONE	NONE
07/26/90	7.95	NONE	NONE	NONE
08/20/90	8.66	NONE	NONE	NONE
09/19/90	9.13	NONE	NONE	NONE
11/27/90	9.49	NONE	NONE	NONE
01/17/91	9.61	NONE	NONE	NONE
03/26/91	9.25	NONE	NONE	NONE
05/02/91	9.31	NONE	NONE	NONE
06/20/91	9.73	NONE	NONE	NONE
09/17/91	9.72	NONE	NONE	NONE
MW-14				
11/27/90	9.88	NONE	NONE	NONE
01/17/91	9.13	NONE	NONE	NONE
03/26/91	8.51	NONE	NONE	NONE
05/02/91	8.45	NONE	NONE	NONE
06/20/91	8.38	NONE	NONE	NONE
09/17/91	9.14	NONE	NONE	NONE
MW-15				
11/27/90	8.67	NONE	NONE	NONE
01/17/91	8.03	NONE	NONE	NONE
03/26/91		covered by soil		
05/02/91	7.09	NONE	NONE	NONE
06/20/91	7.06	NONE	NONE	NONE
09/17/91	7.89	NONE	NONE	NONE

N/A = Not applicable.

TABLE 2
RESULTS OF GROUNDWATER ANALYSES
(page 1 of 5)

Date	Sample No.	TPHg ppm	B ppm	T ppm	E ppm	X ppm	TPHd ppm	TOG ppm	VOC ppm
MW-1									
05/88	W-11-MW1*	0.240	0.090	0.005	0.015	0.025	--	--	ND
12/89	W-11-MW1	0.63	0.012	0.0056	0.0037	0.025	0.24	--	--
04/90	W-09-MW1	<0.020	<0.0005	<0.00050	<0.00050	<0.00050	<0.10	--	--
07/90	W-11-MW1	0.13	0.006	<0.00050	<0.00050	<0.00050	0.16	--	--
11/90	W-10-MW1	<0.050	0.0007	<0.00050	<0.00050	<0.00050	<0.10	--	--
03/91	W-07-MW1	<0.050	<0.0005	<0.0005	<0.0005	<0.0005	<0.10	--	--
06/91	W-10-MW1	<0.050	<0.0005	<0.0005	<0.0005	<0.0005	<0.10	--	--
09/91	W-10-MW1	<0.050	<0.0005	<0.0005	<0.0005	<0.0005	--	--	--
MW-2									
09/87	W-25-MW2	1.445	0.233	0.81	0.056	0.209	--	--	--
05/88	free product								
12/89	free product								
04/90	free product								
07/90	free product								
11/90	free product								
03/91	free product								
06/91	free product								
09/91	free product								
MW-3									
09/87	W-25-MW3	2.101	0.360	1.062	0.068	0.298	0.66	--	--
05/88	W-14-MW3	8.7	3.98	0.28	0.24	0.6	--	--	--
12/89	free product								
04/90	free product								
07/90	free product								
11/90	free product								
03/91	free product								
06/91	free product								
09/91	free product								

See notes on page 5 of 5.

TABLE 2
RESULTS OF GROUNDWATER ANALYSES
(page 2 of 5)

Date	Sample No.	TPHg ppm	B ppm	T ppm	E ppm	X ppm	TPHd ppm	TOG ppm	VOC ppm
MW-4									
09/87	W-25-MW4	0.925	0.070	0.007	0.010	0.016	0.74	--	--
05/88	free product								
12/89	free product								
04/90	free product								
07/90	emulsion								
11/90	free product								
03/91	free product								
06/91	free product								
09/91	free product								
MW-5									
09/87	W-25-MW5	26.66	0.56	1.71	1.58	7.15	37.22	--	--
05/88	free product								
07/89	well destroyed								
MW-6									
05/88	W-15-MW6	29.3	12.82	0.55	1.44	5.50	--	--	--
12/89	W-18-MW6	9.0	0.37	0.013	0.0026	0.43	4.8	--	--
04/90	W-30-MW6	27	3.0	0.12	0.49	2.1	26	--	--
07/90	W-30-MW6	30	5.5	1.4	1.2	3.1	13	--	--
11/90	W-10-MW6	15	4.4	0.12	0.8	2.3	7.6	--	--
03/91	W-08-MW6	55	10	0.38	1.6	6.9	<0.10	--	--
06/91	sheen								
09/91	W-10-MW6	17	4.5	0.16	0.89	3.1	--	--	--

See notes on page 5 of 5.

TABLE 2
RESULTS OF GROUNDWATER ANALYSES
(page 3 of 5)

Date	Sample No.	TPHg ppm	B ppm	T ppm	E ppm	X ppm	TPHd ppm	TOG ppm	VOC ppm
MW-7									
09/87	W-25-MW7	1.531	0.258	0.002	<0.002	0.042	2.79	--	ND
05/88	W-15-MW7	--	0.300**	<0.010**	<0.010**	<0.010**	0.190	--	ND
12/89	W-11-MW7	1.70	0.22	0.0053	0.0050	0.0086	2.5	<5	ND
04/90	W-10-MW7	2.7	0.22	0.0086	0.0070	0.020	3.5	--	ND
07/90	W-17-MW7	2.5	0.38	0.013	0.016	0.035	0.91	--	ND
11/90	W-09-MW7	2.3	0.63	0.016	0.032	0.029	1.3	--	0.0024■
03/91	W-06-MW7	3.5	0.42	0.018	0.017	0.027	<0.10	--	ND
06/91	W-08-MW7	3.1	0.27	0.0088	0.033	0.019	<0.10	--	--
09/91	W-09-MW7	2.4	0.39	0.01	0.015	0.018	--	--	--
MW-8									
09/87	W-25-MW8	1.325	0.081	0.074	0.042	0.182	--	--	--
05/88	free product								
12/89	W-11-MW8	42	2.6	0.63	0.21	3.7	34	--	--
04/90	W-14-MW8	49	2.1	0.82	1.1	4.8	53	--	--
07/90	W-23-MW8	44	4.0	1.5	2.0	6.3	32	--	--
11/90	free product								
03/91	sheen								
06/91	sheen								
09/91	W-10-MW8	57	14	7.8	3.1	12	--	--	--
MW-9									
05/88	W-14-MW9	<0.05	<0.0005	0.001	<0.001	<0.001	--	--	ND
12/89	W-14-MW9	0.1	0.0018	0.0037	0.0014	0.0088	0.11	<5	ND
04/90	W-10-MW9	<0.020	<0.00050	<0.00050	<0.00050	<0.00050	<0.10	--	ND
07/90	W-10-MW9	<0.020	<0.00050	<0.00050	<0.00050	<0.00050	<0.10	--	ND
11/90	W-09-MW9	<0.050	<0.0005	<0.0005	<0.0005	<0.0005	<0.10	--	ND
03/91	covered by soil								
06/91	W-09-MW9	<0.050	<0.0005	<0.0005	<0.0005	<0.0005	<0.10	--	--
09/91	W-10-MW9	<0.050	<0.0005	<0.0005	<0.0005	<0.0005	--	--	--

See notes on page 5 of 5.

TABLE 2
RESULTS OF GROUNDWATER ANALYSES
(page 4 of 5)

Date	Sample No.	TPHg ppm	B ppm	T ppm	E ppm	X ppm	TPHd ppm	TOG ppm	VOC ppm
MW-10									
12/89	W-12-MW10	0.32	0.0037	0.014	0.0056	0.032	<0.10	--	--
04/90	W-09-MW10	<0.020	<0.00050	<0.00050	<0.00050	<0.00050	<0.10	--	ND
07/90	W-11-MW10	<0.020	<0.00050	<0.00050	<0.00050	<0.00050	<0.10	--	--
11/90	W-09-MW10	<0.050	<0.0005	<0.0005	<0.0005	<0.0005	<0.10	--	--
03/91	W-07-MW10	<0.050	<0.0005	<0.0005	<0.0005	<0.0005	<0.10	--	--
06/91	W-09-MW10	<0.050	<0.0005	<0.0005	<0.0005	<0.0005	<0.10	--	--
09/91	W-10-MW10	<0.050	<0.0005	<0.0005	<0.0005	<0.0005	<0.10	--	--
MW-11									
12/89	W-11-MW11	0.078	0.0059	0.00063	<0.0005	48	<0.10	--	--
04/90	W-12-MW11	<0.020	<0.00050	<0.00050	<0.00050	<0.00050	<0.10	--	--
07/90	W-12-MW11	<0.020	<0.00050	<0.00050	<0.00050	<0.00050	<0.10	--	--
11/90	W-10-MW11	<0.050	<0.0005	<0.0005	<0.0005	<0.0005	<0.10	--	--
03/91	W-08-MW11	<0.050	<0.0005	<0.0005	<0.0005	<0.0005	<0.10	--	--
06/91	W-10-MW11	<0.050	<0.0005	<0.0005	<0.0005	<0.0005	<0.10	--	--
09/91	W-11-MW11	<0.050	<0.0005	0.0007	<0.0005	<0.0005	--	--	--
MW-12									
12/89	W-08-MW12	85	6.7	6.3	1.8	7.8	40	--	--
04/90	W-07-MW12	110	6.6	7.4	1.8	11	97	--	--
07/90	W-08-MW12	92	11	11	3.1	13	50	--	--
11/90	W-08-MW12	69	11	10	3.1	12	31	--	--
03/91	W-08-MW12	100	15	16	2.4	11	<0.10	--	--
06/91	sheen								
09/91	W-08-MW12	82	22	18	3.9	16	--	--	--

See notes on page 5 of 5.

TABLE 2
RESULTS OF GROUNDWATER ANALYSES
(page 5 of 5)

Date	Sample No.	TPHg ppm	B ppm	T ppm	E ppm	X ppm	TPHd ppm	TOG ppm	VOC ppm
MW-13									
12/89	W-10-MW13	52	2.1	2.0	1.4	6.1	31	--	--
04/90	W-09-MW13	59	1.8	1.5	1.4	7.2	54	--	--
07/90	W-10-MW13	53	4.5	3.1	2.2	7.8	26	--	--
11/90	W-09-MW13	20	4.5	1.1	0.88	3.3	1.6	--	--
03/91	W-09-MW13	72	10	8.3	1.7	6.9	<0.10	--	--
06/91	W-10-MW13	44	5.6	3.1	0.75	2.6	<0.10	--	--
09/91	W-10-MW13	40	11	6.5	2.4	8.1	--	--	--
MW14									
11/90	W-09-MW14	0.39	<0.0005	<0.0005	0.0036	0.0037	0.12	--	--
03/91	W-07-MW14	0.20	<0.0005	0.0015	0.0008	0.0036	<0.10	--	--
06/91	W-08-MW14	0.11	<0.0005	<0.0005	<0.0005	<0.0005	<0.10	--	--
09/91	W-09-MW14	0.45	<0.0005	<0.0005	0.0032	0.0023	--	--	--
MW-15									
11/90	W-08-MW15	2.7	0.21	0.0055	0.6	0.25	0.34	--	--
03/91	covered by soil								
06/91	W-07-MW15	0.38	<0.0005	<0.0005	<0.0005	0.0013	<0.10	--	--
09/91	W-08-MW15	0.49	0.0029	0.0017	0.033	0.0013	--	--	--

TPHg = Total petroleum hydrocarbons as gasoline
BTEX = Benzene, toluene, ethylebenzene, and total xylenes constituents
TPHd = Total petroleum hydrocarbons as diesel
TOG = Total oil and grease   VOC = Volatile organic compounds
< = Not detected at method detection limit
■ = Chloromethane
ND = No VOC detected other than BTEX
* = W-10-MW1 = water sample - depth - well number
** = Analyzed by Environmental Protection Agency Method 624 (volatile organic compounds)

TABLE 3
PROPOSED GROUNDWATER TREATMENT ALTERNATIVES

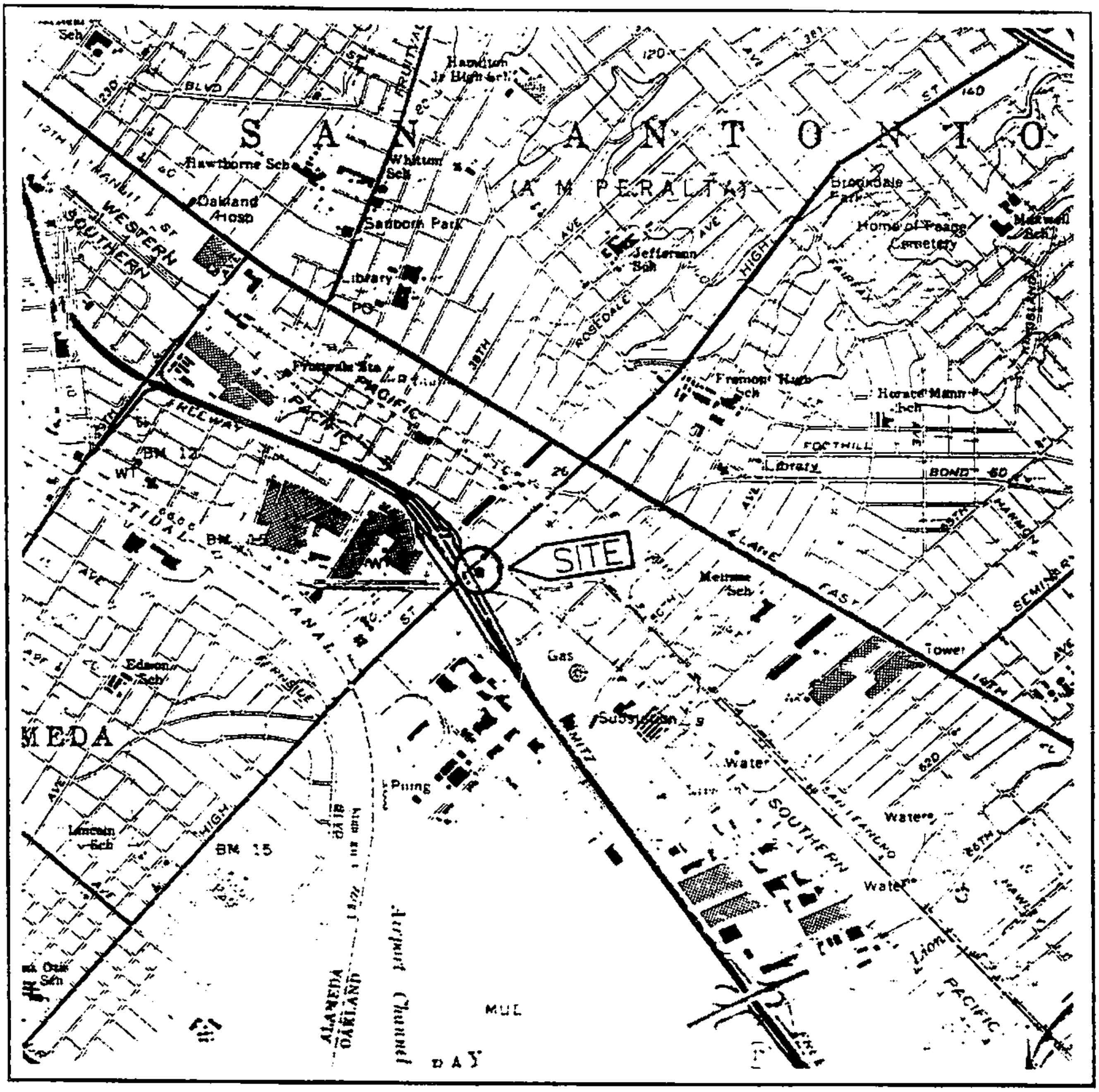
Comparison Item	Bioreactor with Carbon	Carbon Only
1) Capital Cost	$38,600	$12,635
2) Carbon Refill and Disposal (1-year)	$10,000	*$48,000
3) Operational Costs (1-year)**		
Special Maintenance	$13,780	N/A
Energy Cost	$13,560	$7,200
4) Total Costs	$75,940	$67,835
5) Easement of O&M	Bioreactor requires intensive maintenance, warm climate, constant TPH load, and neutral water pH	Easy to maintain and requires minimum operating parameters

* Based on manufacturer's quote

** Bioreactor needs to be shutdown twice a year for cleaning and to cultivate new microorganisms

O&M = Operation and maintenance

Amount of spent carbon is calculated in Appendix B



Source: U.S. Geological Survey
7.5–Minute Quadrangle
Oakland East, California

Approximate Scale

Applied GeoSystems

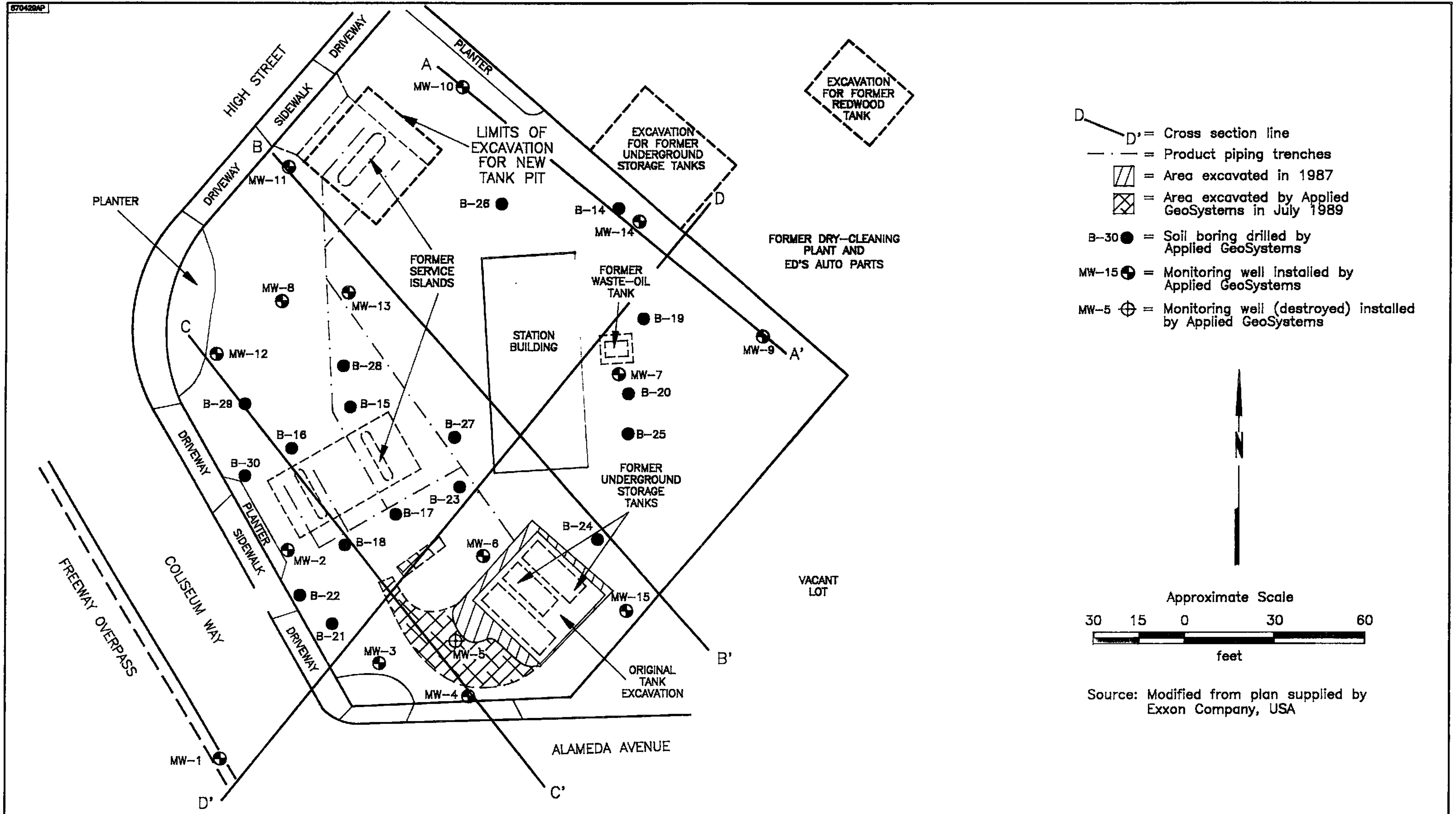
PROJECT NO. 87042-9RAP

SITE VICINITY MAP

Exxon Station No. 7-3006
720 High Street
Oakland, California

PLATE

1



D—D' = Cross section line

— · — = Product piping trenches

▨ = Area excavated in 1987

☒ = Area excavated by Applied GeoSystems in July 1989

B-30 ● = Soil boring drilled by Applied GeoSystems

MW-15 ⊕ = Monitoring well installed by Applied GeoSystems

MW-5 ⊕ = Monitoring well (destroyed) installed by Applied GeoSystems

Source: Modified from plan supplied by Exxon Company, USA

Applied GeoSystems

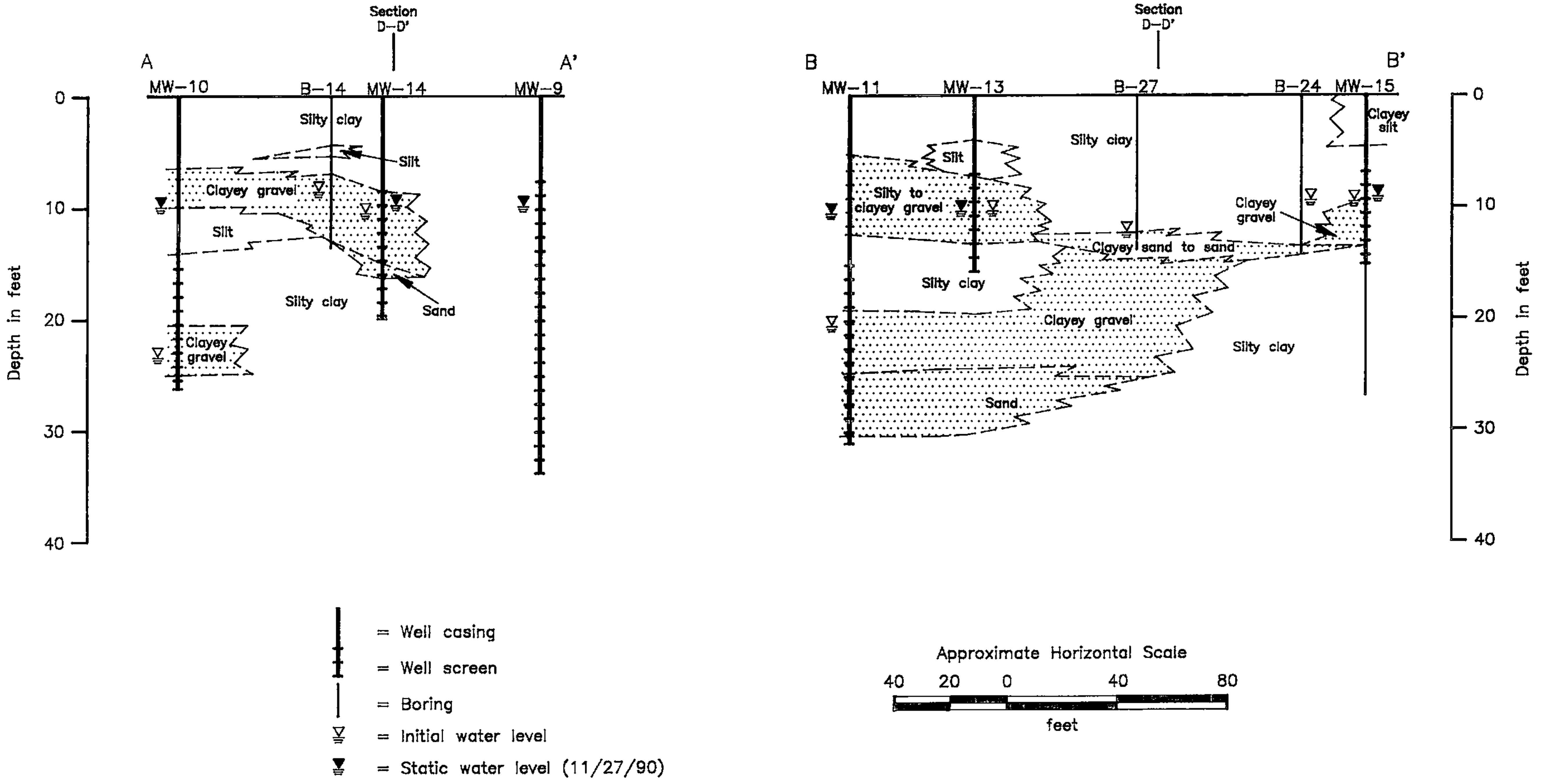
PROJECT NO. 87042-9RAP

GENERALIZED SITE PLAN
Exxon Station No. 7-3006
720 High Street
Oakland, California

PLATE

2

870429RA



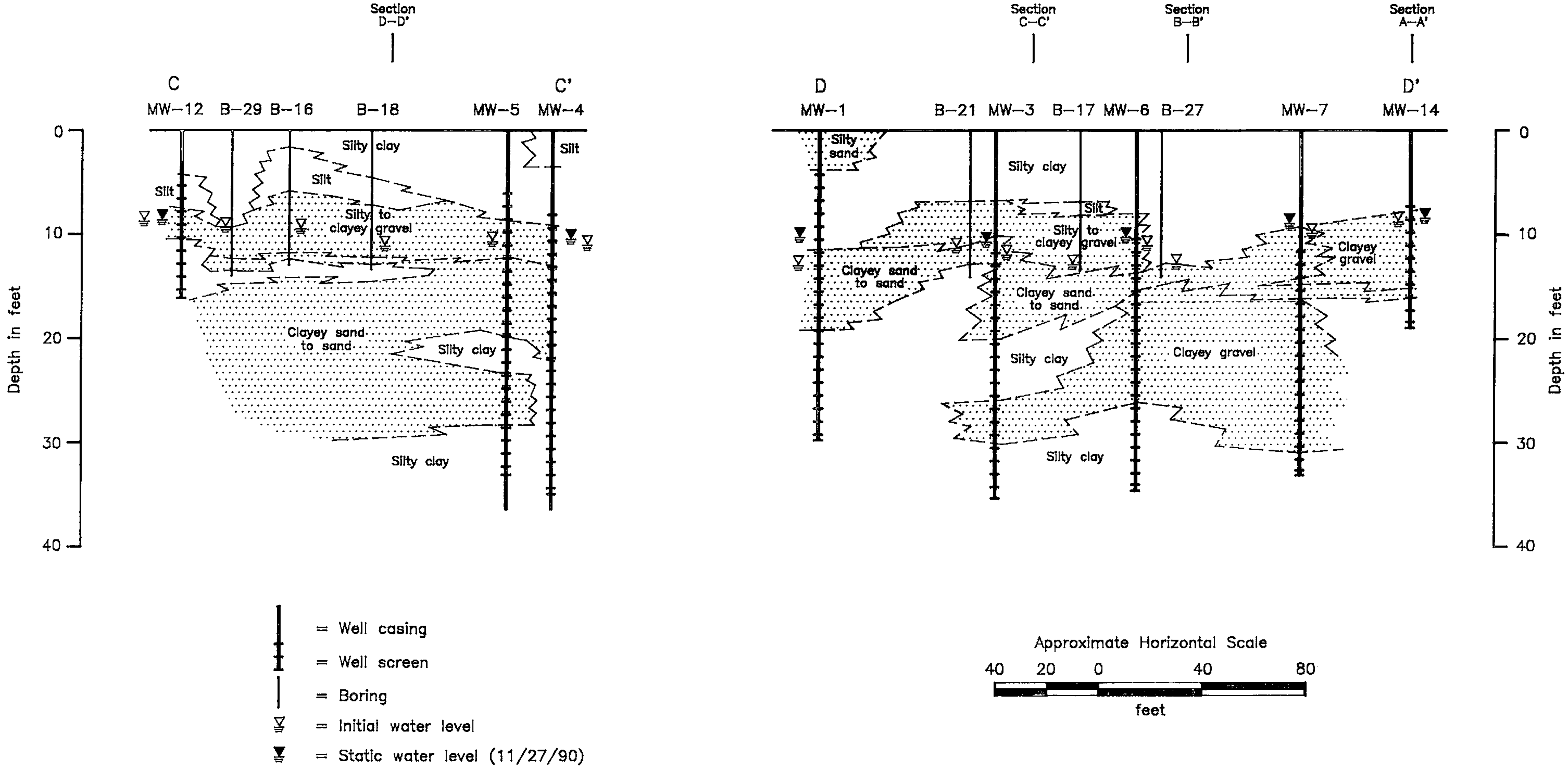
Applied GeoSystems

PROJECT NO. 87042–9RAP

GEOLOGIC CROSS SECTIONS A–A' AND B–B'
Exxon Station No. 7–3006
720 High Street
Oakland, California

PLATE

3



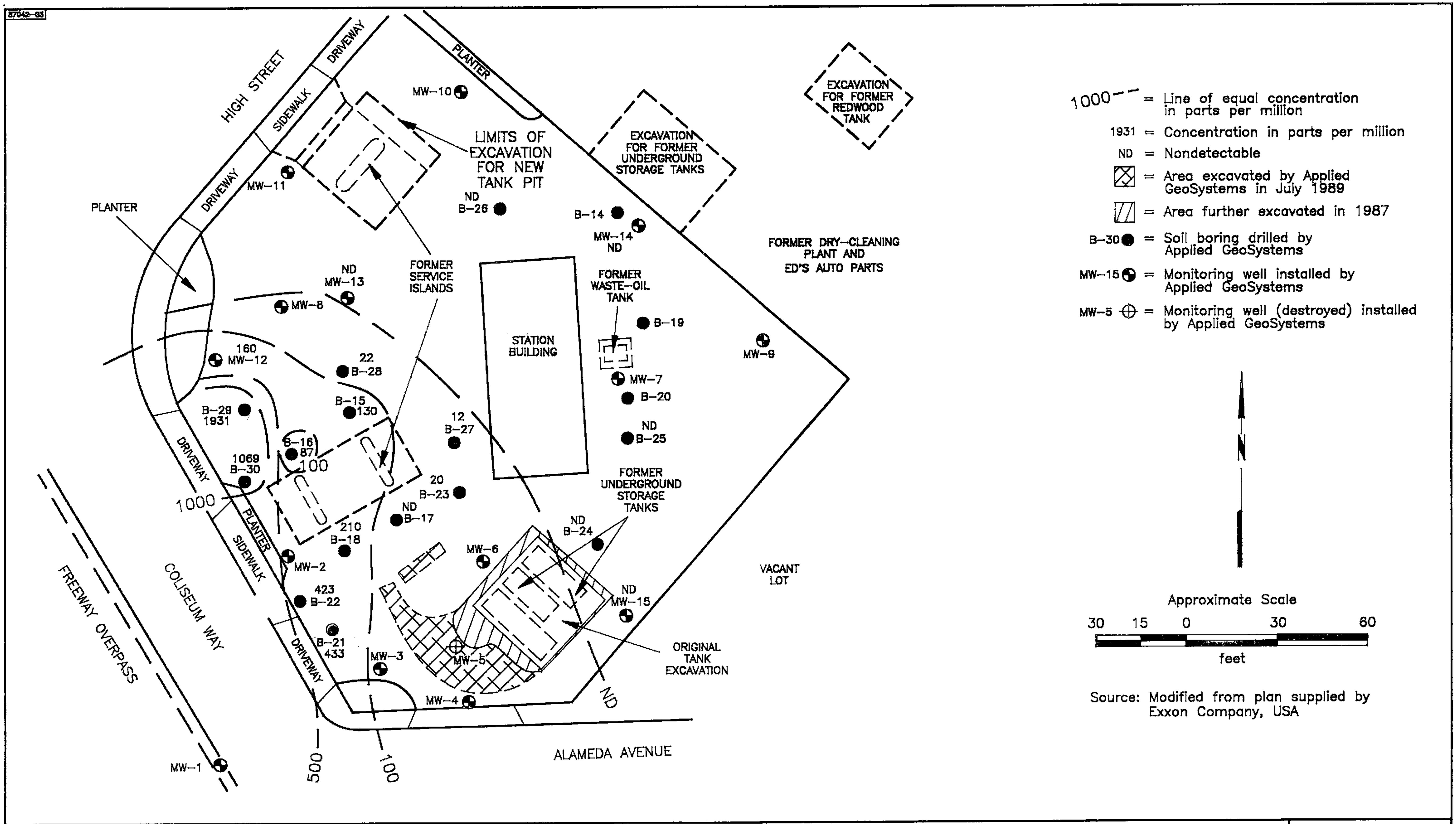
Applied GeoSystems

PROJECT NO. 87042–9RAP

GEOLOGIC CROSS SECTIONS C–C' AND D–D'
Exxon Station No. 7–3006
720 High Street
Oakland, California

PLATE

4



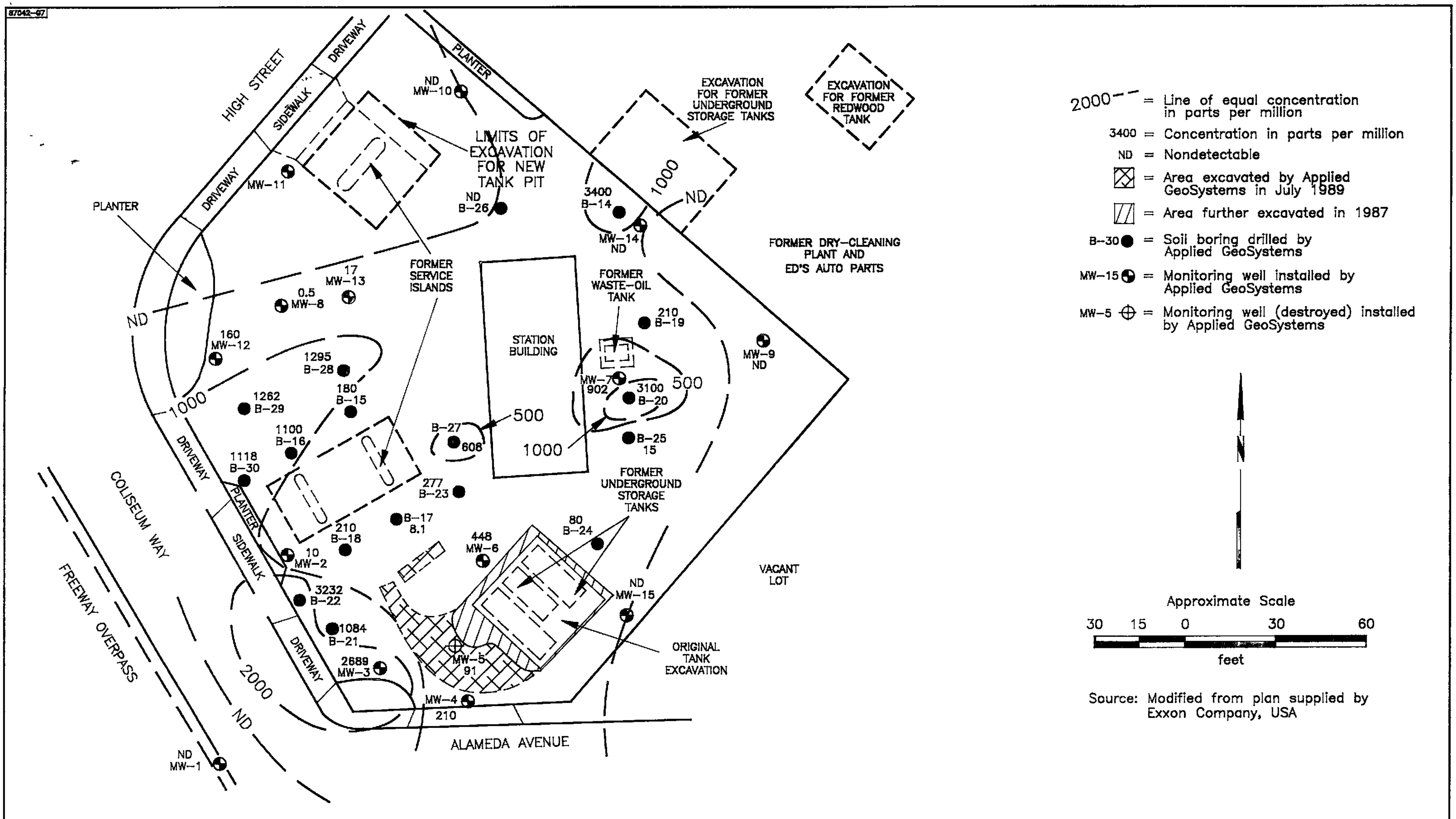
Applied GeoSystems

PROJECT NO. 87042-9RAP

CONCENTRATION OF TPHg IN SOIL
(3- to 5-foot depth interval)
Exxon Station No. 7-3006
720 High Street
Oakland, California

PLATE

5



Source: Modified from plan supplied by Exxon Company, USA

Applied GeoSystems

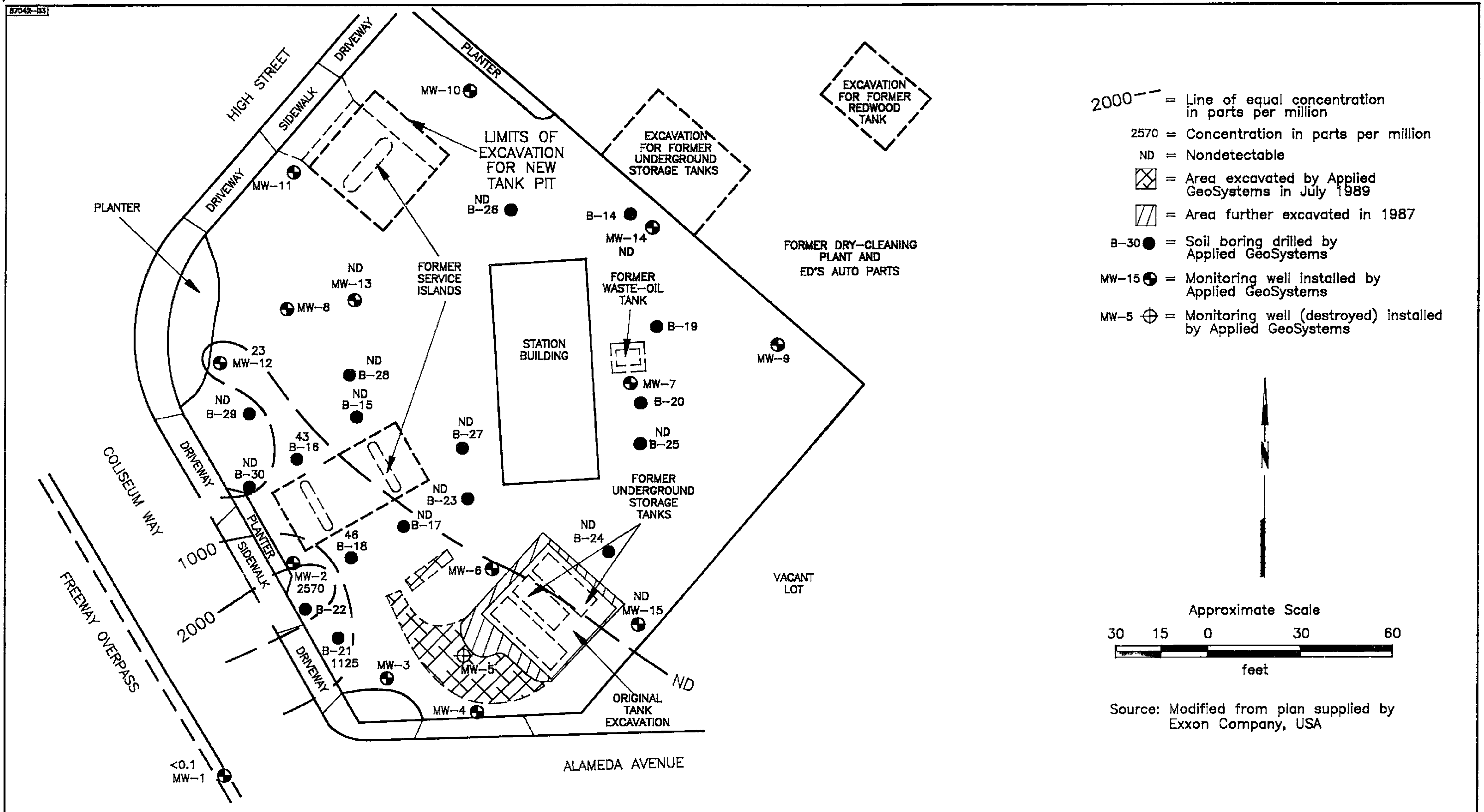
PROJECT NO. 87042-9RAP

CONCENTRATION OF TPHg IN SOIL
(7-1/2- to 10-foot depth interval)
Exxon Station No. 7-3006
720 High Street
Oakland, California

PLATE

6

87042-03



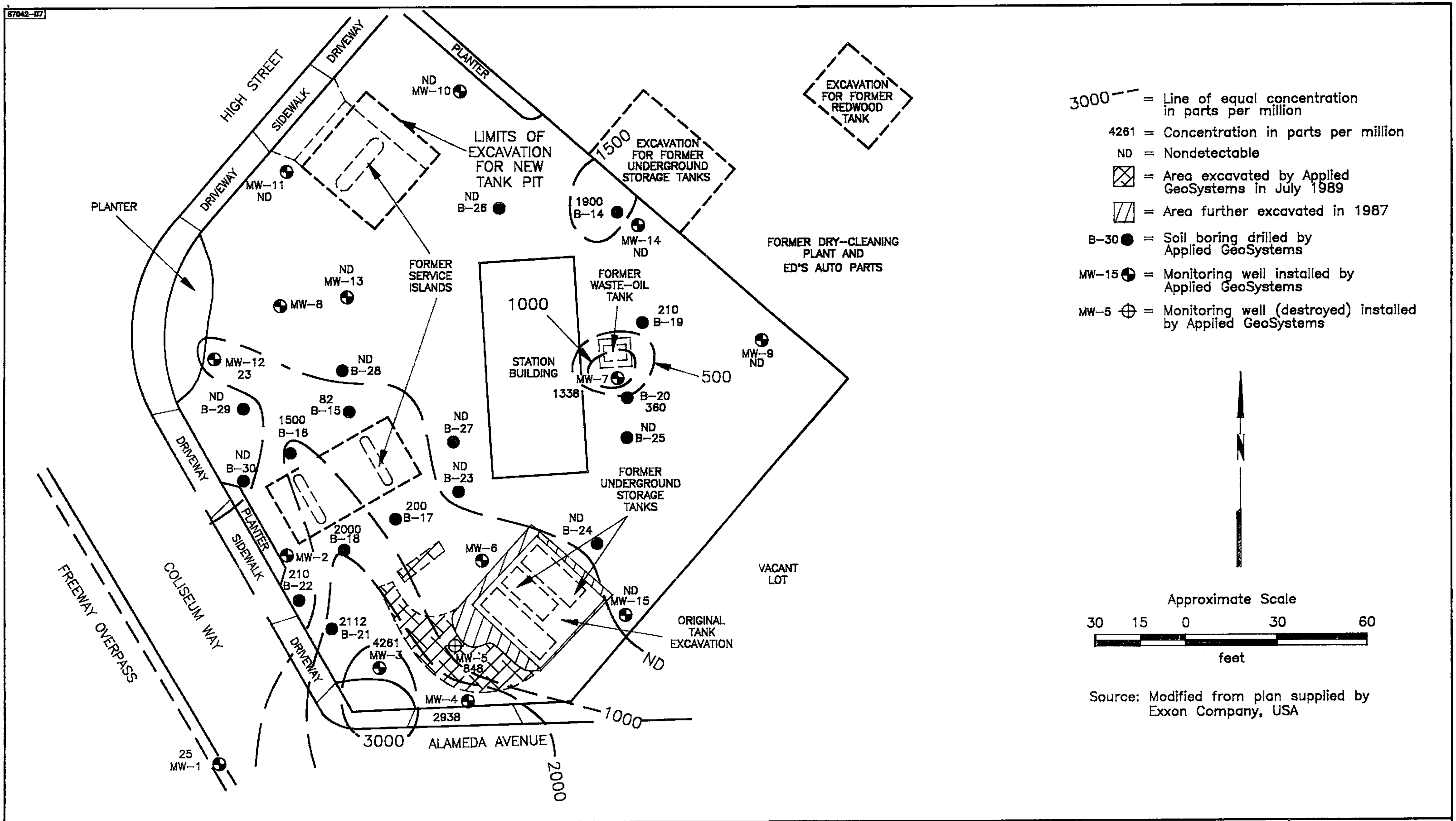
Source: Modified from plan supplied by Exxon Company, USA

Applied GeoSystems

PROJECT NO. 87042-9RAP

CONCENTRATION OF TPHd IN SOIL
(3- to 5-foot depth interval)
Exxon Station No. 7-3006
720 High Street
Oakland, California

PLATE
7



Applied GeoSystems

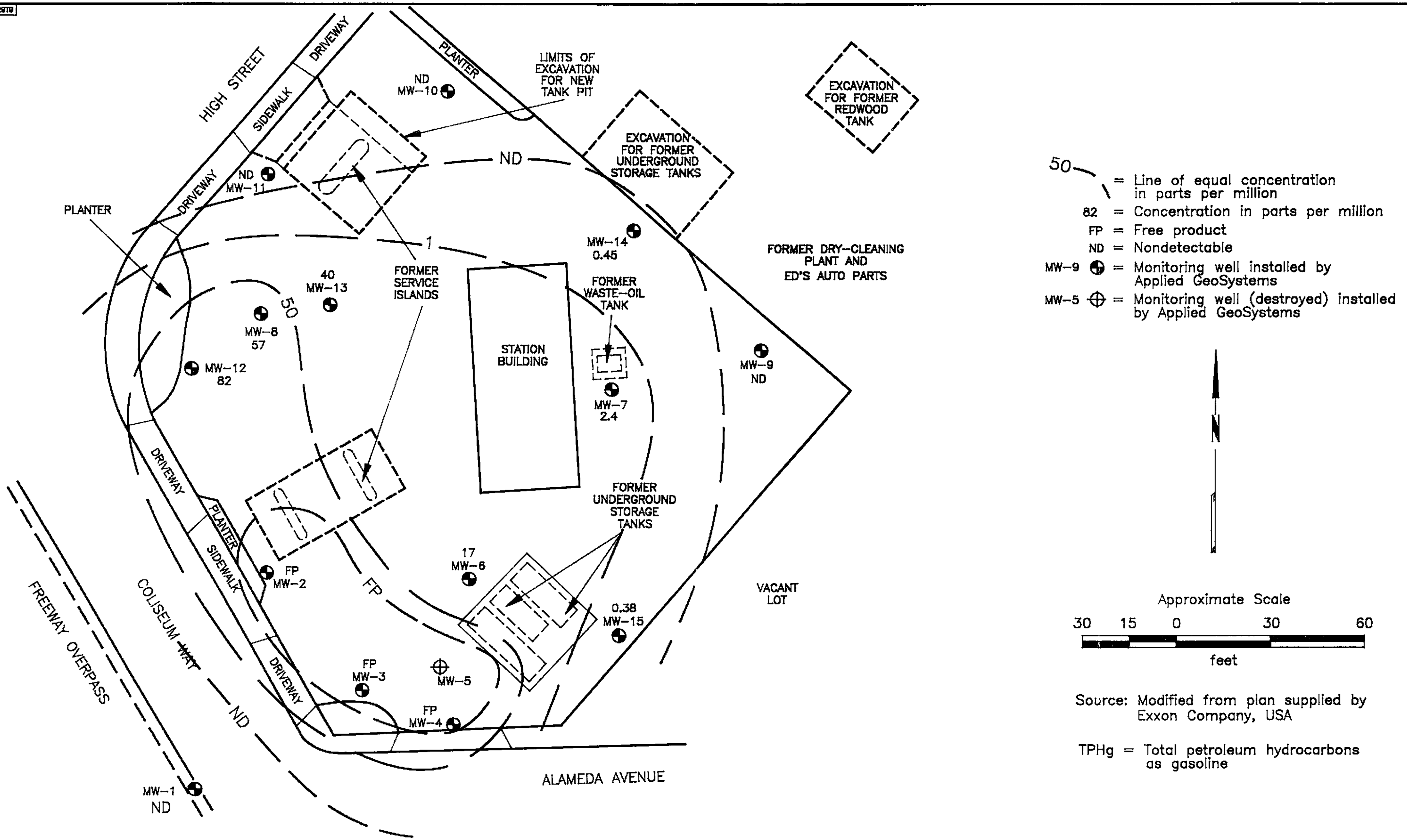
PROJECT NO. 87042-9RAP

CONCENTRATION OF TPHd IN SOIL
(7-1/2- to 10-foot depth interval)
Exxon Station No. 7-3006
720 High Street
Oakland, California

PLATE

8

870429T9



50 = Line of equal concentration in parts per million
82 = Concentration in parts per million
FP = Free product
ND = Nondetectable
MW-9 ⊕ = Monitoring well installed by Applied GeoSystems
MW-5 ⊕ = Monitoring well (destroyed) installed by Applied GeoSystems

Source: Modified from plan supplied by Exxon Company, USA

TPHg = Total petroleum hydrocarbons as gasoline

Applied GeoSystems

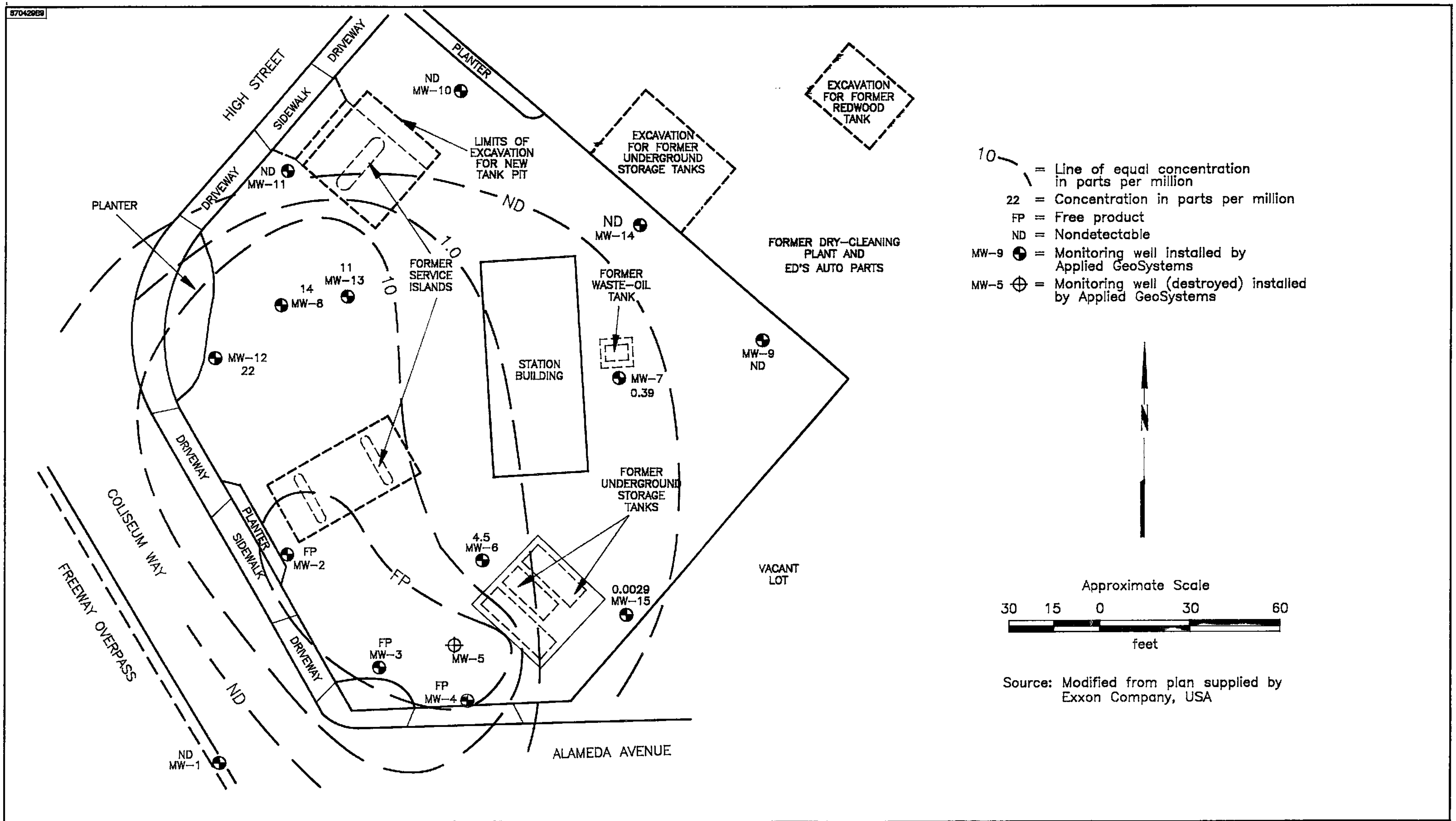
PROJECT NO. 87042-9RAP

CONCENTRATION OF TPHg
IN GROUND WATER
Exxon Station No. 7-3006
720 High Street
Oakland, California

PLATE

9

87042989

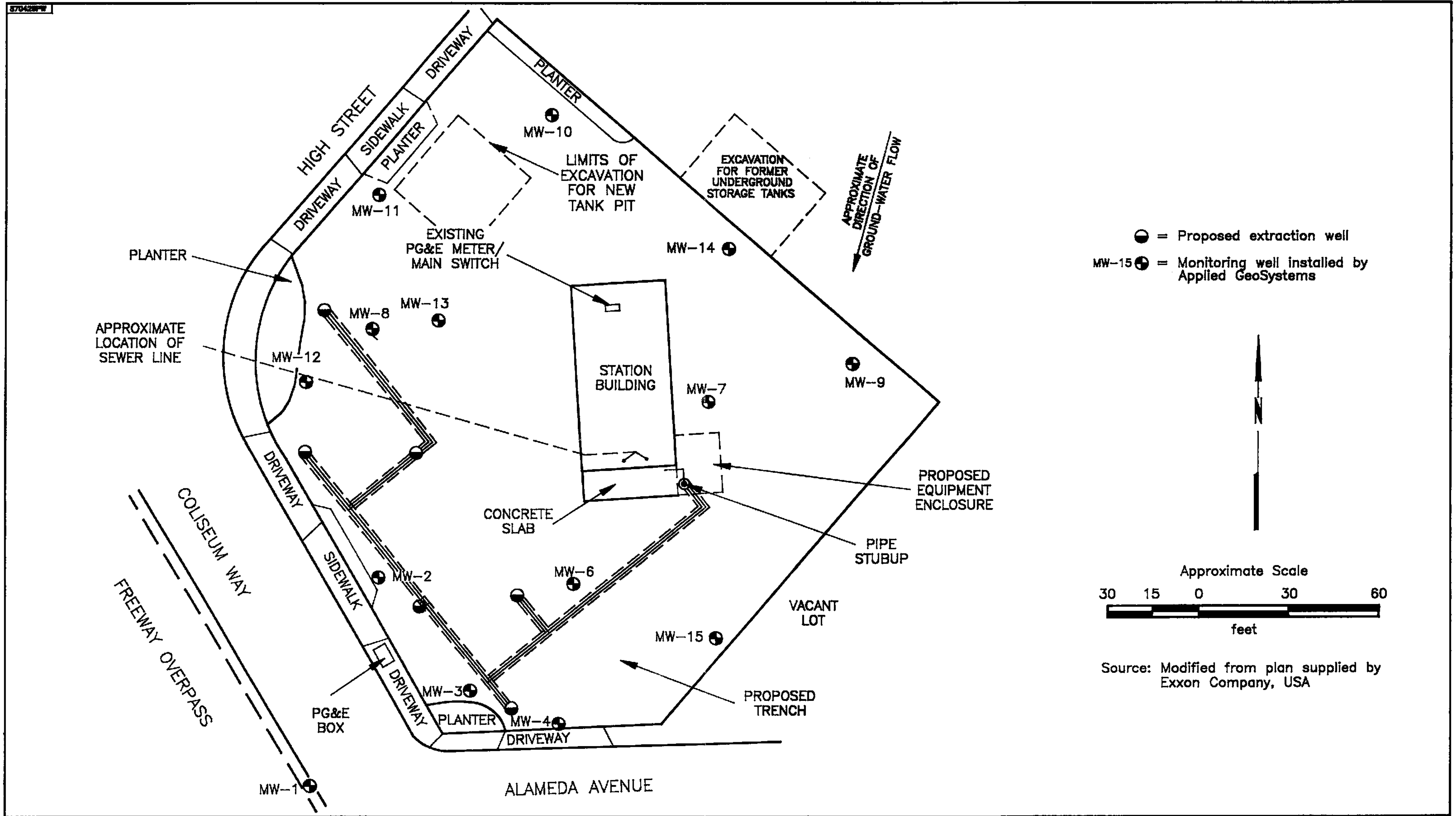


Applied GeoSystems

PROJECT NO. 87042-9RAP

CONCENTRATION OF BENZENE IN GROUND WATER
Exxon Station No. 7-3006
720 High Street
Oakland, California

PLATE
10



Source: Modified from plan supplied by Exxon Company, USA

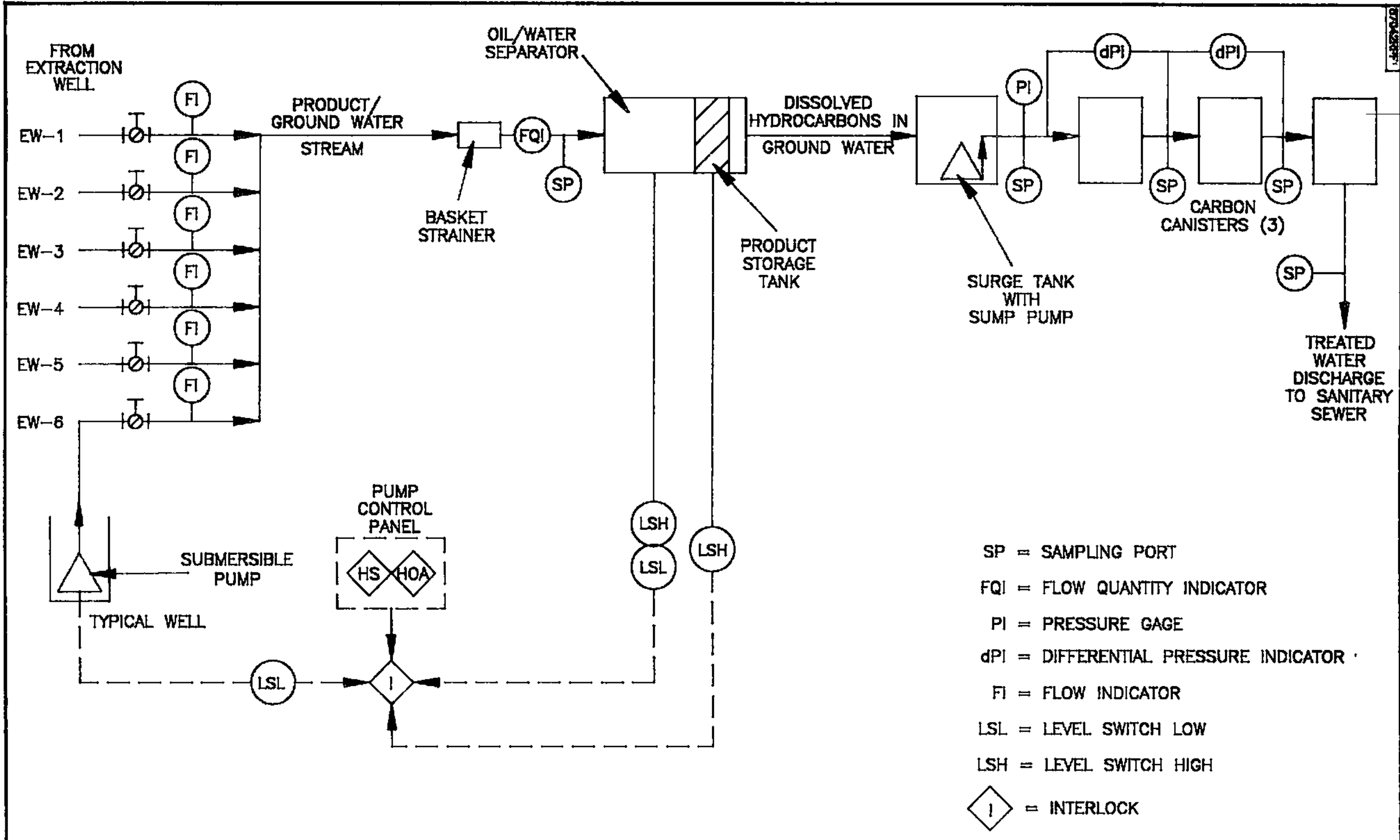
Applied GeoSystems

PROJECT NO. 87042-9RAP

PROPOSED EXTRACTION WELL LOCATIONS
Exxon Station No. 7-3006
720 High Street
Oakland, California

PLATE

11



PLATE

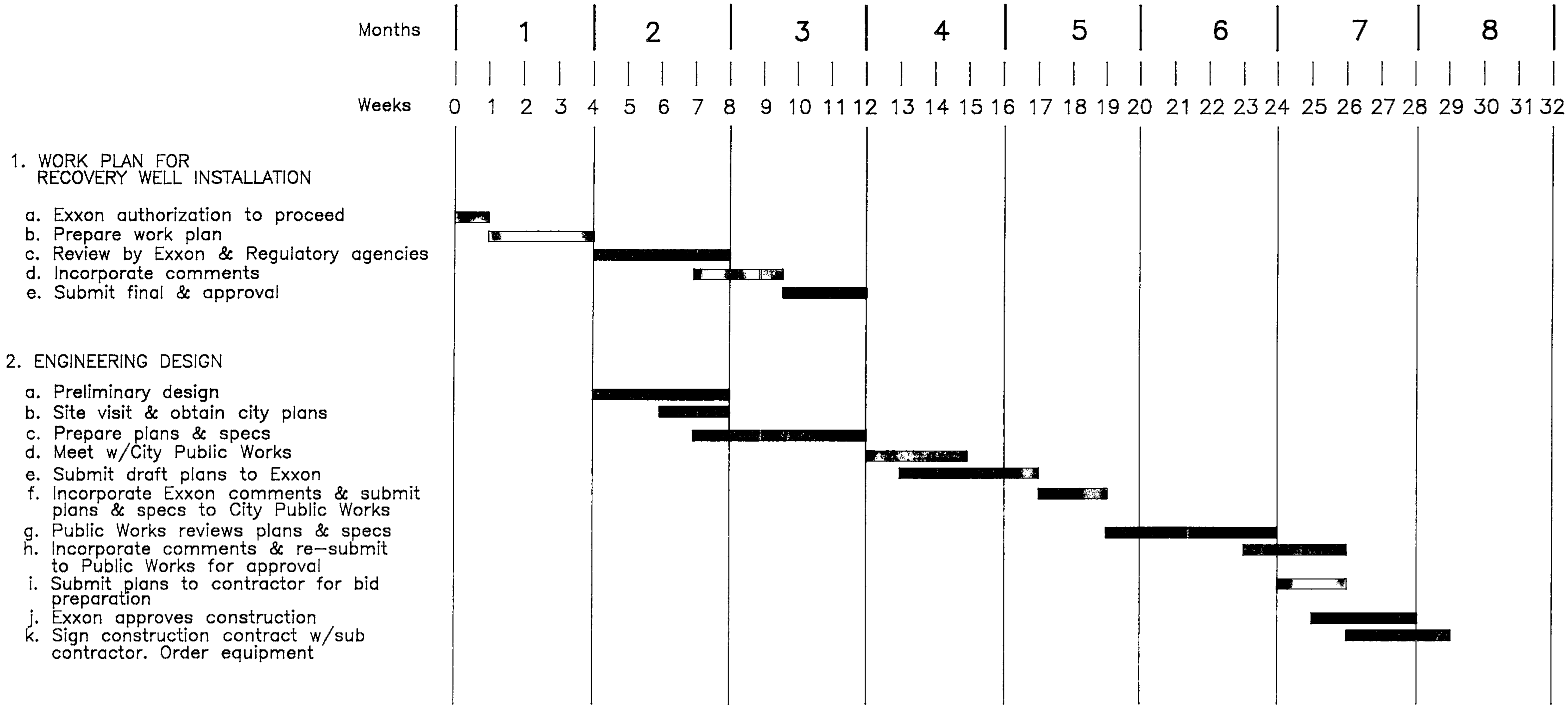
12

PROCESS FLOW DIAGRAM

Exxon Station No. 7-3006
720 High Street
Oakland, California

Applied GeoSystems

PROJECT NO. 87042-9RAP



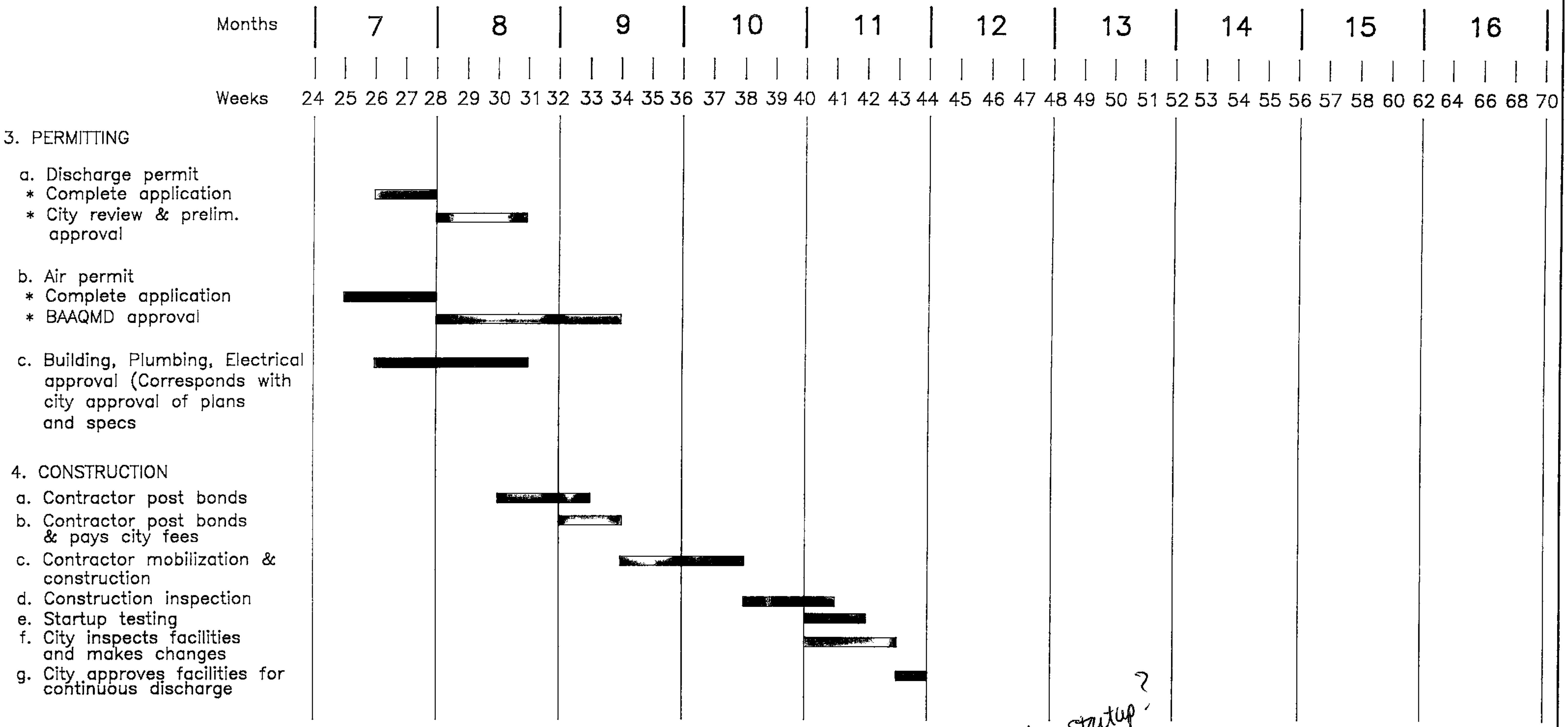
Applied GeoSystems

PROJECT NO. **87042-9RAP**

PRELIMINARY SCHEDULE
OF PROPOSED REMEDIAL ACTION
Exxon Station No. 7-3006
720 High Street
Oakland, California

PLATE

13



what about system startup?

Applied GeoSystems

PROJECT NO. 87042-9RAP

PRELIMINARY SCHEDULE
OF PROPOSED REMEDIAL ACTION
Exxon Station No. 7-3006
720 High Street
Oakland, California

PLATE
14

CALCULATIONS

Calculation for Recovery from Six 4-Foot-Diameter Wells

- The recharge rate for the 10-inch-diameter wellbore of MW-8 is 0.185 gallon per minute (gpm), calculated from the pump test.
- The seepage area of the wellbore of MW-8 below groundwater (approximately 23 feet) is 60.2 square feet.
- The seepage area of a 4-foot-diameter by 23-foot-deep wellbore is 289 square feet.
- Assuming a linear relationship between surface area and recharge rate:

$$\frac{60.2\ \text{ft}^2}{289\ \text{ft}^2} = \frac{0.185\ \text{gpm}}{x}$$

$$x = \frac{(144.5)\ (0.185)}{(30.1)}$$

$$= 0.89\ \text{gpm per well}$$

$$= \mathbf{5.33\ gpm\ for\ six\ wells}$$

Calculations for Recovery from Horizontal Drain Pipe

Modified Darcy's Equation for Horizontal Flow

$$Q_d = \frac{4K\ (b^2 - a^2)}{L}$$

where:

Q_d = design flow per foot of drain
K = hydraulic conductivity (0.0065 ft/min)
b = water level above base of aquifer at equilibrium flow (6 feet)
a = pipe above base of aquifer (5 feet)
L = distance between drain pipes (40 feet)

$$Q_d = \frac{(4)\ (0.0065)\ (6^2 - 5^2)}{40}$$

$= 0.00715\ ft^3/min \times 180$ feet of pipe

$= 1.3\ ft^3/min$

= 9.62 gpm

APPENDIX B

MASS BALANCE AND CARBON BREAKTHROUGH CALCULATIONS

MASS BALANCE CALCULATIONS

ASSUMPTIONS:

1) Total Flow Rate = 6 gpm
2) O/W Separator Effluent TPH concentration (C_{in}) = 50,000 to 130,000 ug/l
3) Maximum benzene, toluene, ethylebenzene, and total xylenes concentrations were found in well MW-12 to be 22,000, 18,000, 3,900, and 16,000 ug/l, respectively.
4) TPH removal efficiency of the Bioreactor = 85%
5) TPH removal efficiency of Activated Carbon = 98%
6) Activated Carbon TPH adsorption efficiency = 8 to 15% by weight

COMPLIANCE WITH EBMUD

A) <u>No Treatment</u>

Since extracted water will be discharged with East Bay Municipal Utility District (EBMUD), concentrations of benzene, toluene, ethylbenzene, and total xylenes are restricted to 5, 22, 5, and 23 ug/l, respectively. Evaluating the proposed locations with respect to benzene concentrations (Plate 10), all wells will be installed inside the 10,000 ug/l isoconcentration line. These concentrations are not accepted by EBMUD. Accordingly; no treatment option is not acceptable.

(ppm)

B) <u>O/W Separator and Bioreactor</u>

Because groundwater treatment will be necessary for discharge, the calculations for mass balance will be carried using benzene concentrations since it is the most critical for this site.

Influent Benzene Concentration (C_{in}) = 22,000 ug/l

Benzene removal by Bioreactor = 0.85 X 22,000 ug/l
= 18,700 ug/l

TPH discharged to sanitary sewer (EBMUD) = 22,000 - 18,700 = 3,300 ug/l
****** Not acceptable by EBMUD

C) <u>O/W Separator, Bioreactor, and Activated Carbon Filtration</u>

C_{in} to Bioreactor = 22,000 ug/l

Benzene influent to first carbon canister = 3,300 ug/l <as calculated above>

Benzene removal by Carbon = 0.98 X 3,300 = 3,234 ug/l

TPH influent to second carbon canister = 66 ug/l

TPH removal by second carbon filter = 0.98 X 66 = 64.7 ug/l

TPH discharged to sanitary sewer = 1.32 ug/l ***** Acceptable by EBMUD

D) <u>O/W Separator and Activated Carbon Filtration</u>

C_{in} to first carbon canister = 22,000 ug/l

TPH removal by first carbon filter = 0.98 X 22,000 = 21,560 ug/l

TPH removal by second carbon filter = 0.98 X 440 = 431 ug/l

TPH removal by third carbon filter = 0.98 X 8.8 = 8.6 ug/l

TPH discharged to sanitary sewer = 0.2 ug/l ****** Acceptable by EBMUD

MASS BALANCE CALCULATIONS

C) <u>O/W Separator, Bioreactor, and Activated Carbon</u>

Influent TPH Mass Flow Rate, lb/day = Q (gpm) X C_{in} (ug/l) X 3.785 (l/gal) X 1440 (min/day) X 1E-6 (g/ug) X 1/454 (lb/g)

= 6 X 130,000 X 3.785 X 1440 X 1E-6 X 1/454
= 9.4 lb/day

TPH mass removed by Bioreactor = 0.85 X 9.4 = 7.96 lbs/day

TPH mass removed by first carbon filter = 0.98 X 1.44 = 1.41 lbs/day

TPH mass removed by second carbon filter = 0.98 X 0.03 = 0.03 lbs/day

D) <u>O/W Separator and Activated Carbon</u>

Influent TPH mass Flow Rate = 9.4 lbs/day

TPH mass removed by first carbon filter = 0.98 X 9.4 = 9.2 lbs/day

TPH mass removed by second carbon filter = 0.98 X 0.19 = 0.18 lb /day

TPH mass removed by third carbon filter = 0.98 X 0.01 = 0.01 lb/day

CARBON BREAKTHROUGH CALCULATIONS

DATA: Carbon Vessel Capacity = 1,000 lbs
Carbon adsorption efficiency for TPH = 8%
Adsorption capacity for TPH per carbon vessel (1,000 lbs) = 80 lbs TPH

C) O/W Separator, Bioreactor, and Activated Carbon

TPH mass removal rate by activated carbon = 1.41 lbs/day <see calculations for mass balance>

First Two Months

TPH mass removed by carbon = 1.41 lbs/day X 30 day/month X 2 months = 84.6 lbs.

Breakthrough for one carbon vessel (1,000 lbs) =
= 80 lbs-TPH / 1.41 lbs/day = 56.7 days = 1.9 months

Next Three Months

Assume TPH concentrations drop by 25%

TPH mass removed by carbon = 0.75 X 1.41 lbs/day X 30 days/month X 3 months
= 95.2 lbs

TPH mass removal rate = 0.75 X 1.41 = 1.05 lbs/day

Breakthrough for one carbon vessel (1,000 lbs) =
= 80 lbs-TPH / 1.05 lbs/day = 76.2 days = 2.5 months

Next Seven Months

Assume TPH concentrations drop by 50 %

TPH mass removed by carbon = 0.5 X 1.41 lbs/day X 30 days/month X 7 months
= 148 lbs

TPH mass removal rate = 0.5 X 1.41 = 0.71 lbs/day

Breakthrough for one carbon vessel (1,000 lbs) =
= 80 lbs-TPH / 0.71 lbs/day = 112.7 days = 3.8 months

Total Carbon Spent = (84.6 + 95.2 + 148) / 0.08 = 4,103 lbs of carbon

No. of Carbon vessels needed = 5 - 1,000-lbs vessels

D) O/W Separator and Activated Carbon

TPH mass removal rate by activated carbon = 9.4 lbs/day <see calculations for mass balance>

First Two Months

TPH mass to be removed by carbon = 9.4 lbs/day X 30 day/month X 2 months = 564 lbs.

Breakthrough for one carbon vessel (1,000 lbs) = 80 lbs-TPH / 9.4 lbs/day = 8.5 days

Breakthrough for one carbon vessel (2,000 lbs) = 160 lbs-TPH / 9.4 lbs/day = 17 days

** Accordingly, it is more appropriate to use the 2,000-lbs carbon vessels

Next Three Months

Assume TPH concentrations drop by 25%

TPH mass to be removed by carbon = 0.75 X 9.4 lbs/day X 30 day/month X 3 months
= 635 lbs.
TPH mass removal rate = 0.75 X 9.4 = 7.1 lbs/day

Breakthrough for one carbon vessel (2,000 lbs) = 160 lbs-TPH / 7.1 lbs/day = 22.5 days

Next Seven Months

Assume TPH concentrations drop by 50 %

TPH mass to be removed by carbon = 0.5 X 9.4 lbs/day X 30 day/month X 7 months =
= 984 lbs.
TPH mass removal rate = 0.5 X 9.4 = 4.7 lbs/day

Breakthrough for one carbon vessel (2,000 lbs)
= 160 lbs-TPH / 4.7 lb/day = 34 days = 1.1 months

Total Carbon Spent = (564 + 635 + 984)/0.08 = 27,375 lbs of carbon

No. of Carbon vessels needed = 14 - 2,000-lb vessels