

ENVIRONMENTAL
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**HUMAN HEALTH RISK ASSESSMENT FOR
THE FORMER SOUTHSORE CAR WASH**

**2351 SHORELINE DRIVE
ALAMEDA, CALIFORNIA**

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Project No. 2210

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Executive Summary

This baseline human health risk assessment (HHRA) report has been prepared by SOMA Environmental Engineering, Inc. (SOMA) on behalf of Soil Tech Engineering, Inc. The project site is the Former Texaco gas station and Southshore Car Wash facility which is the eastern portion of the Southshore Shopping Center, located at 2351 Shore Line Drive, Alameda, California (the "Site").

The Site is owned by Harsch Investment Corp. who have leased it to Kamur Industries. *What site* Currently, the Site is operated by Kamur Industries. Previous Site activities have resulted in soil and groundwater contamination. The source of contamination was leaky underground fuel storage tanks which have been removed from the Site. During the removal of the tank, approximately 250 cubic yards of contaminated soil were also removed from the Site. Although the petroleum impacted soils have been removed and backfilled with clean soils, petroleum constituents in the form of benzene, toluene, ethylbenzene and xylene (BTEX) still remain in the groundwater.

The purpose of this baseline HHRA is to evaluate the adverse potential health impacts of contaminated groundwater beneath the Site. Currently, the Site is zoned for industrial/commercial purposes. The Site is expected to remain industrial/commercial in the future. Therefore, the risk associated with on and off-site residents was not considered in this study.

The report also includes the results of groundwater flow and chemical transport modeling at the Site. The purpose of the chemical transport modeling was to evaluate the impact of groundwater contamination on a lagoon, located half a mile in downgradient direction from the Site.

The chemical transport simulations were conducted without considering the effect of biodegradation which is a fairly conservative assumption. Although, no Site specific

hydrogeologic data such as hydraulic conductivity and porosity of sediments are available, conservative values from literature based on Site lithological data was used in conducting chemical fate and transport modeling. The simulation runs indicated that the benzene plume will travel about 1,500 ft after 30 years. Simulation runs with higher hydraulic conductivity (20 ft/day) indicated that the benzene plume will travel about 2,000 feet, and still will not reach the lagoon. The results of the chemical transport modeling indicated that none of the four chemicals detected in the groundwater will reach the lagoon in a time period of 30 years. →

The results of this HHRA are as follows:

- ✓ For the hypothetical on-site indoor worker, the total excess cancer risk from inhalation of volatile emissions was estimated to be equal to 5.38×10^{-7} . This is well below the acceptable range of risk defined by the EPA (1×10^{-6} to 1×10^{-4}). The non carcinogenic hazard index was estimated to be equal to 9.15×10^{-3} , which is well below 1.0 and would be considered negligible. *(Cw) →* *Maximally*
- ✓ For the hypothetical on-site outdoor worker, the total excess cancer risk, under current conditions, was estimated to be equal to 5.59×10^{-8} . The excess cancer risk under future conditions was estimated to be equal to 6.08×10^{-8} . Both risk estimates are well below the acceptable range defined by the EPA. The hazard index under current and future conditions was estimated to be equal to 9.52×10^{-4} and 1.03×10^{-3} respectively, which is negligible.
- ✓ For the hypothetical off-site indoor worker, under future conditions, the total excess cancer risk, was estimated to be equal to 3.21×10^{-9} . The hazard index was calculated to be equal to 5.52×10^{-5} . Both the risk and the hazard index are negligible.

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- For the hypothetical off-site indoor worker, under future conditions, the total excess cancer risk, was estimated to be equal to 3.21×10^{-9} . The hazard index was calculated to be equal to 5.52×10^{-5} . Both the risk and the hazard index are negligible.

- For the hypothetical off-site outdoor worker, under future conditions, the carcinogenic risk was estimated to be 6.29×10^{-9} . The hazard index was estimated to be equal to 1.07×10^{-4} . Both the risk and the hazard index are negligible.

Based on the results of this HHRA, it can be concluded that the contamination of groundwater underneath the Site does not impose any adverse health effects to potential human receptors.

1.0 Introduction

This baseline human health risk assessment (HHRA) report has been prepared by SOMA Environmental Engineering, Inc. (SOMA) on behalf of Soil Tech Engineering, Inc. The project site is the Former Texaco gas station and Southshore Car Wash facility which is at the eastern portion of the Southshore Shopping Center, located at 2351 Shore Line Drive, Alameda, California (the "Site"), see Figure 1.

The Site is owned by Harsch Investment Corp. who have leased it to Kamur Industries. At present, the Site is operated by Kamur Industries. The previous on-site activities have resulted in soil and groundwater contamination by the petroleum products. The source of subsurface contamination is the release of petroleum hydrocarbons from leaking under-ground fuel storage tanks which reportedly have been removed. Although the petroleum-impacted soil has been removed and backfilled with clean soil, the petroleum-impacted groundwater has not been remediated.

The purpose of this baseline HHRA is to evaluate the adverse potential health impacts of contaminated groundwater beneath the Site to current and future workers. Currently, the Site is zoned for industrial/commercial purposes. The Site is expected to remain industrial/commercial in future. Therefore, the risk associated with on and off-Site residents were not considered in this risk assessment.

The report also includes the results of groundwater flow and chemical transport modeling at the Site. The purpose of the chemical transport modeling was to evaluate the impact of groundwater contamination on a lagoon, located half a mile downgradient direction from the Site.

2.0 Site Characterization

2.1 Previous Site Investigations

The Site was formerly used as a gasoline service station and car wash facility. Since 1991, Kamur Industries has retained Soil Tech Engineering, Inc. (STE) to evaluate the nature and extent of soil and groundwater contamination beneath the Site. The Site investigation was initiated by Kamur Industries in response to a request from the Alameda County Health Services-Department of Environmental Health (ACHS-DEH).

In July 1990, three underground gasoline tanks each with a capacity of 10,000 gallons, were removed from the Site. Soil sampling was conducted by Environmental BioSystems, Inc. (EBS). The results of the laboratory analysis on the soil samples collected beneath the excavation revealed elevated levels of total petroleum hydrocarbons as gasoline (TPH-g) which ranged from 360 parts per million (ppm) to 9,500 ppm.

During the removal of the tanks, approximately 250 cubic yards of soil were removed and transported to an off-site location for treatment/disposal. In addition, soil samples were collected from the undisturbed areas surrounding the former tank excavation. The results of laboratory analysis on soil samples collected from 5.1 to 7.1 feet below the surface revealed moderate levels of TPH-g and benzene, toluene, ethylbenzene, and xylene (BTEX). No previous groundwater investigation was conducted by EBS.

In early 1991, upon the request of the ACHS-DEH, STE conducted additional soil and groundwater investigations which included further removal of contaminated soils and delineating the extent of petroleum hydrocarbons in groundwater. In February 1991, STE installed four groundwater monitoring wells beneath the Site. The hydrogeologic data collected from these wells were used to calculate the local groundwater gradient

and develop a groundwater elevation contour map to determine the direction groundwater flow.

The results of the investigations performed by STE revealed that despite the removal of contaminated soil, total petroleum hydrocarbons (TPH) and chemicals such as (BTEX) remain in the groundwater. Therefore, this HHRA only addresses the impact of groundwater contamination beneath the Site. Chlorinated solvents such as trichlorethylene (TCE) and perchloroethylene (PCE) have been detected in the groundwater in the western portion of the Southshore Shopping Center (to the west of the Site) where the former dry cleaner was located. The risk associated with these chlorinated solvents has been addressed by Kleinfelder, Inc. (Kleinfelder) in their report entitled "Risk Review, Harsch Investment Corp., Southshore Shopping Center, Alameda, California", dated 1996.

2.2 Site Hydrogeology

The stratigraphy of the shallow soil beneath the Site has been explored by STE. The native soil beneath the Site mainly consists of fine to medium grained sandy soil (STE, 1991). Groundwater has been encountered at depths ranging between 8 and 9 feet below ground surface (bgs) (STE, 1991).

In February 1991, STE installed four groundwater monitoring wells (STMW-1 to STMW-4) at the Site. Since then a quarterly groundwater monitoring program was initiated by STE. On January 26, 1993, STE installed two additional monitoring wells (STMW-5 and STMW-6). The locations of these six monitoring wells are shown in Figure 2. The static water levels measured at these monitoring wells during previous Site investigations have been presented in Table 1. The groundwater elevation contour map based on the water levels measured in the February 1993 monitoring event is presented in Figure 3. As Figure 3 shows, groundwater flows toward the north/northwest direction beneath the Site. No pumping or slug tests have been

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conducted in on-site groundwater monitoring wells. However, a review of lithologic logs of groundwater monitoring wells indicate that the saturated sediments beneath the Site are composed of fine to medium sand. Based on Freeze and Cherry (1979), the hydraulic conductivity of fine grained - clean sand ranges between 10^{-3} and 10^{-2} cm/sec (2.8 ft/day - 28 ft/day). In conducting groundwater modeling, it will be assumed that the hydraulic conductivity of saturated material is about 15 ft/day.

2.3 Nature and Extent of Groundwater Contamination

Since April 1991, STE has conducted groundwater investigations at the Site. Groundwater samples collected from these monitoring wells have been analyzed for the presence of BTEX. The results of the laboratory analysis have been tabulated in Tables 2 through 7. These tables also present the maximum and average concentrations of BTEX chemicals used in conducting this HHRA.

A review of the water quality data at the six monitoring wells shows that the maximum concentration of chemicals detected in the groundwater were reported during investigations conducted in 1991 and 1992. The maximum concentration of benzene of 48,500 ppb was detected in a groundwater sample collected at STMW-3 on 10/21/91. The maximum concentration of toluene (41,000 ppb) was detected in the groundwater sample collected at STMW-3 on 01/17/92. The maximum concentration of ethyl benzene (3,200 ppb) was detected at STMW-1 on 04/05/91 and that of xylene equal to 46,000 ppb was detected at STMW-3 on 10/21/91.

2.4 Conceptual Site Model (CSM)

The conceptual model was developed for the Site based on previous Site investigations. The CSM synthesizes site characterization data (geology, hydrogeology, contaminant distribution, migration pathways and potential human receptors) to provide

a framework for selecting pathways for quantitative analysis in this HHRA. The CSM is shown graphically in Figure 4.

The contaminated soil at the Site had been previously excavated and backfilled with clean soil. Therefore, the CSM identifies groundwater beneath the Site as the only source of chemical contamination. Groundwater and ambient air are identified as transport media. Chemicals (BTEX) detected in groundwater can volatilize and able to travel by diffusion toward the land surface, and enter buildings or ambient air. Here they may impact on-site human receptors via inhalation.

BTEX in groundwater can also migrate off-site and discharge into surface water bodies such as the lagoon located approximately 1/2 a mile downgradient from the Site. Groundwater chemical transport modeling was conducted in this study to determine if BTEX detected in groundwater underneath the Site would reach the lagoon in a time period of 30 years.

3.0 Quantitative Modeling

Computer models were used to quantitatively assess chemical transport in the groundwater and air at the Site. The purpose of modeling was to estimate current and future exposure point concentrations for potential human receptors. This study was also conducted to determine whether the chemicals detected in groundwater would reach the lagoon located approximately 1/2 a mile downgradient from the Site in a time period of 30 years. The following computer modeling and quantitative calculations were performed in the evaluation:

- Groundwater flow modeling,
- Groundwater chemical transport modeling;

- Estimation of emission rates of chemicals from affected groundwater to the atmosphere; and
- Air quality modeling to estimate on and off-site chemical concentrations in ambient outdoor and indoor air due to volatilization from affected groundwater.

This section describes the methodology used and the assumptions made in groundwater flow and chemical transport modeling and air quality simulations.

3.1 Groundwater Flow Modeling



3.1.1 Model Description

The U.S. Geological Survey (USGS) Modular Three-Dimensional Finite-Difference Ground-Water Flow Model (MODFLOW) (USGS 1988) was used to simulate groundwater flow within the model domain beneath the Site. MODFLOW is a finite-difference flow model designed to simulate in two dimensions (and in quasi-3-dimensional form), the response of a water-yielding unit to imposed stress conditions. MODFLOW may be used to simulate confined or unconfined (water table) conditions or a combination of both conditions. This model may also be used to simulate heterogeneous and anisotropic geologic units as well as geologic units with irregular boundaries. MODFLOW can be used to simulate a single-or a multi-layer system. It also permits leakage from streams and confining beds, variable flux boundary conditions and well-discharge simulations.

For this study, MODFLOW was used to evaluate steady-state groundwater flow under ambient conditions. The model domain used in groundwater flow and chemical transport modeling is shown in Figure 5.

3.1.2 Overview of Modeling Procedures

Groundwater flow modeling was accomplished through the following steps:

- 1) Conceptualizing a hydrogeologic flow regime;
- 2) Designing a finite-difference grid system;
- 3) Assigning model boundary conditions;
- 4) Assigning a hydraulic conductivity to aquifer materials; and
- 5) Calibrating the computer model using field-measured data.

These modeling steps are described in the following sections.

3.1.2.1 Hydrogeologic Flow Regime

The model domain illustrated in Figure 5 consists of a 2,950-ft by 2,950-ft area that includes the Site and areas to the north of the Site.

The depth of groundwater beneath the Site ranges approximately between 8 and 9 ft. Groundwater flows toward the north/northwest direction beneath the Site. The average hydraulic gradient is about 0.007 ft/ft beneath the study area.

For modeling purposes, it was assumed that the shallow groundwater zone beneath the study area consists of a single unconfined layer and is generally comprised of fine to medium grained sandy materials. The thickness of this layer was assumed to be equal to 25 feet below ground surface (bgs).

3.1.3 Finite-Difference Grid System

The model domain was subdivided into a uniform finite-difference grid covering an area with dimensions of 2,950 ft by 2,950 ft (Figure 5). The grid is comprised of 67 ft - by 67-

ft cells arranged in 45 rows and 45 columns. By convention, the model solution nodes are considered to be located at the center of each cell.

3.1.4 Model Boundary Conditions

Water level data from monitoring wells located within the study area indicate that the groundwater flow direction underneath the Site is generally toward the north and northwest (STE 1993) directions. Based on the results of previous water level measurements, the groundwater flow gradient is relatively consistent and does not change significantly with time.

Accordingly, a second-order general head boundary condition (GHB) was used along all four boundaries of the model domain. This boundary condition specifies that groundwater enters the model domain at a rate that is a function of the hydraulic conductivity of the sediments at the boundary, the cross-sectional area of the flow through the cell, and the hydraulic gradient at the edge of the model domain. Thus, flow conditions are considered to be continuous across the model boundary. The boundary heads rise and fall based on flow conditions within the model domain. The GHB along the boundaries of the model domain specifies a hydraulic gradient across each boundary which remains constant.

3.1.5 Hydraulic Conductivity of Aquifer Materials

A review of the lithologic logs of sediments beneath the Site indicate that saturated sediments beneath the Site is composed of fine to medium grained sand. Based on Freeze and Cherry (1979), the hydraulic conductivity of fine grained to clean sand ranges between 2.8 ft/day to 28 ft/day. In conducting groundwater modeling, the hydraulic conductivity was assumed to be equal to 15 ft/day

3.1.6 Model Calibration

Model calibration was performed to establish the model as adequately representing the groundwater flow system. The model was calibrated using water level measurement data from individual observation wells from the groundwater monitoring event held in 1993.

The groundwater flow model was calibrated by adjusting hydraulic input parameters (e.g., boundary conditions) and comparing the resulting simulated values with observed groundwater elevations at each monitoring well location. Table 8 presents a comparison between the average measured groundwater elevations and simulated groundwater elevations at monitoring well locations predicted by the calibrated groundwater flow model.

3.2 Groundwater Chemical Transport Modeling

3.2.1 Model Description

Chemical transport in groundwater was simulated using MT3D, a modular three-dimensional transport model for simulation of advection, dispersion and chemical reactions of contaminants in groundwater systems developed by S.S. Papadopoulos & Associates, Inc. (Zheng 1992). MT3D is a finite-difference transport model that uses a mixed Eulerian-Lagrangian approach to the solution of three-dimensional advective-dispersive-reactive equations in the method of characteristics, the modified method of characteristics, and a hybrid of the two methods, making it uniquely suitable for a wide range of field problems.

MT3D can be used in conjunction with any block-centered finite-difference flow model such as MODFLOW and is based on the assumption that the flow field is not

measurably affected by any change in the concentration field, allowing separate conceptualization and calibration of a flow model.

Water-quality simulations were accomplished in two steps. In the first step, MODFLOW was run to generate the potentiometric head distribution for the single-layer system. The simulated hydraulic heads and other related flow terms were saved to a data file. In the second step, MT3D was run to simulate the chemical transport. MT3D retrieves the hydraulic heads and the flow and sink/source terms saved by the flow model, automatically incorporating the specified boundary conditions.

3.2.2 Chemical Transport Processes

Advection (flow with the groundwater) is the dominant transport mechanism of dissolved chemicals in groundwater. The two other primary processes that can influence the distribution of chemicals in groundwater are dispersion and sorption. Dispersion results from small-scale variations of groundwater flow velocity and causes spreading of chemicals in a transverse direction or in the direction of groundwater flow. The process of sorption of chemicals onto sediments impedes the transport of those chemicals through soil and groundwater. The effects of sorption were simulated using the retardation coefficient, which is the ratio between calculated groundwater velocity and the apparent chemical velocity in a particular porous medium. The following sections describe how dispersion and sorption processes were simulated in the chemical transport modeling.

3.2.2.1 Dispersion

The dispersion process is responsible for the spreading of contaminants over a greater region than would be predicted solely from the groundwater velocity vectors. Dispersion occurs both longitudinally and transverse to the flow direction. In this simulation, the porous

medium was assumed to be isotropic, and molecular diffusion was considered to be negligible relative to dispersion. Input data that controls the dispersion process include values of longitudinal and transverse dispersivity of the water-yielding sediments. Actual measurement of dispersivity values requires intensive field studies and such field data were not available. For modeling purposes, the saturated sediments beneath the Site were assigned values of 45 and 4.5 feet for longitudinal and transverse dispersivity, respectively.

3.2.2.2 Retardation (Sorption)

MT3D assumes that retardation of contaminant transport is mainly due to sorption, which refers to the mass transfer process between the contaminants dissolved in groundwater (aqueous phase) and the contaminants sorbed on the porous medium (sorbed phase).

The functional relationship between sorbed and dissolved concentrations, called a sorption isotherm, is classified in MT3D in three types: linear, Freundlich and Langmuir. Linear sorption was used in this simulation. The linear sorption assumes that there is a linear relationship between the sorbed concentration and the dissolved concentration.

The retardation of a concentration front in groundwater relative to the bulk mass of water is described by the retardation factor (R) in the following equation (Zheng 1992):

$$R = 1 + \frac{\rho}{\eta} K_d \quad (1)$$

where:

- R = retardation factor (dimensionless);
- ρ = bulk mass density (lbs/ft³);
- η = effective porosity (dimensionless); and

K_d = soil-water partition coefficient (ft^3/lbs).

This approach is based on the assumption that the sorption process is controlled by the organic carbon content of the porous medium. The values of K_d and R used in the modeling are shown in Table 9 for each chemical simulated.

3.2.3 Chemical Source Assumptions Used in Transport Modeling

Important factors in simulating chemical transport in groundwater are the identification of the chemical source area(s) and the rate and duration of release of each chemical into the groundwater flow system.

MT3D was used to simulate future chemical concentration distribution in groundwater (after 30 years), assuming that the concentrations of chemicals in groundwater at the on-site monitoring well locations will remain constant. The use of a non-diminishing source term constitutes a conservative assumption which would be expected to result in an overestimation of future chemical concentrations in groundwater. The average concentrations of the chemicals at the six monitoring wells measured since April 1991 were determined and used as the initial conditions in the simulations (see Tables 2 through 7). It was then conservatively assumed that these chemicals would persist at these same concentrations over the next 30 years.

The model was then used to simulate chemical transport under steady-state groundwater flow conditions for a period of thirty years, based on the previously stated assumptions. Volatilization and biodegradation processes which would be expected to significantly reduce chemical concentrations in groundwater over time, were not included in the simulations

3.2.4 Chemical Transport Simulations

As stated earlier, MT3D was used to simulate future chemical concentrations in groundwater (after 30 years), assuming that the concentrations of chemicals at the on-site monitoring wells will remain constant. Given this conservative assumption, the estimated future chemical concentrations in groundwater predicted by MT3D represent a worst-case scenario, which assumes that no future groundwater remediation or source removal actions will be implemented, and also neglects natural processes such as biodegradation and volatilization which would tend to cause concentrations to decrease over time.

One of the main objectives in this study was to determine whether the chemicals detected in groundwater will reach the lagoon located approximately 1/2 a mile (2,600 ft) downgradient from the Site. Figures 6 through 9 depict the configurations of the benzene, toluene, ethylbenzene and xylene plumes after a period of 30 years. The figures show that benzene is the fastest moving chemical in groundwater underneath the Site. As indicated by the extent of the benzene plume, after 30 years, the leading edge (corresponding to 2 ppb) will migrate only 1,500 ft downgradient from the Site. Therefore, it can be concluded that even after 30 years of simulation, the chemicals will not migrate into the lagoon. Thus, the groundwater contamination beneath the Site will not impose a threat to any form of sensitive habitat in the lagoon.

In order to evaluate the sensitivity of the MT3D model to the hydraulic conductivity of the aquifer materials, the hydraulic conductivity was increased from 15 ft/day to 20 ft/day. However, as indicated by Figure 10, the leading edge of the benzene plume, after 30 years, will migrate only 2,000 ft downgradient from the Site. This indicates that even with an increased hydraulic conductivity of 20 ft/day, benzene which is the fastest moving chemical, will not migrate into the lagoon.

3.2.5 Estimation of Chemical Emission Rates from Groundwater

Steady-state surface vapor emissions from shallow groundwater underlying the Site were estimated for BTEX using a model developed by Farmer et al. (1980). Farmer's model is a modified application of Fick's Law in which the tortuosity factor of Millington and Quirk (1961) takes into account the reduced flow area and the increased flow pathway of diffusing gas in partially saturated soil.

Farmer's model for the emission rate calculation is:

$$E_i = D_{air} \left(\frac{C_v - C_i}{L} \right) \left(\frac{P_a^{10/3}}{P_t^2} \right) \quad (2)$$

where:

- E_i = estimated emission rate of chemical i ($\text{mg}/(\text{m}^2\text{-sec})$);
- D_{air} = chemical air diffusion coefficient (m^2/sec);
- C_v = chemical concentration in vapor phase at depth L (mg/m^3);
- C_i = gas phase chemical concentration immediately above the soil surface (mg/m^3);
- L = the thickness of the overlying soil cover in (m);
- P_a = air-filled porosity of the soil cover in (m^3/m^3); and
- P_t = total porosity of the soil cover in (m^3/m^3).

Chemical property values used in the calculation are listed in Table 10, while soil property values are listed in Table 11

The thickness of the overlying soil cover, or the depth to the top of the aquifer (depth to groundwater), ranges approximately between 8 and 9 ft. For simplicity, L was conservatively assumed to be 2.5 m (8.2 ft) everywhere beneath the study area.

In keeping with the conservative nature of this evaluation, it was assumed that C_i was equal to zero. The vapor concentration of the chemicals in the unsaturated soils above the capillary fringe, C_v , was estimated from groundwater concentrations using Henry's Law:

$$C_v = H \times C_w \quad (3)$$

where:

- C_w = chemical concentration in groundwater in mg/m^3 ;
- H = dimensionless Henry's Law coefficient.

Table 10 lists Henry's Law and air diffusion coefficients for BTEX.

To facilitate chemical vapor emission rate calculations, SOMA developed a computer program to calculate emission rates using Farmer's model for each cell in the finite-difference grid used in the contaminant transport modeling. The program reads the groundwater chemical concentration calculated by MT3D for each cell in the finite difference grid, and can calculate and sum emission rates over any area(s) of interest (i.e., one or more specified blocks of finite-difference grid cells). This program was used to calculate the 95% Upper Confidence Limit (UCL) of the emission rates for each chemical from groundwater in both the on-site and adjacent off-site areas underlain by the contaminant plume (Table 12). The mass flux of the chemicals from each cell was also calculated by multiplying the emission rate from each cell with the area of each cell (67 ft by 67 ft) in the MT3D model domain. The total mass flux from both on-site and

adjacent off-site areas underlain by the contaminant plume was calculated by summing the individual mass fluxes from each cell in the model domain (Table 14).

3.2.6 Air Dispersion Modeling

SOMA used two models to estimate chemical concentrations in ambient outdoor and indoor air associated with volatilization of chemicals from contaminated groundwater based on their emission rates calculated as described above. To estimate chemical concentrations in on-site indoor air for current and future-use scenarios involving occupational exposure inside buildings constructed over the groundwater contaminant plume, a simple mass-balance indoor mixing model was used (Daugherty 1991). For areas overlying contaminated groundwater, we used the "box model" described by Pasquill (1975). The box model is a steady-state analytical mass-balance model which was used to estimate concentrations of BTEX in ambient outdoor air under both current and future use scenarios. These models are described in the following subsections.

3.2.6.1 Indoor Air Quality Model

Indoor air concentrations of BTEX were estimated using the 95% UCL of the emission rates calculated for these chemicals as described in Section 3.2.5. This was done by using a simple mass-balance mixing model (Daugherty 1991). This model is based on the following assumptions:

- Vapor-phase chemical emission rates from groundwater are constant through time (steady-state assumption);
- Chemical vapors emitted from groundwater beneath a building are uniformly and instantaneously mixed within the entire air space within the building; and
- Indoor air is exchanged with clean outdoor air (zero chemical concentration) at a constant rate.



The model uses the following mass balance equation to estimate the chemical concentration in indoor air resulting from vapor-phase emissions:

$$C_{in} = \frac{bxExA}{Q} \quad (4)$$

where:

- C_{in} = chemical concentration in indoor air (mg/m^3);
- b = attenuation factor (unitless);
- E = 95% UCL of the chemical emission rates from groundwater ($\text{mg}/\text{m}^2\cdot\text{s}$);
- A = area covered by building (m^2); and
- Q = ventilation rate (m^3/s).

An attenuation factor of 0.1, representing an order-of-magnitude attenuation of chemical emission rates, was used to account for the effects of the building foundation (i.e., concrete slab construction). The ventilation rate, Q , was calculated assuming an exchange rate with outside air of 120 exchanges per day or 5 exchanges per hour:

$$Q = \frac{AxhxR}{C_f} \quad (5)$$

where:

- h = interior height of building (6 m),
- R = exchange rate (5 hr^{-1}); and
- C_f = unit conversion factor (3600 s/hr).

Estimated on and off-site indoor air concentrations, under present and future conditions are presented in Table 12.

3.2.6.2 Box Model

The box model is a control volume approach used to calculate outdoor air concentrations (Pasquill 1975). This model assumes steady and uniform conditions of dispersion, so that emissions are uniformly distributed throughout a "box" defined by the area of the source and the mixing height.

The box model equation is:

$$C_i = \frac{Q_i}{\frac{H}{2} \times W \times U} \quad (6)$$

where:

- C_i = the outdoor air concentration for chemical i (mg/m^3);
- Q_i = the mass flux rate of the chemical i (mg/sec);
- H = height of the box (mixing height) (m);
- W = cross wind width of the area source (m); and
- U = annual average wind speed (m/sec).

The mass flux rate was calculated by:

$$Q_i = E_i \times A_i \quad (7)$$

where:

- E_i = emission rate of chemical i (mg/m²-sec); and
 A_i = current or simulated area of chemical i in groundwater.

The mixing height (H) was estimated using the following equation presented by Pasquill (1975):

$$X = 6.25 * Z_0 * \left[\frac{H}{Z_0} \ln\left(\frac{H}{Z_0}\right) - 1.58 * \left(\frac{H}{Z_0}\right) + 1.58 \right] \quad (8)$$

where:

- X = downwind distance aligned with wind direction along the Site (m);
H = height of the box (m); and
 Z_0 = roughness height which is used to characterize surface roughness (m).

This expression assumes a neutral stability class (D). At lower stability classes (A, B, and C), the mixing height would be larger, resulting in lower ambient concentrations. At higher stability classes (E and F), the mixing height would be smaller, resulting in higher ambient concentrations.

The height of the box represents the mean vertical height that a vapor molecule would attain after traveling across the entire length of the box. Because exposure to emissions could occur anywhere in the box, not just on the downwind edge, the average air concentration was calculated by using one-half of the calculated box height in the box-model equation. Table 13 lists the parameters and their selected values in conducting air quality modeling.

In estimating the height of the box, the roughness height, Z_0 , was chosen as 0.60 meters, corresponding to a suburban setting with medium size buildings. This

descriptor approximates Site conditions. The annual average wind speed and the prevailing direction were obtained from the RISKPRO database. The prevailing wind direction is toward the west with an average speed of 3.98 meters per second.

Using equation 6, the outdoor air concentrations for BTEX were determined. Table 14 presents the on-site chemical air concentrations detected in groundwater under current and future conditions (after 30 years) respectively. Off-site outdoor air concentrations have also been presented in Table 14 for future conditions (after 30 years).

4.0 Human Health Risk Assessment (HHRA)

The purpose of this HHRA is to provide a screening level approach to evaluate potential impacts to humans that might result from exposure to contaminants (BTEX) in the groundwater beneath the Site.

4.1 Identification of Exposure Pathways and Potential Receptors

Since the contaminated soil has been excavated and backfilled with clean soil; the only source of chemicals on the Site is the groundwater contamination. Currently, the Site and surrounding land are zoned for industrial commercial use. At the present time the only exposure pathway at the Site is inhalation of volatile emissions from groundwater. A hypothetical worker was therefore evaluated with potential exposure to the Site contaminants from inhalation of volatile emissions from the groundwater. In the future, due to downgradient chemical transport in groundwater, off-site workers will also be exposed to inhalation of volatile emissions from the groundwater. Therefore, an exposure pathway through inhalation of volatile emissions from groundwater was evaluated under future conditions, for both on and off-site workers.

4.2 Exposure Point Concentrations

Emission rates and subsequent indoor and outdoor air concentrations for BTEX were estimated according to the fate and transport modeling described in detail in Section 3.2. On-site indoor and outdoor air concentrations under current conditions have been tabulated in Tables 12 and 14 respectively. Future on and off-site indoor and outdoor air concentrations (after a 30 year period) have also been tabulated in Tables 12 and 14, respectively.

4.3 Estimating Chemical Intake (Dose)

The following equation presents the chemical intake from inhalation of volatile emissions in air for the occupational exposure scenario:

$$\text{Inhalation Intake (mg/kg-day)} = \frac{C_a * \text{InhR} * \text{EF} * \text{ED}}{\text{BW} * \text{AT}} \quad (9)$$

where:

C_a = Estimated chemical concentration in air, mg/m^3 ;

InhR = Inhalation rate, (m^3/day)
• 20 m^3/day for a worker (EPA 1991b);

EF = Exposure frequency, (days/year)
• 250 days/year for a worker (EPA 1991b);

ED = Exposure duration, (years)
• 25 years for a worker (EPA 1991b);

BW = Body weight, (kg)
• 70 kg for a worker (EPA 1991b); and

AT = Averaging time, days
= $\text{ED} * 365$ days/year for noncarcinogens
= 70 years * 365 days/year for carcinogens

4.4 Toxicity Assessment

This section describes the process of characterizing the relationship between the

exposure to an agent and the incidence of adverse health effects in exposed populations. In a quantitative carcinogenic risk assessment, the dose-response relationship of a carcinogen is expressed in terms of a slope factor (oral) or unit risk (inhalation), which are used to estimate the probability risk of cancer associated with a given exposure pathway. Cancer slope factors and unit risk factors as published by the California Environmental Protection Agency (Cal-EPA), Office of Environmental Health Hazard Assessment (OEHHA) (Cal-EPA 1994) were used in this HHRA.

For noncarcinogenic effects, toxicity data developed from animal or human studies are typically used to develop non cancerous acceptable levels, or reference doses (RfDs). A chronic RfD is defined as an estimate of daily exposure for the human population, including sensitive subpopulations, that is likely to be without appreciable risk of deleterious effects during a lifetime. The chronic reference doses, as published in IRIS (1995) or HEAST (1992), were used in this evaluation.

Table 15 summarizes the cancer slope factors, reference doses, and data source for the chemicals evaluated in this human health risk assessment.

4.5 Risk Characterization

This section describes the approach used to assess the potential carcinogenic risk and noncarcinogenic health hazard for the populations of concern represented by the chemical contaminants in the groundwater beneath the Site. Potential carcinogenic effects were estimated from the predicted intakes and chemical-specific dose-response information. Potential noncarcinogenic effects were estimated by comparing the predicted intakes of the chemicals to their respective toxicity criteria (i.e. inhalation reference doses (RfD,))

4.5.1 Noncarcinogenic Health Effects

In order to estimate the potential effects from exposure to multiple chemicals, the hazard index (HI) approach was used. The HI is defined as the summation of hazard quotients for each chemical, for each route of exposure, and is represented by the following equation:

$$HI = \frac{\text{Predicted Dose}_a}{RfD_a} + \frac{\text{Predicted Dose}_b}{RfD_b} + \frac{\text{Predicted Dose}_i}{RfD_i} \quad (10)$$

A total HI less than or equal to unity is indicative of acceptable levels of exposure for chemicals assumed to exhibit additive health effects. A HI less than or equal to 1.0 suggests that adverse health effects would not be expected following a lifetime of exposure, even in sensitive members of the population.

4.5.2 Carcinogenic Health Effects

Benzene was the only carcinogenic chemical in this study and the risk associated with it was calculated according to the following equation:

$$R_b = q_b \times E_b \quad (11)$$

where:

- R_b = Estimated incremental risk of cancer associated with benzene;
- q_b = Cancer slope factor for benzene, $(\text{mg}/\text{kg}\text{-day})^{-1}$; and
- E_b = Exposure dose for benzene, $\text{mg}/\text{kg}\text{-day}$.

4.6 Regulatory Context

The EPA, through its Memorandum on the Role of the Baseline Risk Assessment in Superfund Remedy Selection Decisions (OSWER Directive 9355.0-30) states the following:

Where the cumulative carcinogenic Site risk to an individual based on reasonable maximum exposure for both current and future land use is less than 10^{-4} , and the noncarcinogenic hazard quotient is less than 1, action generally is not warranted unless there are adverse environmental impacts.

The regulatory point of departure for cumulative Site carcinogenic risks has been 1×10^{-6} . Consequently, the range of risk between 1×10^{-6} and 1×10^{-4} is considered the acceptable risk range, depending upon Site-specific and surrounding area considerations.

4.7 Receptor Specific Risks and Hazards

The following section presents the estimated carcinogenic risks and noncarcinogenic health hazards for the hypothetical on and off-site indoor and outdoor worker (see Tables 16 and 17). Detailed dose and risk/hazard calculations are presented in Appendix 1.

4.7.1 Hypothetical On Site Indoor Worker

Under both current and future uses of the Site, on-site receptors will only be exposed to inhalation of volatile emissions in the groundwater. For the on-site indoor worker, the total excess cancer risk from inhalation of volatile emissions under current and future conditions was estimated to be equal to 5.38×10^{-7} . The total risk under both current

and future conditions are the same because the chemical concentrations in the on-site monitoring wells are assumed to be constant over the period of simulation (30 year time period). The calculated risk is well below the acceptable range of risk defined by EPA (1×10^{-6} to 1×10^{-4}).

The total noncarcinogenic health hazard under current and future conditions was estimated to be equal to 9.15×10^{-3} . The estimated hazard is well below 1.0, and would be considered negligible.

4.7.2 Hypothetical On-Site Outdoor Worker

For the on-site outdoor worker, the total excess cancer risk from inhalation of volatile emissions under current conditions was estimated to be equal to 5.59×10^{-8} . The excess cancer risk under future conditions was estimated to be equal to 6.08×10^{-8} . Both risk estimates are well below the acceptable range of risk defined by EPA (1×10^{-6} to 1×10^{-4}).

The total non carcinogenic health hazard under current and future conditions was estimated to be equal to 9.52×10^{-4} and 1.03×10^{-3} respectively, which is well below unity and is hence considered negligible.

4.7.3 Hypothetical Off-Site Indoor Worker

Under current conditions, the chemicals have not yet migrated off-site and hence do not impose any risk to off-site workers. The risk associated with the inhalation of volatile emissions under future conditions, after a 30 year period, (due to migration of chemicals off-site) was estimated to be equal to 3.21×10^{-9} . The hazard index under future conditions was estimated to be equal to 5.52×10^{-5} . Both the risk and the hazard index are negligible.

4.7.4 Hypothetical Off-Site Outdoor Worker

The risk associated with the inhalation of volatile emissions under future conditions, after a 30 year period, (due to migration of chemicals off-site) was estimated to be equal to 6.29×10^{-9} . The hazard index under future conditions was estimated to be equal to 1.07×10^{-4} . Both the risk and the hazard index are negligible.

5.0 Conclusions

The following specific conclusions were reached for the Site:

- Based on the results of the chemical transport modeling, none of the four chemicals will reach the lagoon in a time period of 30 years. Hence the chemicals detected in the groundwater beneath the Site will not impact the aquatic species in the lagoon. These simulations are considered conservative because it does not take into account the effects of biodegradation. The simulation runs indicated that the benzene plume will travel only about 1,500 ft after 30 years. Simulation runs with higher hydraulic conductivity (20 ft/day) indicated that the benzene plume will travel about 2,000 ft and will still not reach the lagoon.
- Under current and future conditions, the total carcinogenic risks for on and off-site indoor and outdoor workers were well below the range of the acceptable risk, as defined by the EPA.
- Under current and future conditions, the hazard indices for on and off-site indoor and outdoor workers were well below 1.0 and are considered negligible.

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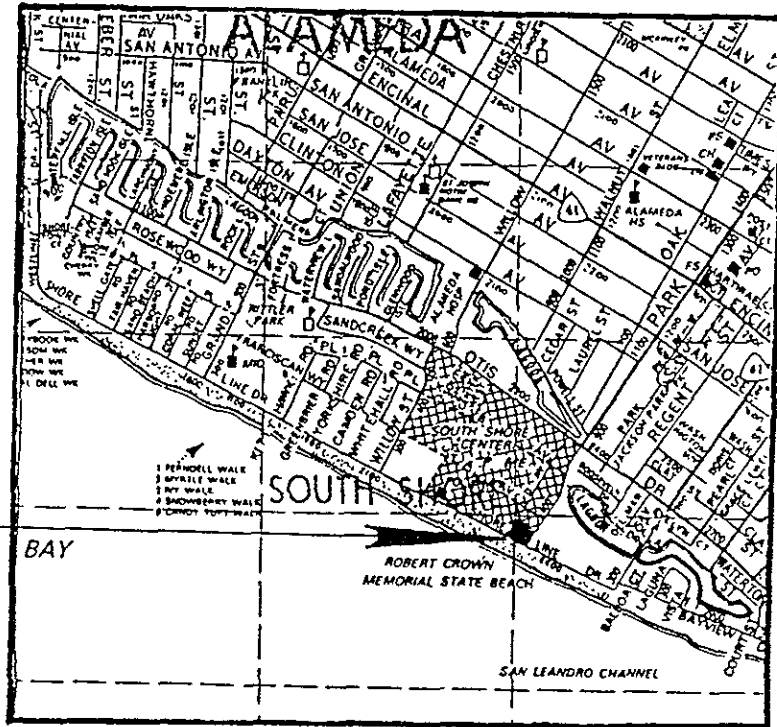
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FIGURES

Site
Location



Thomas Brothers Map 1993 Edition
San Francisco, Alameda
and Contra Costa Counties

Figure 1: Site Vicinity Map

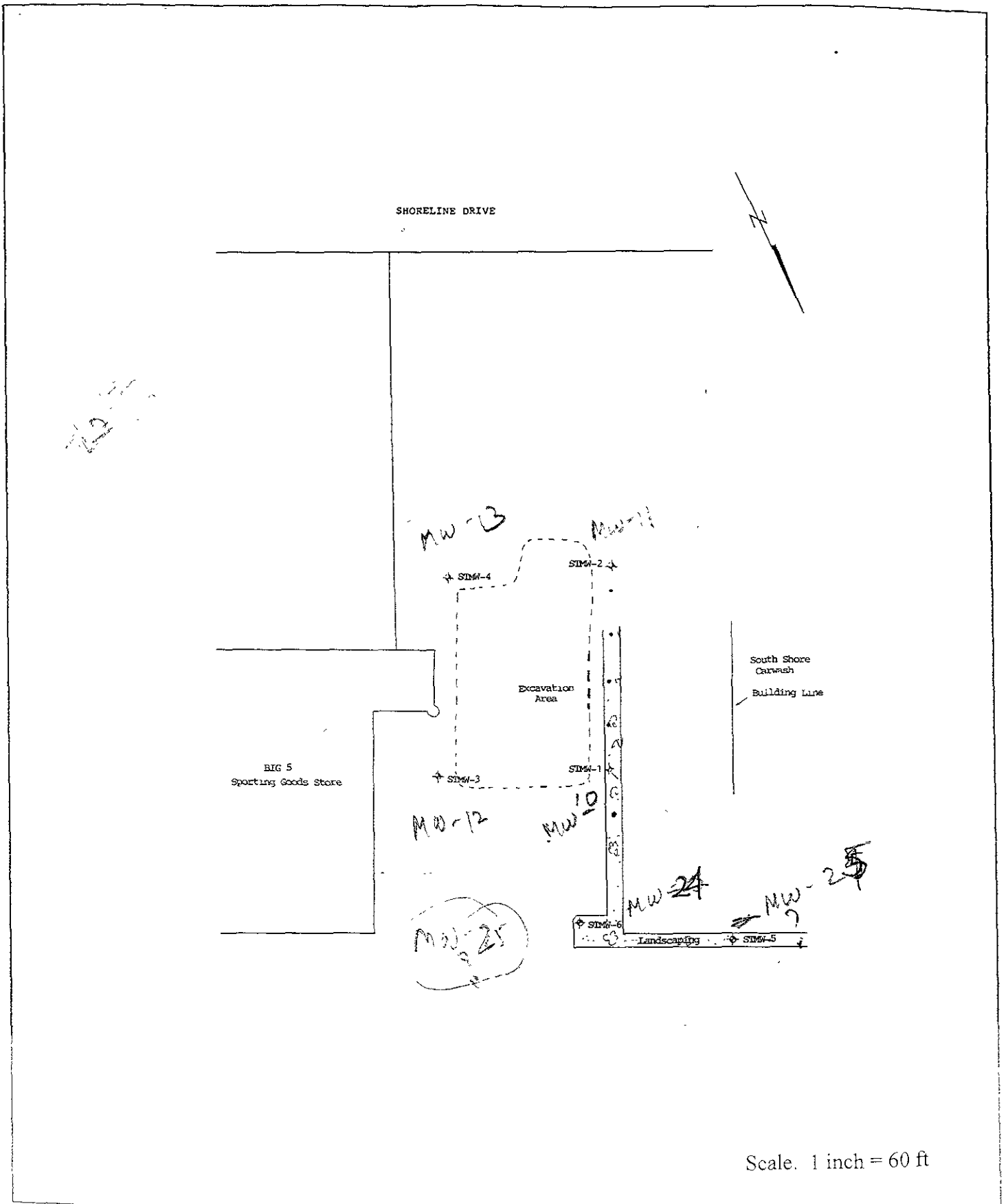


Figure 2: Location of the Soil Tech Monitoring Wells

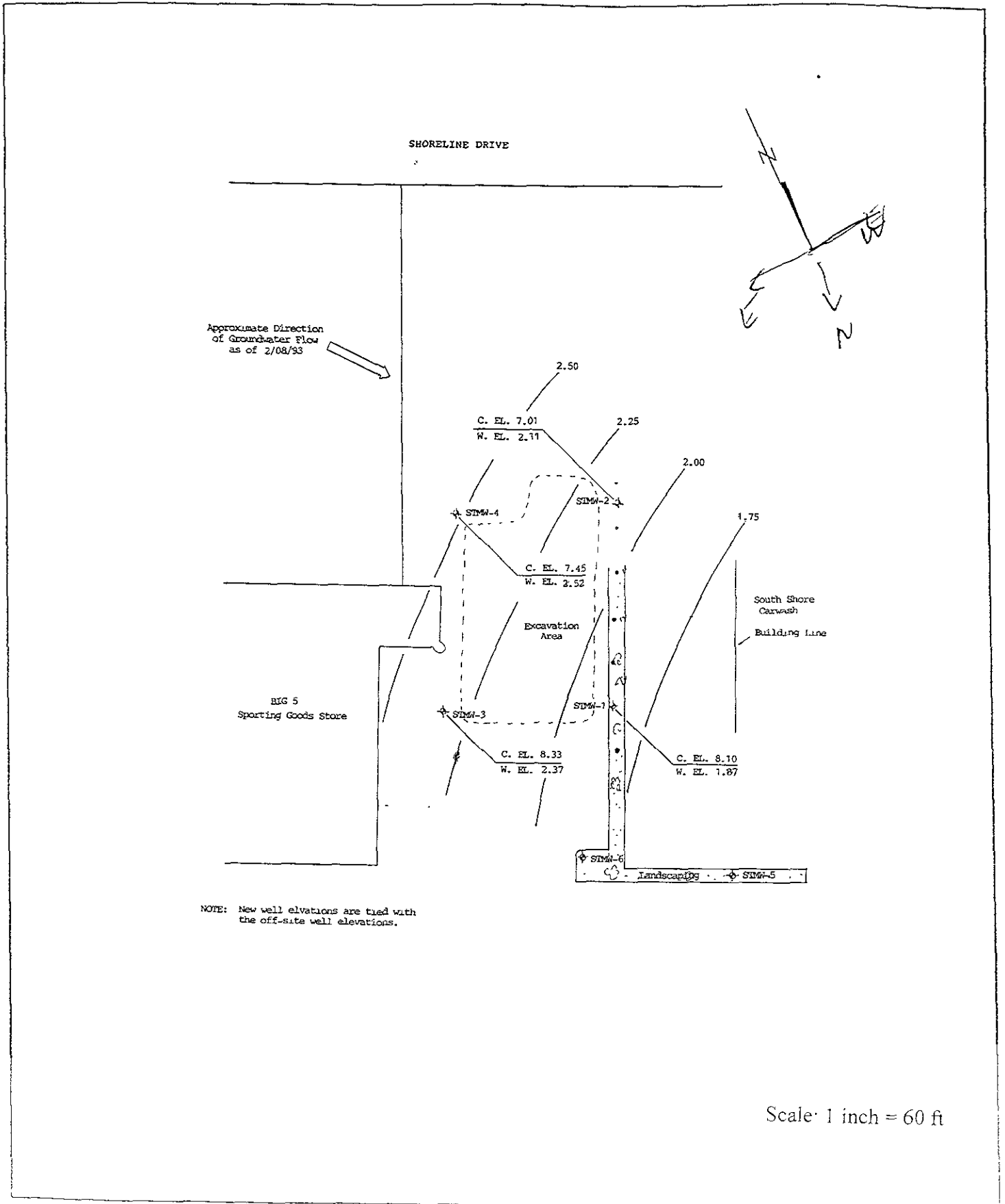


Figure 3: Groundwater Elevation Contour Map (February 1993)

Potential Primary Sources

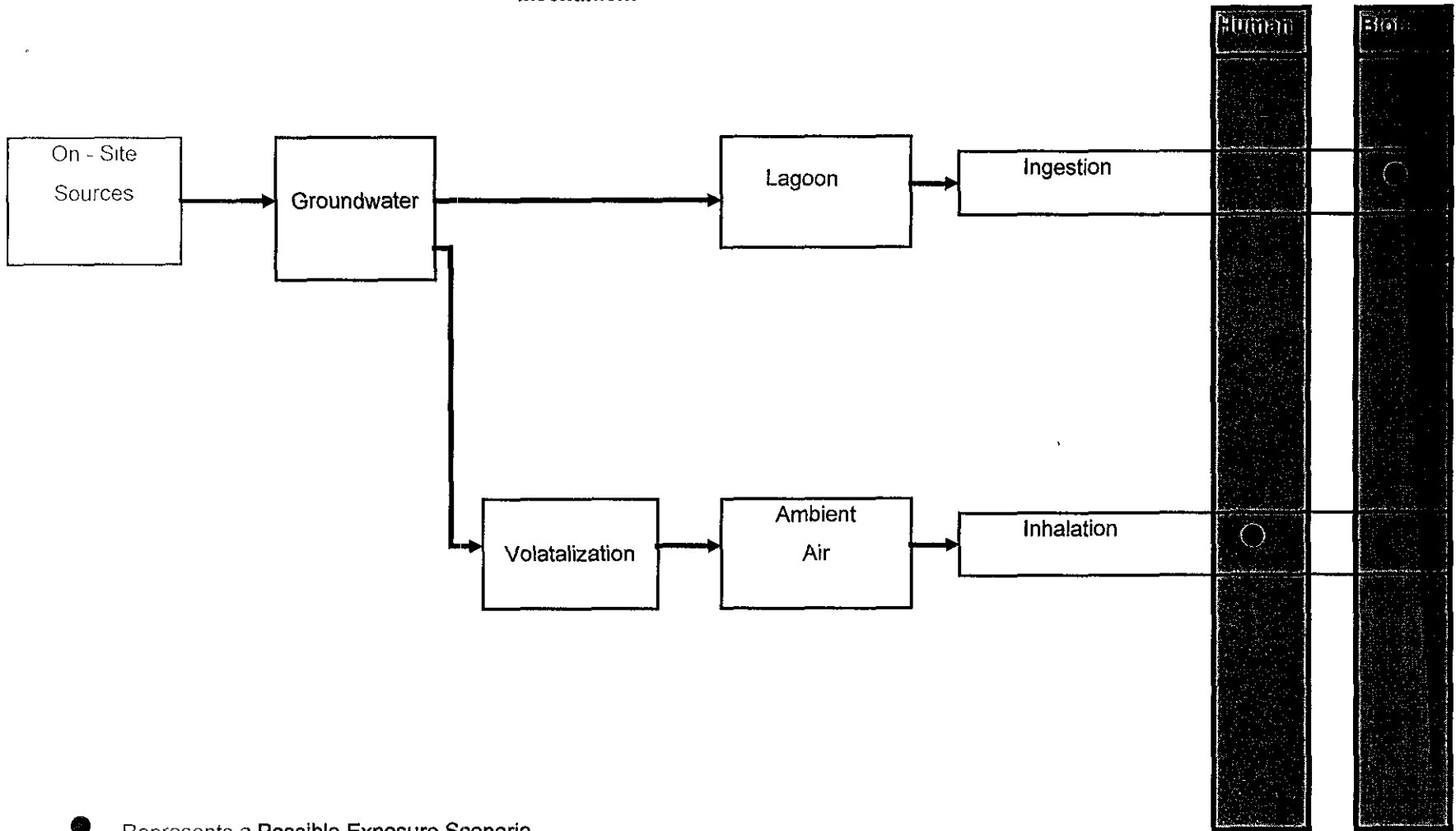
Secondary Sources

Potential Release Mechanism

Exposure Point

Exposure Route

Receptor



● Represents a Possible Exposure Scenario

Figure 4: Conceptual Site Model

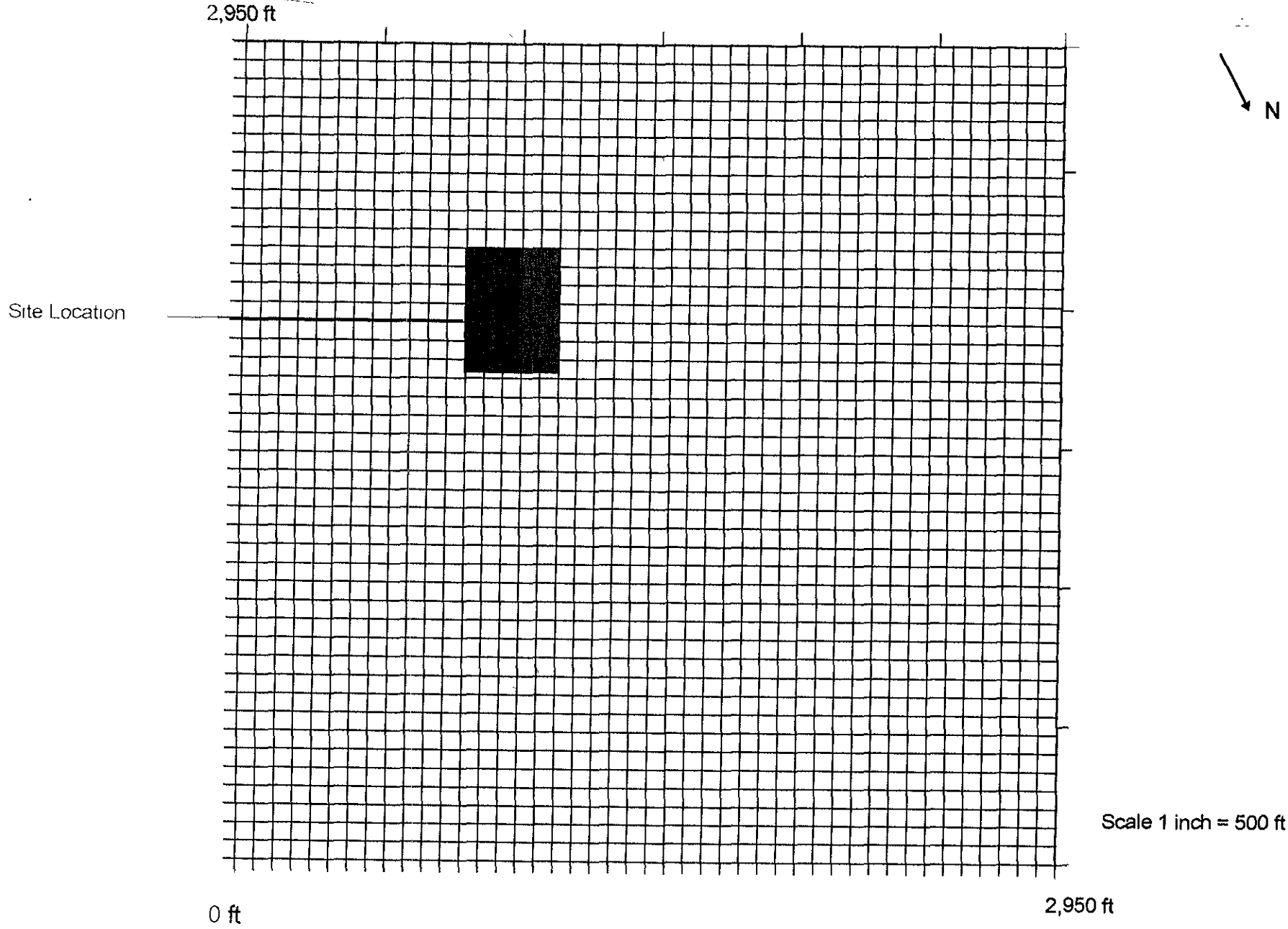


Figure 5: MODFLOW Model Domain

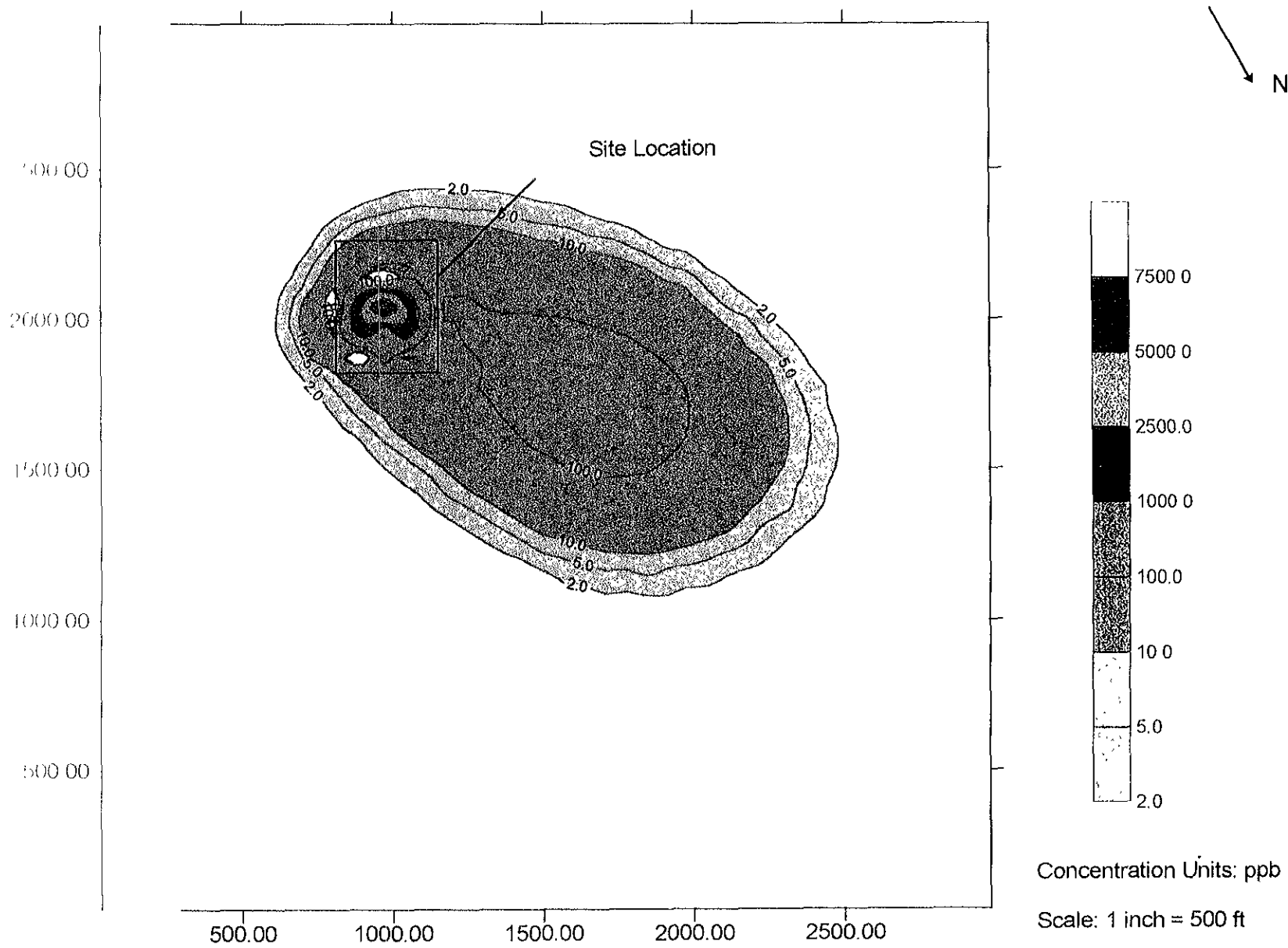


Figure 6: Configuration of the Benzene Plume After 30 Years of Simulation

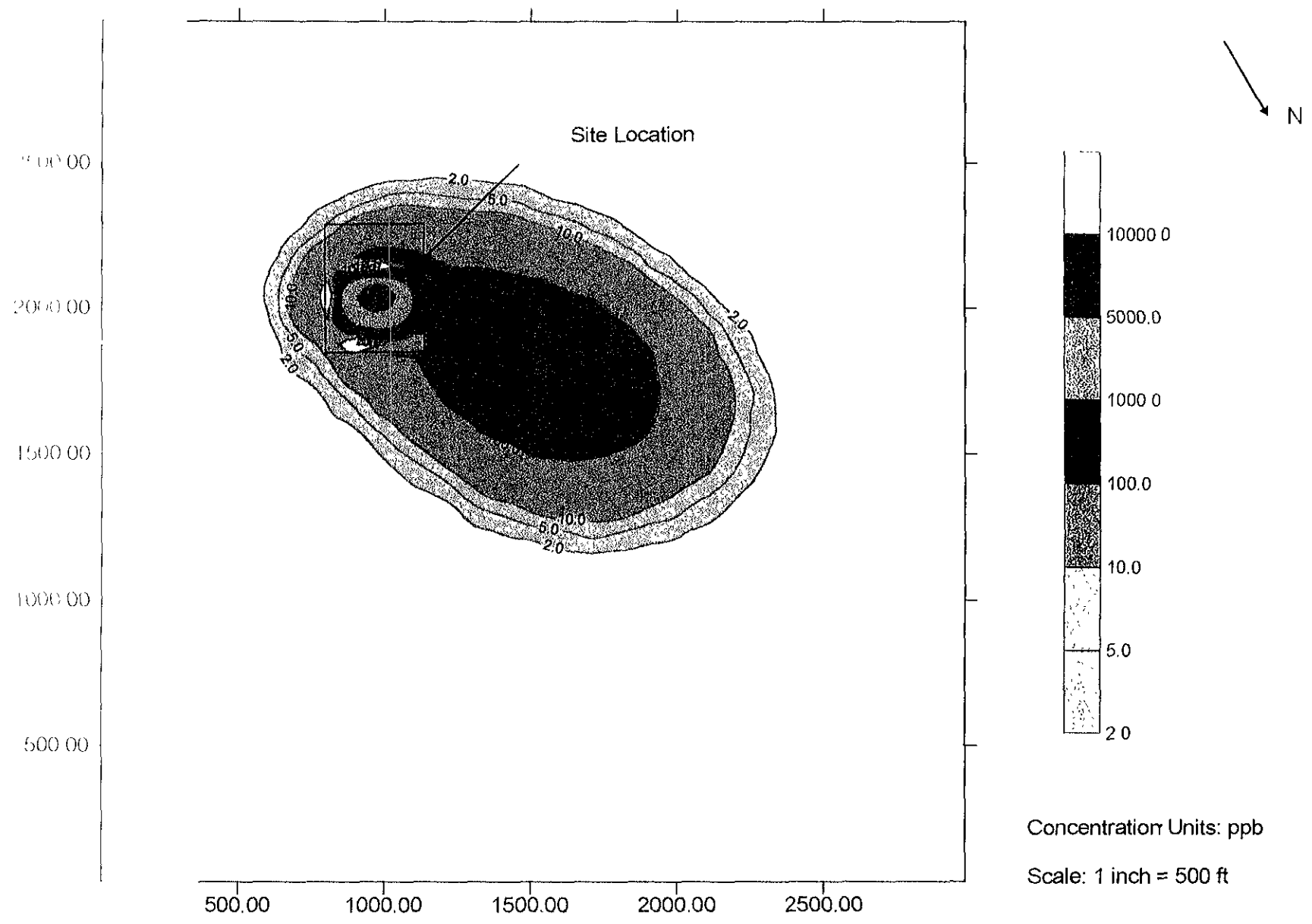


Figure 7: Configuration of the Toluene Plume After 30 Years of Simulation

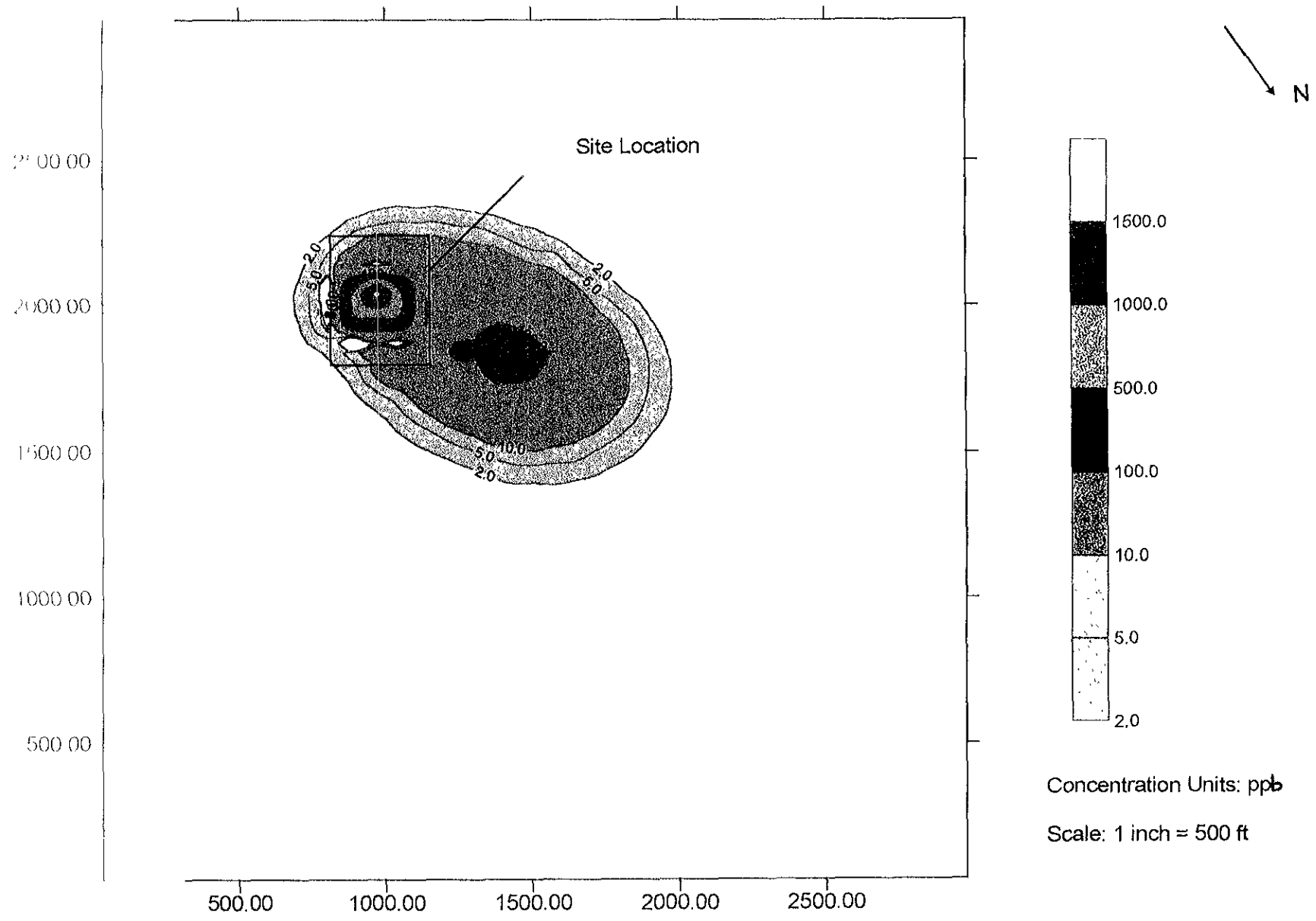


Figure 8: Configuration of the Ethylbenzene Plume After 30 Years of Simulation

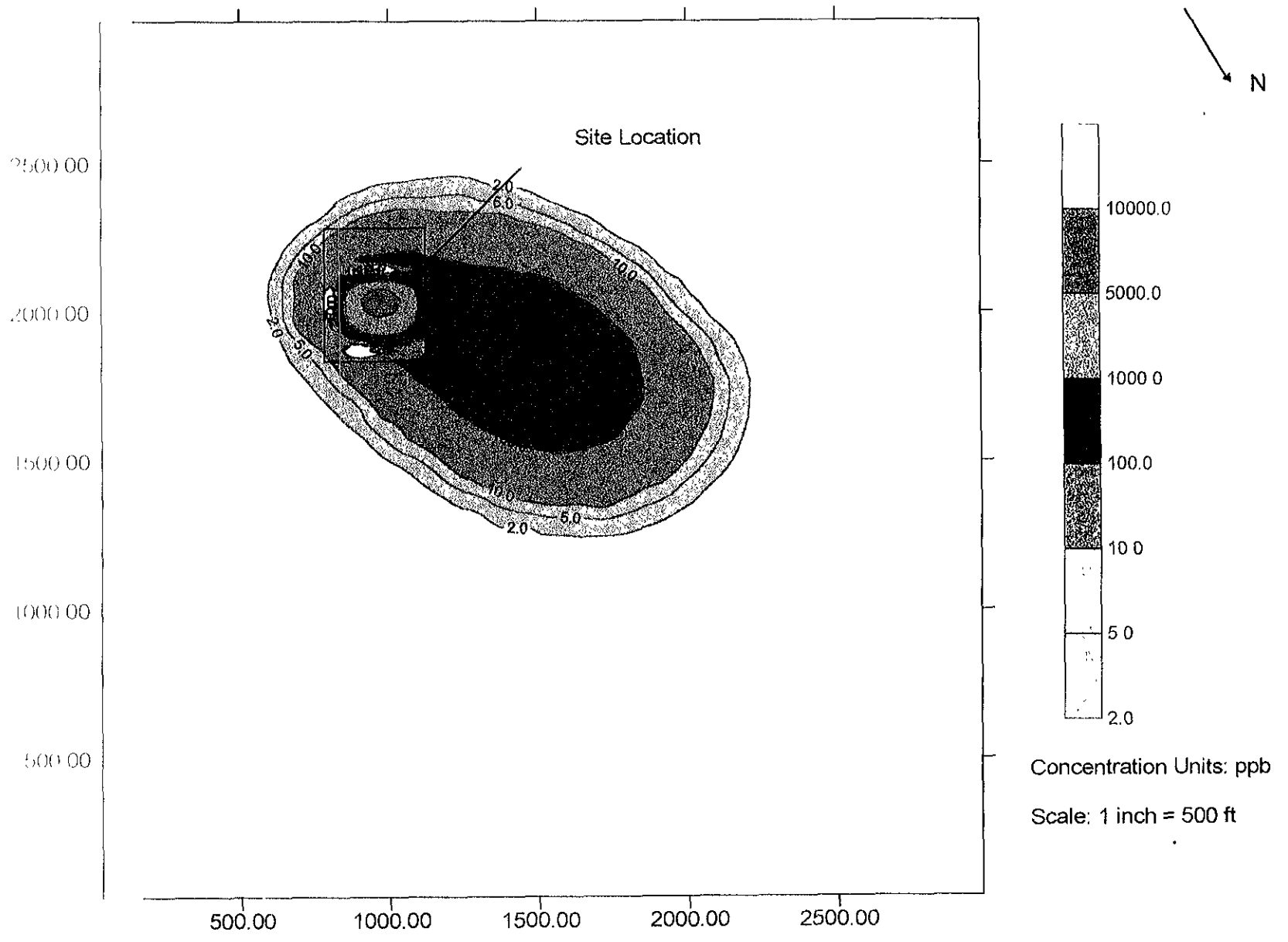


Figure 9: Configuration of the Xylene Plume After 30 Years of Simulation

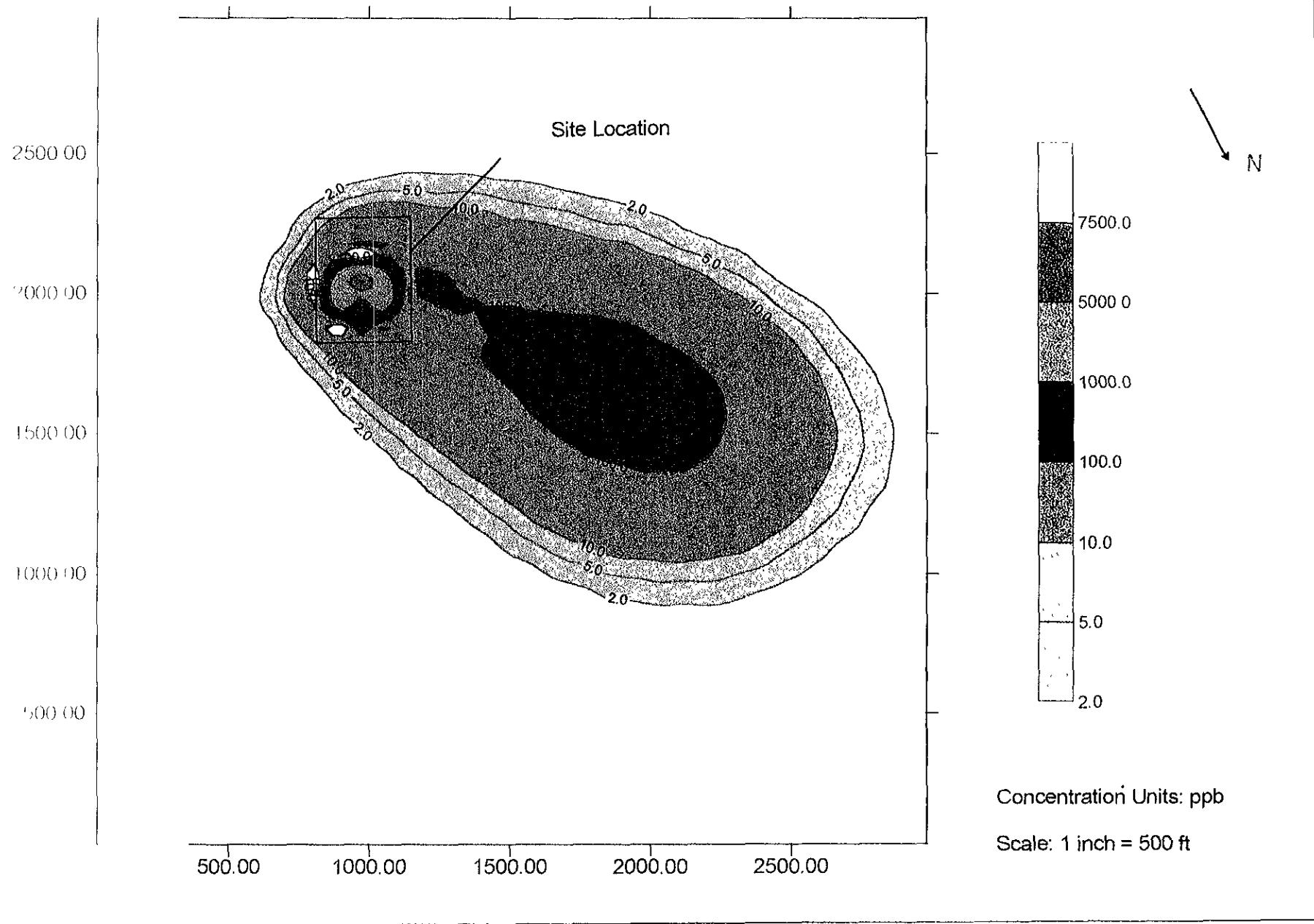


Figure 10 Configuration of the Benzene Plume After 30 Years of Simulation Using Hydraulic Conductivity of 20 ft/day

TABLES

**Table 1
Groundwater Monitoring Data**

Date	Well ID	Well Head Elevation (ft)	Depth to Water (ft)	Water Elevation (ft)
7/8/91	STMW-1	99.46	7.54	91.92
	STMW-2	98.12	6.23	91.89
	STMW-3	99.90	7.96	91.94
	STMW-4	98.78	6.90	91.88
10/21/91	STMW-1	99.46	7.63	91.83
	STMW-2	98.12	6.33	91.79
	STMW-3	99.90	7.83	92.07
	STMW-4	98.78	6.54	92.24
1/17/92	STMW-1	8.10	6.96	1.14
	STMW-2	7.01	5.69	1.32
	STMW-3	8.33	6.71	1.62
	STMW-4	7.45	6.00	1.45
4/27/92	STMW-1	8.10	6.69	1.41
	STMW-2	7.01	5.52	1.49
	STMW-3	8.33	6.86	1.47
	STMW-4	7.45	5.84	1.61
7/30/92	STMW-1	8.10	7.40	0.70
	STMW-2	7.01	6.20	0.81
	STMW-3	8.33	7.71	0.62
	STMW-4	7.45	6.64	0.81
2/8/93	STMW-1	8.10	6.23	1.87
	STMW-2	7.01	4.90	2.11
	STMW-3	8.33	5.96	2.37
	STMW-4	7.45	4.93	2.52
	STMW-5	NA	8.67	NA
	STMW-6	NA	7.88	NA
4/27/94	STMW-1	8.10	6.55	1.55
	STMW-2	7.01	5.52	1.49
	STMW-3	8.33	6.96	1.37
	STMW-4	NA	NA	NA
	STMW-5	NA	8.88	NA
	STMW-6	NA	8.13	NA
10/18/94	STMW-3	8.33	8.00	0.33
	STMW-5	NA	9.51	NA
2/14/95	STMW-3	8.33	5.64	2.69
	STMW-6	NA	7.87	NA
5/9/95	STMW-3	8.33	6.48	1.85
	STMW-6	NA	8.15	NA
11/10/95	STMW-1	8.10	7.59	0.51
	STMW-6	NA	8.97	NA
12/20/96	STMW-1	8.10	6.48	1.62
	STMW-2	7.01	5.37	1.64
	STMW-3	8.33	6.28	2.05
	STMW-5	9.52	8.91	0.61
	STMW-6	9.31	8.11	1.20

Table 2
Groundwater Analytical Results at STMW-1

Date	Benzene (ppb)	Toluene (ppb)	Ethyl Benzene (ppb)	Total Xylenes (ppb)
4/5/91	11,000	20,000	3,200	18,000
7/4/91	14,000	7,000	2,700	8,300
10/21/91	19,600	19,000	ND	16,400
1/17/92	16,000	6,800	2,600	16,000
4/27/92	720	200	500	1,300
7/30/92	1,200	770	1,100	2,740
2/8/93	210	480	510	1,200
4/27/94	3,600	3,200	1,200	5,300
10/18/94	NA	NA	NA	NA
2/14/95	NA	NA	NA	NA
5/9/95	NA	NA	NA	NA
11/10/95	82	22	37	47
12/20/96	180	330	140	300
Max	19,600.0	20,000.0	3,200.0	18,000.0
Average	6,659.2	5,780.2	1,331.9	6,958.7

Table 3
Groundwater Analytical Results at STMW-2

Date	Benzene (ppb)	Toluene (ppb)	Ethyl Benzene (ppb)	Total Xylenes (ppb)
4/5/91	ND	ND	ND	ND
7/4/91	ND	ND	ND	ND
10/21/91	4	ND	ND	ND
1/17/92	ND	ND	ND	ND
4/27/92	ND	ND	ND	ND
7/30/92	ND	2.5	0.9	11
2/8/93	NA	NA	NA	NA
4/27/94	ND	ND	ND	ND
10/18/94	NA	NA	NA	NA
2/14/95	NA	NA	NA	NA
5/9/95	NA	NA	NA	NA
11/10/95	NA	NA	NA	NA
12/20/96	ND	ND	ND	ND
Max	4.0	2.5	0.9	11.0
Average	4.0	2.5	0.9	11.0

Table 4
Groundwater Analytical Results at STMW-3

Date	Benzene (ppb)	Toluene (ppb)	Ethyl Benzene (ppb)	Total Xylenes (ppb)
4/5/91	20,000	34,000	3,600	19,000
7/4/91	11,000	17,000	1,900	8,900
10/21/91	48,500	19,000	ND	46,000
1/17/92	21,000	41,000	6,400	4,700
4/27/92	660	900	480	1,800
7/30/92	1,200	2,200	1,400	9,300
2/8/93	620	1,900	2,200	6,000
4/27/94	1,300	6,300	1,400	12,000
10/18/94	5,200	6,200	2,200	13,000
2/14/95	120	200	180	710
5/9/95	71	130	110	200
11/10/95	NA	NA	NA	NA
12/20/96	15	45	26	59
Max	48,500	41,000	6,400	46,000
Average	9,140.5	10,739.6	1,808.7	10,139.1

Table 5
Groundwater Analytical Results at STMW-4

Date	Benzene (ppb)	Toluene (ppb)	Ethyl Benzene (ppb)	Total Xylenes (ppb)
4/5/91	300.0	300.0	ND	700.0
7/4/91	ND	ND	ND	ND
10/21/91	11.0	5.0	ND	37.0
1/17/92	0.8	2.4	0.5	4.0
4/27/92	ND	ND	ND	ND
7/30/92	ND	ND	ND	ND
2/8/93	NA	NA	NA	NA
4/27/94	NA	NA	NA	NA
10/18/94	NA	NA	NA	NA
2/14/95	NA	NA	NA	NA
Max	300.0	300.0	0.5	700.0
Average	103.9	102.5	0.5	247.0

Table 6
Groundwater Analytical Results at STMW-5

Date	Benzene (ppb)	Toluene (ppb)	Ethyl Benzene (ppb)	Total Xylenes (ppb)
4/5/91				
7/4/91				
10/21/91				
1/17/92				
4/27/92				
7/30/92				
2/8/93	ND	ND	ND	ND
4/27/94	ND	ND	ND	ND
10/18/94	ND	ND	ND	ND
2/14/95	NA	NA	NA	NA
5/9/95	NA	NA	NA	NA
11/10/95	NA	NA	NA	NA
12/20/96	ND	ND	0.8	4.6
Max	ND	ND	0.8	4.6
Average	ND	ND	0.8	4.6

Table 7
Groundwater Analytical Results at STMW-6

Date	Benzene (ppb)	Toluene (ppb)	Ethyl Benzene (ppb)	Total Xylenes (ppb)
4/5/91				
7/4/91				
10/21/91				
1/17/92				
4/27/92				
7/30/92				
2/8/93	100	230	270	500
4/27/94	3,000	1,200	710	2,000
10/18/94	NA	NA	NA	NA
2/14/95	53	21	20	46
5/9/95	180	48	61	150
11/10/95	26	1.7	11	4.7
12/20/96	54	27	22	31
Max	3,000.0	1,200.0	710.0	2,000.0
Average	568.8	254.6	182.3	455.3

Table 8

**Comparison Between Measured and Simulated
Water Levels**

Monitoring Well	Water Level Elevation		Difference (ft)
	Measured (ft)	Simulated (ft)	
STMW-1	1.87	2.36	0.49
STMW-2	2.11	2.58	0.47
STMW-3	2.37	2.91	0.54
STMW-4	2.52	2.85	0.33
Average Difference Between The Measured And The Simulated Water Levels Is 0.45 ft			

*) Water Level Data From February 1993 Monitoring Event Were Used
As Calibration Targets

Table 9

Chemical Parameters Used in MT3D

Name of the Chemical	Organic Carbon Water Partition Coefficient (K_{oc}) (ft³/lb)	Distribution Coefficient (K_d) (ft³/lb)	Retardation Factor (R)
Benzene	1.6	0.0015	1.5
Ethylbenzene	4.3	0.0039	2.4
Toluene	2.5	0.0023	1.8
Xylene	3.4	0.0031	2.1

*)source: Groundwater Chemical Desk Reference by
John. H. Montgomery and Linda Welkom

Table 10

Chemical Property Values Used in the Emission
Rate Calculations

Chemical Name	Henry's Law Constant at 25° C (atm-m ³ /mol)	Ref	Henry's Law Constant at 25° C (Dimensionless)	Molecular Weight (g/mole)	Air Diffusion Coefficient at 25° C (cm ² /sec)
Benzene	5.59E-03	2	2.29E-01	78.11	0.0871
Ethylbenzene	8.68E-03	2	3.56E-01	106.17	0.0641
Toluene	6.74E-03	1	2.76E-01	92.14	0.0738
Xylene	5.27E-03	1	2.16E-01	106.17	0.0641

1) Groundwater Chemicals Desk Reference, John H. Montgomery and Linda M. Welkom

2) Basics of Pump and Treat, Groundwater Remediation Technology, EPA 600/8-90/0033 March 1990)

** Source Superfund Exposure Manual EPA/540/1-88/001

Table 11

Soil Property Values Used in Emission Rate Calculations*

Parameter	Description	Value	Units
p	Dry Soil Bulk Density	105	(lbs/ft ³)
Pt	Total Soil Porosity	0.3	(Dimensionless)
Pa	Air Filled Porosity	0.09	(Dimensionless)

Site Specific Values Were Not Available, Hence Values From Literature Were Used

Table 12

Estimated Indoor Air Concentrations for BTEX

Name of Chemical	On-Site Conditions				Off-Site Conditions	
	Current Conditions		After 30 Years		After 30 Years	
	95% UCL Emission Rate (mg/m ² sec)	Indoor Air Conc (mg/m ³)	95% UCL Emission Rate (mg/m ² sec)	Indoor Air Conc (mg/m ³)	95% UCL Emission Rate (mg/m ² sec)	Indoor Air Conc (mg/m ³)
Benzene	6.4E-06	7.7E-05	6.4E-06	7.7E-05	3.8E-08	4.6E-07
Toluene	9.4E-06	1.1E-04	9.4E-06	1.1E-04	6.9E-08	8.3E-07
Ethylbenzene	1.9E-06	2.3E-05	1.9E-06	2.3E-05	1.7E-08	2.0E-07
Xylene	6.4E-06	7.7E-05	6.4E-06	7.7E-05	5.0E-08	6.0E-07

In case of calculation of on-site Indoor Air, the Emission Rate under the Building was conservatively assumed to be the same under current and future conditions

Table 13**Parameters Used in Box Model**

Parameters	Definition	Value	Units
On -site			
Z	Roughness Height, California Site Mitigation Decision Tree Manual	0.6	m
U	Average Windspeed, Alameda	3.98	m/sec
X	Length of Site Along the Primary Wind Direction'	100	m
H	Height of Box	11.2	m
W	Width of the Site, Perpendicular to the Primary Wind Direction	140	m
Off- site*			
Z	Roughness Height, California Site Mitigation Decision Tree Manual	0.6	m
U	Average Windspeed, Alameda	3.98	m/sec
X	Length of Site Along the Primary Wind Direction'	360	m/sec
H	Height of Box	25.9	m
W	Width of the Site, Perpendicular to the Primary Wind Direction	455	m

*) Off -site Dimensions of the Benzene Plume Were Used in the Calculation of Off-Site Width and Length

Table 14

Estimated Outdoor Air Concentrations for BTEX

Name of Chemical	On-Site Conditions						Off-Site Conditions		
	Current Conditions			After 30 Years			After 30 Years		
	Area (m ²)	Flux Rate (mg/sec)	Outdoor Air Conc (mg/m ³)	Area (m ²)	Flux Rate (mg/sec)	Outdoor Air Conc (mg/m ³)	Area (m ²)	Flux Rate (mg/sec)	Outdoor Air Conc (mg/m ³)
Benzene	6400	2.5E-02	8.0E-06	14000	2.7E-02	8.7E-06	610000	2.1E-02	9.0E-07
Toluene	6400	3.7E-02	1.2E-05	14000	3.9E-02	1.2E-05	555200	3.3E-02	1.4E-06
Ethylbenzene	6400	7.7E-03	2.5E-06	14000	8.3E-03	2.7E-06	421600	6.3E-03	2.7E-07
Xylene	6400	2.6E-02	8.3E-06	14000	2.8E-02	9.0E-06	504880	2.2E-02	9.4E-07

Table 15

Carcinogenic and Non Carcinogenic Human Toxicity Criteria

Name of Chemical	Criteria for Noncarcinogens		Criteria for Carcinogens	
	Inhalation RfD (mg/kg-day)	Source	Inhalation Slope factor (mg/kg-day) ⁻¹	Source
Benzene	1.70E-03	c	1.00E-01	d
Toluene	1.10E-01	b	N/A	
Ethylbenzene	2.90E-01	a	N/A	
Xylene	2.00E-01	b	N/A	

a) USEPA Integrated Risk Information System, September 1995

b) Route to Route Extrapolation

c) USEPA Environmental Criteria and Assessment Office

d) California Environmental Protection Agency (Cal-EPA).

Office of Environmental Health Hazard Assessment (OEHHA)

Table 16

Summary Table of Carcinogenic Risks for Receptors of Concern

Receptor of Concern	Excess Cancer Risks Due to Inhalation of Volatile Emissions		Total Excess Cancer Risk
	Indoor Air	Outdoor Air	
Current Conditions			
On-Site Outdoor Worker	NA	5.59E-08	5.59E-08
On- Site Indoor Worker	5.38E-07	NA	5.38E-07
After 30 years			
On-Site Outdoor Worker	NA	6.08E-08	6.08E-08
On- Site Indoor Worker	5.38E-07	NA	5.38E-07
Off-Site Outdoor Worker	NA	6.29E-09	6.29E-09
Off- Site Indoor Worker	3.21E-09	NA	3.21E-09

Table 17

**Summary Table of Non Carcinogenic Health Hazards
for Receptors of Concern**

Receptor of Concern	Hazard Indices		Total Hazard Index
	Indoor Air	Outdoor Air	
Current Conditions			
On-Site Outdoor Worker	NA	9.52E-04	9.52E-04
On- Site Indoor Worker	9.15E-03	NA	9.15E-03
After 30 years			
On-Site Outdoor Worker	NA	1.03E-03	1.03E-03
On- Site Indoor Worker	9.15E-03	NA	9.15E-03
Off-Site Outdoor Worker	NA	1.07E-04	1.07E-04
Off- Site Indoor Worker	5.52E-05	NA	5.52E-05

APPENDIX 1

**Noncarcinogenic Health Hazards from Inhalation of On-Site Volatile
Emissions in Outdoor Air for a Hypothetical Occupational Scenario
(Current Conditions)**

Name of Chemical	On-Site Outdoor Air Concentration (mg/m ³)	Occupational Chemical Intake (mg/kg-day)	Inhalation RfD (mg/kg-day)	Hazard Quotient (HQ)
<i>Volatiles</i>				
Benzene	8.00E-06	1.57E-06	1.70E-03	9.21E-04
Ethylbenzene	2.50E-06	4.89E-07	2.90E-01	1.69E-06
Toluene	1.20E-05	2.35E-06	1.10E-01	2.13E-05
Xylenes	8.30E-06	1.62E-06	2.00E-01	8.12E-06
		Hazard Index		9.52E-04

**Carcinogenic Risks from Inhalation of On-Site Volatile
Emissions in Outdoor Air for a Hypothetical Occupational Scenario
(Current Conditions)**

Name of Chemical	On-Site Outdoor Air Concentration (mg/m ³)	Occupational Chemical Intake (mg/kg-day)	Inhalation Slope Factor (mg/kg-day) ⁻¹	Incremental Cancer Risk
<i>Volatiles</i>				
Benzene	8.00E-06	5.59E-07	1.00E-01	5.59E-08
		Total Risk		5.59E-08

**Noncarcinogenic Health Hazards from Inhalation of On-Site Volatile
Emissions in Outdoor Air for a Hypothetical Occupational Scenario
(After 30 Years)**

Name of Chemical	On-Site Outdoor Air Concentration (mg/m ³)	Occupational Chemical Intake (mg/kg-day)	Inhalation RfD (mg/kg-day)	Hazard Quotient (HQ)
<i>Volatiles</i>				
Benzene	8.70E-06	1.70E-06	1.70E-03	1.00E-03
Ethylbenzene	2.70E-06	5.28E-07	2.90E-01	1.82E-06
Toluene	1.20E-05	2.35E-06	1.10E-01	2.13E-05
Xylenes	9.00E-06	1.76E-06	2.00E-01	8.81E-06
		Hazard Index		1.03E-03

**Carcinogenic Risks from Inhalation of On-Site Volatile
Emissions in Outdoor Air for a Hypothetical Occupational Scenario
(After 30 Years)**

Name of Chemical	On-Site Outdoor Air Concentration (mg/m ³)	Occupational Chemical Intake (mg/kg-day)	Inhalation Slope Factor (mg/kg-day) ⁻¹	Incremental Cancer Risk
<i>Volatiles</i>				
Benzene	8.70E-06	6.08E-07	1.00E-01	6.08E-08
		Total Risk		6.08E-08

**Noncarcinogenic Health Hazards from Inhalation of Off-Site Volatile
Emissions in Outdoor Air for a Hypothetical Occupational Scenario
(After 30 Years)**

Name of Chemical	Off-Site Outdoor Air Concentration (mg/m ³)	Occupational Chemical Intake (mg/kg-day)	Inhalation RfD (mg/kg-day)	Hazard Quotient (HQ)
<i>Volatiles</i>				
Benzene	9.00E-07	1.76E-07	1.70E-03	1.04E-04
Ethylbenzene	2.70E-07	5.28E-08	2.90E-01	1.82E-07
Toluene	1.40E-06	2.74E-07	1.10E-01	2.49E-06
Xylenes	9.40E-07	1.84E-07	2.00E-01	9.20E-07
Hazard Index				1.07E-04

**Carcinogenic Risks from Inhalation of Off-Site Volatile
Emissions in Outdoor Air for a Hypothetical Occupational Scenario
(After 30 Years)**

Name of Chemical	Off-Site Outdoor Air Concentration (mg/m ³)	Occupational Chemical Intake (mg/kg-day)	Inhalation Slope Factor (mg/kg-day)	Incremental Cancer Risk
<i>Volatiles</i>				
Benzene	9.00E-07	6.29E-08	1.00E-01	6.29E-09
Total Risk				6.29E-09

**Noncarcinogenic Health Hazards from Inhalation of On-Site Volatile
Emissions in Indoor Air for a Hypothetical Occupational Scenario
(Current Conditions and After 30 Years)**

Name of Chemical	On-Site Indoor Air Concentration (mg/m ³)	Occupational Chemical Intake (mg/kg-day)	Inhalation RfD (mg/kg-day)	Hazard Quotient (HQ)
<i>Volatiles</i>				
Benzene	7.70E-05	1.51E-05	1.70E-03	8.86E-03
Ethylbenzene	2.30E-05	4.50E-06	2.90E-01	1.55E-05
Toluene	1.10E-04	2.15E-05	1.10E-01	1.96E-04
Xylenes	7.70E-05	1.51E-05	2.00E-01	7.53E-05
		Hazard Index		9.15E-03

**Carcinogenic Risks from Inhalation of On-Site Volatile
Emissions in Indoor Air for a Hypothetical Occupational Scenario
(Current Conditions and After 30 Years)**

Name of Chemical	On-Site Indoor Air Concentration (mg/m ³)	Occupational Chemical Intake (mg/kg-day)	Inhalation Slope Factor (mg/kg-day)	Incremental Cancer Risk
<i>Volatiles</i>				
Benzene	7.70E-05	5.38E-06	1.00E-01	5.38E-07
		Total Risk		5.38E-07

**Noncarcinogenic Health Hazards from Inhalation of Off-Site Volatile
Emissions in Indoor Air for a Hypothetical Occupational Scenario
(After 30 Years)**

Name of Chemical	Off-Site Indoor Air Concentration (mg/m ³)	Occupational Chemical Intake (mg/kg-day)	Inhalation RfD (mg/kg-day)	Hazard Quotient (HQ)
<i>Volatiles</i>				
Benzene	4.60E-07	9.00E-08	1.70E-03	5.30E-05
Ethylbenzene	2.00E-07	3.91E-08	2.90E-01	1.35E-07
Toluene	8.30E-07	1.62E-07	1.10E-01	1.48E-06
Xylenes	6.00E-07	1.17E-07	2.00E-01	5.87E-07
		Hazard Index		5.52E-05

**Carcinogenic Risks from Inhalation of Off-Site Volatile
Emissions in Indoor Air for a Hypothetical Occupational Scenario
(After 30 Years)**

Name of Chemical	Off-Site Indoor Air Concentration (mg/m ³)	Occupational Chemical Intake (mg/kg-day)	Inhalation Slope Factor (mg/kg-day) ⁻¹	Incremental Cancer Risk
<i>Volatiles</i>				
Benzene	4.60E-07	3.21E-08	1.00E-01	3.21E-09
		Total Risk		3.21E-09