GROUNDWATER MODEL CALIBRATION FOR A HYDROCARBON PLUME IN A SANDY, SURFICIAL AQUIFER

By

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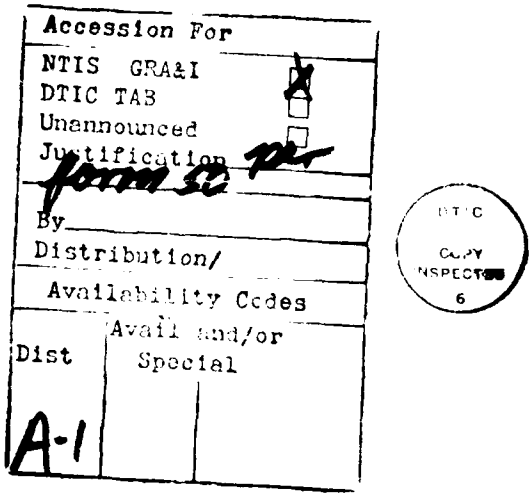
TO MY PARENTS

Lambert and Ellen Scanlan

whose love, support, and encouragement
have played such a key role in my life.



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A gasoline-contaminated surficial aquifer, the site of four years of remediation efforts, was investigated using a semi-quantitative soil extraction procedure to determine the vertical distribution of sorbed contaminants present. The effectiveness of contaminant flushing in highly contaminated soils by aquifer augmentation was demonstrated. The site was modeled using BIOPLUME II, an updated version of the USGS Solute Transport Model. Although the model was effectively calibrated to the groundwater flow through the site, the extreme vertical contaminant distribution and the variation of groundwater contaminant concentrations as a function of aquifer elevations and time prevented the

acceptable calibration of the pollutant transport model to this site. A three dimensional model should be considered.

CHAPTER I
INTRODUCTION

Groundwater is a valuable resource, and has become recognized as such over the past few years. It represents 96 percent of all fresh water resources in the United States, an estimated 36 quadrillion gallons (DeHan, 1981). However, its importance, based on use, varies significantly across the United States. In 1970, groundwater contributed 29 percent of the public water supply for the 31 eastern states and 46 percent for the 17 western states (Freeze and Cherry, 1979). These figures exclude private wells used by an estimated 40 million people in the United States, particularly in rural areas where most water is consumed without significant pretreatment (Miller, 1985). In Florida, 92 percent of all drinking water is obtained from groundwater sources (Florida Department of Environmental Regulation, 1985).

The awareness of groundwater's importance improved as demand for water was increasing, the capacity of known, economically available sources was limited, and the quality of many known sources was deteriorating from outside contamination. The problem with availability of uncontaminated groundwater was further exacerbated by

overpumping of some coastal aquifers, resulting in land subsidence and salt water intrusion.

Potential sources of groundwater contamination are numerous, and have become commonplace in our society. They include underground storage tanks. Across the country, there are an estimated 1,400,000 installed underground storage tank systems with capacities greater than 1,100 gallons, 84 percent of which are made of unprotected steel. About 50 percent of these tanks are used for petroleum products (Kosowatz, 1988), and the United States Environmental Protection Agency estimates that ten percent of these petroleum storage tanks are currently leaking. Based on benzene being one percent of unleaded petroleum products, and the current maximum contaminant level for benzene being one part per billion as established by the Florida Department of Environmental Regulation, one gallon of gasoline has the potential of contaminating over eight million gallons of groundwater (Cherry, 1987). In a 1978 study of leaking petroleum storage systems, the Petroleum Equipment Institute found 81.6 percent of tank leaks and 98 percent of piping leaks were the result of corrosion (Kost and Parish, 1986).

Over the past 15 years, significant legislation at all levels of government has been enacted to regulate or prohibit certain practices commonly linked with groundwater contamination. Although there has been progress,

significant sources of potential contamination remain, and existing contamination plumes continue to spread.

Once an aquifer is contaminated, the recommended cleanup option is dependent upon the characteristics of the contaminant, extent of the contaminant plume, physical characteristics of the site, and sound engineering practices (Nyer, 1985). At best, an aquifer cleanup operation will be expensive, difficul-, and long term. Considering the large investment of time and money for cleanup, predictive models of the groundwater system have proven extremely useful in determining relative effectiveness of plume control and remediation plans (Freeberg et al., 1987).

There have been three types of predictive models commonly applied to groundwater systems: sand tank models, analog models, and mathematical models. A difficulty with all models is readily duplicating conditions found in the field. While the sand tank models and analog models enjoyed considerable use prior to the 1960's, they fell out of favor when high-speed digital computers became available. While mathematical models have been used since the late 1800's, it has been computers that led to their widespread use (Wang and Anderson, 1982). The advent of the personal computer has brought the capability of mainframe computers to the desk top. The major limitations of the personal computer, in comparison to a mainframe, are limited data set/code size, and the speed at which the program is executed (Westly

and Robertson, 1985). With the recent development of the Operating System/2 software, the data set/code size restrictions have been reduced, and technological advances are increasing the personal computer's operating speed. These advances, coupled with the recent proliferation of modeling programs for personal computers, have made mathematical models virtually essential for all who work with groundwater and groundwater contamination problems.

While mathematical models have simplified the predictive process for groundwater contamination assessment, transport and remediation, they still require considerable site specific hydrogeologic information to be effective. They should also incorporate any biological degradation, chemical reactivity, and physical processes such as solute adsorption to and desorption from the soil.

The research described in this thesis concerned a gasoline contaminated surficial aquifer at the University of Florida, Institute for Food and Agricultural Sciences Citrus Research and Education Center (IFAS-CREC), Lake Alfred, Florida. Based on previous hydrogeologic characterization of the site, the objectives were to:

1. Identify the vertical extent of adsorbed hydrocarbons on the site,

2. Develop a water balance for the system,

3. Select a mathematical solute transport model that adequately describes the contaminant transport for the field site under study, and

4. Use water table elevations, aquifer transmissivities, and groundwater contaminant concentrations to validate the selected model.

CHAPTER II
LITERATURE REVIEW

This chapter presents a review of literature pertaining to the contamination site with its operational recovery system, and the development and application of mathematical models. The major areas of discussion are the history of the project site, the development of mathematical models, the model calibration process, and case histories of model application.

The Project Site

The University of Florida, Food and Agricultural Sciences, Citrus Research and Education Center (IFAS-CREC) is located just north of Lake Alfred, Florida, at 81^0 42.9' west longitude, and 28^0 06.1' north latitude. The facility borders on a wetland to the west which eventually drains into Lake Swoope, and the site itself is reclaimed wetland.

The area is underlain by the Hawthorne Formation, a clayey-sand confining layer in excess of 11 feet thick. The surface of this layer ranges in depth between 6.4 feet and 12.8 feet beneath the ground surface in the area under study. This layer maintains the surficial aquifer in the

sandy fill material overlying it. The water table surface generally follows the ground surface elevation, but varies by a few feet depending upon the background flow of the aquifer, the existing climatic conditions, and the volume of recycled groundwater and fresh water being sprayed on the spray field. However, the typical water table elevations vary from a maximum of 140 feet above mean sea level on the spray field to a minimum of 130 feet near the wetlands. The water table is, on average, about four feet below the ground surface. Figure 2-1 shows the physical layout of the site, and identifies the monitoring and recovery wells.

Accidental Release and Subsequent Cleanup Efforts

The following is a summary of Killan's (1987) historical overview, readers are referred to his original document for a more detailed discussion.

The University of Florida, Institute of Food and Agricultural Sciences, Citrus Research and Education Center operated an on-site petroleum refueling system consisting of a 7,000 gallon, on-grade gasoline storage tank, a 3,000 gallon underground gasoline storage tank, a 300 gallon underground diesel storage tank, and the necessary underground piping and pumps to operate the system. In May 1983, a loss of leaded gasoline was detected from the on-grade storage tank. The tank was removed from service in June 1983, and later dismantled for subsequent disposal. Air pressure tests of the tank and the underground fuel

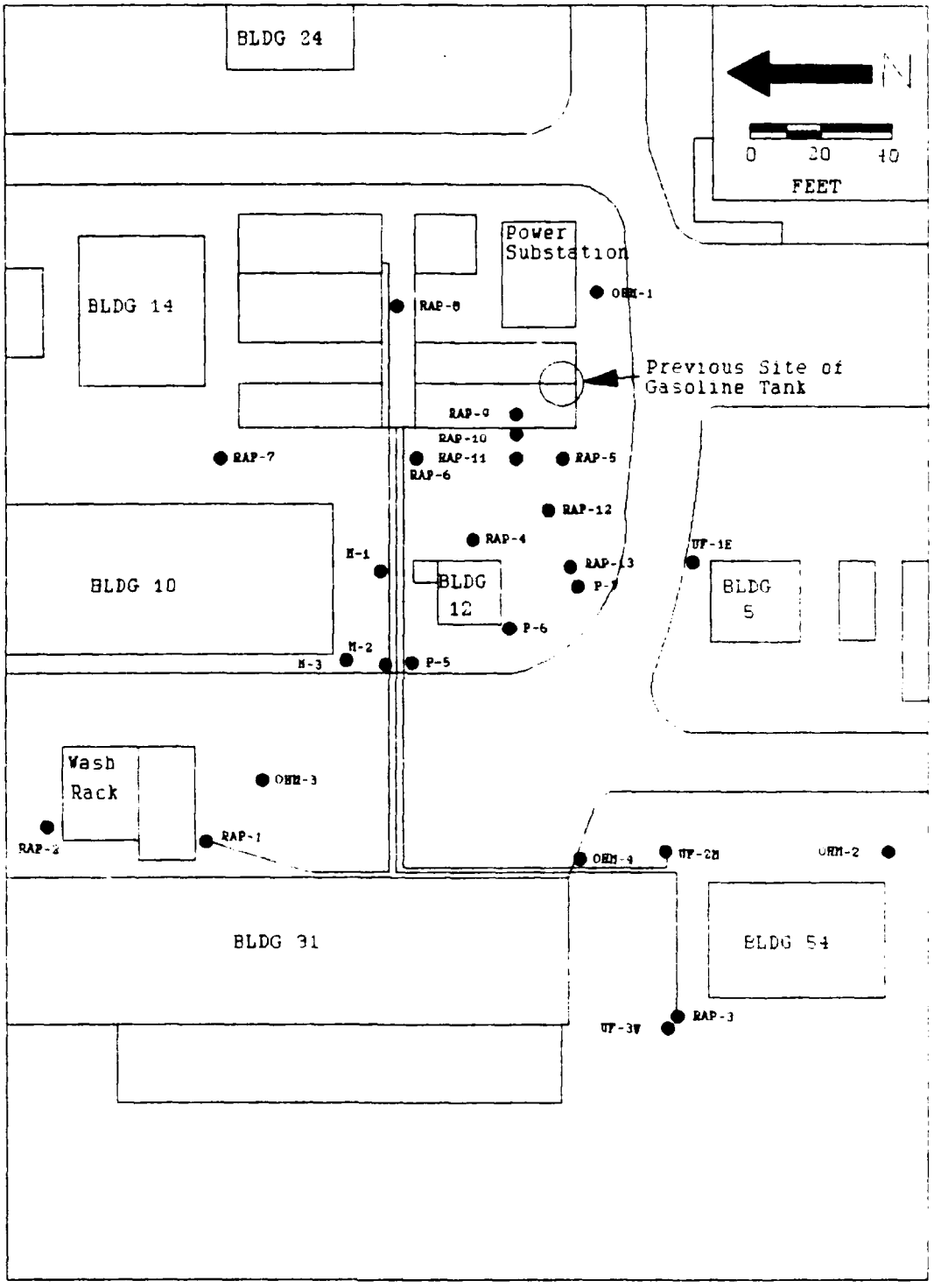

Figure 2-1. Map of Lake Alfred Study Site.

transfer lines were performed, indicating leaks, probably the result of corrosion. A review of the CREC gasoline delivery and pumping records indicated 7,500 to 8,000 gallons of gasoline were released.

Between January and May 1984, a series of 12 monitoring wells were installed to monitor the contaminant plume and facilitate recovery operations. The free product recovery operation was conducted between 17 May and 04 June 1984. Based on the benzene content of water samples taken throughout the operation, an estimated 6,000 gallons of gasoline were removed from the aquifer.

In January 1985, again following a review of their delivery and pumping records, IFAS-CREC personnel discovered a 50 gallon per day gasoline leak from their 3,000 gallon underground storage tank. Subsequently, both underground storage tanks were taken out of service in February 1985, emptied and filled with sand.

There has been virtually no free product observed in any monitoring well since May 1985.

The drinking water supply, drawn from the underlying Floridan Aquifer by a pump housed in building 12, was regularly tested for benzene and total hydrocarbons. The benzene analysis, performed by a contractor, was consistently less than one part per billion. With one notable exception, the total hydrocarbon concentration was less than one part per million. Upon investigation, the

exception was found to be the direct result of a quality control error in the laboratory. The adjacent wetlands were also periodically tested, and a detectable concentration was routinely found, but not in sufficient concentrations to indicate the contaminant plume ever reached the wetland (Killan, 1987).

Groundwater Recovery/Spray Aeration System

The groundwater recovery/spray aeration system depicted in Figure 2-1 has been in use since August 1986, except for the December 1987 addition of the small intermediate-pressure, single nozzle rotating head sprinkler near the northwest corner of the electric power substation. Since completion of the free product recovery, groundwater recovery from select wells, followed by spray aeration has continued to strip the volatile organic compounds from the water, returning the less contaminated, oxygenated water to the aquifer.

The operational groundwater restoration system can be broken down into three distinct components: the groundwater recovery system, the spray aeration system, and the aquifer augmentation system. Each component will be discussed individually.

Groundwater recovery system. The groundwater recovery system is comprised of submersible pumps (Goulds, Model 25EL10422) placed in wells RAP-1, UF-2M, and RAP-3. Each pump is controlled by a Pump Sentry controller (Model

AW100), which allows the well to pump dry, shut off for a preset time period, and then reinitiate the pump cycle. The placement of wells RAP-1 and UF-2M were made to prevent the further expansion of the contaminant plume, as well as provide recovery points in the areas of highest contaminant concentration. RAP-3 serves as a backup well for UF-2M, minimizing the threat of release of contaminated groundwater to the wetland, as well as providing a back flushing capability of the surrounding soil by drawing water from the wetland through the surrounding contaminated soil, and pumping it into the system.

For contaminants with a density less than water, the use of recovery wells and injection wells as a means of hydrodynamic plume control is well documented (Nyer, 1985). The effectiveness of these wells is further supported by the lack of significant plume movement since their operation began (Miller, 1988).

Spray aeration system. The spray aeration system consists of 30 low flow rate spray heads installed on 24 inch vertical risers distributed across the spray field as shown in figure 2-1. The droplet size produced is a function of the water pressure of the system; at low pressures, small droplets are produced, while at high pressures, a fine mist is produced. In both cases, the air/water interface area is significantly increased for a given mass of water. Since the alkylbenzenes, which compose

most of the gasoline, are highly volatile and have relatively high Henry's Law constants (Nyer, 1985), the large air/water interface results in a phase change of the contaminant from the liquid phase to the gaseous phase. In addition, the oxygen concentration gradient at the interface will result in oxygen movement from the gaseous phase to the liquid phase, thus returning an oxygen enriched, cleaned water to the aquifer, when the aerated water infiltrates the spray field and percolates to the underlying aquifer.

Aquifer augmentation system. The aquifer augmentation system consists of a double nozzle, medium intermediate-pressure sprinkler located in the center of the spray field, and the single nozzle, small intermediate-pressure sprinkler at the northwest corner of the electric power substation. These sprinklers can deliver an additional 15,000 gallons of fresh Floridan Aquifer water per day to the spray field.

Since gasoline has a density less than water and is immiscible in water, the released product will move downward under the force of gravity, wetting soil surfaces, with minor capillary forces creating some lateral spreading during the vertical movement of the plume. Once the gasoline reaches the water table, it may create a slight depression in the water table surface, but will spread as a result of elevation gradients and later, capillary forces, with small amounts of hydrocarbons dissolving in the water. Free product recovery operations will generally remove

significant amounts of the product reaching the water table, but some will remain in the soil, either adsorbed to organic material (Jury, 1986), or held between soil particles by capillary forces. However, since the non-ionic, non-polar alkylbenzenes adsorb almost exclusively to organic material, and most sand aquifers with a significant water yield contain little carbon, Cherry (1987) contends adsorption is not a significant process in delaying the contaminant movement through such an aquifer. Should the water table drop in elevation after the free product recovery is completed, the layer of adsorbed and surface tension immobilized product will remain in place (Freeze and Cherry, 1979). These perched contaminated layers are susceptible to biodegradation by native bacteria found in most soils, but as long as the layer remains, it poses further contamination threats to the underlying aquifer because small quantities of the contaminant can be released to the aquifer by the percolation of water through the contaminated zone, or more significant quantities will be released should the water table become elevated and engulf the contaminated soil region. Since the contaminant is immobilized in the soil, the driving force for release of the contaminant is the concentration gradient between the contaminated soil and the "fresh" water moving through it (Nyer, 1985). While the concentration diffusion process is not instantaneous, it is a function of the hydrocarbon solubility, the rate of

transfer from the solid phase to the aqueous phase, and the contact time between the two phases. Therefore, elevation of the water table or a continuous downward percolation of water will have a more significant effect on release of the immobilized contaminant than will an infrequent movement of water such as that resulting from a small rainfall. Additional research on the contaminant transfer from the solid to liquid phase under field conditions needs to be conducted (Cherry, 1987).

The aquifer augmentation with the fresh water sprinklers elevates the water table, provides a continuous flushing action through the soil containing the adsorbed hydrocarbons, and increases the groundwater elevation gradient across the site.

Natural Factors Affecting Groundwater Recirculation System

While the ideal conditions for modeling a groundwater system would be a static situation with neither loss nor gain of water, this is an impossible condition in the field because of natural occurrences, particularly evaporation, evapotranspiration, and precipitation.

Evaporation. Evaporation is the direct vaporization of water from a wet surface. The amount of evaporation occurring is a function of relative humidity, air temperature, and wind speed. To standardize its measurement, the National Weather Service (NWS) has adopted standard dimensions, construction materials, and operating

procedures for evaporation pans in their weather stations (Smajstrla et al., 1982). There is an NWS standard weather station operated by IFAS-CREC personnel at the Lake Alfred site, and daily measurements of pan evaporation are made.

Measured pan evaporation values from a properly maintained pan, corrected with the appropriate pan coefficient, are accurate indicators of the amount of evaporation occurring from free water surfaces and wetted solid surfaces under similar exposure conditions (Decker, 1966).

The use of sprinklers also increases the amount of evaporation occurring. The spray emitting from sprinkler heads is exposed to the same evaporative conditions during its flight through the air, but its increased air/water surface area makes it more susceptible to evaporation. Therefore, the finer the water droplets emitted, the greater the evaporation, under the same climatic and physical conditions. Water loss due to wind drift must also be considered if the drift results in depositing the water outside of the study area.

Experimentation and measurement of evaporation from different types of irrigation sprinklers has been conducted to reduce evaporative losses. Ali and Barefoot (1981) provide an overview of several noteworthy experiments. Early pivoting irrigation sprinklers were set with a trajectory angle of about 26 degrees above horizontal.

Although the evaporation was found to be a function of the existing climatic conditions, operating pressure, and nozzle size, many of these sprinklers were found to have an evaporative loss ranging between 15 and 35 percent for a 7.26 millimeter diameter nozzle to between 40 and 52 percent for a 6.32 millimeter nozzle. To reduce the evaporation from these sprinklers, their trajectory angle has been reduced to seven degrees above horizontal, thus reducing the air/water interface time (Ali and Barefoot, 1981). Low trajectory irrigation sprinklers are used on the Lake Alfred spray field.

Ali and Barefoot (1981) conducted 72 tests of low trajectory irrigation sprinklers under various climatic and operating conditions. Defining evaporative loss as "the combined loss of evaporation from the spray and the drift loss," they used the following equation for its computation:

$$\text{Loss} = \frac{\text{Sprinkler volume} - \text{Collected volume}}{\text{Sprinkler volume}} \times 100\%.$$

The loss results reported from the tests ranged between 0 and 48 percent. The data were analyzed using stepwise and least square regression procedures to provide the following model:

$$\text{Loss} = 7.95 - 0.40\ RH + 0.83\ T + 0.85\ WS + 0.03\ PR + 2.71\ RHT$$

where RH = relative humidity (%),

T = temperature (^{0}C),

WS = wind speed (kilometers/hour),

PR = pressure (kilopascals), and

RHT = riser height (meters).

This model had a square of the multiple correlation coefficient (R^2) of 0.91, a standard deviation (S) of 4.42 percent, and a coefficient of variation of 16 percent (Ali and Barefoot, 1981).

While the evaporative loss of the low pressure spray systems are less studied, they are regularly used as undertree micro irrigation systems in Florida citrus groves. In such applications, the operating pressure is low enough to produce small droplets of water. The shielding effect of the trees reduce the droplets' exposure to the wind and sun, contributing to an average application efficiency of 80 percent (Smajstrla et al., 1988).

An additional complication which may occur is the evaporative effect of the irrigation system may lower the air temperature and raises the relative humidity in the immediate area, thus reducing evaporation from the wetted ground surface (Decker, 1966).

Evapotranspiration. Evapotranspiration is the combination of evaporation and transpiration, the flow of water vapor from the interior of a plant to the atmosphere. The amount of evapotranspiration occurring is again

dependent upon the existing climatic conditions, as well as the crop canopy covering the ground.

While there have been several methods developed for predicting evapotranspiration, the easiest and most widely used is the pan evaporation method. The equation is provided below:

$$\text{Evapotranspiration} = k_c \times k_p \times \text{Pan Evaporation}$$

where k_c = crop coefficient, and

k_p = evaporation pan coefficient.

Experiments conducted in Fort Lauderdale, Florida obtained a crop coefficient of 0.9 for turfgrass. Past experiments have also shown that the evaporation pan coefficient is variable throughout the year, but under Florida conditions, 0.7 is a good year around value (Pair et al., 1983 and Jones et al., 1984).

Precipitation. Precipitation is measured at all NWS Weather Stations, so this information is readily available. Agricultural experts break down precipit.tion into effective rainfall, runoff, and percolation. Effective rainfall is the moisture temporarily stored in the soil to meet the evapotranspiration requirements of the crops, runoff is water lost over the ground surface without ever entering the soil, and percolation is the water moving below the crop root zone toward the aquifer (Jones et al., 1984). This

study will be concerned with effective rainfall and percolation.

Historical Development of Mathematical Modeling

Mathematical models have been used since the late 1800's, but it was not until the availability of high-speed digital computers in the 1960's that their use became widespread.

In 1856, French engineer Henry Darcy published his report on the water supply of Dijon, France. Included in that report were results of experiments of water flow through a sand-filled cylinder. From this, he developed the empirical relationship known as Darcy's Law. This is commonly attributed as the birth of groundwater hydrology as a quantitative science (Freeze and Cherry, 1979).

Groundwater Flow Models

Groundwater flow models are concerned strictly with the flow of water through porous media, the aquifer material. They have proven their worth in groundwater planning and management. Numerical calculations of Darcy's Law and other refinements such as the Theis equation for well drawdown have allowed groundwater flow models to become reliable predictive tools if calibrated with accurate data for the site. The information required includes aquifer parameters (porosity, transmissivity, saturated thickness,

storativity), physical conditions of the site (initial conditions, boundary conditions, locations of pumping and injection wells), and a historical database with which to calibrate the model. There are several available articles and textbooks which discuss these models in detail, including Wang and Anderson (1982), and to a lesser extent, Freeze and Cherry (1979).

Solute Transport Models

By the mid 1970's, groundwater flow models were experiencing widespread use and had become largely accepted in the groundwater community. This was also the period that groundwater contamination problems began receiving considerable attention. These factors resulted in research efforts being extended to include the modeling of physical, chemical and biological processes in groundwater contamination. The legal profession often relies on them as well, making use of solute transport models in litigation cases involving contaminated groundwater (Geraghty, 1984).

In surface waters, solute transport has been modeled using the advective-dispersion equation for many years. However, there is a significant difference between fluid flow and solute transport in surface waters and that through porous media. While all of the requirements of the groundwater flow model still apply, increased dispersion and adsorption effects, lower transport velocities, and greater aquifer heterogeneities prevent the direct translation of

the surface water advective-dispersion equation to groundwater transport. Freeze and Cherry (1979, Appendix X) provide an overview of the derivation of the advective-dispersion equation as it applies to groundwater, while Bear and Bachmat (1984) proceed through a rigorous development of the basic transport equations. Bedient et al. (1985) present an easily understood overview of solute transport modeling and the factors which affect it, targeting the basic level hydrologist, hydrogeologist, and ground water resource manager without a background in modeling.

Advection. Advection is the movement of solute within flowing groundwater. If advection is the sole force moving a solute, it will move in the direction of groundwater flow, at the seepage velocity of the groundwater, and there will be an extremely sharp concentration gradient between the leading edge of the plume and uncontaminated water. While advection is a significant force in groundwater, it should not be considered the sole source of solute movement (Beljin, 1985).

Hydrodynamic dispersion. Hydrodynamic dispersion (or dispersion) is the combination of two known physical effects. The first, and most significant effect is mechanical dispersion caused by velocity variations in magnitude and direction within the pore spaces of the aquifer on the microscopic scale, and variations in permeability on the macroscopic scale. Molecular diffusion

of contaminant from high concentrations to areas of low concentration also contributes to dispersion. While molecular diffusion will be more significant at lower velocities, it is usually considered negligible and is disregarded in groundwater flow (Bear, 1979).

While it is possible to measure in situ dispersion coefficients, it is difficult at best, and the results obtained have been of questionable reliability. As a result, dispersion is normally determined during model calibration (Beljin, 1985).

Biodegradation. It has only been in the past 15 years that sizable bacterial populations were detected in the ground below the root zone. Prior to this discovery, it was assumed to be a sterile region (Wilson et al., 1986). These microbial populations have been found to develop in microcolonies attached to the soil particle surface. Investigators have measured attached microbial populations on the order of 10^6 bacteria per gram of dry soil in surficial aquifer material, to a depth of six meters (Wilson et al., 1983 and Harvey et al., 1984).

Harvey et al. (1984) conducted their experiment in a sewage-contaminated Cape Cod, Massachusetts aquifer. They found no significant difference in the attached microbial population in the contaminated plume or in an uncontaminated section of the aquifer. However, the population of smaller, free-floating bacteria within the contaminant plume had a

strong correlation with the distance from the contaminant source. Similarly, in a southern California gasoline spill, hydrocarbon bacteria of 50,000 per milliliter of sample or more were found in wells containing free product, while a nearby uncontaminated well had only 200 bacteria per milliliter of sample (Borden and Bedient, 1986).

While it is a growing area of research, there is little known about microbial dynamics and simultaneous biodegradation of contaminants in an aquifer system. Under favorable conditions, research has shown significant reduction of degradable organic contaminants, enough to indicate that solute transport models of aquifers under these conditions should account for biodegradation. The favorable environmental conditions include a degradable carbon source, dissolved oxygen, oxidation-reduction potential, and the availability of mineral nutrients. Two vital requirements for the bacteria are the degradable contaminant, serving as a food/energy source, and the dissolved oxygen, serving as the primary electron acceptor (Widdowson et al., 1987).

Given favorable conditions and naturally occurring aerobic bacteria commonly found in aquifers, benzene, toluene, xylenes, and other alkylbenzene components of gasoline are readily degraded (Angley, 1987). These same compounds have also recently been found to be degraded under anaerobic conditions in methanogenic river alluvium

contaminated with landfill leachate and a sandy surficial aquifer contaminated with aviation gasoline. However, anaerobic degradation occurs at a significantly slower rate than aerobic degradation (Wilson et al., 1986).

Aerobic bacterial populations are believed to increase until limited by oxygen, degradable organic material, or essential nutrients. In most contaminated aquifers, dissolved oxygen is assumed to be the limiting factor (Wilson et al., 1986). The oxygen consumption in areas of high contaminant concentration will be great enough to produce significant oxygen concentration gradients. While these gradients may induce the diffusion of oxygen from the phreatic zone or from oxygenated waters outside the plume into the plume (Wheeler et al., 1987), this process is unable to keep up with the oxygen consumption rate. However, there is a great deal of uncertainty concerning the vertical dispersion coefficient of a conservative tracer. Recently measured vertical dispersion coefficients have been on the order of molecular diffusion coefficients, orders of magnitude lower than previously believed (Borden and Bedient, 1986).

The rapid oxygen consumption within the plume produces an anaerobic zone in the region of reduced contaminant concentration, resulting in biomass decay and significant reduction, if not total cessation, of aerobic degradation of the contaminant. Near the fringes of the plume, the biomass

decay appears to be reduced, and this is believed to be the result of oxygen diffusion from surrounding, oxygenated waters. This oxygen diffusion along the lateral edges of the plume is also believed to retard the lateral movement of the plume (Widdowson et al., 1987).

Angley (1987) conducted a series of aromatic hydrocarbon degradation experiments using contaminated groundwater from the Lake Alfred site. Due to the rapid rate of degradation, he concluded the native bacterial population was acclimated to the hydrocarbons present. The first order rate equation provided the best fit to the measured experimental data.

Card (1987) reviews case histories using biological remediation of contaminant plumes, as well as viable methods of oxygen augmentation to the oxygen deficient waters of the plume.

Adsorption. Once a contaminant has adsorbed to a soil surface, it will come to equilibrium with the surrounding fluid, thus gradually reducing the adsorbed contaminant concentration. This has the effect of delaying (retarding) the passage of the contaminant through the aquifer. For compounds undergoing linear instantaneous adsorption, this retardation factor (R) may be calculated as shown below (Borden and Bedient, 1987):

$$R = V_h/V_a = 1 + \rho Kd/n$$

where V_n = ground water velocity of nonadsorbing compound,

V_a = ground water velocity of adsorbing compound,

Kd = partition coefficient (cm^3/g compound adsorbed),

ρ = soil bulk density (g/cm^3) and

n = soil porosity.

Adsorption may significantly increase the rate of biodegradation of a contaminant by allowing oxygenated water to overtake the retarded contaminant plume. This is particularly true of oxygenated water entering the trailing edge of the plume (Wheeler et al., 1987). Without significant adsorption, oxygenated groundwater will be unable to overtake a contaminant plume moving at the same velocity, nor does longitudinal dispersion appear to have much of an effect. In such cases, transverse dispersion has the dominant effect (Borden and Bedient, 1986).

Adsorptive solute transport models may be reduced to two general categories, equilibrium models and kinetic models. The equilibrium models assume there is an instantaneous equilibrium between the adsorbed solid phase and liquid phase solute, while the kinetic models assume solutes are simultaneously moving toward and away from the adsorbing surface at variable rates and different rate constant coefficients (Saleh et al., 1986). The limiting process favoring a kinetic model is normally a chemical

reaction or a diffusion process. Grove and Stollenwerk (1987) provide an overview of groundwater models incorporating chemical reactions, as well as a table providing an extensive list of models discussed in recent literature and their applications.

While adsorption is assumed to play a significant role in the reduction of hydrophobic contaminants in groundwater, there is considerable uncertainty about the solute-soil interaction process. Two additional processes known to occur, producing similar effects, are partitioning and absorption. These three processes are often referred to collectively as sorption. Although these processes are normally considered fully reversible, recent research has demonstrated this is not true under all conditions (Angley, 1987).

Aquifer heterogeneities. Varying values of aquifer transmissivity will alter groundwater flow lines, thus affecting the mechanical dispersion. In surficial aquifers of limited thickness, the surface of the underlying confining layer may also have a significant effect on the groundwater flow patterns. Twenter et al., (1985) found the sloping clay confining layer at a spill site altered the flow of water at different flow levels of the aquifer. This resulted in the displacement of the contaminant plume's lateral edge.

Killan (1987) reported a swale in the confining layer's surface between wells RAP-5 and RAP-6. He also indicated additional heterogeneous effects from underground utility lines, storm sewers, and compression of the aquifer below building foundations . The buried steam lines can also induce thermal convection currents.

Further Modeling Developments

In 1978, the USGS developed their Solute Transport Model, a two dimensional, finite difference model for nonreactive contaminants. This model incorporated several assumptions which are provided below (Konikow and Bredehoeft, 1978, p. 4):

1. Darcy's law is valid and hydraulic-head gradients are the only significant driving mechanism for fluid flow.

2. The porosity and hydraulic conductivity of the aquifer are constant with time, and porosity is uniform in space.

3. Gradients of fluid density, viscosity, and temperature do not affect the velocity distribution.

4. No chemical reactions occur that affect the concentration of the solute, the fluid properties, or the aquifer properties.

5 Ionic and molecular diffusion are negligible contributors to the total dispersive flux.

6. Vertical variations in head and concentrations are negligible.

7. The aquifer is homogeneous and isotropic with respect to the coefficients of longitudinal and transverse dispersivity.

The model uses a block centered, uniformly spaced grid system with the nodes at the center of the cell representing the average value over the area of the cell.

The transport equation in the model incorporates the Method of Characteristics, a method developed to solve hyperbolic differential equations, which the transport equation closely approximates if advection is the dominant mode of transport, a condition existing in most field applications. This method has been used successfully in numerous field problems without introducing significant numerical dispersion. Konikow and Bredehoeft (1978) include a detailed description of the program, an explanation of each program subroutine, and a printed copy of the computer code, written in FORTRAN.

This model has several advantages. It is a well documented and easily understood program that has been verified in both laboratory and field tests. There has been a menu-driven preprocessor added to the program to make it more user friendly, and the program has been updated repeatedly, and improvement efforts are continuing (Rifai et al., 1987).

McDonald and Harbaugh (1985) developed a modular, three-dimensional finite difference model for groundwater flow that is easily modified by the user to fit existing site conditions at a new location. The program consists of a series of discrete packages, from which the user selects

those which apply to the site under consideration, and then executes the program. However, this model does not incorporate solute transport.

The USGS Solute Transport Model was modified to simulate the transport and removal of contaminant and oxygen, as well as microbial activities, under the assumptions of instantaneous degradation reactions and no retardation of the contaminant. Assuming the reaction is oxygen limited and there is an instantaneous reaction between the contaminant and oxygen, the microbial concentration is not necessary, provided it is present in sufficient concentration to degrade the contaminant. Sensitivity analysis performed on the model indicated microbial kinetics did not significantly affect the contaminant distribution, thus justifying the instantaneous reaction simplification. The development took place at Rice University with the support of the United States Environmental Protection Agency and was marketed under the name BIOPLUME (Wheeler et al., 1987).

BIOPLUME II incorporates the additional capability of including adsorption of the contaminant to aquifer material and anaerobic degradation of the contaminant. In both BIOPLUME models, there is no time allowance given for bacterial acclimatization to the contaminants present; this is assumed to have occurred prior to the initiation of modeling. There is also an implicit assumption that three

molecules of oxygen are required to totally degrade one molecule of contaminant (Rifai et al., 1987).

Mathematical models have also been used to solve the "inverse problem," that is, given limited monitoring well data, the model is back calculated to produce the likely source of the contaminant. This same process may also be used to quantify unknown parameters, given sufficient information about the contaminant source and monitoring wells (Chieh et al., 1985). Yeh (1986) reviews the available literature concerning both of these techniques.

While most of the models discussed concentrate on computer codes written in FORTRAN or BASIC, there are several proponents of using computer spreadsheets instead of these special programs (Olsthoorn, 1985 and Highland, 1987).

Model Calibration

The International Ground Water Modeling Center at Butler University has established and promulgated a two step testing process for groundwater models. The two steps are verification and validation.

Verification

The verification process has two purposes, to test the accuracy of the computer code under known conditions, and to ensure the code is fully operational. Both of these purposes are accomplished by running the program with a

given set of conditions and a known answer obtained either from laboratory testing or from an accepted computer model. One benefit of using a published program is this should already have been completed prior to publication (van der Heijde et al., 1985).

Validation

Model validation is intended to determine how well the model simulates the actual behavior of the system. The first method of doing this is known as calibration, and involves adjusting the model's physical parameters to obtain a good correlation between the model's values and the measured field data. The better form of validation is then to take the calibrated model, and use it in a predictive mode beyond the limits of the time period of the data set used for calibration (van der Heijde et al., 1985).

This calibration process is normally done manually, using trial and error. However, there have recently been some numerical estimating processes developed for parameter estimation (Yeh, 1986). One key point concerning groundwater models is that there is not one unique set of system parameters for the calibrated model. This is clearly demonstrated in Freyberg's (1988) article. Another interesting point brought out in the article is the best fit model was the one utilizing a few large regions in the conductivity field, while the worst fit model used numerous

small regions in the conductivity field, attempting to "tweak" the model to match the data.

Case Histories of USGS Model Application

At the Coast Guard's request, the U.S. Geological Survey investigated an organic solvent contamination plume in a surficial aquifer in East Bay Township, Michigan. The long narrow contaminant plume discovered indicated oxygen diffusion into the plume along its lateral edges had significantly retarded the lateral spread of the plume. The model was calibrated using measured field data, and was then used as a design tool to develop the most effective recovery well system to prevent further movement of contaminant from the site (Twenter et al., 1985).

The USGS model was also applied to a creosote waste site in Conroe, Texas. On the site, there is a hydrocarbon plume contained within a larger chloride plume. The chloride is believed to have originated as a contaminant or decomposition product of pentachlorophenol, a compound used in wood treatment processes and present in the waste lagoon. The chloride concentrations and distributions were used to calibrate the model initially, and then the model was applied to the hydrocarbon plume. The original computer code had to be modified to incorporate the biodegradation. These modifications were the basis of the BIOPLUME program.

They provided a good fit of the field measured values (Borden et al., 1986).

Freeberg et al. (1987) applied the United States Geological Survey (USGS) Solute Transport Model to a trichloroethylene-contaminated, shallow, sandy aquifer. Due to curved flow lines on the site's potentiometric surface, the configuration and values for a constant head boundary were adjusted during model calibration. They also found varying transmissivity spatially across the grid produced better results, and the transmissivity values used in the model varied by 23 percent from the measured value. The model was calibrated by minimizing the error (E) between the predicted and measured contaminant plumes, using the following formula:

$$E = \Sigma \, |P_I - M_I|$$

where P_I = predicted concentration of TCE at well x, and

M_I = measured concentration of TCE at well x.

In an experiment to determine in situ retardation factors for naphthalene and paradichlorobenzene, Borden and Bedient (1987) used three wells in a line, six feet on center, with the center well used as an injection well, and the two outer wells were pumped to induce a greater hydraulic gradient and monitoring wells. They attempted to calibrate this system using the USGS Solute Transport Model,

however were unable to obtain an acceptable solution with either uniform or non-uniform permeability distributions. This case illustrates the reason that the code authors do not encourage its use in problems dominated by radially convergent and divergent flow patterns around wells. However, El-Kadi (1988) evaluated three situations of such conditions, finding two produced acceptable results by utilizing a finer mesh. Efforts are presently underway to modify the code to improve this aspect of the model.

CHAPTER III
MATERIALS AND METHODS

The efforts of this study can be divided into three main categories: semi-quantitative soil core analysis, water balance of the system, and validation of a solute transport model at the Lake Alfred site.

Soil Core Analysis

To gain an appreciation for the vertical distribution of sorbed hydrocarbons in the aquifer, soil cores were taken from several locations on the site. These cores were taken by three different methods over the course of this study.

Coring Procedure

The initial method of coring employed a trailer-mounted hydraulic sampler. Although the equipment functioned properly, the cores were difficult to retrieve from the core barrel, and impossible to retrieve intact. A split spoon sampler would have been preferred. In addition, reference marks were not used to differentiate between the undisturbed sample and collapse material from the bore walls following removal of the previous core, which became particularly significant once the aquifer was entered. These problems,

along with questions about the integrity of the samples resulted in the data being discarded.

The second coring method used a stainless steel, manually operated bucket auger. While most problems encountered with the first method were solved, the continual collapse of surrounding aquifer material into the bore hole following the removal of the auger prevented this from being a viable option, particularly since the upper portion of the elevated aquifer was of greatest interest.

In the interest of sample integrity, the final method was developed and used. Since the area of interest was the upper portion of the aquifer, the initial two to three feet of overburden were excavated with the manual bucket auger and discarded. An eight foot length of 1½ inch (1¼ inch inner diameter) LEXAN tubing, sharpened at one end, triple rinsed with 2-propanol and water, was then placed into the existing hole, the length remaining above ground was recorded, and it was driven to the desired depth by using a fabricated six-pound sliding well-point hammer. A steel plunger with a rubber gasket was inserted into the open end of the tube, gasket first, and pushed down until it contacted the sample. A large diameter dowel rod was inserted to occupy the void, and the end of the tube was plugged with a number 6 rubber stopper. The plunger, dowel rod, and stopper minimized the loss of core material due to the suction effect of the aquifer upon tube removal. The

core was then driven from the tube by a horizontal force through the open end, or through controlled, sharp vertical movements, thus allowing the mass of the plunger to drive the core out. The coring assembly is shown in Figure 3-1.

The cores were divided into discrete samples of measured length, with each sample placed in a sealed "zip lock" sample bag, marked, sealed in a second "zip lock" bag, and stored on ice for transport to the laboratory.

Extraction and Analysis Procedure

Within ten hours of taking the first core, this extraction procedure was performed. While still in the sealed bags, the samples were thoroughly kneaded to produce a homogenous mixture. A quantity of the soil mixture, about 15 grams, was placed in a clean 40 milliliter VOC vial, weighed, filled with pesticide grade n-hexane, sealed with a Teflon-lined septum cap and shaken by wrist action for 10 seconds. Although it would have been preferable to extract the hydrocarbons without headspace in the sample vials, this was impossible because of the air entrained in the soil matrix. Instead, the final head space was minimized through careful handling and sealing of the vials. The vial was again weighed to obtain the mass of hexane added. These prepared samples were then stored at room temperature for later analysis.

Based upon the initial site investigation conducted by Killan (1987), the contaminant plume was found to contain 14

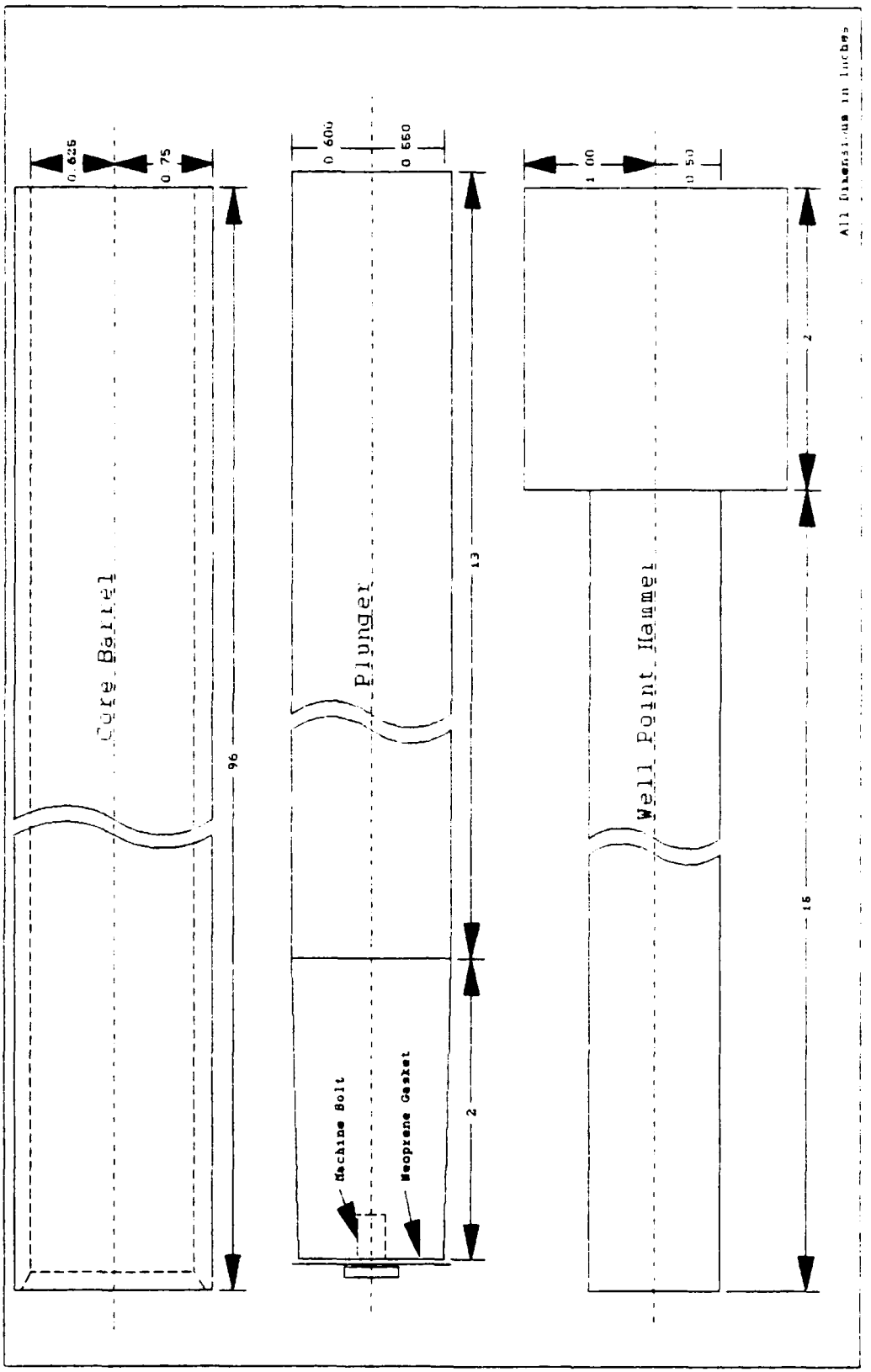

Figure 3-1. Components of the Soil Coring Assembly.

aromatic hydrocarbons in sufficient concentrations to be readily identified through gas chromatography. Since the groundwater was tested monthly for these analytes, they were also used to analyze the soil extracts. The 14 analytes were benzene, toluene, ethylbenzene, meta-xylene, para-xylene, ortho-xylene, isopropylbenzene, propylbenzene, 3-ethyltoluene, 4-ethyltoluene, 1,3,5-trimethylbenzene, 2-ethyltoluene, 1,2,4-trimethylbenzene, and 1,2,3-trimethylbenzene.

Aromatic standard preparation. The stock standard was prepared by adding a known mass of each of the above analytes to pesticide grade methanol to produce a final volume of ten milliliters. Because of co-elution of analytes, about 0.010 grams of each of meta-xylene, para-xylene, 3-ethyltoluene, and 4-ethyltoluene were added, while about 0.020 grams of each of the remaining ten analytes were used. To produce a calibration curve, the stock standard was diluted in pesticide grade n-hexane using dilution ratios of 1:2,000, 1:1,000, 1:250, 1:125, 1:62.5, 1:40, and 1:20. All prepared standards were stored in sealed two milliliter serum vials in an explosion-proof freezer until required. Storage of these standards did not exceed 30 days.

Soil extract analysis. The soil extracts were analyzed on a Perkin-Elmer 8410 Gas Chromatograph having a 30 meter DB-1 capillary column with a 0.53 millimeter inner diameter

and a three micrometer coating. All samples were injected directly through a Thermogreen LB-2 11 millimeter septum, with the septum being replaced after every ten injections. Each sample was analyzed at least twice, and two diluted standards were run after every ten sample runs. All extract samples were taken by syringe through the septum. Once the septum was pierced, the analysis of that sample was completed as soon as this method would allow. The instrument's analytical conditions are provided in Table 3-1.

Recovery study. To verify extraction efficiency of the hexane extraction method for the aromatic compounds of interest, two recovery studies were conducted on representative soil samples obtained from the site. The first recovery study was conducted at low concentrations without sampling head space, while the second study used higher hydrocarbon concentrations and included head space analysis. In both studies, a known mass of soil was placed in a clean 40 milliliter vial, injected with a measured volume of stock standard, sealed with a Teflon lined septum and cap, and allowed to equilibrate at room temperature for 20 minutes. Equilibrium was assumed to have been reached within this 20 minute period. In the first study, the sample vials were opened, filled with pesticide grade n-hexane, resealed, shaken, and later analyzed by the procedures discussed previously. In the second study,

TABLE 3-1. Perkin-Elmer 8410 Analysis Conditions for Soil Extracts.

	1	2	3
Oven Temperature (^{0}C)	35	70	250
Iso Time (minutes)	8.0	15.0	5.0
Ramp Rate (^{0}C/minute)	5.0	30.0	
FID Sensitivity	High		
Detector Zero	On		
Injector Temperature	250 ^{0}C		
Detector Temperature	300 ^{0}C		
Flow Rate of Helium Carrier Gas	10 milliliters/minute		

following the equilibration period, a ten microliter sample of the vial's head space was taken and analyzed using the aforementioned procedure. The head space analysis was repeated before the vial was opened and hexane added.

The results of this recovery study are included in Chapter IV.

System Water Balance

To obtain an estimate of evaporation from the spray heads, an experiment measuring the amount of water reaching the ground surface in a known area under two application pressures was made. The equipment was setup as indicated in Figure 3-2. The pumped volume for each application was metered, and the spray heads were identical full-circle heads. The collected water was drained from the white vinyl collection sheet and stored in small-mouth plastic containers, to minimize evaporation, for later measurement. Upon completion of each test, approximately 20 minutes, the volume of collected water was measured using a graduated cylinder.

Daily pan evaporation and precipitation data were obtained from the Lake Alfred weather station. Using this information, the records of the aquifer augmentation and recovery system, and the sprinkler efficiency rates, an approximate water balance was calculated.

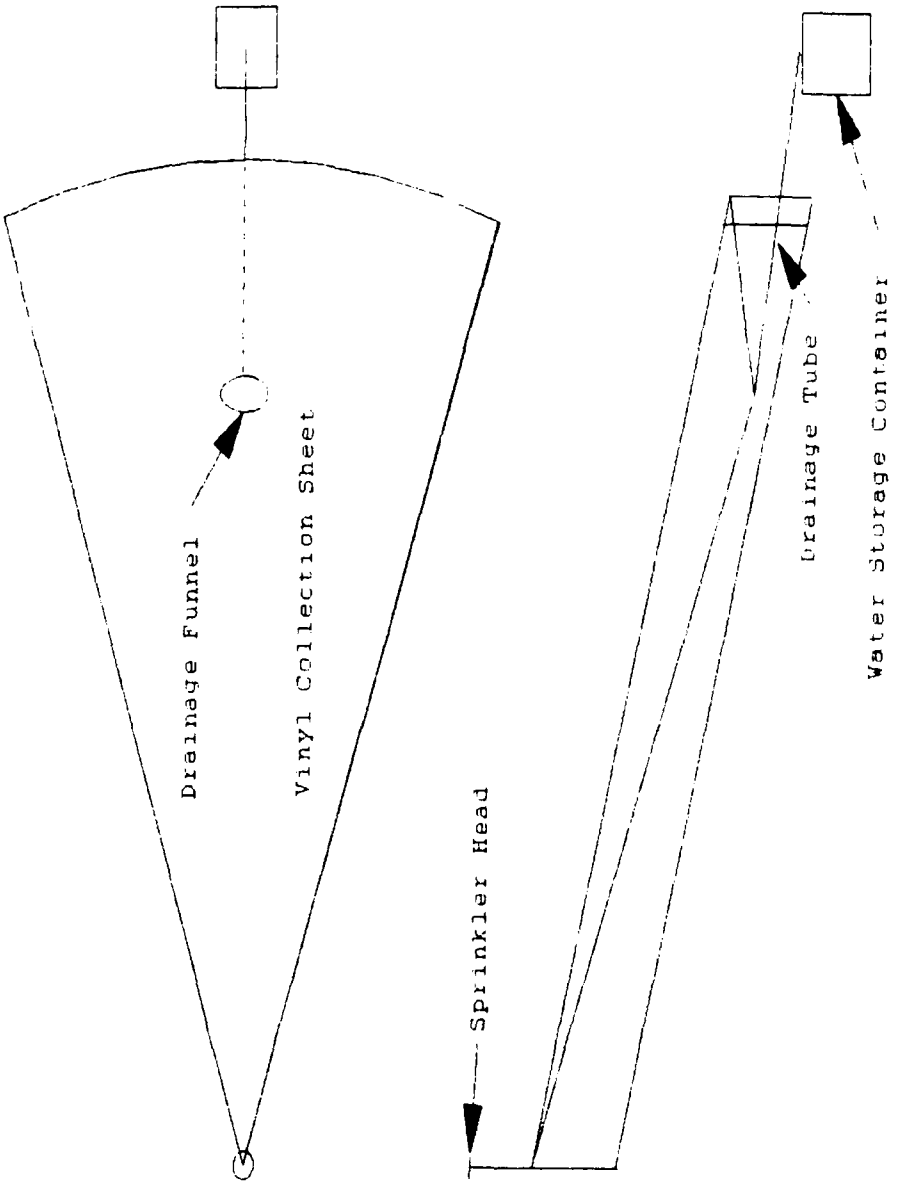

Figure 3-2. Sprinkler Evaporation Measurement System.

Model Validation

While the following two sections are presented as two discrete topics, the inclusion of the Method of Characteristics in the BIOPLUME II code necessitates the particle movement calculations be completed, even if there is no contaminant present. Therefore, to minimize the required computer time, both processes were conducted simultaneously, with the initial emphasis being placed on hydraulic flow. Once this was calibrated, the emphasis was placed upon the solute transport calibration.

Groundwater Flow

A water table database was developed through periodic measurements of the water elevation in each monitoring well. This information is presented in Appendix A. Metered volumes of water were injected into select wells, to evaluate the effect on water table elevation and recovered volume of groundwater. The injection and recovery information is presented in Appendix B. Based on these data and measured aquifer parameters (Appendix C) from Killan (1987), a trial and error method was used to calibrate the groundwater flow portion of the BIOPLUME II model.

Three periods of stable system operation were selected for the calibration procedure, each representing a different aspect of the system: steady flow through the system without injection, injection at the upgradient edge of the study

area in RAP-5 and RAP-7, and injection in the middle of the study area through P-6 and P-7. The model's steady state mode was employed, using one week pumping periods and the average metered injection and pumped volumes over that period.

The error minimization was performed using this Freeberg et al. (1987) equation as a guideline:

$$E = \Sigma \, |P_i - M_i|$$

where P_i = predicted value at well x, and

M_i = measured value at well x.

The water elevations in eight wells (M-1, OHM-3, OHM-4, P-5, RAP-4, RAP-12, RAP-13, and UF-1E) were used.

A K-V Associates' Groundwater Flowmeter (Model 30) was used to obtain the groundwater flow velocity and direction in five selected two-inch monitoring wells. The field procedures used were those specified in the system's operations and maintenance manual (K-V Associates, Inc., 1982). To obtain values under static conditions, the measurements were taken after the recovery wells and spray field had been turned off for over 30 hours. The flow meter had been calibrated in a sandy soil matrix prior to field use.

Solute Transport

The groundwater on site was sampled monthly, in compliance with the contract between IFAS and the Department

of Environmental Engineering Sciences. The hydrocarbon analysis was performed on the Perkin-Elmer model 8410 gas chromatograph utilized for the soil extract analysis. In addition, a Tekmar LSC/ALS purge and trap system was used to concentrate the water samples prior to analysis. The program settings are provided in Table 3-2 (Angley, 1987).

Once the hydraulic flow was calibrated, those parameters remained constant, and the solute transport parameters were adjusted by trial and error. The Freeberg et al. (1987) equation was applied to the meta-xylene and para-xylene concentrations in wells OHM-3, OHM-4, P-5, UF-2M, and UF-3W.

TABLE 3-2. Perkin-Elmer 8410 Analysis Conditions for Water Samples.

	1	2	3	4
Oven Temperature (^{0}C)	50	70	94	200
Iso Time (minutes)	5.0	7.0	0.0	0.0
Ramp Rate (^{0}C/minute)	3.0	3.0	30.0	
FID Sensitivity		High		
Detector Zero		On		
Detector Temperature		300 ^{0}C		
Flow Rate of Helium Carrier Gas		5.5 milliliters/minute		

CHAPTER IV
RESULTS AND DISCUSSION

The information in this chapter is divided into four sections; the first (The Site) includes field work and soil extraction results, the second (System Water Balance) presents the initial assumptions, summarizes the calculations and discusses the results, the third (Model Selection) discusses the model selection criteria, and the fourth (Model Validation) discusses the process used and problems encountered with the model calibration.

The Site

A number of problems arose during the continuous operation of the recovery system.

Operation and Maintenance of Recovery System

Because of the geographic separation of the project site from the University campus, it was not possible to maintain a continuous on-site presence. IFAS-CREC support was enlisted to record daily readings, perform emergency repairs, and ensure proper day-to-day operation of the system.

One significant problem encountered was fouling of the pump intake screens by bacterial growth in RAP-1 and UF-2M. This phenomenon did not occur in RAP-3. The pumps were routinely removed from the well and cleaned. After returning to operation, the pump would experience flow restriction problems after about two months, and would plug after three months. This was overcome by weekly dosing the well with one gallon of five percent sodium hypochlorite solution. With the pump turned off, the hypochlorite solution was added to the water in the casing and allowed to contact the pump and well casing for about 20 minutes before the pump was returned to operation. This periodic dosing kept the biofouling problem under control.

Each pumping well and the irrigation sprinklers in the spray field had a dedicated, in-line water meter measuring the flow volume. These meters were standard multi-jet flow meters, with plastic measuring cylinders. While these meters were not new when installed in the system, they experienced a 100 percent failure rate between the eighteenth and twenty-fourth month of system operation.

Finally, the spray heads in the spray field were not operating efficiently at low-flow periods. This was overcome through reduction in number of operating spray heads, and reducing some full circle spray heads to one-half or one-quarter circle heads. These measures effectively increased the operating pressure of the system, producing a

finer spray, thus increasing the air-stripping ability of the system.

Groundwater Flowmeter

A graphic summary of the results from the field measurement of the groundwater velocity and direction is provided in Figure 4-1, with the numerical values listed in Table 4-1.

Killan (1987) speculated on the aquifer compression experienced beneath building 10, producing an effective barrier to groundwater flow, diverting it to the south for passage between buildings 10 and 12. The test conducted in well M-3 supports this idea with its northwesterly direction. There is a similar effect, although not as dominant, in well OHM-4. The building induced compression and the natural movement of water toward RAP-1, even without pumping, helps explain why the gasoline pooled south of the wash rack, without spreading north to RAP-2 or west of building 31.

The pump house (building 12) has a 79 inch deep concrete wet-well in its south east corner. The physical presence of it would have prevented the passage of free product and severely restricted the flow of dissolved organics through this area, since the confining layer surface is only eight feet below grade at this location. The flows in RAP-4 and RAP-6 toward the opening between buildings 10 and 12, and the flow of RAP-11 away from this

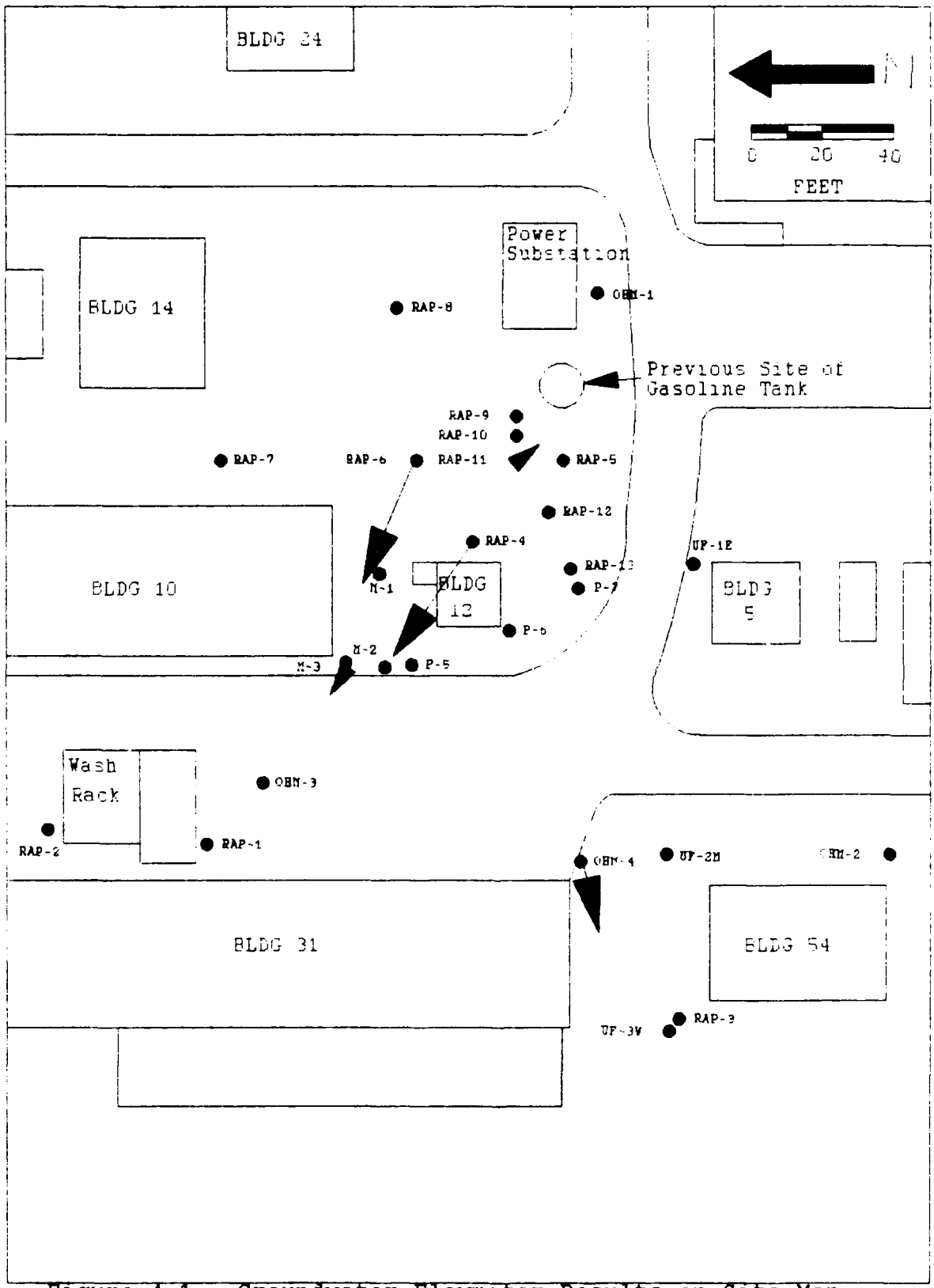

Figure 4-1. Groundwater Flowmeter Results on Site Map.

Table 4-1. Groundwater Flowmeter Results for Select Wells

Well	Computed Reading	Velocity (feet/day)	Direction[a] of Flow
M-3	51.3	1.3	298^0
OHM-4	90.6	2.6	257^0
RAP-4	259	>4.9[b]	305^0
RAP-6	159	4.8	293^0
RAP-11	6.7	<0.9[c]	149^0

[a] 360^0 equals North

[b] The instrument's calibration curve upper limit for these tests was 4.9 feet per day.

[c] The instrument's calibration curve lower limit for these tests was 0.9 feet per day.

opening indicate the existence of a groundwater divide between these two areas, probably induced by a combination of the pump house and variations in the confining layer surface.

During the installation of additional monitoring wells for further research, a shallow swale was discovered between buildings 10 and 12, running toward RAP-1.

Soil Core Analysis

The purpose of this portion of the study was to qualitatively determine the vertical distribution of sorbed contaminants in the soil. While the first two coring methods proved unsuccessful, the final method produced acceptable results.

Coring process. The LEXAN tubing was an effective coring device, withstanding the forces of driving without significant damage. However, it should be noted that the site material was sandy-clayey soil. The maximum core length that could reasonably be extracted from the core barrel by a horizontal driving force was 24 inches, but a 30 inch length of aquifer material was easily recovered by controlled, sharp vertical movements of the core assembly.

Analytical process. Because of the variation in response of the flame ionization detector to each analyte, a separate calibration curve was developed for each of the 12 eluting peaks of interest. There was a minor interference between the benzene peak and a small peak attributed to an

impurity in the hexane. Since the volume of sample injected was kept fairly constant, about 3.0 microliters, this was accounted for in the calibration curve.

The range of each calibration curve varied between 5 and 350 nanograms of analyte. The curves may be found in Appendix D. From these curves, the mass of analyte was determined, given the integrated response of the chromatogram. The mass of sorbed analyte in the soil sample was calculated from the following equation:

$$M_{sorbed} = \frac{M_a \times M_h \times (1000\ \mu l/ml)}{M_s \times Vol_i \times Den_h}$$

where M_{sorbed} = mass of sorbed analyte, nanograms solute/gram soil,

M_a = mass of analyte, nanograms,

M_h = mass of hexane in vial, grams,

M_s = mass of soil, grams,

Vol_i = volume of injected sample, microliters, and

Den_h = density of hexane, at 20°C = 0.6603 grams/milliliter.

The method and instruments used were capable of detecting lower concentrations than the low limits adopted in this study. The calibration curves of several analytes began displaying a nonlinear relationship at levels below these limits. The high limit of the curve was set so as to avoid overloading the column. The curves utilized were

therefore restricted to the region of linear relationship, without threatening column contamination. If the analyte was not detected by the analytical method, it was reported as ND and given a sorbed mass of zero, while if it was detected but in insufficient concentration for the limits of the calibration curves, it was reported as BDL and given the sorbed mass value produced by one-half of the lower limit value of that analyte.

Discussion of results. The sorbed hydrocarbon concentrations as a function of elevation are plotted for each core taken, as Figures 4-2 through 4-6. The samples ranged in length from six to nine inches, and the midpoint elevation of each discrete sample was used for these plots. The tabulated raw data may be found in Appendix E.

Although the less contaminated cores (Figures 4-3, 4-4, and 4-5) appear to vary without a dominate concentration profile, this is attributed to analytical results at or below the calibration curves' lower limit, and slight differences in the soil mass used in the extraction. The highly contaminated soil profiles (Figures 4-2 and 4-6) indicate a narrow, horizontal region of contamination. The contaminated region in Figure 4-6 was reported by Killan (1987) to have contained floating free product prior to the recovery operations.

While the lower sorbed concentrations found at the upper and lower edges of this region may indicate the result

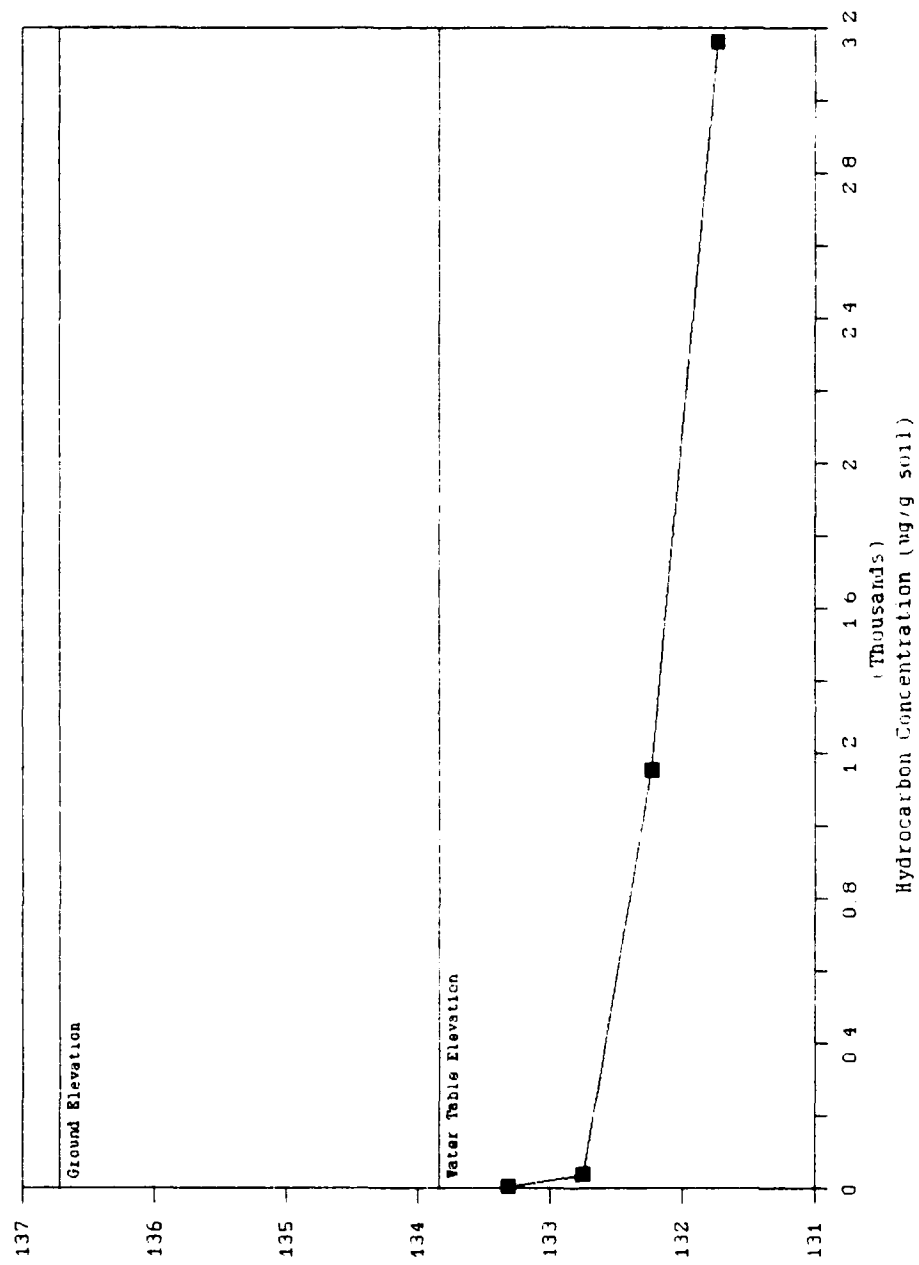

Figure 4-2. Total Sorbed Hydrocarbon Concentration Profile of Core-1, Located South of OHM-4.

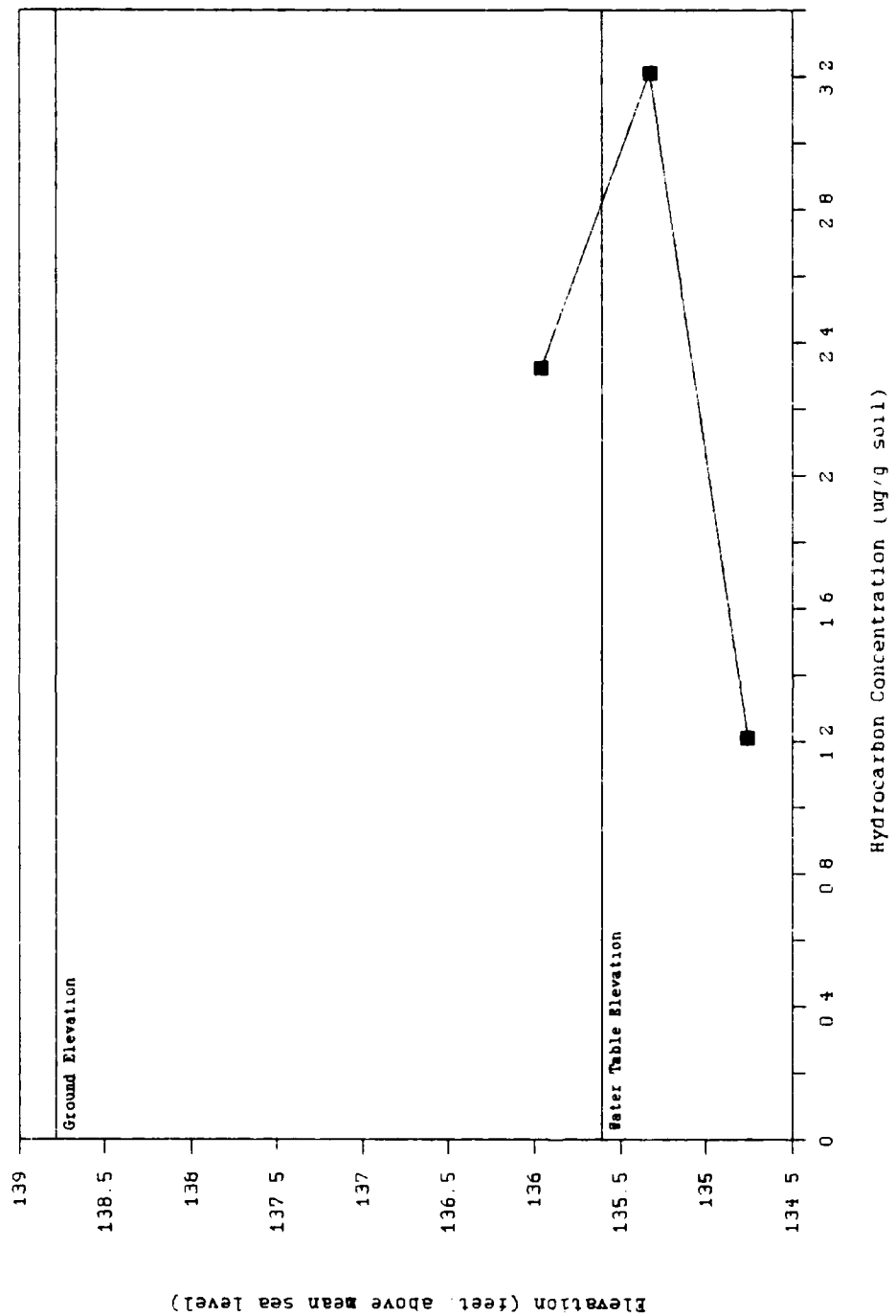

Figure 4-3. Total Sorbed Hydrocarbon Concentration Profile of Core-2, Located between M-1 and M-2.

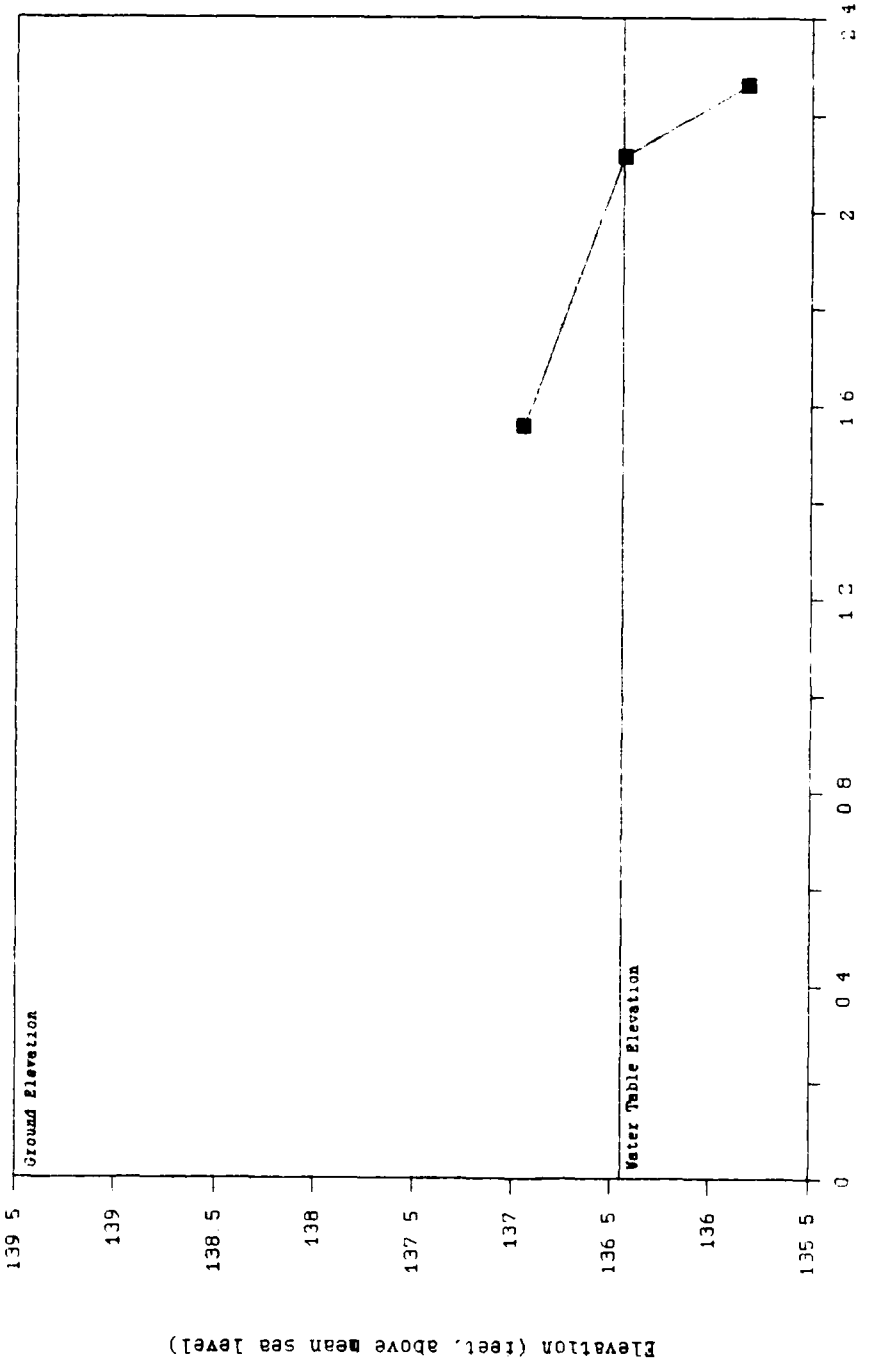

Figure 4-4. Total Sorbed Hydrocarbon Concentration Profile of Core-3, Located between RAP-4 and Building 12.

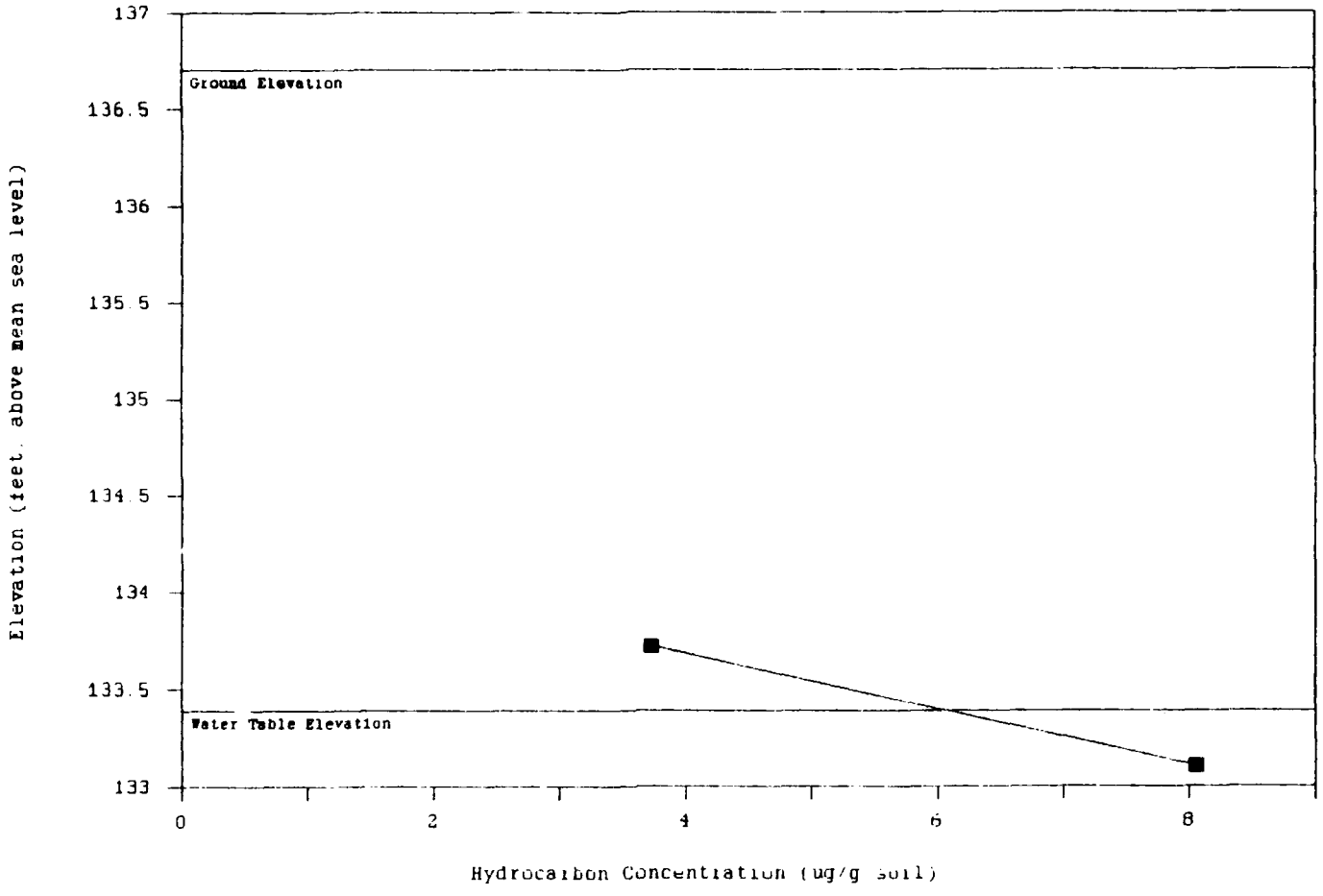

Figure 4-5. Total Sorbed Hydrocarbon Concentration Profile of Core-4, Located South of OHM-4.

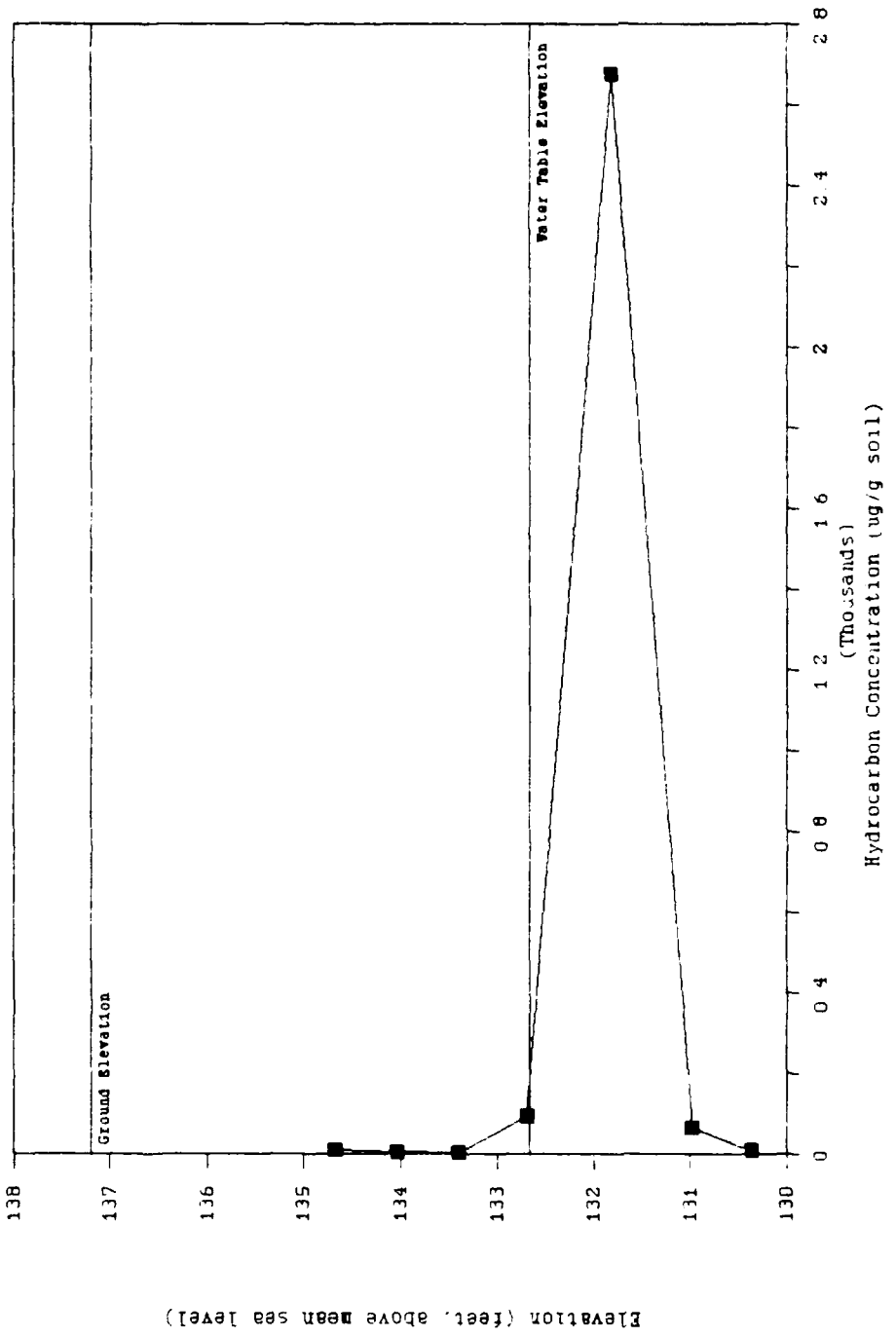

Figure 4-6. Total Sorbed Hydrocarbon Concentration Profile of Core-5, Located North of UF-2M.

of thoroughly mixing the soil from each discrete sample prior to extraction, they may also reflect contaminant volatilization, transport within the capillary fringe, flushing effects of water movement through the region, or biodegradation. More likely, it may be a combination of any or all of the above processes.

Since the free product was known to have pooled east of building 31 and south of the wash rack, this is a likely area of significant sorbed contaminant. Being covered by asphalt, contaminant volatilization and oxygen diffusion from the atmosphere into the soil is prevented.

Angley (1987) reported organic carbon constituted 0.015 percent of the Lake Alfred aquifer material. In laboratory leaking column and equilibrium batch isotherm experiments, he measured this aquifer material's retardation factor ranging from 1.66 to 1.99 for both meta-xylene and para-xylene. Based on these results, a low retardation factor (about 1.8) would be expected in this aquifer under equilibrium conditions. The presence of the highly contaminated soil located just above the saturated zone, and the adjacent highly contaminated soil just below the upper limit of the saturated zone in the elevated aquifer, should serve as a continuous contaminant source until full equilibrium with the surrounding aquifer is reached. The water flowing through the contaminated area rapidly becomes saturated with hydrocarbons, thus preventing the transport

of the total sorbed mass at the seepage velocity of the groundwater, which would indicate a retardation factor of 1.0. The situation is further complicated by small vertical dispersion coefficients. This is the type of problem which has encouraged the development of three-dimensional solute transport models.

All the monitoring wells on site have screen sections fully penetrating the aquifer, and the wells are purged of three casing volumes of water before a sample is taken for hydrocarbon analysis. This produces a composite sample over the depth of the aquifer.

Recovery Study

The first recovery study was unsuccessful. This failure can be attributed to several factors. First, the soil sample used for both studies was slightly contaminated with sorbed hydrocarbons. Although the control sample was analyzed twice for each study, several detected analytes were at or below the lower limit of the calibration curves. In such a case, the mass of solute on the column was estimated by using one-half the calibration curve's lower limit, thus introducing additional errors. Low concentrations of the analyte spike and extensive volatilization of hydrocarbons with the addition of hexane (visible vapors were seen escaping), further complicated the procedure. The results are tabulated in Table 4-2. While the values in this table may appear reasonable, the

Table 4-2. Results of Initial Hydrocarbon Recovery Study

Soil Sample Number	Repetition Number	Mass of Total Hydrocarbons Injected (mg)	Percent Recovered
1	1	0.127	48.3
	2	0.127	37.9
	3	0.127	28.4
1	1	0.637	66.8
	2	0.637	95.1
	3	0.637	95.6
1	1	1.274	64.1
	2	1.274	67.4
	3	1.274	81.8
2	1	0.127	14.5
	2	0.127	-39.0
	3	0.127	-28.5
2	1	0.637	57.2
	2	0.637	59.3
	3	0.637	48.2
2	1	1.274	72.6
	2	1.274	71.1
	3	1.274	73.2

variation between replicate analyses of the same sample becomes more significant, particularly with regard to specific analytes. These tabulated raw data may be found in Appendix F.

The second recovery study included higher analyte spike concentrations, and analyzing the sample vial head space prior to the addition of hexane. The mass of hydrocarbons lost due to the hexane displaced head space was calculated using the following equation:

$$M_{head} = \frac{M_a \times M_h \times (1000\ \mu l/ml)}{Vol_i \times Den_h}$$

where M_{head} = mass of volatilized analyte, nanograms solute,

M_a = mass of analyte, nanograms,

M_h = mass of hexane in vial, grams,

Vol_i = volume of injected sample, microliters, and

Den_h = density of hexane, at 20^0C = 0.6603 grams/milliliter.

The mass of hydrocarbons displaced from the vial, when combined with the total sorbed hydrocarbons in the sample, adequately accounted for the mass of hydrocarbons in the spike and that originally in the sample. The results of this study are presented in Table 4-3.

While sufficient repetitions were not conducted to establish a rigorous quantitative method, the results are

Table 4-3. Results of Second Hydrocarbon Recovery Study

Mass of Total Hydrocarbons Injected (mg)	Repetition Number	Extraction Percent Recovered	Total Percent Recovered
2.517	1	69.5	112
	2	62.0	104
12.59	1	86.7	97.1
	2	82.0	92.4
27.99	1	87.5	92.0
	2	71.6	76.1

sufficient to support the semi-quantitative application used in this study.

Fresh Water Injection.

During this study, metered volumes of water were injected into selected wells to evaluate this method's effectiveness in elevating the water table. The injection wells, and their period of use are presented in Table 4-4. The daily volumes of water injected into each well were normalized to a 24 hour period between 0730 and 0730 the following day. These normalized volumes are included in Appendix B.

Elevations of the water table surface in selected wells as a function of time are presented as Figures 4-7 and 4-8. Both figures demonstrate the hydrodynamic influence high volume injection wells have on the aquifer, particularly between days 727 and 758 (injection in RAP-5 and RAP-7), and between days 814 and 832 (injection in P-6 and P-7). They also provide an indication of the extent of the regularly occurring fluctuations.

Figure 4-9 presents the combined daily volume pumped from the three recovery wells. The general shape of this curve is similar to the water table elevation curves, with the greatest similarity exhibited by wells closest to the recovery wells. It should be noted this is a six day moving average curve, thus introducing a delay in exhibiting the effects shown in the water table elevations. The low points

Table 4-4. Injection Well Utilization

Well	Dates Used	Project Days
RAP-5	30 JAN - 24 APR 1988	727 - 812
RAP-7	30 JAN - 24 APR 1988	727 - 812
RAP-8	30 JAN - 29 APR 1988	727 - 817
P-6	26 APR - 14 MAY 1988	814 - 832
P-7	26 APR - 06 MAY 1988	814 - 824

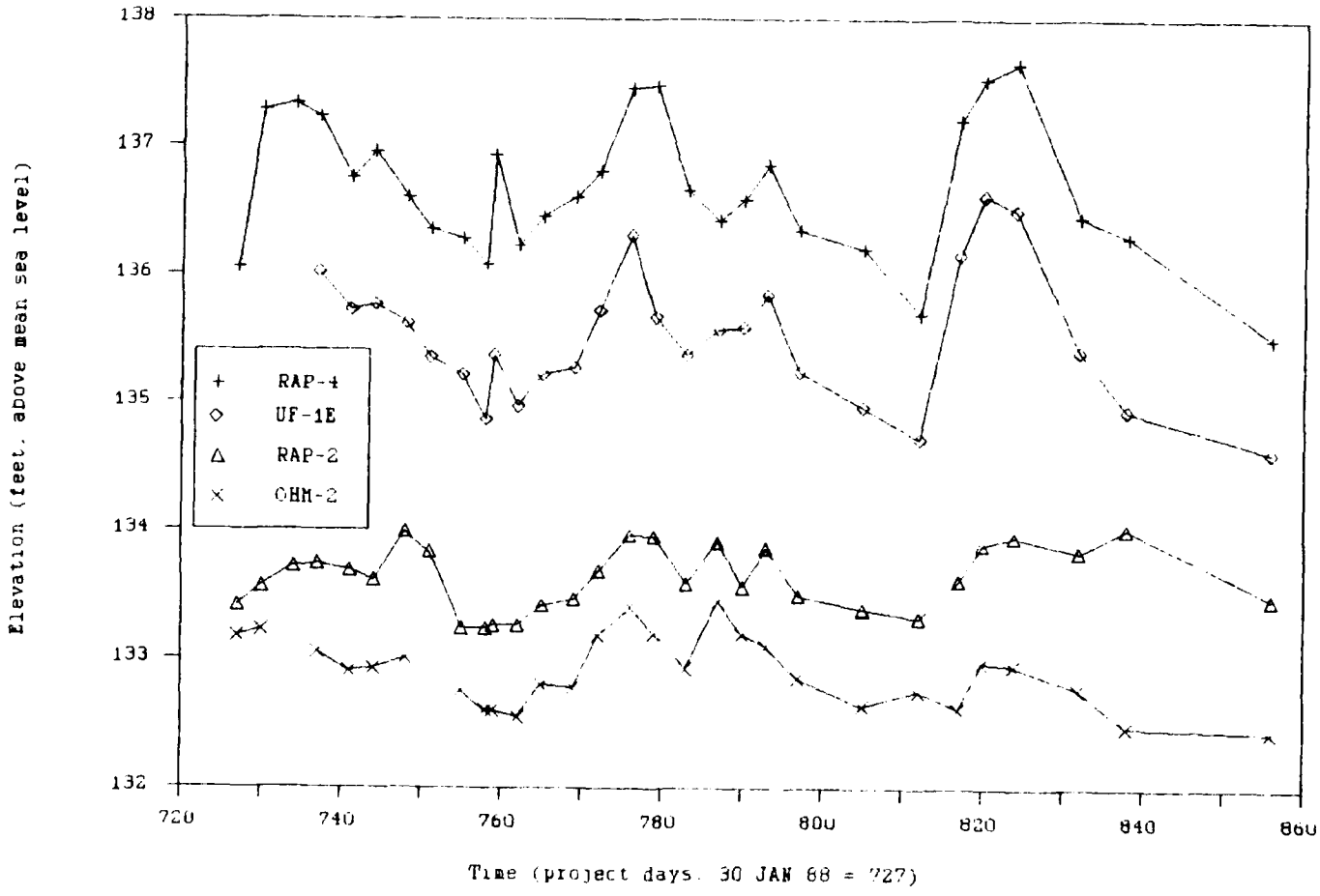

Figure 4-7. Water Table Elevations as a Function of Time in Wells RAP-4, UF-1E, RAP-2, and OHM-2.

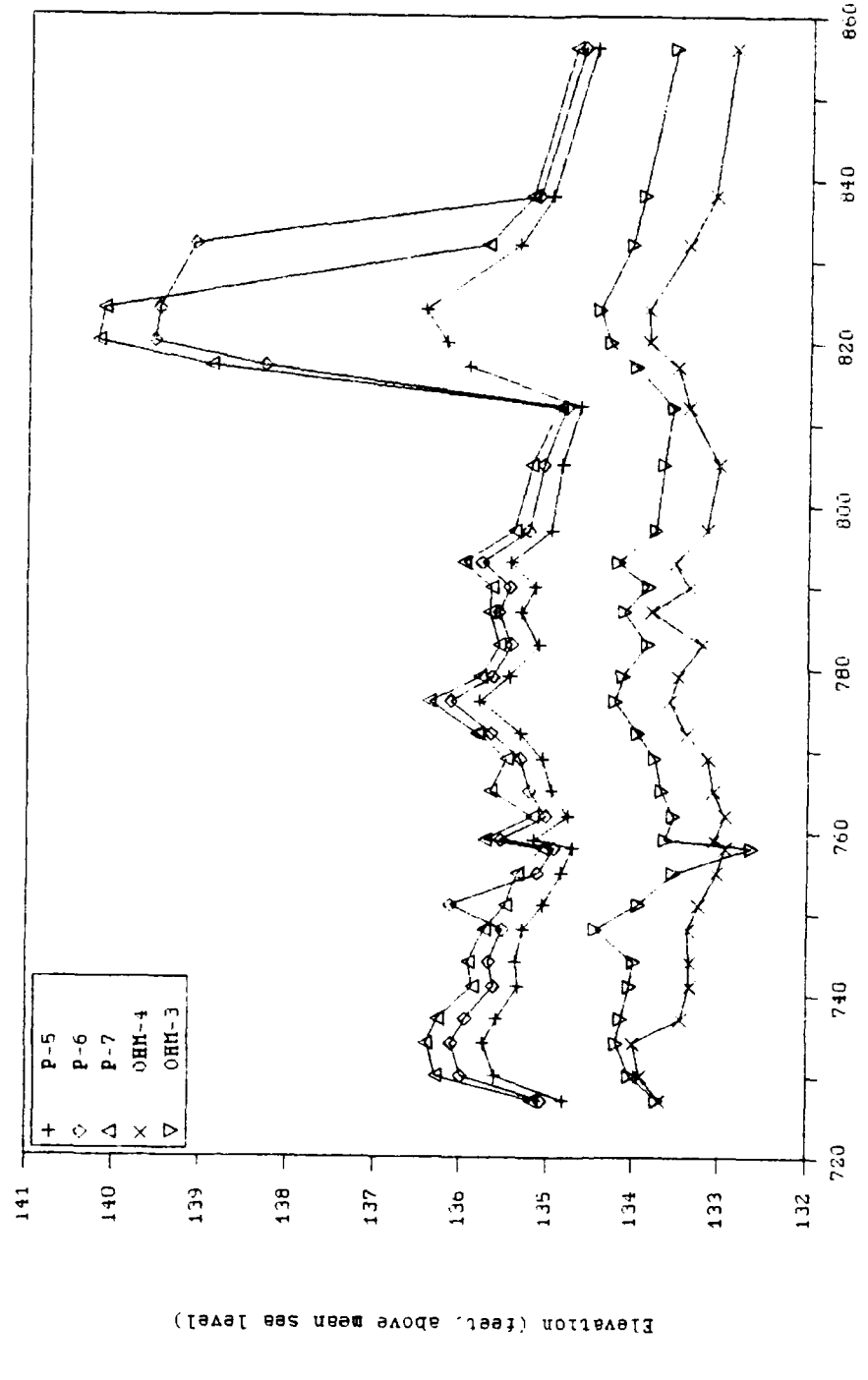

Figure 4-8. Water Table Elevations as a Function of Time in Wells P-5, P-6, P-7, OHM-4, and OHM-3.

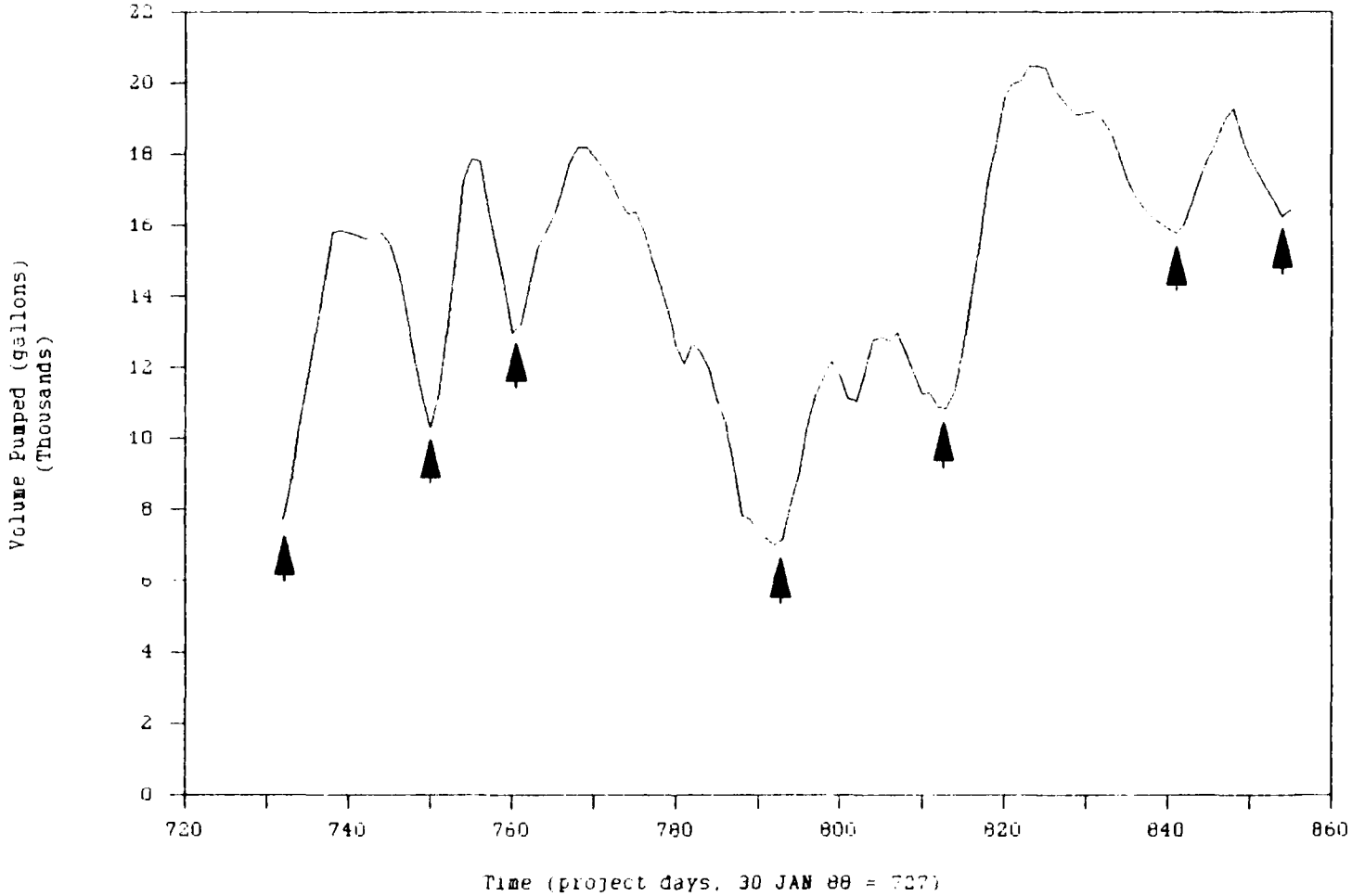

Figure 4-9. Total Daily Volume Pumped from Recovery Wells, a Six Day Moving Average.

at project days 733 and 813 reflect power outages to UF-2M; day 793 reflects the flow meter failure at UF-2M; and days 750 and 761 reflect disruption of the RAP-1 distribution system by an on-site contractor. Similarly, the low points at day 841 coincide with the cessation of injection at P-6 and P-7, and the irrigation sprinklers being secured for two days. The final low point at day 854 was caused by the irrigation sprinklers being secured for a 12 day period.

The flushing capabilities of injection wells were also demonstrated in this study. The effect was most pronounced in the highly contaminated area around P-5, OHM-3, OHM-4, and UF-2M. Figures 4-10 through 4-13 present the combined meta-xylene and para-xylene concentrations for each of the wells. Background data from August 1987 to January 1988 is also included to emphasize the effect of the injection wells.

In P-5, a relatively uncontaminated well in comparison with the other three wells, there was a marked decrease in contaminant concentration following injection in P-6 and P-7. While this concentration has remained suppressed for three monitoring periods since the termination of injection, continued monitoring is necessary to evaluate the extent of recontamination from up gradient areas.

In OHM-3 and OHM-4, the concentration increased with the injection operation in RAP-5 and RAP-7, but considering the variation in concentrations over the preceding months,

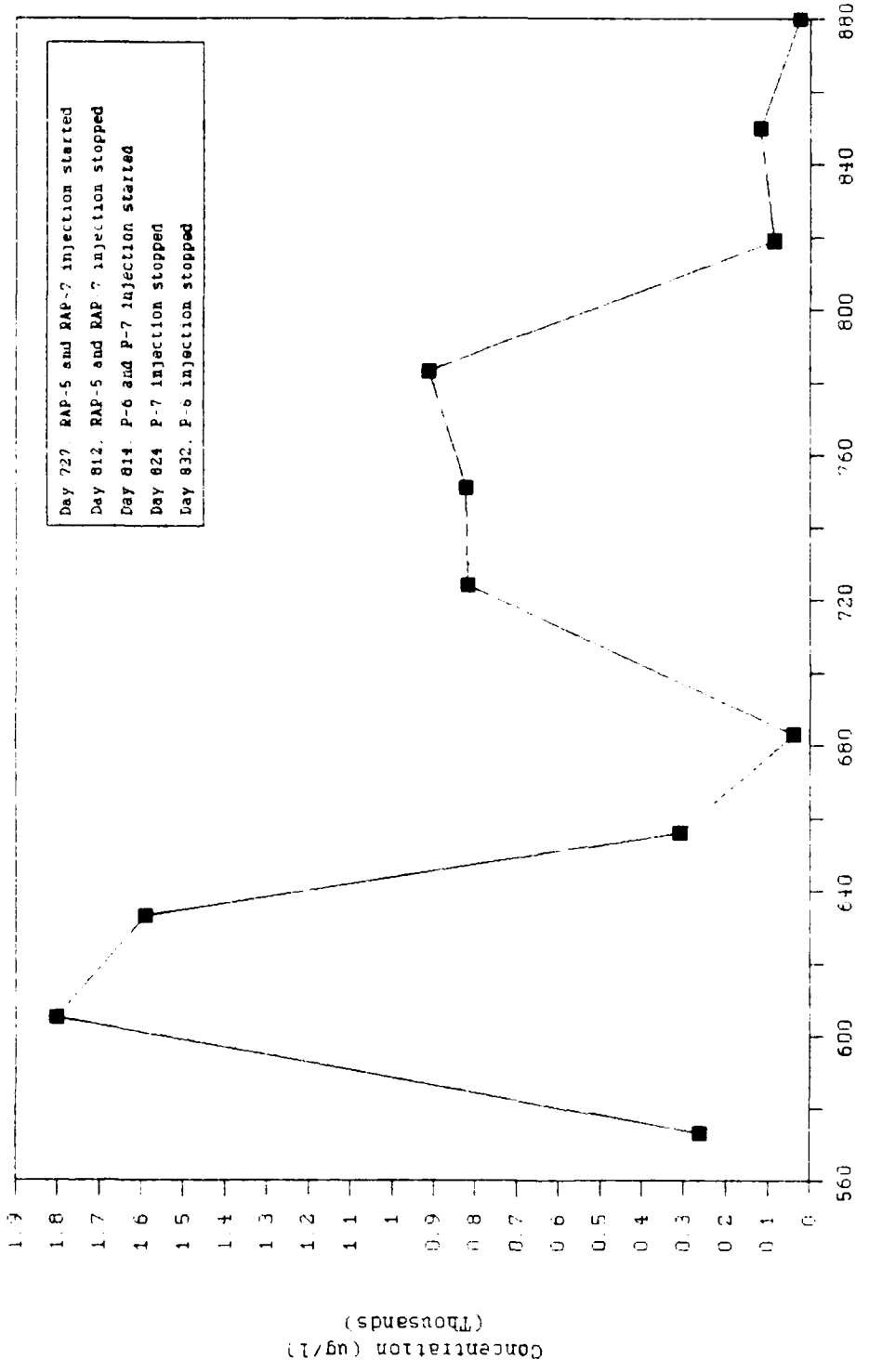

Figure 4-10. Combined Meta-xylene and Para-xylene Concentrations in P-5 as a Function of Time.

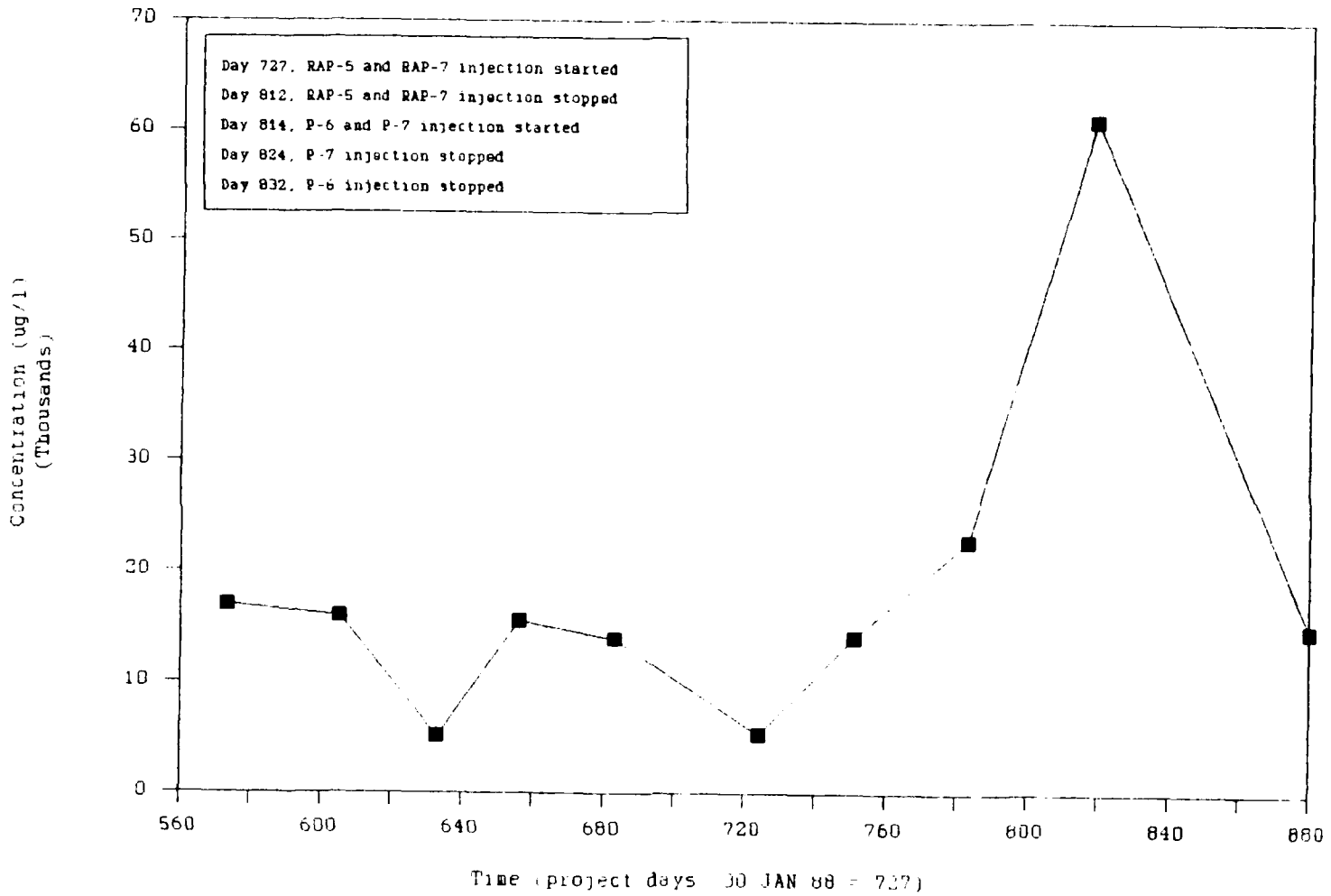

Figure 4-11. Combined Meta-xylene and Para-xylene Concentrations in OHM-3 as a Function of Time.

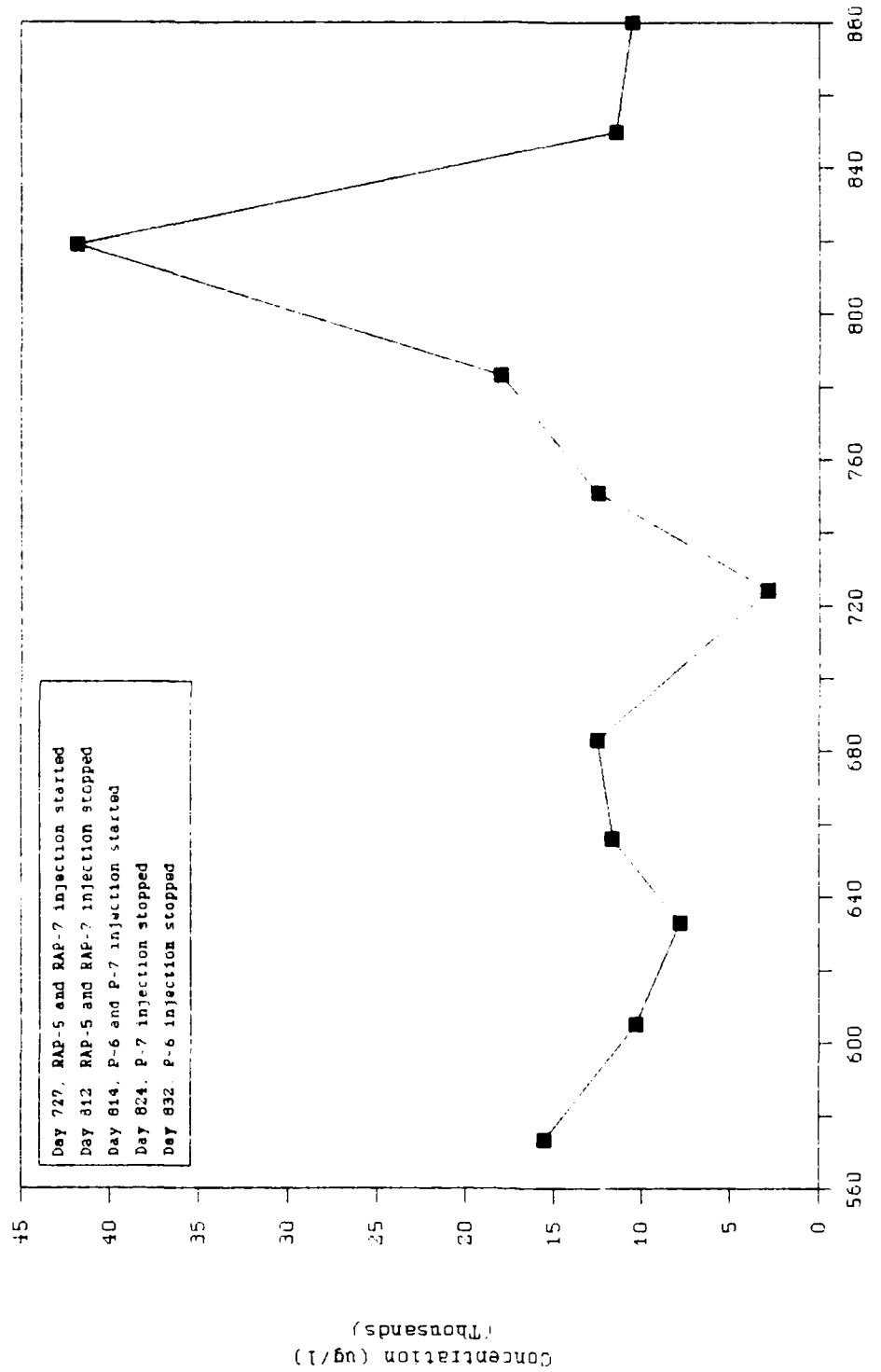

Figure 4-12. Combined Meta-xylene and Para-xylene Concentrations in OHM-4 as a Function of Time.

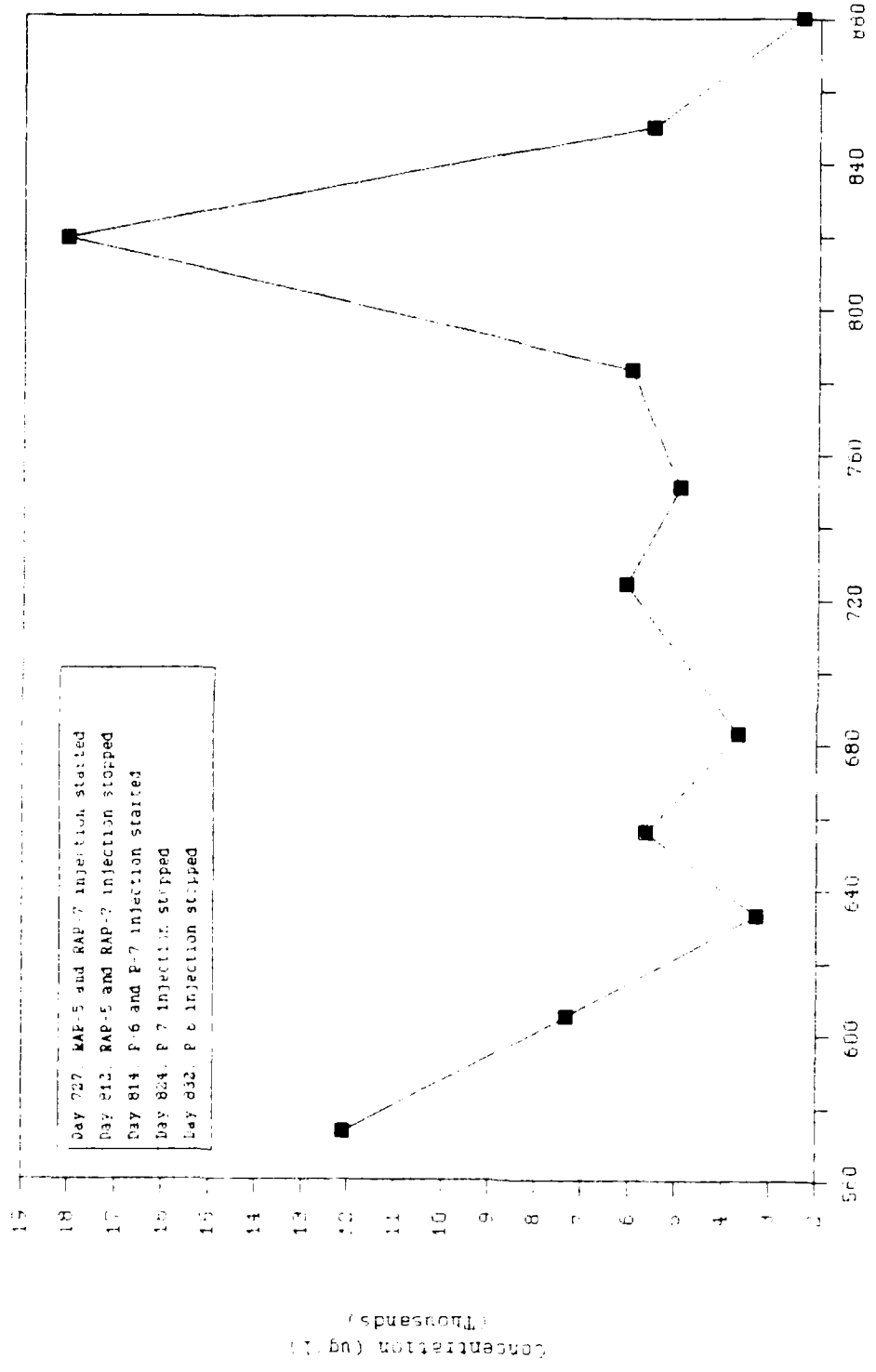

Figure 4-13. Combined Meta-xylene and Para-xylene Concentrations in UF-2M as a Function of Time.

and the decrease in UF-2M's concentration, it is not possible to attribute this increase strictly to the injection of water. However, following the injection in P-6 and P-7, the three wells (OHM-3, OHM-4, and UF-2M) recorded their highest concentrations in the 2.5 year history of the Environmental Engineering Sciences monitoring program. This supports the hypothesis that high levels of contaminant are present under the asphalt surface which were previously not being flushed by the unaugmented groundwater flow.

System Water Balance

Sprinkler Evaporation Test

The sprinklers were not protected from the wind during the sprinkler evaporation experiment, in order to simulate their normal operating conditions. While the wind was not blowing during the 0900 or 0600 tests, it was blowing lightly during the 1800 test, and was a significant factor in the 1200 test. The results are presented in Table 4-5.

Low pressure. In the low pressure test, the spray head was producing a continuous 12 foot diameter spray pattern and the collection sheet covered a 61.3 degree arc, extending the full spray radius of the sprinkler. The spray head was also isolated from possible overspray from surrounding heads. The collection percentage was greatest early in the morning, closely followed by the midnight

Table 4-5. Sprinkler Evaporation Collection Results

Low Pressure

Time	Volume Pumped (gal)	Volume Collected (gal)	Percent Collected
1800	88.0	2.88	3.27
0000	96.4	3.93	4.08
0600	89.3	3.85	4.32
1200	96.5	1.29	1.34

High Pressure

Time	Volume Pumped (gal)	Volume Collected (gal)	Percent Collected
1800	118.2	1.49	1.26
0000	111.1	1.38	1.24
0600	101.0	1.37	1.35
1200	102.1	1.41	1.38

collection period. While the smallest percent collected occurred during the noon sample, as expected, this was also the period the wind had its greatest effect on the spray pattern, and solar radiation and air temperature were nearing their daily peaks. Therefore, it is impossible to evaluate from these limited data the extent of evaporation, and the extent of loss due to the wind affected distribution patterns.

High pressure. The high pressure test produced an intermittent 24 foot diameter spray pattern and was not protected from overspray. This collection sheet only covered the inner 6.5 feet of a 64.2 degree arc through the spray pattern. The results from this phase of the experiment show little deviation in the percent collected at the designated times. This apparent inconsistency is attributed to the unequal spray distribution across the pattern's radius, and overspray from surrounding heads.

Spray System Efficiency Rates

The low pressure system consists of 15 spray heads on the north half of the spray field. Since the prevailing wind is from the north, any wind "loss" will still fall on the spray field. Unlike the watering systems used in citrus groves where the average application efficiency is 80 percent (Smajstrla et al., 1988), this spray is fully exposed to the wind and direct solar radiation. Therefore, an application efficiency of 70 percent was applied to the

volume pumped from RAP-1 and distributed on this section of the field.

The main high pressure system distributes the flow of UF-2M through ten spray heads on the south half of the spray field. The heads produce a mist, readily affected by the prevailing wind which transports considerable quantities to the asphalt road adjacent to the south edge of the spray field, resulting in a loss to the system. The fine spray and wind loss combine to produce a lower than average application efficiency. Therefore, a 50 percent efficiency was applied to the flow from UF-2M.

The intermittent flow from RAP-3 is applied to the 15 spray heads of the low pressure system. During this period, this section also becomes a high pressure system. However, because of its location on the spray field's northern half, it is not subjected to the high wind loss out of the system. Therefore, the flow from RAP-3 was assigned an application efficiency of 60 percent.

The fresh water irrigation sprinklers in the spray field are operated at a relatively low pressure, thus producing a steady stream and large droplets of water. Since Ali and Barefoot (1981) reported evaporative loss ranged from 0 to 50 percent, an efficiency of 80 percent was applied to this flow stream.

Additional Water Sources/Sinks

Evapotranspiration. Under identical climatic conditions, a wetted surface is assumed to experience an evaporation rate equal to the pan evaporation rate multiplied by its pan coefficient. In the spray field, the constant spray will increase the relative humidity and decrease the air temperature, both factors reducing the evapotranspiration rate. However, considering the limited extent of the spray field, 5,250 square feet, and the prevailing wind blowing during the peak evaporation periods, it was assumed there is no reduction in the evapotranspiration rate of the field.

Turfgrass in Florida will transpire an annual average of 63 percent of the measured pan evaporation (Jones et al., 1984). The grass covered surface within the area of interest is approximately 14,200 square feet, excluding the wetted area of the spray field.

Injection wells. During this study, fresh water was injected into the aquifer through select monitoring wells. It was assumed there were no evaporative losses from this augmentation system. In the unique case of RAP-7, injecting adjacent to the model-designated no flow boundary, it was assumed 50 percent of this freshly injected water crossed the boundary and was lost from the system

Precipitation. The site has roof gutter systems and storm sewer systems which are capable of effectively

removing precipitation from improved areas before it can enter the soil. The assumptions listed below were made concerning this potential water source.

1. Surface run-off of rain falling on the grassed areas was assumed to be 10 percent of the total volume, and

2. There was no runoff from the developed areas onto the grassed areas.

Groundwater flow. The naturally occurring groundwater flow through the area should also be considered. Killan (1987) estimated this flow to be 5,500 gallons per day. During this study period, a relative decrease in groundwater flow was indicated by the low levels of water in the adjacent wetlands. This, coupled with the high volume addition of water over the spray field was assumed to produce a hydraulic mound sufficient to divert the background flow around the study area. At lower rates of artificial recharge, this would not be the case.

Aquifer storativity. A rise in the water table reflects an increase in the quantity of water stored in the aquifer. In a surficial aquifer, this quantity is closely approximated by the specific yield of the aquifer. While the quantity of stored water ranged widely over the study period, its level on June 07, 1988 had returned to its January 30, 1988 level, the first day of the study. Therefore, this does not enter into this calculation.

Final Balance. The calculated values discussed above are presented in Table 4-6. This balance indicates an unaccounted for loss of 623,000 gallons during a period of 130 days, or 25 percent of the expected recovered volume. However, it should be noted that these quantities are based on approximations and average values.

Table 4-6. Results of System Water Balance Calculations

Volume pumped from recovery wells	- 1,900,000 gallons
Volume injected into injection wells	493,000 gallons
Volume of effective spray on the spray field	2,150,000 gallons
Volume of effective precipitation	155,000 gallons
Volume of evapotranspiration	- 273,000 gallons
Net volume difference	623,000 gallons

Model Selection

To adequately simulate the Lake Alfred site, a model must include the ability to accommodate aquifer heterogeneities, irregular flow boundaries, solute retardation, and biodegradation to support the bulk of the remediation research being conducted on site. Because of the well defined contaminant layer across the surface of the aquifer, a three-dimensional model would be well suited for modeling the site, but their lack of availability and high computer memory requirements precluded this possibility.

BIOPLUME II was selected because it included solute retardation, aerobic and anaerobic degradation, and had the necessary flexibility to simulate the site. In addition, the program was verified, well documented in the literature, and supported by the Department of Environmental Science and Engineering staff at Rice University. The addition of the menu driven preprocessor and its operation on a personal computer were two additional attractive features.

Model Validation

Before the model could be calibrated, initial conditions were required. Once established, the physical parameters and contaminant concentrations were entered, and the calibration procedure was continued.

Initial Conditions

The BIOPLUME II model, as well as the USGS Solute Transport model, require no-flow boundaries to surround the modeled region. No-flow boundaries have a transmissivity of zero, thus preventing the movement of water or contaminants across the cell's boundaries. A constant-head boundary may also be assigned to cells, indicating a stable water table elevation. Constant-head boundaries, coupled with large leakance terms are used to simulate sections of aquifer under stable flow conditions.

The project site was divided into a 200 by 200 foot grid system containing 400 square cells, ten feet per side. However, 76 of these cells were included in the requisit no-flow boundaries. The orientation of the established grid on the site map is shown in Figure 4-14. Arbitrary no-flow boundaries were established along the northern and southern edges of the study area. Since the wash rack proved an effective barrier to the northward spread of the plume, a boundary was established at its southern edge. Similarly, the no-flow boundary along the southern edge was established between UF-2M and OHM-2, outside of UF-2M's cone of influence.

A constant head boundary on the western edge of the area was established west of RAP-3. The assigned elevation was the water level measured in UF-3W.

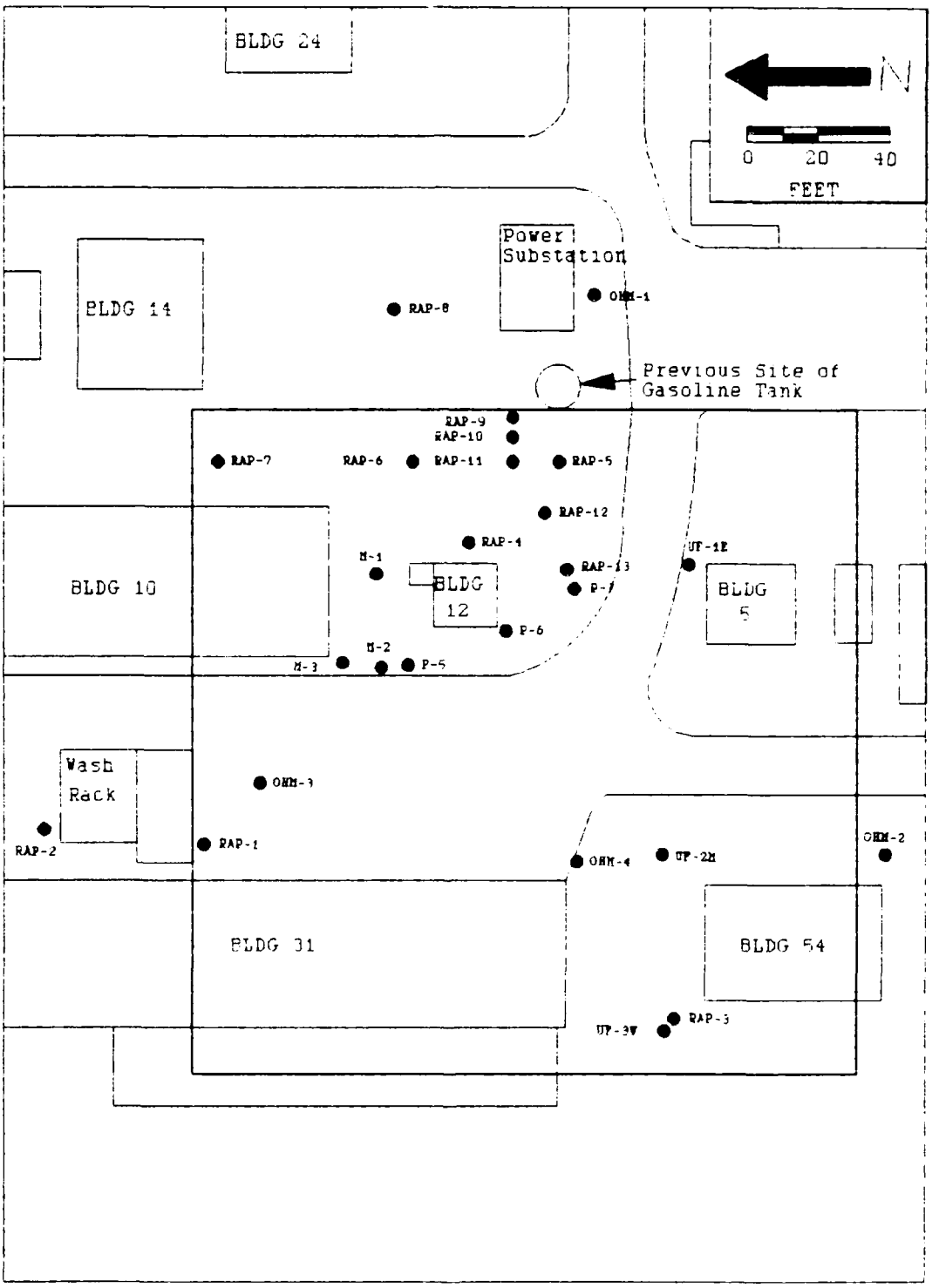

Figure 4-14. Modeled Area of the Lake Alfred Site.

On the remaining side, a boundary was established along the western edge of the spray field. The boundary location was dictated by the line of wells available to generate data to set the upgradient constant head boundary. Measured water table elevations for RAP-5, RAP-6, RAP-7, and RAP-11 were entered into their respective cells and values were interpolated for the intermediate cells. The additional row of cells upgradient are included in the model to minimize boundary effects if these four wells are used as injection wells.

By assigning a leakance factor to constant head boundaries, a net flux of oxygen and contaminant to or from the system may be represented. With a high hydrocarbon removal efficiency of the spray aeration system, the hydrocarbons not removed by air stripping were assumed to be biologically degraded in the upper layer of the soil. Therefore, there was no contaminant flux into the system. This was a reasonable assumption considering the relatively low hydrocarbon contamination levels found in RAP-4, RAP-6, and RAP-7. However, the area of the initial gasoline spill around RAP-5, had a persistent hydrocarbon concentration. To accommodate this contaminant input, the constant head boundary in this area was given a leakance coefficient of 1.0 with contaminant addition, thus allowing the movement of contaminant into the area. An influx of oxygen was also

used to simulate the movement of oxygenated water into the system from the spray field.

Due to indications of aquifer compression below buildings, the transmissivity and thickness of the areas underlying these buildings was assumed to be zero. This is a reasonable simplification when coupled with the areas of relatively high transmissivity surrounding the buildings.

Parameter Selection

Killan (1987) determined the effective porosity of the aquifer to be 25 percent, and the bulk density to be 1.4 grams per cubic centimeter. His measured values of aquifer transmissivity, presented in Appendix C, were used as the original estimates, although they were later adjusted during the calibration phase.

The aquifer thickness map was generated by subtracting the surface elevation of the confining layer from the average augmented water table elevation in each monitoring well, and interpolating between those points over the remainder of the area. Thickness values of injection wells were disregarded during their period of use.

The recharge parameter is based on the measured pan evaporation and precipitation data obtained from the NWS weather station at Lake Alfred. The daily values of these measurements for the study period are listed in Appendix G. Assuming 10 percent of total rainfall is surface runoff, there was an effective rainfall of 13.02 inches during the

course of the study. Based on the average annual evapotranspiration rate for turfgrass, there was 20.25 inches of water lost through this process. The net loss of 7.23 inches of water from grassed areas over the 130 day period of the study produces a recharge rate of 5.4×10^{-8} feet per second. Although this value represents a net loss from the system, it is given a positive value by the numbering convention used in the model. This factor was only applied to unimproved surfaces on the site.

The values of longitudinal dispersivity and the ratio of transverse to longitudinal dispersivity were taken from Freeberg et al. (1987) as ten feet and 0.1 respectively. These values were obtained in a similar calibration study.

A partition coefficient (Kd) of 1.8 was used for the calibration procedure. This value is based on laboratory experiments conducted by Angley (1987).

The anaerobic decay coefficient was set at zero. Although recent research has found anaerobic degradation of alkylbenzenes under restricted conditions, it occurs at a slow rate in comparison with aerobic degradation (Wilson et al., 1986). Therefore, any anaerobic degradation was assumed to be negligible.

The reaeration decay coefficient was also kept at zero. Although there is sure to be some reaeration occurring because of the shallow depth of the aquifer, the area of highest concentration is effectively sealed under the

asphalt surface. Infiltration of dissolved oxygen across the upgradient constant head boundary is the main source of oxygen.

The process of entering data into the BIOPLUME II program is simplified through the use of the menu-driven preprocessor. Its use ensures the input file is properly formatted, as well as providing the allowable parameter ranges. The main loader menu is shown in Figure 4-15. The input file may also be constructed or edited with a commercial program editor. A sample input file is presented in Appendix H, and an edited program output is presented in Appendix I.

Figure 4-16 provides a simplified flow diagram for the model.

Groundwater Flow Calibration

After adjusting the transmissivity values to minimize the summation of errors between the measured water table elevations and the predicted water table elevations in the eight monitoring wells under the three flow conditions, the minimum error obtained was 6.108 feet. A breakdown of this value is provided in Table 4-7.

Sources of error include geologic heterogeneities in the aquifer and variations in the hydraulic gradient not accounted for in the model. The model also uses nodes centrally located in the finite difference cells. Due to the grid-size limitation of the model, there is a maximum of

```
                    Loader
                  Main Menu

      1.    Edit file name
      2.    Edit card 1 (Title)
      3.    Edit card 2 (Grid/timing parameters)
      4.    Edit card 3 (Grid/timing parameters)
      5.    Edit card 4 (Reaction parameters)
      6.    Edit data set 1 (Observation wells)
      7.    Edit data set 2 (Pump/Inject wells)
      8.    Edit data set 3 (Transmissivity map)
      9.    Edit data set 4 (Thickness map)
     10.    Edit data set 5 (Recharge map)
     11.    Edit data set 6 (Nodeid map)
     12.    Edit data set 7 (Nodeid code definitions)
     13.    Edit data set 8 (Water table elevations)
     14.    Edit data set 9 (Initial hydrocarbon conc.)
     15.    Edit data set 10 (Initial oxygen conc.)
     16.    Edit data set 11 (Pumping periods)
     17.    Write data to file
     18.    Quit

Enter the number of your choice (1..18) ...
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Figure 4-15. BIOPLUME II Preprocessor's Main Menu

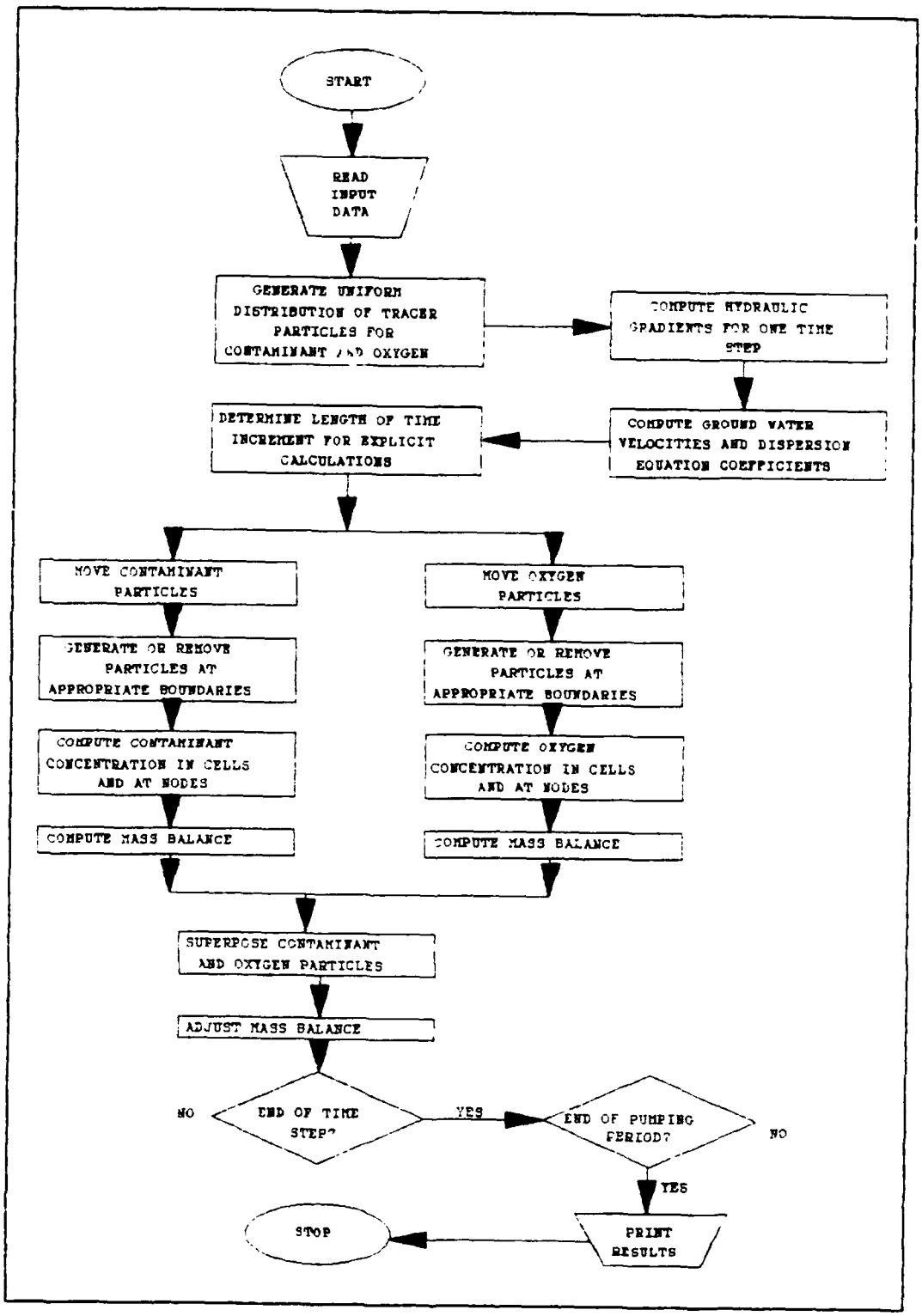

Figure 4-16. Simplified Flowchart of BIOPLUME II (Source: Rifai et al., 1987, p. 2-9).

Table 4-7. Minimized Groundwater Calibration Error

	Condition		
Well	Static	RAP-5 and RAP-7	P-6 and P-7
RAP-4	0.265	-0.067	0.037
RAP-12	-0.218	-0.649	-0.291
M-1	0.318	0.083	-0.079
RAP-13	0.577	0.257	0.139
UF-1E	0.357	-0.024	0.184
P-5	-0.275	-0.451	-0.398
OHM-3	-0.070	-0.036	0.633
OHM-4	0.133	-0.033	0.534

Minimized Total Error = $\Sigma |P_i - M_i|$

= 6.108 feet

seven feet between the actual location of the monitoring well in the field and the mathematical representation of the well in the model. Considering these factors, the variability of the water table elevation, and the similar results obtained under three diverse flow conditions, the model is considered adequately calibrated.

Solute Transport Calibration.

Meta-xylene and para-xylene are present in sufficient quantities in the contaminated groundwater to serve as indicators of the plume movement; therefore, they were used to calibrate the solute transport portion of the model. The sum of both isomers was used since the gas chromatography method used for analysis failed to differentiate between them. Although the same argument could be made for ortho-xylene, the meta- and para- isomers were selected because of their faster degradation rate (Angley, 1987). This tracer method will be effective under conditions without degradation, but where degradation occurs, the oxygen will be consumed in the degradation process of all organics, not just the tracer organics.

The unknown contaminant distribution or concentration beneath the asphalt roadway, the limited database available, and the instability of the database that was available gave additional sources of error.

BIOPLUME II does not effectively model this site for solute transport. The extreme vertical variations of

contaminant concentration involved, make it unrealistic to predict the contaminant concentration in the groundwater. The highly contaminated regions serve as an intermittent source of contaminant whenever the saturated zone enters these areas. Preliminary calculations of the model, and the elevated hydrocarbon concentrations observed after the high volume injections in P-6 and P-7 indicate combined concentrations of 150,000 to 250,000 parts per billion of meta-xylene and para-xylene in the area beneath the asphalt surface.

CHAPTER V
SUMMARY AND CONCLUSIONS

The objectives of this study have been met. A semi-quantitative evaluation of the vertical distribution of sorbed hydrocarbons in the soil was conducted, confirming that high concentrations of solute are localized in areas previously contaminated with free product. The vertical stability of the sorbed contaminants is further supported by the large contaminant concentration swings in the groundwater which correlate with the fluctuations in the water table elevation.

A mass balance of the water flowing through the system was performed, using pan evaporation and precipitation values, pumped water volumes, and sprinkler application efficiencies. There was an unaccounted for loss of 25 percent of the estimated recoverable water, a reasonable margin of error considering the estimations involved in the process. This justified considering the study area as a closed system for the purposes of modeling. The most likely avenue of unaccounted water loss is from the north face of the spray field toward building 14. If the assumptions of total hydrocarbon removal through air stripping and

biological degradation in the surface layer of soil are valid, there will be no adverse impact.

BIOPLUME II was selected as the modeling program based on its adaptability to variable site conditions, thorough documentation of the program and its predecessor, the USGS Solute Transport Model, the program's availability and institutional support, and the user friendly software.

The program was calibrated to the site conditions using a trial and error method to minimize the difference between predicted and actual values. Despite the physical obstructions and heterogeneities within the aquifer, the program was able to readily simulate the groundwater flow conditions; however, the solute transport model was not able to be adequately calibrated. To account for the highly contaminated region at the surface of the elevated water table, intermittent contaminant sources would be required, but the concentration at the source would also depend on the water table elevation and would vary over time. While this aids the overall model, it reduces the model's ability to realistically predict the dissolved contaminant movement. This inability to predict reasonable transport will severely restrict its usefulness. To obtain a more sensitive model, a three-dimensional model would be required.

The database available for model calibration at elevated water table conditions was very limited. Fluctuations in the water table significantly affect the

contaminant concentrations. The transmissivity values of the area remain constant.

The largest area of contamination remains under the road surface between buildings 12 and 31. Flushing the aquifer *via* fresh water injection proved effective at removing large quantities of contaminants. Because of the low cost and high effectiveness, flushing under the road surface, with recovery wells operating, should be an effective remedy on high contaminant concentrations. Follow on work with bioremediation should be much more effective with lower concentrations remaining after flushing.

Development of a more extensive database could improve the calibration of the model. In particular, improved information on the biological parameters and quantification of the distribution and concentration of contaminants under the road surface would improve the reliability of the model.

APPENDIX A

RECORD OF WATER TABLE ELEVATIONS IN MONITORING WELLS

Table A-1. Water Table Elevations

Well Name	Elevation (feet, a.m.s.l.) on Specified Date				
	30 Jan 88	02 Feb 88	06 Feb 88	09 Feb 88	13 Feb 88
M-1	135.28	136.40	136.45	136.33	135.95
M-2	134.72	135.52	135.65	135.52	135.27
M-3	134.81	135.63	135.73	135.63	135.38
OHM-1	133.58	133.98	133.88	133.90	133.68
OHM-2	133.18	133.23	--	133.05	132.90
OHM-3	133.71	134.04	134.19	134.14	134.04
OHM-4	133.69	133.92	133.99	133.44	133.34
P-5	134.82	135.62	135.74	135.59	135.34
P-6	135.08	136.00	136.10	135.95	135.63
P-7	135.19	136.29	136.39	136.26	135.86
RAP-2	133.41	133.56	133.71	133.74	133.69
RAP-4	136.06	137.28	137.33	137.23	136.76
RAP-5	136.70	143.03	144.13	144.13	144.13
RAP-6	137.07	138.34	138.32	138.29	137.77
RAP-7	136.34	140.44	142.14	142.14	142.14
RAP-8	--	145.52	145.52	144.12	142.37
RAP-9	137.52	138.97	138.85	138.97	138.35
RAP-10	137.21	138.81	138.66	138.76	138.11
RAP-11	136.80	138.47	138.32	138.42	137.75
RAP-12	136.02	137.77	137.65	137.57	136.97
RAP-13	134.8	136.05	134.13	136.00	135.55
UF-1E	--	--	--	136.02	135.72
UF-3W	132.59	132.64	132.74	132.47	132.09

Table A-1--continued.

Well Name	Elevation (feet, a.m.s.l.) on Specified Date				
	16 Feb 88	20 Feb 88	23 Feb 88	27 Feb 88	01 Mar 88
M-1	136.08	135.80	135.55	135.43	135.25
M-2	135.30	135.22	134.98	134.75	134.62
M-3	135.38	135.36	135.12	134.86	134.73
OHM-1	133.68	133.48	133.33	133.30	133.08
OHM-2	132.93	133.00	--	132.75	132.60
OHM-3	133.99	134.44	133.94	133.54	133.64
OHM-4	133.34	133.37	133.24	133.04	132.94
P-5	135.37	135.29	135.06	134.84	134.72
P-6	135.68	135.53	136.13	135.13	134.93
P-7	135.91	135.74	135.49	135.36	135.06
RAP-2	133.61	133.99	133.83	133.24	133.24
RAP-4	136.96	136.61	136.36	136.28	136.08
RAP-5	144.13	144.13	144.13	144.13	142.43
RAP-6	138.14	137.57	137.25	136.32	136.12
RAP-7	141.36	142.14	142.14	142.14	141.44
RAP-8	142.52	141.42	--	141.62	141.27
RAP-9	138.85	138.37	137.67	138.07	137.75
RAP-10	138.54	138.09	138.41	137.81	137.44
RAP-11	138.10	137.70	136.75	137.40	137.02
RAP-12	137.12	136.92	136.62	136.55	136.12
RAP-13	135.60	135.43	135.10	135.05	134.73
UF-1E	135.77	135.62	135.35	135.22	134.87
UF-3W	132.09	132.34	132.34	132.22	132.17

Table A-1--continued.

Well Name	Elevation (feet, a.m.s.l.) on Specified Date				
	02 Mar 88	05 Mar 88	08 Mar 88	12 Mar 88	15 Mar 88
M-1	135.45	135.40	135.61	135.76	136.28
M-2	135.07	134.70	134.87	135.00	136.30
M-3	135.13	134.81	136.00	135.12	134.58
OHM-1	133.35	133.23	132.61	133.75	134.28
OHM-2	132.60	132.55	132.80	132.78	133.18
OHM-3	133.64	133.54	133.69	133.76	133.96
OHM-4	133.07	132.94	133.08	133.14	133.39
P-5	135.17	134.77	134.97	135.08	135.33
P-6	135.55	135.03	135.23	135.33	135.67
P-7	135.74	135.19	135.68	135.49	135.83
RAP-2	133.26	133.26	133.41	133.46	133.68
RAP-4	136.93	136.23	136.46	136.61	136.81
RAP-5	142.80	142.55	--	142.76	143.06
RAP-6	138.07	137.34	137.64	137.78	137.92
RAP-7	141.79	141.89	--	142.04	142.14
RAP-8	141.72	141.62	--	141.82	141.97
RAP-9	138.82	137.87	138.07	138.27	139.55
RAP-10	138.56	137.61	137.79	137.99	138.24
RAP-11	138.12	137.22	137.39	137.57	136.75
RAP-12	137.12	136.32	136.47	136.62	136.90
RAP-13	135.50	134.85	135.05	135.16	135.77
UF-1E	135.37	134.97	135.22	135.27	135.72
UF-3W	--	131.99	132.16	131.99	132.01

Table A-1--continued.

Well Name	Elevation (feet, a.m.s.l.) on Specified Date				
	19 Mar 88	22 Mar 88	26 Mar 88	30 Mar 88	02 Apr 88
M-1	136.58	--	135.92	135.80	135.78
M-2	135.72	--	135.05	135.27	135.81
M-3	135.82	--	135.18	135.33	134.43
OHM-1	133.60	134.76	134.65	134.78	134.64
OHM-2	133.40	133.20	132.93	133.45	133.19
OHM-3	134.24	134.14	133.85	134.12	133.84
OHM-4	133.59	133.49	133.22	133.79	133.35
P-5	135.81	135.46	135.12	135.32	135.16
P-6	136.14	135.65	135.43	135.58	135.45
P-7	136.39	135.79	135.58	135.69	135.67
RAP-2	133.96	133.95	133.58	133.91	133.56
RAP-4	137.46	137.48	136.66	136.43	136.59
RAP-5	143.41	139.30	139.28	141.13	142.75
RAP-6	138.69	137.79	137.81	137.21	137.62
RAP-7	142.14	141.64	141.66	137.74	141.55
RAP-8	142.25	141.90	142.32	142.42	142.37
RAP-9	139.27	138.52	138.41	136.82	138.27
RAP-10	138.96	138.21	138.10	137.31	137.99
RAP-11	138.52	137.82	137.67	137.07	137.58
RAP-12	137.59	136.87	136.72	136.52	136.72
RAP-13	136.10	135.48	135.26	135.30	135.33
UF-1E	136.31	135.67	135.37	135.57	135.59
UF-3W	131.42	132.49	132.20	132.49	132.45

Table A-1--continued.

Well Name	Elevation (feet, a.m.s.l.) on Specified Date				
	05 Apr 88	09 Apr 88	17 Apr 88	24 Apr 88	29 Apr 88
M-1	136.04	135.58	135.43	135.03	136.27
M-2	135.34	134.90	134.79	134.55	135.69
M-3	135.43	135.02	134.92	134.68	135.64
OHM-1	134.70	134.50	134.00	133.95	134.27
OHM-2	133.10	132.85	132.64	132.75	132.62
OHM-3	134.20	133.76	133.67	133.57	134.00
OHM-4	133.53	133.16	133.03	133.38	133.51
P-5	135.45	134.98	134.86	134.65	135.94
P-6	135.78	135.24	135.08	134.81	138.29
P-7	135.99	135.41	135.22	134.89	138.90
RAP-2	133.86	133.49	133.39	133.32	133.61
RAP-4	136.86	136.35	136.21	135.70	137.21
RAP-5	142.93	142.12	144.13	136.14	137.90
RAP-6	137.79	137.32	137.21	136.51	137.82
RAP-7	141.56	141.42	142.14	141.51	137.00
RAP-8	142.18	141.09	141.85	142.40	141.57
RAP-9	138.67	137.97	137.76	136.69	138.37
RAP-10	138.37	137.68	137.49	136.48	138.14
RAP-11	137.94	137.28	137.12	136.20	137.84
RAP-12	137.12	136.45	136.29	135.67	137.59
RAP-13	135.68	135.08	134.88	134.49	137.00
UF-1E	135.85	135.24	134.97	134.72	136.16
UF-3W	132.51	132.12	131.74	131.07	130.97

Table A-1--continued.

Well Name	Elevation (feet, a.m.s.l.) on Specified Date				
	02 May 88	06 May 88	14 May 88	20 May 88	07 Jun 88
M-1	136.58	137.07	135.72	135.57	134.83
M-2	135.98	136.35	135.97	134.94	134.42
M-3	135.94	136.40	134.59	135.10	134.58
OHM-1	134.67	134.56	134.52	134.29	134.30
OHM-2	132.97	132.95	132.77	132.48	132.44
OHM-3	134.31	134.43	134.05	133.92	133.56
OHM-4	133.85	133.86	133.39	133.09	132.87
P-5	136.21	136.45	135.36	134.99	134.49
P-6	139.57	139.50	139.10	135.15	134.63
P-7	140.21	140.14	135.74	135.23	134.74
RAP-2	133.89	133.95	133.83	134.01	133.47
RAP-4	137.53	137.66	136.46	136.30	135.51
RAP-5	138.32	138.11	137.05	136.89	136.17
RAP-6	138.14	138.29	137.14	137.30	136.22
RAP-7	137.24	137.37	136.65	136.75	135.82
RAP-8	--	139.45	138.20	138.62	137.47
RAP-9	138.80	138.64	137.50	137.54	136.63
RAP-10	138.55	138.41	137.29	137.29	136.40
RAP-11	138.23	138.13	137.02	136.97	136.12
RAP-12	137.94	137.78	136.52	136.22	135.57
RAP-13	--	137.05	135.35	134.89	134.35
UF-1E	136.62	136.51	135.40	134.94	134.62
UF-3W	131.82	132.03	132.02	131.16	131.72

APPENDIX B

PUMPING RECORD OF THE GROUNDWATER RECYCLING SYSTEM

Table B-1. Pumping Record of the Groundwater Recycling System

Date (1988)	Project Day	Normalized Daily Pumped Volume (gallons) RAP-1	UF-2M	RAP-3	Spray
30 Jan	727	6631	312		18837
31 Jan	728	7015	109		17631
01 Feb	729	8473	534		11246
02 Feb	730	9136	0		10951
03 Feb	731	7200	0		12000
04 Feb	732	7200	0		12000
05 Feb	733	13981	0		9683
06 Feb	734	10016	5778	446	2459
07 Feb	735	8972	7298	549	558
08 Feb	736	8523	7298	1051	13200
09 Feb	737	8077	7125	723	13200
10 Feb	738	6500	8000	510	13000
11 Feb	739	5700	8000	490	13000
12 Feb	740	6656	8776	508	13000
13 Feb	741	6969	8789	503	14213
14 Feb	742	7073	8793	502	14493
15 Feb	743	7073	8793	502	14493
16 Feb	744	6678	8358	559	11416
17 Feb	745	3269	8377	537	10371
18 Feb	746	2718	8413	529	10398
19 Feb	747	0	8464	501	11310
20 Feb	748	0	8772	495	11672
21 Feb	749	0	8863	494	11779

Table B-1 -- continued.

Date (1988)	Project Day	Normalized Daily Pumped Volume (gallons) RAP-1	UF-2M	RAP-3	Spray
22 Feb	750	1142	8770	490	11399
23 Feb	751	8687	8624	546	11427
24 Feb	752	12825	8533	582	11446
25 Feb	753	12825	8533	582	11446
26 Feb	754	12825	8533	582	11446
27 Feb	755	4183	8135	785	11341
28 Feb	756	1140	7987	855	11305
29 Feb	757	1140	7987	855	11305
01 Mar	758	7116	7233	451	11242
02 Mar	759	8037	7364	378	11341
03 Mar	760	6506	7350	418	11122
04 Mar	761	6733	7297	429	11051
05 Mar	762	7323	7806	1102	10997
06 Mar	763	7416	7886	1207	10989
07 Mar	764	8119	7920	1658	11830
08 Mar	765	8531	7719	2049	14129
09 Mar	766	8623	7623	2167	15060
10 Mar	767	9243	8020	2205	13236
11 Mar	768	9371	8019	1325	13161
12 Mar	769	7972	7417	1135	13100
13 Mar	770	7649	7278	1092	13085
14 Mar	771	7959	7617	1068	12979
15 Mar	772	7963	6774	1315	12153

Table B-1 -- continued.

Date (1988)	Project Day	Normalized Daily Pumped Volume (gallons) RAP-1	UF-2M	RAP-3	Spray
16 Mar	773	7925	5545	2837	14000
17 Mar	774	8246	5032	3096	12937
18 Mar	775	8784	4828	3355	12864
19 Mar	776	6565	4838	1203	12792
20 Mar	777	6186	4840	836	12780
21 Mar	778	6186	4840	836	12780
22 Mar	779	6106	4670	816	12782
23 Mar	780	6045	4192	680	12700
24 Mar	781	8170	3968	1643	12688
25 Mar	782	10581	3710	1771	12642
26 Mar	783	7026	2376	994	12844
27 Mar	784	5969	1979	763	12912
28 Mar	785	5764	200	687	12110
29 Mar	786	6023	0	934	9255
30 Mar	787	6120		910	6576
31 Mar	788	6490		807	11439
01 Apr	789	8953		882	10814
02 Apr	790	5757		719	10551
03 Apr	791	4968		679	10477
04 Apr	792	5122		727	10452
05 Apr	793	5965	879	887	10703
06 Apr	794	6900	5200	1710	10280
07 Apr	795	8100	4600	1670	10690

Table B-1 -- continued.

Date (1988)	Project Day	Normalized Daily Pumped Volume (gallons) RAP-1	UF-2M	RAP-3	Spray
08 Apr	796	8621	4891	1477	10122
09 Apr	797	5562	4518	422	10320
10 Apr	798	4542	4394	71	10398
11 Apr	799	4500	4400	1500	10380
12 Apr	800	5300	4600	1320	9960
13 Apr	801	5200	4500	820	10330
14 Apr	802	7932	4940	1913	10144
15 Apr	803	7932	4940	1913	10144
16 Apr	804	7932	4940	1913	10144
17 Apr	805	5415	4582	1044	10107
18 Apr	806	4700	5100	690	9920
19 Apr	807	6400	3700	1770	10120
20 Apr	807	8400	0	3190	10640
21 Apr	809	8300	0	3160	9310
22 Apr	810	8183	0	2947	8919
23 Apr	811	8183	0	2947	8919
24 Apr	812	6135	0	2026	8711
25 Apr	813	4500	4400	2740	8550
26 Apr	814	5400	6000	3300	9340
27 Apr	815	7100	7200	3680	9270
28 Apr	816	9147	8000	3724	9280
29 Apr	817	8783	7721	2655	9425
30 Apr	818	8685	7638	2337	9468

Table B-1 -- continued.

Date (1988)	Project Day	Normalized Daily Pumped Volume (gallons) RAP-1	UF-2M	RAP-3	Spray
01 May	819	8685	7638	2337	9468
02 May	820	9245	8029	4622	9232
03 May	821	9203	7851	3565	9331
04 May	322	9752	7928	3646	9293
05 May	823	9787	7958	3867	9122
06 May	824	8698	7347	2641	9215
07 May	825	8698	7347	2641	9215
08 May	826	8698	7347	2641	9215
09 May	827	8854	6930	3068	9156
10 May	827	9530	6982	3354	4189
11 May	829	9835	6998	3700	1340
12 May	830	9419	6822	2608	0
13 May	831	9030	6789	2736	0
14 May	832	8201	6470	2397	5184
15 May	833	7983	6380	2305	9570
16 May	834	8068	6343	2136	9478
17 May	835	7905	6152	2114	9410
18 May	836	8034	6118	1889	8787
19 May	837	8469	6099	1887	9679
20 May	838	7650	5948	2025	9491
21 May	839	7650	5948	2025	9491
22 May	840	7650	5948	2025	9491
23 May	841	7595	5874	1919	9479

Table B-1 -- continued.

Date (1988)	Project Day	Normalized Daily Pumped Volume (gallons) RAP-1	UF-2M	RAP-3	Spray
24 May	842	8494	6245	2736	9439
25 May	843	9548	6722	4207	909
26 May	844	9325	6386	3828	0
27 May	845	9360	6172	3360	0
28 May	846	9360	6172	3360	0
29 May	847	9360	6172	3360	0
30 May	848	9360	6172	3360	0
31 May	849	8023	5965	1581	0
01 Jun	850	8646	6010	1610	0
02 Jun	851	8646	5979	1620	0
03 Jun	852	8646	5866	1978	0
04 Jun	853	8646	5866	1978	0
05 Jun	854	8646	5866	1978	0
06 Jun	855	8646	5685	2190	0
07 Jun	856	7264	5500	1460	6672

Table B-2. Injection Record in the Well System

Date (1988)	Project Day	Normalized Daily Injected Volume (gallons) RAP-5	RAP-7	RAP-8	P-6	P-7
30 Jan	727	5171	5171	8417	0	0
31 Jan	728	6863	6863	12243	0	0
01 Feb	729	6477	6477	11085	0	0
02 Feb	730	6578	6578	6663	0	0
03 Feb	731	7303	7303	4800	0	0
04 Feb	732	7303	7303	4800	0	0
05 Feb	733	7441	7441	4909	0	0
06 Feb	734	3836	3836	2514	0	0
07 Feb	735	3004	3004	1962	0	0
08 Feb	736	5894	5894	1708	0	0
09 Feb	737	3430	3430	985	0	0
10 Feb	738	6240	6240	800	0	0
11 Feb	739	6640	6640	700	0	0
12 Feb	740	5185	5185	610	0	0
13 Feb	741	3067	3067	714	0	0
14 Feb	742	2510	2510	741	0	0
15 Feb	743	2510	2510	741	0	0
16 Feb	744	2454	2454	697	0	0
17 Feb	745	2464	2464	651	0	0
18 Feb	746	2470	2470	647	0	0
19 Feb	747	2677	2677	726	0	0
20 Feb	748	1893	1893	736	0	0
21 Feb	749	1699	1699	738	0	0

Table B-2 -- continued.

Date (1988)	Project Day	Normalized Daily Injected Volume (gallons) RAP-5	RAP-7	RAP-8	P-6	P-7
22 Feb	750	1726	1726	722	0	0
23 Feb	751	1825	1825	682	0	0
24 Feb	752	1877	1877	662	0	0
25 Feb	753	1877	1877	662	0	0
26 Feb	754	1877	1877	662	0	0
27 Feb	755	982	982	630	0	0
28 Feb	756	707	707	621	0	0
29 Feb	757	707	707	621	0	0
01 Mar	758	703	703	611	0	0
02 Mar	759	659	659	525	0	0
03 Mar	760	659	659	525	0	0
04 Mar	761	659	659	525	0	0
05 Mar	762	616	616	482	0	0
06 Mar	763	609	609	475	0	0
07 Mar	764	609	609	475	0	0
08 Mar	765	602	602	444	0	0
09 Mar	766	598	598	430	0	0
10 Mar	767	598	598	430	0	0
11 Mar	768	598	598	430	0	0
12 Mar	769	597	597	409	0	0
13 Mar	770	597	597	404	0	0
14 Mar	771	597	597	404	0	0
15 Mar	772	618	618	413	0	0

Table B-2 -- continued.

Date (1988)	Project Day	Normalized Daily Injected Volume (gallons) RAP-5	RAP-7	RAP-8	P-6	P-7
16 Mar	773	632	632	418	0	0
17 Mar	774	632	632	418	0	0
18 Mar	775	632	632	418	0	0
19 Mar	776	464	464	291	0	0
20 Mar	777	423	423	259	0	0
21 Mar	778	423	423	259	0	0
22 Mar	779	407	407	409	0	0
23 Mar	780	397	397	499	0	0
24 Mar	781	397	397	499	0	0
25 Mar	782	397	397	499	0	0
26 Mar	783	592	592	390	0	0
27 Mar	784	644	644	354	0	0
28 Mar	785	644	644	354	0	0
29 Mar	786	644	644	354	0	0
30 Mar	787	641	641	344	0	0
31 Mar	788	640	640	338	0	0
01 Apr	789	640	640	338	0	0
02 Apr	790	660	660	347	0	0
03 Apr	791	602	602	349	0	0
04 Apr	792	602	602	349	0	0
05 Apr	793	575	575	334	0	0
06 Apr	794	562	562	326	0	0
07 Apr	795	562	562	326	0	0

Table B-2 -- continued.

Date (1988)	Project Day	Normalized Daily Injected Volume (gallons) RAP-5	RAP-7	RAP-8	P-6	P-7
08 Apr	796	562	562	326	0	0
09 Apr	797	1208	1208	319	0	0
10 Apr	798	1461	1461	316	0	0
11 Apr	799	1461	1461	316	0	0
12 Apr	800	1461	1461	316	0	0
13 Apr	801	1259	1259	316	0	0
14 Apr	802	1236	1236	316	0	0
15 Apr	803	1236	1236	316	0	0
16 Apr	804	1236	1236	316	0	0
17 Apr	805	571	571	272	0	0
18 Apr	806	447	447	264	0	0
19 Apr	807	447	447	264	0	0
20 Apr	808	447	447	264	0	0
21 Apr	809	447	447	264	0	0
22 Apr	810	447	447	264	0	0
23 Apr	811	447	447	264	0	0
24 Apr	812	0	0	264	0	0
25 Apr	813	0	0	264	0	0
26 Apr	814	0	0	264	6852	7449
27 Apr	815	0	0	264	6852	7449
28 Apr	816	0	0	264	6852	7449
29 Apr	817	0	0	0	7017	7576
30 Apr	818	0	0	0	7066	7614

Table B-2 -- continued.

Date (1988)	Project Day	Normalized Daily Injected Volume (gallons) RAP-5	RAP-7	RAP-8	P-6	P-7
01 May	819	0	0	0	7066	7614
02 May	820	0	0	0	6203	6738
03 May	821	0	0	0	5912	6362
04 May	822	0	0	0	5939	6390
05 May	823	0	0	0	5859	6305
06 May	824	0	0	0	4476	0
07 May	825	0	0	0	4476	0
08 May	826	0	0	0	4476	0
09 May	827	0	0	0	4281	0
10 May	828	0	0	0	4189	0
11 May	829	0	0	0	4271	0
12 May	830	0	0	0	4269	0
13 May	831	0	0	0	4242	0

APPENDIX C

HYDRAULIC CHARACTERIZATION OF CONTAMINATION SITE LAKE ALFRED, FLORIDA

Table C-1. Summary of Estimates of Hydraulic Parameters for the IFAS-CREC Project Aquifer.

Relevant Area of Application	Hydraulic Conductivity (fpd)	Transmissivity (gpd/ft)	Specific Yield (%)	Seepage Velocity (fpd)
Within 40 ft of UF-2M	160	4,700	30	18
Within 80 ft of RAP-1	310	12,400	10	10
Between RAP-9 and RAP-10	30	400	21	16
Between RAP-10 and RAP-11	26	580	21	10
Between RAP-11 and P-7	31	580	21	6
Between P-7 and UF-2M	60	810	30	10
Near P-5	11	220	21	2
Near P-6	7	190	21	1
Near P-7	8	140	21	2
Near UF-3W	4	170	30	<1

Source: Killan, 1987.

APPENDIX D

GAS CHROMATOGRAPHY CALIBRATION CURVES

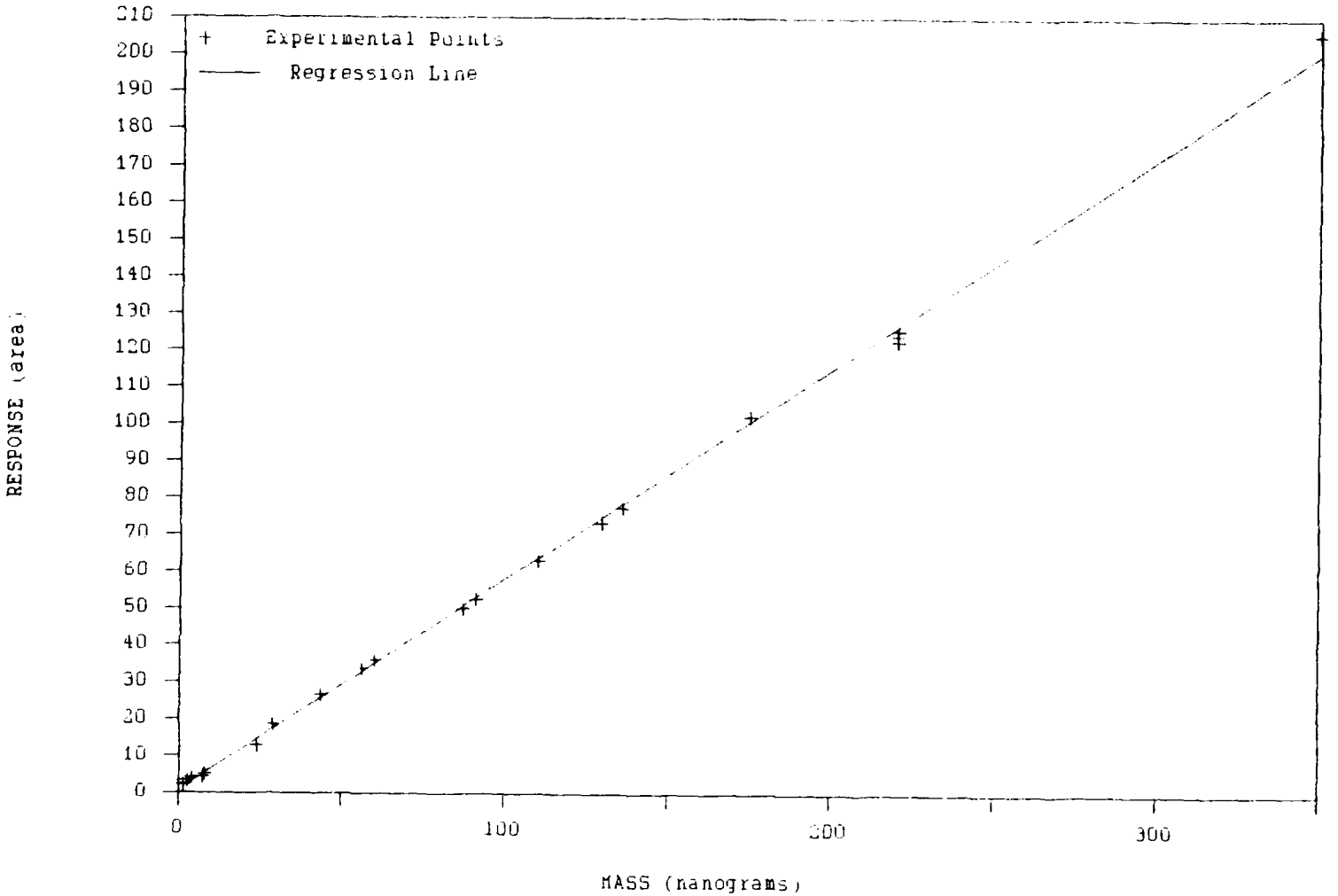

Figure D-1. Gas Chromatography Calibration Curve for Benzene.

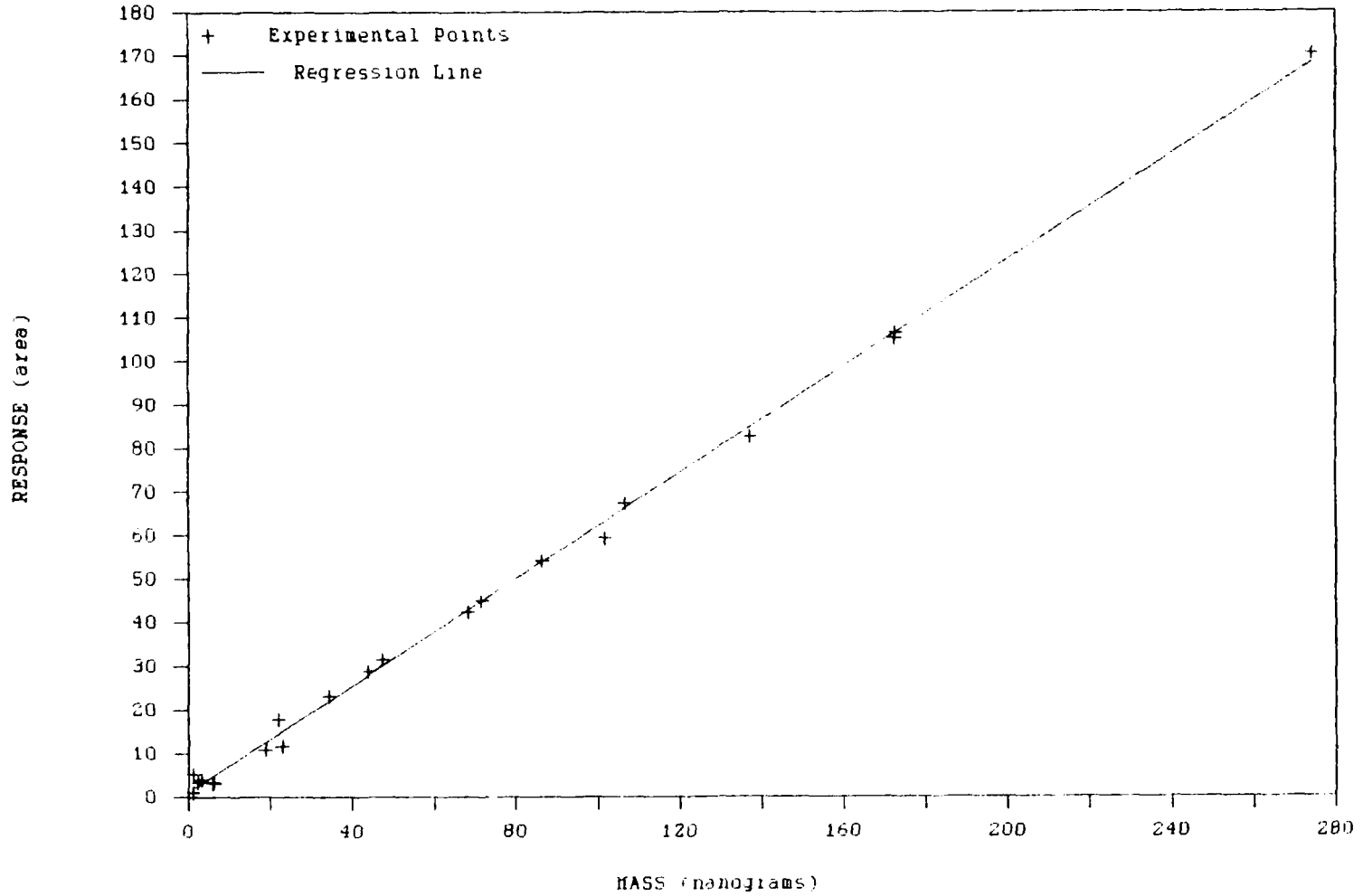

Figure D-2. Gas Chromatography Calibration Curve for Toluene.

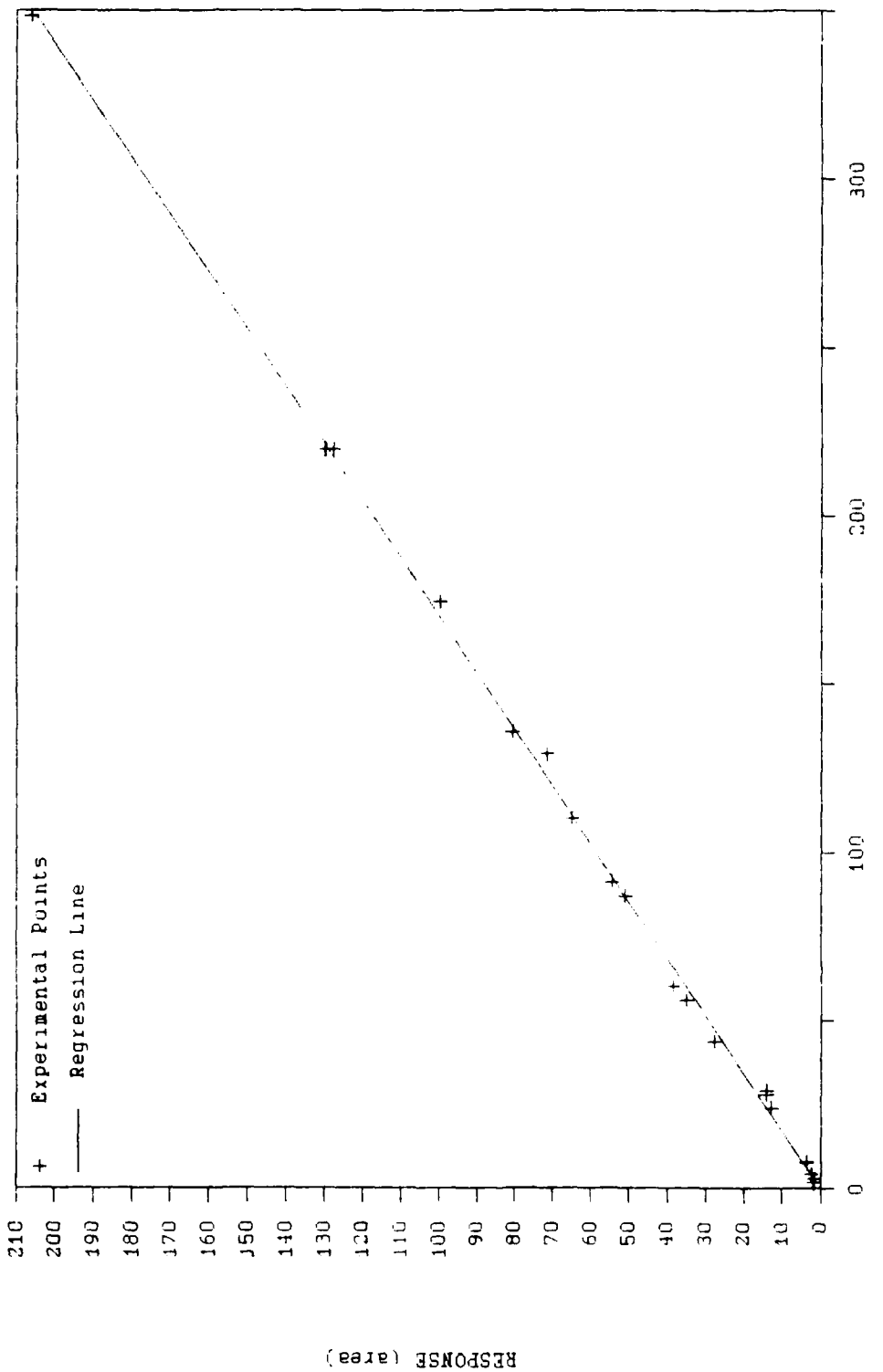

Figure D-3. Gas Chromatography Calibration Curve for Ethylbenzene.

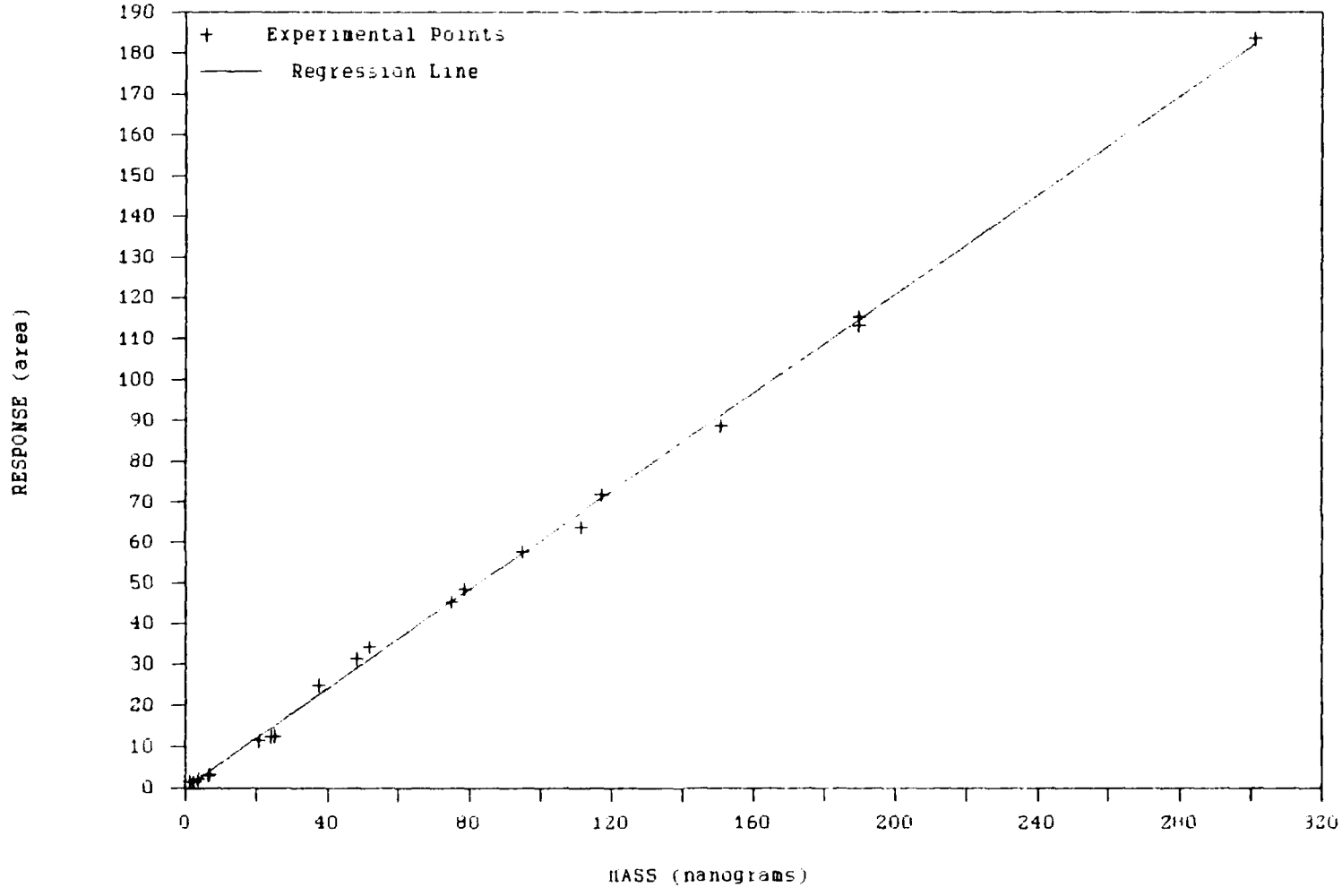

Figure D-4. Gas Chromatography Calibration Curve for both Meta-xylene and Para-xylene.

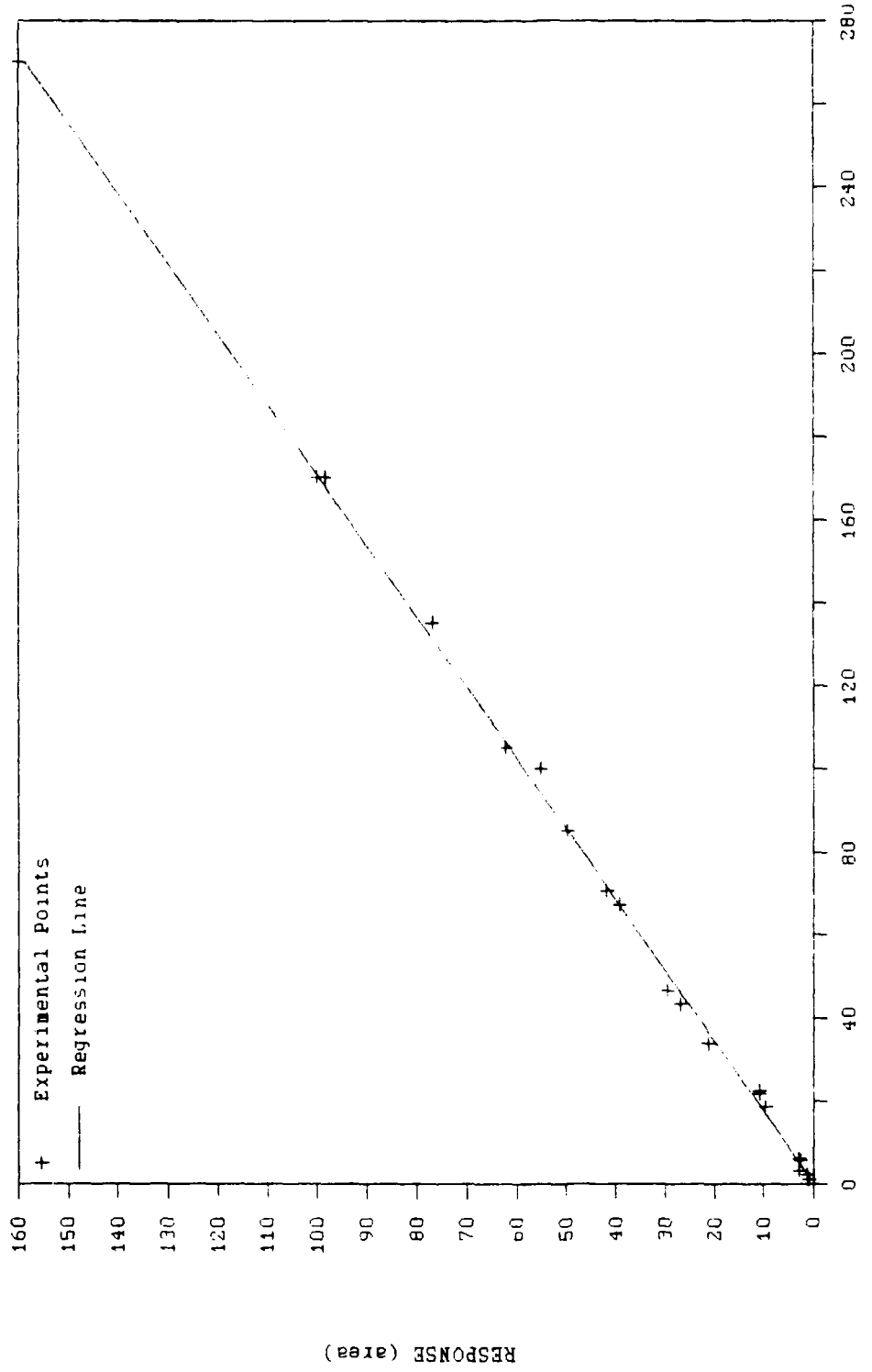

Figure D-5. Gas Chromatography Calibration Curve for Ortho-xylene.

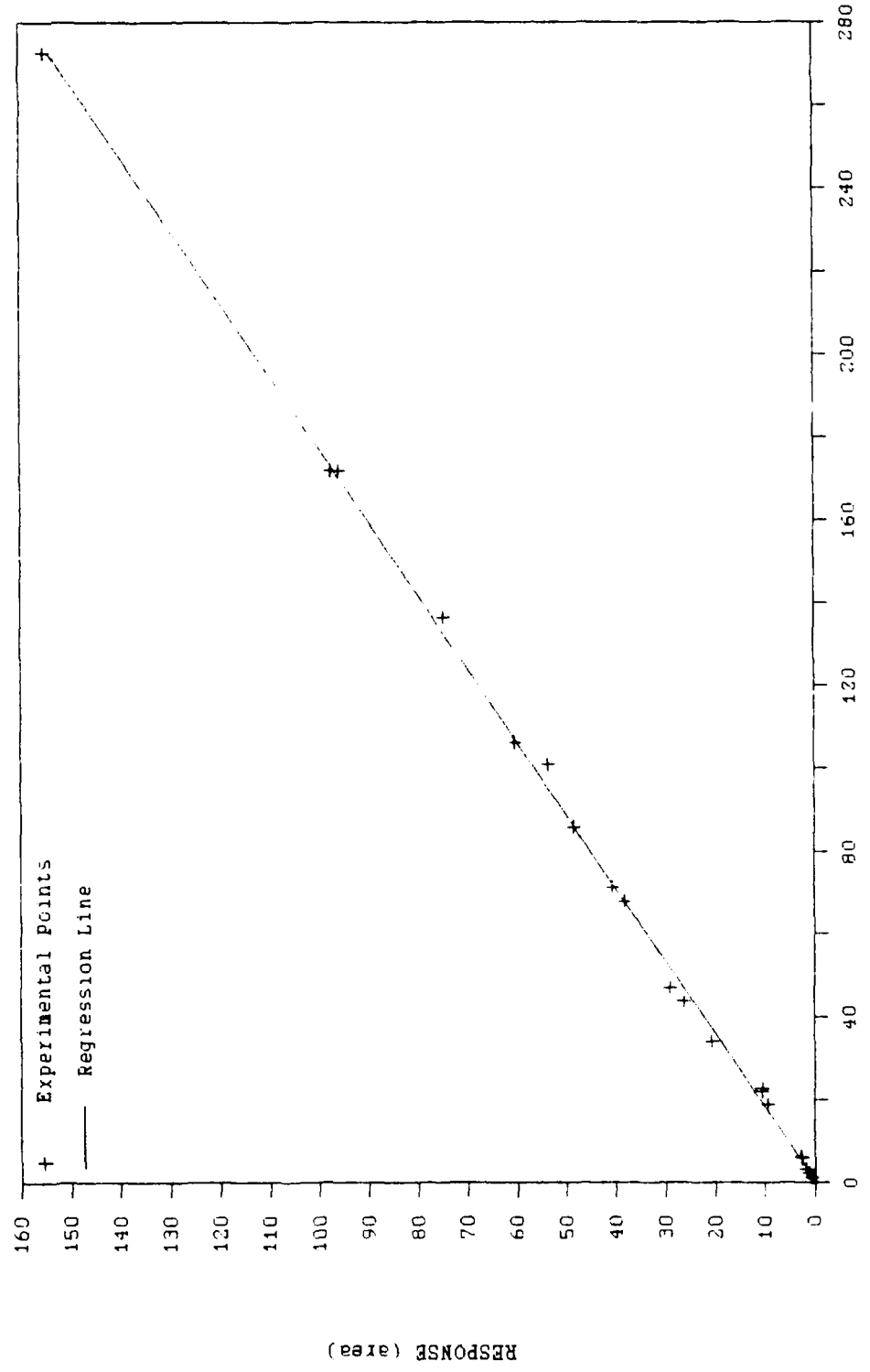

Figure D-6. Gas Chromatography Calibration Curve for Isopropylbenzene.

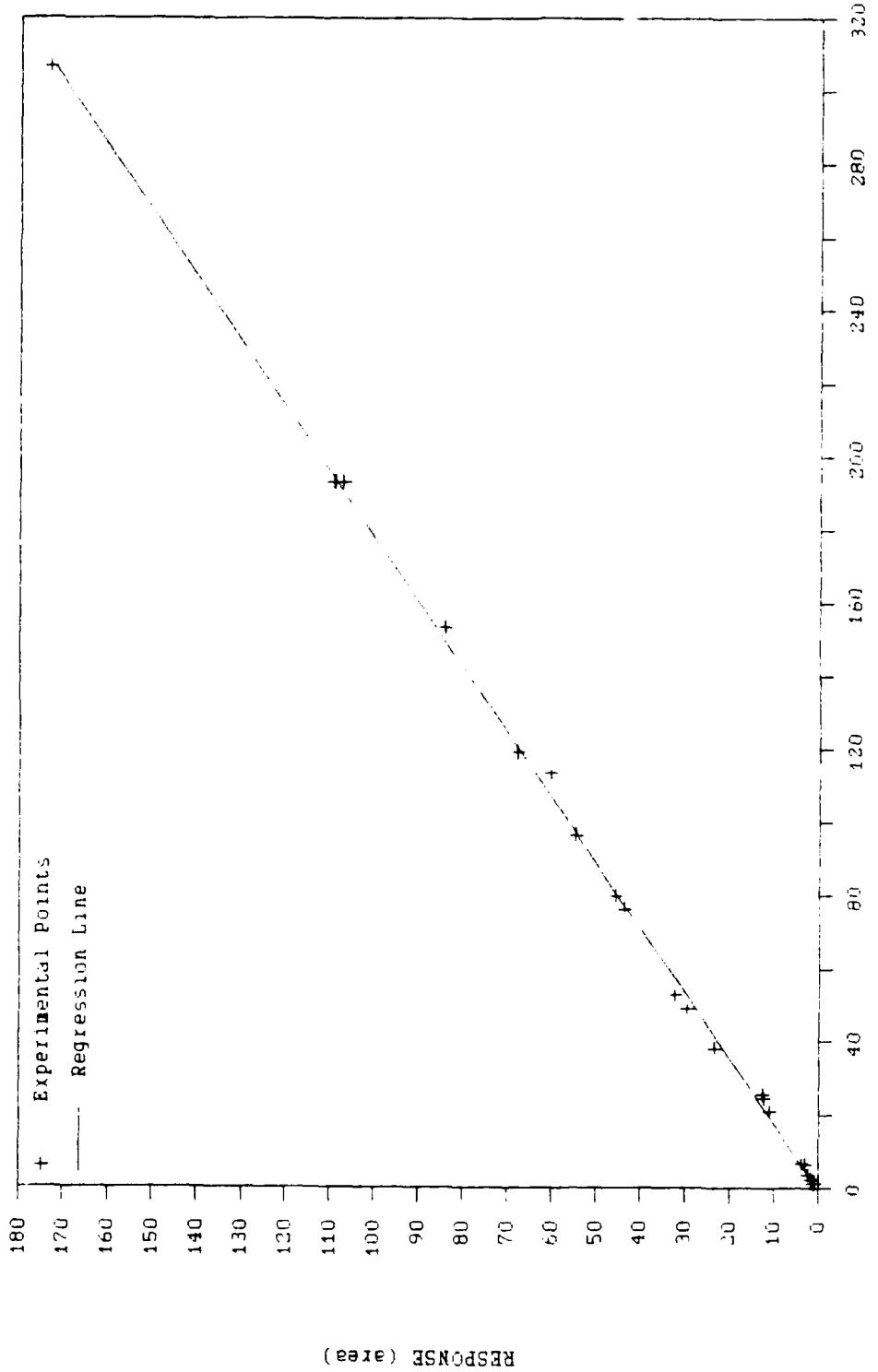

Figure D-7. Gas Chromatography Calibration Curve for Propylbenzene.

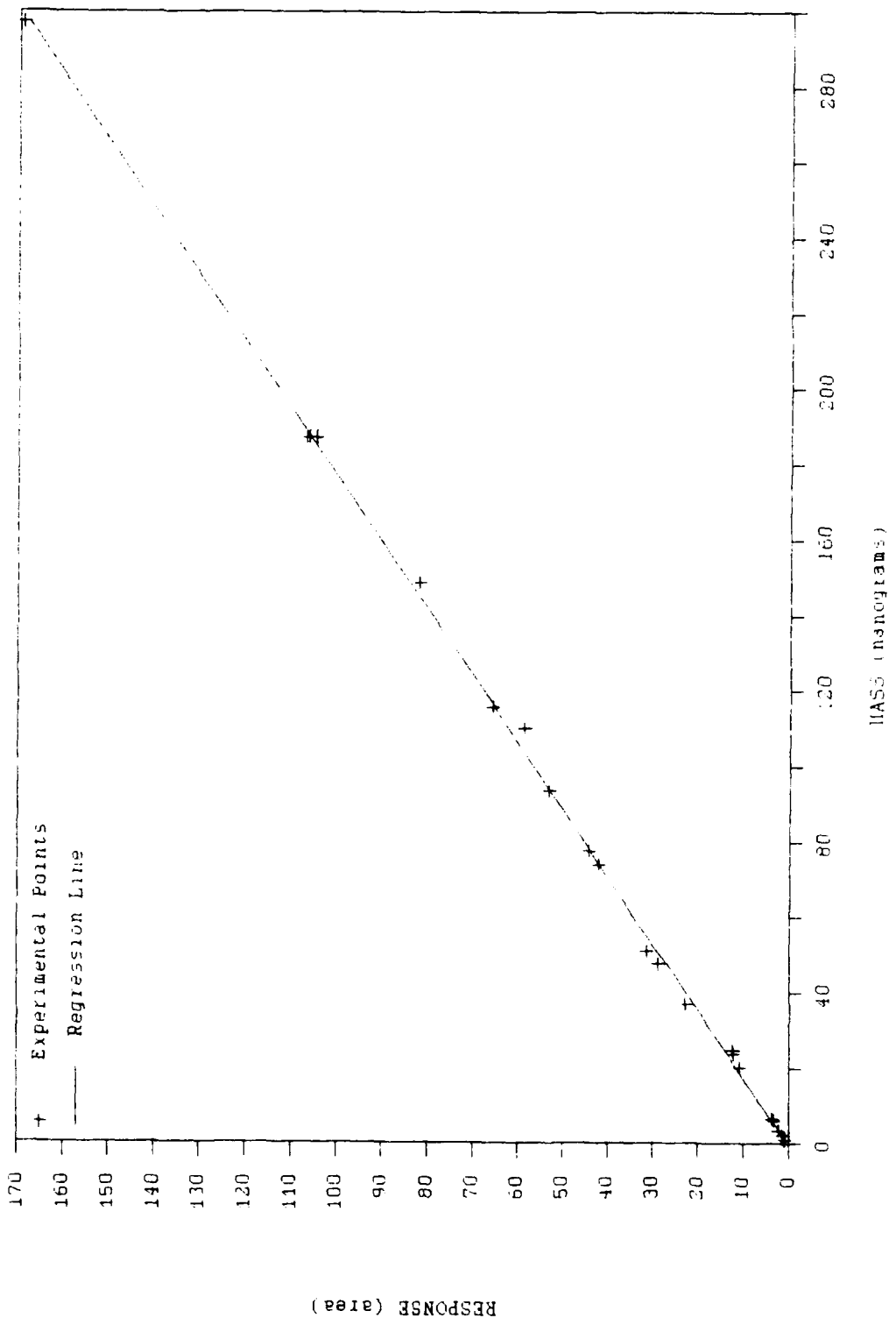

Figure D-8. Gas Chromatography Calibration Curve for both 3-ethyltoluene and 4-ethyltoluene.

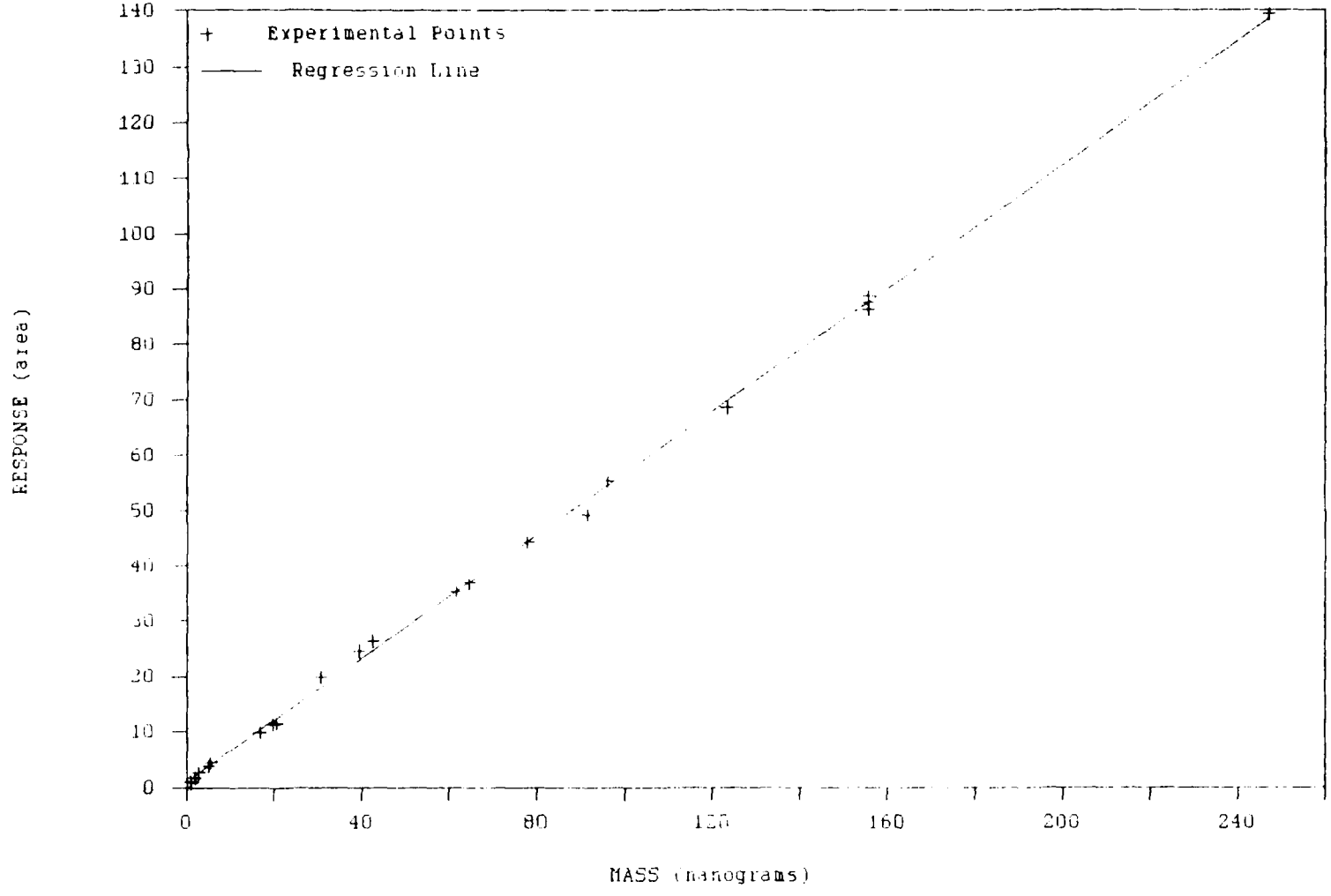

Figure D-9. Gas Chromatography Calibration Curve for 1,3,5-trimethylbenzene.

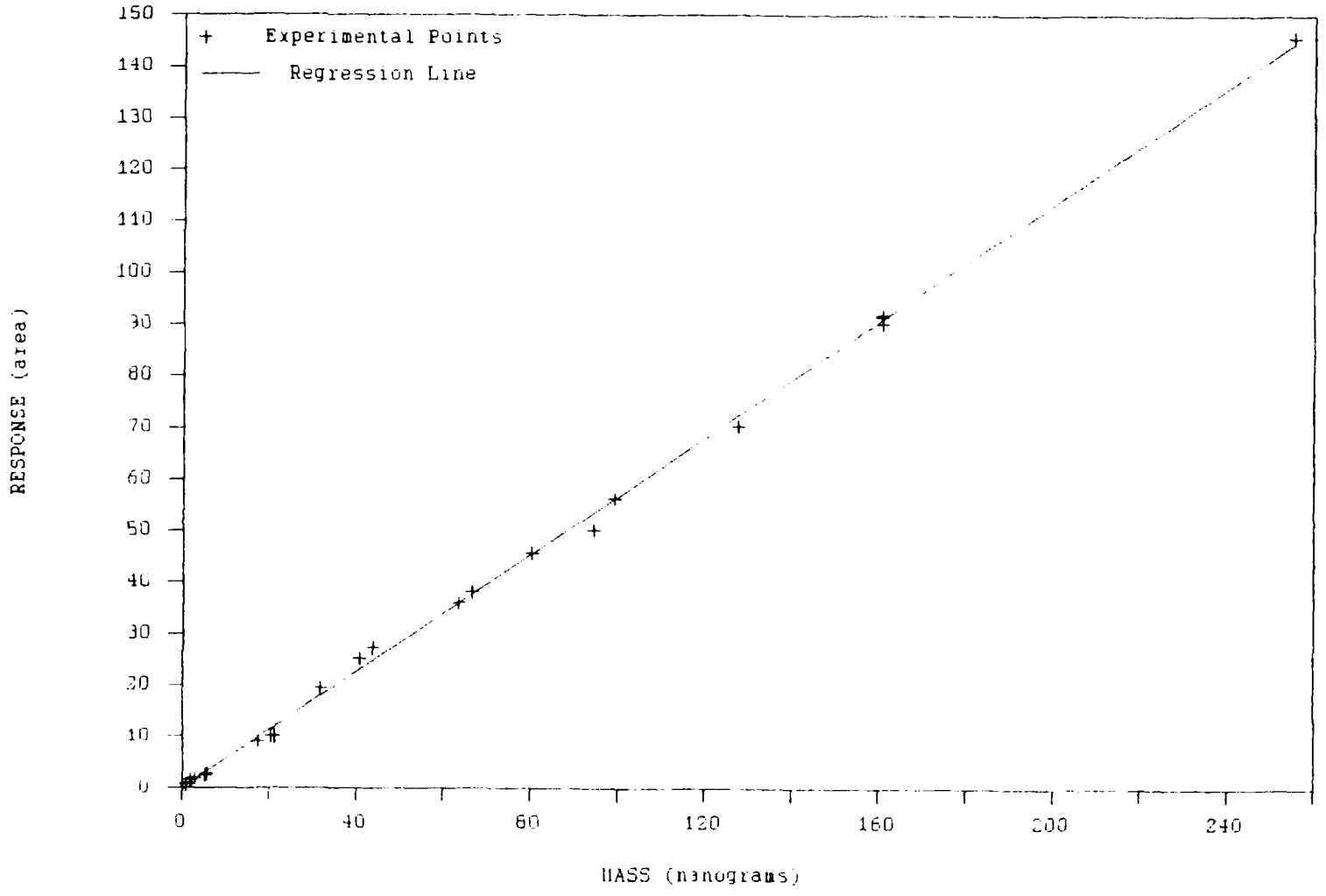

Figure D-10. Gas Chromatography Calibration Curve for 2-ethyltoluene.

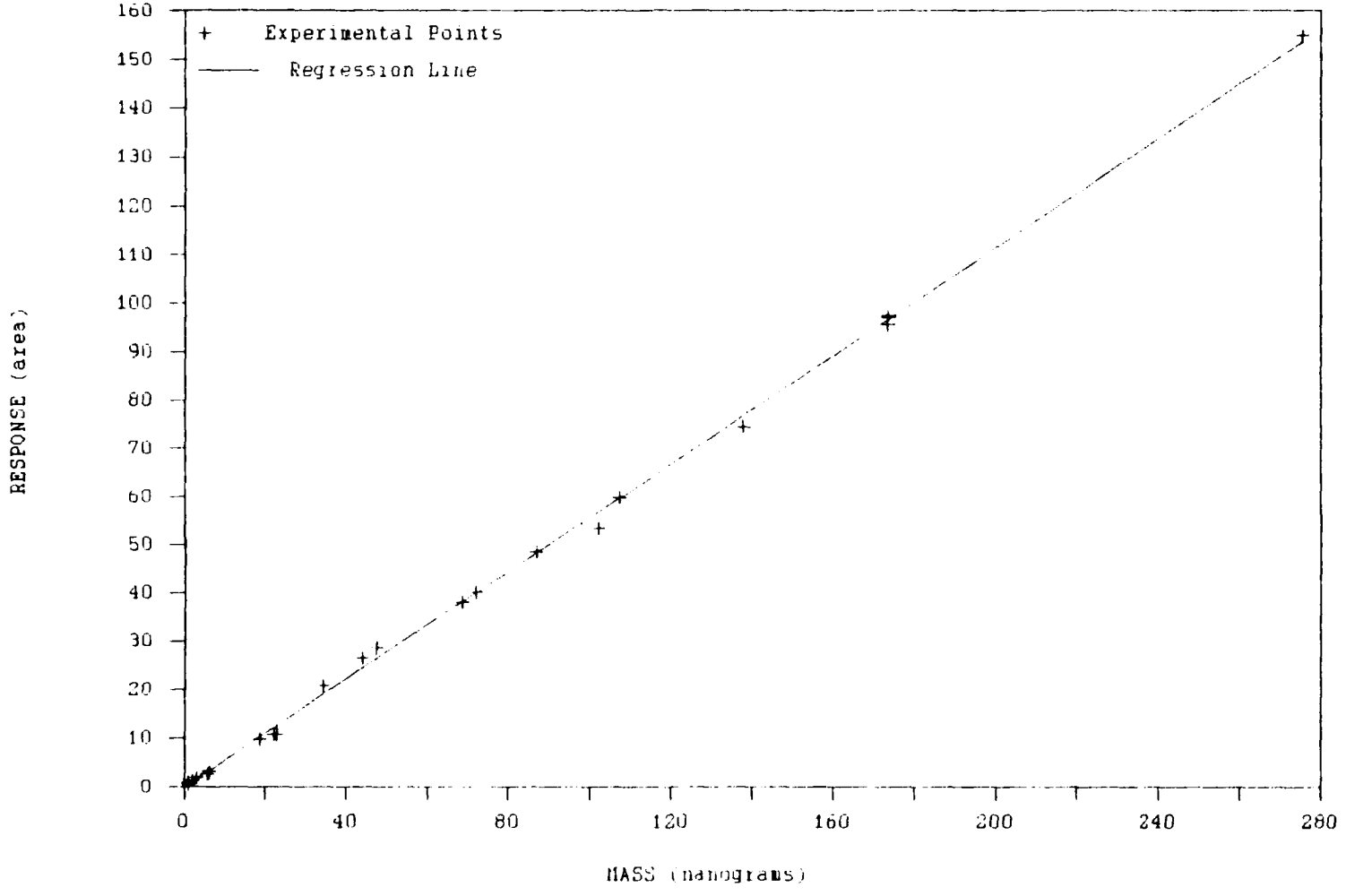

Figure D-11. Gas Chromatography Calibration Curve for 1,2,4-trimethylbenzene.

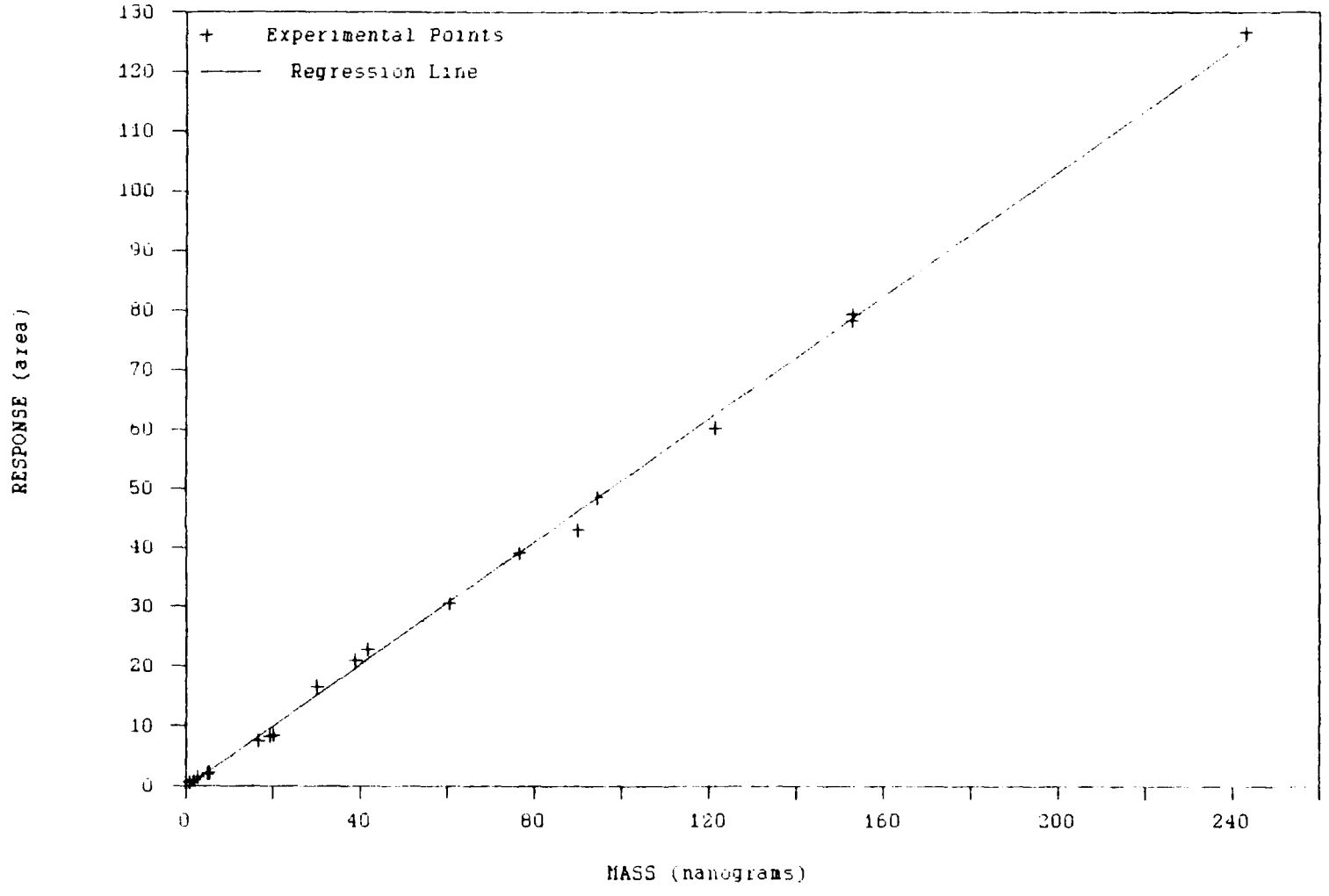

Figure D-12. Gas Chromatography Calibration Curve for 1,2,3-trimethylbenzene.

APPENDIX E

HEXANE EXTRACTION RESULTS OF SOIL CORE SAMPLES

Table E-1. Extraction Results from Soil Core 1, South of OHM-4.

Analyte	Measured Concentration (nanograms hydrocarbon/gram soil)			
Benzene	BDL (300)	BDL (261)	1940	11000
Toluene	BDL (235)	BDL (292)	73300	334000
Ethylbenzene	BDL (440)	2850	61700	176000
Meta-,Para-Xylene	1370	8850	186000	601000
Ortho-Xylene	BDL (422)	4170	69500	186000
Isopropylbenzene	BDL (69)	BDL (135)	13200	31700
Propylbenzene	BDL (156)	1250	52200	125000
3,4-Ethyltoluene	BDL (254)	4420	221000	545000
1,3,5-Trimethylbenzene	BDL (212)	1980	87700	196000
2-Ethyltoluene	BDL (219)	3990	82400	197000
1,2,4-Trimethylbenzene	BDL (236)	5980	248000	608000
1,2,3-Trimethylbenzene	BDL (208)	2160	56700	151000
Total	4120	36300	1150000	1410000
Mean Elevation of Sample (feet above mean sea level)	133.3	132.8	132.2	131.7

Table E-2. Extraction Results from Soil Core 2, Well B.

Analyte	Measured Concentration (nanograms hydrocarbon/gram soil)		
Benzene	BDL (399)	1450	BDL (233)
Toluene	BDL (312)	BDL (223)	BDL (91)
Ethylbenzene	ND (0)	BDL (284)	BDL (116)
M,P-Xylene	973	BDL (444)	BDL (201)
Ortho-Xylene	ND (0)	ND (0)	ND (0)
Isopropylbenzene	ND (0)	BDL (113)	ND (0)
Propylbenzene	BDL (182)	BDL (250)	BDL (204)
3,4-Ethyltoluene	BDL (176)	BDL (242)	BDL (198)
1,3,5-Trimethylbenzene	BDL (282)	BDL (201)	BDL (165)
2-Ethyltoluene	ND (0)	ND (0)	ND (0)
1,2,4-Trimethylbenzene	ND (0)	ND (0)	ND (0)
1,2,3-Trimethylbenzene	ND (0)	ND (0)	ND (0)
Total	2320	3210	1210
Mean Elevation of Sample (feet above mean sel level)	136.0	135.3	134.8

Table E-3. Extraction Results from Soil Core 3, between RAP-4 and the Pump House.

Analyte	Measured Concentration (nanograms hydrocarbon/gram soil)		
Benzene	BDL (405)	BDL (497)	BDL (337)
Toluene	ND (0)	ND (0)	BDL (264)
Ethylbenzene	ND (0)	ND (0)	ND (0)
M,P-Xylene	ND (0)	BDL (227)	BDL (290)
Ortho-Xylene	ND (0)	BDL (181)	BDL (260)
Isopropylbenzene	BDL (164)	ND (0)	BDL (263)
Propylbenzene	BDL (355)	BDL (436)	BDL (295)
3,4-Ethyltoluene	BDL (344)	BDL (423)	BDL (286)
1,3,5-Trimethylbenzene	BDL (286)	BDL (352)	BDL (238)
2-Ethyltoluene	ND (0)	ND (0)	ND (0)
1,2,4-Trimethylbenzene	ND (0)	ND (0)	BDL (265)
1,2,3-Trimethylbenzene	ND (0)	ND (0)	ND (0)
Total	1550	2120	2500
Mean Elevation of Sample (feet above mean sea level)	137.0	136.4	135.8

Table E-4. Extraction Results from Soil Core 4, South of OHM-4.

Analyte	Measured Concentration (nanograms hydrocarbon/gram soil)	
Benzene	BDL (595)	BDL (850)
Toluene	ND (0)	BDL (666)
Ethylbenzene	ND (0)	1720
M,P-Xylene	BDL (512)	2230
Ortho-Xylene	BDL (238)	BDL (215)
Isopropylbenzene	BDL (464)	ND (0)
Propylbenzene	BDL (521)	BDL (623)
3,4-Ethyltoluene	BDL (505)	BDL (722)
1,3,5-Trimethylbenzene	BDL (420)	BDL (600)
2-Ethyltoluene	ND (0)	BDL (203)
1,2,4-Trimethylbenzene	BDL (469)	BDL (219)
1,2,3-Trimethylbenzene	ND (0)	ND (0)
Total	3720	8050
Mean Elevation of Sample (feet above mean sea level)	133.7	133.1

Table E-5. Extraction Results from Soil Core 5, North of UF-2M.

Analyte	Measured Concentration (nanograms hydrocarbon/gram soil)		
Benzene	BDL (550)	BDL (378)	BDL (370)
Toluene	BDL (431)	BDL (296)	BDL (290)
Ethylbenzene	1170	BDL (377)	BDL (369)
Meta-,Para-xylene	1130	BDL (326)	BDL (319)
Ortho-xylene	1230	BDL (292)	ND (0)
Isopropyl-benzene	1080	BDL (295)	BDL (289)
Propylbenzene	1430	BDL (331)	BDL (325)
3,4-Ethyltoluene	1110	BDL (321)	BDL (315)
1,3,5-Trimethyl-benzene	BDL (388)	932	BDL (262)
2-Ethyltoluene	BDL (401)	BDL (276)	ND (0)
1,2,4-Trimethyl-benzene	BDL (433)	BDL (298)	BDL (292)
1,2,3-Trimethyl-benzene	ND (0)	ND (0)	ND (0)
Total	9340	4120	2830
Mean Elevation of Sample (feet above mean sea level)	134.7	134.0	133.4

Table E 5 -- continued.

Analyte	Measured Concentration (nanograms hydrocarbon/gram soil)		
Benzene	BDL (488)	62900	752
Toluene	2790	338000	3120
Ethylbenzene	5720	186000	5180
Meta-,Para-xylene	18800	571000	15000
Ortho-xylene	8180	234000	7000
Isopropyl-benzene	1040	22600	1080
Propylbenzene	3790	87300	2570
3,4-Ethyltoluene	15400	380000	9380
1,3,5-Trimethyl-benzene	5980	143000	3520
2-Ethyltoluene	7470	139000	3910
1,2,4-Trimethyl-benzene	18400	420000	10800
1,2,3-Trimethyl-benzene	4780	93900	2720
Total	92800	2680000	65000
Mean Elevation of Sample (feet above mean sea level)	132.7	131.8	131.0

Table E-5 -- continued.

Analyte	Measured Concentration (nanograms hydrocarbon/gram soil)
Benzene	BDL (226)
Toluene	BDL (177)
Ethylbenzene	735
Meta-,Para-xylene	1530
Ortho-xylene	729
Isopropyl-benzene	BDL (176)
Propylbenzene	BDL (198)
3,4-Ethyltoluene	878
1,3,5-Trimethyl-benzene	BDL (159)
2-Ethyltoluene	428
1,2,4-Trimethyl-benzene	1260
1,2,3-Trimethyl-benzene	557
Total	7050
Mean Elevation of Sample (feet above mean sea level)	130.4

APPENDIX F

RESULTS OF EXTRACTION RECOVERY STUDIES

Table F-1. Results of First Extraction Recovery Study, with 0.127 Milligram Total Hydrocarbon Spike.

Analyte	Percent Hydrocarbons Recovered					
	Soil Sample Number 1			Soil Sample Number 2		
Benzene	23.9	9.3	9.3	-0.2	-5.7	86.1
Toluene	23.9	9.3	9.3	-0.2	-5.7	65.1
Ethylbenzene	67.6	53.0	53.0	124	-5.7	-5.7
Meta-, Para-xylene	23.9	9.3	9.3	219	106	-5.7
Ortho-xylene	23.9	9.3	9.3	79.2	74.4	66.4
Isopropylbenzene	23.9	9.3	9.3	152	62.3	146
Propylbenzene	23.9	9.3	9.3	-0.2	-5.65	-5.7
3-, 4-Ethyltoluene	23.9	9.3	9.3	-0.2	-5.65	-5.7
1,3,5-Trimethylbenzene	23.9	9.3	9.3	-0.2	-5.65	-5.7
2-Ethyltoluene	67.6	53.0	53.0	165	82.5	95.0
1,2,4-Trimethylbenzene	23.9	64.7	9.3	183	113	92.8
1,2,3-Trimethylbenzene	216	199	127	188	62.3	62.3
Average Recovery	45.2	34.8	25.3	90.1	36.6	47.1

Table F-2. Results of First Extraction Recovery Study, with 0.637 Milligram Total Hydrocarbon Spike.

Analyte	Percent Hydrocarbons Recovered					
	Soil Sample Number 1			Soil Sample Number 2		
Benzene	62.7	46.8	225	62.9	65.9	54.5
Toluene	43.4	3.2	11.3	59.7	30.3	17.7
Ethylbenzene	72.8	73.8	81.5	70.7	70.9	58.4
Meta-, Para-xylene	68.8	71.1	78.9	72.1	74.6	62.6
Ortho-xylene	68.2	353	85.1	73.8	78.4	65.3
Isopropylbenzene	71.7	74.1	92.4	88.7	94.2	80.3
Propylbenzene	66.1	81.1	82.4	65.6	71.7	61.0
3-, 4-Ethyltoluene	67.3	81.9	82.3	66.9	73.4	62.6
1,3,5-Trimethylbenzene	41.8	72.1	48.3	39.8	46.4	42.4
2-Ethyltoluene	86.1	93.0	108	81.3	87.1	72.7
1,2,4-Trimethylbenzene	80.0	96.6	105	86.6	86.5	76.2
1,2,3-Trimethylbenzene	102	115	107	75.1	90.7	84.2
Total	66.2	94.5	95.0	70.2	72.3	61.2

Table F-3. Results of First Extraction Recovery Study, with 1.274 Milligrams Total Hydrocarbon Spike.

Analyte	Percent Hydrocarbons Recovered					
	Soil Sample Number 1			Soil Sample Number 2		
Benzene	49.2	51.9	116	63.4	60.2	66.5
Toluene	31.4	34.8	38.6	59.7	49.1	50.5
Ethylbenzene	63.9	67.6	77.5	82.6	79.6	82.1
Meta-, Para-xylene	62.5	66.3	74.9	88.6	89.3	86.3
Ortho-xylene	67.3	69.1	79.2	82.2	83.1	85.2
Isopropylbenzene	69.8	70.0	80.7	90.8	88.9	92.5
Propylbenzene	67.3	70.6	77.6	80.6	78.0	82.9
3-, 4-Ethyltoluene	68.2	70.2	79.9	80.2	79.8	84.6
1,3,5-Trimethylbenzene	52.7	56.4	60.8	64.7	66.4	72.8
2-Ethyltoluene	80.0	82.3	93.7	83.0	83.2	88.5
1,2,4-Trimethylbenzene	75.7	78.7	90.4	85.4	83.9	91.6
1,2,3-Trimethylbenzene	82.2	93.4	103	103	106	86.3
Total	63.7	67.1	81.5	80.0	78.4	80.6

Table F-4. Results of Second Extraction Recovery Study, with 2.517 Milligrams Total Hydrocarbon Spike.

Analyte	Percent Hydrocarbons Recovered			
	w/o Head	w/ Head	w/o Head	w/ Head
Benzene	39.4	105	34.0	99.2
Toluene	39.4	91.7	32.1	84.3
Ethylbenzene	63.9	115	57.2	108
Meta-, Para-xylene	61.0	109	53.7	102
Ortho-xylene	67.6	111	60.1	104
Isopropylbenzene	74.2	119	66.5	111
Propylbenzene	74.8	115	65.9	106
3-, 4-Ethyltoluene	77.9	116	68.9	107
1,3,5-Trimethylbenzene	78.6	110	69.0	101
2-Ethyltoluene	83.6	120	74.1	110
1,2,4-Trimethylbenzene	86.2	119	77.4	111
1,2,3-Trimethylbenzene	85.6	118	83.8	116
Total	69.5	112	62.0	105

Table F-5. Results of Second Extraction Recovery Study, with 12.59 Milligrams Total Hydrocarbon Spike.

Analyte	Percent Hydrocarbons Recovered			
	w/o Head	w/ Head	w/o Head	w/ Head
Benzene	63.0	87.8	59.7	84.5
Toluene	72.9	87.1	68.7	83.0
Ethylbenzene	86.5	97.7	81.9	93.1
Meta-, Para-xylene	84.4	95.0	80.2	90.8
Ortho-xylene	86.5	95.4	81.8	90.7
Isopropylbenzene	91.0	101	86.3	96.3
Propylbenzene	91.0	100	86.1	95.0
3-, 4-Ethyltoluene	91.7	100	86.8	95.1
1,3,5-Trimethylbenzene	90.9	98.0	85.9	93.0
2-Ethyltoluene	93.8	102	88.9	96.7
1,2,4-Trimethylbenzene	94.0	101	89.3	96.7
1,2,3-Trimethylbenzene	94.4	100	87.9	93.7
Total	86.7	97.1	82.0	92.4

Table F-6. Results of Second Extraction Recovery Study, with 27.99 Milligrams Total Hydrocarbon Spike.

Analyte	Percent Hydrocarbons Recovered			
	w/o Head	w/ Head	w/o Head	w/ Head
Benzene	83.3	95.7	69.0	81.4
Toluene	83.3	89.6	68.1	74.3
Ethylbenzene	87.4	92.0	71.6	76.2
Meta-, Para-xylene	87.4	91.8	71.6	75.9
Ortho-xylene	87.3	90.9	71.4	75.0
Isopropylbenzene	88.5	92.3	72.3	76.2
Propylbenzene	90.2	93.7	73.5	77.0
3-, 4-Ethyltoluene	88.9	92.1	72.5	75.8
1,3,5-Trimethylbenzene	85.1	87.8	69.1	71.7
2-Ethyltoluene	88.0	90.8	72.1	74.9
1,2,4-Trimethylbenzene	91.9	94.6	75.5	78.2
1,2,3-Trimethylbenzene	90.0	92.5	73.3	75.8
Total	87.5	92.0	71.6	76.1

APPENDIX G

CLIMATOLOGICAL DATA FOR LAKE ALFRED, FLORIDA
30 JANUARY TO 07 JUNE 1988

Table G-1. Daily Measurements of Pan Evaporation at Lake Alfred, Florida, 30 January to 07 June 1988.

Day of Month	Evaporation (inches)					
	January	February	March	April	May	June
1		0.19	0.20	0.24	0.04	0.37
2		0.13	0.26	0.28	0.44	0.37
3		0.14	0.17	0.19	0.35	0.41
4		0.16	0.11	0.16	0.28	0.33
5		0.14	0.11	0.31	0.41	0.24
6		0.07	0.04	0.37	0.43	0.14
7		0.16	0.20	0.41	0.31	0.15
8		0.05	0.26	0.30	0.36	
9		0.20	0.27	0.19	0.30	
10			0.36	0.32	0.25	
11		0.11	0.19	0.28	0.28	
12		0.31	0.38	0.19	0.37	
13		0.18	0.18	0.27	0.12	
14		0.11	0.43	0.25	0.27	
15		0.10	0.28	0.34	0.27	
16		0.14	0.22	0.24	0.32	
17		0.13	0.18	0.25	0.24	
18		0.19		0.30	0.33	
19		0.16	0.27	0.25	0.31	
20		0.30	0.22	0.25	0.40	
21		0.11	0.17	0.33	0.43	
22		0.17	0.25	0.29	0.28	
23		0.23	0.24	0.29		
24		0.27	0.33	0.30	0.54	
25		0.22	0.26	0.23	0.12	
26		0.21		0.30	0.28	
27		0.24	0.19	0.39	0.26	
28		0.20	0.25	0.42	0.35	
29		0.19	0.26	0.23	0.39	
30	0.12		0.26	0.11	0.37	
31	0.16		0.30		0.34	

Table G-2. Daily Measurements of Precipitation at Lake Alfred, Florida, 30 January to 07 June 1988.

Day of Month	Precipitation (inches) January	February	March	April	May	June
1		0	0	0	0	0
2		0	0	0	0	0
3		0	0	0	0	0
4		***	0.21	0.09	0	0
5		0.07	1.30	0	0	0.03
6		0.21	0.01	0	0	0.13
7		0.58	0	0	0	0
8		0.03	0	0	0	
9		0	0.85	0	0	
10		0.03	0	0	0	
11		0	0	0.14	0	
12		0	1.05	0.24	0.49	
13		0	0.72	0	0.17	
14		0	0	0	0.03	
15		0.63	0	0	0	
16		0	0	0	0	
17		0	0	0	0	
18		0	1.73	0	0	
19		0	0	0.25	0	
20		0.32	0	0	0	
21		0.08	0	0	0.82	
22		0	0	0	0	
23		0.2	0	0	0	
24		0	0	0	1.52	
25		0	0	0	0.02	
26		0	1.51	0	0	
27		0	0	0	0	
28		0	0	0	0	
29		0	0	0	0	
30	0		0	1.01	0	
31	0		0		0	

APPENDIX H

SAMPLE INPUT FILE FOR BIOPLUME II

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run-49  Based on 06 May Data, with 30 Apr - 06 May pumping data

   1   1  20  208000   1   7   0 100   5   9   3   0   0   0   0   0   1
  .02 .0010 .250  2.0  .00  .00   0. 10.0 10.0 .1001.000 1.00
 125.00000   1.40000    .00000    .00000    .00000
 214 .14E-01 .00      .00
1414 .12E-01 .00      .00
1519 .51E-02 .00      .00
10 8-.94E-02 .00      .00
12 7-.91E-02 .00      .00
11.0000
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 0.44.44.44.46.46.47.52.59.62.58.42.29.20.15.10. 7. 7. 6. 0.
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 0. 0. 0. 0. 0.48.45.45.49.51.49.43.38.34.33.33.34.35.36. 0.
 0.51.51.50.50.50.47.49.46.47.46.44.40.37.37.37.38.40.40. 0.
 0.51.52.54.52.52.49.47.47.46.46.44.42.42.42.41.42.43.45. 0.
 0.52.57.57.55.52.50.49.48.47.46.44.44.44.44.45.47.47.50. 0.
 0.53.57.57.55.54.52.50.49.48.47.47.46.47.47.48.50.52.54. 0.
 0.56.58.58.54.52.49.48.48.49.48.49.47.47.48.49.54.55.57. 0.
 0.59.59.59.54.52.49.49.48.47.46.47.46.46.48.49.56.57.60. 0.
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0.	730.	737.	750.	770.	790.	810.	829.	821.	813.	813.	811.	805.	795.	785.	0.	0.	0.	0.	0.
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0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	1.	1.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	1.	1.	3.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	1.	1.	1.	1.	5.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	1.	1.	1.	1.	1.	5.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	80.	50.	1.	0.	0.	1.	2.	10.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	100.	60.	40.	0.	0.	2.	3.	10.	1.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	100.	60.	40.	1.	1.	2.	3.	20.	1.	0.	0.	0.	0.	0.	0.
0.	0.	0.	5.	15.	100.	60.	40.	5.	2.	3.	10.	30.	2.	1.	0.	0.	0.	0.	0.
0.	0.	5.	20.	25.	100.	100.	50.	50.	50.	50.	50.	50.	20.	10.	1.	0.	0.	0.	0.
0.	10.	20.	70.	100.	150.	150.	150.	150.	100.	100.	100.	70.	50.	10.	10.	0.	0.	0.	0.
0.	30.	60.	75.	300.	300.	300.	300.	300.	200.	150.	10C.	70.	50.	30.	20.	1.	0.	0.	0.
0.	75.	75.	100.	300.	300.	300.	300.	300.	300.	200.	100.	60.	80.	45.	30.	10.	0.	0.	0.
0.	80.	100.	200.	300.	300.	300.	300.	300.	300.	200.	120.	60.	70.	60.	45.	20.	1.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	10.	20.	60.	10.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	3.	3.	3.	3.	0.	0.	0.	0.	0.
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0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	1.	2.	3.	1.	0.	0.	0.	0.	0.
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APPENDIX I

SAMPLE OF BIOPLUME II OUTPUT, EDITED

BIOPLUME II

CONTAMINANT TRANSPORT UNDER THE INFLUENCE OF OXYGEN LIMITED BIODEGRADATION

run-49 Based on 06 May Data, with 30 Apr - 06 May pumping data

I N P U T D A T A

GRID DESCRIPTORS

NX	(NUMBER OF COLUMNS) =	20
NY	(NUMBER OF ROWS) =	20
XDEL	(X-DISTANCE IN FEET) =	10.0
YDEL	(Y-DISTANCE IN FEET) =	10.0

TIME PARAMETERS

NTIM	(MAX. NO. OF TIME STEPS) =	1
NPMP	(NO. OF PUMPING PERIODS) =	1
PINT	(PUMPING PERIOD IN YEARS) =	.020
TIMX	(TIME INCREMENT MULTIPLIER) =	.00
TINIT	(INITIAL TIME STEP IN SEC.) =	0.

HYDROLOGIC AND CHEMICAL PARAMETERS

S	(STORAGE COEFFICIENT) =	.000000
POROS	(EFFECTIVE POROSITY) =	.250
BETA	(LONGITUDINAL DISPERSIVITY) =	2.0
DLTRAT	(RATIO OF TRANSVERSE TO LONGITUDINAL DISPERSIVITY) =	.10
ANFCTR	(RATIO OF T-YY TO T-XX) =	1.000000

EXECUTION PARAMETERS

NITP	(NO. OF ITERATION PARAMETERS) =	7
TOL	(CONVERGENCE CRITERIA - ADIP) =	.0010
ITMAX	(MAX.NO.OF ITERATIONS - ADIP) =	100
CELDIS	(MAX.CELL DISTANCE PER MOVE OF PARTICLES - M.O.C.) =	1.000
NPMAX	(MAX. NO. OF PARTICLES) =	8000
NPTPND	(NO. PARTICLES PER NODE) =	9

PROGRAM OPTIONS

NPNT	(TIME STEP INTERVAL FOR COMPLETE PRINTOUT) =	1
NPNTMV	(MOVE INTERVAL FOR CHEM. CONCENTRATION PRINTOUT) =	0
NPNTVL	(PRINT OPTION-VELOCITY 0=NO; 1=FIRST TIME STEP; 2=ALL TIME STEPS) =	0
NPNTD	(PRINT OPTION-DISP.COEF. 0=NO; 1=FIRST TIME STEP; 2=ALL TIME STEPS) =	0
NUMOBS	(NO. OF OBSERVATION WELLS FOR HYDROGRAPH PRINTOUT) =	0
NREC	(NO. OF PUMPING WELLS) =	5
NCODES	(FOR NODE IDENT.) =	3

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          NPNCHV (PUNCH VELOCITIES)        =     0
          NPDELC (PRINT OPT.-CONC. CHANGE) =     0
                   REACTION TERMS

          DK       (DISTRIBUTION COEFFICIENT) =  .12500E+03
          RHOB     (BULK DENSITY OF SOLIDS)   =  .14000E+01
          RF       (RETARDATION FACTOR)       =  .70100E+03
          THALF    (HALF LIFE OF DECAY,IN SEC)=  .00000E+00
          DECAY    (DECAY CONSTANT=LN 2/THALF)=  .00000E+00
                   DECAY TERMS

          DEC1  (ANAEROBIC DECAY COEFF. ) =  .00000E+00
          DEC2  (REAERATION DECAY COEFF.) =  .00000E+00
            STEADY-STATE FLOW

     TIME INTERVAL (IN SEC) FOR SOLUTE-TRANSPORT SIMULATION =  .63115E+06

          LOCATION  OF  PUMPING  WELLS

           I   J   RATE(IN CFS)   CONC.   CONC(02)

           2  14       .0140       .00       .00
          14  14       .0120       .00       .00
          15  13       .0051       .00       .00
          10   8      -.0094       .00       .00
          12   7      -.0091       .00       .00

          AREA OF ONE CELL =    100.0
          X-Y SPACING:
               10.000
               10.000

TRANSMISSIVITY MAP (FT*FT/SEC)

 0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
 0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
 0.00E+00  1.00E-02  1.00E-02  1.00E-02  1.00E-02  1.00E-02  1.00E-02  1.00E-02  1.00E-02  5.00E-03
 5.00E-03  1.00E-02  1.00E-02  1.00E-02  1.00E-02  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
 0.00E+00  1.00E-02  1.00E-02  1.00E-02  1.00E-02  1.00E-02  1.00E-02  1.00E-02  1.00E-02  5.00E-03
 5.00E-03  1.00E-02  1.00E-02  1.00E-02  1.00E-02  1.00E-02  1.00E-02  1.00E-02  0.00E+00  0.00E+00
 0.00E+00  1.00E-02  1.00E-02  1.00E-02  1.00E-02  1.00E-02  1.00E-02  1.00E-02  5.00E-03  5.00E-03
 1.00E-02  1.00E-02  5.00E-03  5.00E-03  1.00E-02  1.00E-02  1.00E-02  1.00E-02  1.00E-02  0.00E+00
 0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  1.00E-02  1.00E-02  1.00E-02  5.00E-03  5.00E-03
 1.00E-02  5.00E-03  5.00E-03  5.00E-03  5.00E-03  1.00E-02  1.00E-02  1.00E-02  1.00E-02  0.00E+00
 0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  1.00E-02  1.00E-02  1.00E-02  0.00E+00  0.00E+00
 1.00E-02  1.00E-02  5.00E-03  5.00E-03  5.00E-03  0.00E+00  0.00E+00  1.00E-02  0.00E+00  0.00E+00
 0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  1.00E-02  1.00E-02  1.00E-02  0.00E+00  0.00E+00
 2.00E-02  1.00E-02  5.00E-03  5.00E-03  5.00E-03  0.00E+00  0.00E+00  1.00E-02  0.00E+00  0.00E+00
 0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  1.00E-02  1.00E-02  2.00E-02  2.00E-02  2.00E-02
 2.00E-02  5.00E-03  5.00E-03  1.20E-02  1.20E-02  1.00E-02  1.00E-02  1.00E-02  1.00E-02  0.00E+00
 0.00E+00  6.00E-02  6.00E-02  2.00E-02  2.00E-02  2.00E-02  2.00E-02  2.00E-02  2.00E-02  5.00E-03
 5.00E-03  5.00E-03  1.00E-02  1.20E-02  1.20E-02  1.00E-02  1.00E-02  1.00E-02  1.00E-02  0.00E+00
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0.00E+00	6.00E-02	6.00E-02	6.00E-02	6.00E-02	2.00E-02	5.00E-03	5.00E-03	5.00E-03	5.00E-03
1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02	2.50E-02	2.50E-02	2.50E-02	2.50E-02	0.00E+00
0.00E+00	6.00E-02	6.00E-02	6.00E-02	6.00E-02	6.00E-02	2.00E-02	2.00E-02	2.00E-02	1.00E-02
1.00E-02	1.00E-02	2.50E-02	2.50E-02	2.50E-02	2.50E-02	2.50E-02	2.50E-02	2.50E-02	0.00E+00
0.00E+00	6.00E-02	6.00E-02	6.00E-02	6.00E-02	6.00E-02	6.00E-02	6.00E-02	6.00E-02	2.00E-02
1.00E-02	2.50E-02	2.50E-02	2.50E-02	2.50E-02	2.50E-02	2.50E-02	2.50E-02	2.50E-02	0.00E+00
0.00E+00	6.00E-02	6.00E-02	6.00E-02	6.00E-02	6.00E-02	6.00E-02	6.00E-02	5.00E-02	1.00E-02
2.00E-02	2.50E-02	2.50E-02	2.50E-02	2.50E-02	2.50E-02	2.50E-02	2.50E-02	2.50E-02	0.00E+00
0.00E+00	6.00E-02	6.00E-02	6.00E-02	6.00E-02	6.00E-02	6.00E-02	6.00E-02	6.00E-02	6.00E-02
2.00E-02	2.50E-02	2.50E-02	2.50E-02	2.50E-02	2.50E-02	2.50E-02	2.50E-02	2.50E-02	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	2.00E-02	2.00E-02	2.00E-02	2.00E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	2.00E-02	2.00E-02	2.00E-02	2.00E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	1.50E-02	1.50E-02	1.50E-02	1.50E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	1.00E-02	1.50E-02	1.50E-02	1.50E-02	1.00E-02	6.00E-03	6.00E-03	6.00E-03	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-03
6.00E-03	6.00E-03	6.00E-03	6.00E-03	6.00E-03	6.00E-03	5.00E-03	5.00E-03	5.00E-03	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

AQUIFER THICKNESS (FT)

.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
.0	.0	4.1	4.1	4.1	4.2	4.3	4.5	4.7	5.0	5.0	4.5	3.3	1.2	.5	.2	.0	.0	.0
.0	.0	4.3	4.3	4.3	4.4	4.5	4.7	5.1	6.0	7.2	6.6	4.0	2.0	1.3	.8	.5	.3	.2
.0	.0	4.4	4.4	4.4	4.6	4.6	4.7	5.2	5.9	6.2	5.8	4.2	2.9	2.0	1.5	1.0	.7	.7
.0	.0	.0	.0	.0	.0	4.2	4.3	4.5	5.4	5.7	5.5	3.6	3.5	3.5	3.0	2.6	1.5	1.7
.0	.0	.0	.0	.0	.0	4.0	4.0	4.3	.0	.0	5.0	4.4	3.5	3.8	3.4	.0	.0	3.4
.0	.0	.0	.0	.0	.0	4.4	4.4	4.0	.0	.0	4.7	4.3	3.6	3.2	2.7	.0	.0	3.0
.0	.0	.0	.0	.0	.0	4.8	4.5	4.5	4.9	5.1	4.9	4.3	3.8	3.4	3.3	3.0	3.4	3.5
.0	.0	5.1	5.1	5.0	5.0	5.0	4.7	4.6	4.6	4.7	4.6	4.4	4.0	3.7	3.7	3.7	3.8	4.0
.0	.0	5.1	5.2	5.4	5.2	5.2	4.9	4.7	4.7	4.6	4.6	4.4	4.2	4.2	4.2	4.1	4.2	4.3
.0	.0	5.2	5.7	5.7	5.5	5.2	5.0	4.8	4.8	4.7	4.6	4.4	4.4	4.4	4.4	4.5	4.7	4.7
.0	.0	5.3	5.7	5.7	5.6	5.4	5.2	5.0	4.9	4.8	4.7	4.7	4.6	4.7	4.7	4.8	5.0	5.2
.0	.0	5.6	5.8	5.8	5.4	5.2	4.9	4.8	4.8	4.8	4.9	4.9	4.7	4.7	4.8	4.9	5.4	5.6
.0	.0	5.9	5.9	5.8	5.4	5.2	4.9	4.9	4.8	4.7	4.6	4.7	4.6	4.6	4.8	4.9	5.6	5.7

```
 .0
      .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0  5.3  5.3  5.4  5.5   .0   .0   .0   .0
 .0
      .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0  5.5  5.6  6.0  5.8   .0   .0   .0   .0
 .0
      .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0  5.7  5.9  6.0  6.2   .0   .0   .0   .0
 .0
      .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0  5.7  6.0  6.3  6.5  6.3  6.0  5.8  5.6
 .0
      .0   .0   .0   .0   .0   .0   .0   .0   .0  5.4  5.5  5.7  6.0  6.3  6.5  6.3  6.0  5.9  5.6
 .0
      .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0   .0
 .0

DIFFUSE RECHARGE AND DISCHARGE (FT/SEC)

   0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
   0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
   0.00E+00  2.10E-09  2.10E-09  2.10E-09  2.10E-09  2.10E-09  2.10E-09  2.10E-09  2.10E-09  2.10E-09
   2.10E-09  2.10E-09  0.00E+00  0.00E+00  2.10E-09  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
   0.00E+00  2.10E-09  2.10E-09  2.10E-09  2.10E-09  2.10E-09  2.10E-09  2.10E-09  2.10E-09  2.10E-09
   2.10E-09  2.10E-09  0.00E+00  0.00E+00  2.10E-09  2.10E-09  2.10E-09  2.10E-09  0.00E+00  0.00E+00
   0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  2.10E-09  2.10E-09  2.10E-09  2.10E-09  2.10E-09
   2.10E-09  2.10E-09  0.00E+00  0.00E+00  2.10E-09  2.10E-09  2.10E-09  2.10E-09  2.10E-09  0.00E+00
   0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  2.10E-09  2.10E-09  2.10E-09  2.10E-09  2.10E-09
   2.10E-09  2.10E-09  0.00E+00  0.00E+00  2.10E-09  2.10E-09  2.10E-09  2.10E-09  2.10E-09  0.00E+00
   0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  2.10E-09  2.10E-09  0.00E+00  0.00E+00  0.00E+00
   2.10E-09  2.10E-09  0.00E+00  0.00E+00  2.10E-09  0.00E+00  0.00E+00  2.10E-09  0.00E+00  0.00E+00
   0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  2.10E-09  2.10E-09  0.00E+00  0.00E+00  0.00E+00
   2.10E-09  2.10E-09  0.00E+00  0.00E+00  2.10E-09  0.00E+00  0.00E+00  2.10E-09  0.00E+00  0.00E+00
   0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  2.10E-09  2.10E-09  2.10E-09  2.10E-09  2.10E-09
   2.10E-09  2.10E-09  0.00E+00  0.00E+00  2.10E-09  2.10E-09  2.10E-09  2.10E-09  2.10E-09  0.00E+00
   0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  2.10E-09  2.10E-09  2.10E-09  2.10E-09  2.10E-09
   2.10E-09  0.00E+00  0.00E+00  0.00E+00  2.10E-09  2.10E-09  2.10E-09  2.10E-09  2.10E-09  0.00E+00
   0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
   0.00E+00  0.00E+00  0.00E+00  0.00E+00  2.10E-09  2.10E-09  2.10E-09  2.10E-09  2.10E-09  0.00E+00
   0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
   0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
   0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
   0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
   0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
   0.00E+00  0.00E+00  2.10E-09  2.10E-09  2.10E-09  2.10E-09  2.10E-09  2.10E-09  2.10E-09  0.00E+00
   0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
   0.00E+00  2.10E-09  2.10E-09  2.10E-09  2.10E-09  2.10E-09  2.10E-09  2.10E-09  2.10E-09  0.00E+00
   0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
   0.00E+00  2.10E-09  2.10E-09  2.10E-09  2.10E-09  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
   0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
   0.00E+00  2.10E-09  2.10E-09  2.10E-09  2.10E-09  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
   0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
   0.00E+00  2.10E-09  2.10E-09  2.10E-09  2.10E-09  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
   0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
   0.00E+00  2.10E-09  2.10E-09  2.10E-09  2.10E-09  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
```

0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	2.10E-09	2.10E-09	2.10E-09	2.10E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

PERMEABILITY MAP (FT/SEC)

0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	2.44E-03	2.44E-03	2.44E-03	2.38E-03	2.33E-03	2.22E-03	2.13E-03	2.00E-03	1.30E-03
1.11E-03	4.35E-03	8.33E-02	2.00E-02	5.00E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	2.33E-03	2.33E-03	2.33E-03	2.27E-03	2.22E-03	2.13E-03	1.96E-03	1.67E-03	6.94E-04
7.58E-04	2.50E-03	5.00E-03	7.69E-03	1.25E-02	2.00E-02	5.00E-02	5.00E-02	0.00E+00	0.00E+00
0.00E+00	2.27E-03	2.27E-03	2.27E-03	2.17E-03	2.17E-03	2.13E-03	1.92E-03	8.47E-04	8.96E-04
1.72E-03	2.38E-03	1.72E-03	2.50E-03	6.67E-03	1.00E-02	1.43E-02	1.43E-02	1.67E-02	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.38E-03	2.22E-03	2.22E-03	9.26E-04	8.77E-04
1.82E-03	1.39E-03	1.43E-03	2.00E-03	2.50E-03	6.25E-03	6.67E-03	5.88E-03	5.88E-03	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.50E-03	2.50E-03	2.33E-03	0.00E+00	0.00E+00
2.00E-03	2.27E-03	1.43E-03	1.79E-03	2.08E-03	0.00E+00	0.00E+00	4.17E-03	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.27E-03	2.27E-03	2.50E-03	0.00E+00	0.00E+00
4.26E-03	2.33E-03	1.39E-03	1.56E-03	1.85E-03	0.00E+00	0.00E+00	3.33E-03	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.08E-03	2.22E-03	4.44E-03	4.08E-03	3.92E-03
4.08E-03	1.16E-03	1.32E-03	3.53E-03	3.64E-03	3.03E-03	2.34E-03	2.38E-03	2.78E-03	0.00E+00
0.00E+00	1.18E-02	1.19E-02	4.00E-03	4.00E-03	4.00E-03	2.13E-03	4.08E-03	4.35E-03	1.06E-03
1.09E-03	1.14E-03	2.50E-03	3.24E-03	3.24E-03	2.70E-03	2.63E-03	2.50E-03	2.50E-03	0.00E+00
0.00E+00	1.18E-02	1.15E-02	1.11E-02	1.15E-02	3.85E-03	1.02E-03	1.06E-03	1.06E-03	1.09E-03
2.17E-03	2.27E-03	2.38E-03	2.86E-03	2.86E-03	6.10E-03	5.95E-03	5.81E-03	4.44E-03	0.00E+00
0.00E+00	1.15E-02	1.05E-02	1.05E-02	1.09E-02	1.15E-02	4.00E-03	4.17E-03	4.17E-03	2.13E-03
2.17E-03	2.27E-03	5.68E-03	5.68E-03	5.68E-03	5.56E-03	5.32E-03	5.32E-03	5.00E-03	0.00E+00
0.00E+00	1.13E-02	1.05E-02	1.05E-02	1.09E-02	1.11E-02	1.15E-02	1.20E-02	1.22E-02	4.17E-03
2.13E-03	5.32E-03	5.43E-03	5.32E-03	5.32E-03	5.21E-03	5.00E-03	4.81E-03	4.63E-03	0.00E+00
0.00E+00	1.07E-02	1.03E-02	1.03E-02	1.11E-02	1.15E-02	1.22E-02	1.25E-02	1.04E-02	4.98E-03
4.17E-03	5.10E-03	5.32E-03	5.32E-03	5.21E-03	5.10E-03	4.63E-03	4.55E-03	4.39E-03	0.00E+00
0.00E+00	1.02E-02	1.02E-02	1.03E-02	1.11E-02	1.15E-02	1.22E-02	1.22E-02	1.25E-02	1.36E-02
4.35E-03	5.32E-03	5.43E-03	5.43E-03	5.21E-03	5.10E-03	4.46E-03	4.39E-03	4.17E-03	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	3.77E-03	3.77E-03	3.70E-03	3.64E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	3.64E-03	3.57E-03	3.33E-03	3.45E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	2.63E-03	2.54E-03	2.50E-03	2.42E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	1.75E-03	2.50E-02	3.38E-03	2.31E-03	1.59E-03	1.00E-03	1.03E-03	1.07E-03	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.11E-03
1.09E-03	1.05E-03	1.00E-03	9.52E-04	9.22E-04	9.52E-04	1.00E-03	1.02E-03	1.07E-03	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

NO. OF FINITE-DIFFERENCE CELLS IN AQUIFER = 233

AREA OF AQUIFER IN MODEL = 23300. SQ. FT.

NZCRIT (MAX. NO. OF CELLS THAT CAN BE VOID OF
PARTICLES; IF EXCEEDED, PARTICLES ARE REGENERATED) = 5

NODE IDENTIFICATION MAP

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	2	2	2	2	2	2	2	2	3	3	3	3	2	2	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

NO. OF NODE IDENT. CODES SPECIFIED = 3

THE FOLLOWING ASSIGNMENTS HAVE BEEN MADE:

CODE NO.	LEAKANCE	SOURCE CONC.	O2 CONC	RECHARGE
1	.100E+01	.00	.00	
2	.100E+01	.00	2.00	
3	.100E+01	100.00	.00	

VERTICAL PERMEABILITY/THICKNESS (FT/(FT*SEC))

0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

```
0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  1.00E+00
1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  1.00E+00  0.00E+00
0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
```

WATER TABLE

```
    0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
0.
    0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
0.
    0.   7.   7.   8.   8.   8.   8.   8.   8.   8.   8.   8.   8.   8.   8.   0.   0.   0.   0.
0.
    0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
0.
    0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
0.
    0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
0.
    0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
0.
    0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
0.
    0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
0.
    0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
0.
    0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
0.
    0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
0.
    0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
```

```
0.
    0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
0.
    0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
0.
    0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
0.
    0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
0.
    0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
0.
    0.   0.   0.   0.   0.   0.   0.   0.   0.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.
0.
    0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
0.

 HEAD DISTRIBUTION - ROW
 NUMBER OF TIME STEPS =      0
        TIME(SECONDS) =   .00000
        TIME(DAYS)    =   .00000E+00
        TIME(YEARS)   =   .00000E+00

0    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000
 .0000000    .0000000
0    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000
 .0000000    .0000000
0    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000
 .0000000    .0000000
0    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000
 .0000000    .0000000
0    .0000000   7.3000000   7.3700000   7.5000000   7.7000000   7.9000000   8.1000000   8.2900000
8.2100000   8.1300000
0   8.1300000   8.1100000   8.0500000   7.9500000   7.8500000    .0000000    .0000000    .0000000
 .0000000    .0000000
0    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000
 .0000000    .0000000
0    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000
 .0000000    .0000000
0    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000
 .0000000    .0000000
0    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000
 .0000000    .0000000
0    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000
 .0000000    .0000000
0    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000
 .0000000    .0000000
0    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000
 .0000000    .0000000
0    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000
 .0000000    .0000000
0    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000
 .0000000    .0000000
```

```
0    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000
 .0000000    .0000000
0    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000
 .0000000    .0000000
0    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000
 .0000000    .0000000
0    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000
 .0000000    .0000000
0    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000
 .0000000    .0000000
0    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000
 .0000000    .0000000
0    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000
 .0000000    .0000000
0    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000
 .0000000    .0000000
0    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000
 .0000000    .0000000
0    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000
 .0000000    .0000000
0    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000
 .0000000    .0000000
0    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000
 .0000000    .0000000
0    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000
 .0000000    .0000000
0    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000
 .0000000    .0000000
0    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000
 .0000000    .0000000
0    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000
 .0000000    .0000000
0    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000
 .0000000    .0000000
0    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000
 .0000000    .0000000
0    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000
 .0000000    .0000000
0    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000
 .0000000    .0000000
0    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000
 .0000000    .0000000
0    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000
 .0000000   2.0300000
0   2.0300000   2.0300000   2.0300000   2.0300000   2.0300000   2.0300000   2.0300000   2.0300000
2.0300000    .0000000
0    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000
 .0000000    .0000000
0    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000
 .0000000    .0000000
1ITERATION PARAMETERS
            .259726E-02
```

.700535E-02
.188949E-01
.509634E-01
.137459
.370754
1.00000
.000000
.000000
.000000
.000000
.000000
.000000
.000000
.000000
.000000
.000000
.000000
.000000

CONCENTRATION OF CONTAMINANT

NUMBER OF TIME STEPS = 0
TIME(SECONDS) = .00000
CHEM.TIME(SECONDS) = .00000E+00
CHEM.TIME(DAYS) = .00000E+00
TIME(YEARS) = .00000E+00
CHEM.TIME(YEARS) = .00000E+00
NO. MOVES COMPLETED = 0

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0
0 0 0 0 0 0 0 0 0 0 0 0 100 100 0 0 0 0 0 0
0
0 0 0 0 0 0 0 0 0 0 0 100 100 300 0 0 0 0 0 0
0
0 0 0 0 0 0 0 0 0 100 100 100 100 500 0 0 0 0 0 0
0
0 0 0 0 0 0 0 0 100 100 100 100 100 500 0 0 0 0 0 0
0
0 0 0 0 0 0 8000 5000 100 0 0 100 200 1000 0 0 0 0 0 0
0
0 0 0 0 0 010000 6000 4000 0 0 200 300 1000 100 0 0 0 0 0
0
0 0 0 0 0 010000 6000 4000 100 100 200 300 2000 100 0 0 0 0 0
0
0 0 0 0 500 150010000 6000 4000 500 200 300 1000 3000 200 100 0 0 0 0
0
0 0 0 500 2000 25001000010000 5000 5000 5000 5000 5000 5000 2000 1000 100 0 0 0
0
0 0 1000 2000 700010000150001500015000150001000010000010000 7000 5000 1000 1000 0 0 0
0

```
0    0 3000  6000  75003000030000300003000030000200001500010000   7000 5000 3000 2000  100    0    0
0
0    0 7500  750010000300003000030000300003000030000200001000 0   8000 8000 4500 3000 1000    0    0
0
0    0 8000100002000030000300003000030000300003000020000120 00   6000 7000 6000 4500 2000  100    0
0
0    0    0    0    0    0    0    0    0    0    0    0 1000 2000 6000 1000    0    0    0    0
0
0    0    0    0    0    0    0    0    0    0    0    0  300  300  300  300    0    0    0    0
0
0    0    0    0    0    0    0    0    0    0    0    0  300  300  300  300    0    0    0    0
0
0    0    0    0    0    0    0    0    0    0    0    0  200  200  300  200    0    0    0    0
0
0    0    0    0    0    0    0    0    0    0    0    0  100  200  300  100    0    0    0    0
0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0
```

CONCENTRATION OF OXYGEN

```
 NUMBER OF TIME STEPS =      0
         TIME(SECONDS) =   .00000
   CHEM.TIME(SECONDS) =   .00000E+00
   CHEM.TIME(DAYS)     =   .00000E+00
         TIME(YEARS)   =   .00000E+00
   CHEM.TIME(YEARS)    =   .00000E+00
  NO. MOVES COMPLETED =      0
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0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0
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0
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0
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0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0
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0
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0
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0
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0
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0
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0
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0
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0
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0
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0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0
0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
0
0
   N =     1
   NUMBER OF ITERATIONS =   35
1HEAD DISTRIBUTION - ROW
 NUMBER OF TIME STEPS =      1
       TIME(SECONDS) =   .63115E+06
       TIME(DAYS)    =   .73050E+01
       TIME(YEARS)   =   .20000E-01

0    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000
 .0000000    .0000000
0    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000    .0000000
 .0000000    .0000000
0    .0000000   7.3531925   7.4263873   7.5459748   7.7115460   7.8886930   8.0545849   8.1751291
8.1809111   8.1460156
0   8.1155542   8.0819247   8.0314900   7.3625726   7.3062485    .0000000    .0000000    .0000000
 .0000000    .0000000
0    .0000000   7.3000188   7.3700156   7.5000120   7.6999913   7.8999691   8.0999536   8.2299122
8.2099778   8.1299917
0   8.1299739   8.1099609   8.0499727   7.9499792   7.8499455   7.4849065   7.2651767   7.1411446
 .0000000    .0000000
0    .0000000   7.3547730   7.4095387   7.5038195   7.6018982   7.6018822   7.6914830   7.7970542
7.8802499   7.8422036
0   7.7698848   7.7932357   7.7276529   7.6185467   7.5136005   7.3394826   7.1695662   7.0171331
6.9480738    .0000000
0    .0000000    .0000000    .0000000    .0000000    .0000000   7.2141964   7.2670547   7.3543290
7.5896384   7.6128273
0   7.4582205   7.4130843   7.3194518   7.2074711   7.1655110   7.1898568   7.0563626   6.8096729
6.8789457    .0000000
0    .0000000    .0000000    .0000000    .0000000    .0000000   6.7736825   6.8082244   6.8420441
 .0000000    .0000000
0   7.0695949   7.0804853   6.9235490   6.7263366   6.6271500    .0000000    .0000000   6.2860237
 .0000000    .0000000
0    .0000000    .0000000    .0000000    .0000000    .0000000   6.2986533   6.3501179   6.3635868
 .0000000    .0000000
```

0 6.7699750 6.9702717 6.5155238 5.1470678 5.9896134 .0000000 .0000000 5.7621154
.0000000 .0000000
0 .0000000 .0000000 .0000000 .0000000 .0000000 5.7721729 5.9299654 6.0148265
6.0862698 6.3995081
0 6.4367204 6.2953048 5.8695141 5.5871945 5.4265508 5.1978484 5.1332073 5.2284399
5.0888331 .0000000
0 .0000000 4.8031795 4.8170323 4.8681012 4.9889860 5.2590367 5.5544927 5.7674569
5.8444733 5.9147063
0 5.8379798 5.5949152 5.3644945 5.2524032 5.1427227 5.0128781 4.9636578 4.9693859
4.9391528 .0000000
0 .0000000 4.7893128 4.8053841 4.8385741 4.8895514 4.9900997 5.1557264 5.3115570
5.3623910 5.3281508
0 5.2443141 5.1177468 4.9963909 4.9253633 4.8674771 4.8187337 4.8063386 4.8066070
4.8040454 .0000000
0 .0000000 4.7593646 4.7766921 4.8060419 4.8405288 4.8672800 4.8917218 4.9212320
4.9335127 4.9464016
0 4.9192468 4.7944305 4.7079305 4.6783686 4.6699327 4.6884493 4.7039051 4.7163466
4.7203708 .0000000
0 .0000000 4.7120745 4.7360449 4.7684248 4.7992241 4.8204436 4.8261130 4.8285771
4.8216137 4.7888055
0 4.6918913 4.5672225 4.5231246 4.4970209 4.5150140 4.5611201 4.6044355 4.6348680
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0 .0000000 4.6407908 4.6870451 4.7324197 4.7674478 4.7892091 4.7965447 4.7915978
4.7704584 4.6991718
0 4.5580797 4.4102290 4.3202082 4.2715408 4.3321907 4.4364542 4.5177961 4.5692710
4.5939112 .0000000
0 .0000000 4.5232327 4.6389916 4.7067892 4.7488698 4.7724681 4.7792467 4.7688083
4.7355191 4.6639295
0 4.4921107 4.2118308 4.0758496 3.9367364 4.1059740 4.3345599 4.4603804 4.5309336
4.5623262 .0000000
0 .0000000 .0000000 .0000000 .0000000 .0000000 .0000000 .0000000 .0000000
.0000000 .0000000
0 .0000000 3.8613718 3.8043937 3.7531714 3.7948864 .0000000 .0000000 .0000000
.0000000 .0000000
0 .0000000 .0000000 .0000000 .0000000 .0000000 .0000000 .0000000 .0000000
.0000000 .0000000
0 .0000000 3.5289489 3.4969877 3.4662201 3.4598806 .0000000 .0000000 .0000000
.0000000 .0000000
0 .0000000 .0000000 .0000000 .0000000 .0000000 .0000000 .0000000 .0000000
.0000000 .0000000
0 .0000000 3.1784467 3.1369598 3.1028993 3.0732926 .0000000 .0000000 .0000000
.0000000 .0000000
0 .0000000 .0000000 .0000000 .0000000 .0000000 .0000000 .0000000 .0000000
.0000000 .0000000
0 .0000000 2.7236386 2.7181048 2.6832131 2.6018794 2.3194397 2.1569545 2.0807845
2.0553932 .0000000
0 .0000000 .0000000 .0000000 .0000000 .0000000 .0000000 .0000000 .0000000
.0000000 2.0300000
0 2.0300000 2.0300525 2.0300590 2.0300560 2.0299980 2.0300217 2.0300076 2.0300030
2.0300015 .0000000
0 .0000000 .0000000 .0000000 .0000000 .0000000 .0000000 .0000000 .0000000
.0000000 .0000000

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0    .0000000     .0000000     .0000000     .0000000     .0000000     .0000000     .0000000     .0000000
 .0000000     .0000000

1HEAD DISTRIBUTION - ROW
 NUMBER OF TIME STEPS =     1
        TIME(SECONDS)  =   .62115E+06
        TIME(DAYS)     =   .71850E+01
        TIME(YEARS)    =   .20000E-01
```

1DRAWDOWN

```
      0   -4   -4   -4   -4   -4   -4   -4   -4   -4   -4   -4   -4   -4   -4   -4   -4   -4   -4
 0
      0   -4   -4   -4   -4   -4   -4   -4   -4   -4   -4   -4   -4   -4   -4   -4   -4   -4   -4
 0
      0   -4   -4   -4   -4   -4   -4   -4   -4   -4   -4   -4   -4   -4   -4   -4   -4   -4   -4
 0
      0   -4   -4   -4   -4   -4   -4   -4   -4   -4   -4   -4   -4   -4   -4   -4   -4   -4   -4
 0
      0    0    0    0    0    0    0    0    0    0    0   -1   -1   -2   -2    0    0    0    0
 0
      0    0    0    0    0    0    0    0    0    0    0   -2   -2   -2   -2    0    0    0    0
 0
      0    0    0    0    0    0    0    0    0    0    0   -2   -2   -2   -2   -1   -1   -1   -1
 0
      0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
 0
      0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
 0

0  CUMULATIVE MASS BALANCE -- (IN FT**3)


    RECHARGE AND INJECTION      =  -.11676E+05
    PUMPAGE AND E-T WITHDRAWAL  =   .13646E+05
    CUMULATIVE  NET  PUMPAGE    =   .73692E+04
    WATER RELEASE FROM STORAGE  =   .00000E+00
    LEAKAGE INTO AQUIFER        =   .23611E+05
    LEAKAGE OUT OF AQUIFER      =  -.15631E+05
    CUMULATIVE  NET  LEAKAGE    =   .79798E+04
0       MASS BALANCE RESIDUAL   =   10.541
        ERROR  (AS PERCENT)     =   .29976E-01

0  RATE MASS BALANCE --  IN C.F.S..


    LEAKAGE INTO AQUIFER        =   .37409E-01
    LEAKAGE OUT OF AQUIFER      =  -.24766E-01
    NET LEAKAGE     (QNET)      =   .12643E-01
    RECHARGE AND INJECTION      =  -.18500E-01
    PUMPAGE AND E-T WITHDRAWAL  =   .31126E-01
    NET WITHDRAWAL    (TPUM)    =   .12626E-01
1          STABILITY CRITERIA --- M.O.C.


0      FLUID VELOCITIES
  VMAX =  3.44E-03      VMAY =  1.24E-03
  VMXBD=  3.51E-03      VMYBD=  1.27E-03
0      EFFECTIVE SOLUTE VELOCITIES
  VMAX =  4.90E-06      VMAY =  1.77E-06
  VMXBD=  3.58E-06      VMYBD=  1.67E-06
```

```
      EFFECTIVE OXYGEN VELOCITIES
  VMAX =  2.44E-03      VMAY =  1.24E-03
  VMXBD=  2.51E-03      VMYBD=  1.17E-03
 TMV (MAX. INJ.) =   3669.0
  TIMV (CELDIS)   =   2309.0
 TIMV =  2.91E+03      NTIMV =   216     NMOV =   217

   TIM (N)  =   .63115E+06
   TIMEVELO =   2908.5
   TIMEDISP =   .78446E+04
 TIMV =  2.91E+03      NTIMD =    80     NMOV =   217
          THE LIMITING STABILITY CRITERION IS CELDIS
          NO. OF PARTICLE MOVES REQUIRED TO COMPLETE THIS TIME STEP  =  217

CONCENTRATION OF CONTAMINANT

 NUMBER OF TIME STEPS =     1
        DELTA T       =   .63115E+06
        TIME(SECONDS) =   .63115E+06
   CHEM.TIME(SECONDS) =   .63115E+06
   CHEM.TIME(DAYS)    =   .73050E+01
        TIME(YEARS)   =   .20000E-01
   CHEM.TIME(YEARS)   =   .20000E-01
  NO. MOVES COMPLETED =   217

 0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
 0
 0   0   0   0   0   0   0   0   0   0   0   0 100 100   1   0   0   0   0   0
 0
 0   0   0   0   0   0   0   0   0   0   0 100 100 230   0   0   0   0   0   0
 0
 0   0   0   0   0   0   0   0   0  99 100 100 100 498   0   0   0   0   0   1
 0
 0   0   0   0   0   0  56  43 100  99 100 100 101 501   0   0   0   0   0   0
 0
 0   0   0   0   0   0 7949 4966  135   0   0 101 201 996   1   0   0   0   0   0
 0
 0   0   0   0   0   0 9980 5996 3368   1   0 199 282 999  99   1   0   0   0   0
 0
 0   0   0   0   0   0 9993 6008 4003 113  34 201 310 1391 103   1   0   0   0   0
 0
 0   0   0   0 502 1542 3912 6023 4005 525 224 331 1017 2997 216 100   0   0   0   0
 0
 0   0   2 501 1997 254310010 9994 5045 5030 5000 5000 5000 4995 2010 324 105   0   0   0
 0
 0   0 1003 2011 697010024150411502615020150221001S  9991 9964 6986 4980 1016 1001   1   0   0
 0
 0   0 3016 5994 752729899299562996129945299221998614975  9993 7010 5025 2000 2002 105   1   0
 0
 0   0 7469 749810050299652999929999300003000829948199867:0031  7993 7954 4504 3002 1004   1   0
 0
 0   0 792910031199852997530000300003000030000299322002211331  7971 7019 5319 4490 2001 103   0
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 0    0    0    0    0    0    0    0    0    0    0  1896 2028 5960 1018    0    0    0
 0    0    0    0    0    0    0    0    0    0    0   306  311  339  306    0    0    0
 0    0    0    0    0    0    0    0    0    0    0   299  299  300  299    0    0    0
 0    0    0    0    0    0    0    0    0    0    0   200  201  299  198    0    0    0
 0    0    0    0    0    0    0    0    0    0    0   101  199  278   70    0    0    0
 0    0    0    0    0    0    0    0    0    0    0     0    0    0    0    0    0    0
```

CHEMICAL MASS BALANCE

```
       MASS IN BOUNDARIES      =   .83617E+06
       MASS OUT BOUNDARIES     =  -.21365E+07
       MASS PUMPED IN          =   .00000E+00
       MASS PUMPED OUT         =  -.12417E+09
       MASS LOST W. BIODEG.    =   .28564E+05
       MASS LOST BY RADIO. DCY=    .00000E+00
       MASS LOST BY ANAER. DCY=    .00000E+00
       MASS LOST BY AEABB. DCY=    .00000E+00
       MASS ADSORBED ON SOLIDS=    .31455E+11
       INITIAL MASS ADSORBED   =   .31455E+11
       INFLOW MINUS OUTFLOW    =  -.12568E+09
       INITIAL MASS DISSOLVED  =   .13065E+09
       PRESENT MASS DISSOLVED  =   .13062E+09
       CHANGE MASS DISSOLVED   =  -.35920E+04
       CHANGE TOTL.MASS STORED=   -.25103E+07
     COMPARE RESIDUAL WITH NET FLUX AND MASS ACCUMULATION:
       MASS BALANCE RESIDUAL   =  -.12315E+09
       ERROR  -AS PERCENT):    =  -.19360E+05
     COMPARE INITIAL MASS STORED WITH CHANGE IN MASS STORED:
       ERROR   AS PERCENT):    =   .13439E+00
```

CONCENTRATION OF OXYGEN

```
NUMBER OF TIME STEPS =     .
       DELTA T       =   .63115E+06
       TIME(SECONDS) =   .63115E+06
  CHEM.TIME(SECONDS) =   .63115E+06
  CHEM.TIME(DAYS)    =   .73050E+01
       TIME(YEARS)   =   .20000E-01
  CHEM.TIME(YEARS)   =   .20000E-01
 NO. MOVES COMPLETED =   219
```

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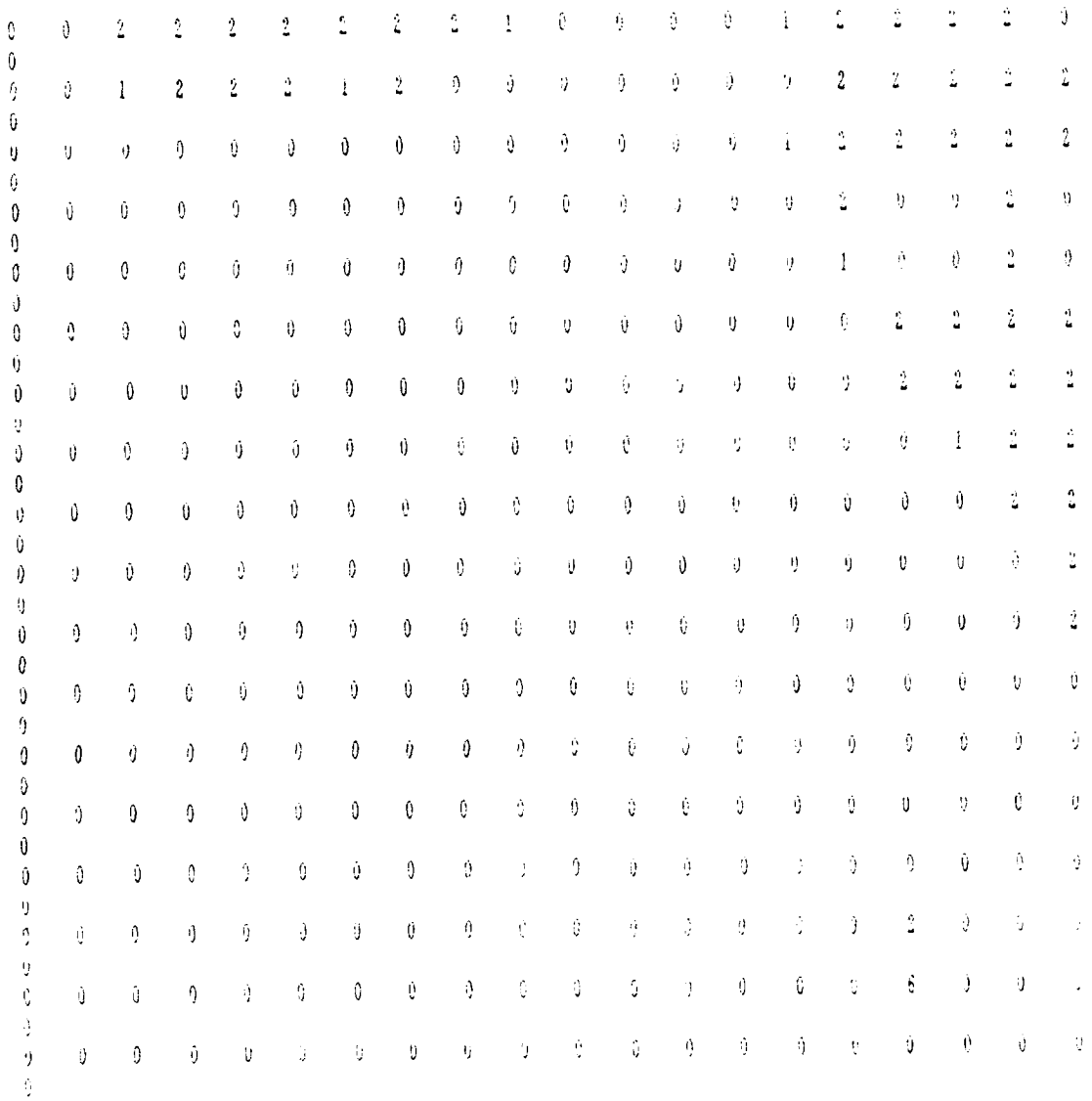

CHEMICAL MASS BALANCE FOR OXYGEN

MASS IN BOUDARIES	=	.34249E+05
MASS OUT BOUNDARIES	=	-.18936E+05
MASS PUMPED IN	=	.00000E+00
MASS PUMPED OUT	=	-.12744E+06
MASS LOST W. BIODEG.	=	.85693E+05
INFLOW MINUS OUTFLOW	=	-.11212E+06
INITIAL MASS DISSOLVED	=	.00000E+00
PRESENT MASS DISSOLVED	=	.97627E+04
CHANGE MASS DISSOLVED	=	.95455E+05
CHANGE TOTL.MASS STORED	=	.95455E+05

COMPARE RESIDUAL WITH NET FLUX AND MASS ACCUMULATION FOR OXYGEN:

MASS BALANCE RESIDUAL	=	-.20758E+06
ERROR (AS PERCENT)	=	-.60609E+03

BIOGRAPHICAL SKETCH

Steven Raymond Scanlan was born in West Spokane, Washington, on March 10, 1960. He attended high school in Woomera, South Australia, and Colorado Springs, Colorado, where he graduated from William J. Palmer High School in 1978. He attended Iowa State University on a Naval Reserve Officer Training Corps scholarship, and received a Bachelor of Science degree in civil engineering in 1982.

Upon graduation, he was commissioned an ensign in the Civil Engineer Corps, United States Navy. Since being commissioned, he has served in Gulfport, Mississippi; Guam; Thurmont, Maryland; and Port Hueneme, California, before attending the University of Florida. He is currently a lieutenant.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Engineering.

W. Lamar Miller, Chairman
Professor of Environmental
Engineering Sciences

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Engineering.

Paul A. Chadik, Cochairman
Assistant Professor of
Environmental Engineering Sciences

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Engineering.

Joseph J. Delfino
Professor of Environmental
Engineering Sciences

This thesis was submitted to the Graduate Faculty of the College of Engineering and to the Graduate School and was accepted as partial fulfillment of the requirements for the degree of Master of Engineering.

December 1988

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