APPLICABILITY OF BIOSCREEN TO A
HYDROCARBON CONTAMINATED
UNDERGROUND STORAGE
TANK SITE

By

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NOMENCLATURE

Acronyms

BGS	Below Ground Surface
BTEX	Benzene, toluene, ethylbenzene, xylenes
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
DO	Dissolved Oxygen
EPA	Environmental Protection Agency
FID	Flame Ionization Detector
GC	Gas Chromatograph
IC	Ion Chromatograph
MT3D	Modular 3-Dimensional Transport Model
MT3DMS	Modular 3-Dimensional Transport Model with Multi Species
MW	Monitoring Well
OCC	Oklahoma Corporation Commission
ODOT	Oklahoma Department of Transportation
ORBCA	Oklahoma Risk-Based Correction Action
TOC	Total Organic Carbon
USGS	United States Geological Survey
UST	Underground Storage Tank
VOC	Volatile Organic Compounds

Units of Measure

Δ	change in concentration
°C	degrees Celsius
cm	centimeter
d	day
eq	equivalent
ft	feet
g	gram
in	inch
Kcal	kilocalorie
kg	kilogram
L	liter
m	meters
mg	milligram
mL	milliliter
mm	millimeter
pH	power of hydrogen
s	second
yr	year

1.0 INTRODUCTION

Thousands of sites across the United States are contaminated with hazardous chemicals that are dangerous to the public and the welfare of the environment. These include 32,000 sites plus a significant number of the approximately 7,000,000 underground storage tank sites (Baker and Herson, 1994). The cleanup of United States' existing environmental contamination carries a one trillion dollar price tag (USGS, 1997).

Natural attenuation is a process in which chemicals in the subsurface are destroyed by naturally occurring microorganisms (Baker and Herson, 1994). Although natural attenuation of wastes exhibits a slow rate of cleanup, it is receiving an increased amount of research since the process minimizes surface site disturbances and requires low capital cost. Some of the advantages of natural attenuation are reduced cost, reduced risk of exposure, minimal environmental impact and liability, application to large scale contamination, and ability to safeguard a water supply (Environmental Microbiology, 1997a).

However, there are disadvantages to natural attention. Natural attenuation may not be capable of achieving the very high destruction rates obtainable through thermal and chemical processes (Skinner et al., 1991). In addition, if the environmental conditions (e.g. electron acceptors, nutrients, temperature, pH, and microorganisms) are not within certain parameters, the conditions at the site will not allow natural attenuation to be effective. Finally, since the public may view natural attenuation as a passive alternative, problems may arise. For example, the general population may demand that a site be cleaned up as quickly as possible, without regard to the cost (Mast, 1997). Natural attenuation is not the quickest alternative available. However, in today's realm of environmental contamination, the use of an alternative that is low in cost, requires little labor, disturbs the site only slightly, and is still effective is becoming more and more popular. Prior to 1994, few states considered natural attenuation to be an acceptable strategy for petroleum hydrocarbon remediation; however, by 1996, most states had developed policies for considering natural attenuation (Chapelle, 1999).

Due the many advantages of natural attenuation, many natural attenuation computer models and contaminant fate and transport models have become available in recent years. These models simulate the plume's natural attenuation, or intrinsic bioremediation, under alternate electron accepting conditions, and evaluate the maximum plume concentrations and maximum plume length. This aids decision makers in estimating a site's hazard to the environment and public health. BIOPLUME, BIOSCREEN, RT3D, BioF&T 3D, and SEAM3D are examples of modeling programs that simulate biodegradation and allow the use of multiple electron acceptors (Rifai et al., 1998; Newell et al., 1996; Waddill and Widdowson, 1998; BOSS International, 1998; Striegel, 1998). The number of models incorporating biodegradation is relatively low compared to the number of models available for contaminant fate and transport simulation (Striegel, 1998). As environmental decision making relies increasingly on risk analysis, the applicability of these models to contaminated sites increases.

With so many models available and each based on varying equations, assumptions, methods of evaluation, etc., a given model may or may not be applicable to a given site. For example, where Model A is calibrated for Site A and, based upon monitoring data, accurately depicts the plume's characteristics (extent of plume, significance of plume, reduction of plume over time), when Model A is applied to Site B, it exhibits results that are in error by several orders of magnitude. Hence, as research continues, further information must be acquired regarding the applicability of screening models. Modeled predictions need to be compared to actual conditions, and the model's weaknesses and strengths need evaluation.

Determining the applicability of contaminant fate and transport models has only recently become an issue as risk-based approaches to site clean-up have increased. The Environmental Protection Agency (EPA) granted over $250,000 to a research project (NCERQA, 1999) that quantitatively evaluated the performance and reliability of contaminant transport models used for assessing human exposure and health risk from soils contaminated with volatile organic compounds (VOCs). The goal of the project was to "identify typical model performance for practical risk assessment applications based on input parameters developed from standard site data collection methods, rather than based on model calibrations that cannot be accomplished for most contaminated sites (NCERQA, 1999)." This type of information, an analysis of current models, is essential for today's decision makers to establish model uncertainty and error. At the current time, based on satisfying Oklahoma Risk-Based Corrective Action (ORBCA) requirements, performing required modeling and obtaining actual data through monitoring, a contaminated site can be closed even though contamination is still present in the subsurface (OCC, 1997). Based on this, and based on the limited input data available at small petroleum contaminated sites (Striegel, 1998), the capability of today's screening models should be investigated.

The objectives of this thesis include the following: to review current literature regarding natural attenuation and the use of alternate electron acceptors, as well as literature on bioremediation models; to determine the changing levels over time of BTEX, sulfate, nitrate, phosphate, dissolved oxygen, and total organic carbon through periodic monitoring at an Oklahoma Department of Transportation (ODOT) Residency Facility contaminated with petroleum hydrocarbons; to determine the applicability of BIOSCREEN to the ODOT Site reviewed in this thesis based on modeling predictions and monitoring results; to investigate BIOSCREEN results under alternate electron conditions using site-specific parameters from the ODOT Site; to examine the sensitivity of BIOSCREEN to ΔSO_4 and ΔNO_3 anions that are common in groundwater and can occur at high concentrations in groundwater in Oklahoma (Wood and Burton, 1968); and to examine variability in BIOSCREEN results with normal variability in monitoring data. Based on the findings of this study, recommendations will be made regarding the applicability of BIOSCREEN to the ODOT Site and to sites with subsurface characteristics similar to the ODOT Site's subsurface characteristics.

2.0 LITERATURE REVIEW

Natural attenuation, or intrinsic bioremediation, causes measurable changes in groundwater chemistry by indigenous microorganisms reducing the total mass of contamination in the subsurface without addition of nutrients (Wiedemeier et al., 1995). This chapter will cover the processes involved in natural attenuation, including biodegradation, dispersion, adsorption, and volatilization. The chapter then reviews modeling of bioremediation including required model parameters and calibration methods.

2.1 Natural Attenuation Processes

Following Sun Oil Company's reporting of an in situ bioremediation success effort in 1972, engineers, scientists and microbiologists performed studies and designed several in situ bioremediation projects to interpret their performance (Brubaker, 1995). In 1979, a crude oil spill occurred in Bemidji, Minnesota. The site was studied by USGS scientists who discovered that the toxic chemicals leaching from the crude oil plume were rapidly degraded by naturally-occurring microbial populations. In addition, as the rates of microbial degradation came into balance with the rates of contaminant leaching, the plume stopped enlarging. This example of intrinsic bioremediation was the first and best documented case of natural attenuation (USGS, 1997).

Several processes are involved in natural attention, including biodegradation, dispersion, adsorption, and volatilization. Each of these processes is discussed in the following sections.

2.1.1 Biodegradation

In natural attenuation, naturally-occurring microorganisms are responsible for breaking down the hazardous substance, also known as the substrate (e.g. BTEX), by using the substrate as a carbon or energy source, and producing less toxic end products. This process is known as biodegradation, which is the principal mechanism for mass loss from BTEX plumes (Ollila, 1996). For biodegradation to be successful, four main requirements must be satisfied. These requirements are:

- presence of microorganisms (primarily bacteria);
- availability of an energy source and an electron acceptor;
- availability of nutrients;
- favorable environmental factors (moisture, pH, temperature;
- absence of toxicity;
- removal of metabolites; and
- absence of competitive organisms.

(Cookson, 1995)

Of these requirements, the availability of electron acceptors is considered to have the most influence on the rate of in-situ biodegradation; in fact, other factors rarely limit the amount of biodegradation occurring at petroleum contaminated sites (Rifai et al., 1998). The following sections will cover each of these requirements.

2.1.1.1 Microorganisms

The ability of microorganisms to degrade hydrocarbons is well known (Borden et al., 1995). As early as 1946, researchers identified over 100 microbial species that could degrade some types of hydrocarbon. In 1972, researchers found 50,000 or more hydrocarbon-degrading organisms per mL in samples from wells containing traces of gasoline, while a noncontaminated well had only 200 organisms per mL (Borden et al., 1995). Microorganisms obtain energy for cell production and maintenance by facilitating the transfer of electrons from electron donor to electron acceptors.

Microorganisms fall into one of two categories: procaryotes or eucaryotes. Examples of procaryotes are bacteria and blue green algae. A procaryote has a simple cell structure and a typical length and weight of five microns and ten pico grams, respectively. Eucaryote organisms, including algae and fungi, are larger and have a more advanced cell structure than procaryotes (Grasso, 1993). A eucaryote has a typical length of 20 microns (Reynold and Richards, 1996).

A microorganism can further be classified based upon the carbon source, energy source and electron acceptor. A bacterial cell in a bioactive microbial zone that uses organic compounds as a carbon and energy source, and uses oxygen as the electron acceptor is considered a hetero-organotrophic aerobe (Grasso, 1993).

The procaryotic organisms are the most important to bioremediation. Of the procaryotic organisms, the bacteria are most important in the bioremediation process (Cookson, 1995). Laboratory and field studies have identified many microorganisms responsible for degradation of hazardous chemicals, including, but not limited to, *Alcaligenes denitrificans, Inonotus circinatus, Methanobacteriaceae, Nocardia corallina, Pseudomonas stutzeri, and Serratia marcescens* (Cookson, 1995).

Various chemical formulas have been used to represent bacteria, but the most common of these is $C_5H_7NO_2$. A bacteria cell typically contains 50% carbon, 20% oxygen, 10-15% nitrogen, and 5% hydrogen (Grasso, 1993).

Requirements necessary for anaerobic bacteria to degrade fuel hydrocarbon are: absence of dissolved oxygen; availability of carbon sources, electron acceptors, and essential nutrients; and proper ranges of pH, temperature, and salinity. Molecular oxygen is toxic to some anaerobic enzyme systems used for electron transfer and energy production (Wiedemeier et al., 1995).

2.1.1.2 Electron Acceptors

Bioremediation of a contaminant, either aerobically (where oxygen is present) or anaerobically (where oxygen is not present), requires the presence of an electron acceptor for successful oxidation of the substrate. This oxidation occurs in small steps, each step involving the removal of electrons, and the simultaneous loss of protons. The electrons and protons are transferred to an acceptor molecule which will not accept the protons until it has accepted the electrons; thus, the acceptor molecule is known as an electron acceptor (Skinner et al., 1997)

In aerobic processes, molecular oxygen (O_2) is used as the electron acceptor. Common electron donors at fuel hydrocarbon contaminated sites (aerobic or anaerobic) are natural organic carbon and fuel-related organic compounds, including BTEX (Wiedemeier et al., 1995). The availability of dissolved oxygen to the process can be the rate limiting step (Bordon, 1995) The reaction with oxygen will proceed in the plume until all of the required electron acceptor is depleted This is due to the low solubility of oxygen in water and may also be due to the characteristics of the subsurface soil. One mg of dissolved oxygen is required to metabolize 0.32 mg of BTEX (Wiedemeier et al., 1995). Since oxygen has the greatest available energy (shown later in Table 2.1) it is most preferred for the degradation reaction (Wiedemeier et al., 1995).

Once oxygen has become depleted, the conditions become anaerobic. For anaerobic processes, alternate electron acceptors include nitrate, ferric iron, sulfate, water, manganese (IV), or carbon dioxide. Anaerobic biodegradation can occur by denitrification, iron (III) reduction, sulfate reduction, or methanogenesis, depending upon the types of electron acceptors present. pH conditions, and oxidation-reduction (redox) potential. Denitrification typically occurs first, followed by iron (III) reduction, sulfate reduction, and finally methanogenesis, although sulfate reduction and methanogenesis appear to account for the greatest reduction in dissolved BTEX mass. Ultimately, the relative importance of aerobic processes, methanogenesis, sulfate reduction, denitrification, and iron reduction depends upon the geochemical characteristics of the host groundwater (Wiedemeier et al., 1995).

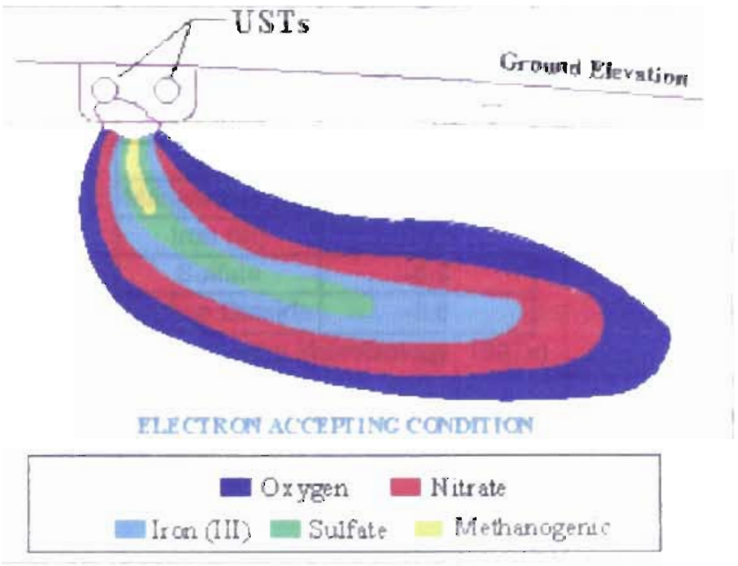
Typical reactions for biodegradation of benzene are:

- Aerobic respiration $7.5CO_2 + C_6H_6 = 6CO_{2,g} + 3H_2O$
- Denitrification $6NO_3^- + 6H^+ + C_6H_6 = 6CO_{2,g} + 6H_2O + 3N_{2,g}$
- Iron reduction $60H^+ + 30Fe(OH)_3 + C_6H_6 = 6CO_{2,g} + 30Fe^{2+} + 78H_2O$
- Sulfate reduction $7.5H^+ + 3.75SO_4^{2-} + C_6H_6 = 6CO_{2,g} + 3.75H_2S^0 + 3H_20$
- Methanogenesis $4.5H_2O + C_6H_6 = 2.25CO_{2,g} + 3.75CH_4$

(Wiedemeier et al., 1995)

Of the electron-accepting processes, methanogenesis appears to be the most important and accounted for 39 percent of the total degradation capacity in a study funded in part by the EPA (Wiedemeier et al., 1995). Figure 2.1 below indicates the location of the above electron-accepting processes within a contaminant plume.

Figure 2.1: Relative Electron-Accepting Process Locations



(Lyngkilde et al., 1991)

The trends that are observed in alternate electron accepting environments are depicted above in Figure 2.1. The figure indicates that respiratory conditions of the plume vary from highly reactive aerobic conditions, through anoxic nitrate and iron reduction, to highly reduced sulfate and methanogenic conditions. Note that the order of electron acceptor respiration agrees well with the utilization order predicted by the electron tower theory presented below in Figure 2.2 (Lyngkilde et al., 1991) discussed later

Aerobic conditions are most preferred since they liberate more energy, thus remediation occurs faster under aerobic conditions (Skinner et al., 1991). However, anaerobic processes may account for 90 percent (or greater) of the total contaminant mass being biodegraded in groundwater contaminated with fuel hydrocarbons. Thus, over time, anaerobic processes are more important than aerobic processes for natural bioremediation (Wiedemeier et al., 1995). In either process, in order to completely break down the contaminant, a consortium of bacteria must be present under favorable environmental conditions, as discussed in Section 2.1.1.4.

Water and carbon dioxide are the least preferred alternate electron acceptors, because microorganisms gain the least energy from these reactions (Borden et al., 1995). Some of the electron acceptors' energy production capabilities are presented below in Table 2.1.

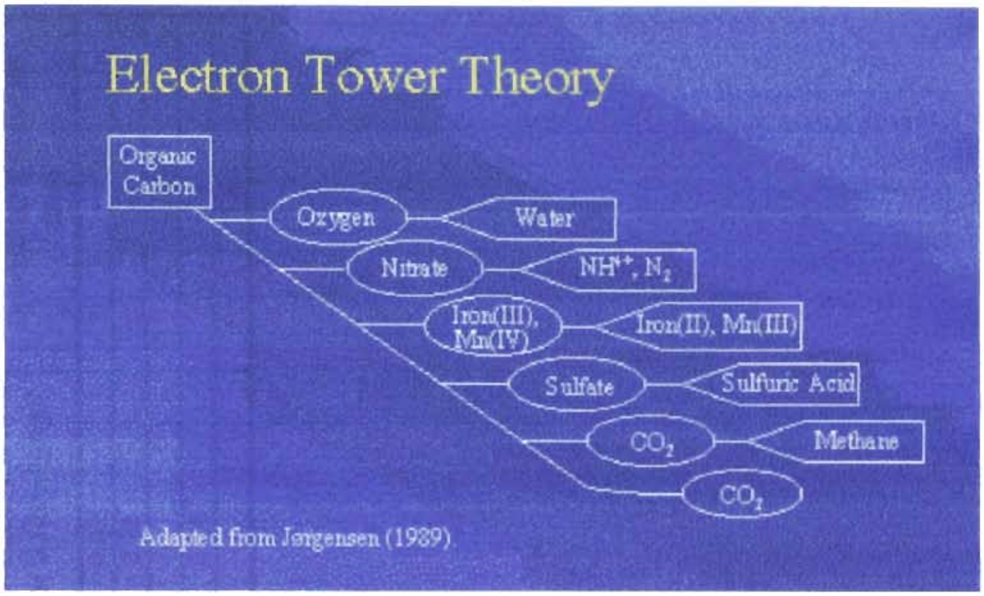
Table 2.1: Electron Acceptor Energy Production

Electron Acceptor	Free Energy Change, Kcal/Eq.
Oxygen	-29.9
Nitrate	-28.4
Manganese (IV)	-23.3
Iron (III)	-10.1
Sulfate	-5.9
Carbon Dioxide	-5.6

(Environmental Microbiology, 1997a)

Figure 2.2 below shows the electron Tower Theory as described by Jorgensen (1989).

Figure 2.2: Electron Tower Theory



Electron Tower Theory

Adapted from Jorgensen (1989)

(Adapted from Jorgensen, 1989)

According to Jorgensen (1989), the Tower Theory relates the amount of energy a given microbial population can gain from an electron acceptor to the electron acceptor's position on the tower. Microbes tend to oxidize organic substrates using the electron acceptor that provides the most energy. Note that oxygen, which is at the top of the electron tower, provides microbes with more free energy (via oxygen reduction) than any other electron acceptor. Carbon dioxide, which is used as the electron acceptor by methanogenic bacteria, yields the least energy of all the electron acceptors, and is therefore located at the bottom of the tower. Thus, the electron tower provided above schematically depicts the order of electron acceptor utilization based upon the free energy a given microbial population can gain from reduction of a given electron acceptor (Jorgensen, 1989). Table 2.2 on the following page shows the ratios and relationships between mass of utilized electron acceptors and biodegradation reactions.

2.1.1.3 Nutrients

Certain elements are required in various quantities for efficient transformation of hazardous compounds to carbon dioxide. The nutrients needed in large quantities are carbon, potassium, magnesium, calcium, hydrogen, nitrogen, oxygen, sulfur, phosphorus, sodium, and

Table 2.2: Stoichiometry of Common Biodegradation Reactions				
Biodegradation Reactions	**Average Mass Ratio of Electron Acceptor to Total BTEX***	**Average Mass Ratio of Metabolic Byproduct to Total BTEX***	**Mass of BTEX Degraded per unit mass of Electron Acceptor Utilized (mg)***	**Mass of BTEX Degraded per unit mass of Metabolic Byproduct Produced (mg)***
Aerobic Respiration	3.14:1	--	0.32	--
Denitrification	4.9:1	--	0.21	--
Iron Reduction	--	21.8:1	--	0.046
Sulfate Reduction	4.7:1	--	0.21	--
Methanogenesis	--	0.78:1	--	1.28

**This stoichiometry assumes no cellular mass is produced.*

Adapted from Wiedemeier et al., 1995.

chloride. Other nutrients are required in lesser amounts. They are cobalt, nickel, iron, zinc, molybdenum, copper, manganese and selenium (Grasso, 1993).

Of these nutrients, those that are not naturally present in the subsurface at levels required will inhibit microbe growth. However, nutrients that are present in excess can also inhibit microbe growth. The carbon:nitrogen: phosphorus ratio required is between 100:10:1 and 100:1:0.5 (Grasso, 1993).

2.1.1.4 Favorable Environment

Both the pH and temperature of the subsurface environment are important parameters for microbial growth. Although the optimum pH varies based upon the organisms present, most bacteria have maximum growth rates at a pH between 6.5 and 7.5 (Grasso, 1993). Relatively few microbes can grow in acidic (pH<4) or basic (pH>10) environments. The pH of a system will continue to change as hydrogen ions are generated and consumed, so pH monitoring is important to sustain a high rate of remediation. Decreases in pH have been observed downgradient of contaminant sources at several sites resulting from organic acid accumulation associated with the incomplete anaerobic degradation of aromatic compounds. Therefore, low pH may be both an indicator of previous biodegradation and a signal of inhibitory conditions (Lewandowski and DeFilippi, 1998). The concentration of hydrogen ions in groundwater is governed by the types of compounds produced by bacterial activity, as it is controlled by CO_3^{2-} $:HCO_3^{-}:CO_2$ equilibrium rates (Wilber, 1997).

Just as with pH, the temperatures at which microbes can grow also vary. Some can grow at temperatures below 0°C, while others can grow above 93°C. In general, most microorganisms will grow best in a temperature range of 25 to 30°C (Grasso, 1993). Typically, the rates of bioremediation double for every 10°C increase in temperature (Lewandowski and DeFilippi, 1998). Colder temperatures will slow biodegradation rates (Lewandowski and DeFilippi, 1998).

Separately, microorganisms cannot mineralize most hazardous compounds. When several types of microorganisms are combined, a degradation sequence occurs where a second organism degrades the metabolic products of the first, and a third, etc., to yield complete mineralization of an organic compound. Hence, a mixed microbial consortium is required for complete bioremediation to occur (Cookson, 1995). The multiple roles of microbial synergism are below.

- Stepwide or sequential degradation
- Synthesis of a necessary component
- Removal of toxic metabolites
- Enhancing overall rate of degradation
- Microbial web, the need of complex associations
- Favorable thermodynamics

(Cookson, 1995)

As stated previously, there is no single organism responsible for bioremediation of a contaminated site. However, frequently identified active members of microbial consortiums in bioremediation processes include, but are not limited to *Arthrobacter globiforms, Nocardia corallina, Pseudomonas fluorescens, Pseudomonas paucimobilis, and Pseudomonas vesicularis* (Cookson, 1995).

2.1.1.5 Biodegradation Rate and Verification

Through monitoring, the rate and extent of natural attenuation can be assessed based upon the changing concentration of carbon dioxide (Borden et al., 1995). The ease of biodegradation also depends on the type of hydrocarbon. As the molecular weight of the hydrocarbon increases, so does the resistance to biodegradation (Borden et al., 1995). When monitoring a site, changes in certain parameters should be evaluated to be assured degradation is occurring. Table 2.3 on the following pages details techniques for demonstrating biodegradation is occurring in the field.

Table 2.3: Techniques for Demonstrating Biodegradation in the Field

Technique	Purpose	Implementation Methods
Measurements of Field Samples		
Number of bacteria	To determine whether the number of contaminant degrading bacteria has increased over usual field conditions	Standard and emerging cell-counting techniques from microbiology
Number of protozoans	To determine whether the population of protozoans that prey on bacteria has increased	Standard microbiological techniques for counting protozoans, including the most-probable-number technique
Rates of bacterial activity	To estimate the potential rates at which bacteria from the field can degrade the contaminant	Determination of contaminant loss rate and other relevant markers of biodegradation in laboratory microcosms
Bacterial adaptation	To assess whether bacteria from the contaminated site can metabolize the contaminate more quickly than before bioremediation began	Microcosm studies before and after the initiation of bioremediation or using samples from the bioremediation zone and contaminated area outside the bioremediation zone; gene probing to analyze changes in the bacteria's genetic makeup
Inorganic carbon concentration	To determine whether the inorganic carbon concentration in subsurface samples has increased, indicating possible conversion of contaminants to inorganic carbon	Gas chromatography for determining gaseous carbon dioxide; inorganic carbon analysis for determining aqueous species
Carbon isotope ratios	To evaluate whether the inorganic carbon at the site originates from contaminant biodegradation	Measurement of the $^{13}C/^{12}C$ ratio using a mass spectrometer
Electron acceptor concentration	To determine decreases in concentration of O_2 or other electron acceptors used during biodegradation	Standard analytical methods from wet chemistry
Byproducts of anaerobic activity	In oxygen-depleted environments, to determine whether byproducts of anaerobic metabolism such as methane, sulfides, reduced forms of metals, and nitrogen gas have accumulated	Standard chemical analytical methods
Intermediary metabolite formation	To determine the presence of intermediary metabolites unique to the biodegradation of a particular contaminant.	Gas chromatography, high-performance liquid chromatography, and/or mass spectrometry

Table 2.3: Techniques for Demonstrating Biodegradation in the Field, continued

Technique	Purpose	Implementation Methods
Ratio of nondegradable to degradable substances	To analyze whether the ratio of nonbiodegradable to degradable components of a contaminant has increased	Standard chemical analytical methods
Experiments Run in the Field		
Simulating bacteria within subsites	To establish whether the contaminant loss rate increases when growth-stimulating materials are added to the site	Comparison of amended and unamended subsites within the contaminated area
Measuring the electron acceptor uptake rate	To estimate the rate of consumption of oxygen or other electron acceptors necessary for contaminant metabolism	Measurement of the rate at which oxygen (or another electron acceptor) is consumed once the flow of the material is stopped (e.g., using an oxygen probe)
Monitoring conservative tracers	To distinguish abiotic contamianant losses from losses due to biodegradation	Comparison of the fate of nondegradable tracer compounds to the fate of the degradable contaminant
Labeling contaminants	To determine the fate of carbon contained in organic contaminants	Monitoring of ^{13}C-labeled versions of the contaminant
Modeling Experiments		
Modeling mass losses	To analyze whether abiotic mechanism (e.g., dilution, transport, volatilization) can explain all of the losses of the contaminant mass	Use of mathematical models to represent abiotic loss mechanisms and comparison of the result with the contaminant loss rate in the field
Direct modeling	To estimate the biodegradation rate	Use of mathematical models to directly estimate the biodegradation rate and compare it with observations from the field

(MacDonald and Rittman, 1993)

Relative to background concentrations, a reduction in nitrate or sulfate concentration or an enrichment in iron (III) or methane concentrations within an existing BTEX plume is a strong indication that indigenous bacteria are established and actively biodegrading fuel contamination (Wiedemeier et al., 1995). Loss of electron acceptors is one method of verifying biodegradation is occurring.

Patterns and rates of intrinsic bioremediation can vary markedly from site to site, depending on the physical and chemical processes (Wiedemeier et al., 1995). Studies have indicated first-order BTEX decay rates in the laboratory of approximately 0.016 to 0.045d^{-1} and field decay rates ranging from approximately 0.0002 to 0.038 d^{-1} for various sites (Borden et al., 1997, Hutchins et al., 1991, and Wiedemeier et al., 1996).

2.1.2 Dispersion

Dispersion is one way a contaminant is transported in groundwater. Dispersion, or mixing, occurs in groundwater as a result of continuous splitting, slowing down, and deflecting of water particles in the pores (Novotny and Olem, 1994). Since dissolved constituents migrate through subsurface materials that are not homogeneous, there are inherently different constituent migration rates in different portions of the plume (Lewandowski and DeFilippi, 1998). This results in spreading which is represented by transverse and longitudinal dispersivity. Dispersion is usually stronger in the transverse (perpendicular) direction than it is in the longitudinal direction.

Where diffusion is molecular mixing, dispersion is mechanical mixing. Since mechanical dispersion cannot be distinguished from molecular diffusion (a process of molecular movement along a concentration gradient in the liquid or gaseous phase), the two concepts can be combined to produce a diffusion/dispersion coefficient. The equations follow:

$$DL = aL*v + De = \text{Perpendicular coefficient}$$
$$DT = aT*v + De = \text{Longitudinal coefficient}$$

(Rong, 1999)

Where DL(T) = diffusion/dispersion coefficient parallel (perpendicular) to the principal direction of groundwater flow, L^2/T

aL(T) = longitudinal (transverse) dispersivity, L

v = groundwater velocity, L/T

De = effective diffusion coefficient, L^2/T

In the saturated zone, the higher the groundwater velocity, the greater the dispersion process (Rong, 1999). At lower velocities, diffusion is more of a factor. Usually, transverse dispersivity is about one order of magnitude smaller than longitudinal dispersivity, and vertical dispersivity is about two orders of magnitude less than longitudinal (Zheng and Bennett, 1995). In large field scale studies, a typical range of longitudinal dispersivity was found to be 1-100 meters and the average value was found to be 25 meters (Schnoor, 1996).

2.1.3 Adsorption

Adsorption is a process in which the contaminant is adsorbed onto a soil or sediment particle. Adsorption is usually reversible. Hence, when conditions permit, the adsorbed contaminant will detach from the soil particle and move back into solution or groundwater. Adsorption can account for small fluctuations in contaminant concentrations in groundwater (Novotny and Olem, 1994). The Freundlich isotherm is frequently used to represent the adsorption equilibrium.

$x/m = X = KC_e^{1/n}$ (Reynolds and Richards, 1996),

where x = mass of solute adsorbed

m = mass of adsorbent

X = mass ratio of the solid phase - that is, the mass of adsorbed solute per mass of adsorbent

C_e = equilibrium concentration of solute, mass/volume

K, n = experimental constants

Another isotherm used to represent the adsorption equilibrium is the Langmuir isotherm:

$x/m = X = (aKC_e) / (1 + KC_e)$ (Reynolds and Richards, 1996)

Where: a = mass of adsorbed solute required to saturate completely a unit mass of adsorbent

K = experimental constant

For the situation of groundwater contaminated with hydrocarbons, the equations can be narrowed to obtain a relationship for the sorption of hydrocarbons onto soil. Two very similar equations are presented below, the first proposed by Karickhoff, Brown, and Scott and the latter by Rao and Davidson (Novotny and Olem, 1994):

$$K_{OC} = 0.63K_{OW} \quad ; \quad K_{OC} = 0.66K_{OW}^{1.07}$$

Where: K_{OC} = the partitioning coefficient normalized by the organic carbon.

K_{OW} = octanol partition coefficient

The K_{OW} for various chemicals can be found in environmental reference manuals. For BTEX, the K_{OW} values are the following:

- Benzene: $K_{OW} = 10^{2.13}$
- Toluene: $K_{OW} = 10^{2.69}$
- Ethylbenzene: $K_{OW} = 10^{3.15}$
- Xylene: $K_{OW} = 10^{3.38}$ (m- and o-)
  $= 10^{3.39}$ (p-)

(Novotny and Olem, 1994)

The rate of adsorption is limited by the following mechanisms:

- the movement of the solute from the bulk solution to the liquid film or boundary layer surrounding the adsorbent solid;
- the diffusion of the solute through the liquid film (film diffusion);
- the diffusions of the solute inward through the capillaries or pores within the adsorbent solid (pore diffusion); and
- the adsorption of the solute onto the capillary walls or surfaces .

(Reynolds and Richards, 1996)

2.1.4 Volatilization

Volatilization is the transfer of chemicals or contaminants from the liquid phase to a gaseous phase or to the atmosphere. The relationship between the contaminant vapor density and the concentration of the contaminant in water is given by Henry's Law as follows:

$K_H = V_P / C$ (Wilson et al., 1995),

where C = concentration of dissolved pollutant, μg/L

K_h = Henry's constant for the contaminant, dimensionless

V_P = vapor pressure of the contaminant, $\mu g/L$

Volatilization tends to contribute most to contaminant mass loss at sties where the water table is shallow or highly fluctuating (ASTM, 1996).

2.2 Modeling Bioremediation

2.2.1 Introduction to Modeling

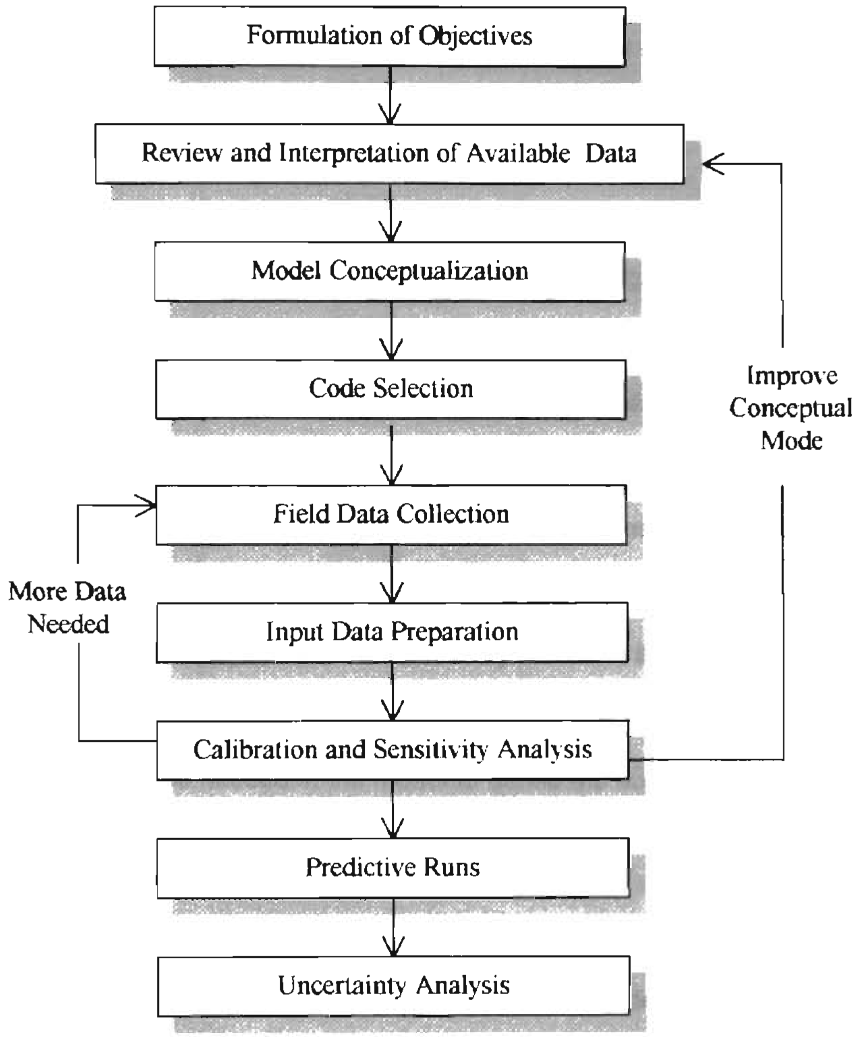
Because actual site conditions are complex and extensive, a model simplifies a site's conditions by introducing a set of mathematical assumptions which express the nature of the system and those features of its behavior that are relevant to the problem under investigation (Bear et al., 1992). In a 1992 EPA publication titled "Fundamentals of Ground-Water Modeling" presented the steps required for proper application of a groundwater model (Bear et al., 1992). These steps are included as Figure 2.3 on the following page.

Many analytical and numerical computer models for use in evaluating groundwater contamination exist. These models can address saturated, unsaturated, and fracture flow; saturated and unsaturated multiphase transport, and geochemical and biological processes. Models simulate the plume's movement by considering the quantity of contaminant release, advection, dispersion, and sorption. Some models also incorporate biodegradation simulation. Numerical models are capable of simulating heterogeneous systems but are more complex and require more data than analytical models (Striegel, 1998). Analytical models are typically limited to simplified hydrogeologic scenarios (Bear et al., 1992).

Modeling methods for assessing intrinsic bioremediation usually rely on three approaches for measuring biodegradation rates in groundwater systems. They are the following:

1) documenting contaminant mass along a flow path, subtracting out the effects of dilution and sorption, and applying a rate law to the data;
2) using controlled field tracer studies to estimate biodegradation rates; and
3) obtaining aquifer materials and performing laboratory microcosm studies or in situ columns to estimate biodegradation rates.

Figure 2.3: Model Application Process



(Bear et al., 1992)

Models vary in how they simulate biodegradation. In modeling, two basic approaches to mass and energy balances are 1) the eularian approach, and 2) the lagrangian approach. The eularian approach calculates balances relative to volume elements which have constant sizes and spatial locations. The lagrangian approach tracks a fixed unit of mass as it moves through space and time (Zheng and Bennett, 1995).

2.2.2 Required Model Parameters

Two types of data are needed for bioremediation modeling. The first is the required parameters that define hydrogeologic and hydrogeochemical conditions in the contaminated area. The second type of data needed includes measured hydraulic heads, flow rates, contaminant arrival times, solute concentrations, and/or mass removal rates at the available monitoring points. The data required for bioremediation models include specific information describing the characteristics of the site being investigated. When site-specific data are inadequate to support the model, fieldwork is necessary to collect additional data (Zheng and Bennett, 1995). The hydraulic conductivity and storage coefficient (confined aquifer) or specific yield (unconfined aquifer) are needed in the model to define the flow of the groundwater. Hydraulic conductivity is a property of both the porous medium and the moving fluid.

To define transport in a model, porosity and dispersivity are required. Porosity is a factor in determining the seepage velocity and the pore volume of a model cell available for storage of solute mass. Dispersivity is strongly influenced by the aquifer heterogeneity and the degree to which heterogeneity is represented and is discussed in Section 2.1.2. Usually, transverse dispersivity is about one order of magnitude smaller than longitudinal dispersivity, and vertical dispersivity is about two orders of magnitude less than longitudinal (Zheng and Bennett, 1995).

Surface and subsurface hydrogeologic conditions can greatly influence the three-dimensional configurations of groundwater flow. Vertical groundwater flow is greatly influenced by water depths, presence and thickness of fine-grained bottom sediments, and locations of surface water bodies relative to buried high-permeability zones (Lewandowski and DeFilippi, 1998). Table 2.4 below shows the porosity and hydraulic conductivity of different types of geologic materials.

Table 2.4: Physical Properties of Geologic Materials

	Porosity, %	**Hydraulic Conductivity, cm/s**
Clay	33-71	10^{-10} - $10^{-3.3}$
Sandy clay	20-64	
Silt	20-52	10^{-7}-10^{-3}
Sand	15-50	$10^{-5.5}$-1
Fine sand	29-50	10^{-3}-10^{-2}
Medium sand		10
Coarse sand	33-44	10^{-2}-1
Gravelly sand	12-46	10^{-1}-1
Gravel	25-80	10^{-1}-10^{2}
Fine gravel		>1
Peat		10^{-7}-10^{-2}
Loam	20-50	
Sandstone	3.5-30	10^{-8}-$10^{-4.5}$
Limestone	0.5-20	$10^{-7.2}$-$10^{-3.5}$
Shale	0.5-10	10^{-11}-10^{-7}
Granite		10^{-12}-10^{-9}
Unfractured	.02-5	
Fractured	0-10	

(Lewandowski and DeFilippi, 1998)

Table 2.4 shows that as the porosity of the material decreases, so does the hydraulic conductivity.

Chemical parameters of a model are defined by sorption constants and kinetic reaction rates. Sorption isotherms are adequate only in idealized situations. The most common isotherms used are the linear, Freundlich, and Langmuir isotherms, the linear isotherm being the most popular. Because of organic contaminants' limited solubilities, they generally tend to adsorb, or partition, to other forms of organic carbon in the subsurface. This can lead to adsorption of these constituents to the organic coatings of the solid particles or to their adsorbed water. The simplest of the kinetic reaction rates is the first order irreversible rate reaction and is used most often (Lewandowski and DeFilippi, 1998).

2.2.3 Model Calibration

Calibration of a model is done by adjusting model parameters until modeled results match actual monitored field conditions. The adjustable variables include hydraulic heads, flow rates, solute concentrations, contaminant arrival times or mass removal rates (Zheng and Bennett, 1995). Model calibration is an inverse process where field observed data are used to derive optimal input parameters.

2.2.4 Sensitivity Analysis

Sensitivity measures the effect on one factor of changing another factor. Repeated runs are needed to calculate a sensitivity coefficient. The sensitivity coefficient measures the sensitivity of the model response to a given parameter. The sensitivity analysis is useful for:

- examining the overall responses of simulation results to changes in the model input parameters;
- examining the likely uncertainty in simulations results due to uncertainty in model input parameters; and
- examining how well parameters are likely to be estimated from the data available for model calibration.

(Zheng and Bennett, 1995).

2.2.5 Examples of Bioremediation Models

One of the most recent bioremediation models is the new version of MT3D, called MT3DMS, Modular 3-Dimensional Transport Model with Multi-Species. MT3DMS is able to accommodate add-on reaction packages. The developer of MT3D, Chun Miao Zheng of the University of Alabama, originally introduced the model in 1988 (K.S.B., 1997). The new version combines the three major classes of transport solution techniques (the standard finite difference method; the particle-tracking-based Eularian-Lagrangian methods; and the higher-order finite-volume total variation diminishing method) into a single code. These three classes had been used individually in the past and were shown not to be effective for all transport conditions (HydroGroup, 1999). The modular structure of the MT3D and MT3DMS is similar to that implemented in the U.S. Geological Survey modular three-dimensional finite-difference groundwater flow model, MODFLOW (HydroGroup, 1999).

Jose E. Munoz and Manuel J. Irarrazaval developed another model that considers only aerobic conditions. The model supports the idea that bioremediation of hydrocarbons is controlled by (1) groundwater flow rate (dependent on soil and fluid characteristics); (2) contaminant transport through a porous medium (dependent on soil, fluid, and contaminant characteristics); and (3) biodegradation and interaction among the three transported solutes-hydrocarbons, oxygen, and microorganisms (dependent on the characteristics of the contaminant and of microorganisms present in the medium). The numerical model represents the interactions of the three solutes using Monod kinetics and a Freundlich adsorption isotherm. The model may be a useful tool in gauging the efficiency of treatment methods (Munoz and Irarrazaval, 1998).

Models capable of simulating biodegradation that incorporate multiple electron acceptor processes include BioF&T 3D, BIOSCREEN, SEAM3D, BIOPLUME III, and RT3D (Newell et al., 1996; Rafai et al., 1998; Waddill and Widdowson, 1998; Boss International, 1998). BIOSCREEN is based on the 1987 Domenico three-dimensional analytical solute transport model. This model will be further discussed in Section 3.4.

SEAM3D is capable of simulating transport and biodegradation of multiple constituents in three dimensions, is a block-centered, finite-difference computer algorithm, and interfaces with the groundwater flow model MODFLOW. SEAM3D assumes Monod kinetics and includes manganese as an electron acceptor whereas BIOPLUME III and BIOSCREEN do not (Waddill and Widdowson, 1998; Rafai et al., 1998; Newell et al., 1996).

BIOPLUME III is a two-dimensional numerical model that uses Monod, first order, or instantaneous reaction assumptions. The model applies an instantaneous reaction to both aerobic and anaerobic biodegradation if the microbial reaction is assumed to occur at a much faster rate than the rate of electron acceptor replenishment via groundwater flow, and assumes biodegradation is limited by the amount of electron acceptor available (Rifai et al., 1998).

RT3D incorporates three dimensional reactive groundwater transport. RT3D includes instantaneous reactions utilizing oxygen, nitrate, ferric iron, sulfate, and carbon dioxide as electron acceptors. Multiple sorbed and aqueous phase contaminants and reactions can be defined, and user-defined kinetic expressions can be employed (BOSS International, 1998). The model can be used to analyze different types of subsurface contaminant reactions, microbial metabolisms, and microbial transport kinetics (Clement et al., 1998). In studies, RT3D simulation results were shown to compare favorably against an analytical solution and against the results from BIOPLUME III. The study also shows that RT3D is general enough to solve any type of kinetic reactions with any number of mobile and immobile species (Clement et al., 1998).

The most common method for simulating biodegradation in more recent models is through Monod kinetics, which describe microbial growth in first-order, mixed-order, and zero-order regions. The Monod equation is:

$$\mu = \mu_{max} [C / (K_c + C)]$$

where μ is the growth rate (time^{-1}), μ_{max} is the maximum specific growth rate (time^{-1}), and C is the concentration of the growth-limiting substrate (mg/L). K_c is the half-saturation constant or the substrate concentration that allows the microorganism to grow at the half the maximum specific growth rate (Rafai and Bedient, 1995).

2.3 ORBCA

The models described in the previous section could be used to support closure of a site under a risk-based approach. The ODOT Site under investigation in this study was closed based partially on the results of the AT123D model which indicated the subsurface contamination was not posing an immediate threat to human health or the environment, nor would the contamination pose a threat in the future. The closure of the ODOT Site was based on the Oklahoma Risk-Based Correction Action (ORBCA) process (Caldwell, 1996). The ORBCA process is based on considerations of risk and exposure, and is a major component of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) program. An ORBCA report, or a Risk Assessment, is prepared using site specific conditions. The report determines target levels which contaminants must not exceed. If the target levels are exceeded, the regulatory agency, being the Oklahoma Corporation Commission in Oklahoma, requires corrective action of the contaminated site. The Risk Assessment report includes the following:

- identification of chemicals of concern,
- identification of receptors,
- exposure analysis,
- dose-response analysis,
- risk and sensitivity/uncertainty quantification, and
- risk management.

(OCC, 1999)

These basic activities are included in all risk assessments whether the site is a small underground storage tank (UST) release site or a large-scale Superfund site. The degree of complexity of the above items depends on the goal of the assessment and the site's characteristics and surroundings.

3.0 METHODOLOGY

3.1 Site Description

The information contained in the following Section 3.1 (location, description, site history, site characterization, and site hydrogeology) is derived from information obtained from the Risk Assessment Report completed by Caldwell Environmental Associates, Inc. (Caldwell) (Caldwell, 1996) in May, 1996 for the Edmond ODOT Residency Facility and from site visits during sampling events.

3.1.1 Location and Description

Figure 3.1 below identifies the ODOT Site location on a general location map.

Figure 3.1: General Site Location Map

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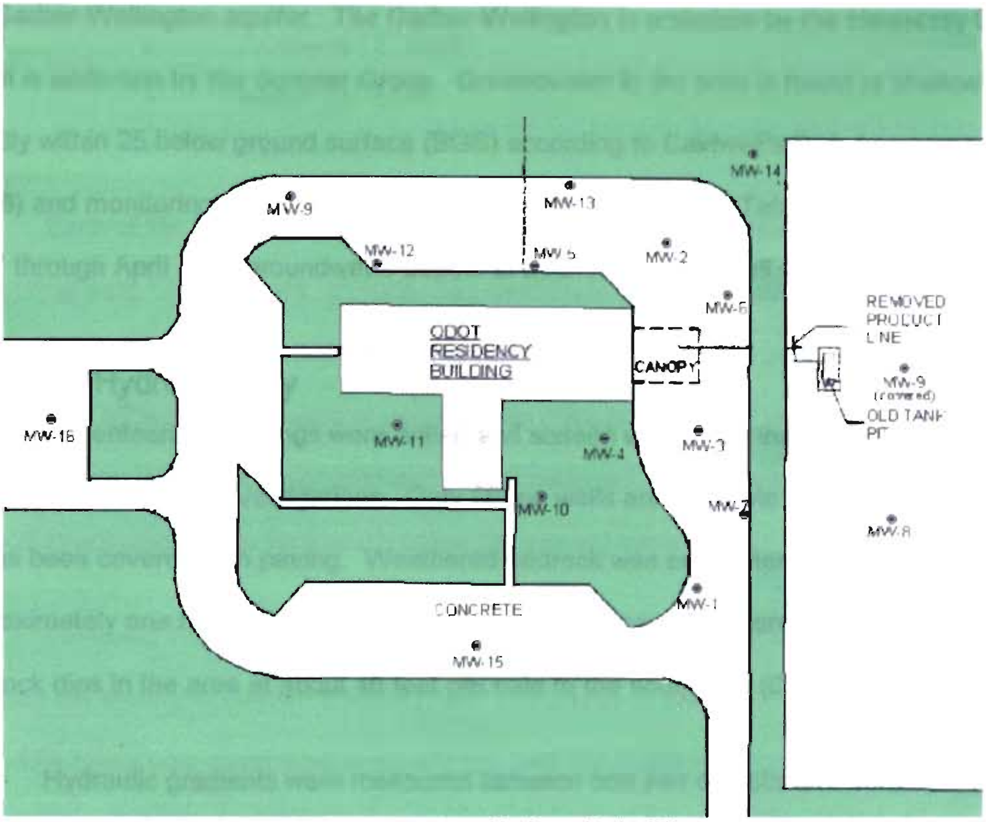
The ODOT Site, located about 1,000 feet northwest of the intersection of Interstate 35 and Memorial Road in Oklahoma County, is used as office space for ODOT personnel working on Logan County and north Oklahoma County projects. The facility layout is presented in Figure 3.2.

Figure 3.2: Site Map



(Caldwell, 1996)

3.1.2 Site History

In early 1991, a fuel dispenser line leak was discovered at the ODOT Site. The quantity of leaked fuel is unknown. The dispenser line and an UST were removed from the ODOT Site in early February 1992 and September 1994, respectively. Initial Response, Initial Abatement Measures and Site Check, Initial Site Characterization, and Tier 1A Reports were subsequently completed and submitted to the Oklahoma Corporation Commission. The subsurface investigations at the ODOT Site found a dissolved petroleum groundwater plume in the subsurface (Caldwell, 1996).

3.1.3 Site Characterization

The ODOT Site is located on a hill, with land use north and east of the ODOT Site being commercial, and land use to the west being residential. East of the ODOT Site is the ODOT Maintenance Facility and I-35. Surface water run-off at the ODOT Site is to the northwest, toward an unnamed intermittent creek located about 0.5 miles to the northwest, and eventually to the Canadian River. Principal groundwater resources include alluvial and terrace deposits and the Garber-Wellington aquifer. The Garber-Wellington is underlain by the Hennessy Group which is underlain by the Sumner Group. Groundwater in the area is found at shallow depths, usually within 25 below ground surface (BGS) according to Caldwell's Risk Assessment Report (1996) and monitoring results of this study (Caldwell, 1996). See Table 4.17 for specific October 1997 through April 1998 groundwater depths at each monitoring well (MW).

3.1.4 Site Hydrogeology

Seventeen soil borings were drilled and sixteen wells were installed at the ODOT Site during the subsurface investigations. Only fifteen wells are available for monitoring as one (MW-9) has been covered with paving. Weathered bedrock was encountered at depths of approximately one to five feet BGS, and groundwater was encountered at less than 25 feet BGS. Bedrock dips in the area at about 40 feet per mile to the southwest (Caldwell, 1996).

Hydraulic gradients were measured between one pair of wells on February 20, 1996 and another pair of wells on May 21, 1996, and were found to be 0.006 and 0.005 foot/foot, respectively. Aquifer slug test performed at the ODOT Site resulted in a hydraulic conductivity of 6.3×10^{-4} cm/sec. The average horizontal groundwater flow velocity, based on hydraulic conductivity (1.0×10^{-3} cm/s), hydraulic gradient (0.006 foot/foot), and porosity (20%), was calculated to be 0.077 feet/day in the southwest direction (Caldwell, 1996).

3.2 Sampling Procedure

Groundwater sampling at the ODOT Site was performed on six occasions during this study spanning a period of approximately six months. The sampling events occurred on the following dates:

- October 20, 1997
- December 15, 1997
- January 20, 1998
- February 17, 1998
- March 24, 1998
- April 14, 1998

Each of the six sampling events included several tasks which were performed at each monitoring well. Occasionally, a monitoring well would be dry and could not be sampled or analyzed. Each monitoring well had a dedicated one-liter open top bailer with ball stop. Initially, if conditions allowed, four bailers of groundwater were purged from the monitoring well to allow a representative sample of the groundwater to be collected. Depth to groundwater was estimated at each event using the baler's depth below the ground surface.

Following the purging of the well, the dissolved oxygen concentration was analyzed by lowering the dissolved oxygen meter's probe (discussed in Section 3.3.4) into the monitoring well. The meter was given time to equilibrate, and the dissolved oxygen quantity for the well was recorded in a field book. After each use of the dissolved oxygen meter, the probe was rinsed with deionized water.

Following dissolved oxygen analysis, the groundwater sample was collected. Groundwater samples were collected in cleaned one-liter plastic bottles. After the sample was collected, the pH was tested with a pH meter (discussed in Section 3.3.4). The sample bottle and sample bottle lid were completely filled with groundwater (to avoid air bubbles in the sample) from the monitoring well, and the bottle was capped. The sample was then stored at $4^{O}C$ until analysis.

Once the sampling was complete for each of the fifteen wells, the samples were returned to the laboratory. Necessary sample preservation was accomplished before storage of samples. Forty mL of each sample was preserved with 6N HCl. This HCl preserved sample was used for the BTEX analysis and total organic carbon analysis. The anion analysis was performed within 24 hours of sampling with filtered, non-preserved sample.

3.3 Materials

3.3.1 BTEX Analysis

The general physical and chemical properties of the BTEX compounds are presented in Table 3.1 below.

Table 3.1: Physical and Chemical Properties of BTEX Compounds

Property	Benzene	Toluene	Ethylbenzene	o-Xylene
Empirical Formula	C_6H_6	C_7H_8	C_8H_{10}	C_8H_{10}
Formula Weight	78.11	92.14	106.17	106.17
Boiling Point (°C)	80.10	92.14	136.20	144.40
Henry's Law Constant (atm*m3/mol, @25°C)	0.00548	0.00674	0.00868	0.00535
Log K_{oc}	1.69	2.05	1.98	2.11
Log K_{ow}	2.13	2.65	3.13	2.95
Solubility in Water (mg/L, @25°C)	1800	524	206	204
Specific Density (@25°C)	0.87366	0.86233	0.86250	0.87596
Vapor Density (g/L, @25°concentration)	3.19	3.77	4.34	4.34
Vapor Pressure (mm Hg, @25°C)	95.2	22	10	10

(Montgomery and Welkom, 1990; Nielsen, 1980)

The BTEX concentration in the groundwater samples was analyzed using a Hewlett Packard 5890 Series II gas chromatograph (GC) with Flame Ionization Detector (FID). The 6' long by 1/8" inner diameter stainless steel column packed with 5.0% SP-1200/1.75% Bentone® on 100/120 SUPELCOPORT separates the BTEX components from the groundwater sample according to their affinities for the column material and releases each component separately to the FID. The GC was connected to a HP 3396 Series II integrator. The carrier gas used was helium flowing at 20 ml/min, and the FID gas was a combination of hydrogen and air. The flow of the helium was adjusted to acquire distinctly separate peaks for each of the BTEX components. One μl of groundwater sample was injected using a 5 μl syringe and analyzed at a constant 75°C. The injector and detector temperatures were set at 200°C and 275°C, respectively. Under these conditions, the BTE peak times were approximately 1.5, 2.8, and 5.2 minutes, respectively. The o- and p-xylene peak times were 5.5 and 6.5 minutes, respectively.

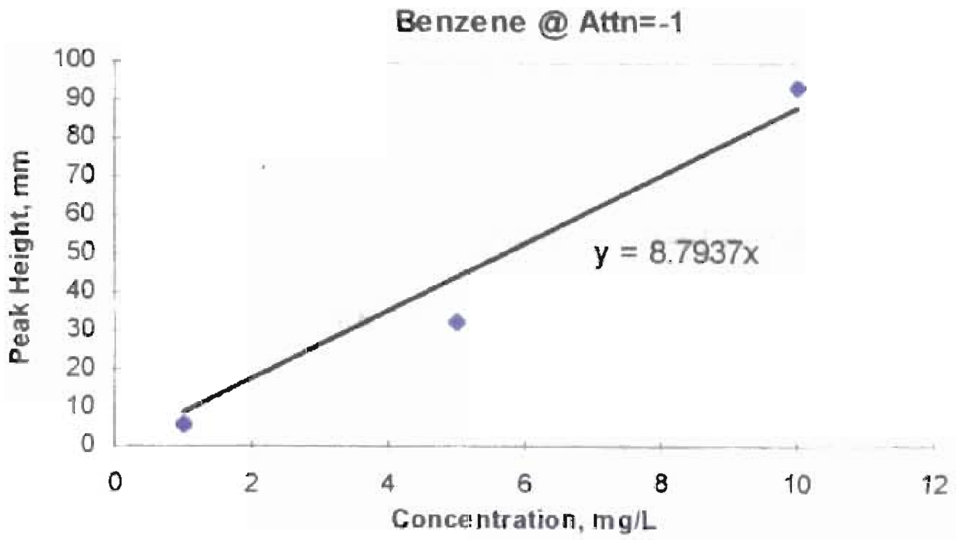
BTEX standards (from Fisher Scientific Company) were prepared for each sampling event and were analyzed to determine a relationship between the standards and the resulting chromatograph peaks. A combination standard prepared from benzene, o-xylene, p-xylene, ethylbenzene, and toluene dissolved in methanol was prepared and diluted in deionized water to make 20, 10, 5, 2.5, 1, 0.1, 0.05, and 0.005 mg/L. Each dilution was analyzed in the GC at various attenuations. As an example, the January GC calibration for the benzene results are presented below in Table 3.2.

Table3.2: January Benzene Standard Results

Conc., mg/L	**Peak Height, mm**		
	Attn: -2	**Attn: -1**	**Attn: 0**
0.005			
0.1			
1	13	5.5	
5	60.5	32.5	9
10		94	45
20			75
EXN	y = 12.135x	y = 8.794x	y = 3.8x

In the above derived equations presented in the EXN row of Table 3.2, y is the resultant GC peak of the unknown sample analysis and x is the resulting concentration. The equations presented were derived by graphing the concentrations versus the peak height. An example, Figure 3.3, of the January benzene graph for attenuation -1 is below.

Figure 3.3: Calibration Curve for Benzene (January)



The derived equation was used to calculate the unknown sample's concentration. For example, the MW-3 benzene peak for January was 105 mm at an attenuation of -1. Therefore, 105 / 8.794 = 11.94 mg/L. The correlation coefficient, R^2 for the curve was 0.9565. The lowest R^2 value observed during the BTEX standards analyses was 0.647 for ethylbenzene at an attenuation of 0. Results of the BTEX analysis are presented in Section 4.1.1. Sample GC chromatographs are presented in Appendix A.

3.3.2 Anion Analysis

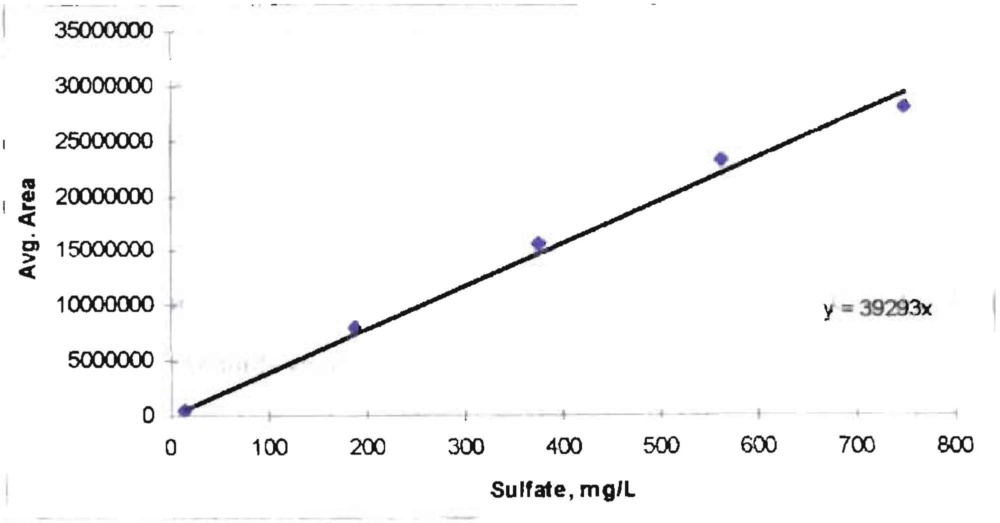
A Dionex 2000i/SP Ion Chromatograph (IC) using the AS4A-SC 4mm column was used to analyze the anion concentrations in the groundwater samples. The IC was connected to a HP 3380A Integrator. The IC works similarly to a GC in that the anion constituents are separated and released to the detector at discrete times. However, the IC measures the concentrations according to their conductivity. The eluent solution was prepared by dissolving 0.5712 g $NaHCO_3$ and 0.7632 g Na_2CO_3 (both obtained from Fisher Scientific Company) and diluting to 4 L with deionized water. The regenerant solution was prepared by diluting 2.8 mL concentrated H_2SO_4 to 4L with deionized water. A series of 1000mg/L standards was prepared by diluting 1.3707 g $NaNO_3$, 1.4330 g KH_2PO_4, and 1.8141g K_2SO_4 to 1L each. The standards were then combined to create a working standard solution that was analyzed in the IC. A linear relationship between the standards and the IC chromatograph peaks was determined. Each standard was analyzed twice and an average area was calculated. As an example, January's sulfate set of standard results follows in Table 3.3:

Table 3.3: January Sulfate Standard Results

mg/L	Run #1 Area	Run #2 Area	Avg Area
750	24566115	31587057	28076586
562.5	22945109	23437622	23191366
375	15585472	15610715	15598094
187.5	7783989	8131561	7957775
15	524253	424278	474265.5

Similar to the benzene standard analysis, a linear relationship was derived for each standard of the anion analysis. Figure 3.4 below is an example of the January sulfate concentration versus area graph.

Figure 3.4: Calibration Curve for Sulfate (January)



The derived equation was used to calculate the unknown sample's concentration. For example, the MW-3 sulfate average area for January was 306,416. Therefore, 306,416 / 39,293 = 7.8 mg/L. The correlation coefficient, R^2, for the January standard curve was 0.9915. The lowest R^2 value for the anion standards analysis, 0.926, was observed for the phosphate analysis during the October 1997 sampling event. The results of the anion analyses can be found in Section 4.1.2. A sample chromatograph is presented in Appendix A.

3.3.3 Organic Carbon Analysis

The organic carbon is determined by the difference between the total carbon and the inorganic carbon tested by a Shimadzu 5000A Total Organic Carbon (TOC) Analyzer with ASI-5000A Auto Sampler. A TOC Analyzer measures the total carbon a sample contains by oxidizing the carbon to CO_2 and H_2O. The CO_2 is transported through the carrier gas stream (ultra pure air flowing at 150 mL/min) and is measured by a nondispersive infrared analyzer resulting in a measurement of total carbon. The inorganic carbon is measured under acidic conditions where inorganic carbon is converted to CO_2. The total organic carbon is calculated as the difference between the total carbon and the inorganic carbon.

The carrier and purging gas used in the TOC Analyzer was ultra pure air. H_3PO_4, phosphoric acid, was used as the acidifying agent for the inorganic carbon analysis. A 1g/L total carbon standard was prepared by dissolving 2.1254g anhydrous potassium biphthalate, $C_8H_5KO_4$, in deionized water and diluting to 1L. An 1g/L inorganic carbon standard was prepared by dissolving 4.4122g anhydrous sodium carbonate, Na_2CO_3, and 3.497g anhydrous sodium bicarbonate, $NaHCO_3$, and diluting to 1L.

The total carbon standards analyzed were at concentrations of 50, 100, and 200 mg/L. The inorganic carbon standards were at concentrations of 10, 25, and 50 mg/L. The TOC Analyzer created and stored a linear relationship (a calibration curve) using the results from the total and inorganic carbon standards.

After determining the calibration curves, the TOC Analyzer tested each unknown sample's total and inorganic carbon content and provided a printout of the results. Total organic carbon was then calculated from the difference of total and inorganic carbon. Total organic carbon results are presented in Section 4.1.3. Sample output from the TOC Analyzer can be found in Appendix A.

3.3.4 Dissolved Oxygen, pH, Temperature, and Groundwater Depth

Dissolved oxygen (DO), pH and temperature were measured during the sampling process using a DO probe and pH meter. The DO analysis was performed using the YSI Model 52 Dissolved Oxygen Meter. The pH was analyzed using the HACH EC10 Portable pH Meter. Depth to groundwater was measured using the depth of the baler below ground surface BGS. Iron (II) was sampled during April.

3.4 Bioremediation Modeling

Bioremediation modeling was accomplished using BIOSCREEN Version 1.3. BIOSCREEN is an EPA provided natural attenuation decision support software package produced by C. J. Newell and R. K. McLeod of Groundwater Services, Inc., and J. R. Gonzales of the Air Force Center for Environmental Excellence (Newell et. al, 1996). BIOSCREEN is a Microsoft® Excel spreadsheet in a user-friendly format readily available for free download from the EPA internet site (www.epa.gov). BIOSCREEN allows for identification of sites where natural attenuation is most likely to protect human health and the environment (Newell et al., 1996). Three different model types are included in the model:

- Solute transport without decay,
- Solute transport with biodegradation modeled as a first-order decay process (simple, lumped-parameter approach),
- Solute transport with biodegradation modeled as an "instantaneous" biodegradation reaction (approach used by BIOPLUME models).

(Newell et al., 1996)

Information contained in the BIOSCREEN User Manual states that BIOSCREEN simulates natural attenuation using aerobic and/or anaerobic conditions and attempts to answer two questions: (1) How far will the dissolved contaminant plume extend if no engineered controls or further source zone reduction measures are implemented? and (2) How long will the plume persist until natural attenuation processes cause it to dissipate? BIOSCREEN is intended to be used as a screening model to determine the feasibility of natural attenuation at a site and as the primary groundwater model at smaller sites. The model's limitations include assuming simple groundwater flow and only approximating complex sites where detailed, accurate results are required (Newell et al., 1996).

BIOSCREEN is based on the Domenico analytical solute transport model and accounts for the effects of advective transport, three-dimensional dispersion, adsorption, and first-order decay. BIOSCREEN assumes a fully penetrating vertical plane source oriented perpendicular to groundwater flow, to simulate the release of organics to moving groundwater (Newell et al., 1996).

Alternate electron acceptor processes modeled in BIOSCREEN include oxygen, nitrate, ferric iron, sulfate, and carbon dioxide. Input data required by BIOSCREEN includes the following: seepage velocity; hydraulic conductivity; hydraulic gradient; effective porosity; longitudinal, transverse, and vertical dispersivity; estimated plume length; retardation factor; soil bulk density; organic carbon partition coefficient; fraction organic carbon; contaminant first-order decay coefficient; dissolved plume solute half-life; delta oxygen; delta nitrate; observed ferrous iron; delta sulfate; observed methane; model area length and width; simulation time; source thickness in saturated zone; source zone width; source zone concentration; and soluble mass in source zone. The model equation, boundary conditions, assumptions, and limitations are presented in Appendix B.

Due to limit monitoring data, the instaneous model was chosen over the first-order decay model of BIOSCREEN. First-order rate constants could not be calculated based on six months of data. In addition, reverse calibration canot be achieved with an unknown amount of initial release.

4.0 RESULTS AND DISCUSSION

4.1 Results of Analyses

The following sections present results of the BTEX, anion, carbon, dissolved oxygen, pH, temperature, and groundwater depth analyses. Since the initial Caldwell Environmental Tier1A report was completed, monitoring well (MW) 9 has been covered with pavement and is not accessible for monitoring. In the tables of this section, the word "dry" indicates groundwater was not present in the MW at the time of sampling in a great enough quantity to perform an analysis. Figure 3.2 presents the locations of the monitoring wells and contaminant source.

4.1.1 BTEX Concentrations

The concentrations of the hydrocarbons varied widely from month to month. The BTEX concentrations determined for each of the sampling events are presented in the following sections. A discussion of the results follows each table. The BTEX detection limits for the GC under the conditions described in Section 3.3.1 were approximately 0.2, 0.005, 0.005, and 0.005 mg/L, respectively.

4.1.1.1 Benzene

The results of the benzene analysis are presented below in Table 4.1. Section 3.3.1 details the gas chromatograph used to obtain these results.

Table 4.1: Benzene Concentration Results

Benzene Concentration in Groundwater, mg/L						
MW	20-Oct-97	15-Dec-97	20-Jan-98	17-Feb-98	24-Mar-98	14-Apr-98
1	*	*	*	*	*	*
2	*	*	*	*	*	*
3	8.95	12.51	11.94	12.63	2.31	10.01
4	7.85	16.03	40.26	25.53	5.77	9.48
5	*	*	*	*	*	*
6	1.11	3.54	3.30	2.97	0.74	1.57
7	1.65	2.60	2.80	2.97	*	0.45
8	*	*	*	*	*	*
10	dry	*	*	0.21	*	dry
11	*	*	*	*	*	*
12	*	*	*	*	*	*
13	*	*	*	*	*	*
14	*	*	*	*	*	*
15	*	*	*	*	*	*
16	*	*	*	*	*	*
Notes: Refer to Figure 3.2: Site Map for locations of MWs.						
An asterisk (*) indicates concentration was below the detection limit.						

Benzene was found to be present in MWs 3, 4, 6, 7, and 10. The maximum benzene concentration observed was 40.26 mg/L found in MW-4 during the January 20, 1999 sampling event. The average concentration for each of the five MWs over the six sampling events is contained in Table 4.2 below.

Table 4.2: Average Benzene Concentrations

MW	Avg. Benzene Concentration, mg/L
3	9.72
4	17.49
6	2.20
7	1.74
10	0.05

As Table 4.2 indicates, MW-4 contains the highest concentration of benzene. MW-10, farthest from the contaminant source with respect to the above five MWs, contained the lowest concentration of benzene.

4.1.1.2 Toluene

Table 4.3 below presents the toluene concentration results.

Table 4.3: Toluene Concentration Results

	Toluene Concentrations in Groundwater, mg/L					
MW	**20-Oct-97**	**15-Dec-97**	**20-Jan-98**	**17-Feb-98**	**24-Mar-98**	**14-Apr-98**
1	0.13	*	*	*	*	*
2	0.09	*	*	0.04	*	*
3	11.43	19.88	18.47	24.12	3.44	14.16
4	4.86	18.29	59.46	30.56	4.39	5.89
5	0.26	0.17	0.09	0.09	*	*
6	0.26	3.70	0.43	0.26	0.52	0.17
7	1.91	3.18	3.36	2.49	*	0.22
8	*	*	0.09	*	*	0.04
10	dry	*	*	0.60	0.04	dry
11	*	0.09	0.34	*	*	*
12	0.17	*	*	*	*	0.09
13	0.09	0.09	*	*	*	*
14	0.09	*	*	*	*	*
15	*	*	*	*	*	*
16	*	*	*	*	0.13	*

Notes: Refer to Figure 3.2: Site Map for locations of MWs.

An asterisk (*) indicates concentration was below the detection limit.

The maximum toluene concentration observed was 59.46 mg/L found in MW-4 during the January 20, 1999 sampling event. The average concentrations in the MWs are presented below in Table 4.4.

Table 4.4: Average Toluene Concentrations

MW	**Avg. Toluene Concentrations, mg/L**	**MW**	**Avg. Toluene Concentrations, mg/L**
1	0.02	**8**	0.02
2	0.02	**10**	0.16
3	15.25	**11**	0.07
4	20.58	**12**	0.04
5	0.10	**13**	0.03
6	0.89	**14**	0.01
7	1.86	**16**	0.02

The high toluene concentrations were found in MWs 3, 4, 6, and 7. The maximum average toluene concentration was found in MW-4. These results were consistent with the results of the benzene analysis.

4.1.1.3 Ethylbenzene

Ethylbenzene concentrations are presented below in Table 4.5.

Table 4.5: Ethylbenzene Concentration Results

Ethylbenzene Concentrations in Groundwater, mg/L						
MW	**20-Oct-97**	**15-Dec-97**	**20-Jan-98**	**17-Feb-98**	**24-Mar-98**	**14-Apr-98**
1	0.07	*	*	*	*	*
2	0.05	*	*	*	*	*
3	0.33	1.32	1.47	0.84	0.28	0.84
4	0.42	3.81	4.53	2.18	0.65	0.60
5	0.09	*	*	*	*	*
6	0.05	0.05	0.09	0.09	0.09	0.05
7	0.19	0.28	0.33	0.28	*	*
8	*	*	*	*	*	*
10	dry	*	*	0.05	*	dry
11	*	0.03	0.09	0.09	*	*
12	*	*	*	*	*	*
13	*	*	*	*	*	*
14	*	*	*	*	*	*
15	*	*	*	*	*	*
16	*	*	*	*	0.13	*
Notes: Refer to Figure 3.2: Site Map for locations of MWs.						
An asterisk (*) indicates concentration was below the detection limit.						

Groundwater samples from MWs 1 – 7, 10, 11, and 16 contained ethylbenzene. The maximum ethylbenzene concentration observed was 4.53 mg/L found in MW-4 during the January 20, 1999 sampling event. The table below provides the average concentrations of the results.

Table 4.6: Average Ethylbenzene Concentrations

MW	Avg. Ethylbenzene Concentrations, mg/L	MW	Avg. Ethylbenzene Concentrations, mg/L
1	0.01	5	0.02
2	0.01	6	0.07
3	0.84	7	0.18
4	2.03	10	0.01

Once again, the high concentrations are present in MWs 3, 4, 6 and 7 and the maximum ethylbenzene concentration was found in MW-4.

4.1.1.4 Xylene

Finally, the xylene (ortho and para) concentrations are reported below in Table 4.7.

Table 4.7: Xylene Concentration Results

Xylene Concentrations in Groundwater, mg/L						
MW	**20-Oct-97**	**15-Dec-97**	**20-Jan-98**	**17-Feb-98**	**24-Mar-98**	**14-Apr-98**
1	0.07	*	*	*	*	*
2	0.10	*	*	*	0.05	*
3	1.30	4.91	4.08	7.38	0.95	3.39
4	0.30	3.48	10.90	6.37	0.87	0.95
5	0.10	*	0.05	*	*	*
6	0.09	0.25	0.32	0.17	0.17	0.06
7	0.35	0.65	0.80	0.55	*	0.05
8	*	*	*	*	*	*
10	dry	*	*	0.10	*	dry
11	*	0.10	0.05	*	*	*
12	*	*	*	*	*	*
13	*	*	*	*	*	*
14	*	0.05	*	*	*	*
15	*	*	*	*	*	*
16	*	*	*	*	0.13	*
Notes: Refer to Figure 3.2: Site Map for locations of MWs.						
An asterisk (*) indicates concentration was below the detection limit.						

Xylene was found in groundwater samples from MWs 1-7, 10, 11, 14, and 16. The maximum concentration of ethylbenzene observed was 10.9 mg/L found in MW-4 during the January 20, 1999 sampling event. The average concentrations from the MWs showing the presence of xylene are presented below in Table 4.8.

Table 4.8: Average Xylene Concentrations

MW	Avg. Xylene Concentrations, mg/L	MW	Avg. Xylene Concentrations, mg/L
1	0.01	6	0.18
2	0.02	7	0.40
3	3.67	10	0.02
4	3.81	11	0.02
5	0.02	14	0.01

The high xylene concentrations were found in groundwater samples from MWs 3, 4, 6 and 7. The maximum xylene concentration was present in MW-4.

Although the concentrations fluctuate from month to month, the tables presented above show that for each BTEX constituent, the high average concentrations consistently existed in MWs 3, 4, 6 and 7. These MWs are in close proximity to the source of contamination (see Figure 3.2 for MW locations). Groundwater in MW-4 consistently exhibited the maximum average concentration for each of the four hydrocarbons.

4.1.2 Anion Concentrations

The anions (sulfate, nitrate, iron and phosphate) act as electron acceptors as described previously in the Literature Review (Section 2.1.1.2) of this document. The results of the anion analyses for sulfate, nitrate, iron and phosphate are presented on the following pages. In the following tables, the word "dry" indicates groundwater was not present in the MW at the time of sampling in a great enough quantity to perform an analysis.

4.1.2.1 Sulfate

Once the available oxygen, nitrate, and iron (III) in the groundwater system have been depleted, sulfate-reducing bacteria can begin degrading fuel hydrocarbons (Wiedemeier et al., 1995). Relative to background concentrations, a reduction in sulfate concentrations within an existing BTEX plume is a strong indication that indigenous bacteria are established and actively biodegrading fuel contamination (Wiedemeier et al., 1995). During monitoring, a strong sulfur smell was observed when purging and sampling MWs with high BTEX concentrations. The sulfate results are presented below in Table 4.9.

Table 4.9: Sulfate Concentration Results

Sulfate Concentrations in Groundwater, mg/L

MW	20-Oct-97	15-Dec-97	20-Jan-98	17-Feb-98	24-Mar-98	14-Apr-98	AVG.
1	33.65	26.72	26.23	25.16	41.86	26.02	29.94
2	639.33	537.51	565.99	562.24	578.00	607.81	581.81
3	8.56	7.34	24.56	4.14	10.29	13.14	11.34
4	7.71	2.88	1.11	1.36	3.15	2.85	3.18
5	776.06	637.61	787.47	756.88	722.79	887.79	761.43
6	764.64	543.29	743.51	704.41	734.43	855.74	724.34
7	212.40	229.50	248.62	208.01	352.02	440.08	281.77
8	163.58	131.30	123.06	70.86	105.75	165.78	126.72
10	dry	35.75	38.07	163.64	30.18	dry	33.40
11	86.37	62.57	51.65	41.33	39.30	42.56	53.97
12	244.45	171.91	187.03	199.41	173.33	185.03	193.53
13	483.87	402.87	455.12	448.34	449.04	501.51	456.79
14	313.42	185.45	179.88	158.51	232.09	264.76	222.35
15	62.65	47.16	54.74	51.31	55.84	64.15	55.97
16	569.48	455.25	273.60	181.03	339.93	242.23	343.59
Notes: Refer to Figure 3.2: Site Map for locations of MWs.							

The sulfate concentrations found in the groundwater at the ODOT Site were high compared to normal values. Normal sulfate background values ranged from 0 to 96.6 mg/L at seven sites summarized in the BIOSCREEN User Manual (Newell et al., 1996). In a 1968 study, only ten of 55 groundwater samples taken from the Garber-Wellington formation in Cleveland and Oklahoma County contained more than 250 mg/L of SO_4; however, the maximum SO_4 concentration was found to be 1,450 mg/L (Wood and Burton, 1968). The maximum sulfate concentration observed at the ODOT Site was 887.79 mg/L found in MW-5 during the April 14, 1999 sampling event. On average, MWs 2, 5, 6, and 13 exhibited the highest sulfate concentrations. Each of these MWs is upgradient from the source of contamination. MW-5 exhibited a maximum average sulfate concentration of 761.43 mg/L. The low average sulfate concentrations were observed in MWs 1, 3 and 4. The lowest values were observed in MWs 3 and 4. During sampling events, a strong sulfur odor was detected in these wells exhibiting low sulfate concentrations. This odor may be evidence of sulfate reduction.

4.1.2.2 *Nitrate*

After almost all free dissolved oxygen has been removed from the aquifer and anaerobic conditions prevail in the groundwater, nitrate can be used as an electron acceptor by microorganisms to mineralize the BTEX compounds via denitrification (Wiedemeier et al., 1995). The results of the nitrate analysis are presented below in Table 4.10.

Table 4.10: Nitrate Concentration Results

Nitrate Concentrations in Groundwater, mg/L							
MW	**20-Oct-97**	**15-Dec-97**	**20-Jan-98**	**17-Feb-98**	**24-Mar-98**	**14-Apr-98**	**AVG.**
1	0.04	0.08	0.40	1.19	0.88	0.52	0.52
2	18.53	14.21	25.39	13.57	15.26	17.24	17.37
3	0.04	0.17	0.79	0.04	0.19	0.30	0.26
4	0.07	0.13	0.05	0.12	0.16	0.77	0.22
5	24.75	18.39	22.54	21.94	22.73	28.03	23.06
6	5.66	1.46	3.05	0.93	1.76	20.58	5.57
7	5.29	6.89	5.55	4.30	7.00	7.60	6.11
8	19.71	13.44	13.71	6.98	13.99	19.09	14.49
10	dry	0.95	1.06	0.79	1.40	dry	1.05
11	0.35	0.42	0.11	0.19	0.45	0.89	0.40
12	7.32	5.18	5.72	6.05	5.66	5.94	5.98
13	31.72	25.44	34.64	34.37	36.46	44.36	34.50
14	16.74	11.78	13.84	10.74	15.29	17.19	14.26
15	4.52	3.02	3.69	3.40	3.63	4.27	3.75
16	32.48	26.61	19.42	14.77	22.73	19.19	22.53
Notes: Refer to Figure 3.2: Site Map for locations of MWs.							

MW-13 exhibited the maximum nitrate concentration observed, averaging 44.36 mg/L over the six sampling events. The average high concentrations were observed in MWs 2, 5, 8. 13, 14, and 16. Of these, MWs 2, 5, 13, and 14 are upgradient from the contaminant source. The low average concentrations were observed in MWs 3 and 4.

4.1.2.3 *Phosphate*

Phosphorus is a necessary nutrient for bacteria cell growth and reproduction. It is used by the microorganisms in the synthesis of phospholipids and nucleic acids and is essential for the electron-accepting process to occur (Scalzi, 1999). When phosphorus is limited, the metabolism of microorganisms decreases, reducing their capacity to use the hydrocarbons as organic sources. Table 4.11 below presents the phosphate concentrations observed in groundwater at the ODOT Site.

Table 4.11: Phosphate Concentration Results

Phosphate Concentrations in Groundwater, mg/L							
MW	**20-Oct-97**	**15-Dec-97**	**20-Jan-98**	**17-Feb-98**	**24-Mar-98**	**14-Apr-98**	**AVG.**
1	0.00	0.33	0.41	0.27	0.06	0.00	0.18
2	0.16	2.96	2.82	0.45	0.45	0.54	1.23
3	0.00	0.16	0.13	0.00	0.00	0.00	0.05
4	0.00	0.27	0.39	0.00	0.00	0.00	0.11
5	0.00	5.24	5.65	0.47	0.40	0.76	2.09
6	0.00	1.98	4.97	0.30	0.46	0.51	1.37
7	0.00	1.08	1.10	0.00	0.00	0.00	0.36
8	0.00	0.56	0.50	0.00	0.23	0.00	0.22
10	dry	0.19	0.00	0.00	0.15	dry	0.06
11	0.00	0.30	0.28	0.00	0.23	0.00	0.14
12	0.01	0.80	0.59	0.00	0.20	0.18	0.30
13	0.08	2.61	2.71	0.28	0.45	1.38	1.25
14	0.00	3.21	0.78	0.00	0.25	0.40	0.77
15	3.39	0.52	0.45	0.18	0.23	0.23	0.83
16	0.00	2.04	1.31	0.11	0.18	0.25	0.65
Notes: Refer to Figure 3.2: Site Map for locations of MWs.							

As Table 4.11 indicates, the phosphate concentrations in groundwater were consistently low. The high average phosphate concentrations were observed in MWs 2, 5, 6, and 13, with MW-5 exhibiting a maximum average phosphate concentration of 2.09 mg/L. MWs 3, 10, and 11 exhibited the lowest average concentrations.

4.1.2.4 Iron

Once the available dissolved oxygen and nitrate in the aquifer have been depleted, iron (II) can be used as an electron acceptor. Iron (II) concentrations at the ODOT Site were analyzed; however, iron (II) was analyzed only during one sampling event. Table 4.12 below presents the iron results for the April 14, 1998 sampling event.

Table 4.12: Iron (II) Concentration Results

Iron (II) Conc. in Groundwater, mg/L			
MW	**14-Apr-98**	**MW**	**14-Apr-98**
1	1.56	**9**	covered
2	0.18	**10**	0.15
3	2.74	**11**	0.19
4	>	**12**	0.07
5	0.00	**13**	0.28
6	0.09	**14**	0.85
7	>	**15**	*
8	0.00	**16**	*
Notes: (1) * indicates groundwater too turbid to analyze; (2) > indicates result was out of range (>3 mg/L); and (3) refer to Figure 3.2: Site Map for locations of MWs.			

4.1.3 Total Organic Carbon Concentrations

The results of the TOC analysis are presented below in Table 4.13.

Table 4.13: TOC Concentration Results

TOC Concentrations in Groundwater, mg/L							
MW	**20-Oct-97**	**15-Dec-97**	**20-Jan-98**	**17-Feb-98**	**24-Mar-98**	**14-Apr-98**	**AVG.**
1	29.54	56.72	2.45	24.14	15.08	20.16	24.68
2	30.46	43.16	NA	29.42	14.0	9.37	20.38
3	72.90	93.17	47.65	81.72	55.17	51.19	66.97
4	140.96	151.7	68.85	72.05	46.84	39.97	86.73
5	32.68	40.02	18.88	38.97	19.98	13.45	27.33
6	40.47	62.5	13.95	45.09	20.83	11.5	32.39
7	42.52	37.66	21.78	39.49	15.2	11.79	28.07
8	34.27	37.92	16.45	24.82	18.34	10.97	23.80
10	dry	47.31	17.57	27.61	18.68	dry	23.4
11	40.72	82.14	25.30	39.17	23.91	10.16	36.90
12	34.24	56.09	17.27	29.77	16.79	6.06	26.70
13	34.53	55.02	17.82	26.54	16.05	6.58	26.09
14	30.20	52.59	17.30	29.51	14.55	6.79	25.16
15	27.71	29.35	13.21	24.86	11.7	10.44	19.55
16	32.14	64.02	16.29	27.01	10.52	8.13	26.35
Notes: Refer to Figure 3.2: Site Map for locations of MWs.							

On average, the maximum TOC concentration was observed in MW-4. As expected, the maximum average TOC concentration corresponded to the maximum average BTEX concentrations. The minimum average concentration of 19.55 mg/L was observed in MW-15.

4.1.4 Dissolved Oxygen, pH, Temperature, and Groundwater Depth

Dissolved oxygen (DO), pH, temperature, and groundwater depth were measured in the field during each sampling event. The results of the analyses are presented in table format on the following pages.

DO is an electron acceptor and should behave as the anions (phosphate, nitrate, and sulfate) by showing a minimum value where the BTEX concentrations were highest. Table 4.14 below presents the results of the DO analyses.

Table 4.14: DO Concentration Results

DO Concentrations in Groundwater, mg/L							
MW	**20-Oct-97**	**15-Dec-97**	**20-Jan-98**	**17-Feb-98**	**24-Mar-98**	**14-Apr-98**	**AVG.**
1	0.21	0.21	0.63	0.77	0.84	1.7	0.73
2	1.45	2.58	1.98	1.82	2.21	3.2	2.21
3	2.9	4.4	3.1	0.99	3.64	5.1	3.36
4	0.19	0.22	0.08	0.2	0.81	0.8	0.38
5	5.01	5.48	4.67	4.07	4.46	4.2	4.65
6	0.18	0.23	0.25	0.52	0.32	0.8	0.38
7	0.23	0.18	2.33	0.62	0.56	0.9	0.80
8	1.06	0.22	0.33	0.71	0.6	1.6	0.75
10	dry	dry	dry	dry	dry	dry	-
11	5.11	0.85	0.57	1.13	1.48	2.6	1.96
12	3.2	2.9	3.11	3.02	3.3	6.2	3.62
13	4	6.03	5.15	4.58	4.79	8	5.43
14	5.5	5.36	5.39	5.3	4.48	6.5	5.42
15	5.21	4.55	4.8	4.9	4.65	7.7	5.30
16	5.37	6.23	5.37	5.23	5.84	8.1	6.02
Notes: Refer to Figure 3.2: Site Map for locations of MWs.							

As expected, the average minimum DO concentration was observed in MW-4 where the BTEX constituents were at maximum concentrations. The DO concentration in MW-4 was 0.38 mg/L. The maximum average DO concentration, 6.02 mg/L, was observed in MW-16.

The results of the pH field tests can be found in Table 4.15 below.

Table 4.15: pH Results

pH in Groundwater						
MW	**20-Oct-97**	**15-Dec-97**	**20-Jan-98**	**17-Feb-98**	**24-Mar-98**	**14-Apr-98**
1	NA	6.60	6.92	NA	6.57	6.42
2	6.66	6.92	6.70	7.18	6.62	6.62
3	7.00	6.73	7.16	7.36	7.00	6.99
4	6.85	6.70	6.93	7.33	6.80	6.79
5	6.90	7.01	6.94	7.12	6.79	6.80
6	6.75	6.65	6.79	NA	6.76	6.69
7	6.76	6.81	6.92	NA	6.74	6.67
8	6.67	6.78	6.60	NA	6.55	6.54
10	dry	7.15	7.43	7.35	7.29	dry
11	7.04	6.90	6.85	7.27	6.85	6.96
12	6.93	6.89	7.02	7.37	6.69	6.79
13	6.99	6.65	6.80	7.48	6.70	6.89
14	6.97	6.96	6.77	7.34	6.87	6.91
15	6.77	6.78	6.96	7.32	6.63	6.68
16	6.81	7.08	7.07	7.53	6.87	6.90
Notes: Refer to Figure 3.2: Site Map for locations of MWs.						

As stated in Section 2.1.1.4, although the optimum pH varies based upon the organism present, most bacteria have maximum growth rates in a pH range of 6.5 and 7.5 (Grasso, 1993). According to Table 4.15 above, the pH in the groundwater at the ODOT Site allows for optimum growth of bacteria. In a 1968 study of Oklahoma and Cleveland County groundwater resources, groundwater in the Garber-Wellington ranged from 6.1 – 8.9 (Wood and Burton, 1968).

The temperature data of the groundwater at the ODOT Site during each sampling event are presented below in Table 4.16.

Table 4.16: Temperature Results

Temperature of Groundwater, degrees Celsius							
MW	**20-Oct-97**	**15-Dec-97**	**20-Jan-98**	**17-Feb-98**	**24-Mar-98**	**14-Apr-98**	**AVG.**
1	NA	19.7	19.2	17.8	17.9	18.10	18.5
2	19.9	20.0	19.7	17.6	17.8	17.60	18.8
3	21.5	19.8	19.4	17.7	18.7	18.20	19.2
4	19.7	19.4	19.1	18.3	18.3	17.90	18.8
5	19.7	19.7	18.9	18.0	17.7	18.20	18.7
6	19.7	19.9	19.5	17.8	18.5	18.40	19.0
7	19.3	19.6	18.6	18.3	19.1	19.10	19.0
8	19.9	20.3	20.3	18.4	19.6	19.90	19.7
10	dry	19.2	18.6	17.2	19.0	dry	18.5
11	19.8	19.3	19.2	18.0	18.4	18.60	18.9
12	20.1	19.2	18.8	17.4	17.7	17.40	18.4
13	19.7	19.7	19.1	17.7	17.6	17.40	18.5
14	15.7	NA	19.1	17.9	18.0	17.60	17.7
15	19.8	19.5	18.9	17.5	17.6	18.40	18.6
16	20.6	20.4	19.8	18.9	18.8	18.60	19.5
Notes: Refer to Figure 3.2: Site Map for locations of MWs. NA indicates data was not available for MW.							

As stated previously in Section 2.1.1.2, in general, most microorganisms will grow best in a temperature range of 25 to 30°C (Grasso, 1993). The temperatures of the groundwater at the ODOT Site maintain an average level below 20°C.

Below, in Table 4.17, the depth to groundwater in each MW is presented.

Table 4.17: Depth to Groundwater Results

Depth of Groundwater, feet							
MW	**20-Oct-97**	**15-Dec-97**	**20-Jan-98**	**17-Feb-98**	**24-Mar-98**	**14-Apr-98**	**AVG.**
1	20.5	20.0	20.0	22.0	22.0	22.50	21.2
2	23.0	22.0	23.0	25.0	23.0	23.08	23.2
3	20.0	24.0	22.0	22.0	NA	22.33	18.4
4	22.5	23.0	24.0	24.0	22.0	23.25	23.1
5	23.0	22.0	22.0	23.0	22.0	23.75	22.6
6	22.0	21.0	22.0	24.0	21.0	22.58	22.1
7	22.5	22.0	25.0	23.0	25.0	23.25	23.5
8	25.0	24.0	25.0	24.0	24.0	24.33	24.4
10	dry	23.0	25.0	23.0	24.0	24.33	23.9
11	24.0	24.0	24.0	24.0	24.0	25.00	24.2
12	21.0	23.0	24.0	25.0	22.0	23.83	23.1
13	24.0	21.0	23.0	22.0	22.0	22.67	22.4
14	25.0	22.0	20.0	24.0	24.0	24.17	23.2
15	22.0	23.0	25.0	23.0	23.0	24.00	23.3
16	21.0	23.0	23.5	23.0	24.0	23.75	23.0
Notes: Refer to Figure 3.2: Site Map for locations of MWs.							

4.2 Interpretation of Isopleth Maps

A convenient way of determining whether the electron-accepting process is active in a given area is to prepare isopleth maps for the contaminant and each of the electron acceptors (Wiedemeier et al., 1995). If it can be shown that there is a relationship between the distribution of electron acceptors and total BTEX at a site, then it can be assumed that the electron-accepting process is active (Wiedemeier et al., 1995).

Isopleths for benzene, toluene, ethylbenzene, xylene, sulfate, nitrate, phosphate, TOC and DO are presented in Appendix C. The isopleths were plotted using Surfer, Version 6.02 and analyzed by the kriging method. Kriging is a geostatistical gridding method that attempts to express data trends so that high points are connected along a ridge, rather than isolated by bull's-eye type contours. Non-detectable limits were assumed to be a concentration of zero mg/L for averaging purposes.

The BTEX isopleths show the extent of the plume and the plume boundaries. The high concentration areas of the plume were to the southwest of the contamination source (near MW-4). The TOC isopleths were similar to the BTEX isopleths: the center of the plume was near MW-4, and the concentrations decrease outwardly from MW-4 in a radial nature.

The electron acceptor isopleths (nitrate, sulfate, and DO) reveal an inverse relationship to the BTEX isopleths: low concentrations of electron acceptors occur where there are high concentrations of BTEX. Based on the study performed by Wiedemeier et al. (1995), evidence of biodegradation is present based on the relationship between the BTEX and electron acceptor isopleth maps.

4.3 Rainfall Data

Rainfall data were obtained from The Oklahoma Climatological Survey. Significant rainfall can result in increased BTEX concentrations due to desorption as discussed in Section

2.1.3. Rainfall for the months of March and April 1998 were 6.78 and 3.45 inches. No conclusions or trends were observed based on the rainfall data.

4.4 Bioremediation Modeling Results

The instantaneous model of BIOSCREEN was chosen to model the ODOT Site as suggested by the BIOSCREEN User Manual for sites under anaerobic conditions. Because electron acceptor limitations are not considered in a first-order decay equation, a more accurate prediction of biodegradation effects may be realized by incorporating the instantaneous reaction equation into a transport model (Newell et al., 1996).

4.4.1 BIOSCREEN Inputs

BIOSCREEN-required parameters were obtained from both the Risk Assessment Report prepared by Caldwell Environmental Associates, Inc. (Caldwell, 1996) and the sampling results of this study as detailed in Section 4.0. Site specific data such as hydrogeology and dispersion were obtained from Caldwell as presented in Section 3.1. Below are the details of these input parameters which remained constant through out each of the seven runs.

- Seepage velocity: 25.0 ft/yr
- Longitudinal dispersivity: 23.0 ft
- Transverse dispersivity: 1.5 ft
- Vertical dispersivity: 0.2 ft
- Retardation factor: 1.2
- Modeled area length: 300 ft
- Modeled area width: 300 ft

To use the instantaneous reaction model of BIOSCREEN, changes in electron acceptor concentrations are required. Several background concentrations for each electron acceptor were averaged to obtain an initial value, and down-gradient concentrations were averaged to obtain final values. The wells were chosen to obtain the best representative sample for each required parameter. For DO, NO_3, and SO_4, the background MWs are 14; 8, 13, and 14; and 8 and 14, respectively. The downgradient MWs chosen for DO, NO_3, and SO_4 are 4, 6, and 7; 1, 3, and 4; and 1, 3, and 4, respectively. An explanation of the chosen background and downgradient wells follows.

MWs 8, 13, and 14 are the most upgradient wells at the ODOT Site (see Figure 3.2) based on source location and groundwater flow direction. However, since DO is the first electron acceptor to be utilized by the hydrocarbons, the DO value in MWs 8 and 13 had been reduced (see Table 4.14 for DO values). Therefore, the DO background well used was MW-14. For nitrate, MWs 3, 13, and 14 were chosen as the background wells. Sulfate concentrations at the ODOT Site were high. The average sulfate values for MW 8, 13, and 14 were approximately 126, 456, and 222 mg/L, respectively. From a study completed by Striegel (1998), using the ODOT Site's sulfate data, BIOSCREEN predicted attenuation of the plume in less than two years. Based on this, and in an attempt to obtain an reasonably calibrated model for the ODOT Site, only MWs 8 and 14, exhibiting the lower of the three sulfate concentrations in the upgradient wells, were chosen as the background wells.

MWs 1, 3, and 4 were the wells most affected by the hydrocarbon plume based on the source location and the monitoring results presented in Section 4.0. Thus, these wells were chosen as the downgradient wells for SO_4 and NO_3. However, the data for the DO concentration indicated the lower DO values were exhibited in MWs 4, 6 and 7. Thus, these wells were used as the downgradient wells for DO. The following table provides the resulting background concentrations of electron acceptors on an averaged basis over the six sampling events. These are the amounts of electron acceptors available for anaerobic alternate electron accepting processes.

Table 4.18: Delta Electron Acceptor Values

e^- acceptor	Δ Value, mg/L
DO	5.42
NO_3	21.1
SO_4	174

Ferrous iron, Fe^{2+}, was also a required input of BIOSCREEN. The ΔFe^{2-} value used for the ODOT Site was 0.4 mg/L based on sampling results in April 1998 and successful

BIOSCREEN model calibration of the ODOT Site in a 1998 study (Striegel, 1998). Methane was not sampled; this value is set equal to 0 in the BIOSCREEN model runs.

4.4.2 Calibration

Before analyzing BIOSCREEN for its applicability to the ODOT Site, appropriate and site-specific parameters were used to achieve a calibrated model providing consistent and realistic predictions that were similar to actual conditions. Using the sampling results, depth of contamination, and porosity, a contaminant mass was determined based on the results of each sampling event. A mass was calculated from the monitored contaminant concentrations, porosity, and depth of contamination. This calculated mass was projected seven years back (when release was reported to have occurred (Caldwell, 1996)) to the point of assumed release by assuming 33% of the contaminant mass had degradeded in seven years (Cookson, 1995) which is a conservative assumption. For each sampling event, the projected BTEX mass is presented below.

Table 4.19: Projected Mass

1991 Projected Mass, kg	
Event Date	**BTEX, kg**
20-Oct-97	11
15-Dec-97	19
20-Jan-98	46
17-Feb-98	30
24-Mar-98	8
14-Apr-98	12

Table 4.19 reveals wide fluctuations in model results from month to month showing that January BTEX was projected at 46 kg, but two months later in March, BTEX was projected at only 8 kg.

A BIOSCREEN simulation time of seven years was used. Initially, the high ΔSO_4 input value resulted in the a simulated remediation in less than seven years. As the plume had not remediated in seven years, the initial ΔSO_4 value was reduced to 10 mg/L based on the average range of ΔSO_4 in groundwater according the BIOSCREEN User Manual (Newell et al. 1996) and successful BIOSCREEN model calibration of the ODOT Site in a 1998 study (Striegel, 1998). Each sampling event's individual monitoring results (monthly contaminant mass and Δ nutrients) were used to calibrate six different model variations. The varying parameters used in the Calibration Run are detailed on the following page in Table 4.21.

Calibration was considered satisfactory when the field data curve and the instantaneous reaction model curve were equal. The output results for the Calibration Run are presented in Appendix D.

4.4.3 Model Run #1

Following calibration, the simulation time was increased until the instantaneous reaction curve revealed that natural attenuation had remediated the plume to satisfactory contaminant levels. Based on the risk-based screening levels determined in the Risk Assessment Report prepared by Caldwell Environmental Associates, Inc. for the ODOT Site, the Category II Soil and Groundwater Cleanup Levels were determined to be the applicable remediation goal for the site. For BTEX in groundwater, the Category II Cleanup Levels are 0.05. 10, 7, and 100 mg/L. respectively. Since BIOSCREEN does not model separate constituents and this study summed the individual BTEX contaminants to reach a total soluble mass amount, the lowest of the Cleanup Levels was set as the cleanup goal for the modeling. Therefore, the plume was required to be remediated to less than 0.05 mg/L before attenuation was satisfactory.

Table 4.21 on the following page presents the soluble mass amounts, electron acceptor values, and source zone concentration used for Run #1. The results of the run are summarized below in Table 4.20 and presented in Appendix E.

Table 4.20: Run #1 Results

Run #1	
Event Date	**Approx. Remediation Time, yrs**
20-Oct-97	16
15-Dec-97	48
20-Jan-98	104
17-Feb-98	85
24-Mar-98	16
14-Apr-98	19

Table 4.21: Calibration Run Varying Parameters

	Oct-97			Dec-97			Jan-98			Feb-98			Mar-98			Apr-98		
Soluble Mass	11			19			46			30			8			12		
Δ E⁻ Acceptors																		
Oxygen	5.3			5.15			4.5			4.85			4			5.67		
Nitrate	22.7			16.8			20.29			16.95			21.5			26.27		
Iron	0.4			0.4			0.4			0.4			0.4			0.4		
Sulfate	10			10			10			10			10			10		
Methane	0			0			0			0			0			0		
Source Zone																		
Width, ft	5	8	12	5	5	10	1	5	10	0.1	5	10	1	10	10	1	10	10
Conc, mg/L	5	20	23	0.01	6	20	0.01	20	35	0.01	8	30	1	8	15	1	15	22

The results for Run #1 range from 16 years to 104 years for October 1997 and January 1998, respectively. The table shows that the minimum month varies from the maximum by almost an order of magnitude. The results above vary widely due to the wide fluctuations in BTEX sampling results. In addition, the electron acceptor concentrations varied slightly for each event.

In order to obtain more consistent runs, the next run was altered from Run #1 by using the same contaminant mass and Δ electron acceptor concentrations for each month's model and varying only the source zone concentrations. That attempt, Run #2, is detailed in the following section.

4.4.4 Model Run #2

In Model Run #2, electron acceptor concentrations were kept constant for each month's run rather than varying the concentration of electron acceptors from month to month. The averaged electron acceptor values are listed above in Table 4.18. In addition, the initial contaminant mass was held constant at 16 kg, based on Caldwell's Risk Assessment (Caldwell 1996), J. Striegel's thesis (Striegel, 1998), and monitoring data from this study. Each month's run was calibrated as discussed in Section 4.4.2. The input parameters used in Run #2 are presented in Table 4.23 on the following page.

The results of this run are presented below.

Table 4.22: Run #2 Results

Run #2	
Event Date	**Approx. Remediation Time, yrs**
20-Oct-97	18
15-Dec-97	34
20-Jan-98	30
17-Feb-98	44
24-Mar-98	21
14-Apr-98	26

Table 4.23: Run #2 Variable Parameters

	Oct-97			Dec-97			Jan-98			Feb-98			Mar-98			Apr-98		
Soluble Mass	16																	
Δ E$^-$ Acceptors																		
Oxygen	5.42																	
Nitrate	21.1																	
Iron	0.4																	
Sulfate	10																	
Methane	0																	
Source Zone																		
Width, ft	5	7	10	5	5	10	0.2	4	12	0.1	3	10	5	7	10	5	6	10
Conc, mg/L	20	18	20	3	8	22	0.01	20	55	0.01	8	37	7	6	11	8	14	18

Compared to Run #1's results, these results are much more comparable from month to month. The remediation times range from 18 to 44 years, with the minimum and maximum occurring during October 1997 and February 1998, respectively. The BIOSCREEN output for this run is presented in Appendix F.

4.4.5 Model Run #3

As mentioned in Section 4.4.2, using the initially calculated ΔSO_4 value of 174 mg/L resulted in remediation times of the contaminant plume less than the seven year calibration period in most instances. Run #3 provides results obtained from BIOSCREEN when the ΔSO_4 value of 174 mg/L is used to model the ODOT Site. The input parameters used for Run #3 are presented in Table 4.25.

Note that the source zone concentrations remain unchanged from Run #2 in order to consider the effects of increasing the ΔSO_4 concentration. In Run #3, BIOSCREEN resulted in a simulated remediation time sooner than the seven year calibration time in most instances as presented below in Table 4.24 and in Appendix G.

Table 4.24: Run #3 Results

Run #3	
Event Date	**Approx. Remediation Time, yrs**
20-Oct-97	3
15-Dec-97	4
20-Jan-98	8
17-Feb-98	8
24-Mar-98	2
14-Apr-98	3

Table 4.24 shows the October, December, March and April plumes being remediated in less than eight years. However, monitoring results reveal that the BTEX still exists seven years later; hence, BIOSCREEN does not accurately predict the actual conditions at the ODOT Site. BIOSCREEN does not have any electron acceptor limits, nor is there any known BIOSCREEN

Table 4.25: Run #3 Variable Parameters																		
	Oct-97			Dec-97			Jan-98			Feb-98			Mar-98			Apr-98		
Soluble Mass	16																	
Δ E$^-$ Acceptors																		
Oxygen	5.42																	
Nitrate	21.1																	
Iron	0.4																	
Sulfate	174																	
Methane	0																	
Source Zone																		
Width, ft	5	7	10	5	5	10	0.2	4	12	0.1	3	10	5	7	10	5	6	10
Conc, mg/L	20	18	20	3	8	22	0.01	20	55	0.01	8	37	7	6	11	8	14	18

studies at sites with very high ΔSO_4 values similar to those at the ODOT Site (Newell, 1999). In addition, although the BIOSCREEN source mass input box says "soluble mass", Charles J Newell reported that the required mass is actually the total non-aqueous phase liquid mass present in both the soil and groundwater (Newell, 1999). However, an individual using BIOSCREEN to model a site inputs the soluble mass into the source mass input box, not the total non-aqueous phase liquid. For this study, the source mass value was assumed to be 16 kg.

4.4.6 Model Run #4

The model FORTRAN AT123D was used by Caldwell Environmental Associates, Inc. (Caldwell) to model the ODOT Site in 1996 for completion of the Risk Assessment Report. The input values used in FORTRAN AT123D by Caldwell were input into BIOSCREEN for comparison between the two models. The parameters used by Caldwell for AT123D in the 1996 Risk Assessment for the ODOT Site are presented below.

- Seepage velocity: 31.0 ft/yr
- Longitudinal dispersivity: 10.0 ft
- Transverse dispersivity: 7 ft
- Vertical dispersivity: 0.1 ft
- Retardation factor: 2.7
- First-order decay coeff.: 7.3E-2 d^{1}
- Modeled area length: 250 ft
- Modeled area width: 250 ft

Caldwell used AT123D to model 620 feet downgradient of the plume which is the distance to the closest possible shallow groundwater user. Therefore, the comparison between BIOSCREEN and AT123D was made at 620 feet downgradient and was performed in ten-year increments in order to compare the two models. The AT123D model uses first-order reactions rather than instantaneous reactions; therefore the BIOSCREEN results below are first order results rather than instantaneous results. In addition, AT123D modeled only the amount of benzene contamination in groundwater. Electron acceptors were not used for this run. This BIOSCREEN Run #4 analyzed the same amount of contaminant mass, four kg, that AT123D used as input. The results are presented below and can be found in Appendix H.

Table 4.26: Run #4 Comparison Values

Run #4		
Time, years	**AT123D BTEX, mg/L**	**BIOSCREEN BTEX, mg/L**
10	0.000	0.000
15	0.000	0.000
20	0.000	0.000
30	0.003	0.0005
40	0.003	0.001
50	0.0014	0.002
60	0.001	0.009
70	0.0001	0.002

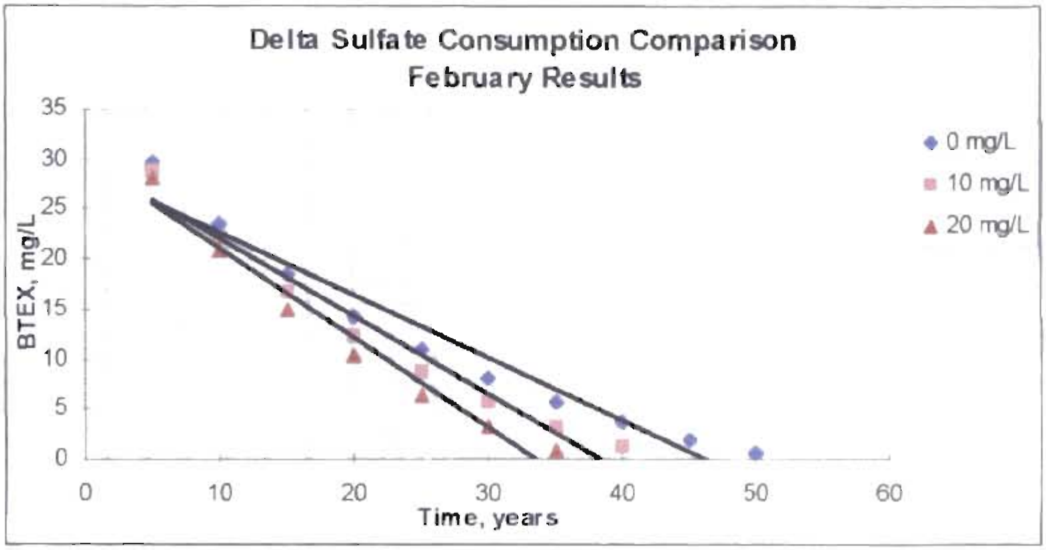
The comparison in the above table shows that AT123D and BIOSCREEN results are within an order of magnitude in most cases when considering first-order reactions. The BIOSCREEN simulated increase then decrease in BTEX concentrations is due to the outer boundary of the plume reaching the evaluation point (620 feet), and then the center of the plume reaching the evaluation point later.

4.4.7 Model Run #5

Model Run #5 examined the effects of varying ΔSO_4 on the simulated remediation time of the contaminant plume calibrated in Model Run #2. The following figure shows the effects of increasing the amount of ΔSO_4 available to the contaminant. The Run was performed using the same parameters and input as in Model Run #2 but with varying ΔSO_4 values. See Table 4.27 for the input parameters used in this Run.

Table 4.27: Run #5 Variable Parameters																		
	Oct-97			Dec-97			Jan-98			Feb-98			Mar-98			Apr-98		
Soluble Mass	16																	
Δ E$^-$ Acceptors																		
Oxygen	5.42																	
Nitrate	21.1																	
Iron	0.4																	
Sulfate	varies																	
Methane	0																	
Source Zone																		
Width, ft	5	7	10	5	5	10	0.2	4	12	0.1	3	10	5	7	10	5	6	10
Conc, mg/L	20	18	20	3	8	22	0.01	20	55	0.01	8	37	7	6	11	8	14	18

Figure 4.1: Effects of ΔSO_4 Variation



As Figure 4.1 shows, as ΔSO_4 increases, the time required for plume remediation decreases. With 0 mg/L ΔSO_4 , the plume takes approximately 46 years to remediate. However, increasing ΔSO_4 to 10 mg/L and 20 mg/L, the plume is remediated in approximately *38 years and* 33 years, respectively. The BIOSCREEN output for this run is presented in Appendix I.

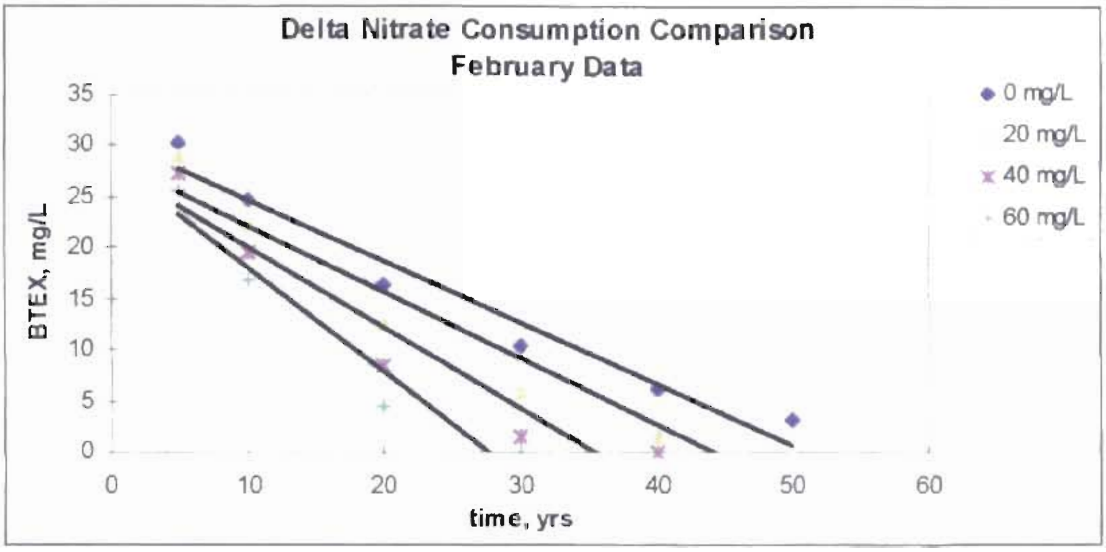
4.4.8 Model Run #6

Similar to Run #5, Model Run #6 analyzes the effects on the estimated time to remediation of varying the available ΔNO_3. See Table 4.28 for the input parameters used in this run. The figure below shows the results of this Run.

Table 4.28: Run #6 Variable Parameters

	Oct-97			Dec-97			Jan-98			Feb-98			Mar-98			Apr-98		
Soluble Mass	16																	
Δ E																		
Oxygen	5.42																	
Nitrate	varies																	
Iron	0.4																	
Sulfate	10																	
Methane	0																	
Source Zone																		
Width, ft	5	7	10	5	5	10	0.2	4	12	0.1	3	10	5	7	10	5	6	10
Conc, mg/L	20	18	20	3	8	22	0.01	20	55	0.01	8	37	7	6	11	8	14	18

Figure 4.2: Effects of ΔNO_3 Variation



The results of this Run are similar to the results when ΔSO_4 is varied: as ΔNO_3 increases, the time required for remediation decreases. The results shown above indicate that with 0 mg/L ΔNO_3, the plume is remediated in approximately 50 years. As the available ΔNO_3 is increased to 20, 40, and 60 mg/L, the time to remediation decreases to approximately 44, 35, and 28 years, respectively. The BIOSCREEN output for this run is presented in Appendix J.

4.4.9 Model Run #7

After analyzing the effects of both ΔNO_3 and ΔSO_4 on the plume in Model Runs #5 and #6, Model Run #7 compares ΔNO_3 and ΔSO_4 to each other. Data presented in Section 4.3.4 are averaged for the six sampling events and the resultant ΔNO_3 value was 21.1 mg/L NO_3. Model Run #7 compares two conditions: (1) Run #2 with varying ΔSO_4 and keeping ΔNO_3 constant at 21.1 mg/L; and (2) Run #2 with varying ΔNO_3 and keeping ΔSO_4 constant at 21.1 mg/L ΔNO_3 equivalents, or 16.32 mg/L ΔSO_4. The figure representing the results is below

Figure 4.3: ΔNO_3 and ΔSO_4 Comparison

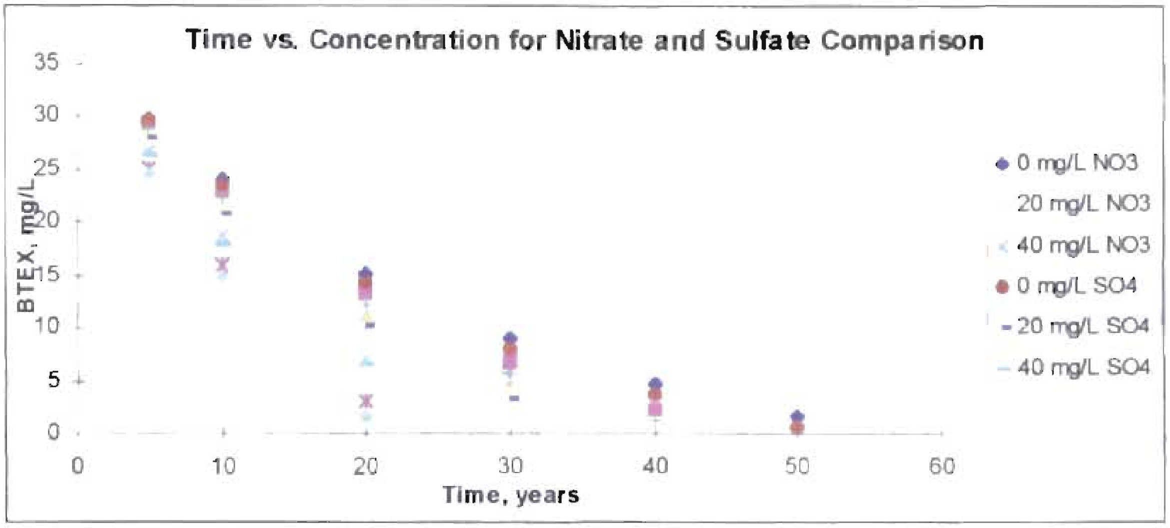


Figure 4.3 above shows only a slight difference in the time to remediation when ΔSO_4 and ΔNO_3 are varied. For each equivalent comparison, the BTEX plume appears to be remediated at a quicker rate with available ΔSO_4 than with available ΔNO_3. BIOSCREEN appears to be more sensitive to SO_4 than to NO_3 and over time, the difference between the two increases. For example at 10 mg/L ΔSO_4 and ΔNO_3, the BTEX concentation difference at five years is 0.336 mg/L, but at 40 years, the BTEX concentration difference is 1.06 mg/L. The BIOSCREEN output for this run is presented in Appendix K.

5.0 SUMMARY AND CONCLUSIONS

The objectives of this thesis are presented on page 3. A review of current literature regarding natural attenuation and the use of alternate electron acceptors, as well as literature on bioremediation models was presented in Section 2.0. Natural attenuation causes measurable changes in chemistry by indigenous (naturally occuring) microorganisms, reducing the total mass of contamination in the subsurface without the addition of nutrients. The processes involved in natural attenuation include biodegradation, dispersion, adsorption, and volatilization. Of these processes, biodegradation is the principal mechanism for BTEX plume remediation (Ollila, 1996). Biodegradation can occur aerobically (with oxygen) or anaerobically (without oxygen) by microorganisms breaking down the contaminant and using it as an energy source or an electron donor. The availability of electron acceptors has the most influence on the rate of biodegradation (Rifai et al., 1998).

Literature on bioremediation models was also reviewed. Because actual conditions at contaminated sites are often complex and extensive, a model, analytical or numerical, simplifies a site's conditions by introducing a set of mathematical assumptions which express the nature of the system and those features of its behavior that are relevant to the problem under investigation (Bear et al., 1992). Models simulate the plume's movement by considering the quantity of contaminant release, advection, dispersion, sorption, and sometimes biodegradation. In modeling, two basic approaches to mass and energy balances are 1) the eularian approach, and 2) the lagrangian approach (Zheng and Bennett, 1995). The most common method for simulating biodegradation in more recent models is through Monod kinetics, which describes microbial growth and is composed of first-order, mixed-order, and zero-order regions (Rifai and Bedient, 1995).

Models vary in how they simulate biodegradation. Two types of data are needed for bioremediation modeling: 1) hydrogeologic and hydrogeochemical parameters; and 2) hydraulic heads, flow rates, contaminant arrival times, solute concentrations, and/or mass removal rates (Zheng and Bennett, 1995). Models capable of simulating biodegradation and that incorporate multiple electron acceptor processes are BioF&T 3D, BIOSCREEN, SEAM3D, BIOPLUME III, and RT3D, among others (Newell et al., 1996; Rifai et al., 1998; Waddill and Widdowson, 1998; Boss International, 1998).

Calibration of a model is done by adjusting model parameters until modeled results match actual monitored field conditions. The adjustable variables include hydraulic heads, flow rates, solute concentrations, contaminant arrival times or mass removal rates (Zheng and Bennett, 1995). Sensitivity measures the effect on one factor of changing another factor. Repeated runs are needed to calculate a sensitivity coefficient.

The Oklahoma Department of Transportation (ODOT) Residency Facility located in Edmond, Oklahoma experienced a leaking fuel dispenser line in 1991 that contaminated the subsurface with BTEX. The changing levels over time of BTEX, sulfate, nitrate, phosphate, dissolved oxygen, and total organic carbon were periodically monitored. These results are presented in Section 4.0. Isopleths were prepared for BTEX, nitrate, sulfate, phosphate, DO, and organic carbon for the ODOT Site. The relationships between isopleths show that electron-accepting processes are active at the ODOT Site. Results show that in areas of high BTEX concentration, nitrate, sulfate, and dissolved oxygen have been reduced relative to measured background concentrations. This phenomenon indicates that natural attenuation through biodegradation is occuring at the ODOT Site.

Caldwell Environmental Associates, Inc. completed the Risk Assessment report in 1996 according to Oklahoma Risk Based Corrective Action (ORBCA) closure requirements. These requirement were presented in Section 3.0 of this study. The ORBCA program is a three-tiered approach: 1) qualitative analysis, 2) site-specific impact, and 3) probabilistic evaluations and sophisticated modeling. The user of the process starts at Tier 1 and advances only if required to do so. If target levels, determined through the tiered process, are exceeded, corrective action is necessary. However, if the target levels are not exceeded, the site may be approved for closure. Currently, the ODOT Site is closed.

The applicability of BIOSCREEN, an EPA provided natural attenuation decision support software package, to the ODOT Site monitored in this study was investigated. The ODOT Site was monitored for a period of approximately six months. Based on monitoring results, and site-specific data obtained from the Risk Assessment Report prepared by Caldwell Environmental, Inc., modeling predictions were inaccurate. BIOSCREEN's instantaneous reaction model, which incorporates alternate electron acceptor processes, was used to model the site. The BIOSCREEN model predicted the plume's remediation in two to eight years which assumes remediation of the plume in 1993 to 1999. However, monitoring data obtained through sampling in Fall 1997 and Spring 1998 indicated that the plume was still active with BTEX concentrations averaging 9.72, 15.25, 0.84, and 3.67 mg/L, respectively, in MW-3 (located near the original source of contamination, see Figure 3.2). These results were obtained using a conservative value for ΔSO_4 of 174 mg/L although actual ΔSO_4 values reached approximately 850 mg/L. Thus, based on the data obtained in this study, BIOSCREEN did not accurately represent plume characteristics at the ODOT Site. Charles J. Newell reported that there are no electron accepter boundaries in BIOSCREEN and that he has no knowledge of any BIOSCREEN studies where the ΔSO_4 observed were as high as those observed at the ODOT Site. C. Newell also reported that the source mass required in BIOSCREEN is the total non-aqueous phase liquid in the groundwater and soil, although the BIOSCREEN source mass input box indicates the source mass is the soluble mass of the contaminants. C. Newell indicated that the next BIOSCREEN update would better clarify the source mass requirements (Newell, 1999).

To investigate the variability in BIOSCREEN results with normal monitoring variability, BIOSCREEN model analysis was performed using the ODOT Site data with a reduced ΔSO_4 value of 10 mg/L. Using averaged (over the six months of sampling events) electron acceptor monitoring results and averaged soluble contaminant mass results, the model simulated the remediation of the BTEX plume in 18 to 44 years.

The sensitivity of BIOSCREEN to ΔSO_4 and ΔNO_3 anions was investigated by holding ΔNO_3 constant at 21.1 mg/L (site-specific change in nitrate concentration) and varying ΔSO_4 and then holding ΔSO_4 equal to 21.1 mg/L ΔNO_3 equivalents and varying ΔNO_3 . Using the site-specific data obtained from the Risk Assessment report prepared by Caldwell Environmental Associates, Inc. and monitoring data collected in this study, BIOSCREEN appears to be more sensitive to SO_4 than to NO_3. This finding supports a study by Wiedemeier et al. that indicated although denitrification typically occurs before sulfate reduction, 25 sites across the country shouwed that sulfate reduction accounts for 29 percent of the anaerobic biodegradation capacity, while denitrification only accounts for 14 percent (Wiedemeier et al., 1995).

In summary, using the ODOT Site-specific groundwater data obtained during monitoring and subsurface geological input data obtained from a Risk Assessment Report for the ODOT Site prepared by Caldwell Environmental Associates, Inc., BIOSCREEN predicted natural attenuation of the groundwater in two to eight years. However, monitoring results prove that the groundwater remains contaminated with BTEX seven years later; thus, BIOSCREEN is not applicable to the ODOT Site under the conditions indicated in the study and careful consideration must be given when using BIOSCREEN at a site with high sulfate concentration depressions. The high changes in sulfate concentrations found at the ODOT Site were lowered for modeling analysis purposes. Monthly data was averaged, modeling was repeated, and results revealed natural attenuation of the ODOT Site in 18 to 44 years. Comparing various BIOSCREEN model runs showed that as changes in nitrate and sulfate concentrations increase, time required for natural attenuation decreases. Comparing equivalents of nitrate and sulfate changes revealed the BTEX plume attenuated at a faster rate with sulfate than with nitrate. Comparing the results of BIOSCREEN to AT123D using identical parameters resulted in BTEX concentration variations typically within an order of magnitude.

6.0 RECOMMENDATIONS

Since 1972, when in-situ bioremediation was first practiced commercially, bioremediation has matured from a novel process to an important, technically recognized and economical method of remediating groundwater (Scalzi, 1999). Research will continue at sites across the United States as long as the desire for a more effective, more efficient, lower cost process continues. Although natural attenuation holds promise for the future, the interactions of microorganisms with different hydrologic environments must continue to be studied. There exists an agreement among the research community that field-based research is needed to realize the full potential of natural attenuation and its applications (Environmental Microbiology, 1997b). As the understanding increases, so should the incidents of natural attenuation site closures.

This study, using site-specific data obtained from a Risk Assessment report prepared by Caldwell Environmental Associates, Inc. along with additional monitoring data, investigated one model, BIOSCREEN, at one site, an Oklahoma Department of Transportation site with subsurface BTEX contamination, and found the model to misrepresent the actual plume conditions. Careful consideration and evaluation should be given when using BIOSCREEN to model a site with subsurface characteristics similar to those of the ODOT Site. When BIOSCREEN is to be used at a site with observed high ΔSO_4 values, BIOSCREEN should be compared to other models or to actual site plume delineation.

As more and more models are introduced with varying equations, assumptions, methods of evaluation. etc., investigations of the models by researchers, consultants, and regulatory officials should continue. Additionally, when modeling a site, if the site-specific data is altered unreasonably in order to obtain calibration, the model may not be appropriate for the site.

Several models exist that simulate bioremediation through aerobic and anerobic processes. Site A's specific characteristics should be compared to characteristics of Site B that has had success with a particular model. If Site A and Site B have similar characteristics, then it is more likely that the same model may be appropriate for Site A also.

The technology that exists in today's world provides unlimited communication between regulatory agencies, the public, researchers, consulting firms, and commercial entities via the internet. As more and more studies are performed and research is completed about the applicability of various models to certain sites, the findings and conclusions should be made available so that the entire environmental community can benefit. This process would save time and money, would decrease the incidence of model uncertainty, and would enhance and perhaps quicken the current process of risk-based closure by showing that a site with similar characteristics was accurately simulated by the same model used in the Risk Assessment for the site under investigation.

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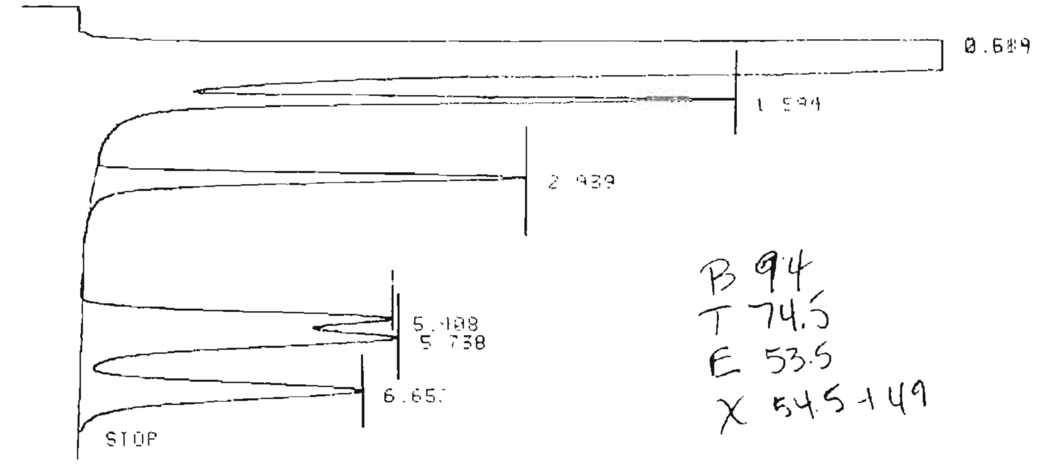
APPENDICES

APPENDIX A
SAMPLE CHROMATOGRAPHS

SAMPLE GC CHROMATOGRAPH

10mg/L 75°C 1ul inj. vol.
Attn = -1

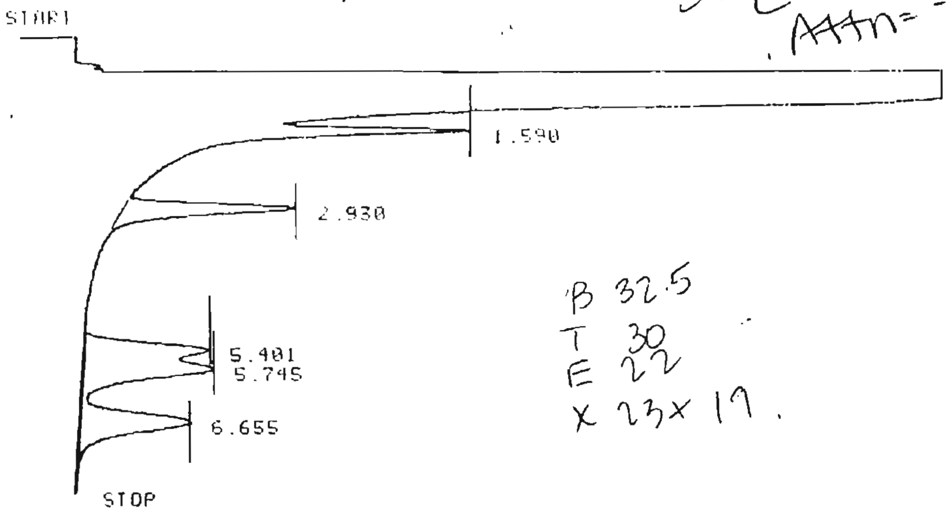
```
+
+
+
+  RUN # 4468      JAN 14, 1998  12:36:20
START
```



B 94
T 74.5
E 53.5
X 54.5 + 49

```
RUN#  4468           JAN 14, 1998  12:36:20

METHOD NAME: M+BTEX.MET

AREA%
      RT       AREA TYPE  WIDTH       AREA%
    .614     332861   VB    067    71.26579
   1.594      21440   BP    138     4 59032
   2 939      26444   BP    220     5 66168
   5.408      24836   BV    286     5.31740
   5 738      30820   VV   .348     6.59858
   6.652      30669 I VP    388     6 56625

TOTAL AREA= 467070
MUL FACTOR=1 0000E+00
```

```
RUN # 4467      JAN 14, 1998  12:27:25
```



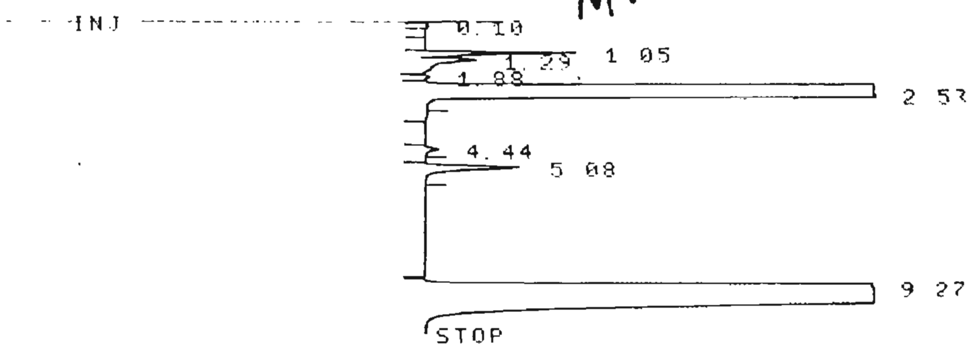
5mg/L

Attn= -1

B 32.5
T 30
E 22
X 23x 17.

```
RUN#  4467            JAN 14, 1998  12:27:25

METHOD NAME: M*BTEX.MET

AREA%
       RT         AREA TYPE  WIDTH       AREA%
    1.590  [illegible]   BB  [illegible]  [illegible]
    2.930  [illegible]   BP  [illegible]  20.[illegible]
    5 401         9981   PV   .286     20.33080
    5.745        12742   VV   .351     25 95482
    6 655        11936   VV   .389     24 31304

TOTAL AREA=   49093
MUL FACTOR=1.0000E+00
```

MW-7

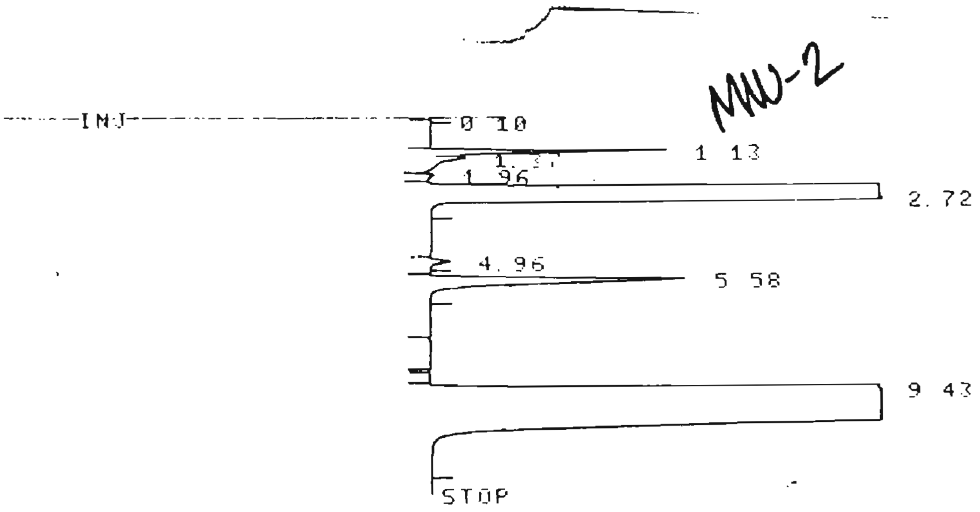


```
                 AREA %
   RT    TYPE       AREA
   10                772              .003 081
 1 05             127188              .507 6
 1 29     M        83060               331 5
 1 88     T         6586               026 28
 2 53    *M     16176278            64.55
 4 44              14079              .056 18
 5 08             1 3734               553 6
 9 27     I     8     15            33 97


HP 3380A
DLY OFF           ST   9          REJECT OFF
MV/M    30        AT           8
```

MW-7

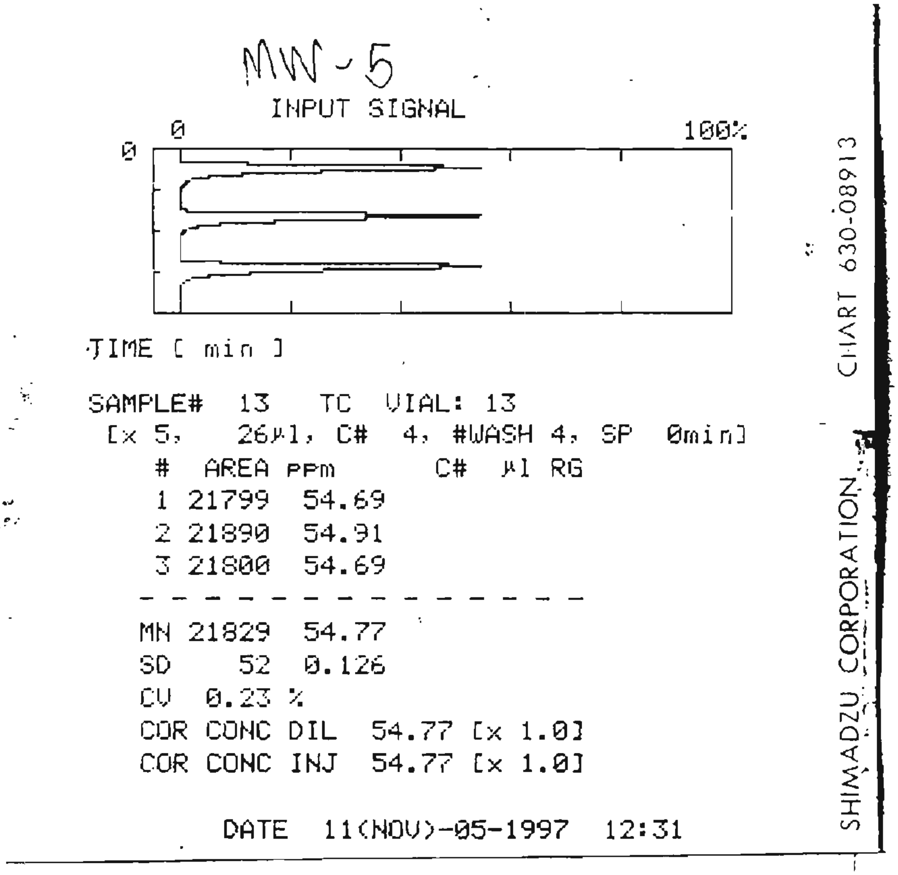
SAMPLE IC CHROMATOGRAPH

MW-2



```
                AREA %
   RT    TYPE      AREA
   10               714              001 568
 1 13            213513              469
 1 37     M       72090              158 4
 1 96     T        9709              021 33
 2 72    *M    20232664           44 45
 4 96             23671              052
 5 58            462699            1 016
 9 43          24507637           53 84


HP 3380A
DLY OFF          STOP 90         REJECT OFF
MV/M   30        ATTN   128
```

SAMPLE TOC ANALYZER CHROMATOGRAPH



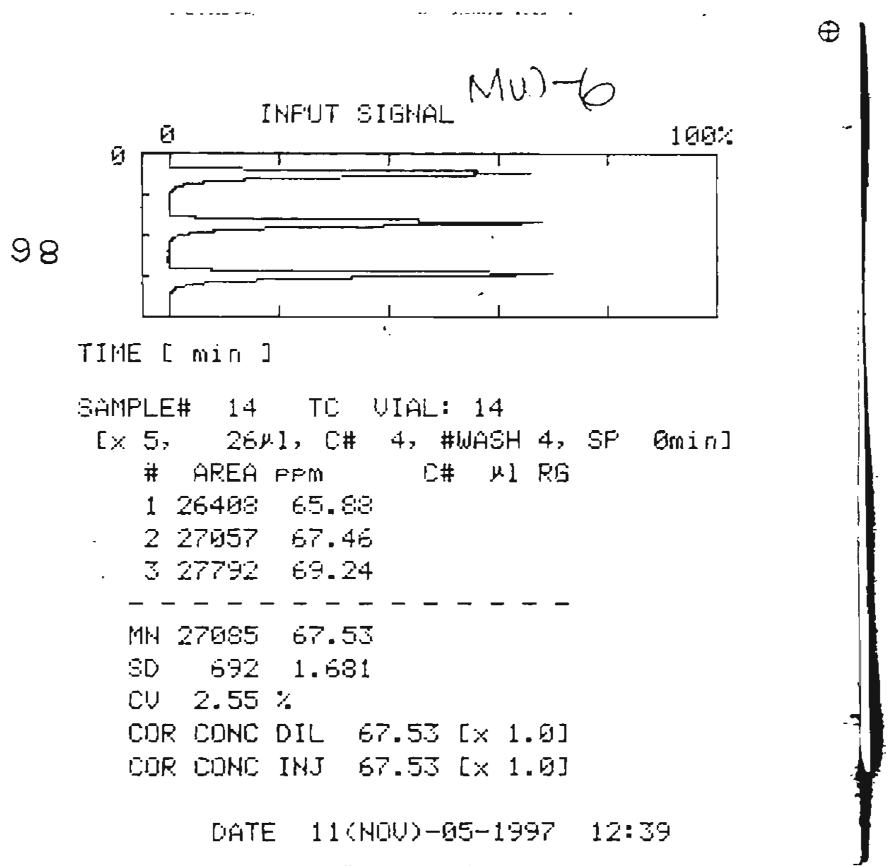
MW-5

```
          INPUT SIGNAL
   0                              100%
0

TIME [ min ]

SAMPLE#  13    TC  VIAL: 13
 [x 5,    26µl, C#  4, #WASH 4, SP  0min]
    #  AREA ppm       C#  µl RG
    1 21799  54.69
    2 21890  54.91
    3 21800  54.69
   - - - - - - - - - - - - - - -
   MN 21829  54.77
   SD    52  0.126
   CV  0.23 %
   COR CONC DIL   54.77 [x 1.0]
   COR CONC INJ   54.77 [x 1.0]

       DATE  11(NOV)-05-1997  12:31
```

SHIMADZU CORPORATION CHART 630-08913

98

MW-6



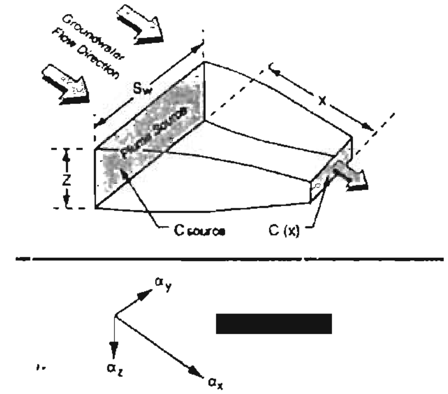
```
TIME [ min ]

SAMPLE#  14    TC   VIAL: 14
 [x 5,   26µl, C#  4, #WASH 4, SP  0min]
    #  AREA ppm        C#  µl RG
    1 26408  65.88
    2 27057  67.46
    3 27792  69.24
   - - - - - - - - - - - - - - -
   MN 27085  67.53
   SD   692  1.681
   CV  2.55 %
   COR CONC DIL  67.53 [x 1.0]
   COR CONC INJ  67.53 [x 1.0]

        DATE  11(NOV)-05-1997  12:39
```

APPENDIX B
BIOSCREEN EQUATIONS AND ASSUMPTIONS

APPENDIX A.1 DOMENICO ANALYTICAL MODEL

The Domenico (1987) analytical model, used by BIOSCREEN, is designed for the multidimensional transport of a decaying contaminant species. The model equation, boundary conditions, assumptions, and limitations are discussed below.

Domenico Model with Instantaneous Reaction Superposition Algorithm



$$\frac{C(x,y,o,t)}{(Co+BC)} = \frac{1}{8}\exp\left[\frac{x}{\alpha_x 2}\left(1-(1+4\lambda\alpha_x/v)^{1/2}\right)\right]$$

$$erfc\left[\frac{\left(x-vt(1+4\lambda\alpha_x/v)^{1/2}\right)}{2(\alpha_x vt)^{1/2}}\right]$$

$$\left\{erf\left[\frac{(y+Y/2)}{2(\alpha_y x)^{1/2}}\right]-erf\left[\frac{(y-Y/2)}{2(\alpha_y x)^{1/2}}\right]\right\}$$

$$\left\{erf\left[\frac{(Z)}{2(\alpha_z x)^{1/2}}\right]-erf\left[\frac{(-Z)}{2(\alpha_z x)^{1/2}}\right]\right\}-BC$$

where: $v = \frac{K \cdot i}{\theta_e R}$ $BC = \Sigma \frac{C(ea)_n}{UF_n}$

Definitions

BC	Biodegradation capacity (mg/L)
C(x,y,z,t)	Concentration at distance x downstream of source and distance y off centerline of plume at time t (mg/L)
C_s	Concentration in Source Zone (mg/L)
Co	Concentration in Source Zone at t=0 (mg/L)
x	Distance downgradient of source (ft)
y	Distance from plume centerline of source (ft)
z	Distance from surface to measurement point (assumed to be 0; concentration is always assumed to be at top of water table).
$C(ea)_n$	Concentration of electron acceptor n in groundwater (mg/L)
UF_n	Utilization factor for electron acceptor *n* (i.e., mass ratio of electron acceptor to hydrocarbon consumed in biodegradation reaction)
α_x	Longitudinal groundwater dispersivity (ft)
α_y	Transverse groundwater dispersivity (ft)
α_z	Vertical groundwater dispersivity (ft)
θ_e	Effective Soil Porosity
λ	First-Order Degradation Rate (day^{-1})
υ	Groundwater Seepage Velocity (ft/yr)
K	Hydraulic Conductivity (ft/yr)
R	Constituent retardation factor
i	Hydraulic Gradient (cm/cm)
Y	Source Width (ft)
Z	Source Depth (ft)

The initial conditions are:

1) $c(x, y, z, 0) = 0$ (Initial concentration = 0 for x, y, z, > 0)
2) $c(0, Y, Z, 0) = C_0$ (Source concentration for each vertical plane source = C_0 at time 0)

The key assumptions in the model are:

1) The aquifer and flow field are homogenenous and isotropic.
2) The groundwater velocity is fast enough that molecular diffusion in the dispersion terms can be ignored (may not be appropriate for simulation of transport through clays).
3) Adsorption is a reversible process represented by a linear isotherm.

The key limitations to the model are:

1) The model should not be applied where pumping systems create a complicated flow field.
2) The model should not be applied where vertical flow gradients affect contaminant transport.
3) The model should not be applied where hydrogeologic conditions change dramatically over the simulation domain.

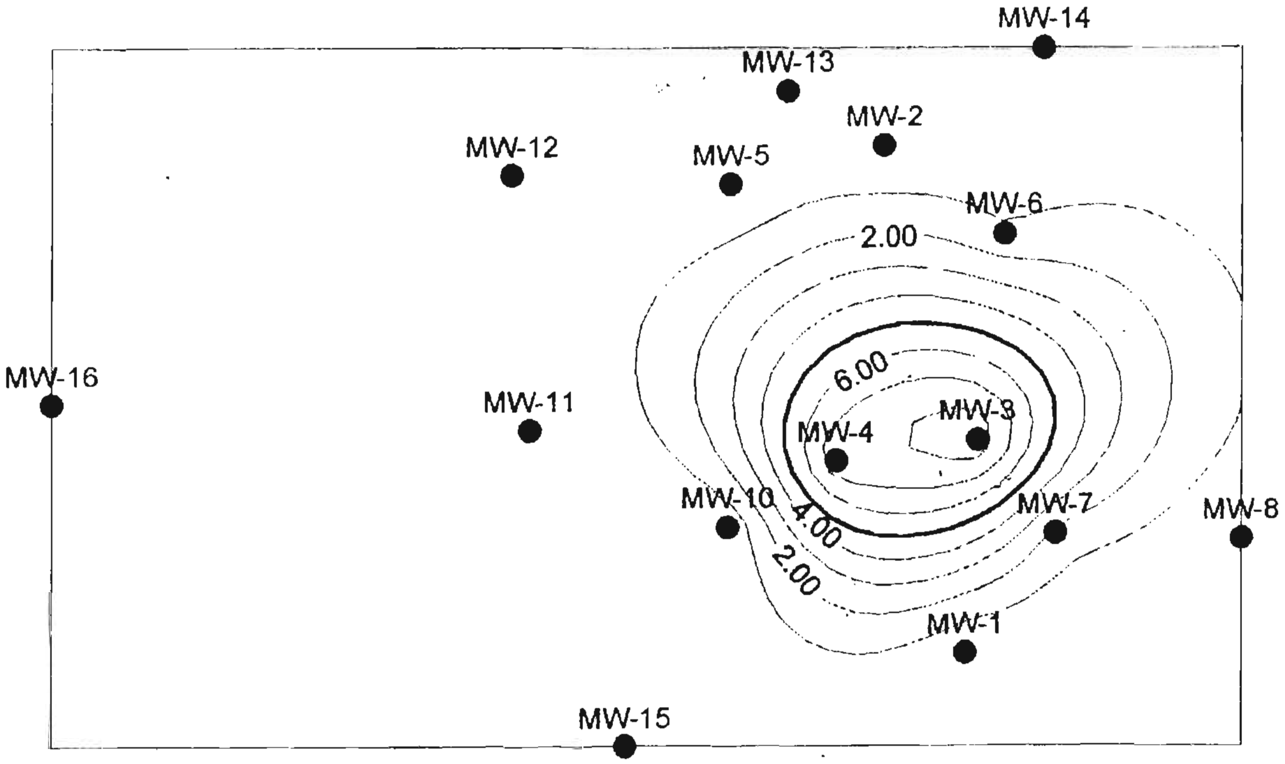
The most important modifications to the original Domenico model are:

1) The addition of "layer cake" source terms where three Domenico models are superimposed one on top of another to yield the 5-source term used in BIOSCREEN (see Connor et al., 1994; and the Source Width description in the BIOSCREEN Data Entry Section).
2) Addition of the instantaneous reaction term using the superposition algorithm (see Appendix A.2, below). For the instantaneous reaction assumption, the source concentration is assumed to be an "effective source concentration" (Coe) equal to the observed concentration in the source zone plus the biodegradation capacity (see "Source Concentration" on the BIOSCREEN Data Entry section).

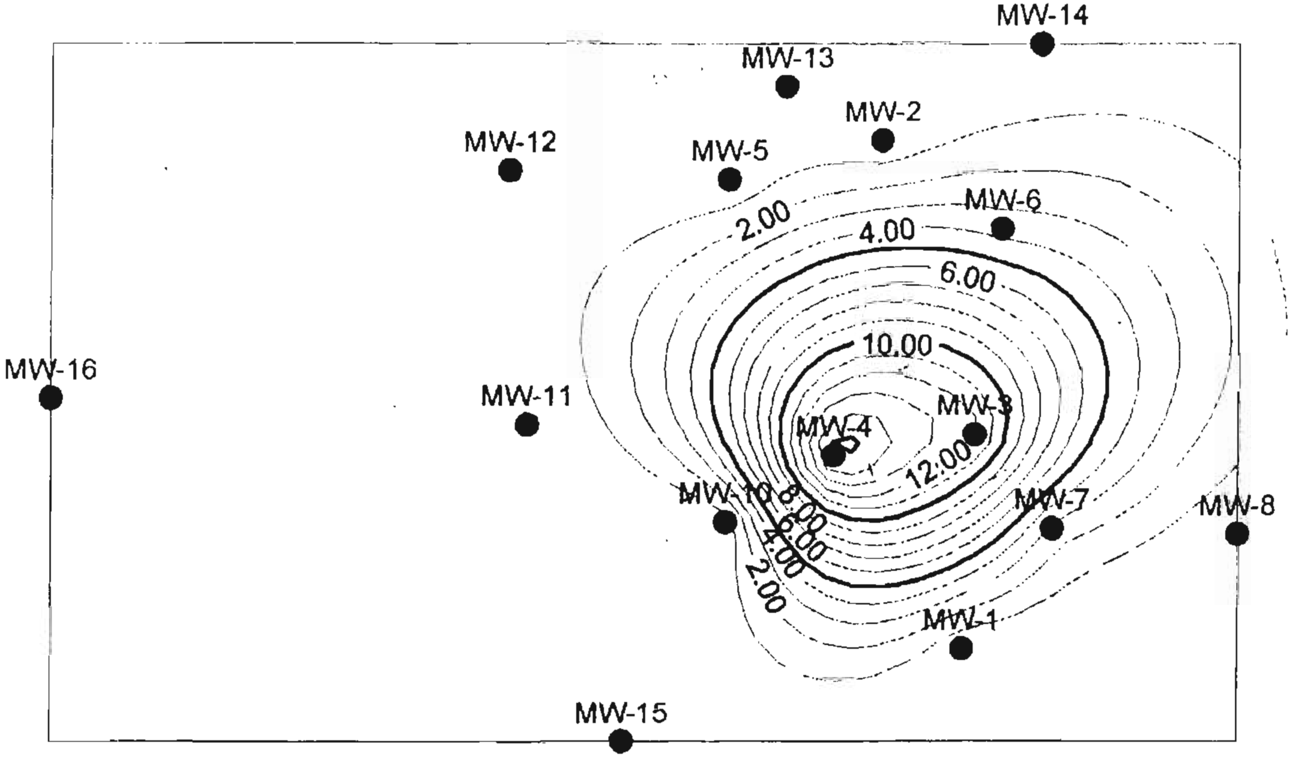
APPENDIX C
ISOPLETH MAPS

BENZENE ISOPLETH MAPS

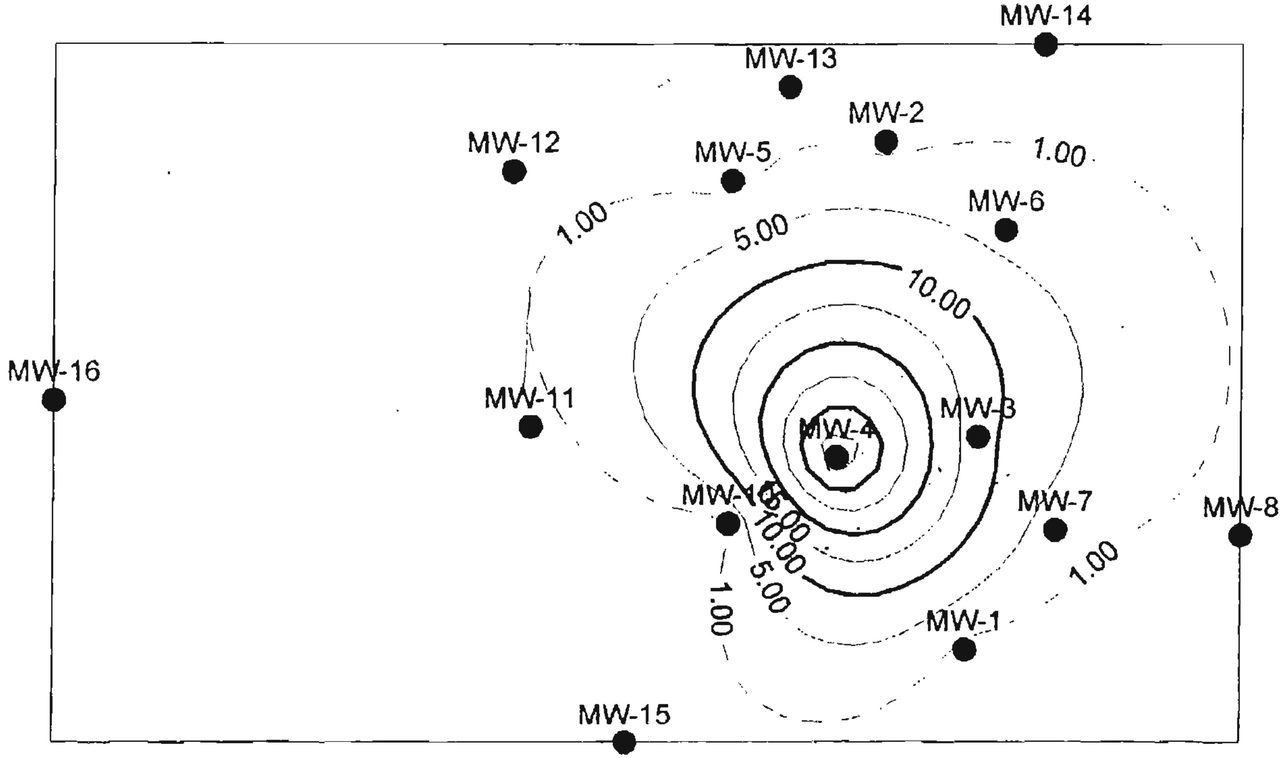
Benzene Isopleth Map (mg/L)
October 20, 1997
Kriging Method



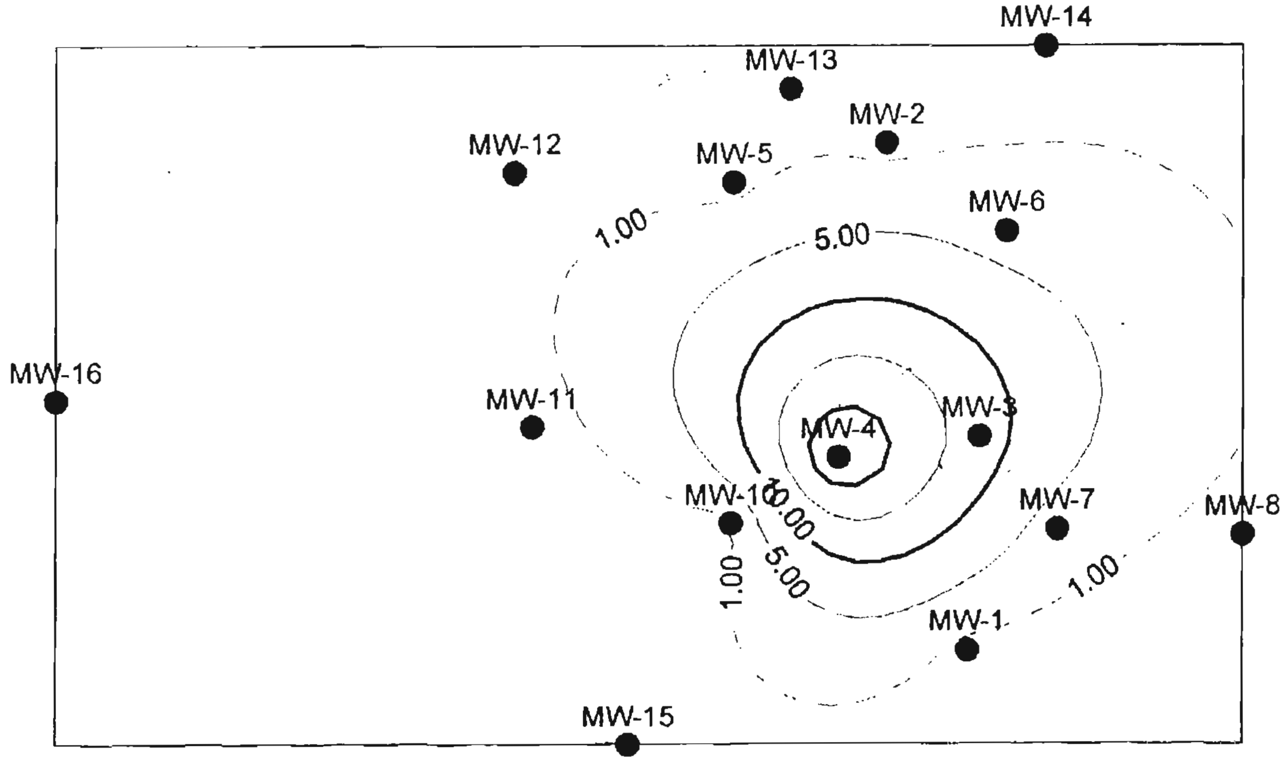
Benzene Isopleth Map (mg/L)
December 15, 1997
Kriging Method



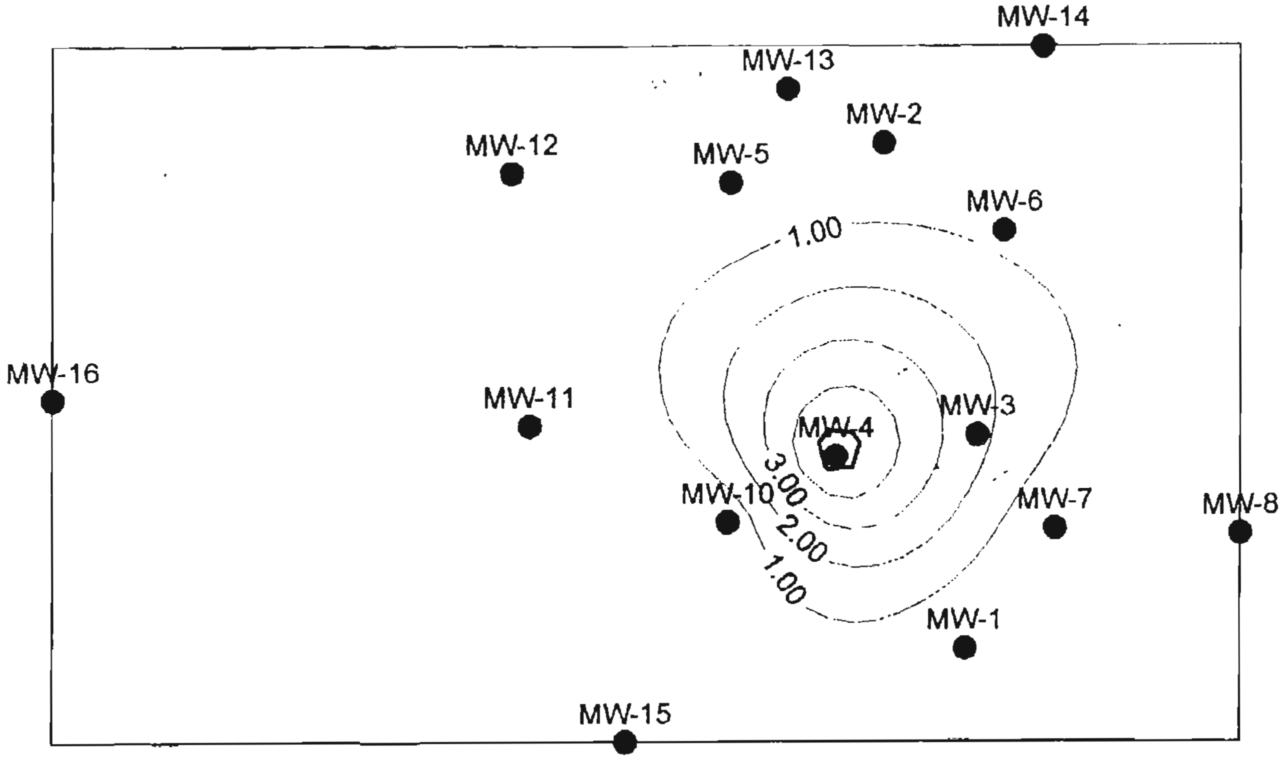
Benzene Isopleth Map (mg/L)
January 20, 1998
Kriging Method



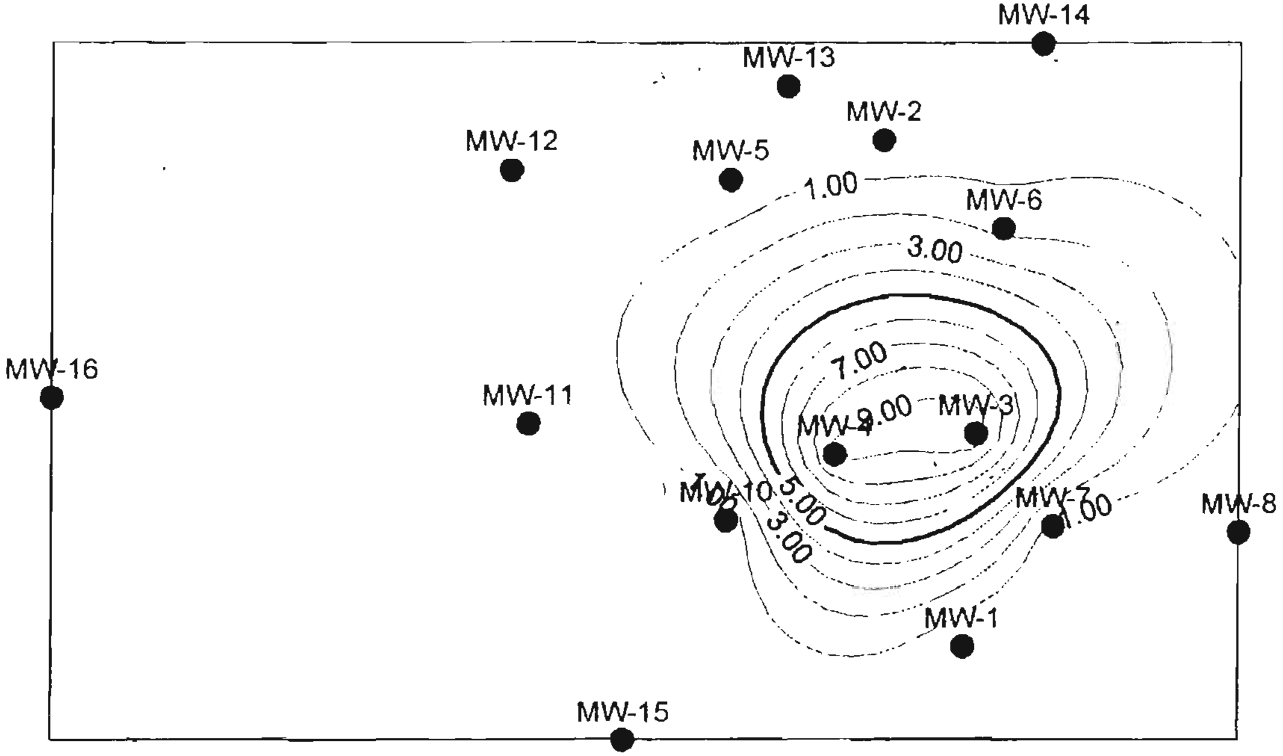
Benzene Isopleth Map (mg/L)
February 17, 1998
Kriging Method



Benzene Isopleth Map (mg/L)
March 24, 1998
Kriging Method

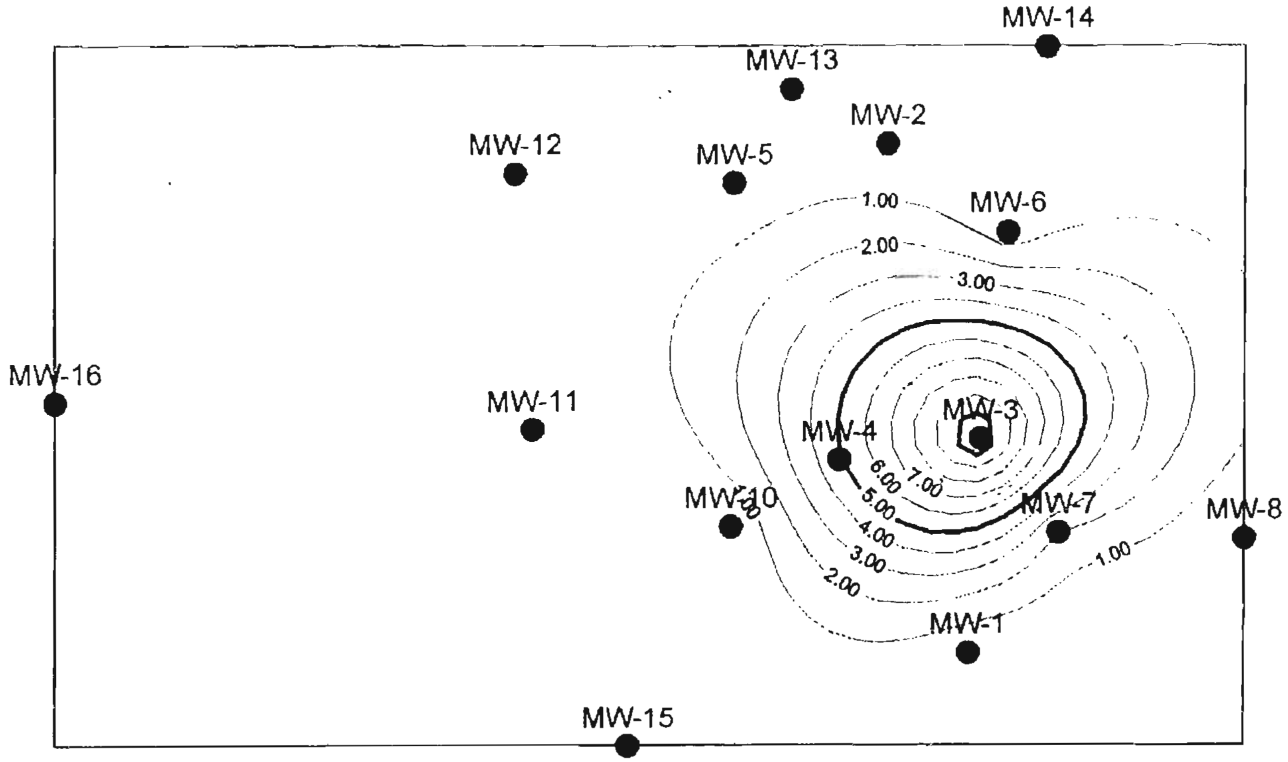


Benzene Isopleth Map (mg/L)
April 14, 1998
Kriging Method

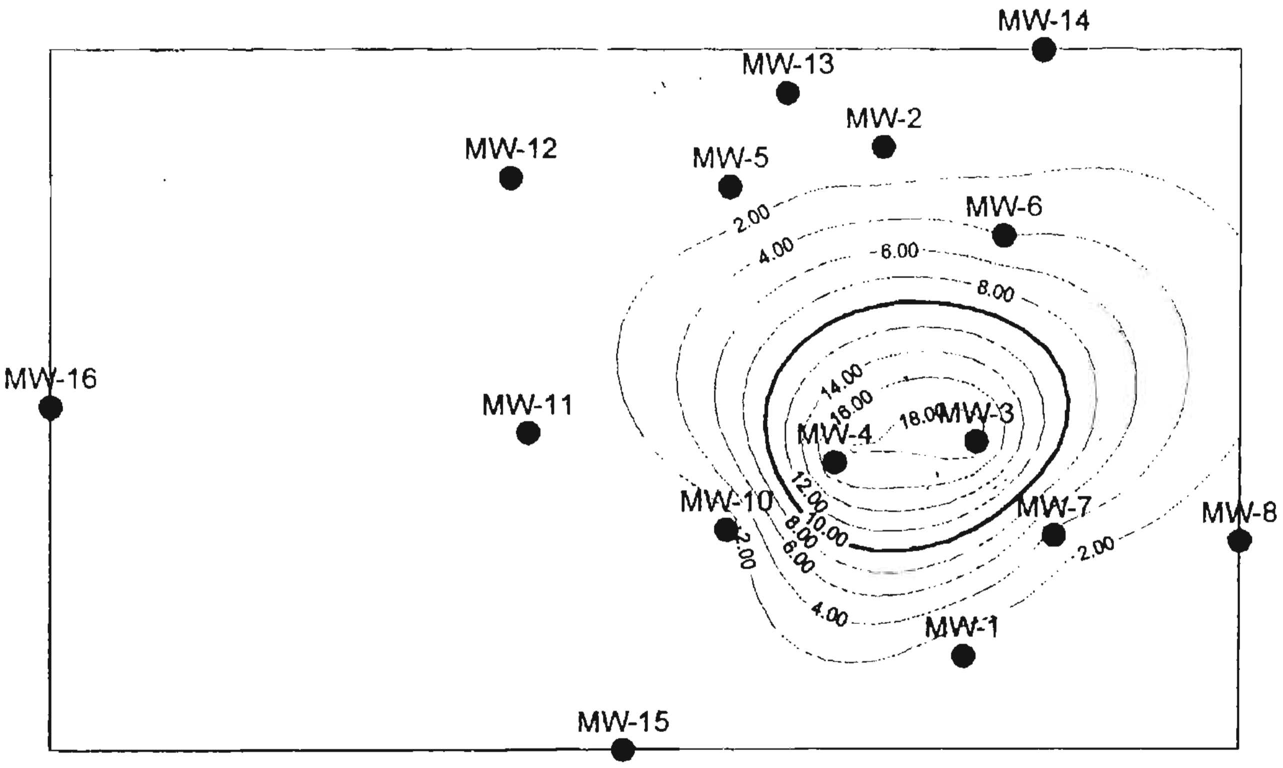


TOLUENE ISOPLETH MAPS

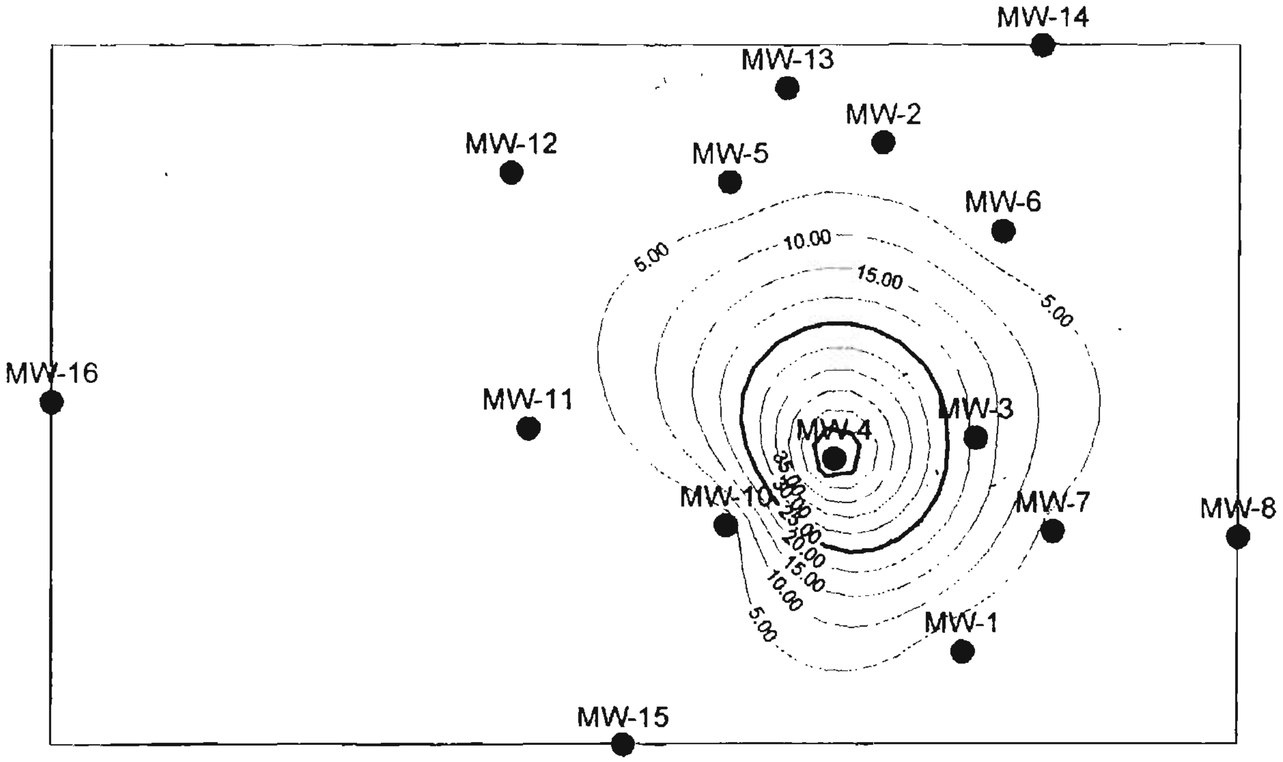
Toluene Isopleth Map (mg/L)
Oct. 20, 1997
Kriging Method



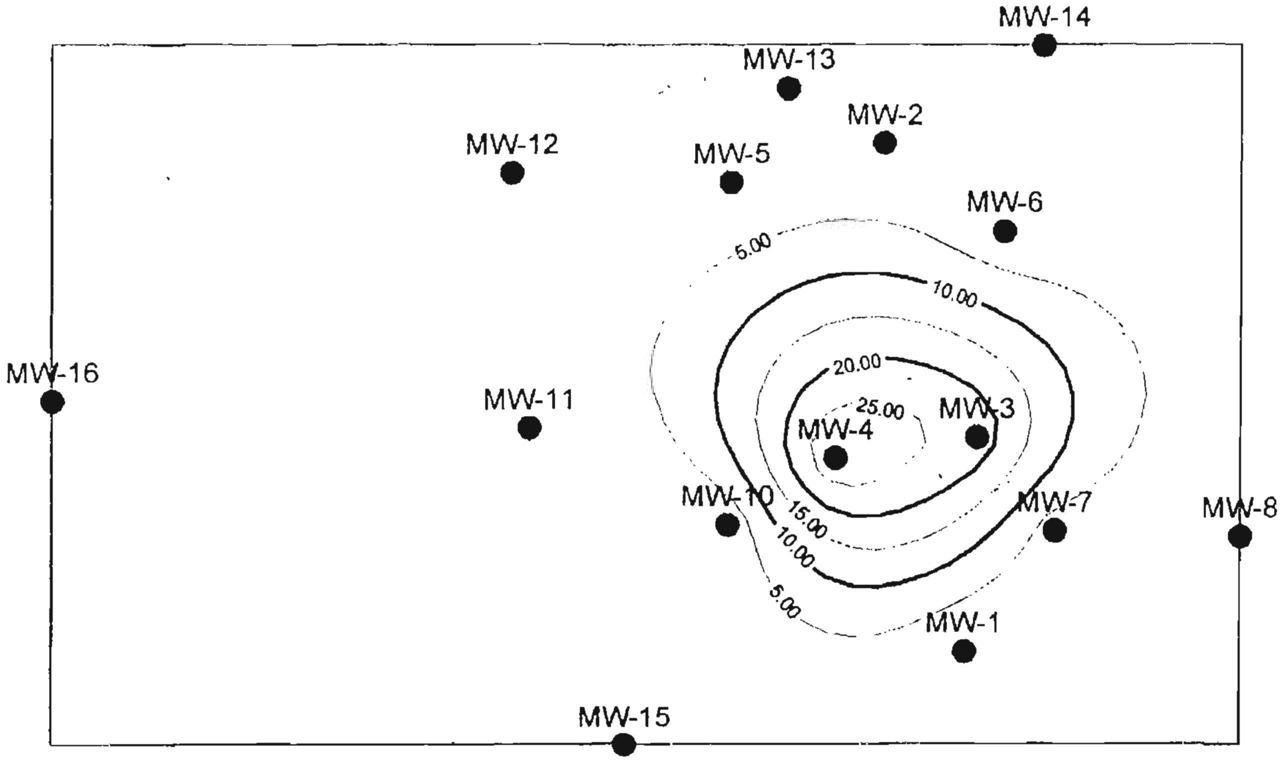
Toluene Isopleth Map (mg/L)
Dec. 15, 1997
Kriging Method



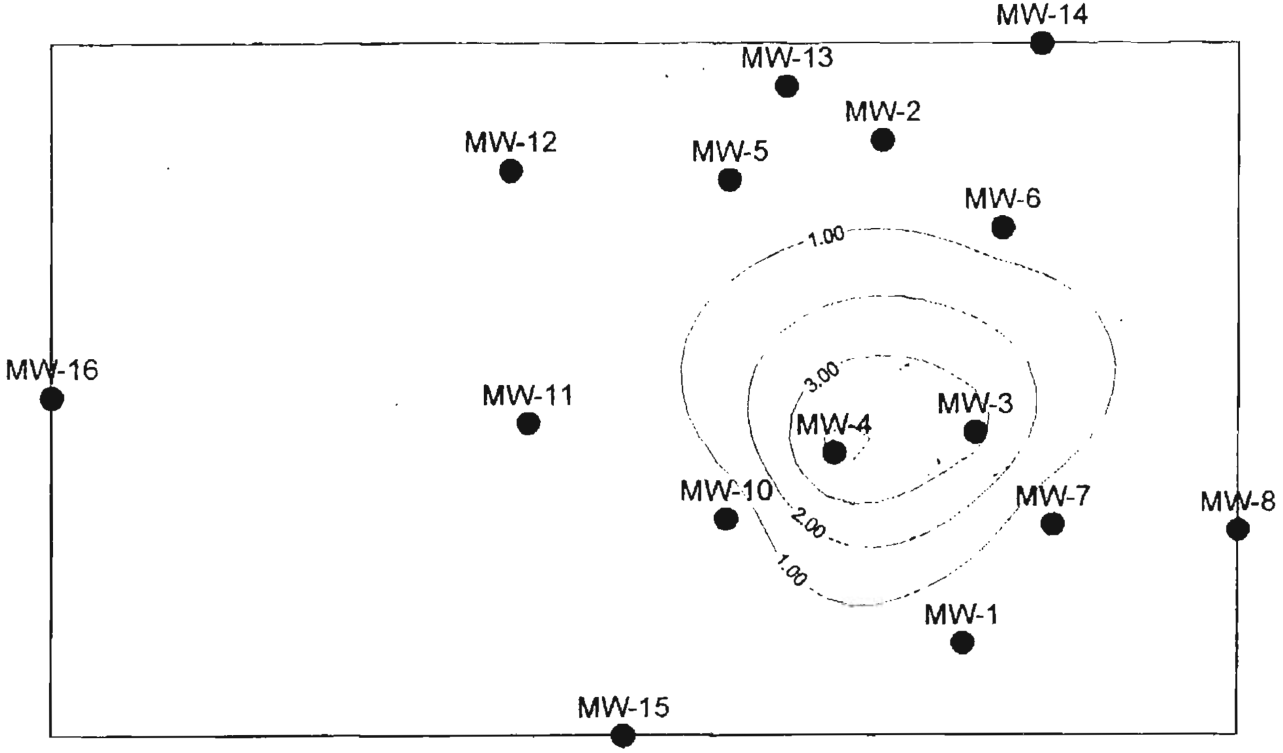
Toluene Isopleth Map (mg/L)
Jan. 20, 1998
Kriging Method



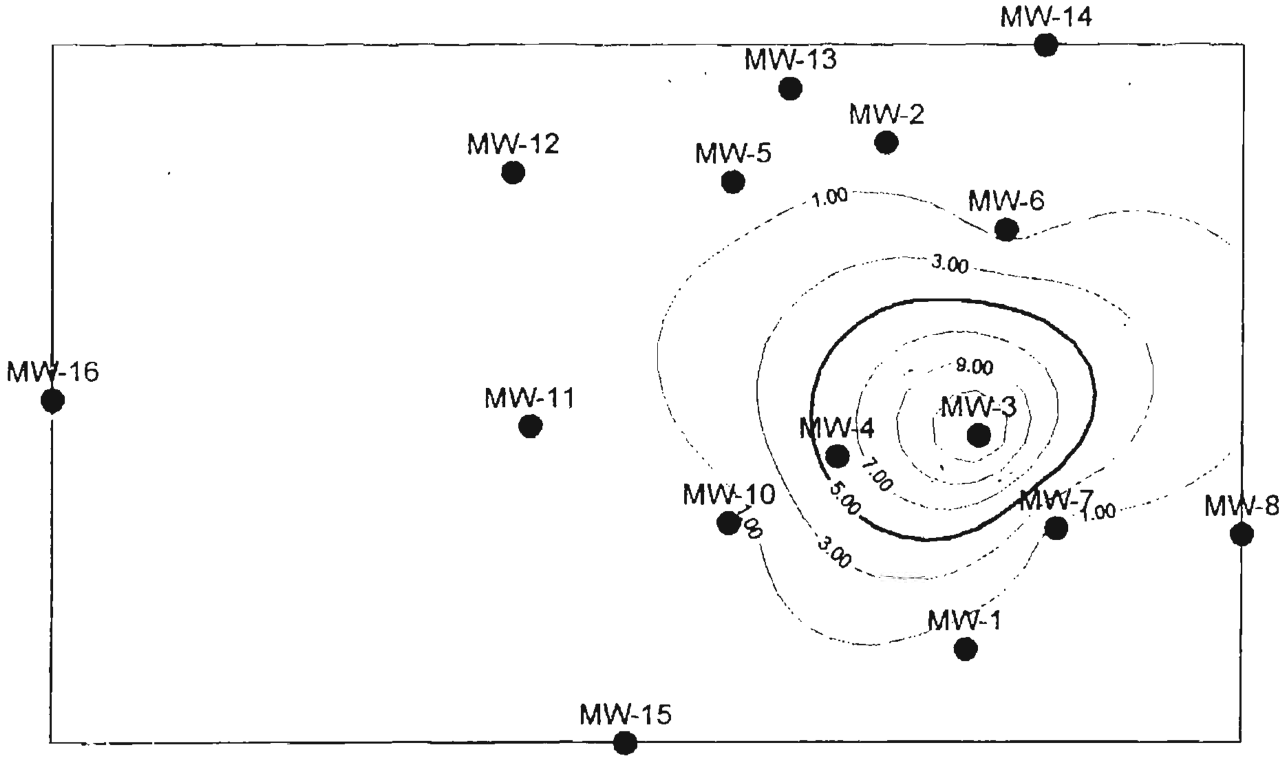
Toluene Isopleth Map (mg/L)
Feb. 17, 1998
Kriging Method



Toluene Isopleth Map (mg/L)
Mar. 24, 1998
Kriging Method

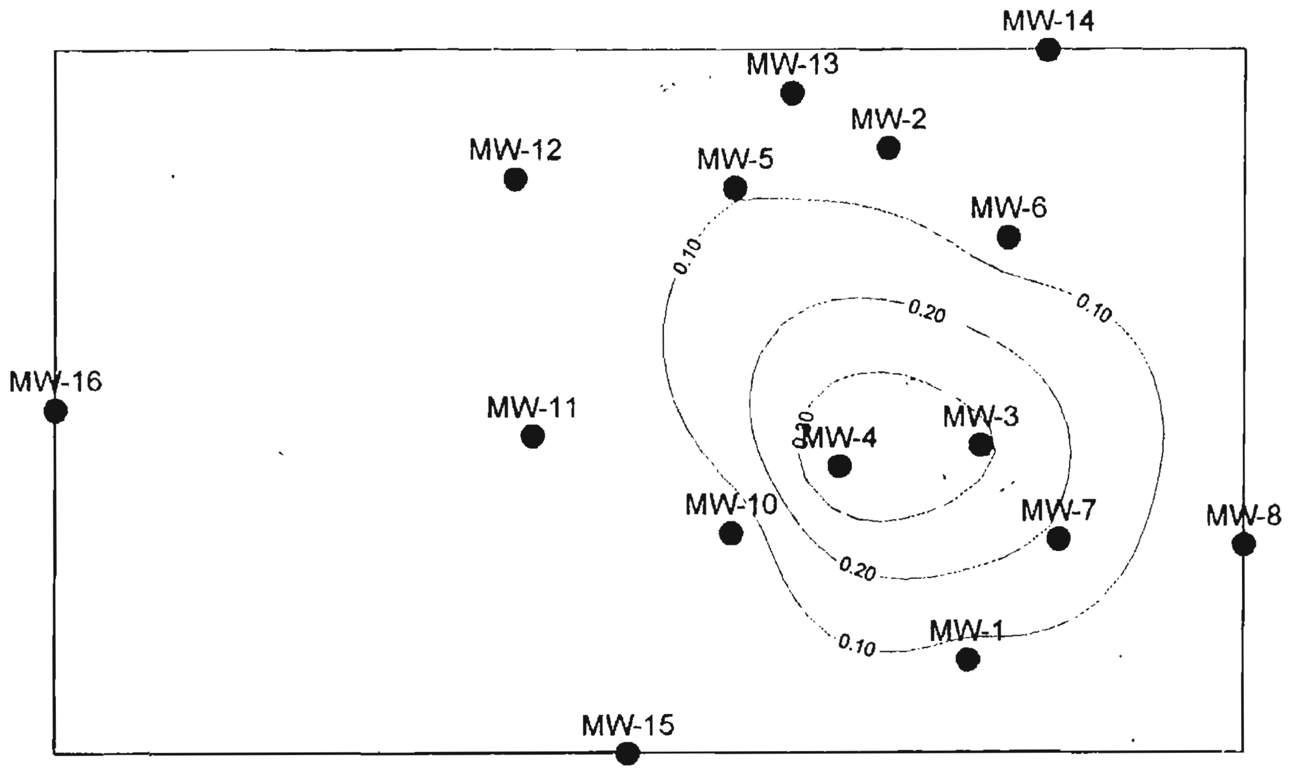


Toluene Isopleth Map (mg/L)
Apr. 14, 1998
Kriging Method

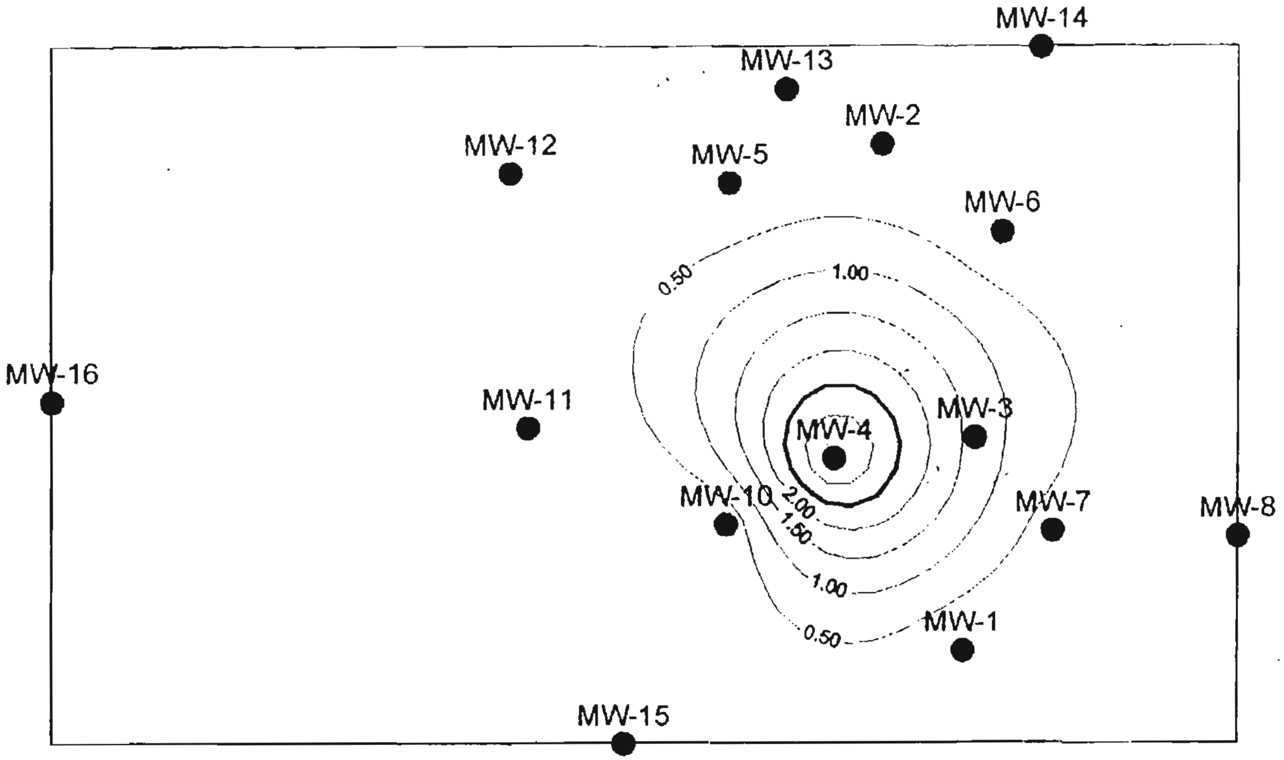


ETHYLBENZENE ISOPLETH MAPS

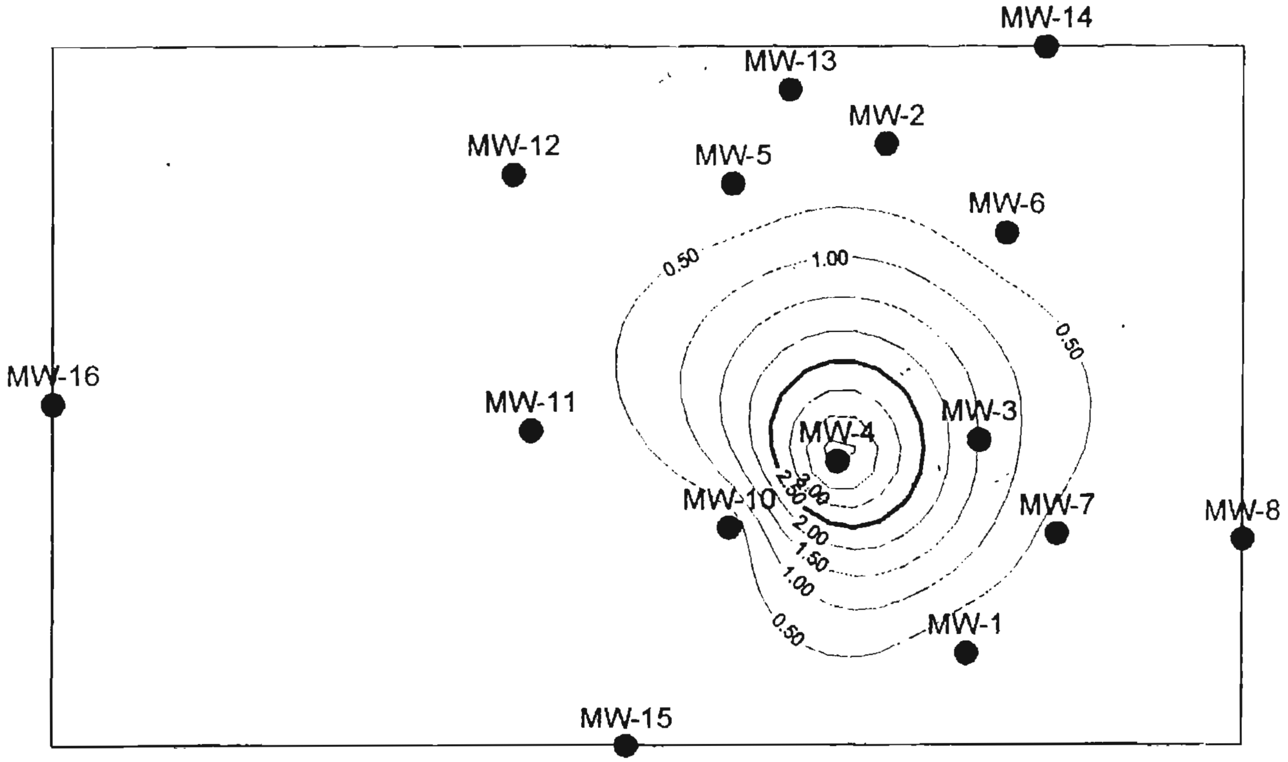
Ethylbenzene Isopleth Map (mg/L)
Oct. 20, 1997
Kriging Method



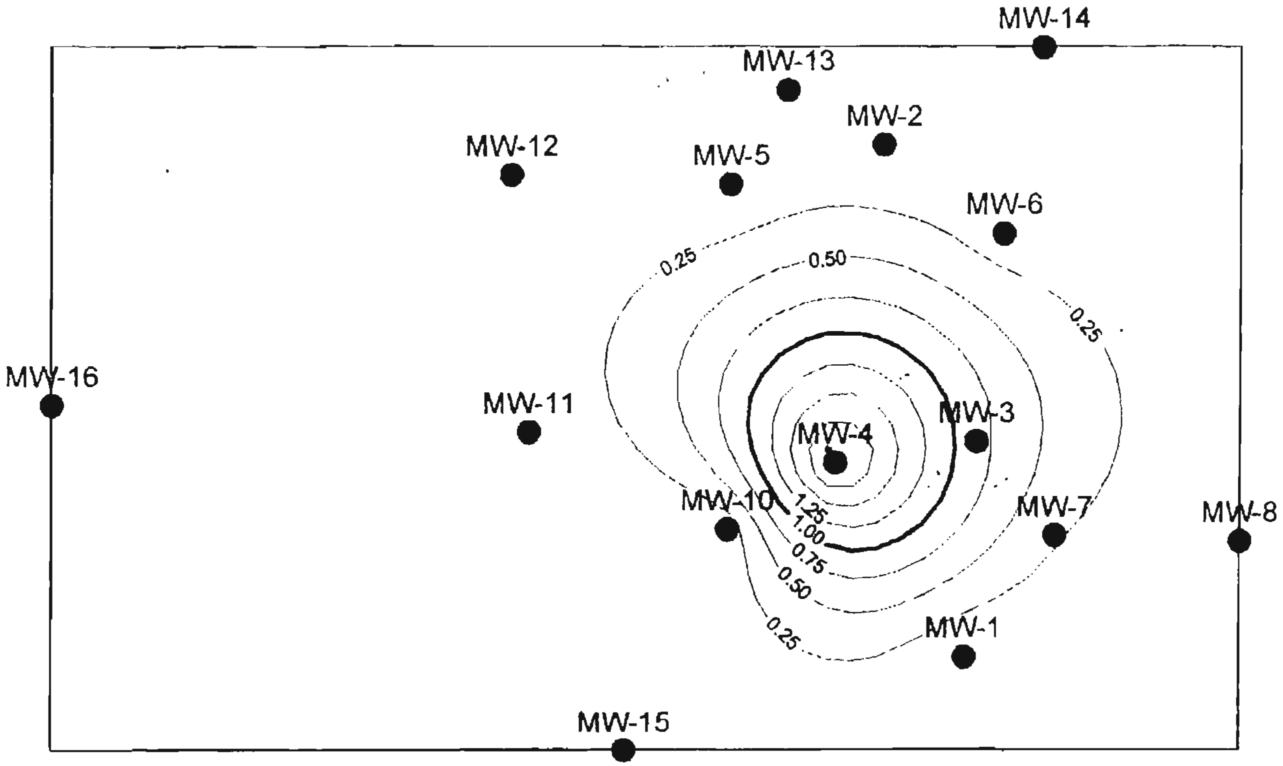
Ethylbenzene Isopleth Map (mg/L)
Dec. 15, 1997
Kriging Method



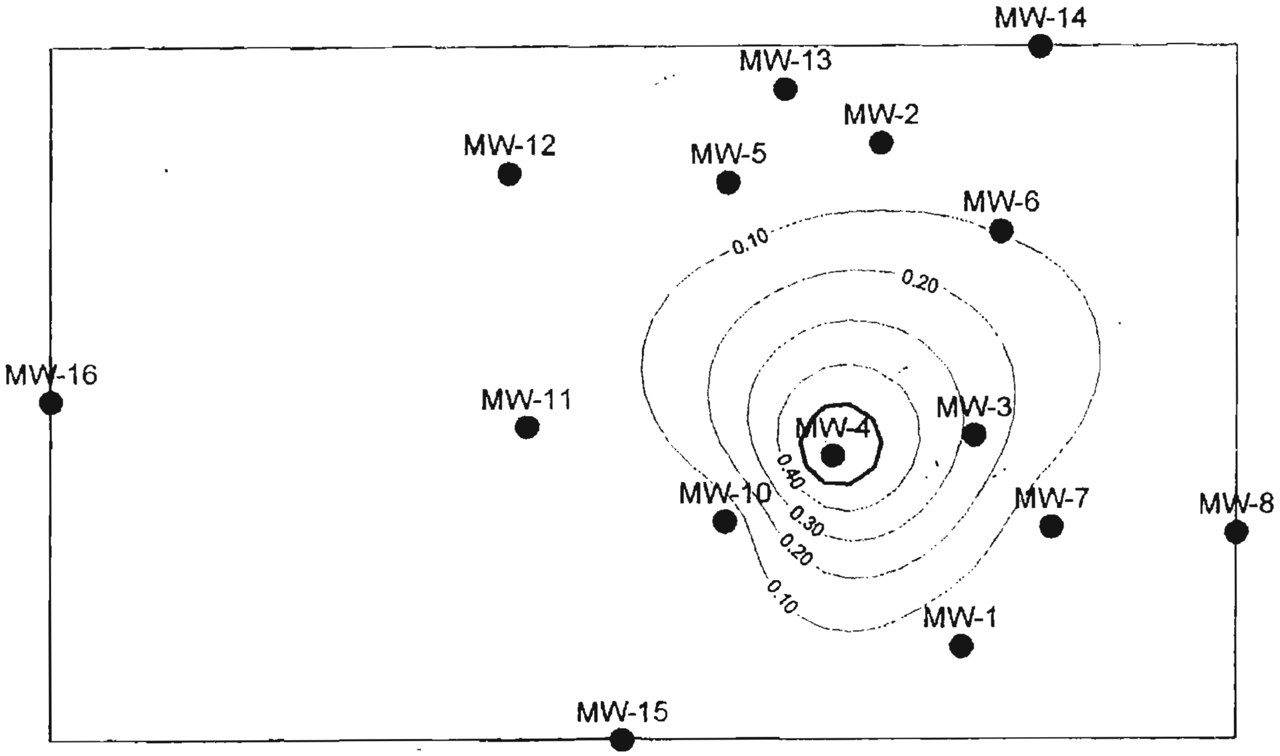
Ethylbenzene Isopleth Map (mg/L)
Jan. 20, 1998
Kriging Method



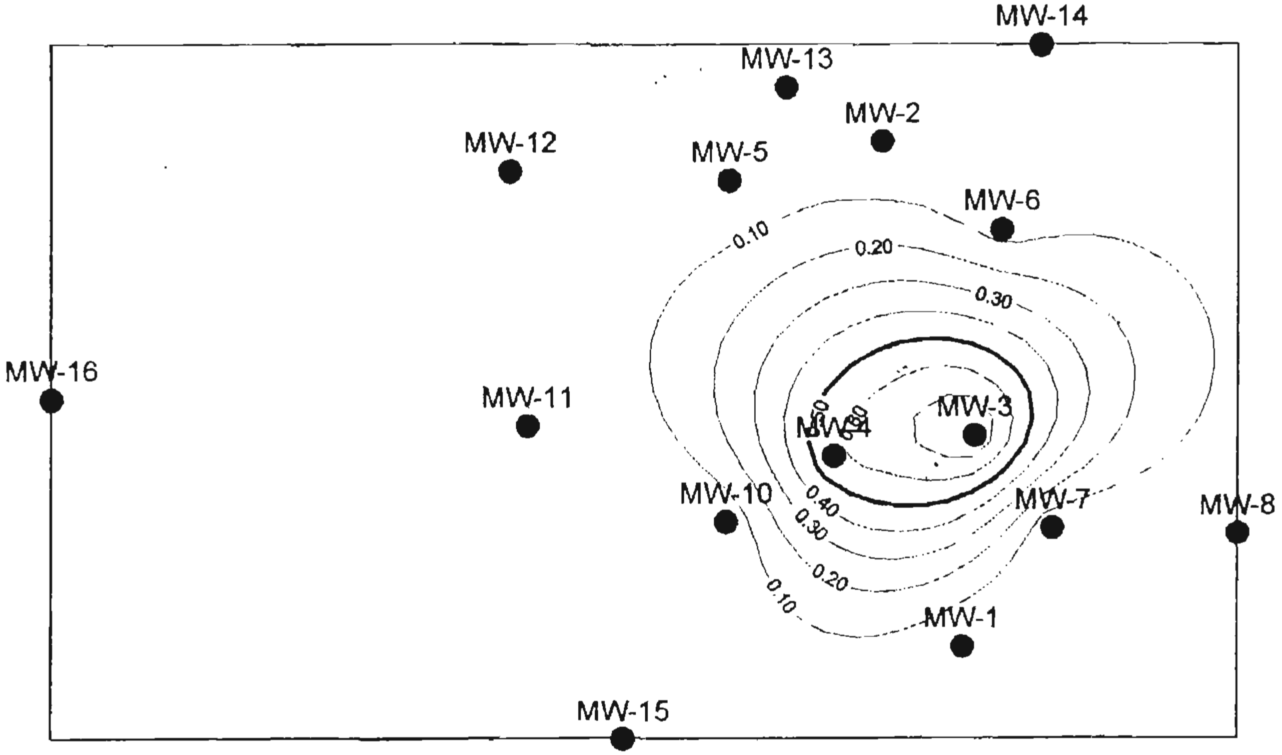
Ethylbenzene Isopleth Map (mg/L)
Feb. 17, 1998
Kriging Method



Ethylbenzene Isopleth Map (mg/L)
Mar. 24, 1998
Kriging Method

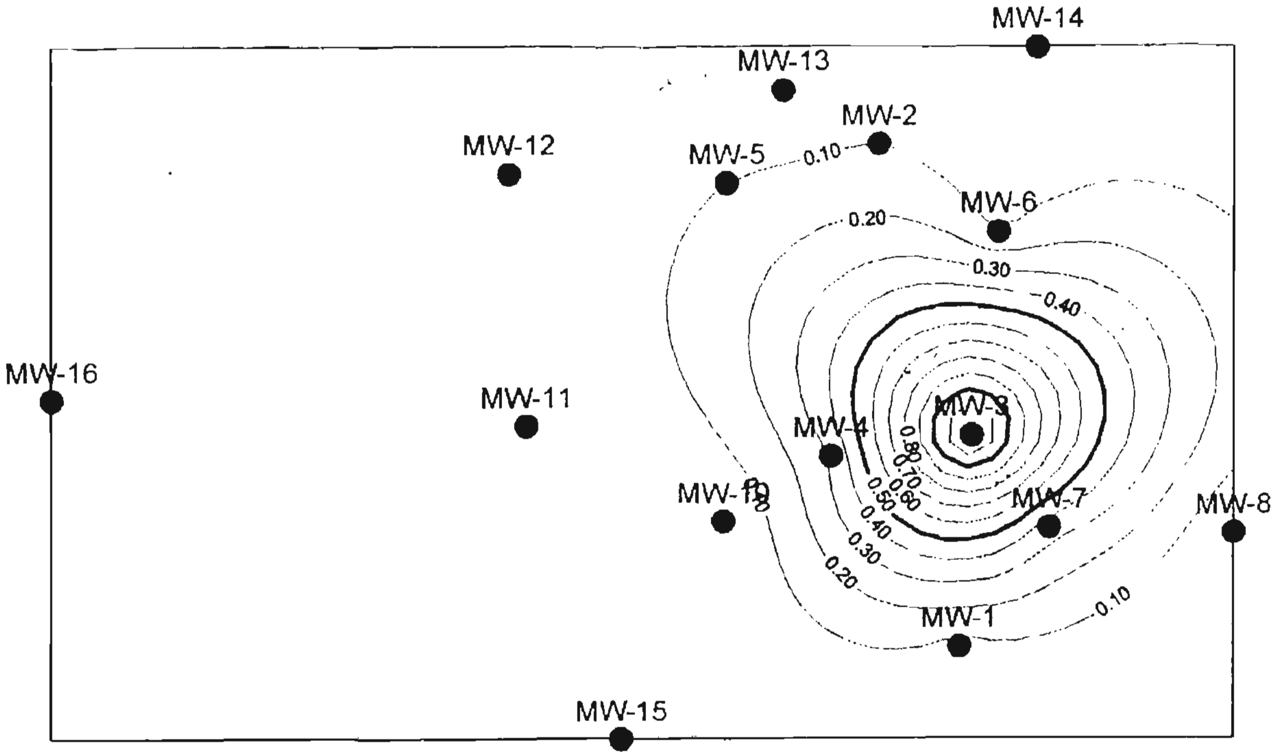


Ethylbenzene Isopleth Map (mg/L)
Apr. 14, 1998
Kriging Method

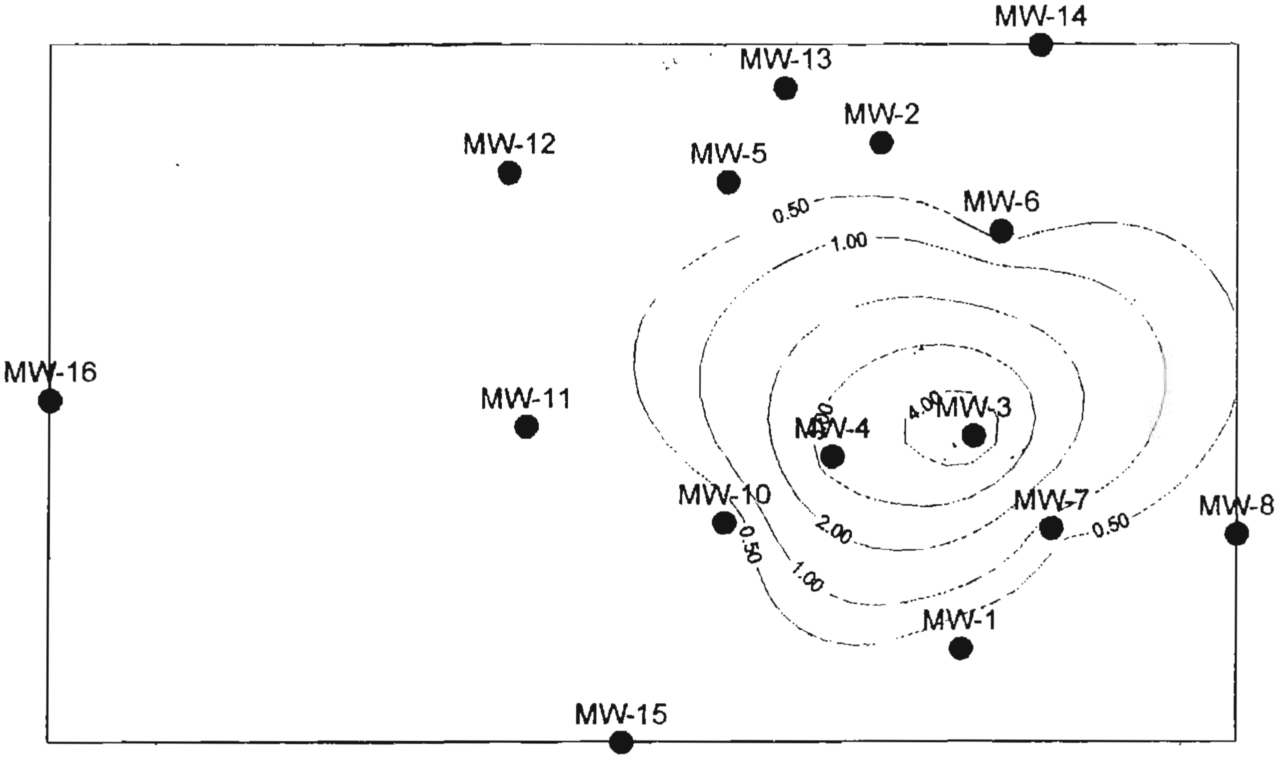


XYLENE ISOPLETH MAPS

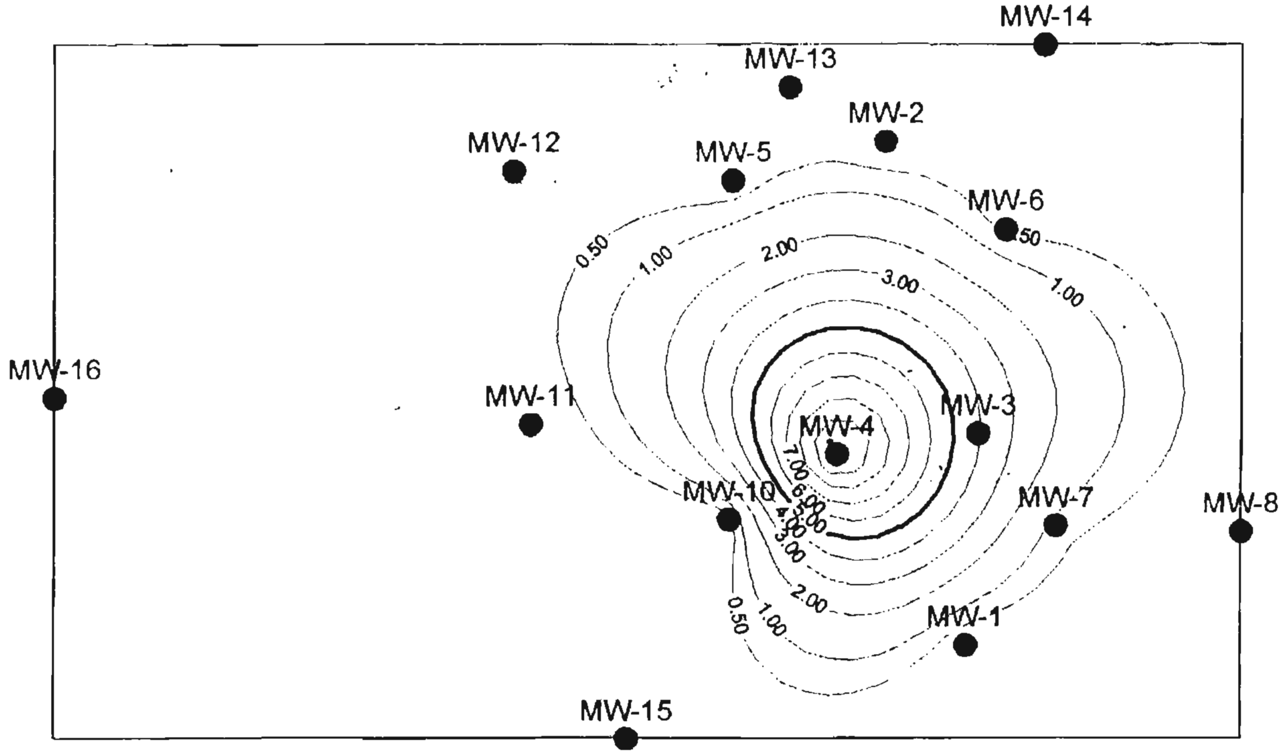
Xylene Isopleth Map (mg/L);
Oct. 20, 1997
Kriging Method



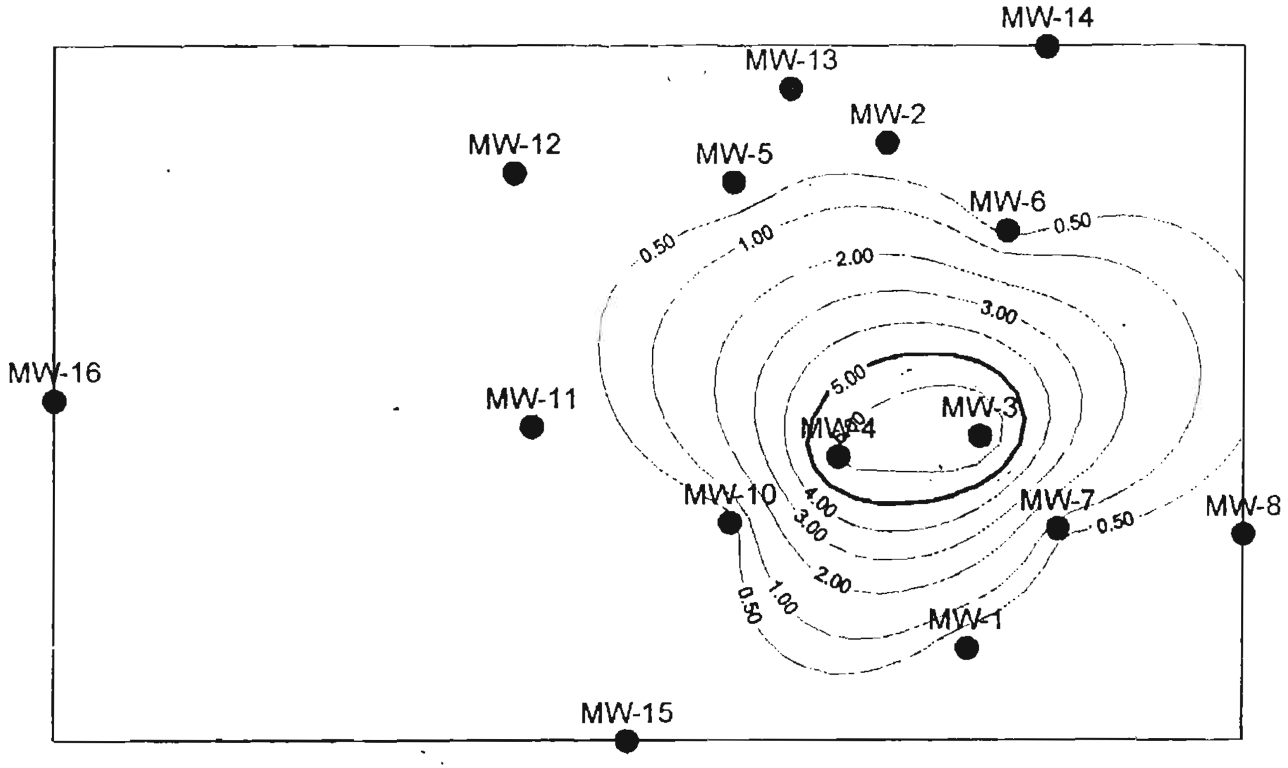
Xylene Isopleth Map (mg/L)
Dec. 15, 1997
Kriging Method



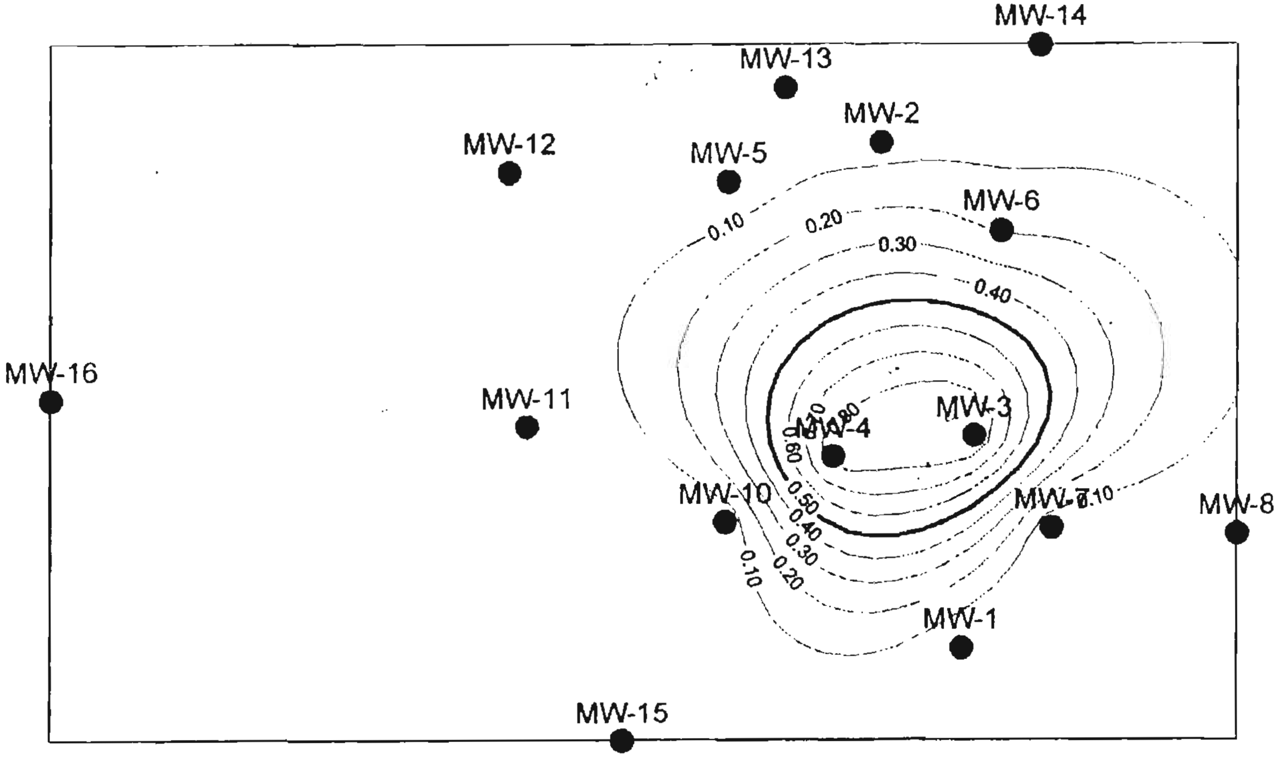
Xylene Isopleth Map (mg/L)
Jan 20, 1998
Kriging Method



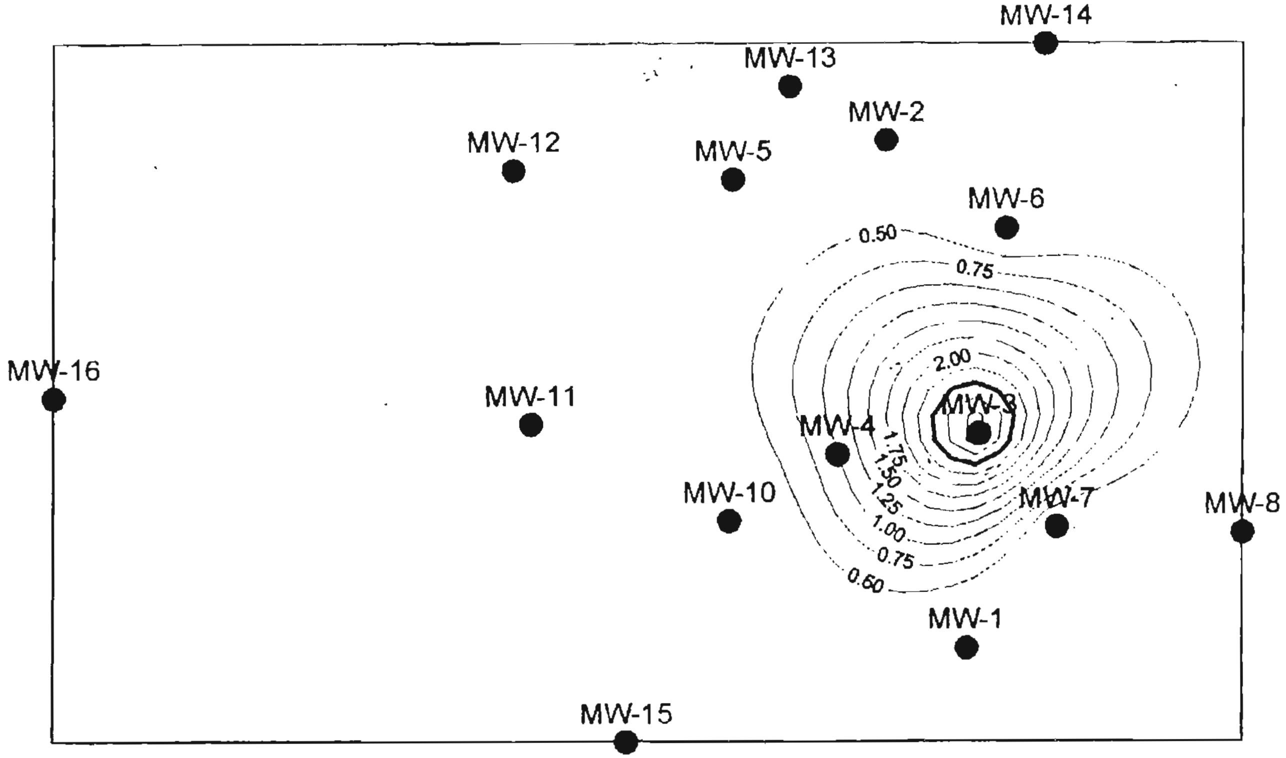
Xylene Isopleth Map (mg/L)
Feb. 17, 1998
Kriging Method



Xylene Isopleth Map (mg/L)
Mar. 24, 1998
Kriging Method

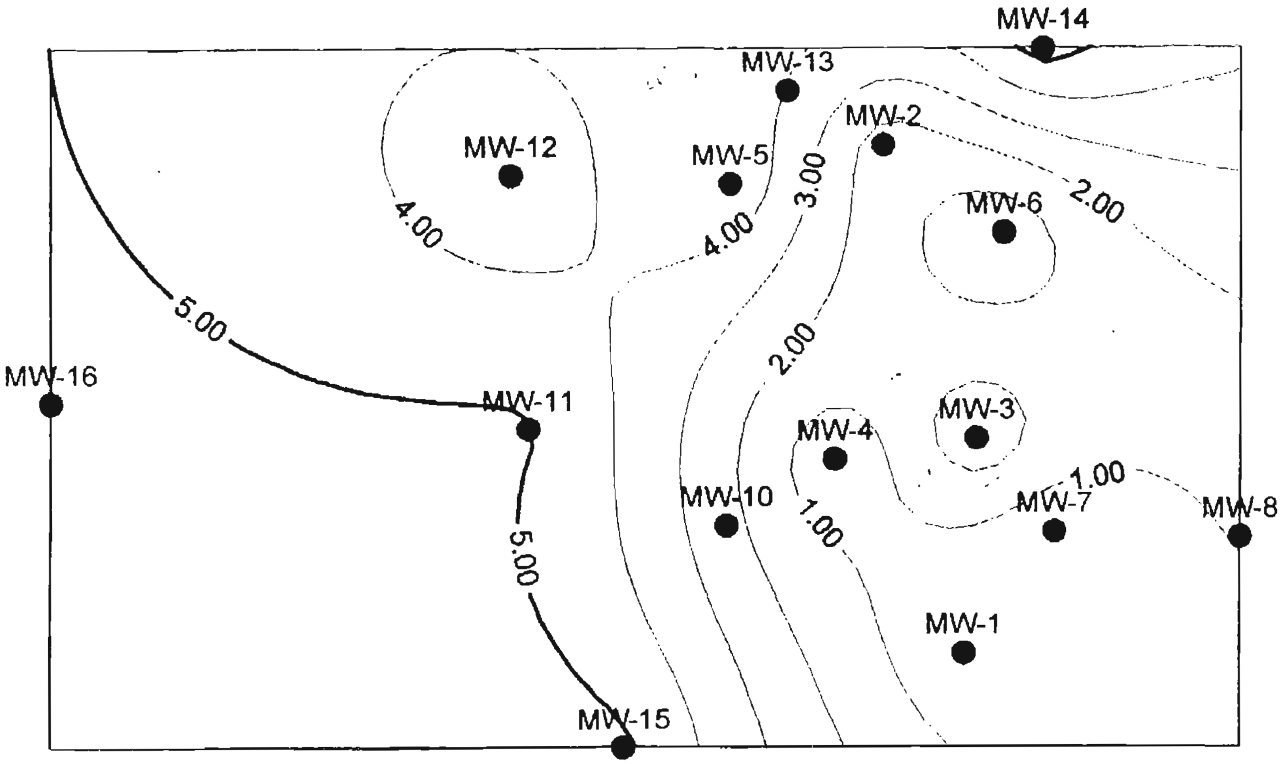


Xylene Isopleth Map (mg/L)
Apr. 14, 1998
Kriging Method

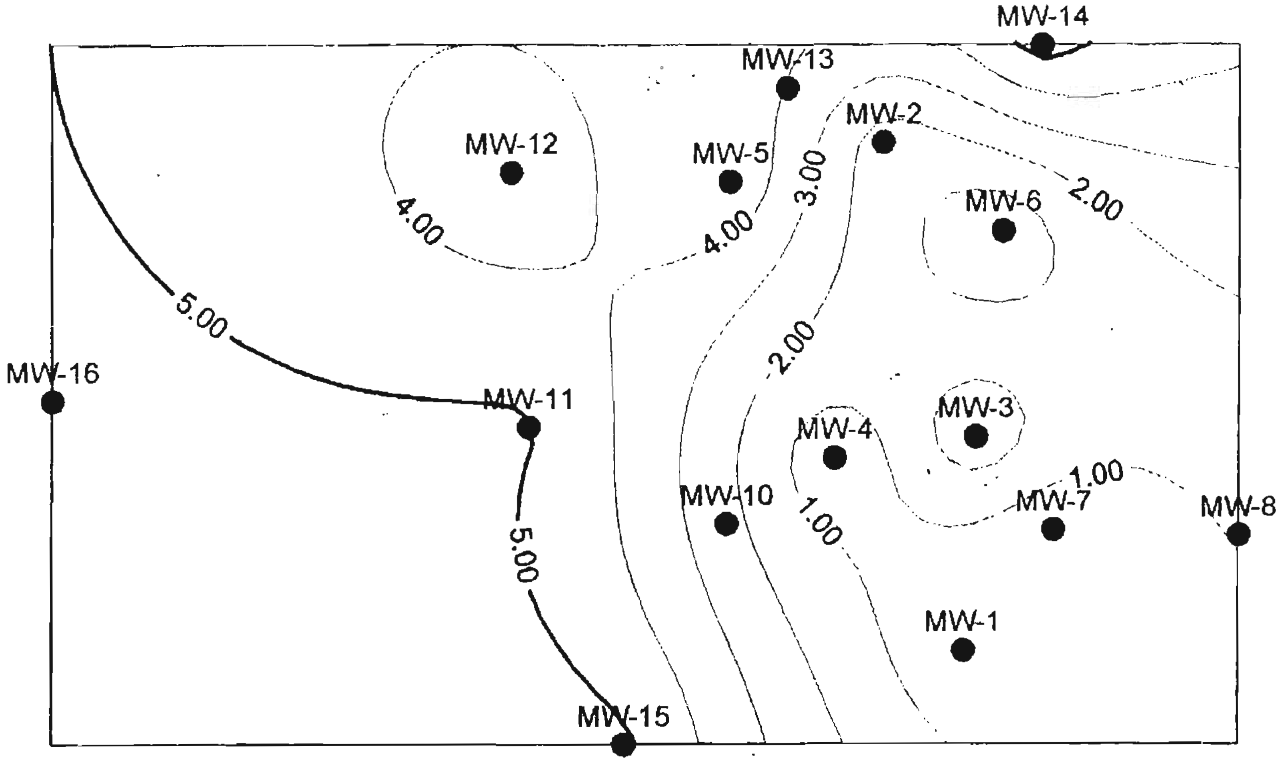


DO ISOPLETH MAPS

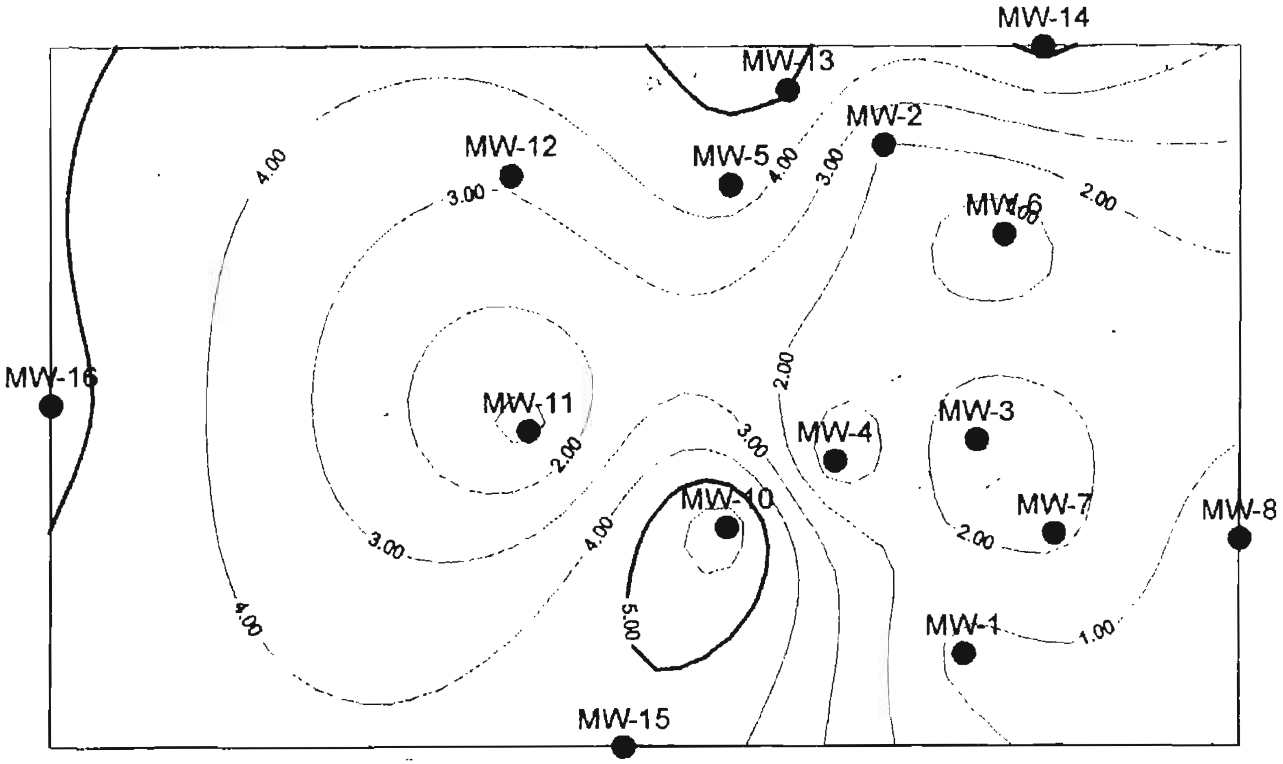
Dissolved Oxygen (DO) Isopleth Map (mg/L)
Oct. 20, 1997
Kriging Method



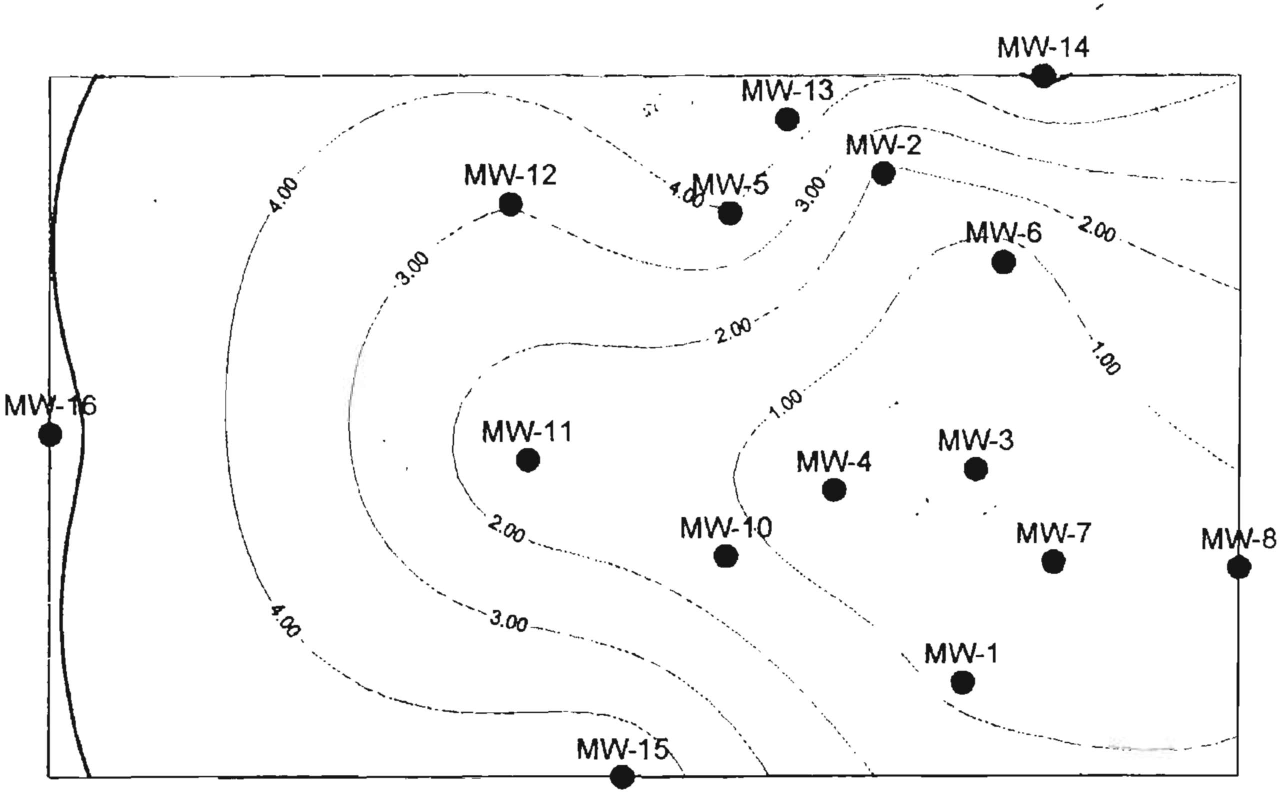
Dissolved Oxygen (DO) Isopleth Map (mg/L)
Dec 15, 1997
Kriging Method



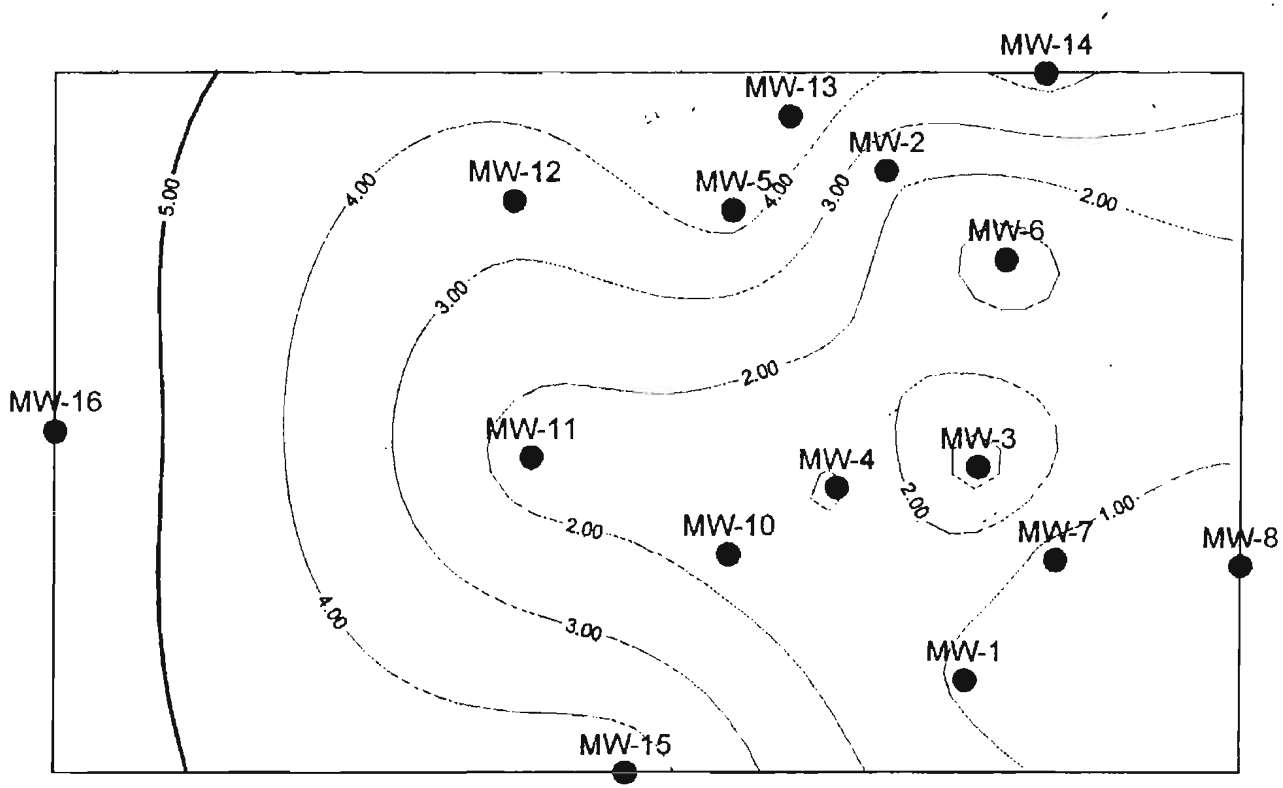
Dissolved Oxygen (DO) Isopleth Map (mg/L)
Jan. 20, 1998
Kriging Method



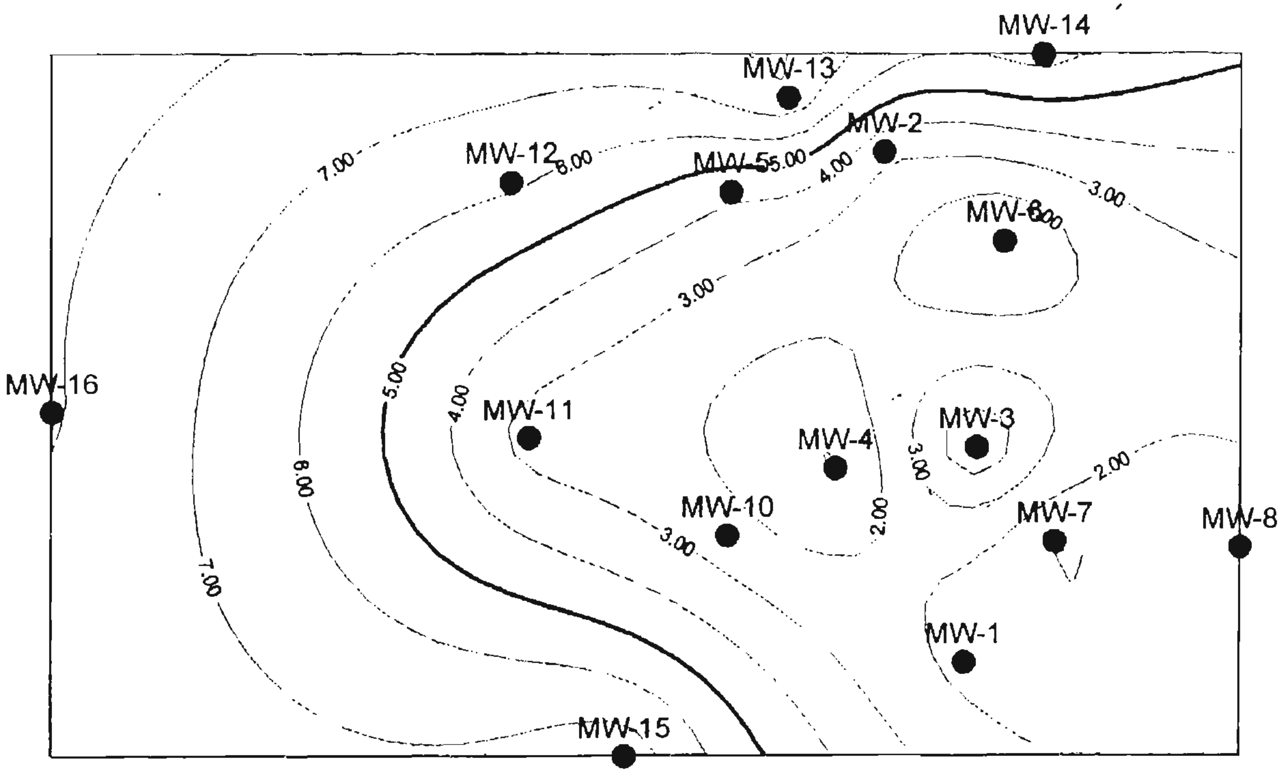
Dissolved Oxygen (DO) Isopleth Map (mg/L)
Feb. 17, 1998
Kriging Method



Dissolved Oxygen (DO) Isopleth Map (mg/L)
Mar. 24, 1998
Kriging Method

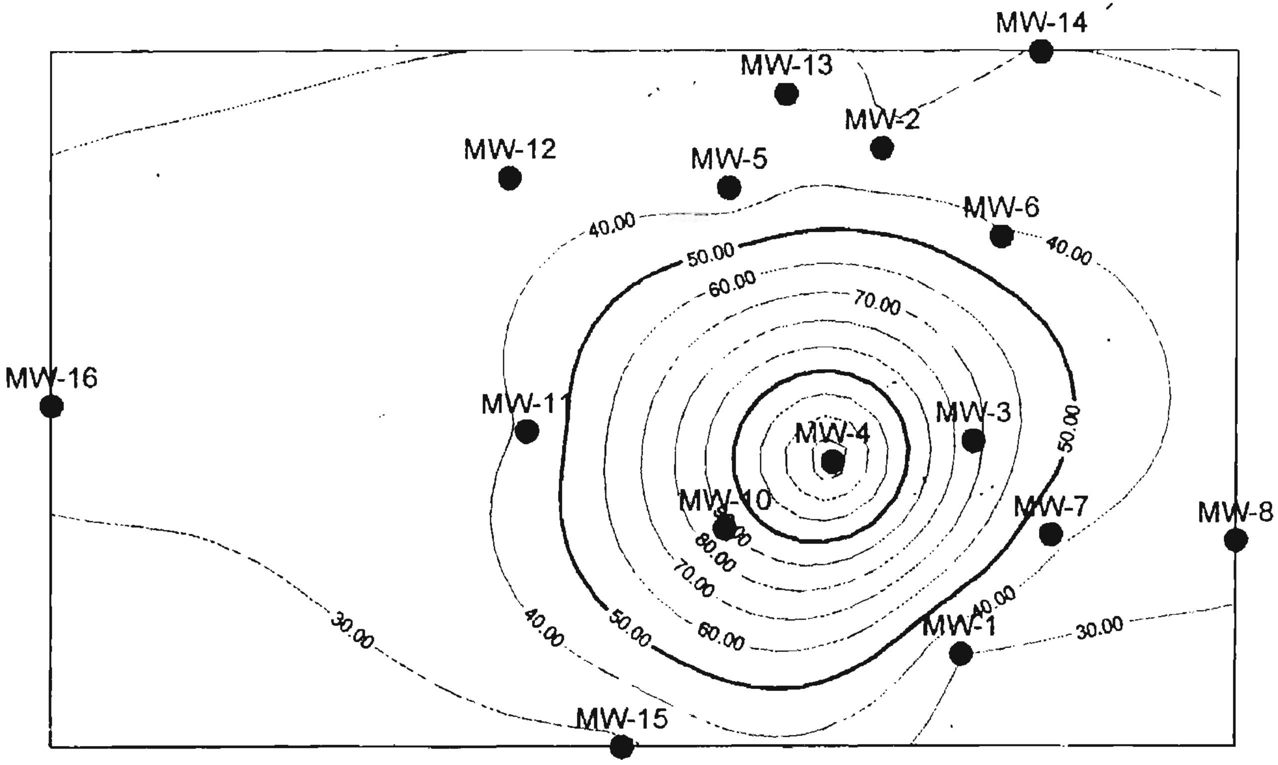


Dissolved Oxygen (DO) Isopleth Map (mg/L)
Apr. 14, 1998
Kriging Method

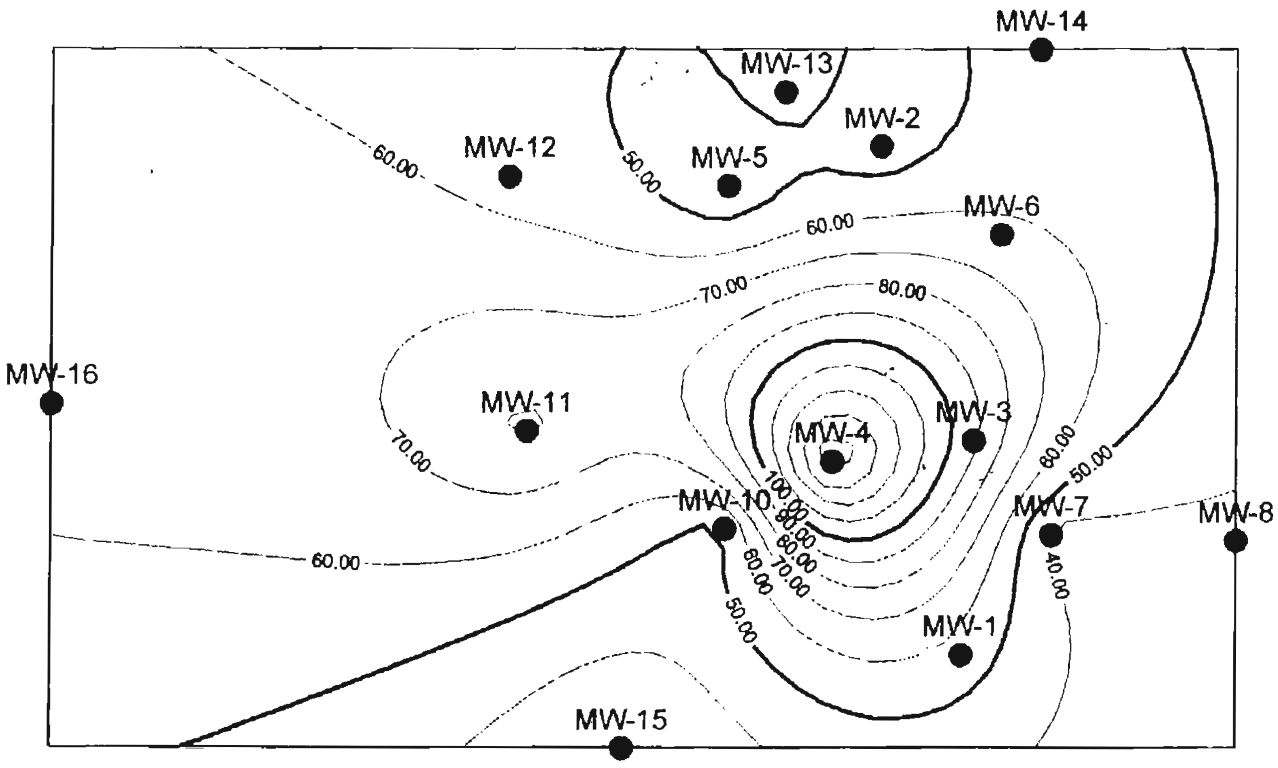


TOC ISOPLETH MAPS

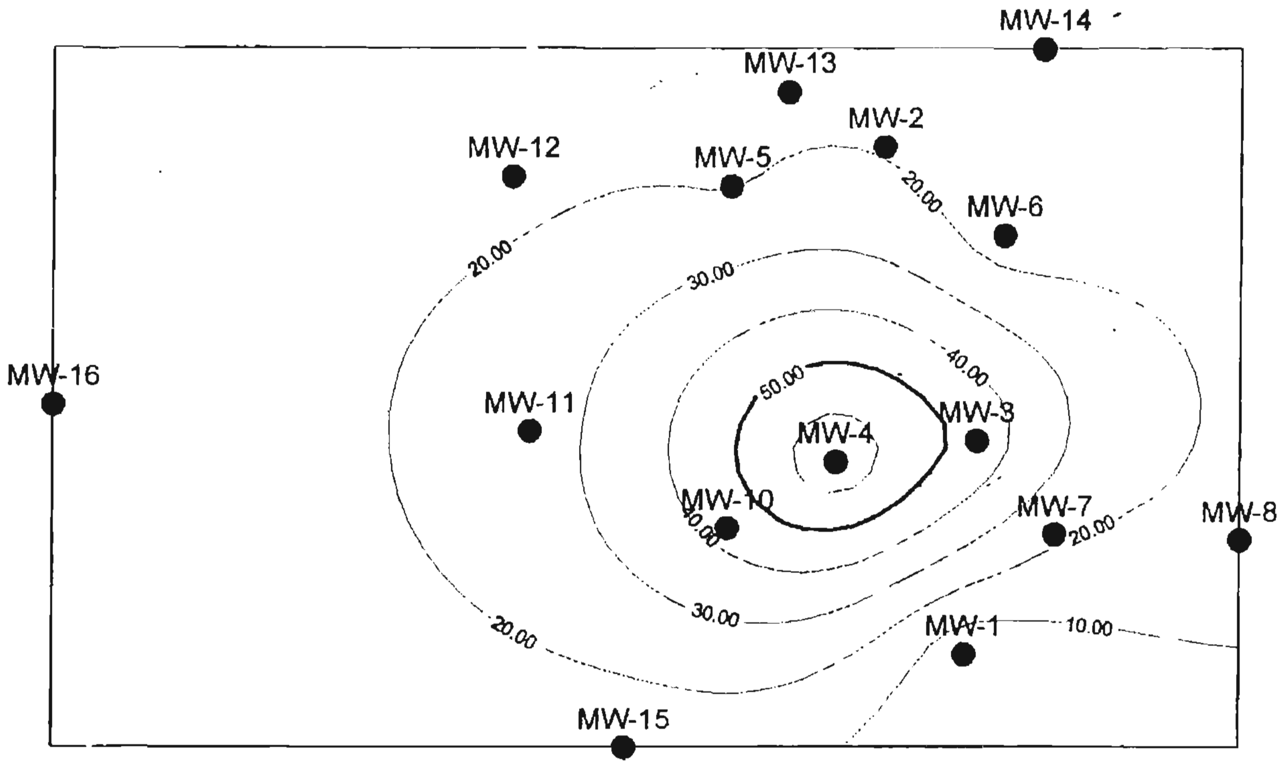
Total Organic Carbon (TOC) Isopleth Map (mg/L)
Oct. 20, 1997
Kriging Method



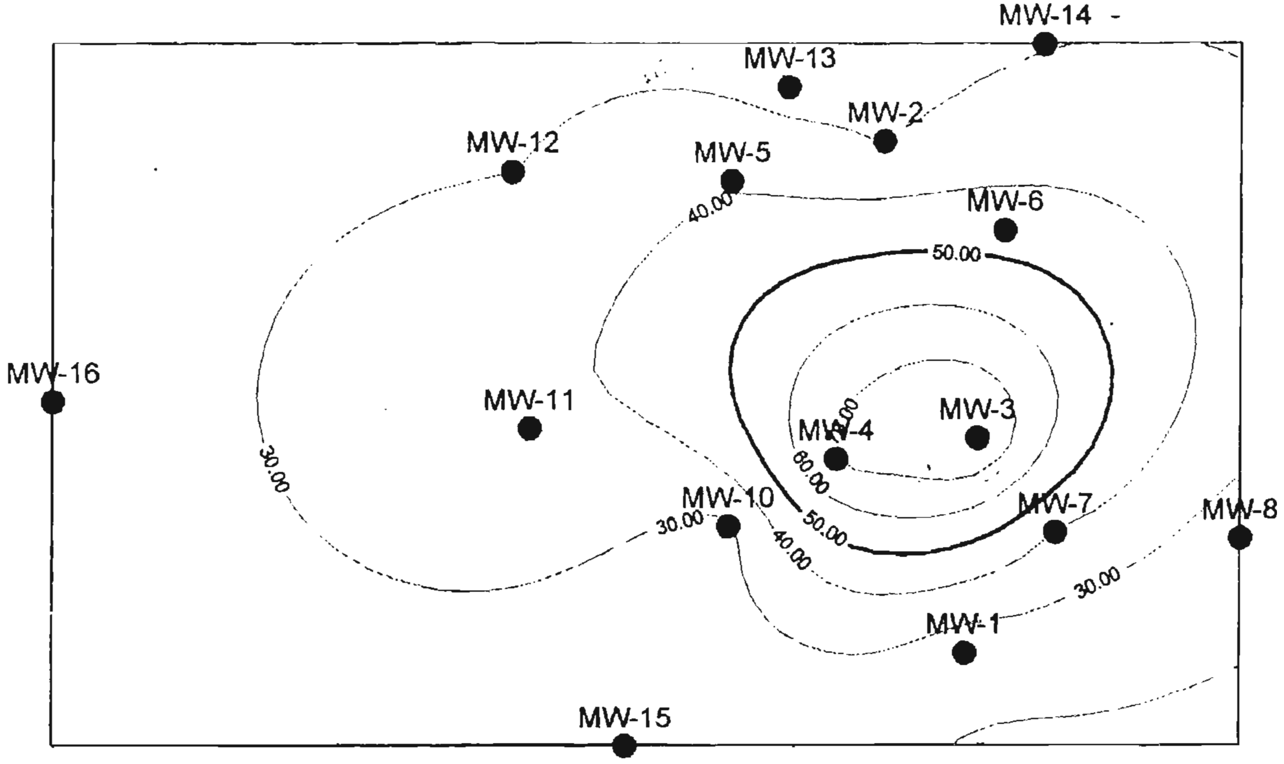
Total Organic Carbon (TOC) Isopleth Map (mg/L)
Dec. 15, 1997
Kriging Method



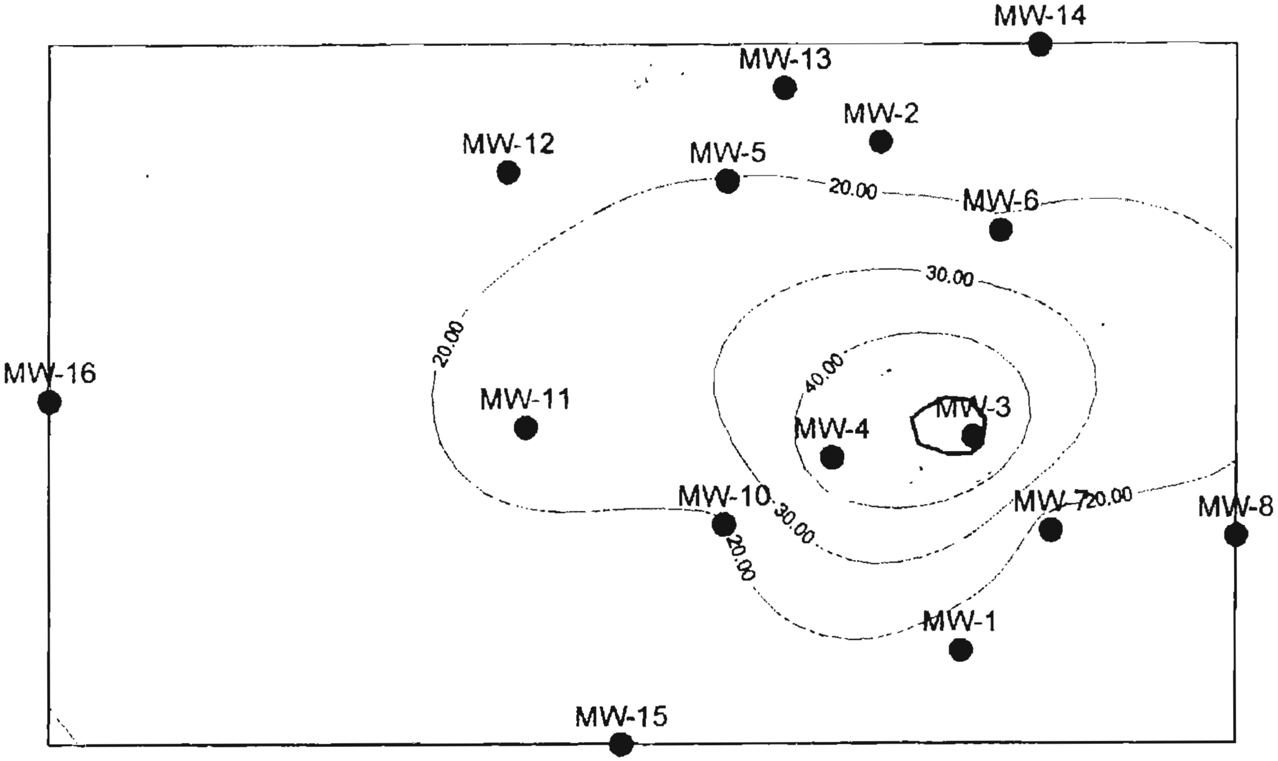
Total Organic Carbon (TOC) Isopleth Map (mg/L)
Jan. 20 ,1998
Kriging Method



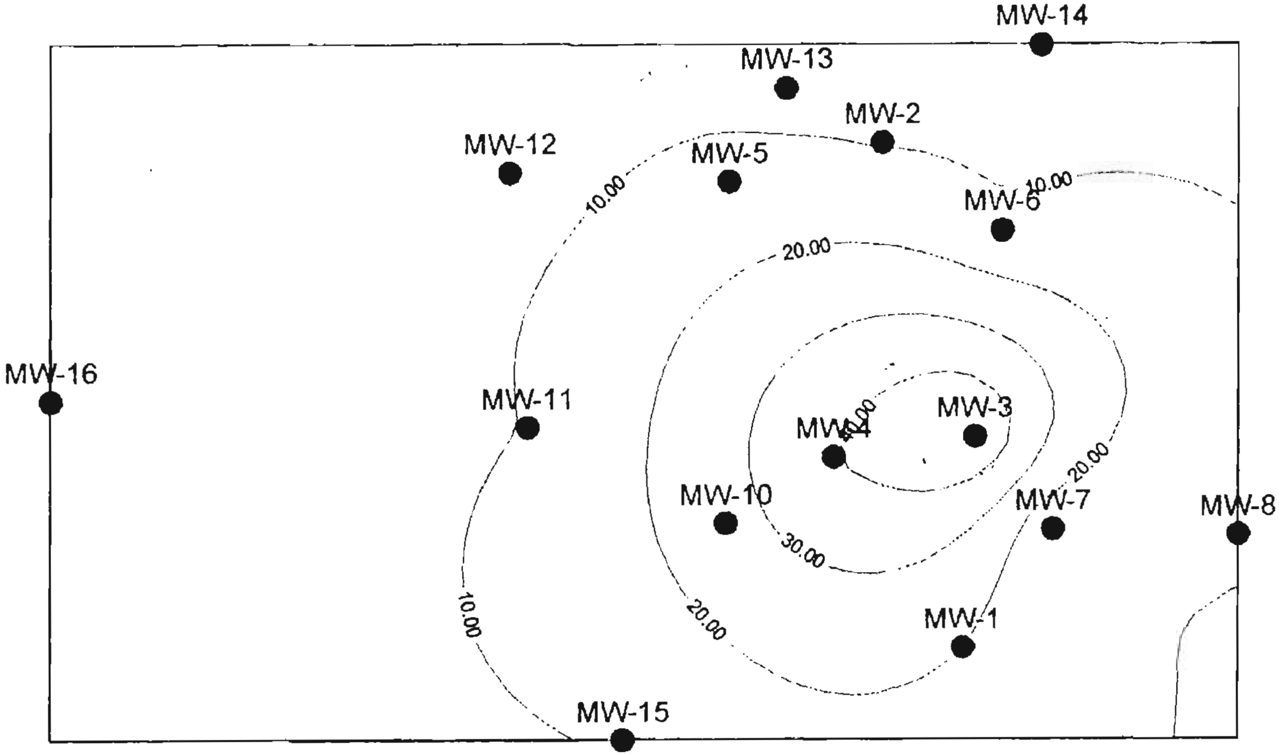
Total Organic Carbon (TOC) Isopleth Map (mg/L)
Feb. 17, 1998
Kriging Method



Total Organic Carbon (TOC) Isopleth Map (mg/L)
Mar. 24, 1998
Kriging Method

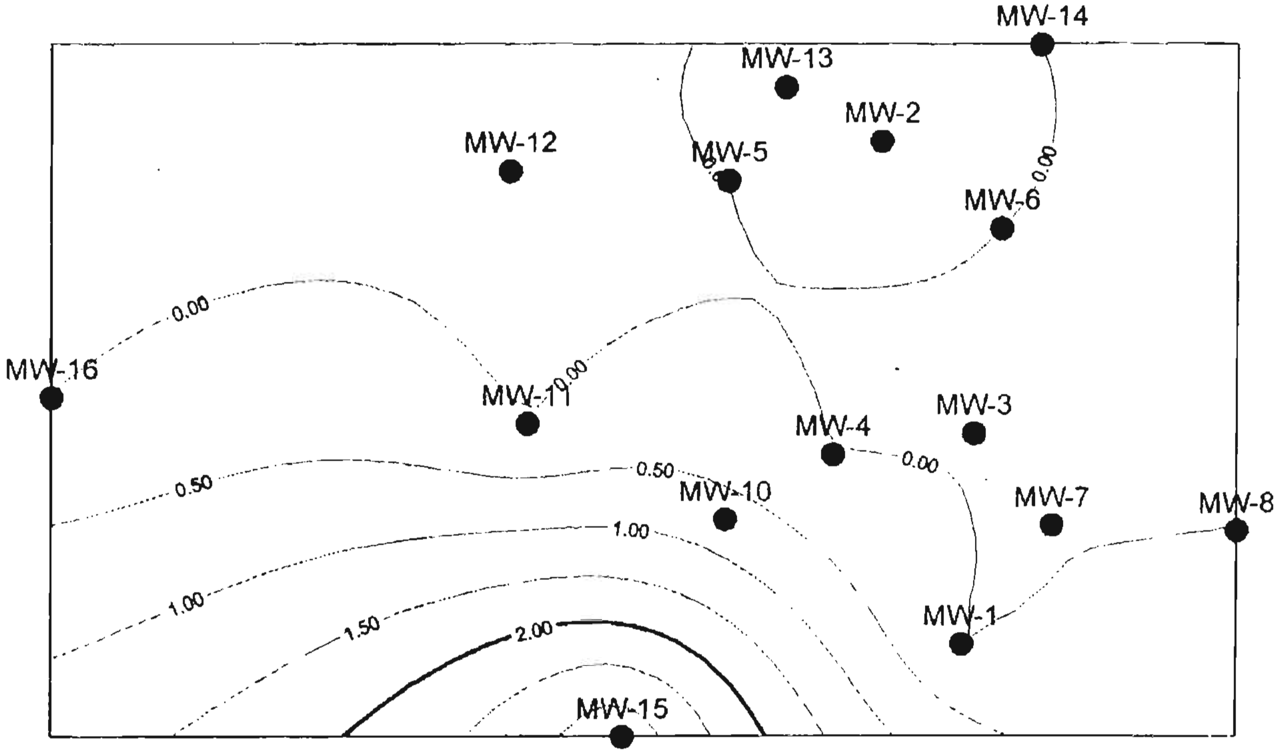


Total Organic Carbon (TOC) Isopleth Map (mg/L)
Apr. 14, 1998
Kriging Method

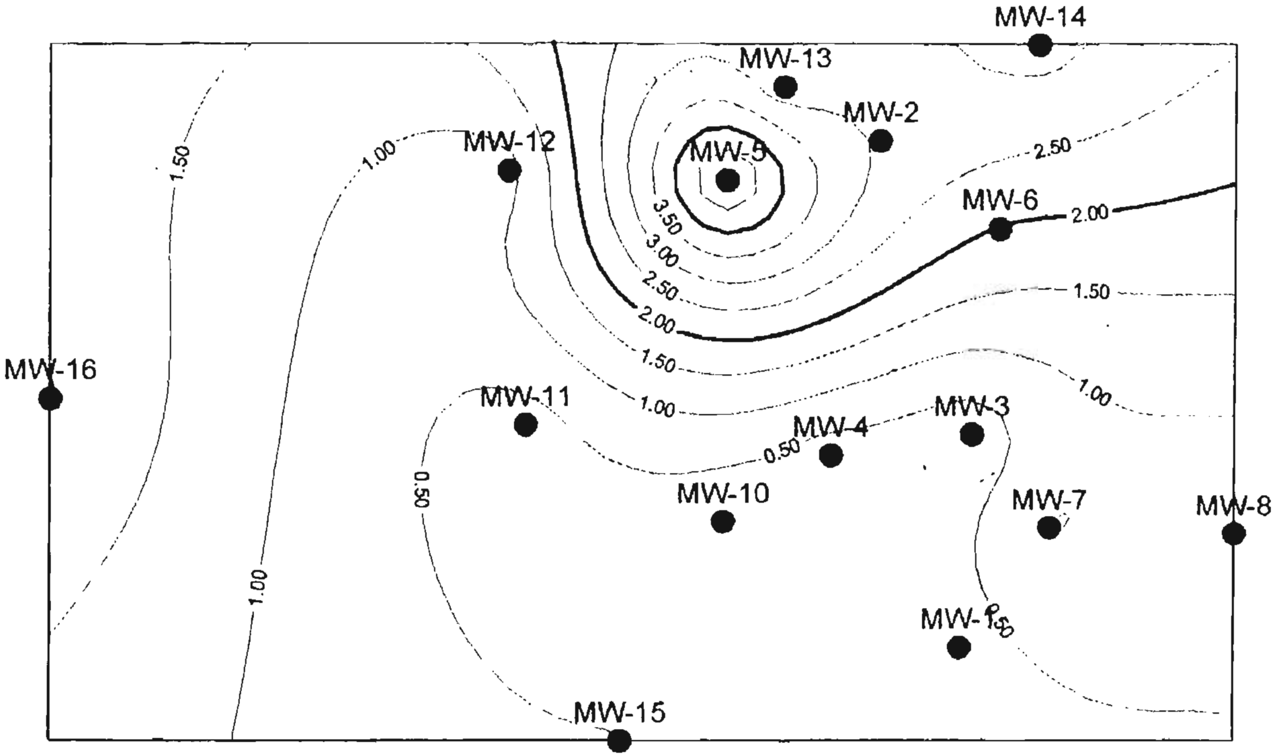


PHOSPHATE ISOPLETH MAPS

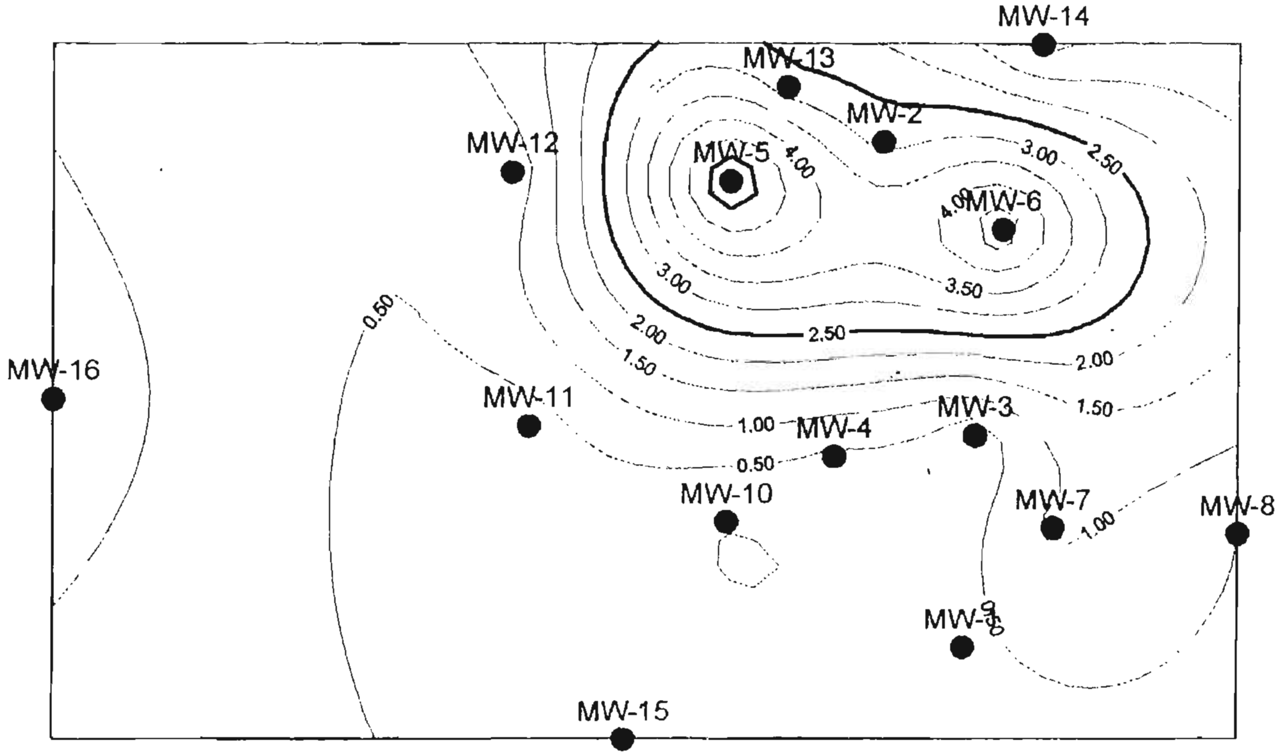
Phosphate Isopleth Map (mg/L)
Oct. 20, 1997
Kriging Method



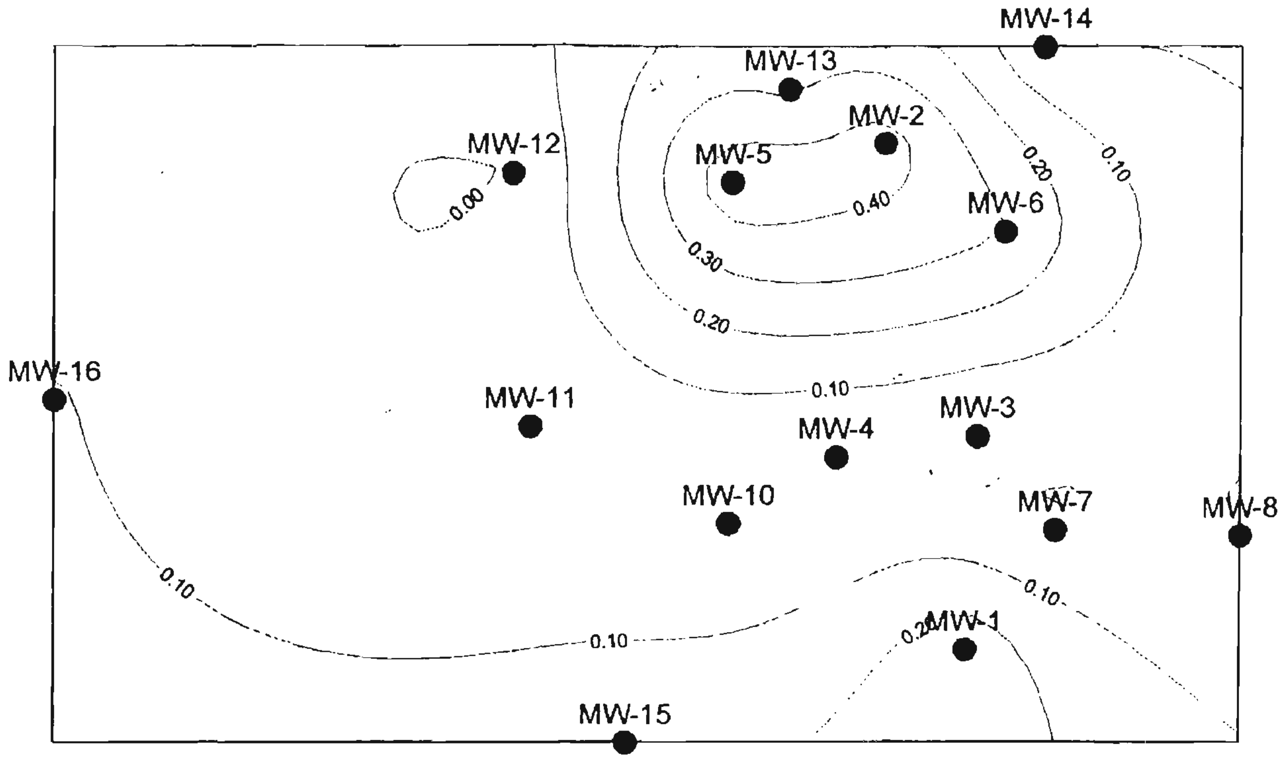
Phosphate Isopleth Map (mg/L)
Dec. 15, 1997
Kriging Method



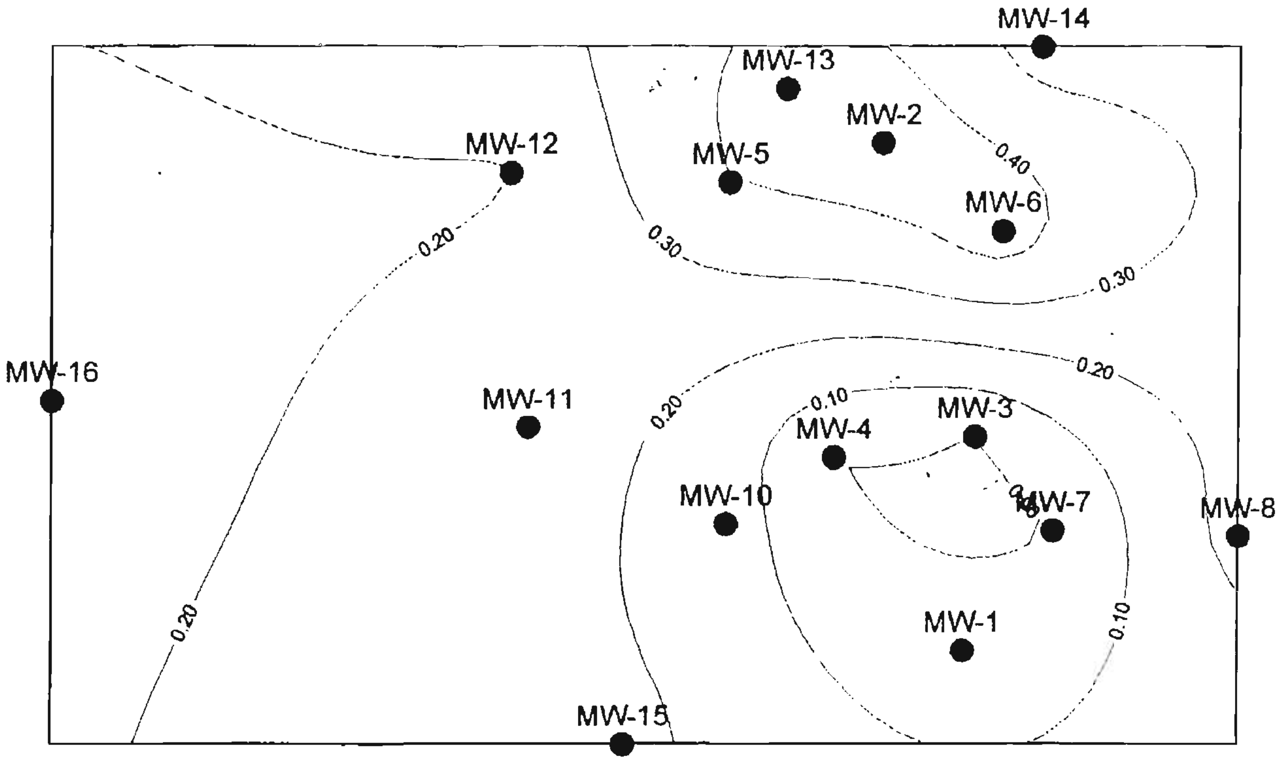
Phosphate Isopleth Map (mg/L)
Jan. 20, 1998
Kriging Method



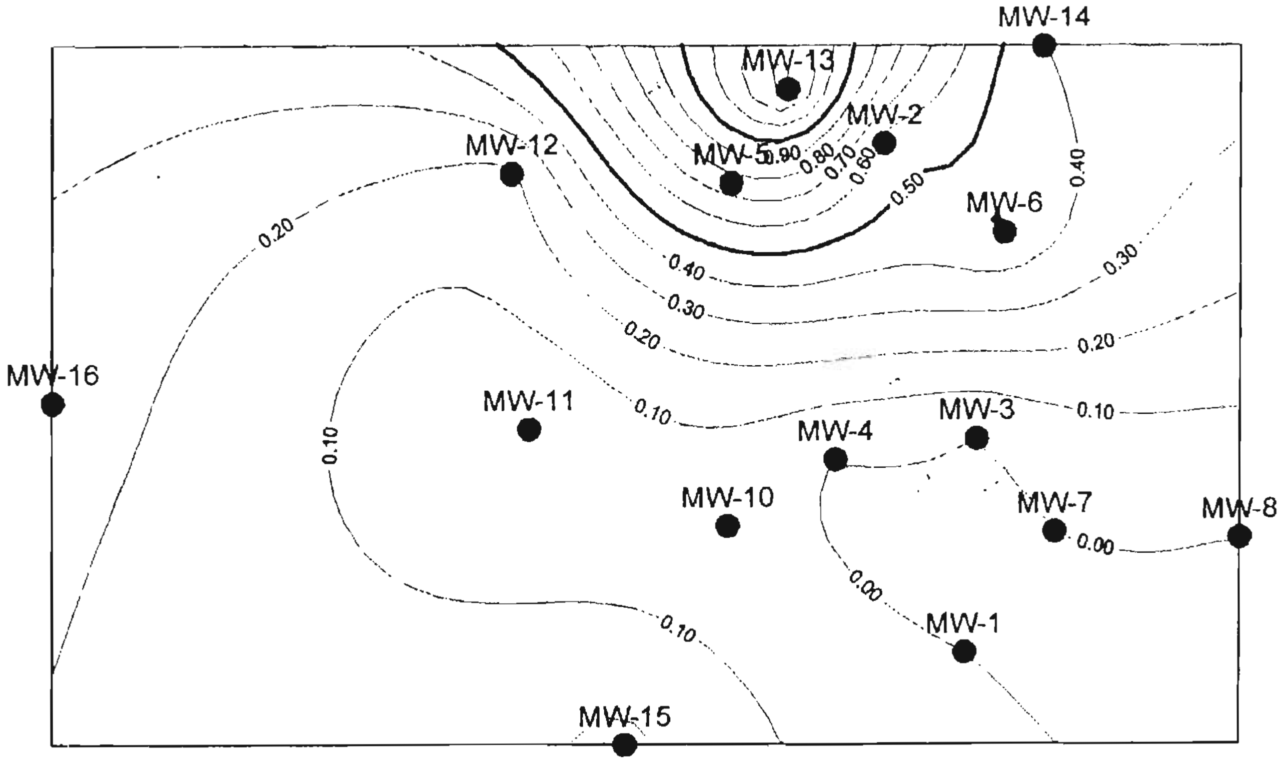
Phosphate Isopleth Map (mg/L)
Feb. 17, 1998
Kriging Method



Phosphate Isopleth Map (mg/L)
Mar. 24, 1998
Kriging Method

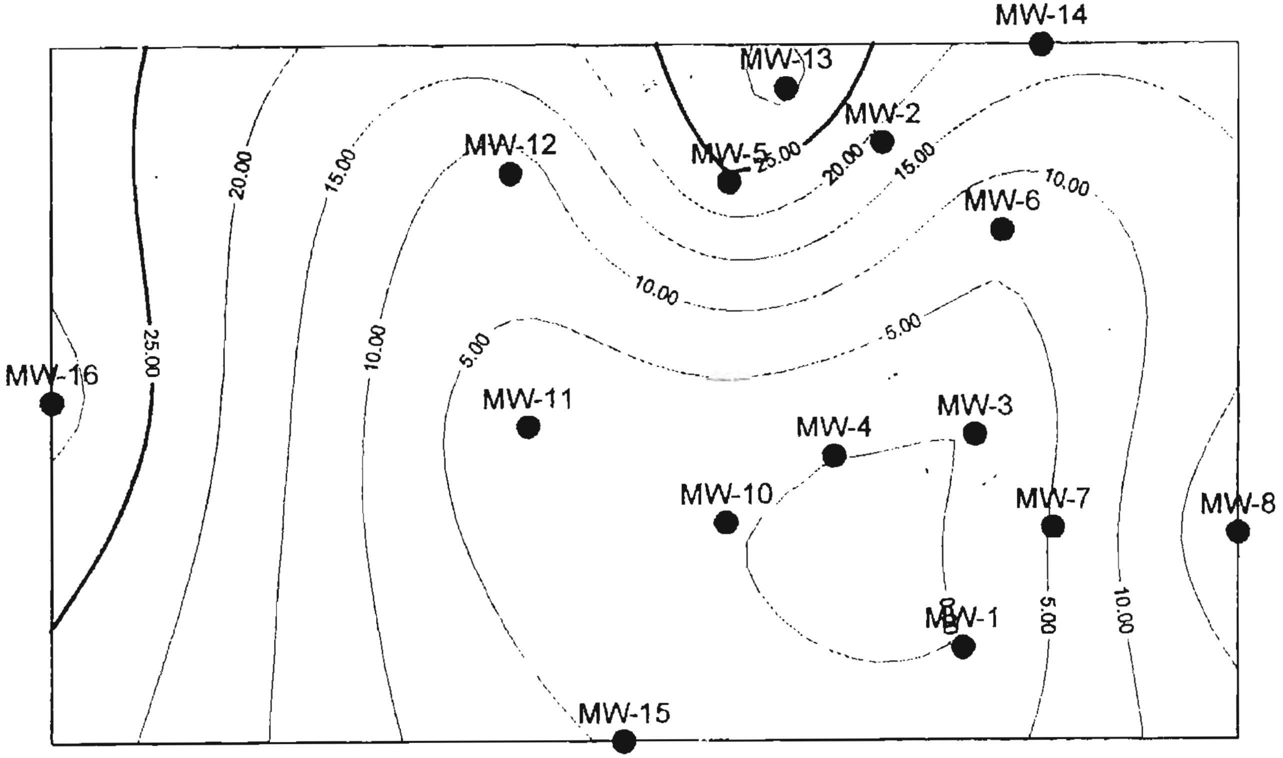


Phosphate Isopleth Map (mg/L)
Apr. 14, 1998
Kriging Method

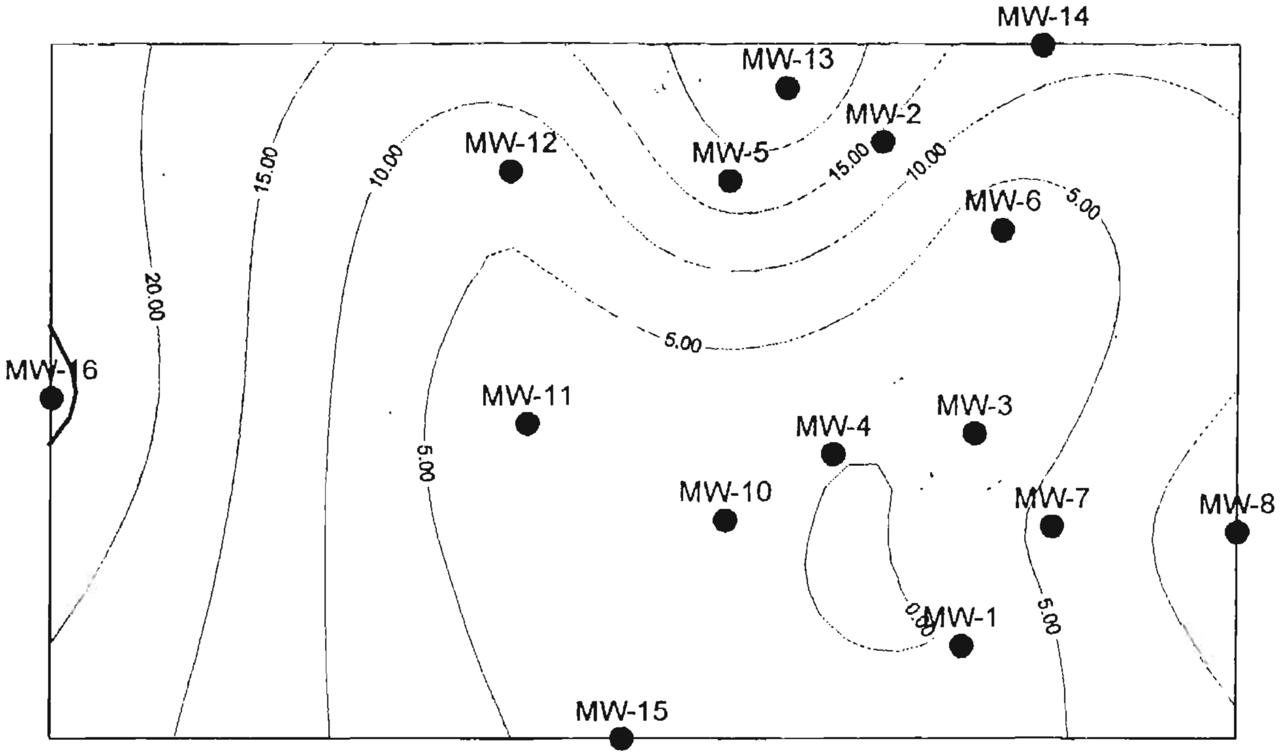


NITRATE ISOPLETH MAPS

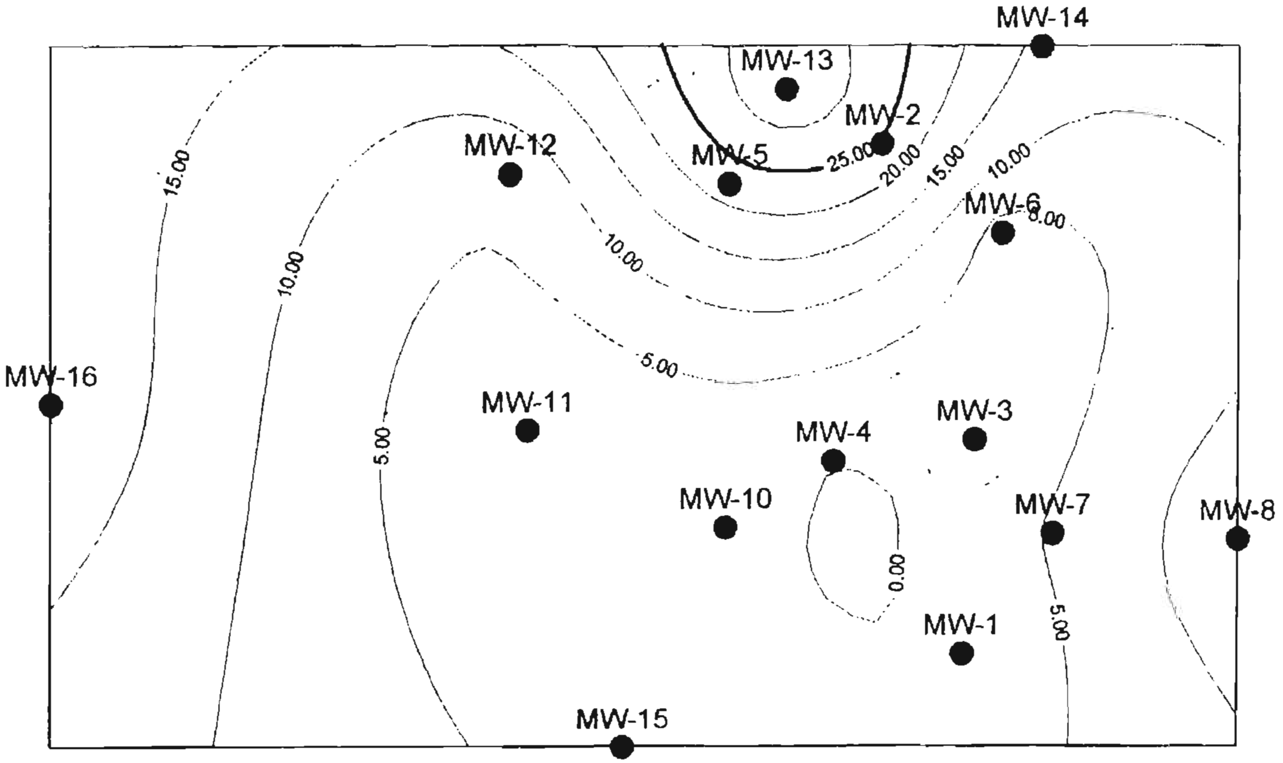
Nitrate Isopleth Map (mg/L)
Oct. 20, 1997
Kriging Method



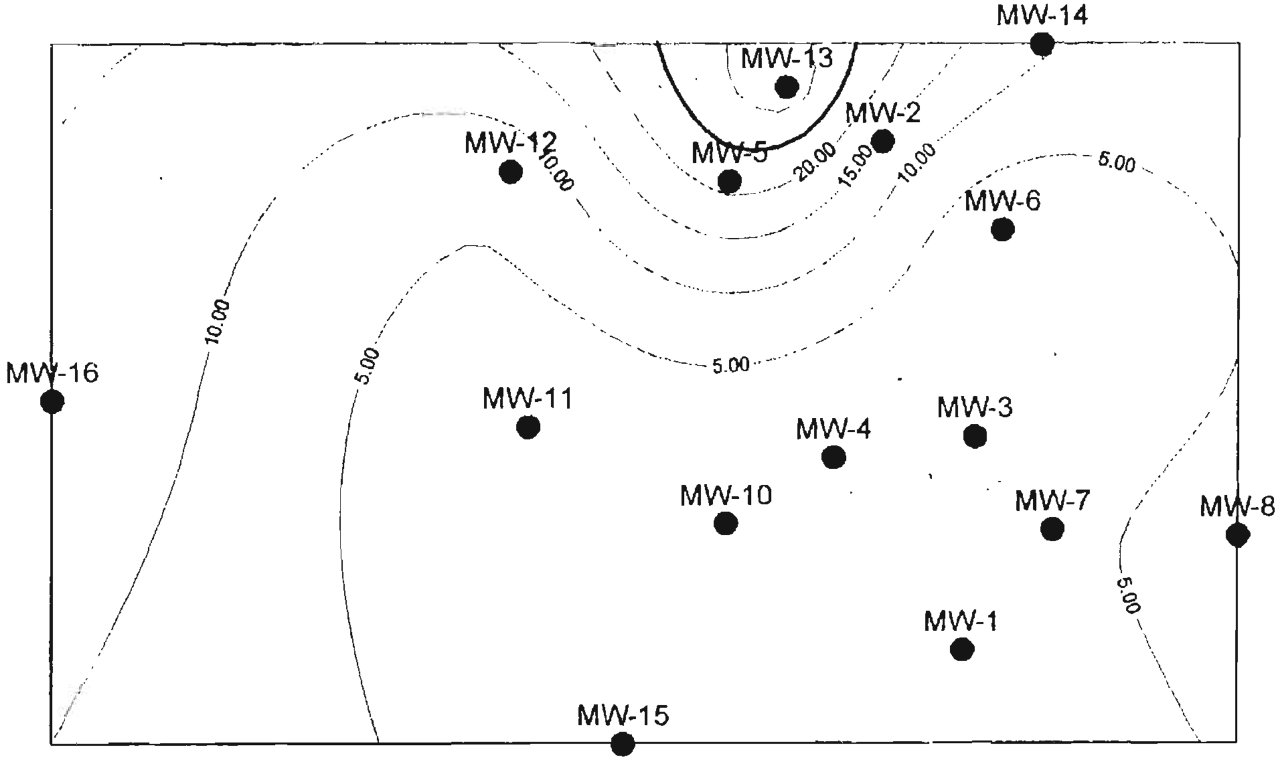
Nitrate Isopleth Map (mg/L)
Dec. 15, 1997
Kriging Method



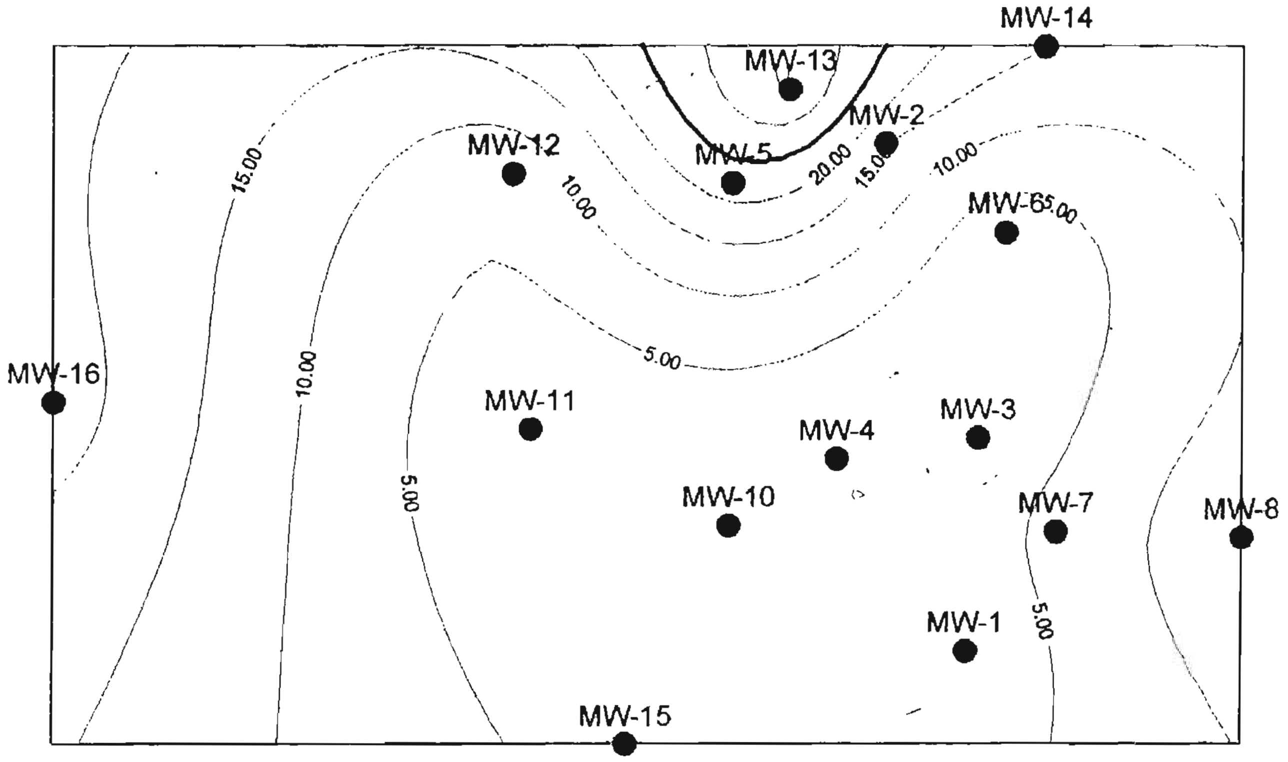
Nitrate Isopleth Map (mg/L)
Jan. 20, 1998
Kriging Method



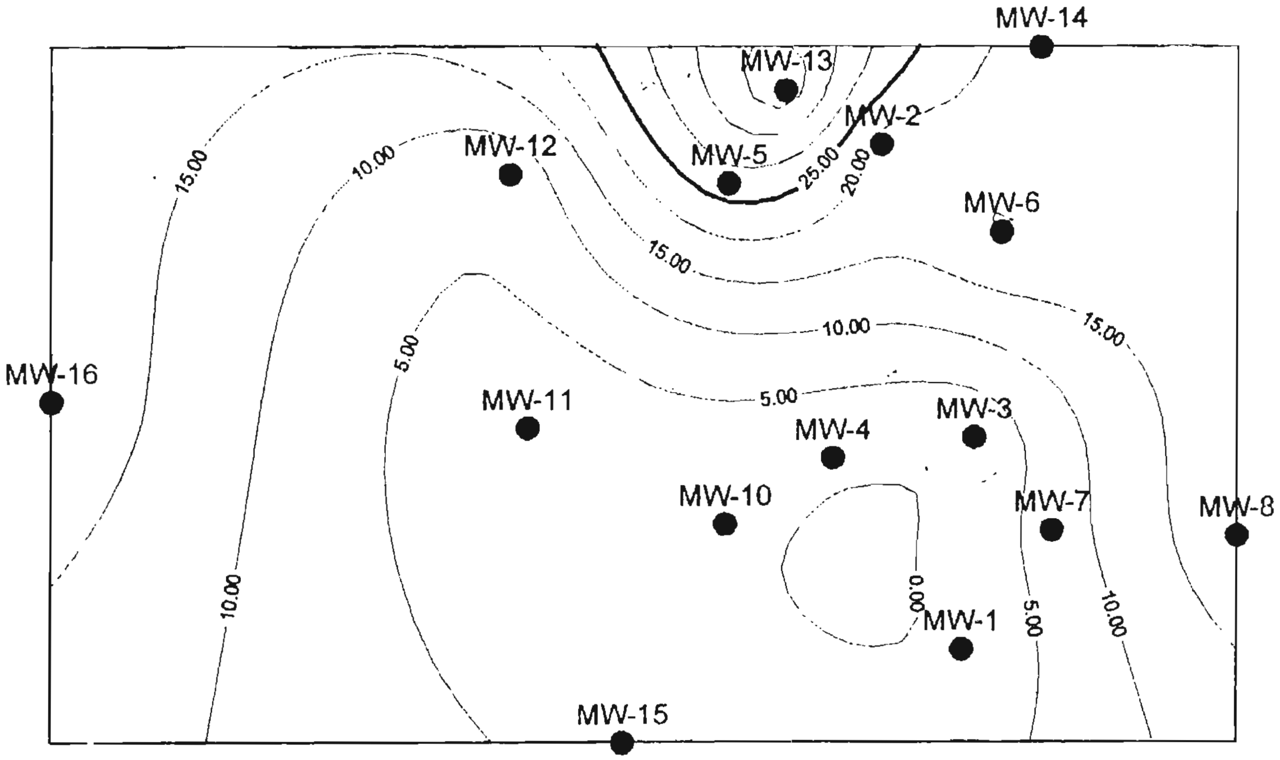
Nitrate Isopleth Map (mg/L)
Feb. 17, 1998
Kriging Method



Nitrate Isopleth Map (mg/L)
Mar. 24, 1998
Kriging Method

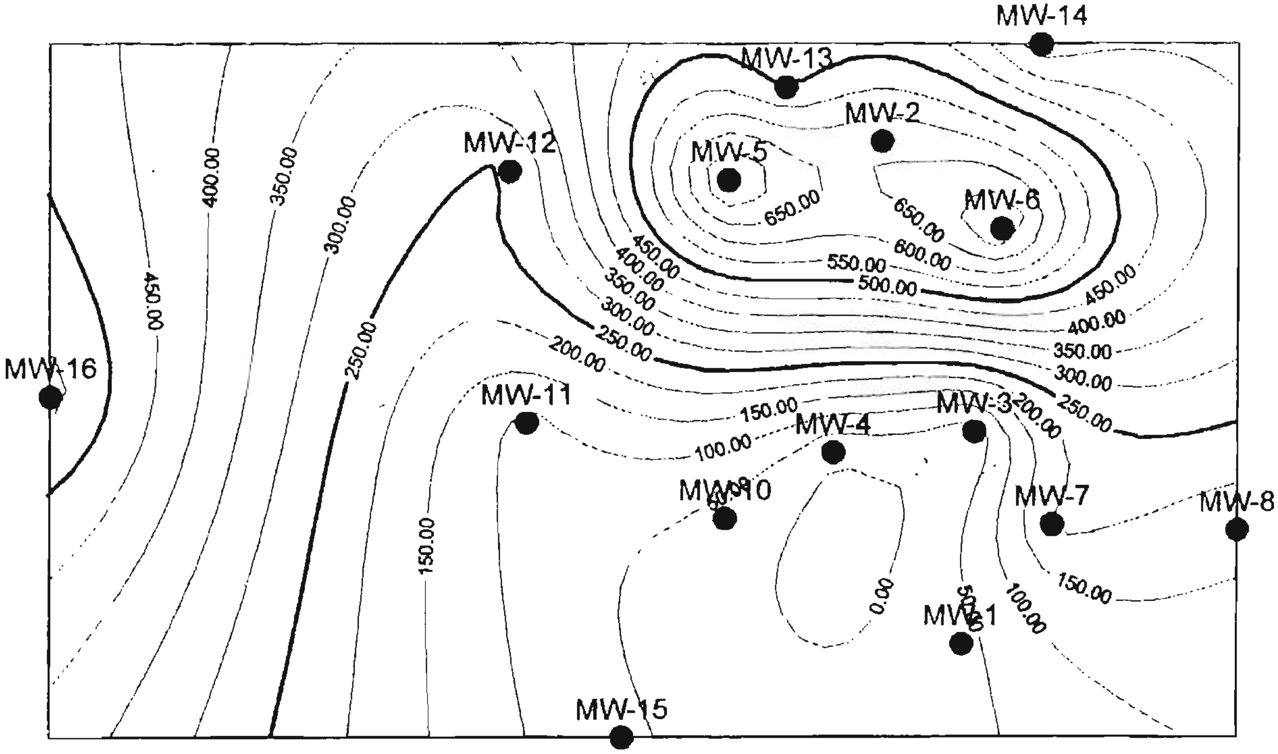


Nitrate Isopleth Map (mg/L)
Apr. 14, 1998
Kriging Method

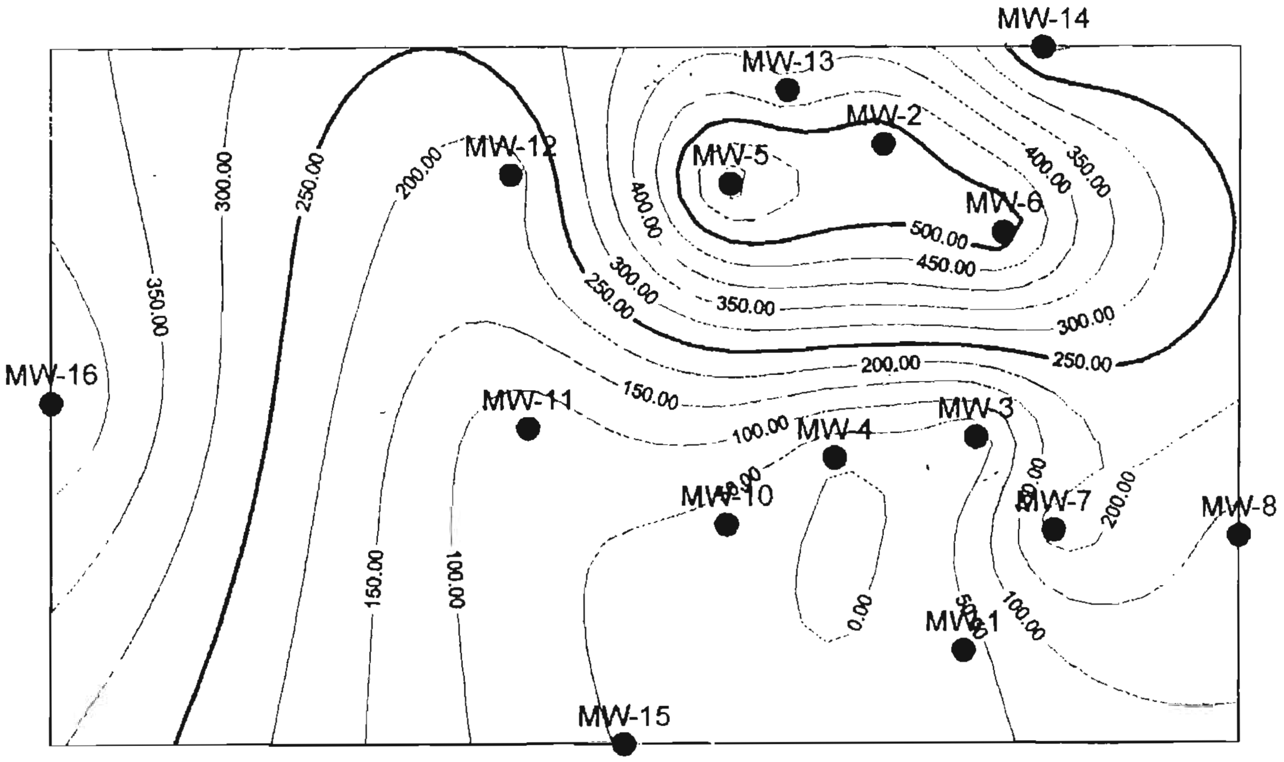


SULFATE ISOPLETH MAPS

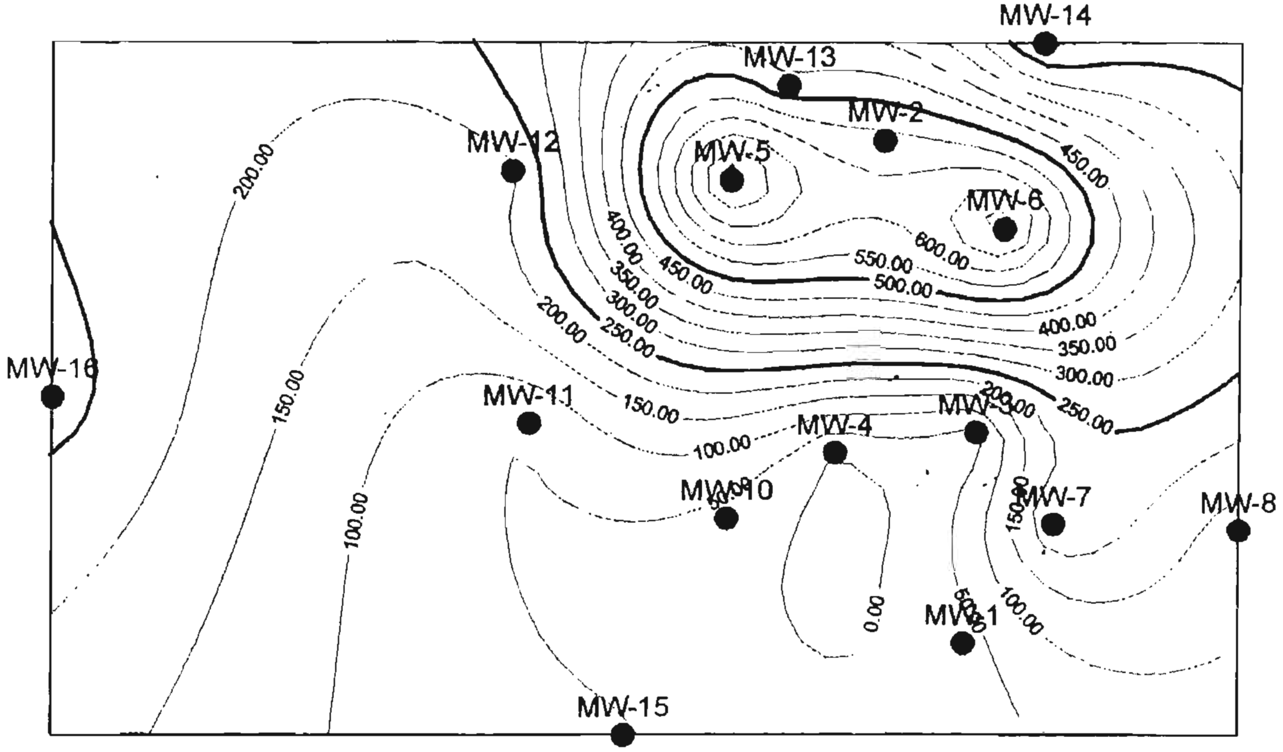
Sulfate Isopleth Map (mg/L)
Oct. 20, 1997
Kriging Method



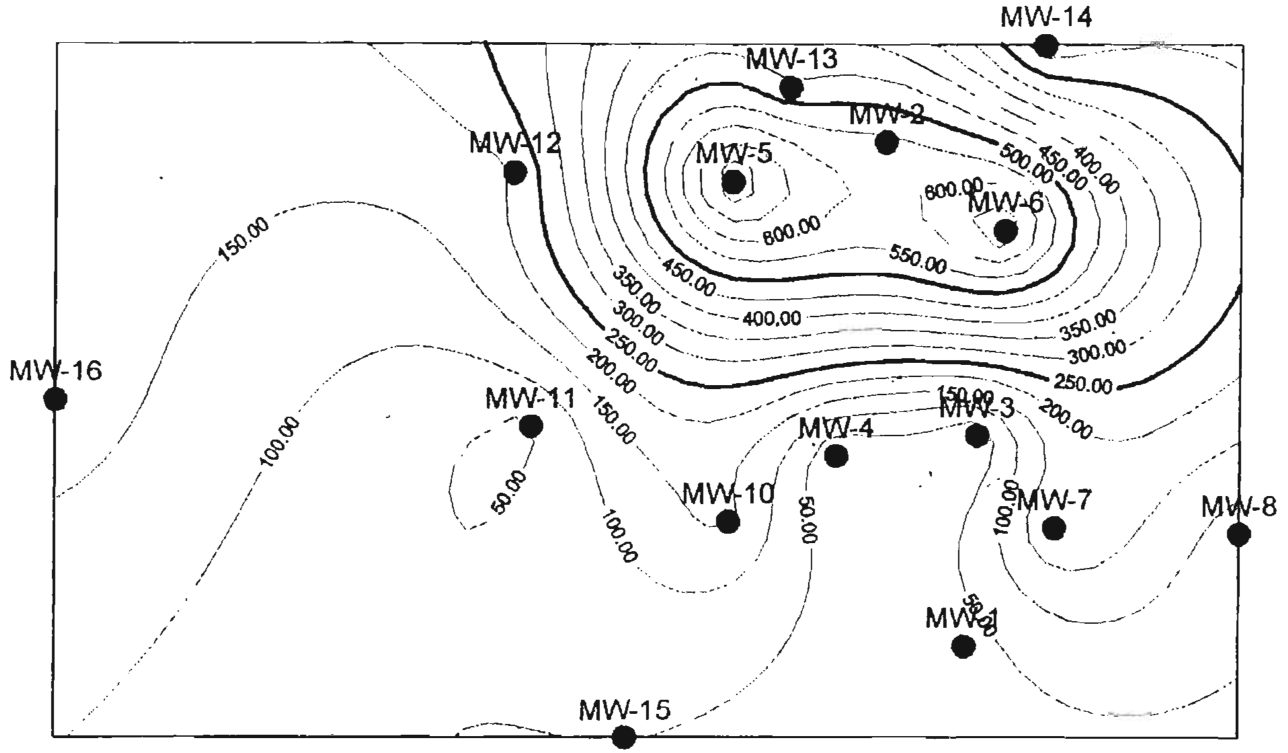
Sulfate Isopleth Map (mg/L)
Dec. 15, 1997
Kriging Method



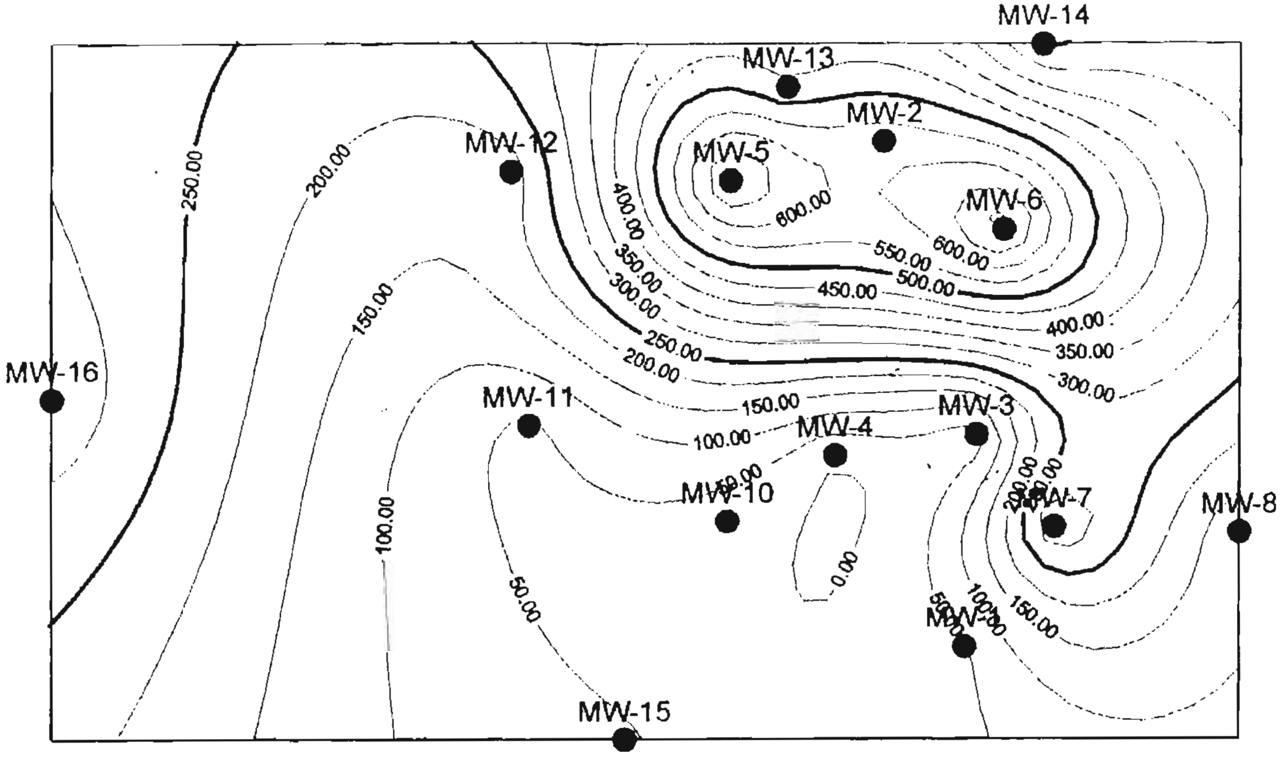
Sulfate Isopleth Map (mg/L)
Jan. 20, 1998
Kriging Method



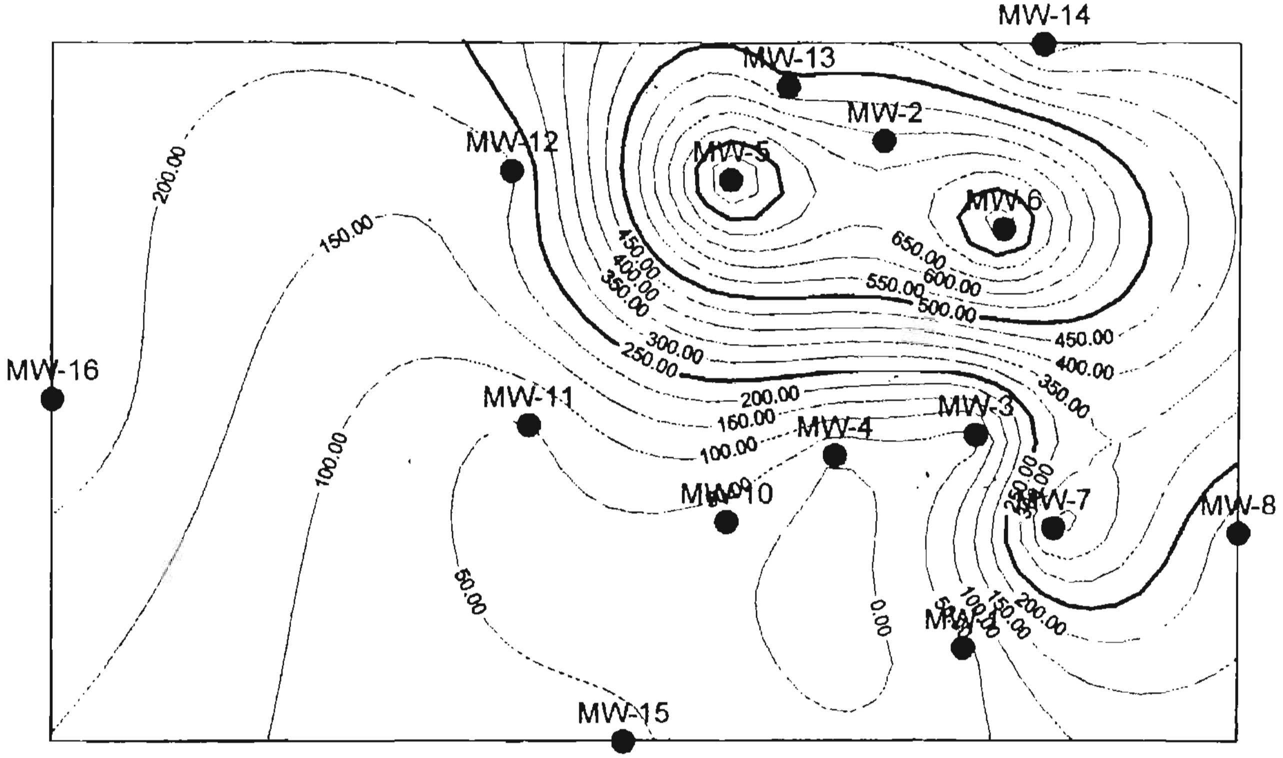
Sulfate Isopleth Map (mg/L)
Feb. 17, 1998
Kriging Method



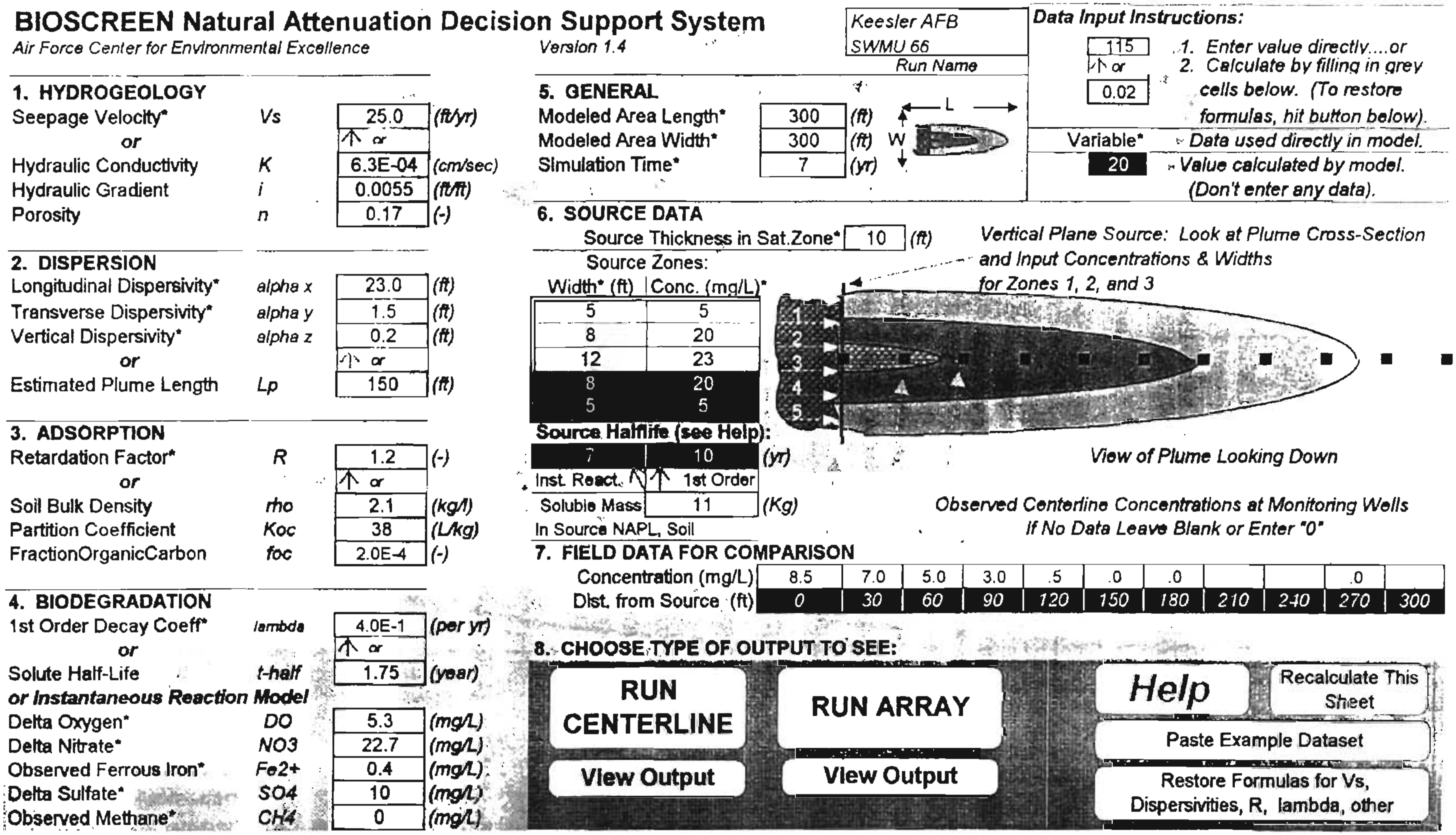
Sulfate Isopleth Map (mg/L)
Mar. 24, 1998
Kriging Method



Sulfate Isopleth Map (mg/L)
Apr. 14, 1998
Kriging Method



APPENDIX D
BIOSCREEN OUTPUT – CALIBRATION



BIOSCREEN Natural Attenuation Decision Support System
Air Force Center for Environmental Excellence
Version 1.4

Keesler AFB
SWMU 66
Run Name

Data Input Instructions:
115 — 1. Enter value directly....or
↑ or — 2. Calculate by filling in grey
0.02 — cells below. (To restore formulas, hit button below).
Variable* — Data used directly in model.
20 — Value calculated by model. (Don't enter any data).

1. HYDROGEOLOGY
Seepage Velocity* Vs 25.0 (ft/yr)
or ↑ or
Hydraulic Conductivity K 6.3E-04 (cm/sec)
Hydraulic Gradient i 0.0055 (ft/ft)
Porosity n 0.17 (-)

2. DISPERSION
Longitudinal Dispersivity* alpha x 23.0 (ft)
Transverse Dispersivity* alpha y 1.5 (ft)
Vertical Dispersivity* alpha z 0.2 (ft)
or ↑ or
Estimated Plume Length Lp 150 (ft)

3. ADSORPTION
Retardation Factor* R 1.2 (-)
or ↑ or
Soil Bulk Density rho 2.1 (kg/l)
Partition Coefficient Koc 38 (L/kg)
FractionOrganicCarbon foc 2.0E-4 (-)

4. BIODEGRADATION
1st Order Decay Coeff* lambda 4.0E-1 (per yr)
or ↑ or
Solute Half-Life t-half 1.75 (year)
or Instantaneous Reaction Model
Delta Oxygen* DO 5.3 (mg/L)
Delta Nitrate* NO3 22.7 (mg/L)
Observed Ferrous Iron* Fe2+ 0.4 (mg/L)
Delta Sulfate* SO4 10 (mg/L)
Observed Methane* CH4 0 (mg/L)

5. GENERAL
Modeled Area Length* 300 (ft)
Modeled Area Width* 300 (ft)
Simulation Time* 7 (yr)

6. SOURCE DATA
Source Thickness in Sat.Zone* 10 (ft)
Source Zones:

Width* (ft)	Conc. (mg/L)*
5	5
8	20
12	23
8	20
5	5

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths for Zones 1, 2, and 3

Source Halflife (see Help):
7 | 10 (yr)
Inst. React. ↑ | ↑ 1st Order
Soluble Mass 11 (Kg)
In Source NAPL, Soil

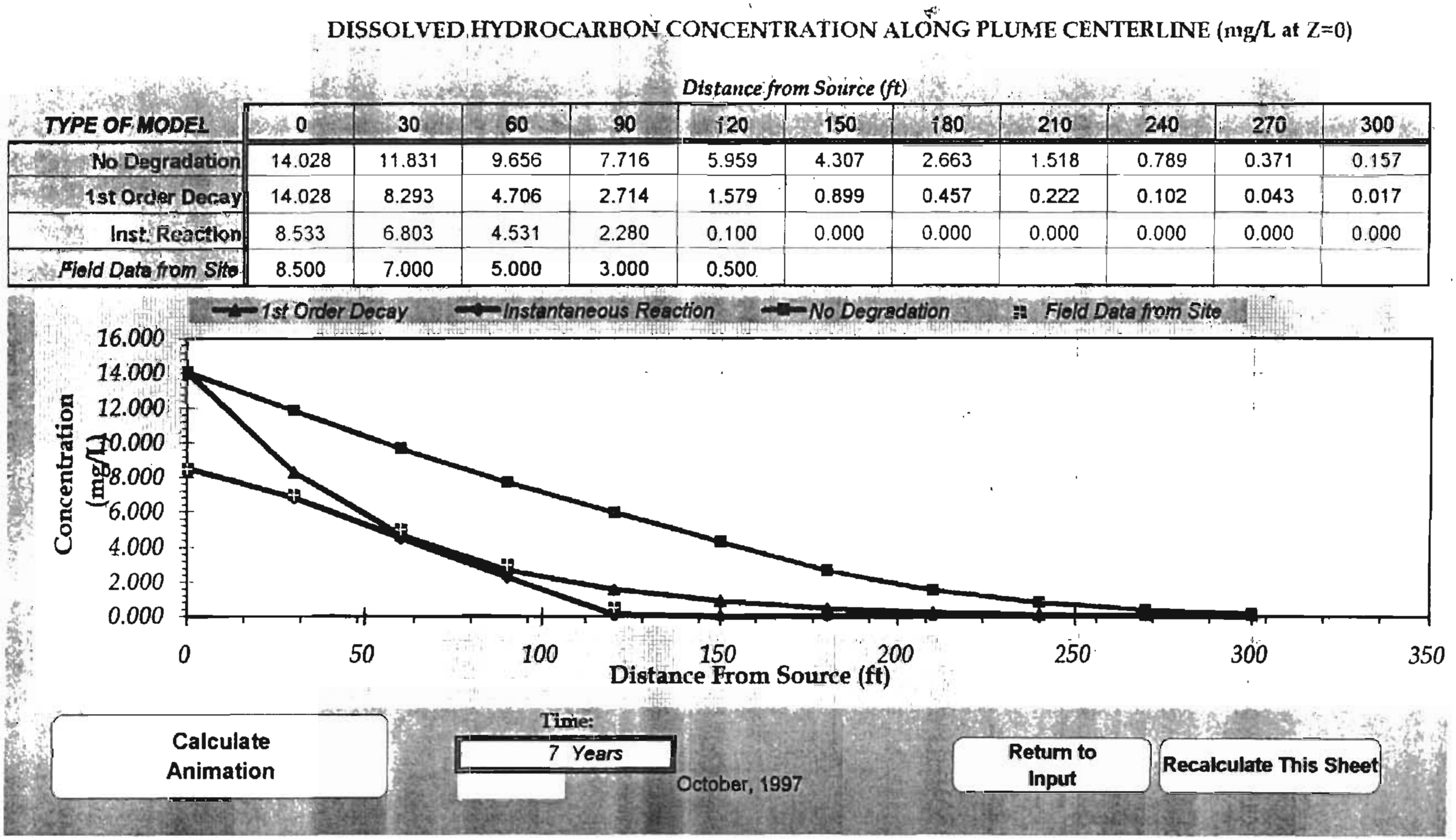
View of Plume Looking Down

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

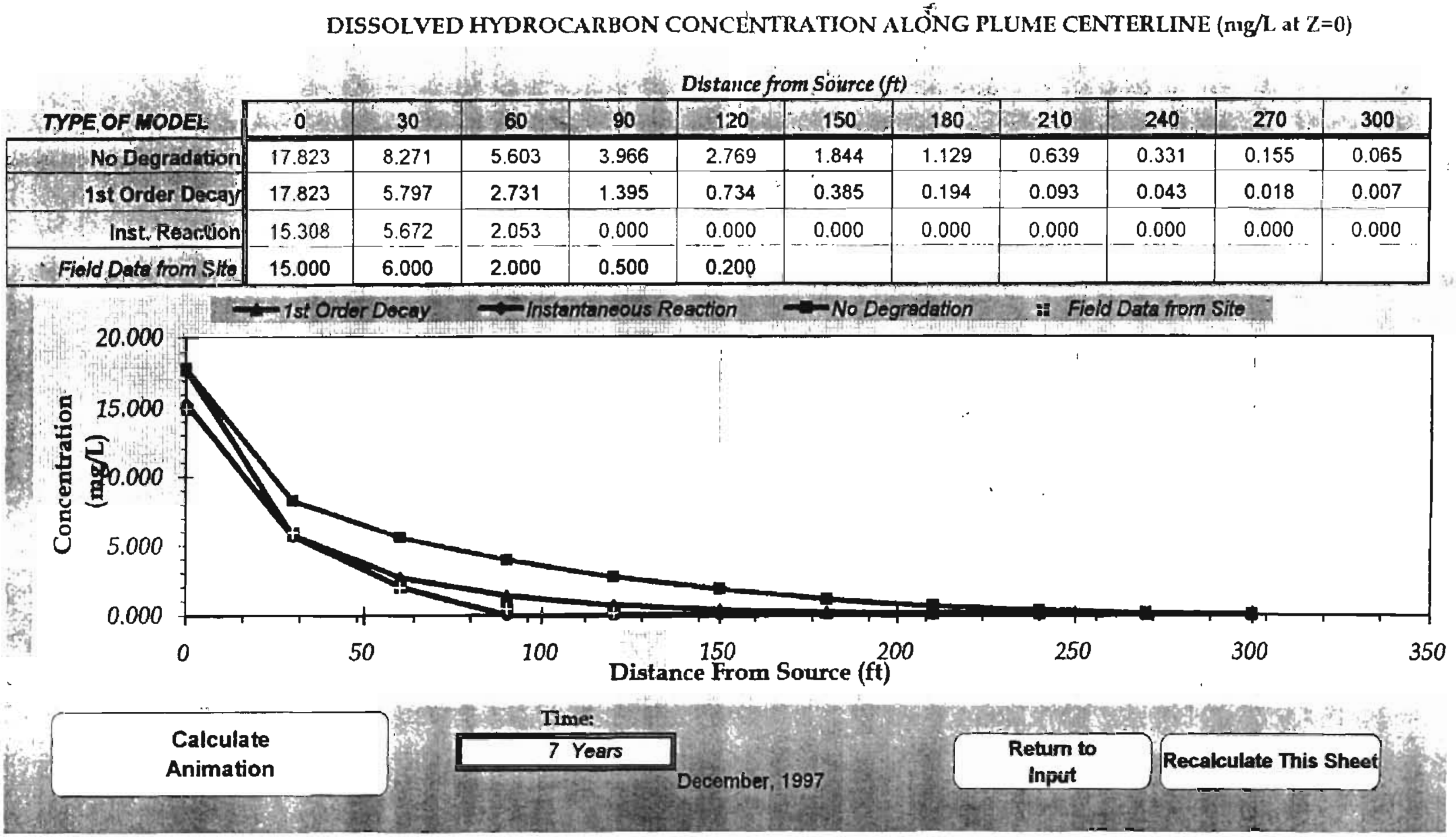
Concentration (mg/L)	8.5	7.0	5.0	3.0	.5	.0	.0			.0	
Dist. from Source (ft)	0	30	60	90	120	150	180	210	240	270	300

8. CHOOSE TYPE OF OUTPUT TO SEE:



DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

	Distance from Source (ft)										
TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	14.028	11.831	9.656	7.716	5.959	4.307	2.663	1.518	0.789	0.371	0.157
1st Order Decay	14.028	8.293	4.706	2.714	1.579	0.899	0.457	0.222	0.102	0.043	0.017
Inst. Reaction	8.533	6.803	4.531	2.280	0.100	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	8.500	7.000	5.000	3.000	0.500						

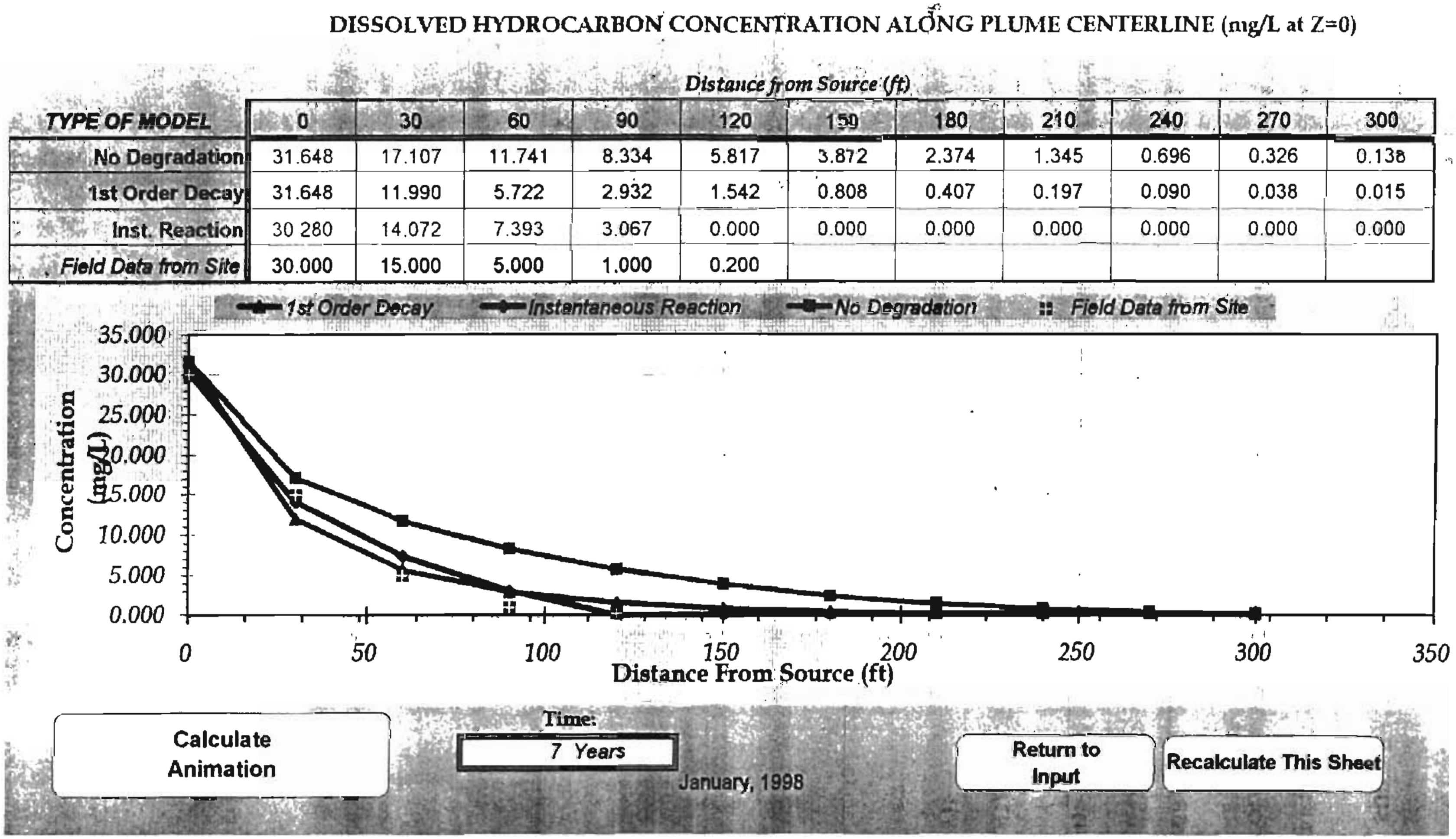


DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

TYPE OF MODEL	Distance from Source (ft) 0	30	60	90	120	150	180	210	240	270	300
No Degradation	17.823	8.271	5.603	3.966	2.769	1.844	1.129	0.639	0.331	0.155	0.065
1st Order Decay	17.823	5.797	2.731	1.395	0.734	0.385	0.194	0.093	0.043	0.018	0.007
Inst. Reaction	15.308	5.672	2.053	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	15.000	6.000	2.000	0.500	0.200						

Time: 7 Years

December, 1997

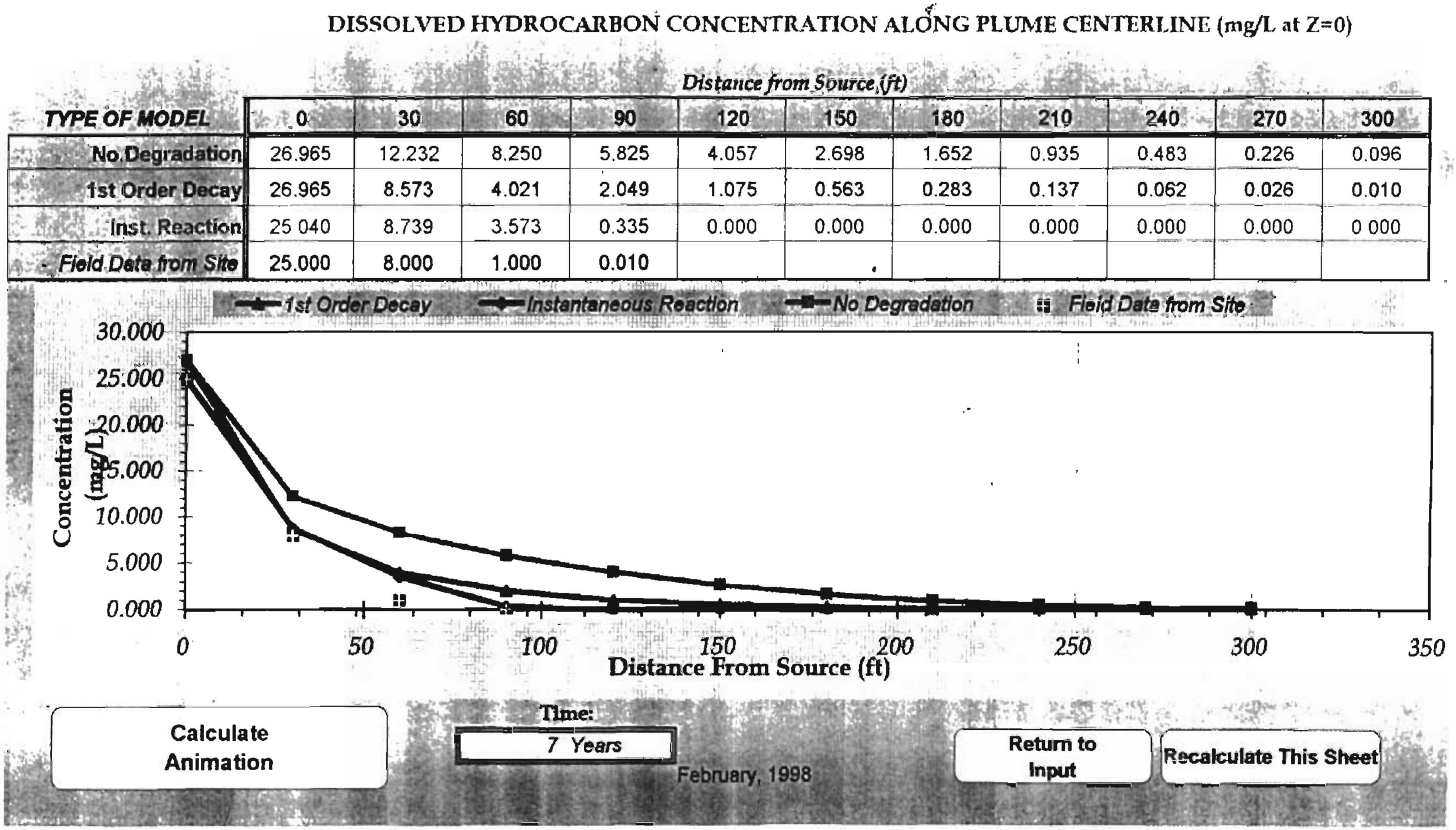


DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

	Distance from Source (ft)										
TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	31.648	17.107	11.741	8.334	5.817	3.872	2.374	1.345	0.696	0.326	0.138
1st Order Decay	31.648	11.990	5.722	2.932	1.542	0.808	0.407	0.197	0.090	0.038	0.015
Inst. Reaction	30.280	14.072	7.393	3.067	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	30.000	15.000	5.000	1.000	0.200						

Time: 7 Years

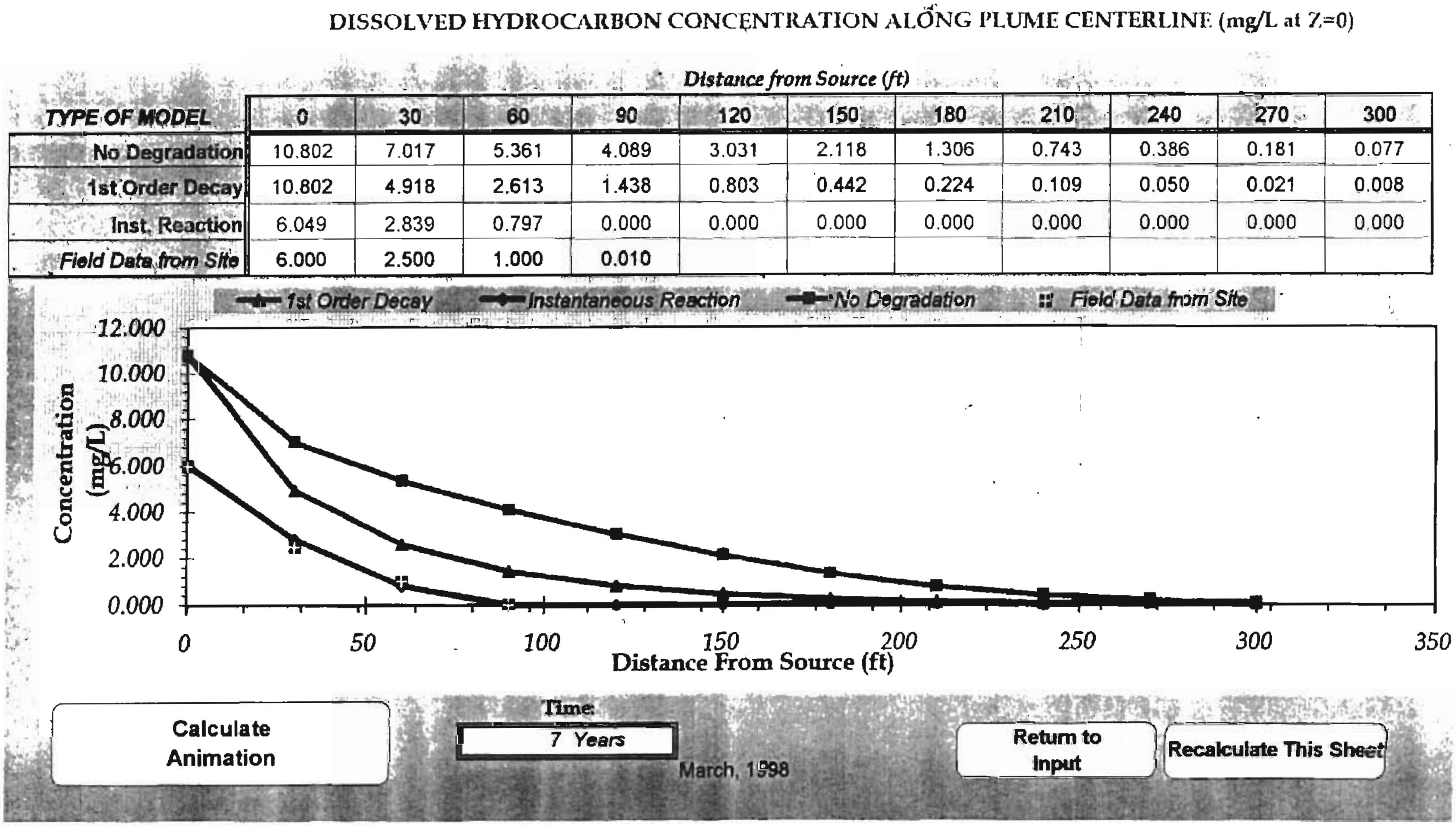
January, 1998



DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

TYPE OF MODEL	Distance from Source (ft)										
	0	30	60	90	120	150	180	210	240	270	300
No Degradation	26.965	12.232	8.250	5.825	4.057	2.698	1.652	0.935	0.483	0.226	0.096
1st Order Decay	26.965	8.573	4.021	2.049	1.075	0.563	0.283	0.137	0.062	0.026	0.010
Inst. Reaction	25.040	8.739	3.573	0.335	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	25.000	8.000	1.000	0.010							

February, 1998

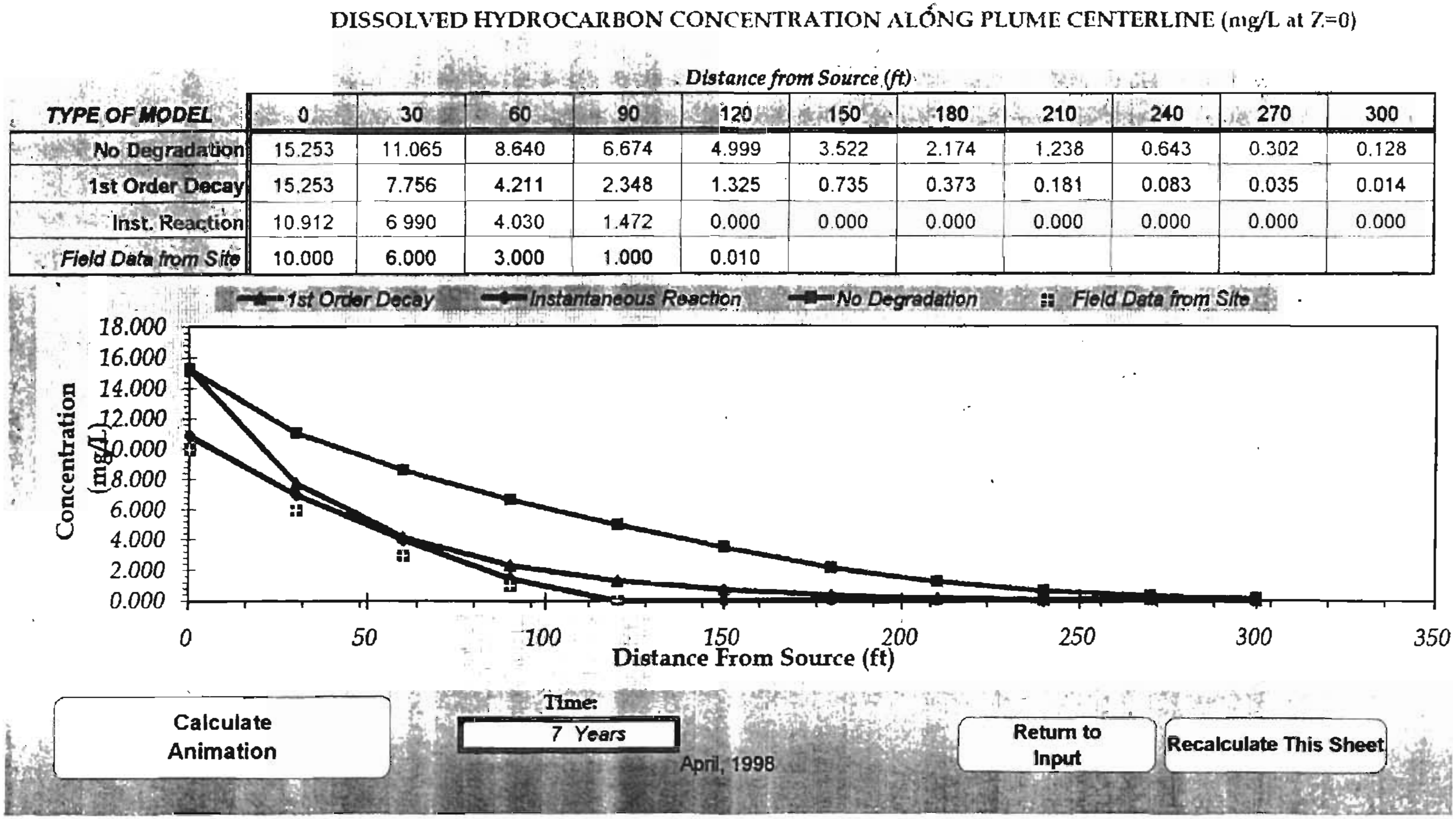


DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

TYPE OF MODEL	*Distance from Source (ft)* 0	30	60	90	120	150	180	210	240	270	300
No Degradation	10.802	7.017	5.361	4.089	3.031	2.118	1.306	0.743	0.386	0.181	0.077
1st Order Decay	10.802	4.918	2.613	1.438	0.803	0.442	0.224	0.109	0.050	0.021	0.008
Inst. Reaction	6.049	2.839	0.797	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	6.000	2.500	1.000	0.010							

Time: 7 Years

March, 1998



DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

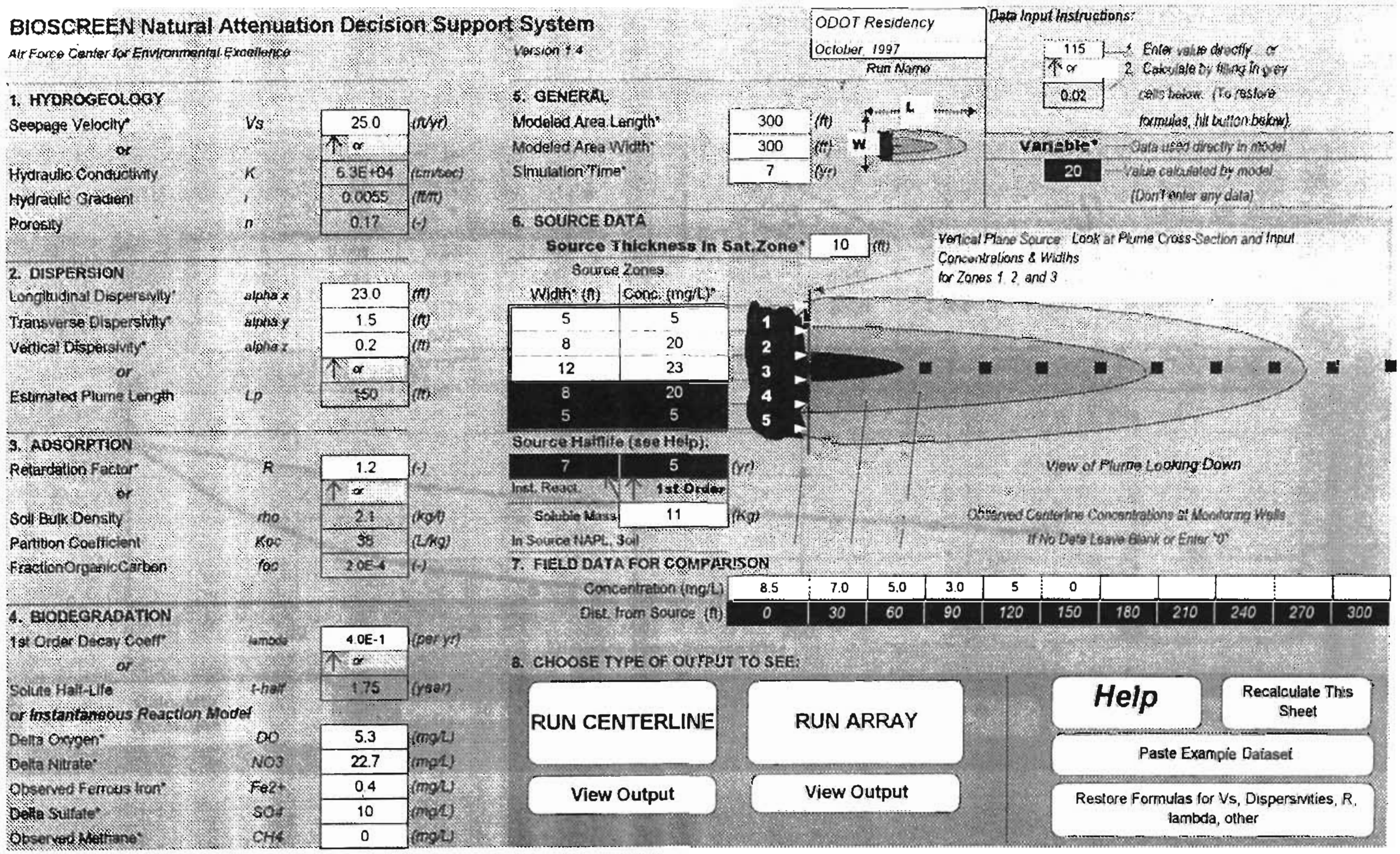
	Distance from Source (ft)										
TYPE OF MODEL	**0**	**30**	**60**	**90**	**120**	**150**	**180**	**210**	**240**	**270**	**300**
No Degradation	15.253	11.065	8.640	6.674	4.999	3.522	2.174	1.238	0.643	0.302	0.128
1st Order Decay	15.253	7.756	4.211	2.348	1.325	0.735	0.373	0.181	0.083	0.035	0.014
Inst. Reaction	10.912	6.990	4.030	1.472	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	10.000	6.000	3.000	1.000	0.010						

Time:

7 Years

April, 1998

APPENDIX E
BIOSCREEN OUTPUT – RUN #1



BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence

Version 1.4

ODOT Residency	
October, 1997	
Run Name	

Data Input Instructions:

115 — 1. Enter value directly... or
↑ or — 2. Calculate by filling in grey
0.02 — cells below. (To restore formulas, hit button below).

Variable* — Data used directly in model
20 — Value calculated by model (Don't enter any data)

1. HYDROGEOLOGY

Seepage Velocity*	Vs	25.0	(ft/yr)
or		↑ or	
Hydraulic Conductivity	K	6.3E+04	(cm/sec)
Hydraulic Gradient	i	0.0055	(ft/ft)
Porosity	n	0.17	(-)

2. DISPERSION

Longitudinal Dispersivity*	alpha x	23.0	(ft)
Transverse Dispersivity*	alpha y	1.5	(ft)
Vertical Dispersivity*	alpha z	0.2	(ft)
or		↑ or	
Estimated Plume Length	Lp	150	(ft)

3. ADSORPTION

Retardation Factor*	R	1.2	(-)
or		↑ or	
Soil Bulk Density	rho	2.1	(kg/l)
Partition Coefficient	Koc	38	(L/kg)
FractionOrganicCarbon	foc	2.0E-4	(-)

4. BIODEGRADATION

1st Order Decay Coeff*	lambda	4.0E-1	(per yr)
or		↑ or	
Solute Half-Life	t-half	1.75	(year)
or Instantaneous Reaction Model			
Delta Oxygen*	DO	5.3	(mg/L)
Delta Nitrate*	NO3	22.7	(mg/L)
Observed Ferrous Iron*	Fe2+	0.4	(mg/L)
Delta Sulfate*	SO4	10	(mg/L)
Observed Methane*	CH4	0	(mg/L)

5. GENERAL

Modeled Area Length*	300	(ft)
Modeled Area Width*	300	(ft)
Simulation Time*	7	(yr)

6. SOURCE DATA

Source Thickness in Sat.Zone* 10 (ft)

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths for Zones 1, 2, and 3

Source Zones

Width* (ft)	Conc. (mg/L)*
5	5
8	20
12	23
8	20
5	5

Source Halflife (see Help):

7	5	(yr)
Inst. React.	1st Order	

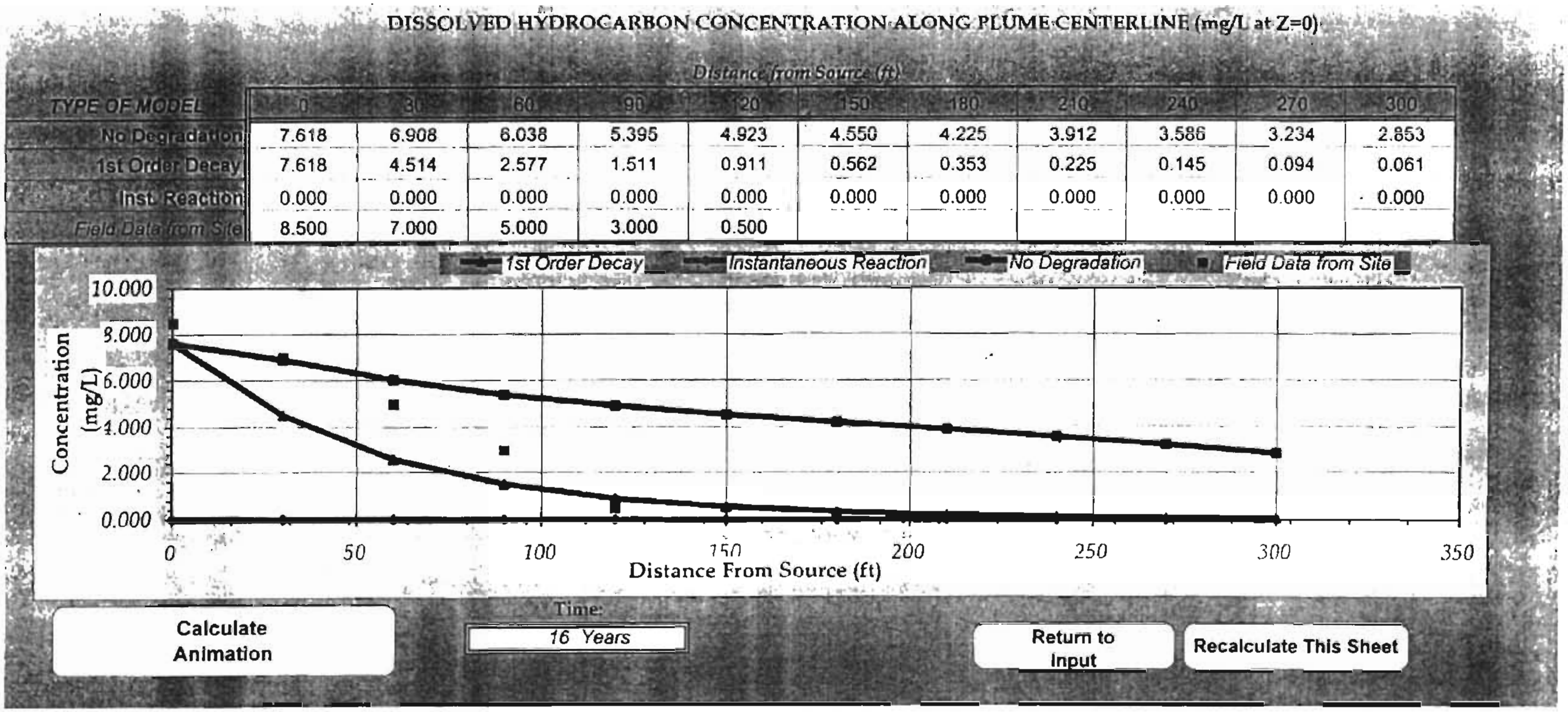
Soluble Mass 11 (Kg)
In Source NAPL, Soil

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Concentration (mg/L)	8.5	7.0	5.0	3.0	5	0					
Dist. from Source (ft)	0	30	60	90	120	150	180	210	240	270	300

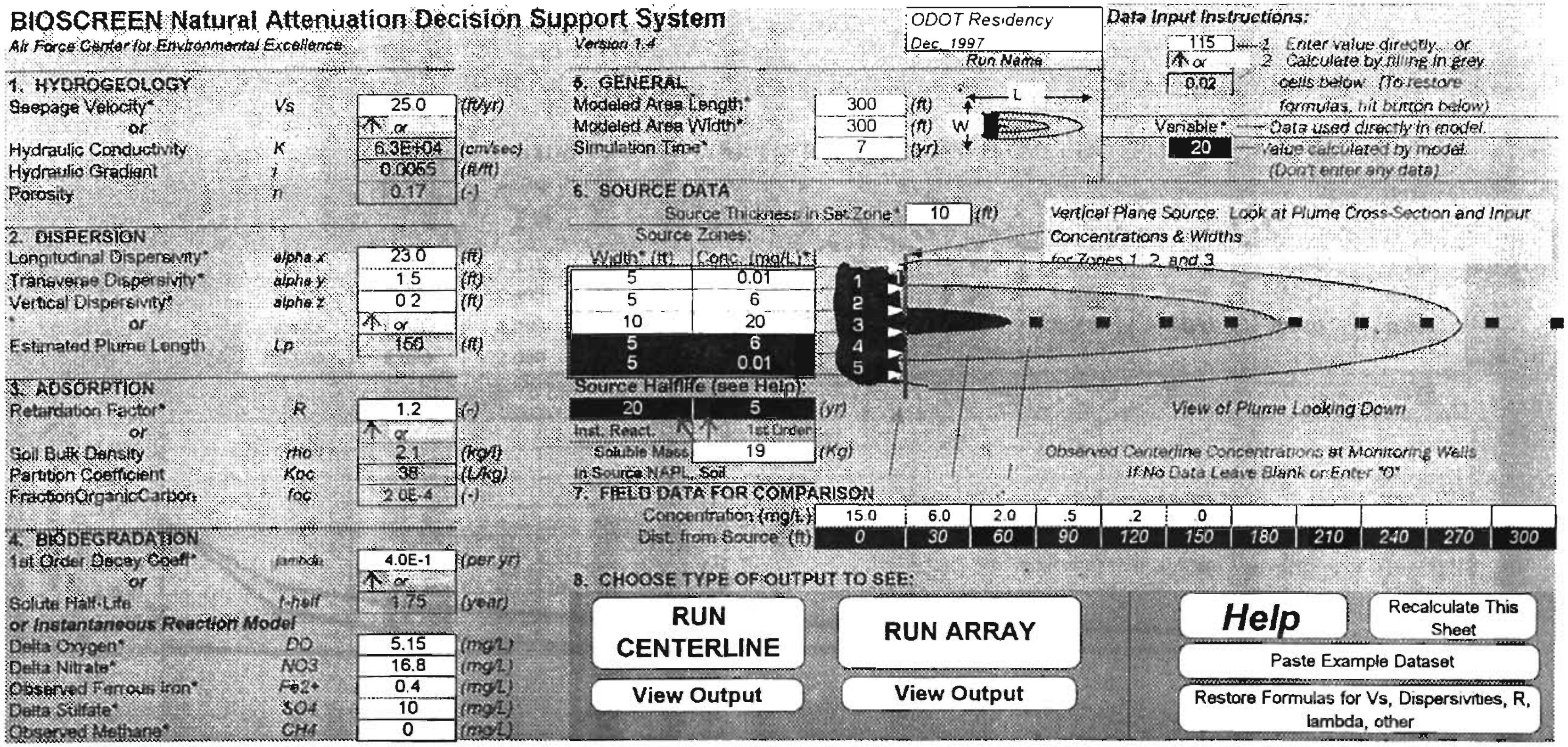
8. CHOOSE TYPE OF OUTPUT TO SEE:



DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

	Distance from Source (ft)										
TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	7.618	6.908	6.038	5.395	4.923	4.550	4.225	3.912	3.586	3.234	2.853
1st Order Decay	7.618	4.514	2.577	1.511	0.911	0.562	0.353	0.225	0.145	0.094	0.061
Inst. Reaction	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	8.500	7.000	5.000	3.000	0.500						

Time: 16 Years



BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence

Version 1.4

ODOT Residency
Dec. 1997
Run Name

Data Input Instructions:

115 — 1. Enter value directly... or
or — 2. Calculate by filling in grey
0.02 — cells below. (To restore formulas, hit button below).

Variable* — Data used directly in model.
20 — Value calculated by model. (Don't enter any data).

1. HYDROGEOLOGY

Seepage Velocity*	Vs	25.0	(ft/yr)
or		or	
Hydraulic Conductivity	K	6.3E+04	(cm/sec)
Hydraulic Gradient	i	0.0055	(ft/ft)
Porosity	n	0.17	(-)

2. DISPERSION

Longitudinal Dispersivity*	alpha x	23.0	(ft)
Transverse Dispersivity*	alpha y	1.5	(ft)
Vertical Dispersivity*	alpha z	0.2	(ft)
* or		or	
Estimated Plume Length	Lp	150	(ft)

3. ADSORPTION

Retardation Factor*	R	1.2	(-)
or		or	
Soil Bulk Density	rho	2.1	(kg/l)
Partition Coefficient	Koc	38	(L/kg)
FractionOrganicCarbon	foc	2.0E-4	(-)

4. BIODEGRADATION

1st Order Decay Coeff*	lambda	4.0E-1	(per yr)
or		or	
Solute Half-Life	t-half	1.75	(year)
or Instantaneous Reaction Model			
Delta Oxygen*	DO	5.15	(mg/L)
Delta Nitrate*	NO3	16.8	(mg/L)
Observed Ferrous Iron*	Fe2+	0.4	(mg/L)
Delta Sulfate*	SO4	10	(mg/L)
Observed Methane*	CH4	0	(mg/L)

5. GENERAL

Modeled Area Length*	300	(ft)
Modeled Area Width*	300	(ft)
Simulation Time*	7	(yr)

6. SOURCE DATA

Source Thickness in Sat.Zone* 10 (ft)

Source Zones:

Width* (ft)	Conc. (mg/L)*
5	0.01
5	6
10	20
5	6
5	0.01

Source Halflife (see Help):

20	5	(yr)
Inst. React.	1st Order	
Soluble Mass	19	(Kg)
In Source NAPL, Soil		

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths for Zones 1, 2, and 3

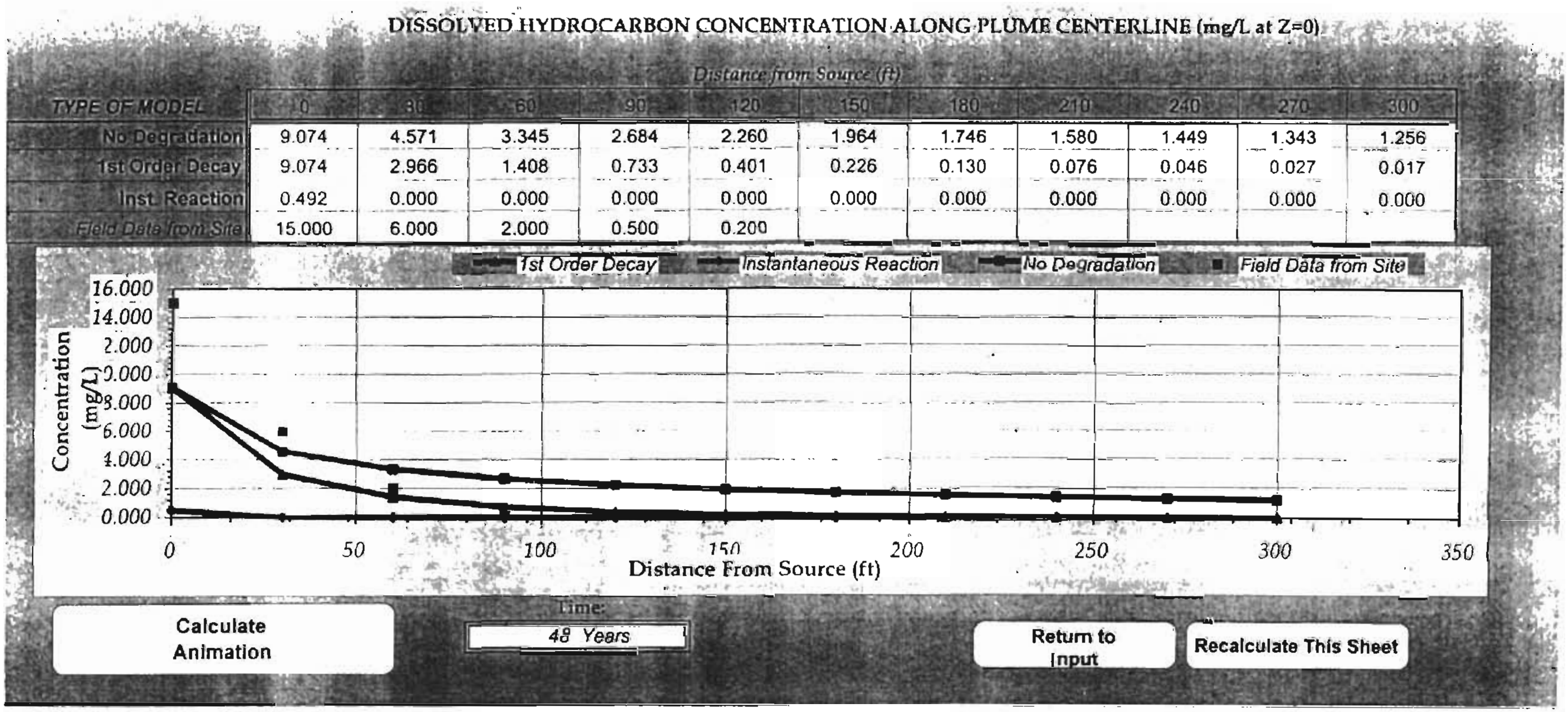
View of Plume Looking Down

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

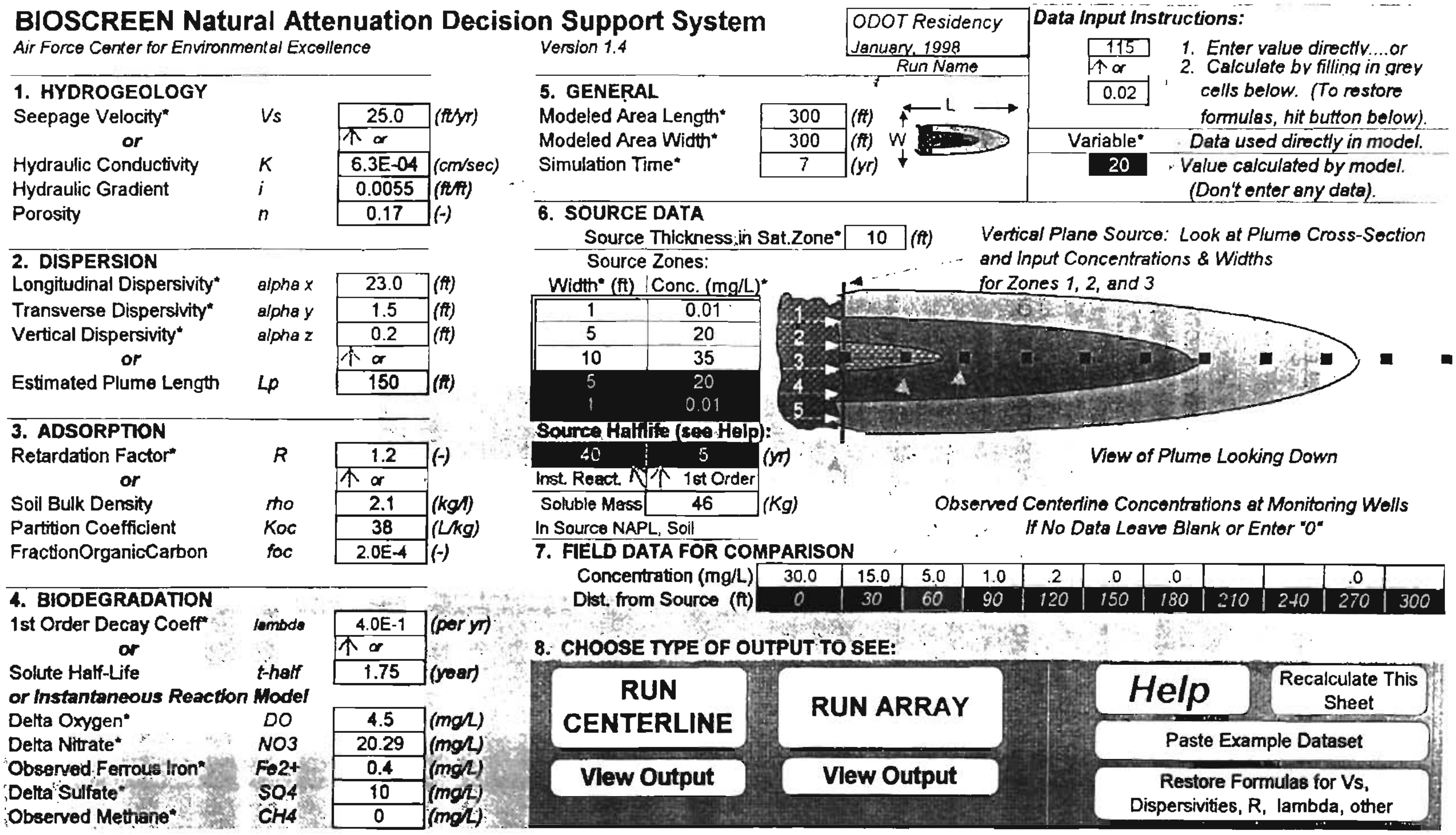
Concentration (mg/L)	15.0	6.0	2.0	.5	.2	0					
Dist. from Source (ft)	0	30	60	90	120	150	180	210	240	270	300

8. CHOOSE TYPE OF OUTPUT TO SEE:



DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

TYPE OF MODEL	Distance from Source (ft) 0	30	60	90	120	150	180	210	240	270	300
No Degradation	9.074	4.571	3.345	2.684	2.260	1.964	1.746	1.580	1.449	1.343	1.256
1st Order Decay	9.074	2.966	1.408	0.733	0.401	0.226	0.130	0.076	0.046	0.027	0.017
Inst. Reaction	0.492	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	15.000	6.000	2.000	0.500	0.200						



BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence

Version 1.4

ODOT Residency	*January, 1998*
Run Name	

Data Input Instructions:

115	1. *Enter value directly....or*
↑ or	2. *Calculate by filling in grey*
0.02	*cells below. (To restore formulas, hit button below).*
Variable*	*Data used directly in model.*
20	*Value calculated by model. (Don't enter any data).*

1. HYDROGEOLOGY

Seepage Velocity*	*Vs*	25.0	*(ft/yr)*
or		↑ or	
Hydraulic Conductivity	*K*	6.3E-04	*(cm/sec)*
Hydraulic Gradient	*i*	0.0055	*(ft/ft)*
Porosity	*n*	0.17	*(-)*

2. DISPERSION

Longitudinal Dispersivity*	*alpha x*	23.0	*(ft)*
Transverse Dispersivity*	*alpha y*	1.5	*(ft)*
Vertical Dispersivity*	*alpha z*	0.2	*(ft)*
or		↑ or	
Estimated Plume Length	*Lp*	150	*(ft)*

3. ADSORPTION

Retardation Factor*	*R*	1.2	*(-)*
or		↑ or	
Soil Bulk Density	*rho*	2.1	*(kg/l)*
Partition Coefficient	*Koc*	38	*(L/kg)*
FractionOrganicCarbon	*foc*	2.0E-4	*(-)*

4. BIODEGRADATION

1st Order Decay Coeff*	*lambda*	4.0E-1	*(per yr)*
or		↑ or	
Solute Half-Life	*t-half*	1.75	*(year)*
or Instantaneous Reaction Model			
Delta Oxygen*	*DO*	4.5	*(mg/L)*
Delta Nitrate*	*NO3*	20.29	*(mg/L)*
Observed Ferrous Iron*	*Fe2+*	0.4	*(mg/L)*
Delta Sulfate*	*SO4*	10	*(mg/L)*
Observed Methane*	*CH4*	0	*(mg/L)*

5. GENERAL

Modeled Area Length*	300	*(ft)*
Modeled Area Width*	300	*(ft)*
Simulation Time*	7	*(yr)*

6. SOURCE DATA

Source Thickness in Sat.Zone* 10 *(ft)*

Source Zones:

Width* (ft)	Conc. (mg/L)*
1	0.01
5	20
10	35
5	20
1	0.01

Source Halflife (see Help):

40	5	*(yr)*
Inst. React. ↑	↑ 1st Order	
Soluble Mass	46	*(Kg)*
In Source NAPL, Soil		

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths for Zones 1, 2, and 3

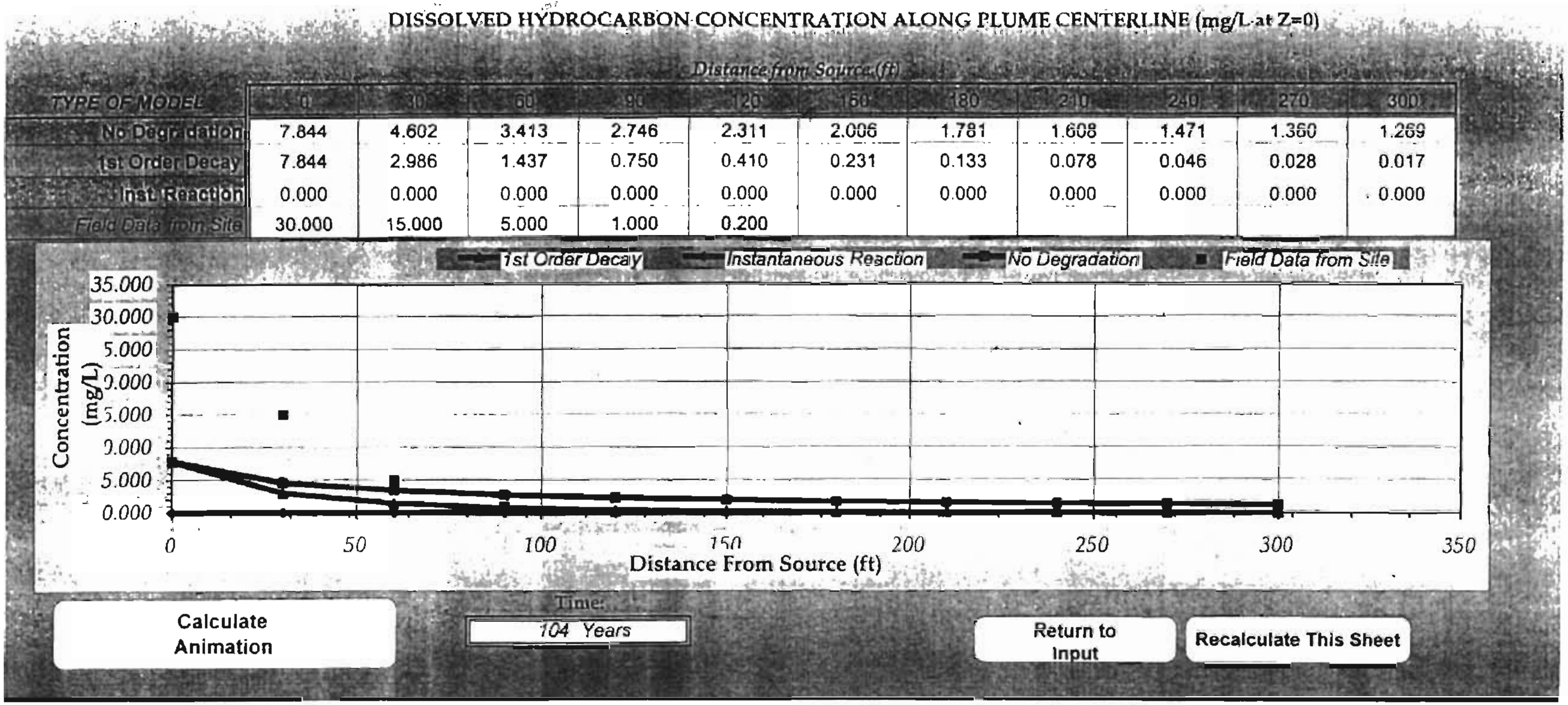
View of Plume Looking Down

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Concentration (mg/L)	30.0	15.0	5.0	1.0	.2	.0	.0			.0	
Dist. from Source (ft)	0	30	60	90	120	150	180	210	240	270	300

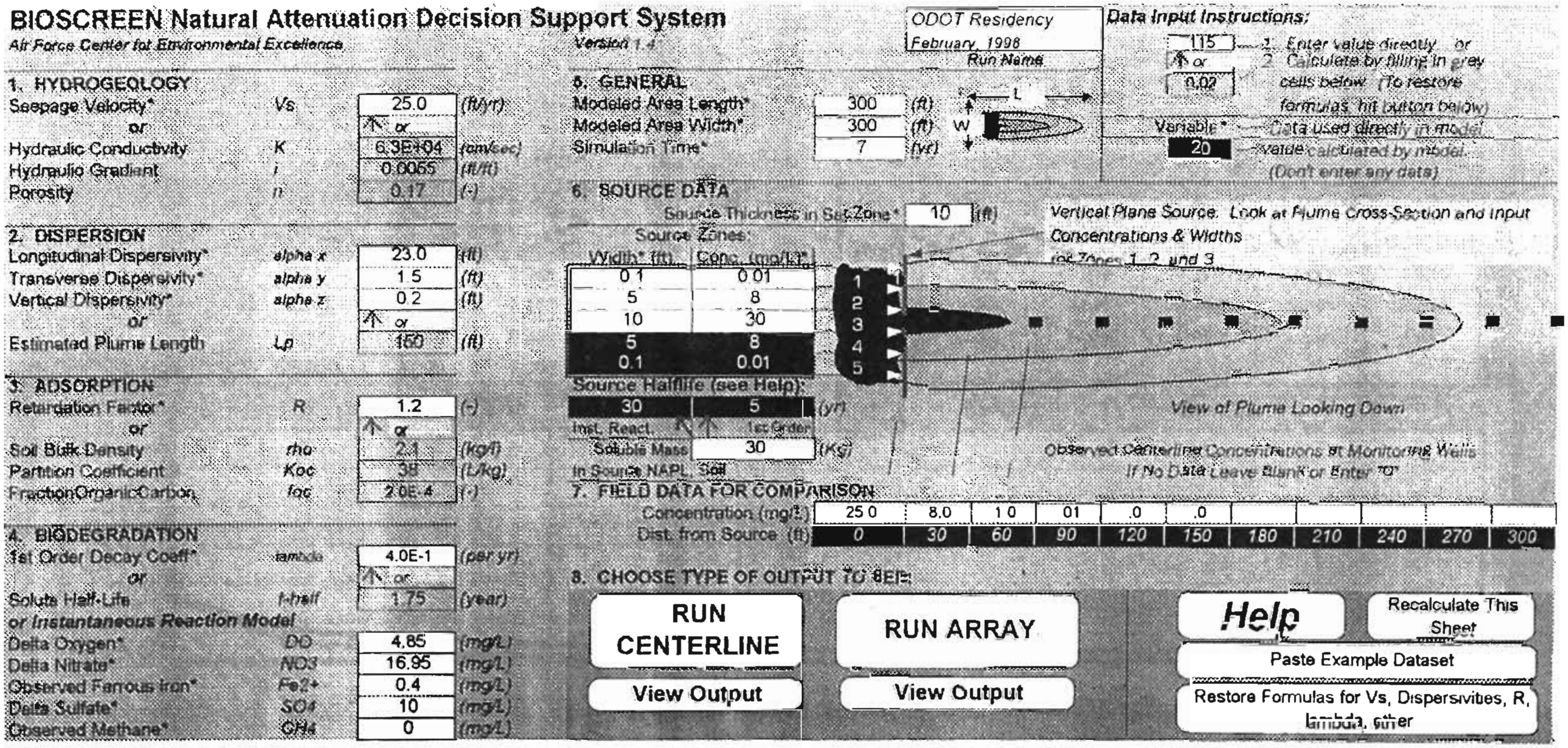
8. CHOOSE TYPE OF OUTPUT TO SEE:



DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

	Distance from Source (ft)										
TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	7.844	4.602	3.413	2.746	2.311	2.006	1.781	1.608	1.471	1.360	1.269
1st Order Decay	7.844	2.986	1.437	0.750	0.410	0.231	0.133	0.078	0.046	0.028	0.017
Inst. Reaction	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	30.000	15.000	5.000	1.000	0.200						

Time: 104 Years



BIOSCREEN Natural Attenuation Decision Support System
Air Force Center for Environmental Excellence
Version 1.4

ODOT Residency
February, 1998
Run Name

Data Input Instructions;

115 — 1. Enter value directly or
↑ or — 2. Calculate by filling in grey
0.02 — cells below. (To restore formulas, hit button below)
Variable* — Data used directly in model.
20 — Value calculated by model. (Don't enter any data)

1. HYDROGEOLOGY

Seepage Velocity*	Vs	25.0	(ft/yr)
or		↑ or	
Hydraulic Conductivity	K	6.3E+04	(cm/sec)
Hydraulic Gradient	i	0.0055	(ft/ft)
Porosity	n	0.17	(-)

2. DISPERSION

Longitudinal Dispersivity*	alpha x	23.0	(ft)
Transverse Dispersivity*	alpha y	1.5	(ft)
Vertical Dispersivity*	alpha z	0.2	(ft)
or		↑ or	
Estimated Plume Length	Lp	150	(ft)

3. ADSORPTION

Retardation Factor*	R	1.2	(-)
or		↑ or	
Soil Bulk Density	rho	2.1	(kg/l)
Partition Coefficient	Koc	38	(L/kg)
FractionOrganicCarbon	foc	2.0E-4	(-)

4. BIODEGRADATION

1st Order Decay Coeff*	lambda	4.0E-1	(per yr)
or		↑ or	
Solute Half-Life	t-half	1.75	(year)
or Instantaneous Reaction Model			
Delta Oxygen*	DO	4.85	(mg/L)
Delta Nitrate*	NO3	16.95	(mg/L)
Observed Ferrous Iron*	Fe2+	0.4	(mg/L)
Delta Sulfate*	SO4	10	(mg/L)
Observed Methane*	CH4	0	(mg/L)

5. GENERAL

Modeled Area Length*	300	(ft)
Modeled Area Width*	300	(ft)
Simulation Time*	7	(yr)

6. SOURCE DATA

Source Thickness in Sat.Zone* 10 (ft)

Source Zones:

Zone	Width* (ft)	Conc. (mg/L)*
1	0.1	0.01
2	5	8
3	10	30
4	5	8
5	0.1	0.01

Source Halflife (see Help):

Inst. React.	1st Order	
30	5	(yr)

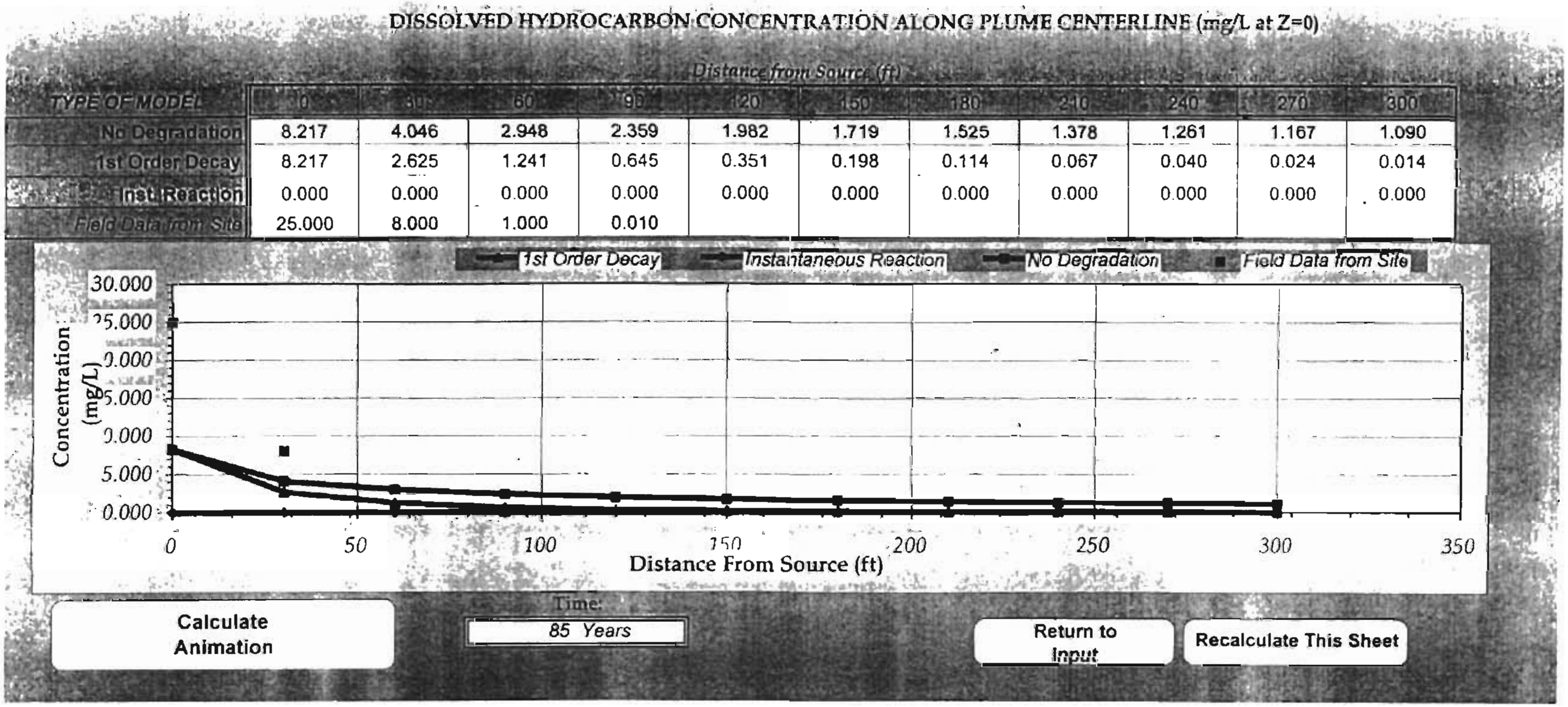
Soluble Mass 30 (Kg)
In Source NAPL, Soil

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths for Zones 1, 2, and 3

7. FIELD DATA FOR COMPARISON

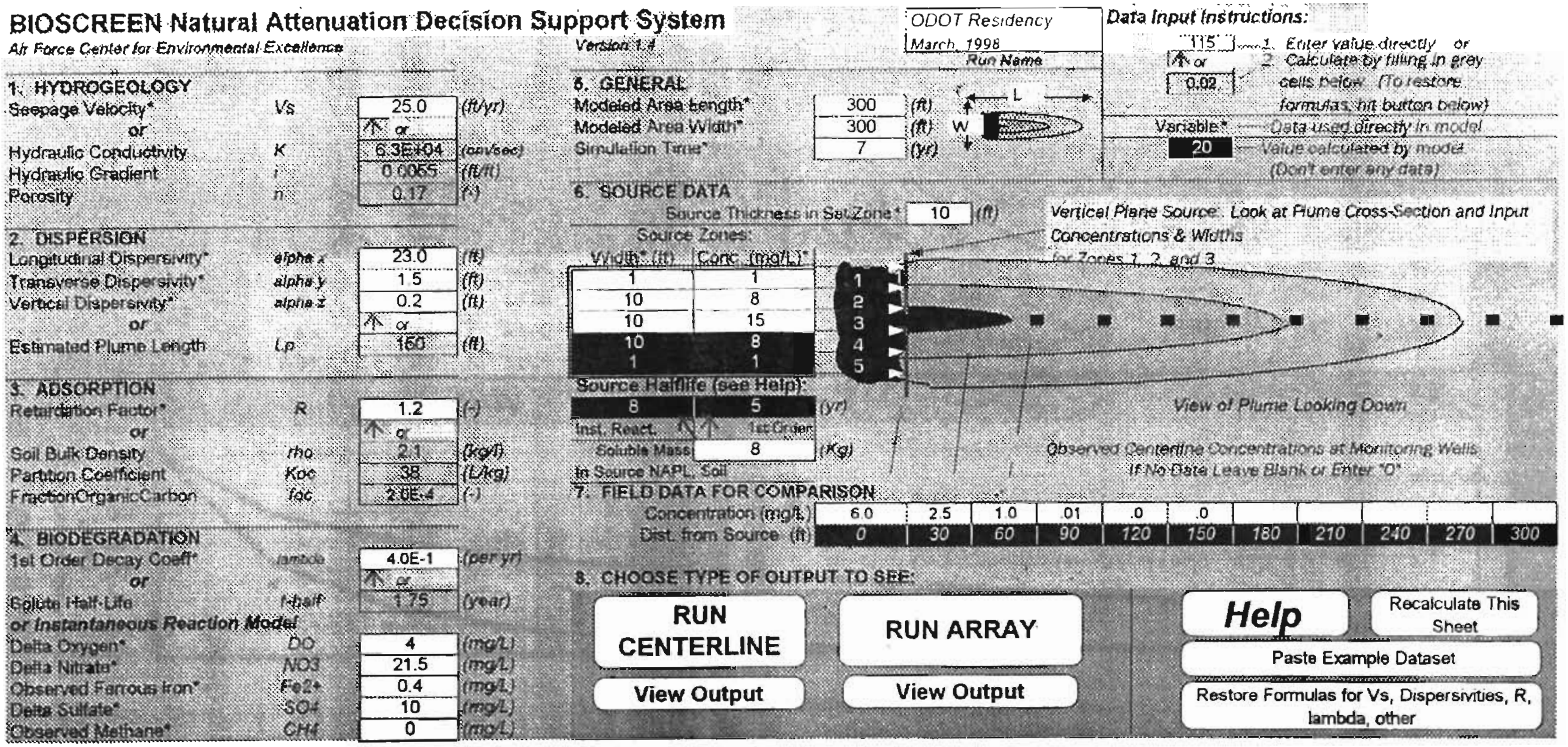
Concentration (mg/L)	25.0	8.0	1.0	.01	.0	.0					
Dist. from Source (ft)	0	30	60	90	120	150	180	210	240	270	300

8. CHOOSE TYPE OF OUTPUT TO SEE:



DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

	Distance from Source (ft)										
TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	8.217	4.046	2.948	2.359	1.982	1.719	1.525	1.378	1.261	1.167	1.090
1st Order Decay	8.217	2.625	1.241	0.645	0.351	0.198	0.114	0.067	0.040	0.024	0.014
Inst. Reaction	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	25.000	8.000	1.000	0.010							



BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence

Version 1.4

ODOT Residency
March, 1998
Run Name

Data Input Instructions:
115 — 1. Enter value directly or
↑ or — 2. Calculate by filling in grey cells below. (To restore formulas, hit button below)
0.02
Variable* — Data used directly in model
20 — Value calculated by model (Don't enter any data)

1. HYDROGEOLOGY

Seepage Velocity*	Vs	25.0	(ft/yr)
or		↑ or	
Hydraulic Conductivity	K	6.3E+04	(cm/sec)
Hydraulic Gradient	i	0.0065	(ft/ft)
Porosity	n	0.17	(-)

2. DISPERSION

Longitudinal Dispersivity*	alpha x	23.0	(ft)
Transverse Dispersivity*	alpha y	1.5	(ft)
Vertical Dispersivity*	alpha z	0.2	(ft)
or		↑ or	
Estimated Plume Length	Lp	160	(ft)

3. ADSORPTION

Retardation Factor*	R	1.2	(-)
or		↑ or	
Soil Bulk Density	rho	2.1	(kg/l)
Partition Coefficient	Koc	38	(L/kg)
FractionOrganicCarbon	foc	2.0E-4	(-)

4. BIODEGRADATION

1st Order Decay Coeff*	lambda	4.0E-1	(per yr)
or		↑ or	
Solute Half-Life	t-half	1.75	(year)
or Instantaneous Reaction Model			
Delta Oxygen*	DO	4	(mg/L)
Delta Nitrate*	NO3	21.5	(mg/L)
Observed Ferrous Iron*	Fe2+	0.4	(mg/L)
Delta Sulfate*	SO4	10	(mg/L)
Observed Methane*	CH4	0	(mg/L)

5. GENERAL

Modeled Area Length*	300	(ft)
Modeled Area Width*	300	(ft)
Simulation Time*	7	(yr)

6. SOURCE DATA

Source Thickness in Sat.Zone* 10 (ft)

Source Zones:

Width* (ft)	Conc. (mg/L)*
1	1
10	8
10	15
10	8
1	1

Source Halflife (see Help):

8	5	(yr)
Inst. React. ↑	↑ 1st Order	
Soluble Mass	8	(Kg)

In Source NAPL, Soil

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths for Zones 1, 2, and 3

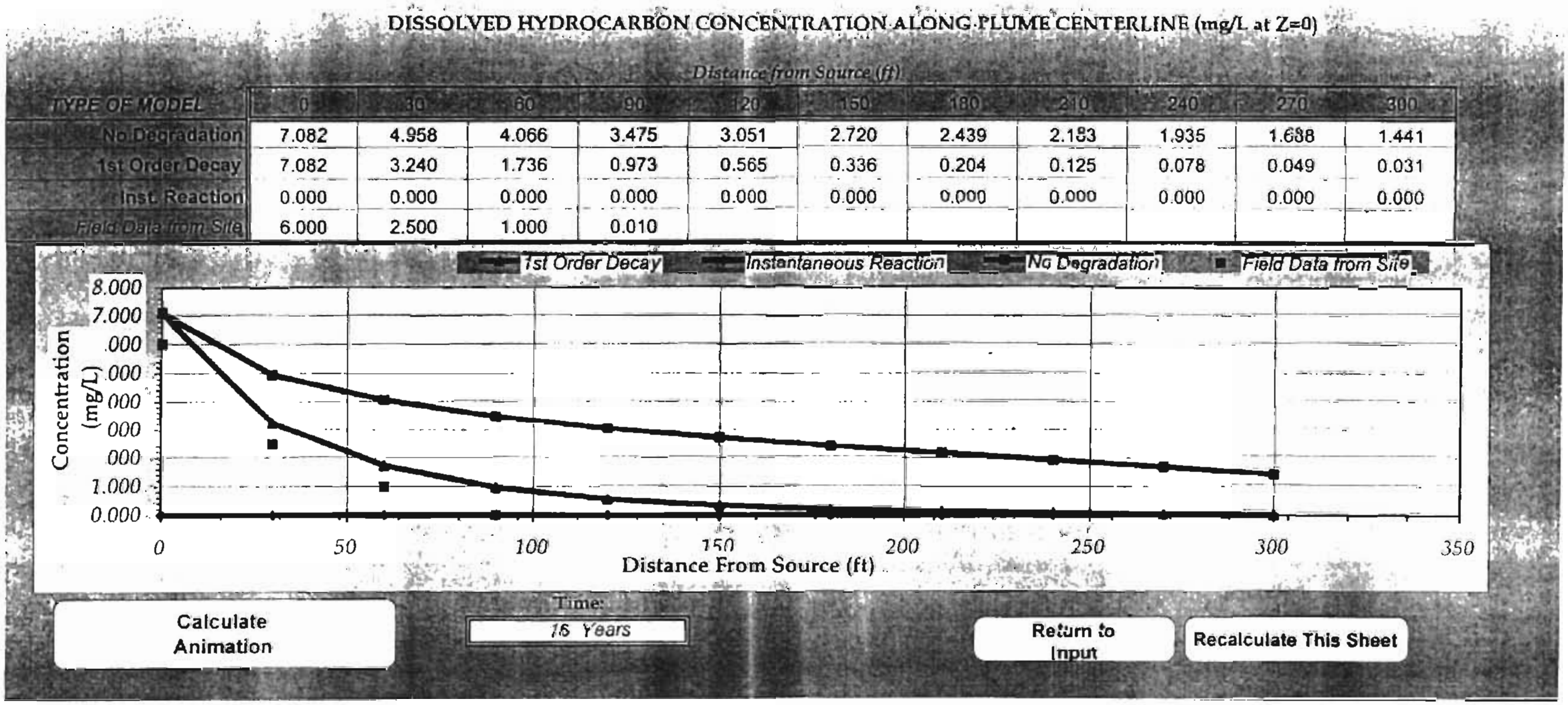
View of Plume Looking Down

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Concentration (mg/L)	6.0	2.5	1.0	.01	.0	.0					
Dist. from Source (ft)	0	30	60	90	120	150	180	210	240	270	300

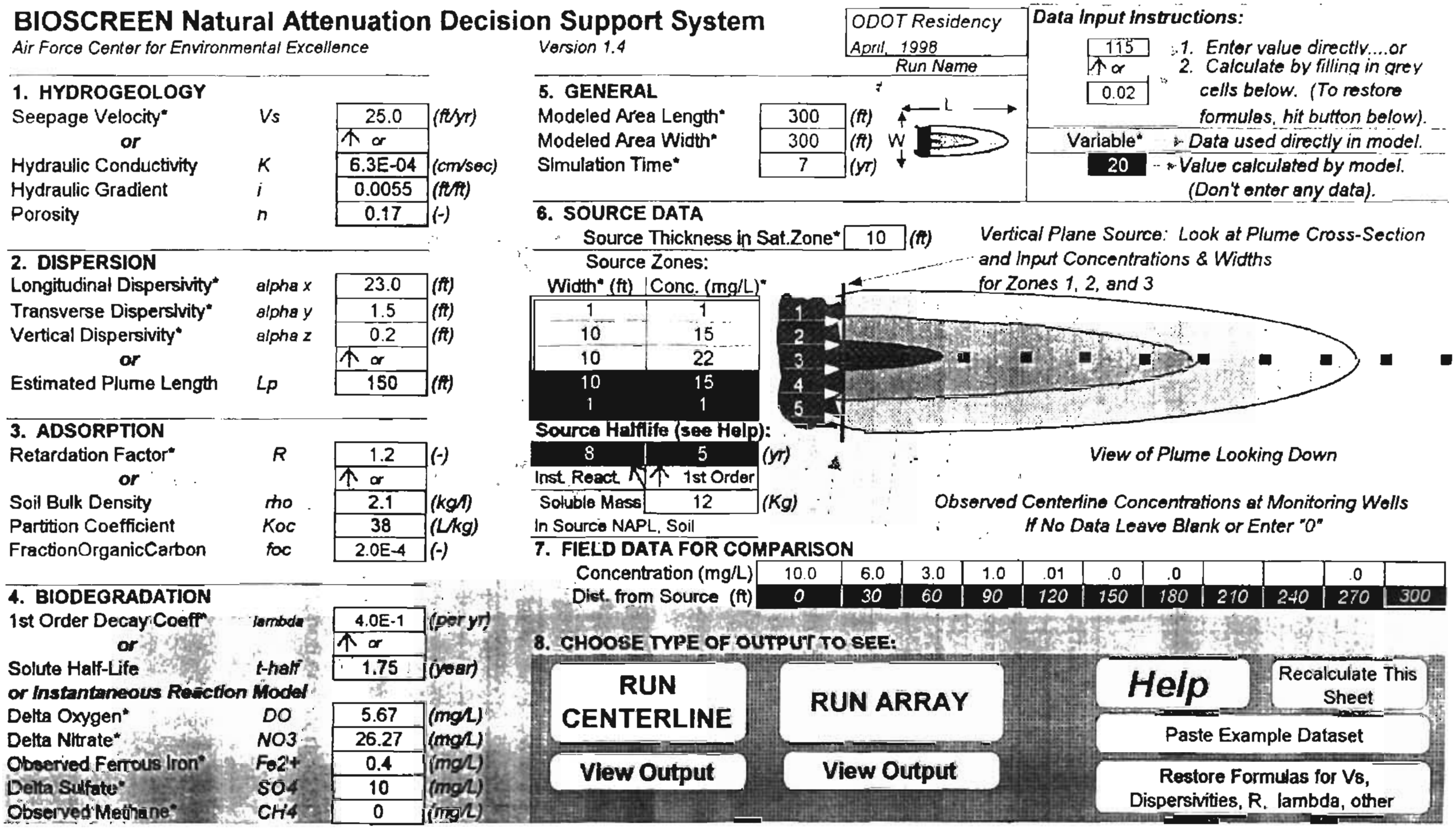
8. CHOOSE TYPE OF OUTPUT TO SEE:



DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

	Distance from Source (ft)										
TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	7.082	4.958	4.066	3.475	3.051	2.720	2.439	2.183	1.935	1.688	1.441
1st Order Decay	7.082	3.240	1.736	0.973	0.565	0.336	0.204	0.125	0.078	0.049	0.031
Inst. Reaction	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	6.000	2.500	1.000	0.010							

Time: 16 Years



BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence *Version 1.4*

ODOT Residency
April, 1998
Run Name

Data Input Instructions:

115 ↑ or 0.02
1. Enter value directly....or
2. Calculate by filling in grey cells below. (To restore formulas, hit button below).

Variable* → Data used directly in model.
20 → Value calculated by model. (Don't enter any data).

1. HYDROGEOLOGY

Seepage Velocity* Vs 25.0 (ft/yr)
or ↑ or
Hydraulic Conductivity K 6.3E-04 (cm/sec)
Hydraulic Gradient i 0.0055 (ft/ft)
Porosity n 0.17 (-)

2. DISPERSION

Longitudinal Dispersivity* alpha x 23.0 (ft)
Transverse Dispersivity* alpha y 1.5 (ft)
Vertical Dispersivity* alpha z 0.2 (ft)
or ↑ or
Estimated Plume Length Lp 150 (ft)

3. ADSORPTION

Retardation Factor* R 1.2 (-)
or ↑ or
Soil Bulk Density rho 2.1 (kg/l)
Partition Coefficient Koc 38 (L/kg)
FractionOrganicCarbon foc 2.0E-4 (-)

4. BIODEGRADATION

1st Order Decay Coeff* lambda 4.0E-1 (per yr)
or ↑ or
Solute Half-Life t-half 1.75 (year)
or Instantaneous Reaction Model
Delta Oxygen* DO 5.67 (mg/L)
Delta Nitrate* NO3 26.27 (mg/L)
Observed Ferrous Iron* Fe2+ 0.4 (mg/L)
Delta Sulfate* SO4 10 (mg/L)
Observed Methane* CH4 0 (mg/L)

5. GENERAL

Modeled Area Length* 300 (ft)
Modeled Area Width* 300 (ft)
Simulation Time* 7 (yr)

6. SOURCE DATA

Source Thickness in Sat.Zone* 10 (ft)

Source Zones:

Width* (ft)	Conc. (mg/L)*
1	1
10	15
10	22
10	15
1	1

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths for Zones 1, 2, and 3

View of Plume Looking Down

Source Halflife (see Help):

8	5	(yr)
Inst. React. ↑	↑ 1st Order	
Soluble Mass	12	(Kg)

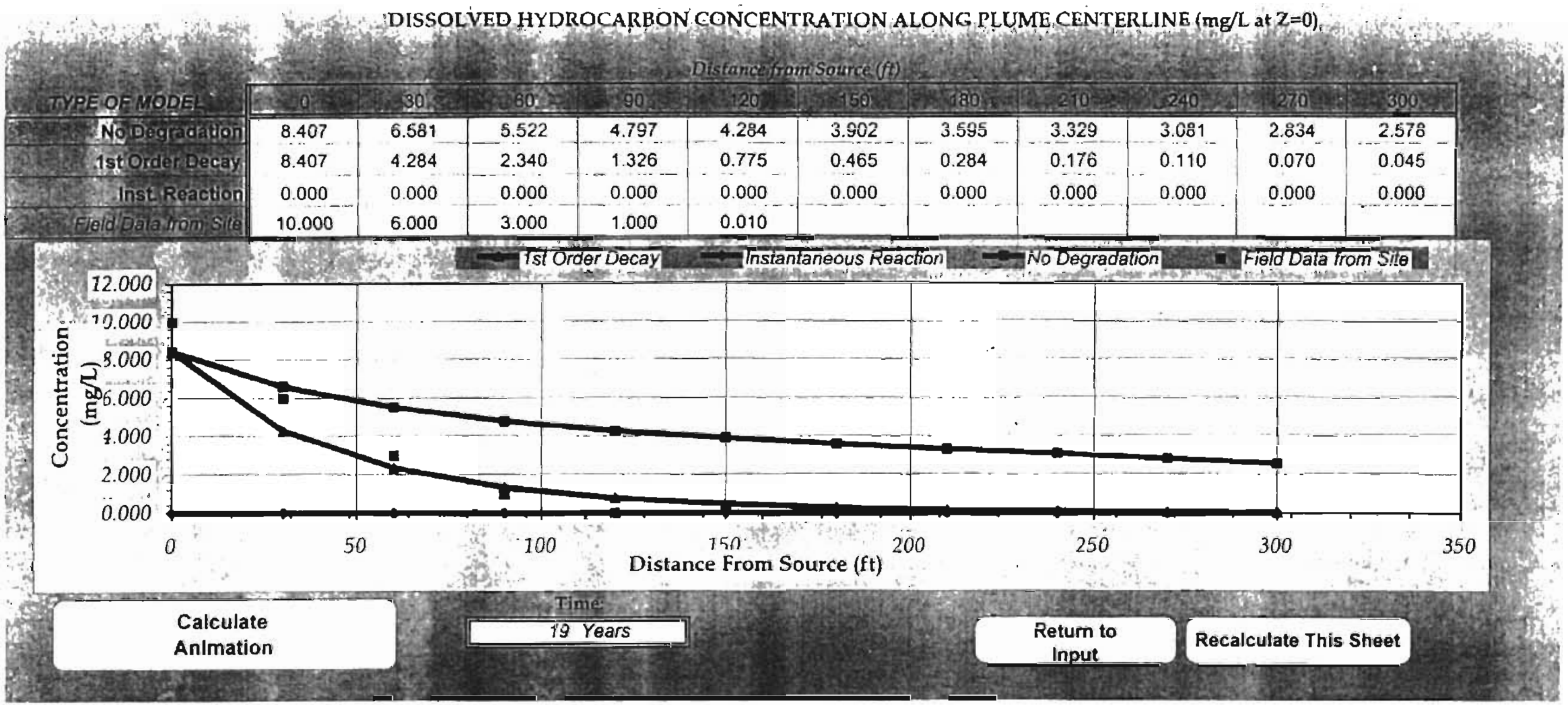
In Source NAPL, Soil

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Concentration (mg/L)	10.0	6.0	3.0	1.0	.01	.0	.0			.0	
Dist. from Source (ft)	0	30	60	90	120	150	180	210	240	270	300

8. CHOOSE TYPE OF OUTPUT TO SEE:

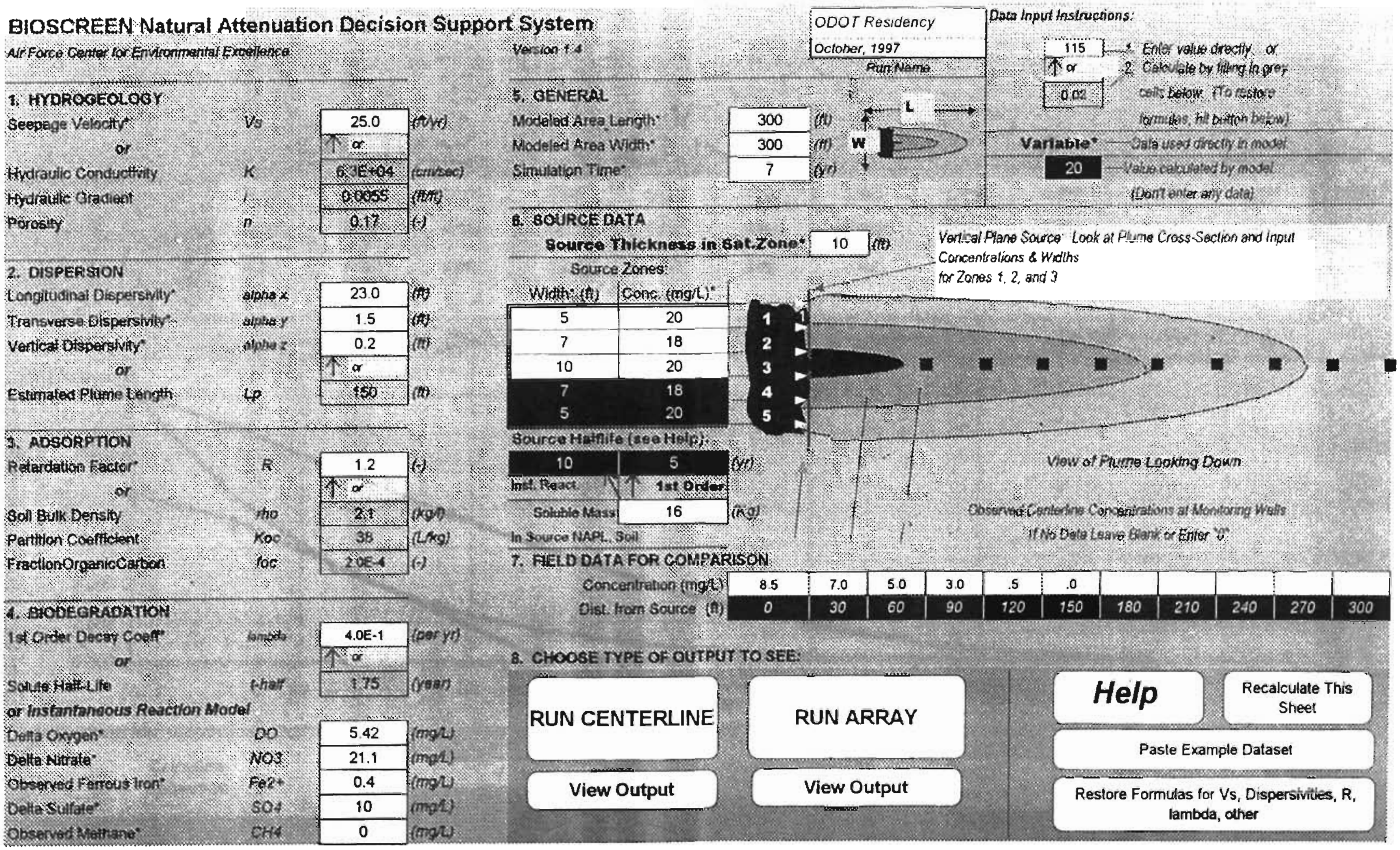


DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

	Distance from Source (ft)										
TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	8.407	6.581	5.522	4.797	4.284	3.902	3.595	3.329	3.081	2.834	2.578
1st Order Decay	8.407	4.284	2.340	1.326	0.775	0.465	0.284	0.176	0.110	0.070	0.045
Inst. Reaction	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	10.000	6.000	3.000	1.000	0.010						

Time: 19 Years

APPENDIX F
BIOSCREEN OUTPUT – RUN #2



BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence

Version 1.4

ODOT Residency
October, 1997
Run Name

Data Input Instructions:
115 — 1. Enter value directly ... or
or — 2. Calculate by filling in grey cells below. (To restore formulas, hit button below)
0.02
Variable* — Data used directly in model
20 — Value calculated by model (Don't enter any data)

1. HYDROGEOLOGY

Seepage Velocity*	Vs	25.0	(ft/yr)
or		or	
Hydraulic Conductivity	K	6.3E+04	(cm/sec)
Hydraulic Gradient	i	0.0055	(ft/ft)
Porosity	n	0.17	(-)

2. DISPERSION

Longitudinal Dispersivity*	alpha x	23.0	(ft)
Transverse Dispersivity*	alpha y	1.5	(ft)
Vertical Dispersivity*	alpha z	0.2	(ft)
or		or	
Estimated Plume Length	Lp	150	(ft)

3. ADSORPTION

Retardation Factor*	R	1.2	(-)
or		or	
Soil Bulk Density	rho	2.1	(kg/l)
Partition Coefficient	Koc	38	(L/kg)
FractionOrganicCarbon	foc	2.0E-4	(-)

4. BIODEGRADATION

1st Order Decay Coeff*	lambda	4.0E-1	(per yr)
or		or	
Solute Half-Life	t-half	1.75	(year)
or Instantaneous Reaction Model			
Delta Oxygen*	DO	5.42	(mg/L)
Delta Nitrate*	NO3	21.1	(mg/L)
Observed Ferrous Iron*	Fe2+	0.4	(mg/L)
Delta Sulfate*	SO4	10	(mg/L)
Observed Methane*	CH4	0	(mg/L)

5. GENERAL

Modeled Area Length*	300	(ft)
Modeled Area Width*	300	(ft)
Simulation Time*	7	(yr)

6. SOURCE DATA

Source Thickness in Sat.Zone* 10 (ft)

Source Zones:

Width* (ft)	Conc. (mg/L)*
5	20
7	18
10	20
7	18
5	20

Source Halflife (see Help):

Inst. React.	1st Order	
10	5	(yr)

Soluble Mass 16 (Kg)
In Source NAPL, Soil

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths for Zones 1, 2, and 3

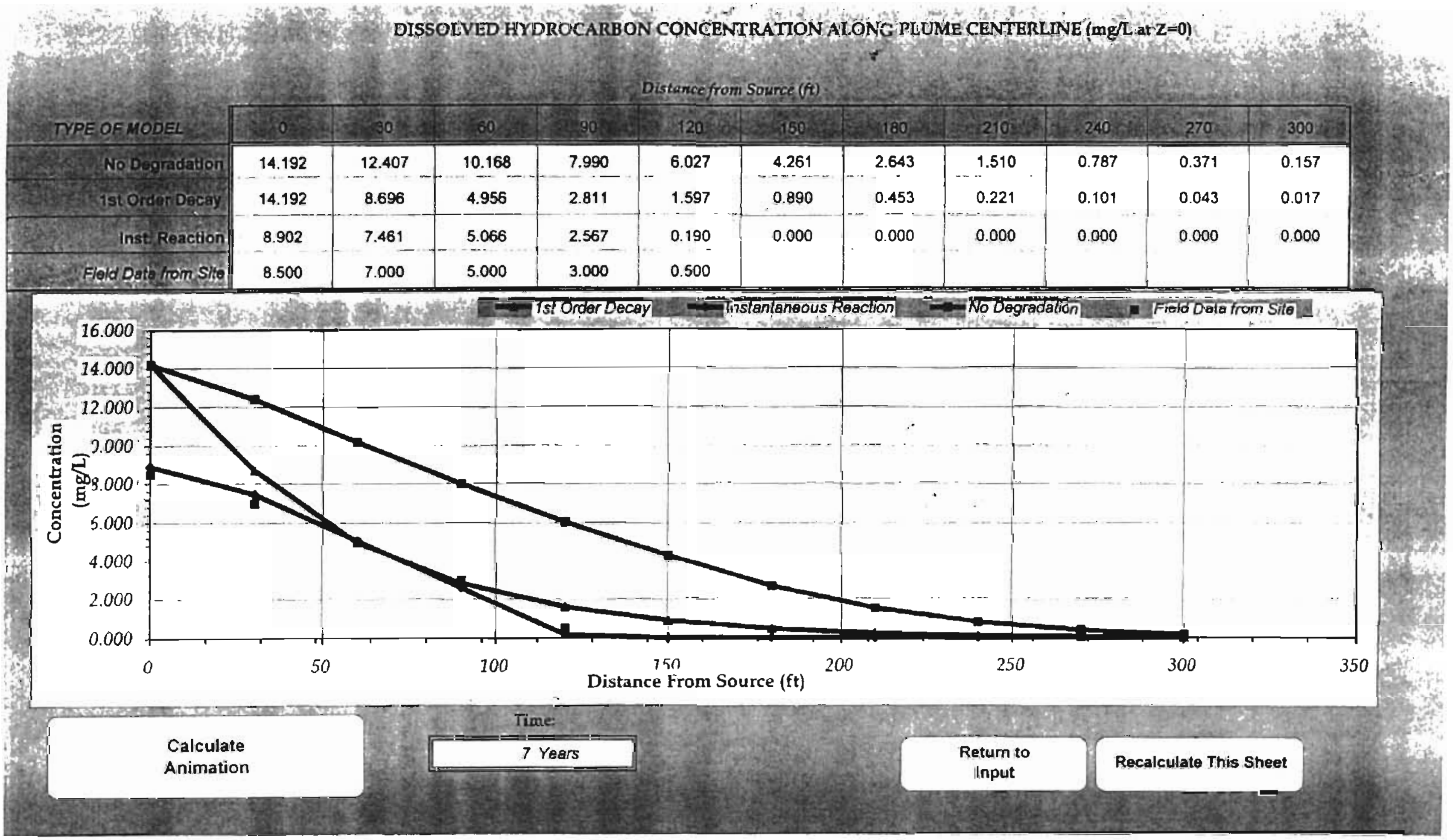
View of Plume Looking Down

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Concentration (mg/L)	8.5	7.0	5.0	3.0	.5	.0					
Dist. from Source (ft)	0	30	60	90	120	150	180	210	240	270	300

8. CHOOSE TYPE OF OUTPUT TO SEE:

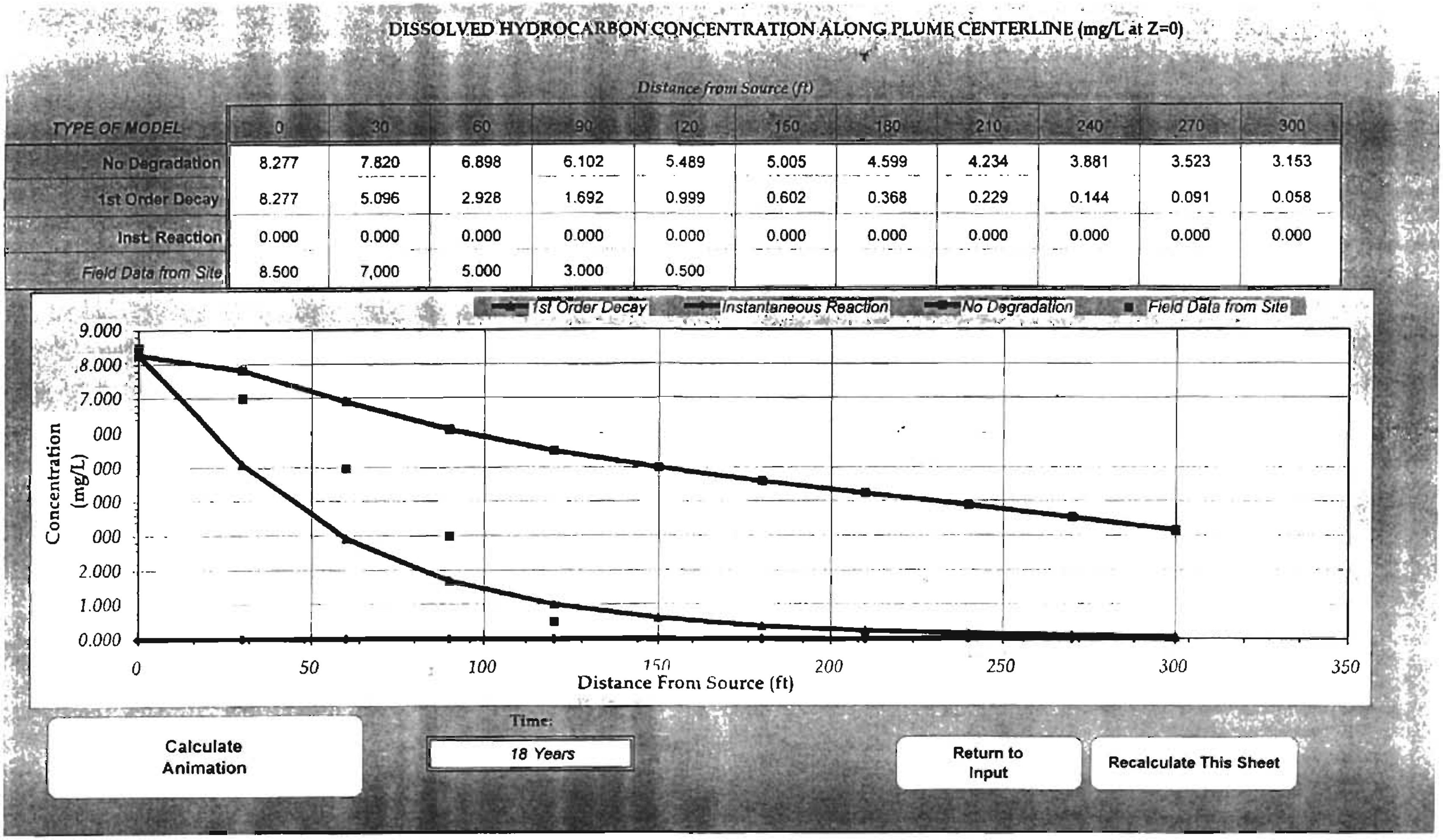


DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

	Distance from Source (ft)										
TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	14.192	12.407	10.168	7.990	6.027	4.261	2.643	1.510	0.787	0.371	0.157
1st Order Decay	14.192	8.696	4.956	2.811	1.597	0.890	0.453	0.221	0.101	0.043	0.017
Inst. Reaction	8.902	7.461	5.066	2.567	0.190	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	8.500	7.000	5.000	3.000	0.500						

Time:

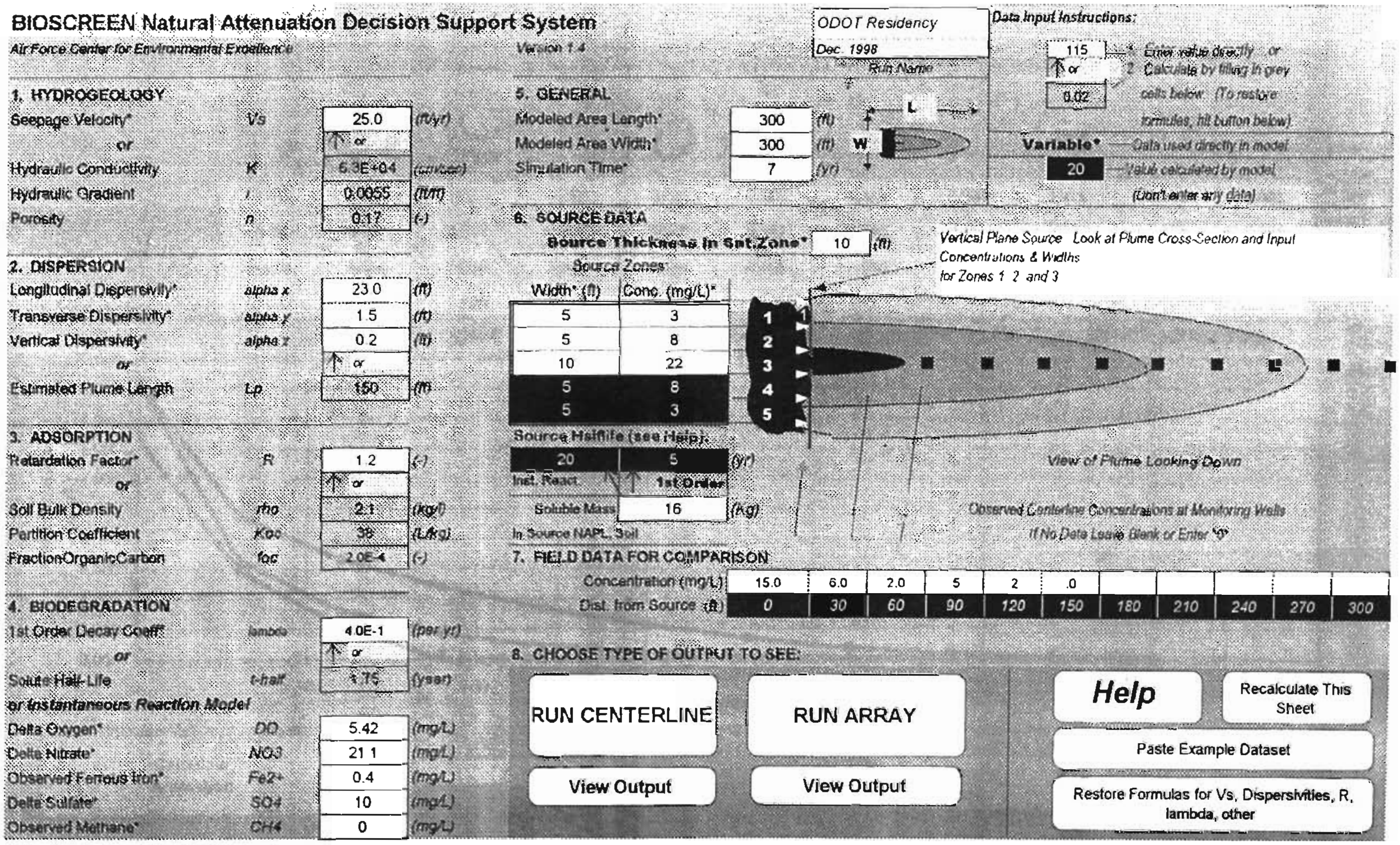
7 Years



DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

	Distance from Source (ft)										
TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	8.277	7.820	6.898	6.102	5.489	5.005	4.599	4.234	3.881	3.523	3.153
1st Order Decay	8.277	5.096	2.928	1.692	0.999	0.602	0.368	0.229	0.144	0.091	0.058
Inst. Reaction	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	8.500	7.000	5.000	3.000	0.500						

Time: 18 Years



BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence

Version 1.4

ODOT Residency

Dec. 1998

Run Name

1. HYDROGEOLOGY

Seepage Velocity*	Vs	25.0	(ft/yr)
or		or	
Hydraulic Conductivity	K	6.3E+04	(cm/sec)
Hydraulic Gradient	i	0.0055	(ft/ft)
Porosity	n	0.17	(-)

2. DISPERSION

Longitudinal Dispersivity*	alpha x	23.0	(ft)
Transverse Dispersivity*	alpha y	1.5	(ft)
Vertical Dispersivity*	alpha z	0.2	(ft)
or		or	
Estimated Plume Length	Lp	150	(ft)

3. ADSORPTION

Retardation Factor*	R	1.2	(-)
or		or	
Soil Bulk Density	rho	2.1	(kg/l)
Partition Coefficient	Koc	38	(L/kg)
FractionOrganicCarbon	foc	2.0E-4	(-)

4. BIODEGRADATION

1st Order Decay Coeff*	lambda	4.0E-1	(per yr)
or		or	
Solute Half-Life	t-half	1.75	(year)
or Instantaneous Reaction Model			
Delta Oxygen*	DO	5.42	(mg/L)
Delta Nitrate*	NO3	21.1	(mg/L)
Observed Ferrous Iron*	Fe2+	0.4	(mg/L)
Delta Sulfate*	SO4	10	(mg/L)
Observed Methane*	CH4	0	(mg/L)

5. GENERAL

Modeled Area Length*	300	(ft)
Modeled Area Width*	300	(ft)
Simulation Time*	7	(yr)

Data Input Instructions:

115 — 1. Enter value directly ... or

or — 2. Calculate by filling in grey cells below. (To restore formulas, hit button below).

0.02

Variable* — Data used directly in model.

20 — Value calculated by model. (Don't enter any data).

6. SOURCE DATA

Source Thickness in Sat.Zone* 10 (ft)

Source Zones:

Width* (ft)	Conc. (mg/L)*
5	3
5	8
10	22
5	8
5	3

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths for Zones 1, 2, and 3

Source Halflife (see Help):

20	5	(yr)
Inst. React.	1st Order	

Soluble Mass 16 (kg)

In Source NAPL, Soil

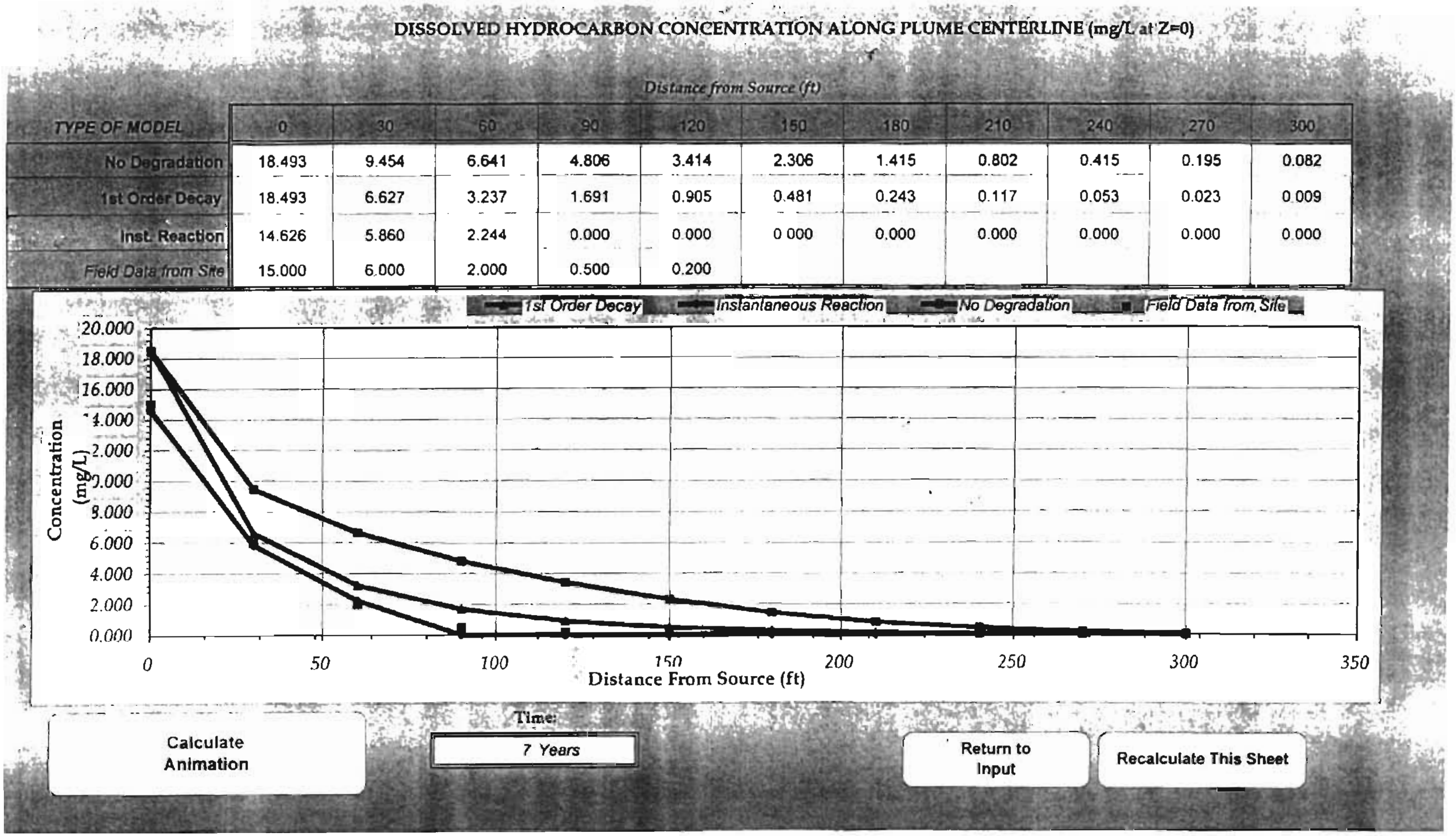
Observed Centerline Concentrations at Monitoring Wells

If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Concentration (mg/L)	15.0	6.0	2.0	5	2	.0					
Dist. from Source (ft)	0	30	60	90	120	150	180	210	240	270	300

8. CHOOSE TYPE OF OUTPUT TO SEE:



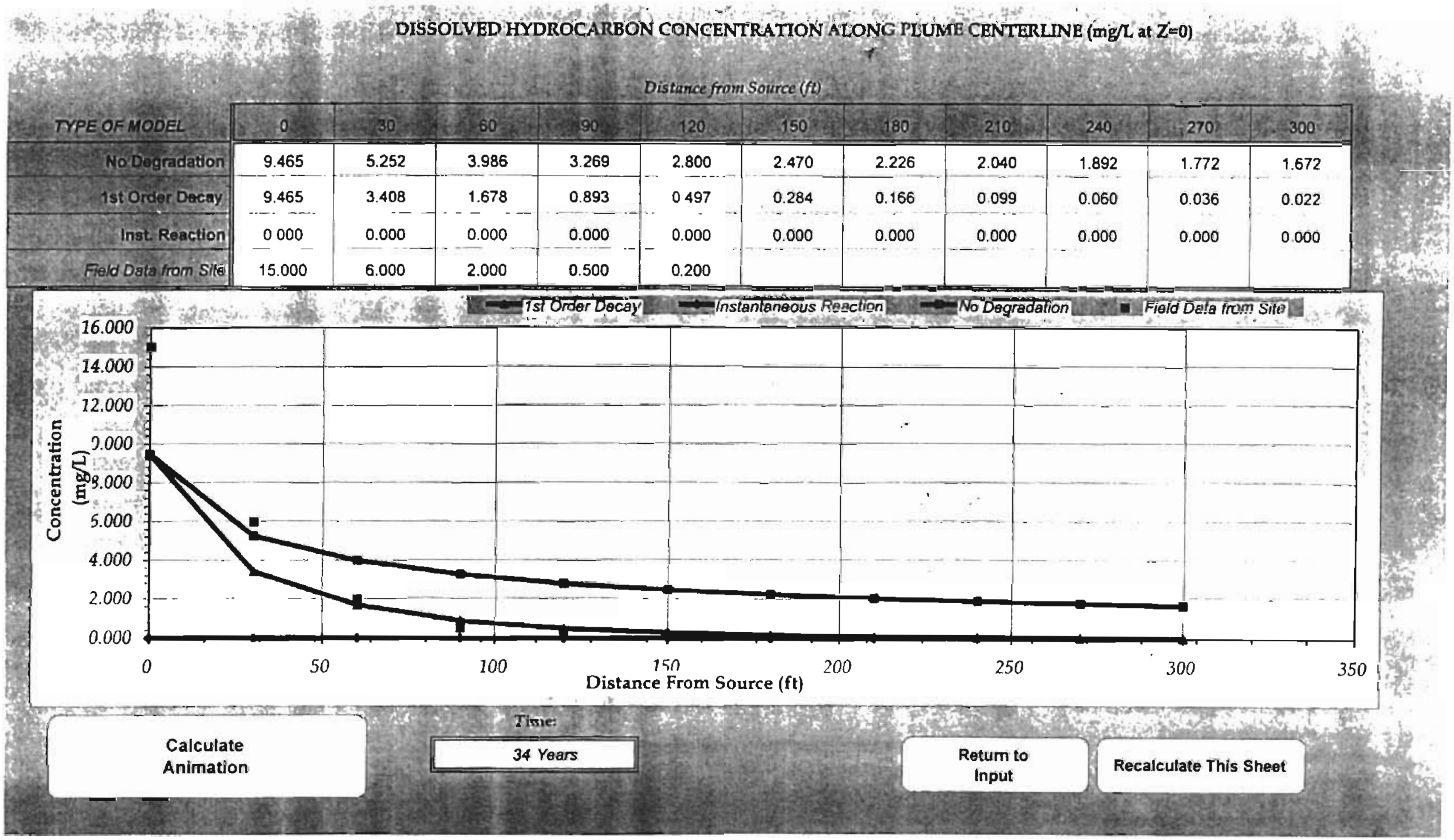
DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	18.493	9.454	6.641	4.806	3.414	2.306	1.415	0.802	0.415	0.195	0.082
1st Order Decay	18.493	6.627	3.237	1.691	0.905	0.481	0.243	0.117	0.053	0.023	0.009
Inst. Reaction	14.626	5.860	2.244	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	15.000	6.000	2.000	0.500	0.200						

Time:

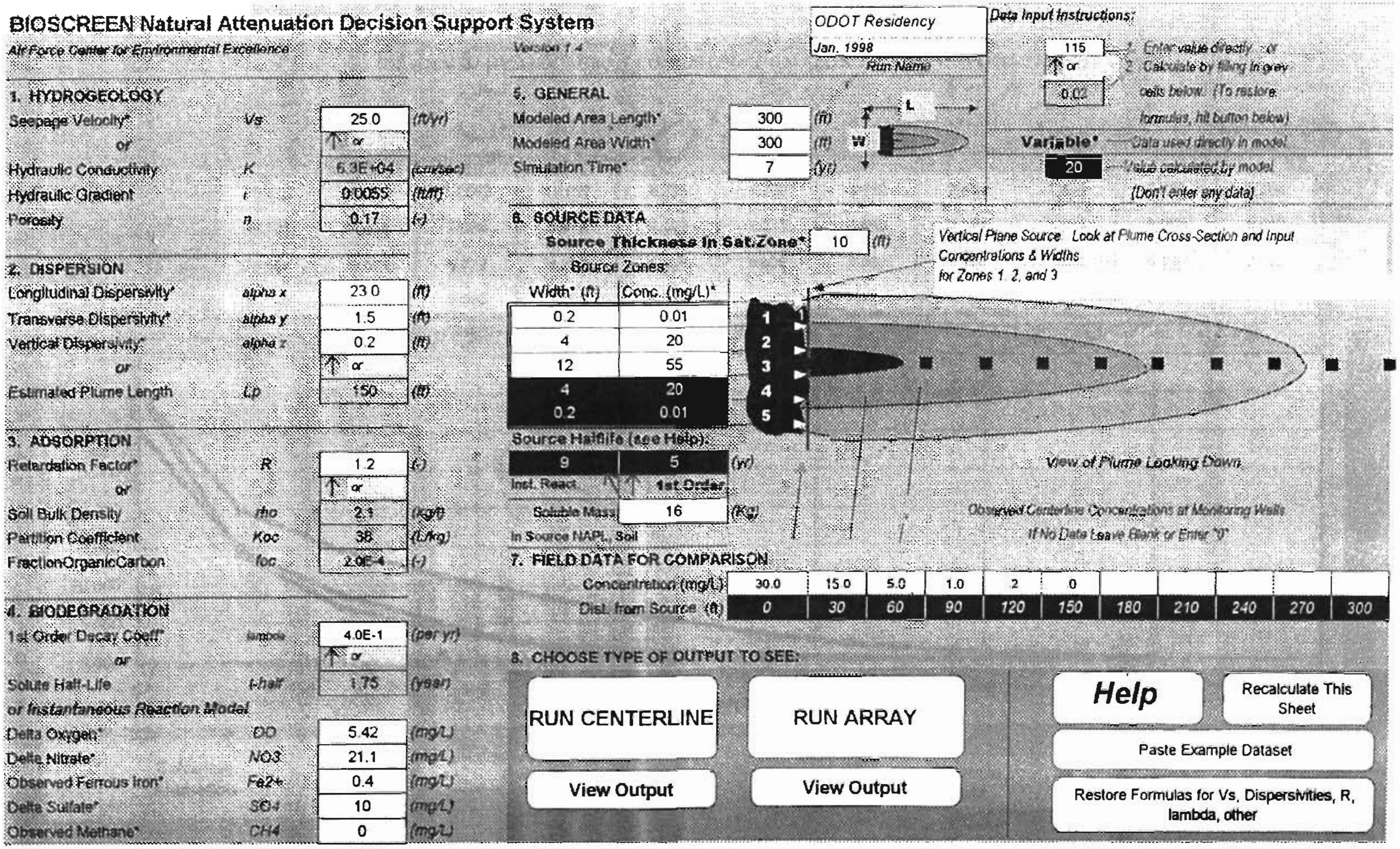
7 Years



DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

TYPE OF MODEL	Distance from Source (ft) 0	30	60	90	120	150	180	210	240	270	300
No Degradation	9.465	5.252	3.986	3.269	2.800	2.470	2.226	2.040	1.892	1.772	1.672
1st Order Decay	9.465	3.408	1.678	0.893	0.497	0.284	0.166	0.099	0.060	0.036	0.022
Inst. Reaction	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	15.000	6.000	2.000	0.500	0.200						

Time: 34 Years



BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence

Version 1.4

ODOT Residency
Jan. 1998
Run Name

Data Input Instructions:

115 — 1. Enter value directly ... or
↑ or
0.02 — 2. Calculate by filling in grey cells below. (To restore formulas, hit button below)

Variable* — Data used directly in model

20 — Value calculated by model (Don't enter any data)

1. HYDROGEOLOGY

Seepage Velocity*	Vs	25.0	(ft/yr)
or		↑ or	
Hydraulic Conductivity	K	6.3E+04	(cm/sec)
Hydraulic Gradient	i	0.0055	(ft/ft)
Porosity	n	0.17	(-)

2. DISPERSION

Longitudinal Dispersivity*	alpha x	23.0	(ft)
Transverse Dispersivity*	alpha y	1.5	(ft)
Vertical Dispersivity*	alpha z	0.2	(ft)
or		↑ or	
Estimated Plume Length	Lp	150	(ft)

3. ADSORPTION

Retardation Factor*	R	1.2	(-)
or		↑ or	
Soil Bulk Density	rho	2.1	(kg/l)
Partition Coefficient	Koc	38	(L/kg)
FractionOrganicCarbon	foc	2.0E-4	(-)

4. BIODEGRADATION

1st Order Decay Coeff*	lambda	4.0E-1	(per yr)
or		↑ or	
Solute Half-Life	t-half	1.75	(year)
or Instantaneous Reaction Model			
Delta Oxygen*	DO	5.42	(mg/L)
Delta Nitrate*	NO3	21.1	(mg/L)
Observed Ferrous Iron*	Fe2+	0.4	(mg/L)
Delta Sulfate*	SO4	10	(mg/L)
Observed Methane*	CH4	0	(mg/L)

5. GENERAL

Modeled Area Length*	300	(ft)
Modeled Area Width*	300	(ft)
Simulation Time*	7	(yr)

6. SOURCE DATA

Source Thickness in Sat.Zone* 10 (ft)

Source Zones:

Width* (ft)	Conc. (mg/L)*
0.2	0.01
4	20
12	55
4	20
0.2	0.01

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths for Zones 1, 2, and 3

Source Halflife (see Help):

Inst. React.	1st Order	
9	5	(yr)

Soluble Mass 16 (Kg)
In Source NAPL, Soil

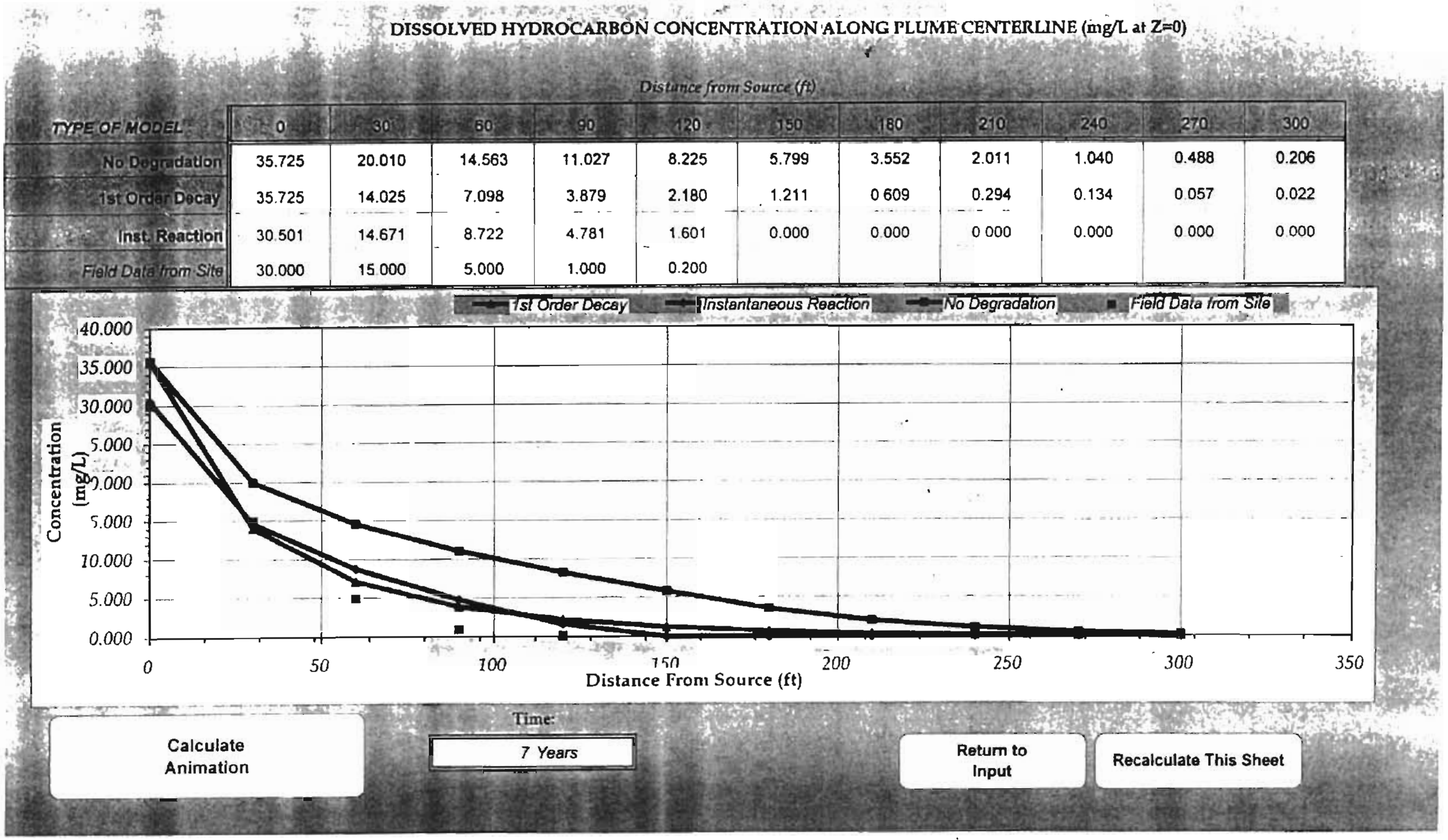
View of Plume Looking Down

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Concentration (mg/L)	30.0	15.0	5.0	1.0	2	0					
Dist. from Source (ft)	0	30	60	90	120	150	180	210	240	270	300

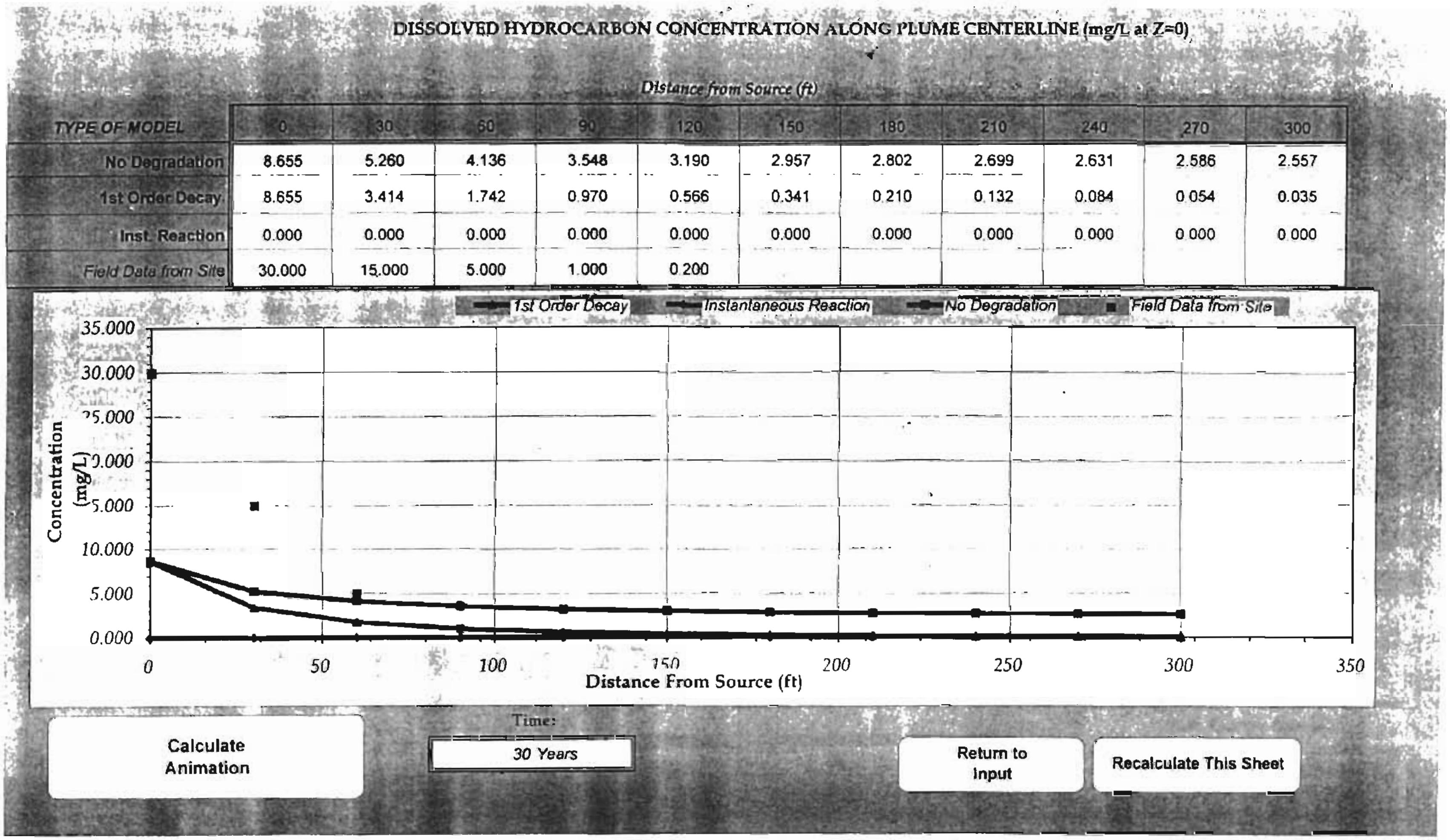
8. CHOOSE TYPE OF OUTPUT TO SEE:



DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

	Distance from Source (ft)										
TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	35.725	20.010	14.563	11.027	8.225	5.799	3.552	2.011	1.040	0.488	0.206
1st Order Decay	35.725	14.025	7.098	3.879	2.180	1.211	0 609	0.294	0.134	0.057	0.022
Inst. Reaction	30.501	14.671	8.722	4.781	1.601	0.000	0.000	0 000	0.000	0 000	0.000
Field Data from Site	30.000	15.000	5.000	1.000	0.200						

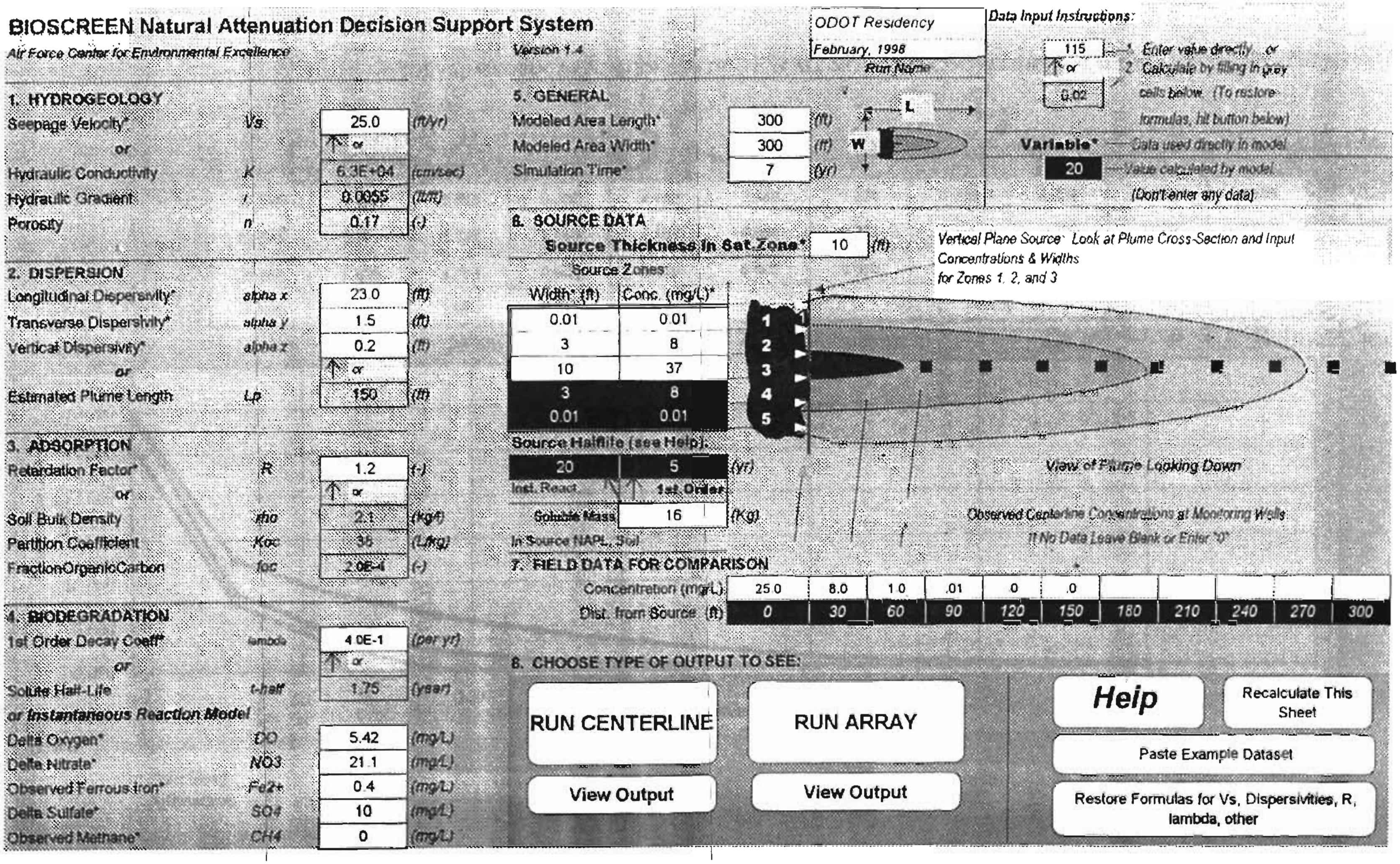
Time: 7 Years



DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

TYPE OF MODEL	Distance from Source (ft) 0	30	60	90	120	150	180	210	240	270	300
No Degradation	8.655	5.260	4.136	3.548	3.190	2.957	2.802	2.699	2.631	2.586	2.557
1st Order Decay	8.655	3.414	1.742	0.970	0.566	0.341	0.210	0.132	0.084	0.054	0.035
Inst. Reaction	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	30.000	15.000	5.000	1.000	0.200						

Time: 30 Years



BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence

Version 1.4

ODOT Residency
February, 1998
Run Name

Data Input Instructions:

115 — 1. Enter value directly ... or
↑ or — 2. Calculate by filling in grey
0.02 — cells below. (To restore formulas, hit button below)

Variable* — Data used directly in model
20 — Value calculated by model (Don't enter any data)

1. HYDROGEOLOGY

Seepage Velocity*	Vs	25.0	(ft/yr)
or		↑ or	
Hydraulic Conductivity	K	6.3E+04	(cm/sec)
Hydraulic Gradient	i	0.0055	(ft/ft)
Porosity	n	0.17	(-)

2. DISPERSION

Longitudinal Dispersivity*	alpha x	23.0	(ft)
Transverse Dispersivity*	alpha y	1.5	(ft)
Vertical Dispersivity*	alpha z	0.2	(ft)
or		↑ or	
Estimated Plume Length	Lp	150	(ft)

3. ADSORPTION

Retardation Factor*	R	1.2	(-)
or		↑ or	
Soil Bulk Density	rho	2.1	(kg/l)
Partition Coefficient	Koc	38	(L/kg)
FractionOrganicCarbon	foc	2.0E-4	(-)

4. BIODEGRADATION

1st Order Decay Coeff*	lambda	4.0E-1	(per yr)
or		↑ or	
Solute Half-Life	t-half	1.75	(year)
or Instantaneous Reaction Model			
Delta Oxygen*	DO	5.42	(mg/L)
Delta Nitrate*	NO3	21.1	(mg/L)
Observed Ferrous Iron*	Fe2+	0.4	(mg/L)
Delta Sulfate*	SO4	10	(mg/L)
Observed Methane*	CH4	0	(mg/L)

5. GENERAL

Modeled Area Length*	300	(ft)
Modeled Area Width*	300	(ft)
Simulation Time*	7	(yr)

6. SOURCE DATA

Source Thickness in Sat.Zone* 10 (ft)

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths for Zones 1, 2, and 3

Source Zones:

Width* (ft)	Conc. (mg/L)*
0.01	0.01
3	8
10	37
3	8
0.01	0.01

Source Halflife (see Help):

Inst. React.	1st Order	
20	5	(yr)

Soluble Mass 16 (Kg)
In Source NAPL, Soil

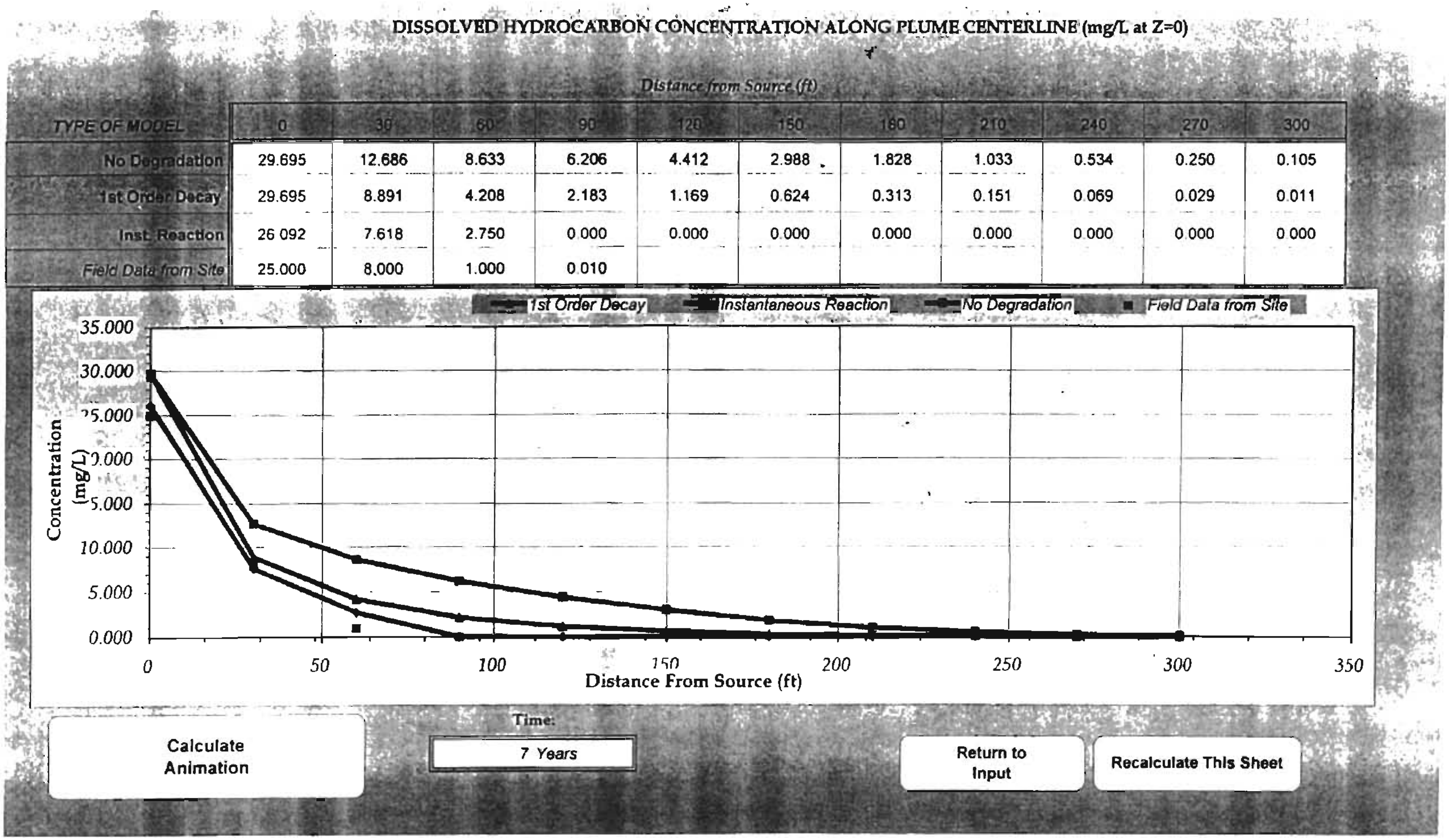
View of Plume Looking Down

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Concentration (mg/L)	25.0	8.0	1.0	.01	0	.0					
Dist. from Source (ft)	0	30	60	90	120	150	180	210	240	270	300

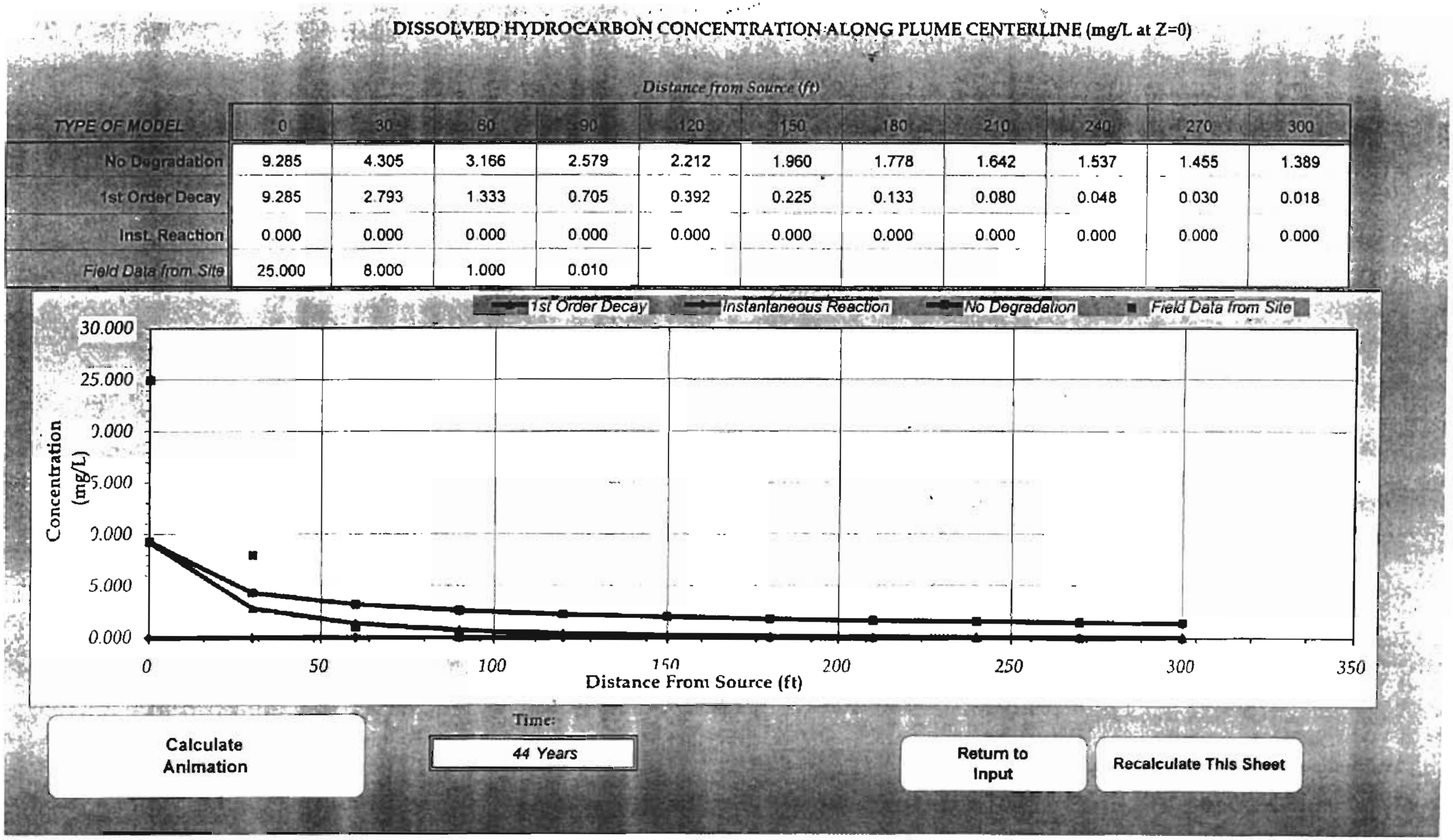
8. CHOOSE TYPE OF OUTPUT TO SEE:



DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

TYPE OF MODEL	Distance from Source (ft)										
	0	30	60	90	120	150	180	210	240	270	300
No Degradation	29.695	12.686	8.633	6.206	4.412	2.988	1.828	1.033	0.534	0.250	0.105
1st Order Decay	29.695	8.891	4.208	2.183	1.169	0.624	0.313	0.151	0.069	0.029	0.011
Inst. Reaction	26.092	7.618	2.750	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	25.000	8.000	1.000	0.010							

Time: 7 Years

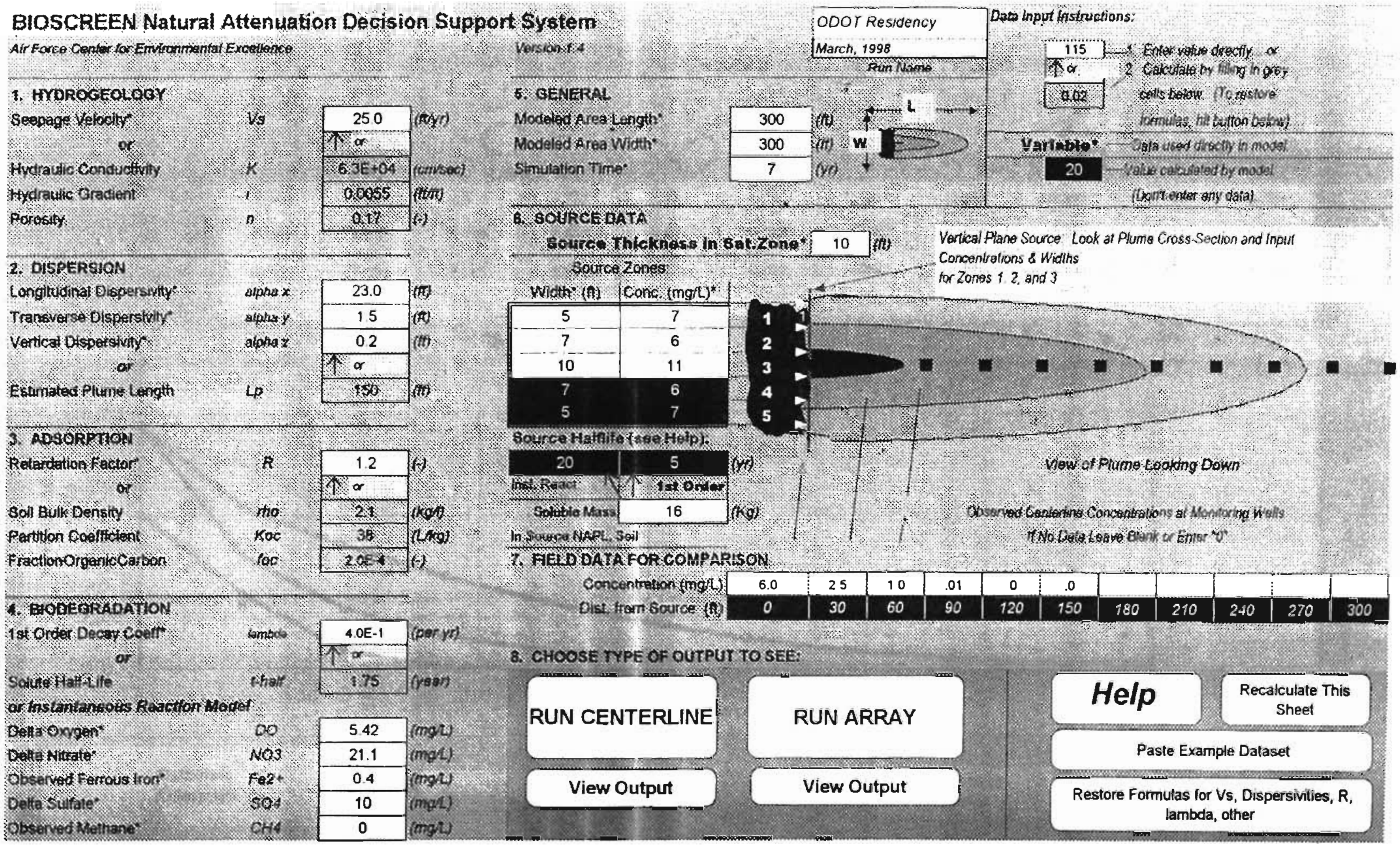


DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

	Distance from Source (ft)										
TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	9.285	4.305	3.166	2.579	2.212	1.960	1.778	1.642	1.537	1.455	1.389
1st Order Decay	9.285	2.793	1.333	0.705	0.392	0.225	0.133	0.080	0.048	0.030	0.018
Inst. Reaction	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	25.000	8.000	1.000	0.010							

Time:

44 Years



BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence

Version 1.4

ODOT Residency
March, 1998
Run Name

Data Input Instructions:

115	1. Enter value directly ... or
↑ or	2. Calculate by filling in grey
0.02	cells below. (To restore formulas, hit button below)
Variable*	Data used directly in model
20	Value calculated by model (Don't enter any data)

1. HYDROGEOLOGY

Seepage Velocity*	Vs	25.0	(ft/yr)
or		↑ or	
Hydraulic Conductivity	K	6.3E+04	(cm/sec)
Hydraulic Gradient	i	0.0055	(ft/ft)
Porosity	n	0.17	(-)

2. DISPERSION

Longitudinal Dispersivity*	alpha x	23.0	(ft)
Transverse Dispersivity*	alpha y	1.5	(ft)
Vertical Dispersivity*	alpha z	0.2	(ft)
or		↑ or	
Estimated Plume Length	Lp	150	(ft)

3. ADSORPTION

Retardation Factor*	R	1.2	(-)
or		↑ or	
Soil Bulk Density	rho	2.1	(kg/l)
Partition Coefficient	Koc	38	(L/kg)
FractionOrganicCarbon	foc	2.0E-4	(-)

4. BIODEGRADATION

1st Order Decay Coeff*	lambda	4.0E-1	(per yr)
or		↑ or	
Solute Half-Life	t-half	1.75	(year)
or Instantaneous Reaction Model			
Delta Oxygen*	DO	5.42	(mg/L)
Delta Nitrate*	NO3	21.1	(mg/L)
Observed Ferrous Iron*	Fe2+	0.4	(mg/L)
Delta Sulfate*	SO4	10	(mg/L)
Observed Methane*	CH4	0	(mg/L)

5. GENERAL

Modeled Area Length*	300	(ft)
Modeled Area Width*	300	(ft)
Simulation Time*	7	(yr)

6. SOURCE DATA

Source Thickness in Sat.Zone* 10 (ft)

Source Zones:

Width* (ft)	Conc. (mg/L)*
5	7
7	6
10	11
7	6
5	7

Source Halflife (see Help):

20	5	(yr)
Inst. React.	1st Order	
Soluble Mass	16	(Kg)

In Source NAPL, Soil

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths for Zones 1, 2, and 3

View of Plume Looking Down

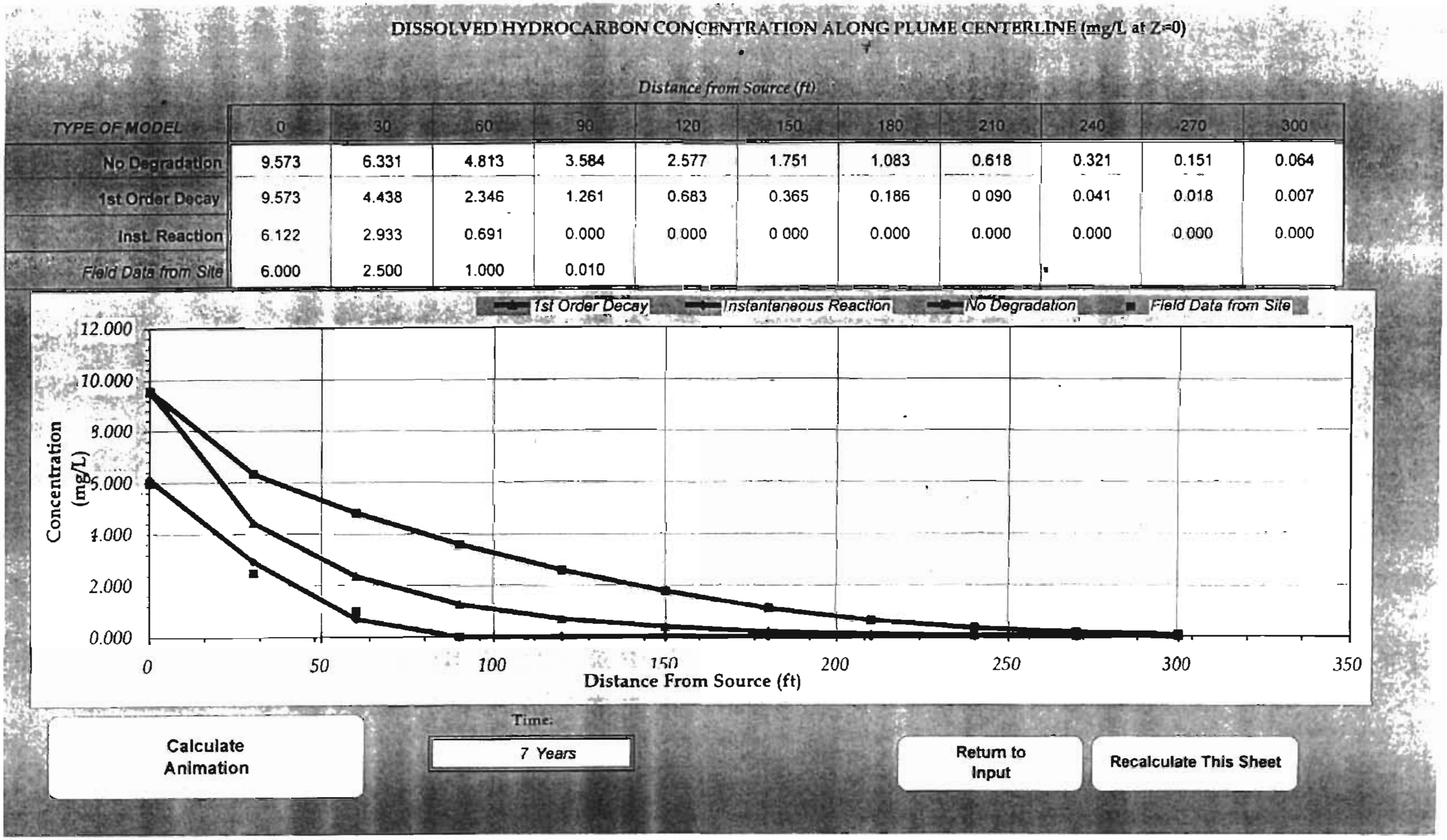
Observed Centerline Concentrations at Monitoring Wells

If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Concentration (mg/L)	6.0	2.5	1.0	.01	0	.0					
Dist. from Source (ft)	0	30	60	90	120	150	180	210	240	270	300

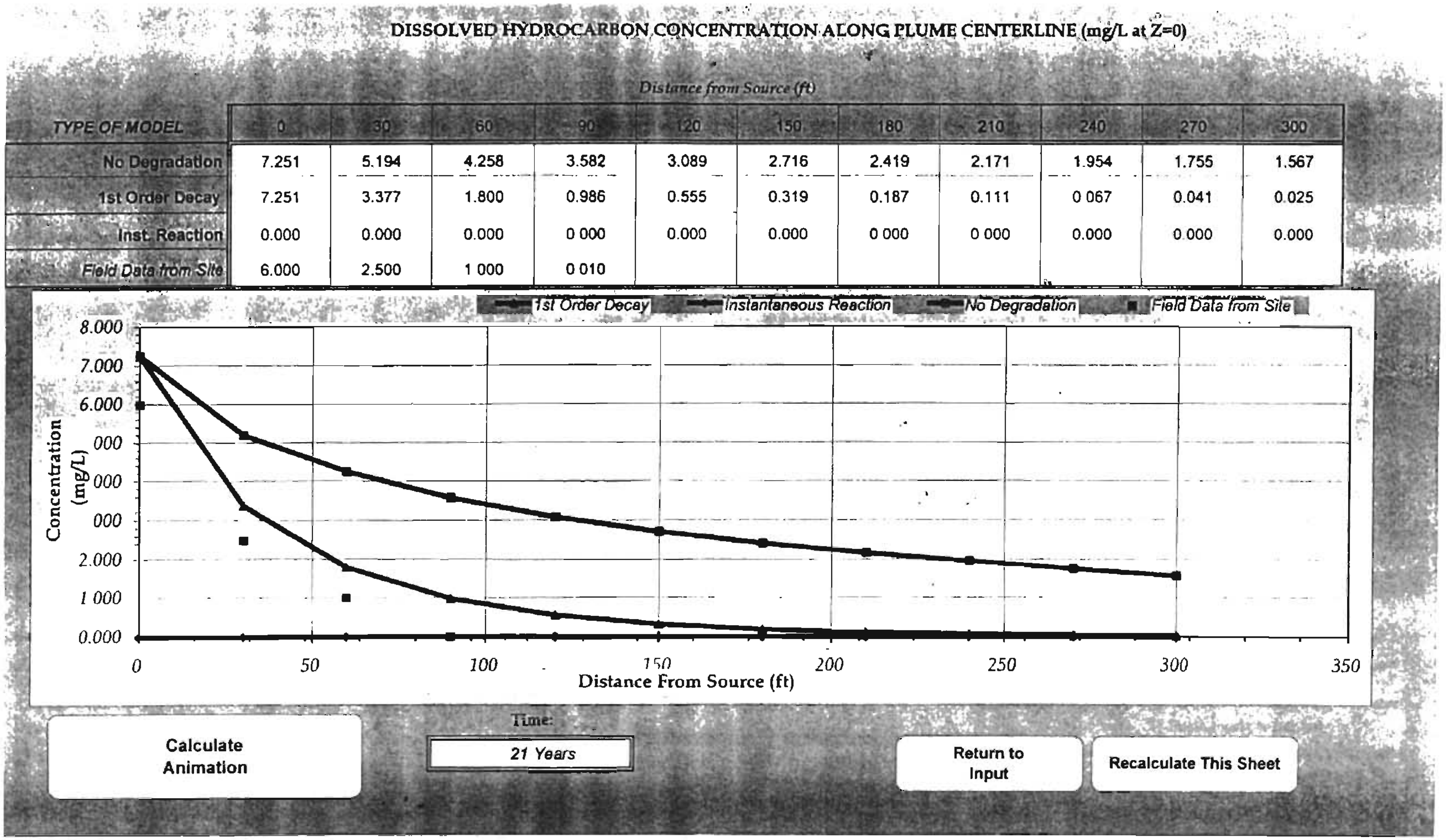
8. CHOOSE TYPE OF OUTPUT TO SEE:



DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

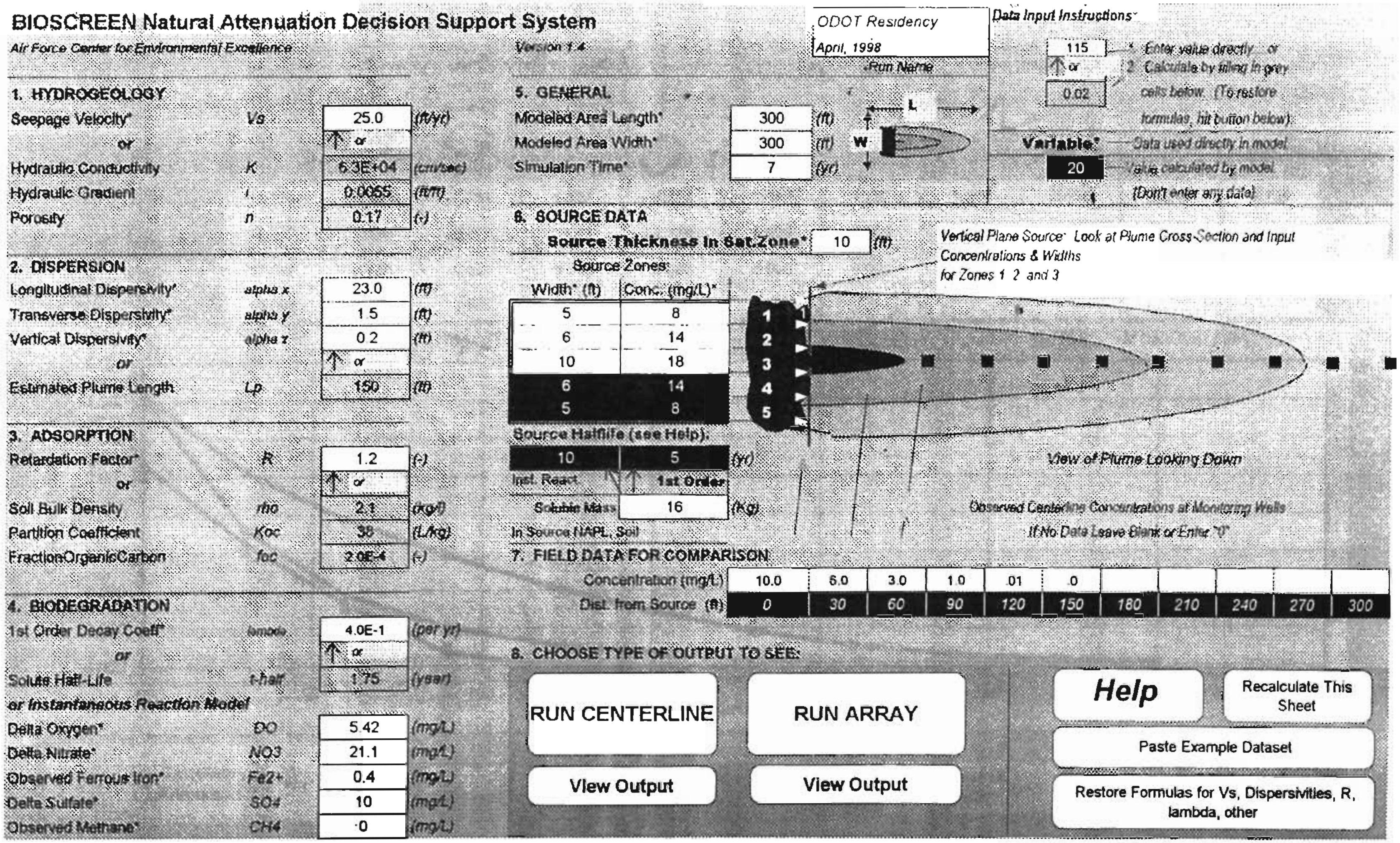
Distance from Source (ft)

TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	9.573	6.331	4.813	3.584	2.577	1.751	1.083	0.618	0.321	0.151	0.064
1st Order Decay	9.573	4.438	2.346	1.261	0.683	0.365	0.186	0.090	0.041	0.018	0.007
Inst. Reaction	6.122	2.933	0.691	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	6.000	2.500	1.000	0.010							



DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

	Distance from Source (ft)										
TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	7.251	5.194	4.258	3.582	3.089	2.716	2.419	2.171	1.954	1.755	1.567
1st Order Decay	7.251	3.377	1.800	0.986	0.555	0.319	0.187	0.111	0.067	0.041	0.025
Inst. Reaction	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	6.000	2.500	1.000	0.010							



BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence

Version 1.4

ODOT Residency
April, 1998
Run Name

Data Input Instructions:

115	1. Enter value directly... or
↑ or	2. Calculate by filling in grey
0.02	cells below. (To restore formulas, hit button below).
Variable*	Data used directly in model.
20	Value calculated by model. (Don't enter any data).

1. HYDROGEOLOGY

Seepage Velocity*	Vs	25.0	(ft/yr)
or		↑ or	
Hydraulic Conductivity	K	6.3E+04	(cm/sec)
Hydraulic Gradient	i	0.0055	(ft/ft)
Porosity	n	0.17	(-)

2. DISPERSION

Longitudinal Dispersivity*	alpha x	23.0	(ft)
Transverse Dispersivity*	alpha y	1.5	(ft)
Vertical Dispersivity*	alpha z	0.2	(ft)
or		↑ or	
Estimated Plume Length	Lp	150	(ft)

3. ADSORPTION

Retardation Factor*	R	1.2	(-)
or		↑ or	
Soil Bulk Density	rho	2.1	(kg/l)
Partition Coefficient	Koc	38	(L/kg)
FractionOrganicCarbon	foc	2.0E-4	(-)

4. BIODEGRADATION

1st Order Decay Coeff*	lambda	4.0E-1	(per yr)
or		↑ or	
Solute Half-Life	t-half	1.75	(year)
or Instantaneous Reaction Model			
Delta Oxygen*	DO	5.42	(mg/L)
Delta Nitrate*	NO3	21.1	(mg/L)
Observed Ferrous Iron*	Fe2+	0.4	(mg/L)
Delta Sulfate*	SO4	10	(mg/L)
Observed Methane*	CH4	0	(mg/L)

5. GENERAL

Modeled Area Length*	300	(ft)
Modeled Area Width*	300	(ft)
Simulation Time*	7	(yr)

6. SOURCE DATA

Source Thickness in Sat.Zone* 10 (ft)

Source Zones:

Width* (ft)	Conc. (mg/L)*
5	8
6	14
10	18
6	14
5	8

Source Halflife (see Help):

10	5	(yr)
Inst. React.	1st Order	

Soluble Mass 16 (Kg)
In Source NAPL, Soil

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths for Zones 1, 2, and 3

View of Plume Looking Down

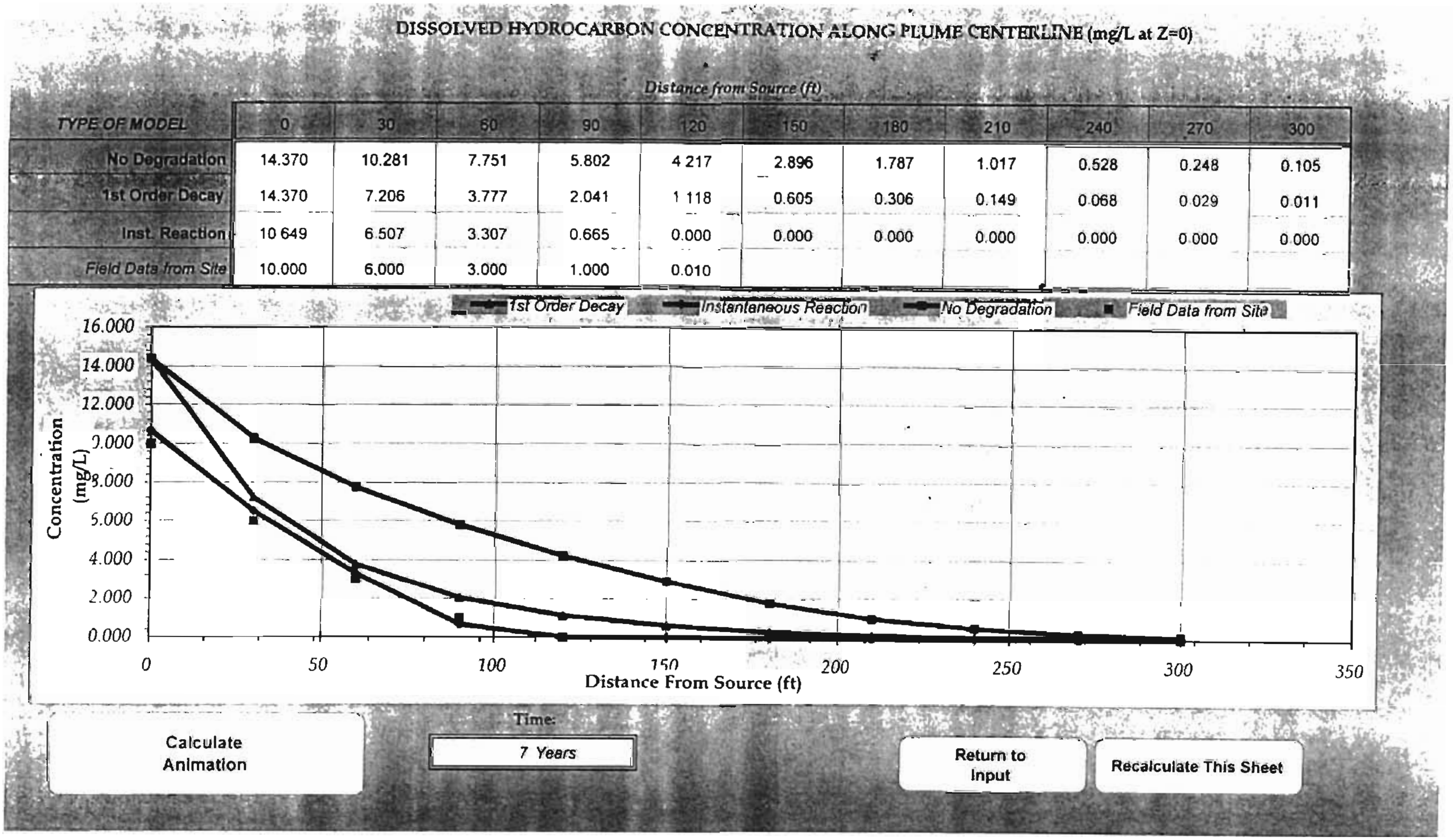
Observed Centerline Concentrations at Monitoring Wells

If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Concentration (mg/L)	10.0	6.0	3.0	1.0	.01	.0					
Dist. from Source (ft)	0	30	60	90	120	150	180	210	240	270	300

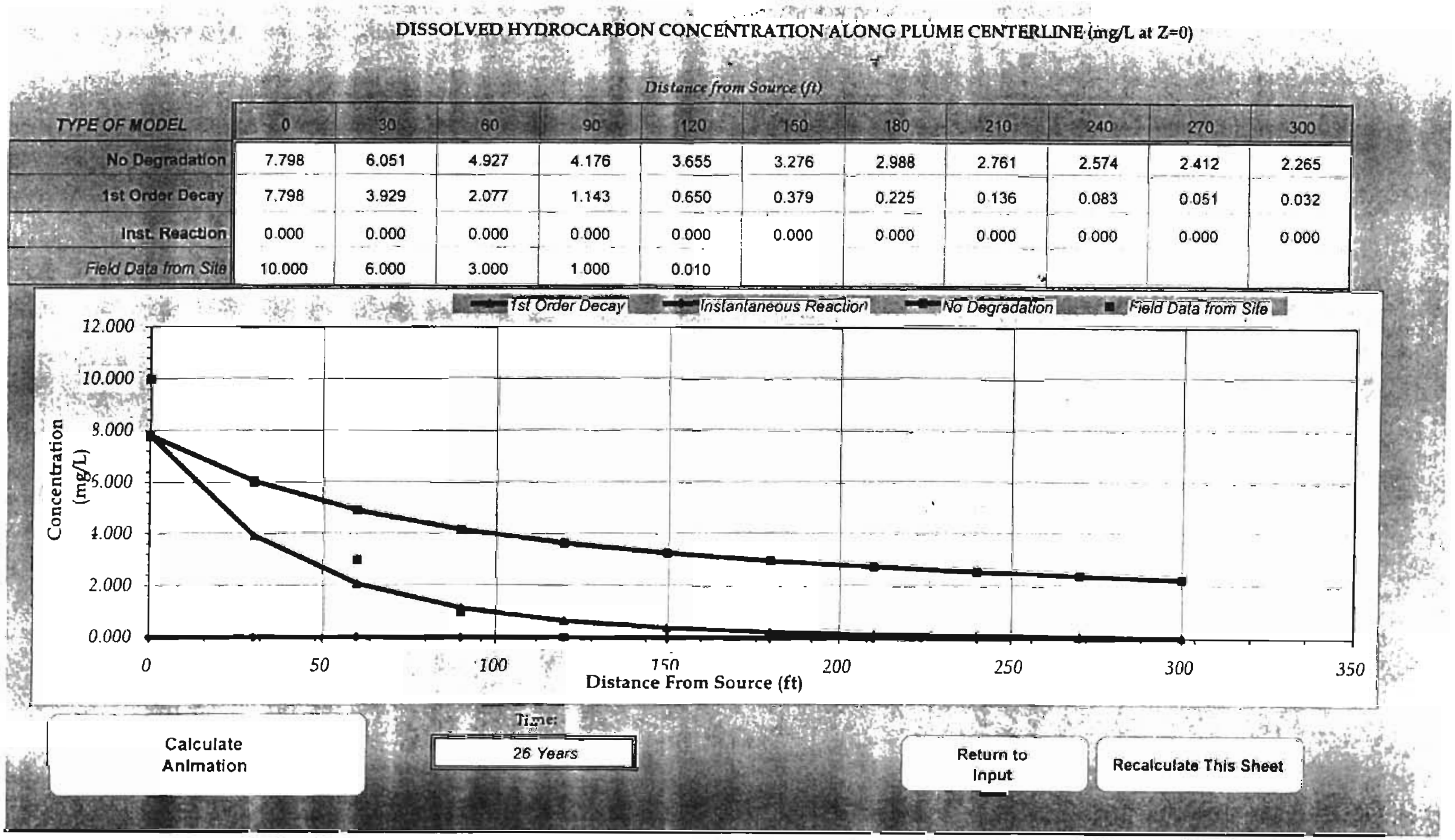
8. CHOOSE TYPE OF OUTPUT TO SEE:



DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	14.370	10.281	7.751	5.802	4 217	2.896	1.787	1.017	0.528	0.248	0.105
1st Order Decay	14.370	7.206	3.777	2.041	1 118	0.605	0.306	0.149	0.068	0.029	0.011
Inst. Reaction	10 649	6.507	3.307	0.665	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	10.000	6.000	3.000	1.000	0.010						



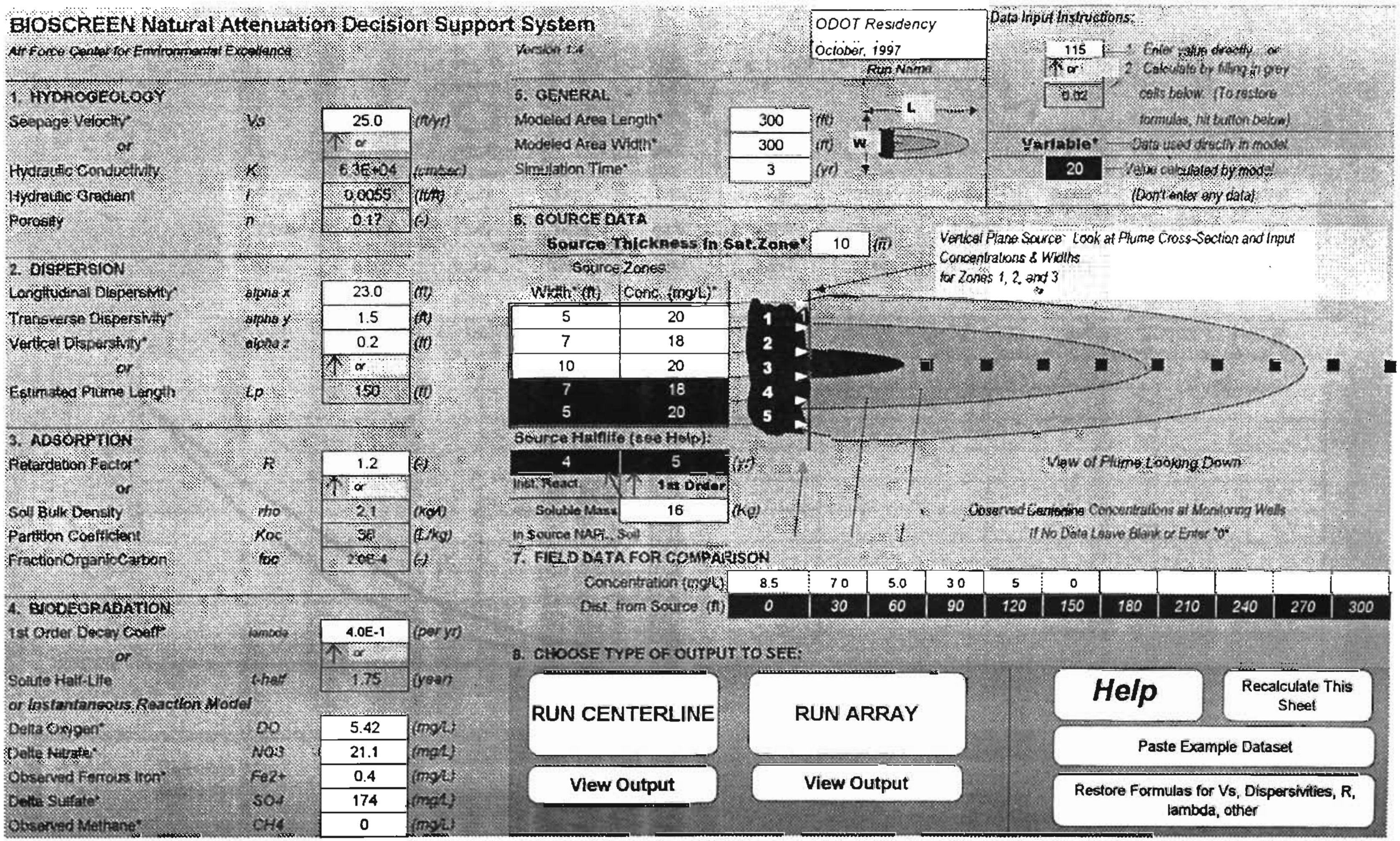
DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	7.798	6.051	4.927	4.176	3.655	3.276	2.988	2.761	2.574	2.412	2.265
1st Order Decay	7.798	3.929	2.077	1.143	0.650	0.379	0.225	0.136	0.083	0.051	0.032
Inst. Reaction	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	10.000	6.000	3.000	1.000	0.010						

Time: 26 Years

APPENDIX G
BIOSCREEN OUTPUT – RUN #3



BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence *Version 1.4*

ODOT Residency
October, 1997
Run Name

Data Input Instructions:
115 — 1. Enter value directly ... or
↑ or — 2. Calculate by filling in grey
0.02 — cells below. (To restore formulas, hit button below)
Variable* — Data used directly in model
20 — Value calculated by model (Don't enter any data)

1. HYDROGEOLOGY

Seepage Velocity*	Vs	25.0	(ft/yr)
or		↑ or	
Hydraulic Conductivity	K	6.3E+04	(cm/sec)
Hydraulic Gradient	i	0.0055	(ft/ft)
Porosity	n	0.17	(-)

2. DISPERSION

Longitudinal Dispersivity*	alpha x	23.0	(ft)
Transverse Dispersivity*	alpha y	1.5	(ft)
Vertical Dispersivity*	alpha z	0.2	(ft)
or		↑ or	
Estimated Plume Length	Lp	150	(ft)

3. ADSORPTION

Retardation Factor*	R	1.2	(-)
or		↑ or	
Soil Bulk Density	rho	2.1	(kg/l)
Partition Coefficient	Koc	38	(L/kg)
FractionOrganicCarbon	foc	2.0E-4	(-)

4. BIODEGRADATION

1st Order Decay Coeff*	lambda	4.0E-1	(per yr)
or		↑ or	
Solute Half-Life	t-half	1.75	(year)
or Instantaneous Reaction Model			
Delta Oxygen*	DO	5.42	(mg/L)
Delta Nitrate*	NO3	21.1	(mg/L)
Observed Ferrous Iron*	Fe2+	0.4	(mg/L)
Delta Sulfate*	SO4	174	(mg/L)
Observed Methane*	CH4	0	(mg/L)

5. GENERAL

Modeled Area Length*	300	(ft)
Modeled Area Width*	300	(ft)
Simulation Time*	3	(yr)

6. SOURCE DATA

Source Thickness in Sat.Zone* 10 (ft)

Source Zones

Width* (ft)	Conc. (mg/L)*
5	20
7	18
10	20
7	18
5	20

Source Halflife (see Help):

4	5	(yr)
Inst. React.	↑ 1st Order	

Soluble Mass 16 (kg)
In Source NAPL, Soil

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths for Zones 1, 2, and 3

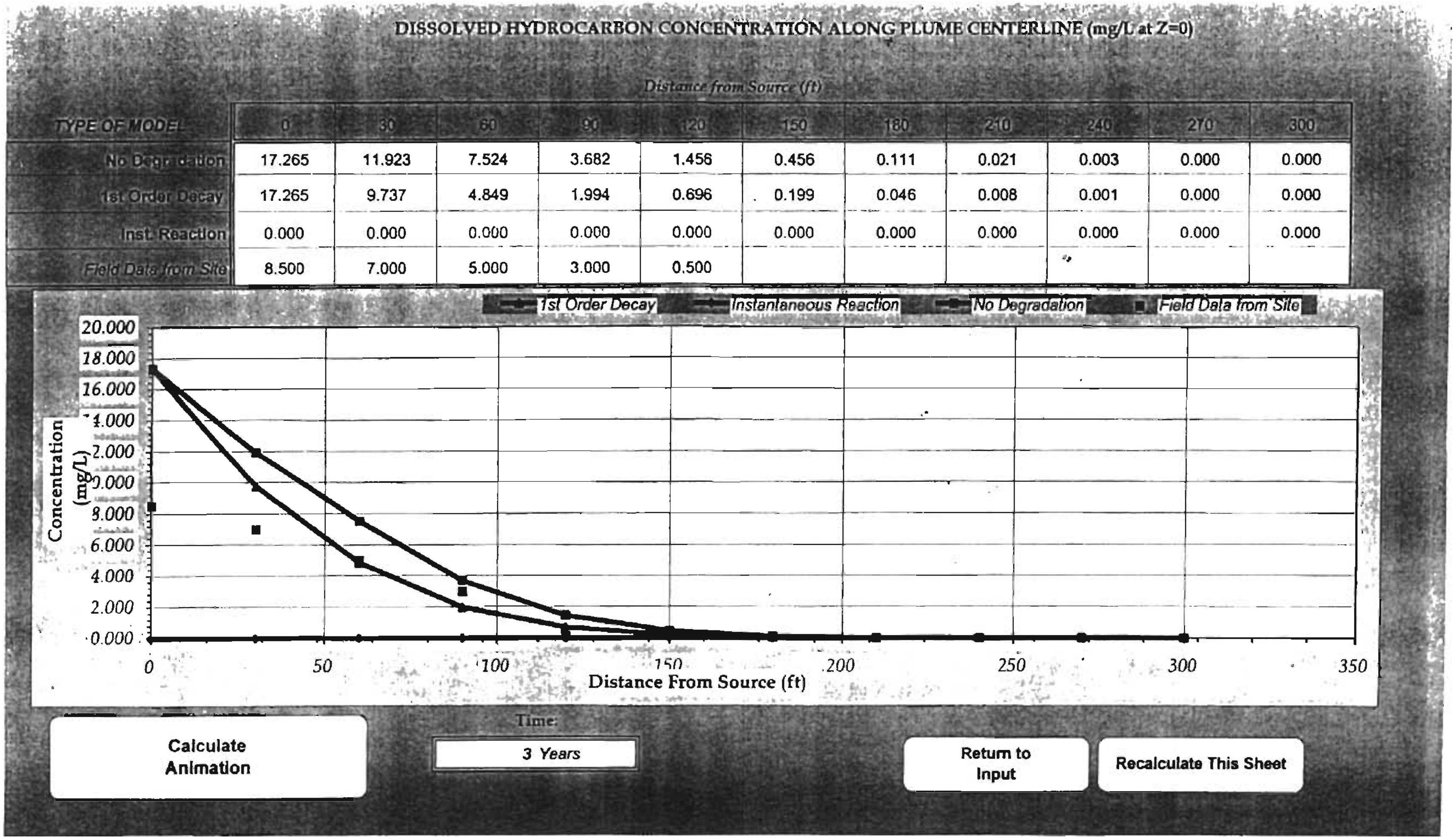
View of Plume Looking Down

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Concentration (mg/L)	8.5	7.0	5.0	3.0	5	0					
Dist. from Source (ft)	0	30	60	90	120	150	180	210	240	270	300

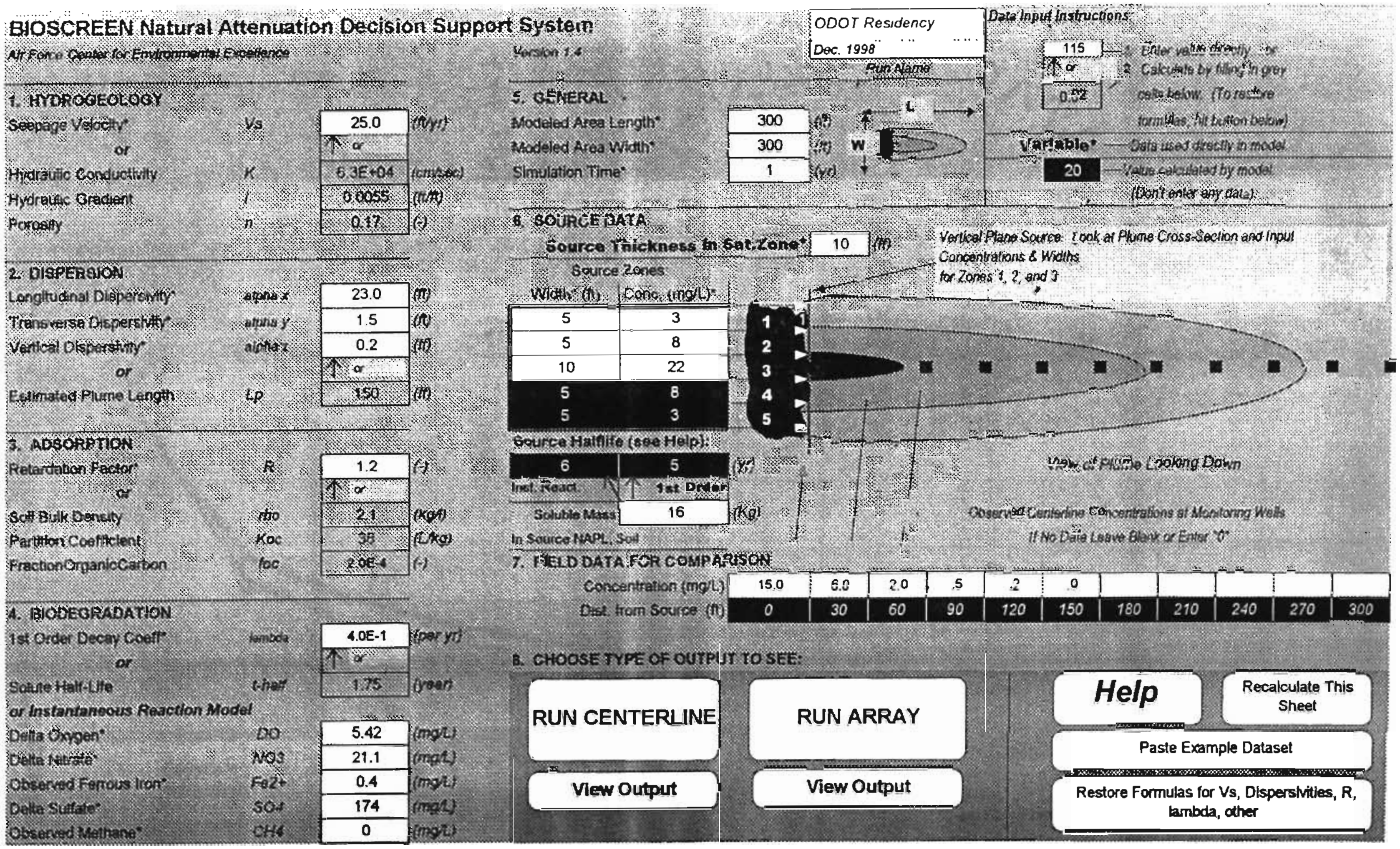
8. CHOOSE TYPE OF OUTPUT TO SEE:



DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

	Distance from Source (ft)										
TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	17.265	11.923	7.524	3.682	1.456	0.456	0.111	0.021	0.003	0.000	0.000
1st Order Decay	17.265	9.737	4.849	1.994	0.696	0.199	0.046	0.008	0.001	0.000	0.000
Inst. Reaction	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	8.500	7.000	5.000	3.000	0.500						

Time: 3 Years



BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence

Version 1.4

ODOT Residency
Dec. 1998
Run Name

Data Input Instructions:
115 — 1. Enter value directly... or
↑ or — 2. Calculate by filling in grey cells below. (To restore formulas, hit button below)
0.02
Variable* — Data used directly in model.
20 — Value calculated by model. (Don't enter any data).

1. HYDROGEOLOGY

Seepage Velocity*	Vs	25.0	(ft/yr)
or		↑ or	
Hydraulic Conductivity	K	6.3E+04	(cm/sec)
Hydraulic Gradient	i	0.0055	(ft/ft)
Porosity	n	0.17	(-)

2. DISPERSION

Longitudinal Dispersivity*	alpha x	23.0	(ft)
Transverse Dispersivity*	alpha y	1.5	(ft)
Vertical Dispersivity*	alpha z	0.2	(ft)
or		↑ or	
Estimated Plume Length	Lp	150	(ft)

3. ADSORPTION

Retardation Factor*	R	1.2	(-)
or		↑ or	
Soil Bulk Density	rho	2.1	(kg/l)
Partition Coefficient	Koc	38	(L/kg)
FractionOrganicCarbon	foc	2.0E-4	(-)

4. BIODEGRADATION

1st Order Decay Coeff*	lambda	4.0E-1	(per yr)
or		↑ or	
Solute Half-Life	t-half	1.75	(year)
or Instantaneous Reaction Model			
Delta Oxygen*	DO	5.42	(mg/L)
Delta Nitrate*	NO3	21.1	(mg/L)
Observed Ferrous Iron*	Fe2+	0.4	(mg/L)
Delta Sulfate*	SO4	174	(mg/L)
Observed Methane*	CH4	0	(mg/L)

5. GENERAL

Modeled Area Length*	300	(ft)
Modeled Area Width*	300	(ft)
Simulation Time*	1	(yr)

6. SOURCE DATA

Source Thickness in Sat.Zone* 10 (ft)

Source Zones

Width* (ft)	Conc. (mg/L)*	
5	3	1
5	8	2
10	22	3
5	8	4
5	3	5

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths for Zones 1, 2, and 3

Source Halflife (see Help):

6	5	(yr)
Inst. React. ↑	↑ 1st Order	
Soluble Mass	16	(Kg)

In Source NAPL, Soil

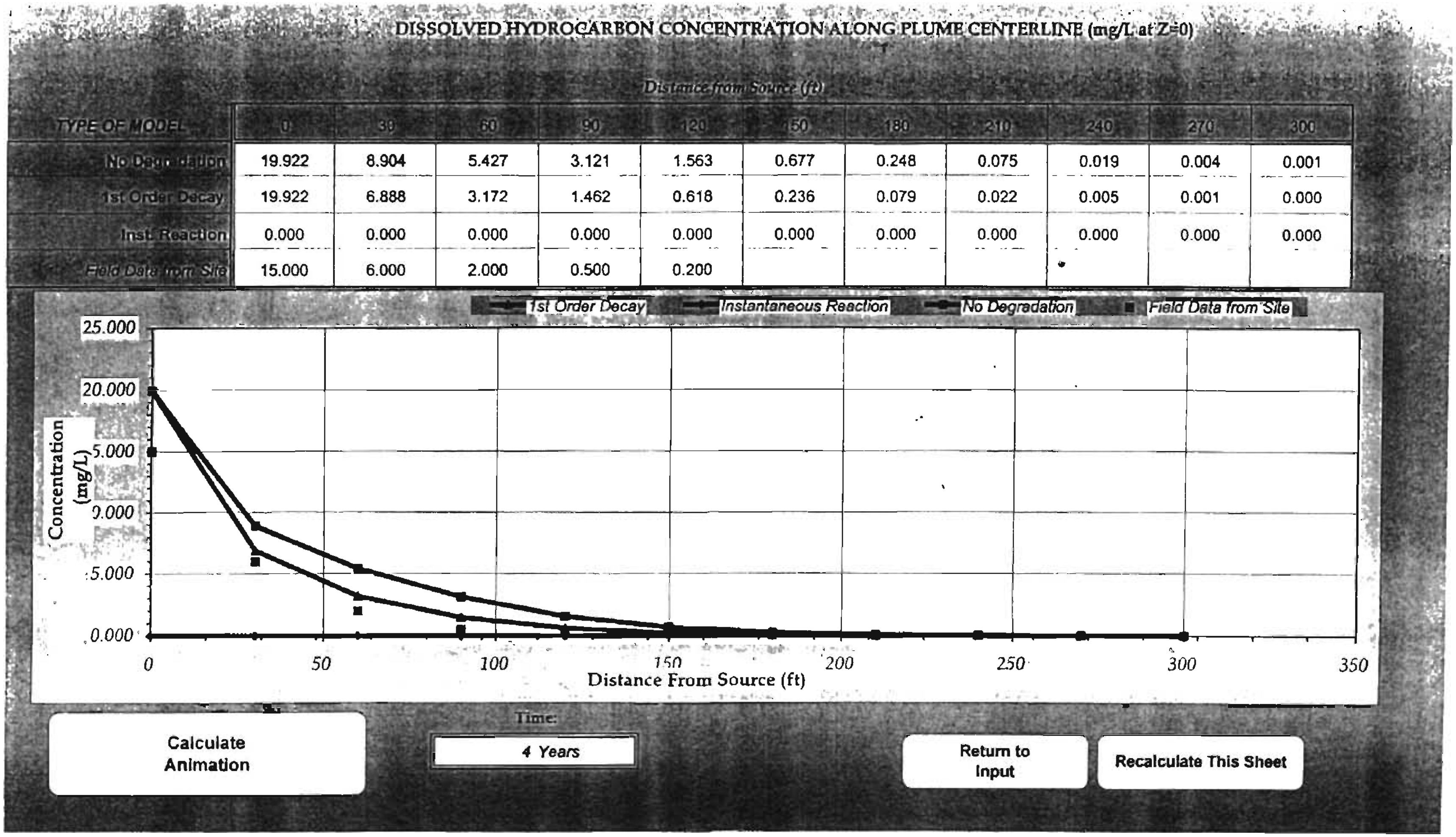
View of Plume Looking Down

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Concentration (mg/L)	15.0	6.0	2.0	.5	.2	0					
Dist. from Source (ft)	0	30	60	90	120	150	180	210	240	270	300

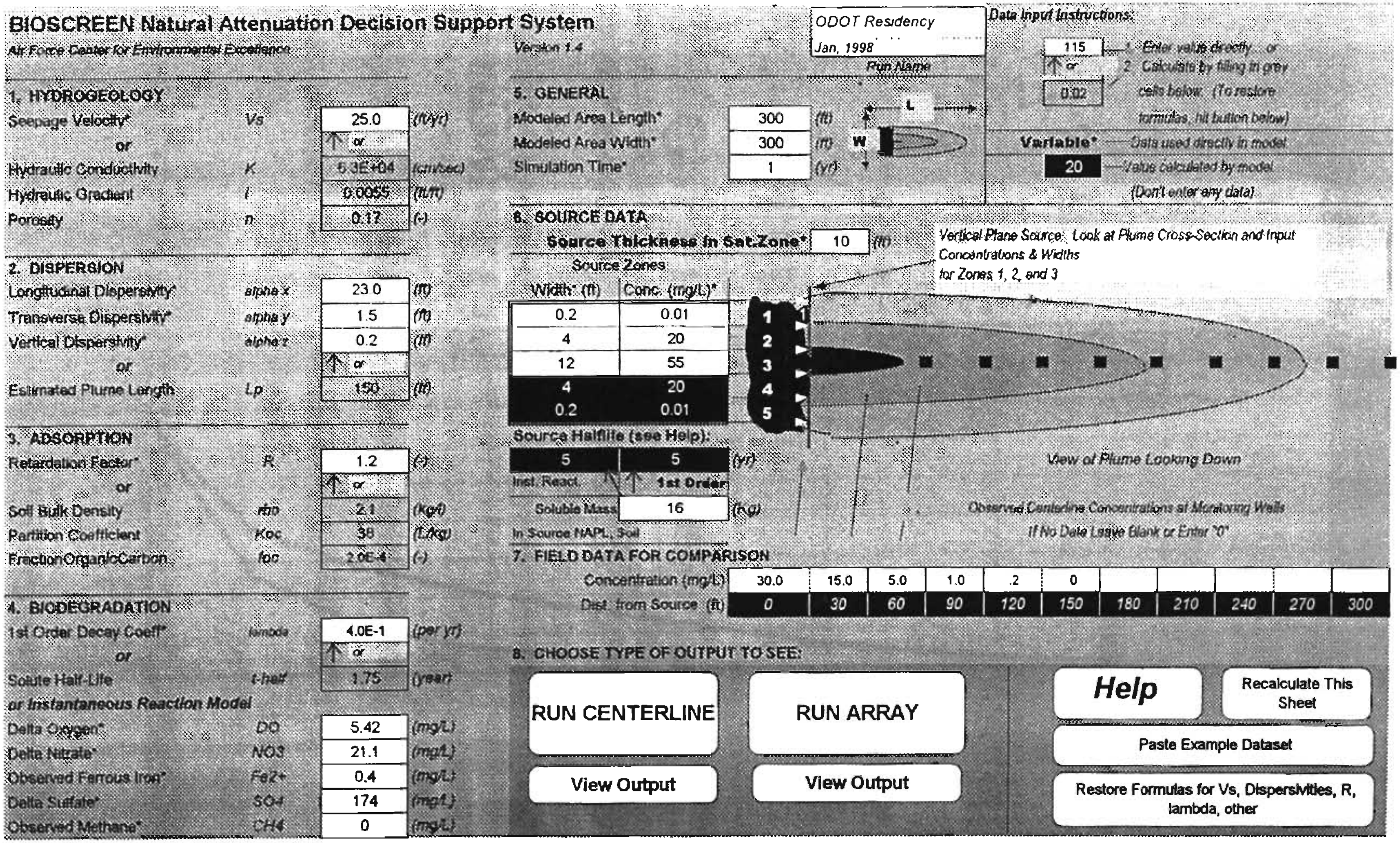
8. CHOOSE TYPE OF OUTPUT TO SEE:



DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

TYPE OF MODEL	Distance from Source (ft)										
	0	30	60	90	120	150	180	210	240	270	300
No Degradation	19.922	8.904	5.427	3.121	1.563	0.677	0.248	0.075	0.019	0.004	0.001
1st Order Decay	19.922	6.888	3.172	1.462	0.618	0.236	0.079	0.022	0.005	0.001	0.000
Inst. Reaction	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	15.000	6.000	2.000	0.500	0.200						

Time: 4 Years



BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence

Version 1.4

ODOT Residency
Jan, 1998
Run Name

1. HYDROGEOLOGY

Seepage Velocity*	*Vs*	25.0	*(ft/yr)*
or		or	
Hydraulic Conductivity	*K*	5.3E+04	*(cm/sec)*
Hydraulic Gradient	*i*	0.0055	*(ft/ft)*
Porosity	*n*	0.17	*(-)*

2. DISPERSION

Longitudinal Dispersivity*	*alpha x*	23.0	*(ft)*
Transverse Dispersivity*	*alpha y*	1.5	*(ft)*
Vertical Dispersivity*	*alpha z*	0.2	*(ft)*
or		or	
Estimated Plume Length	*Lp*	150	*(ft)*

3. ADSORPTION

Retardation Factor*	*R*	1.2	*(-)*
or		or	
Soil Bulk Density	*rho*	2.1	*(kg/l)*
Partition Coefficient	*Koc*	38	*(L/kg)*
FractionOrganicCarbon	*foc*	2.0E-4	*(-)*

4. BIODEGRADATION

1st Order Decay Coeff*	*lambda*	4.0E-1	*(per yr)*
or		or	
Solute Half-Life	*t-half*	1.75	*(year)*
or Instantaneous Reaction Model			
Delta Oxygen*	*DO*	5.42	*(mg/L)*
Delta Nitrate*	*NO3*	21.1	*(mg/L)*
Observed Ferrous Iron*	*Fe2+*	0.4	*(mg/L)*
Delta Sulfate*	*SO4*	174	*(mg/L)*
Observed Methane*	*CH4*	0	*(mg/L)*

5. GENERAL

Modeled Area Length*	300	*(ft)*
Modeled Area Width*	300	*(ft)*
Simulation Time*	1	*(yr)*

Data Input Instructions:

115 — *1. Enter value directly ... or*
or — *2. Calculate by filling in grey*
0.02 — *cells below. (To restore formulas, hit button below)*

Variable* — *Data used directly in model*
20 — *Value calculated by model (Don't enter any data)*

6. SOURCE DATA

Source Thickness in Sat.Zone* 10 *(ft)*

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths for Zones 1, 2, and 3

Source Zones

Zone	Width* (ft)	Conc. (mg/L)*
1	0.2	0.01
2	4	20
3	12	55
4	4	20
5	0.2	0.01

Source Halflife (see Help):

Inst. React.	1st Order	
5	5	*(yr)*

Soluble Mass 16 *(kg)*
In Source NAPL, Soil

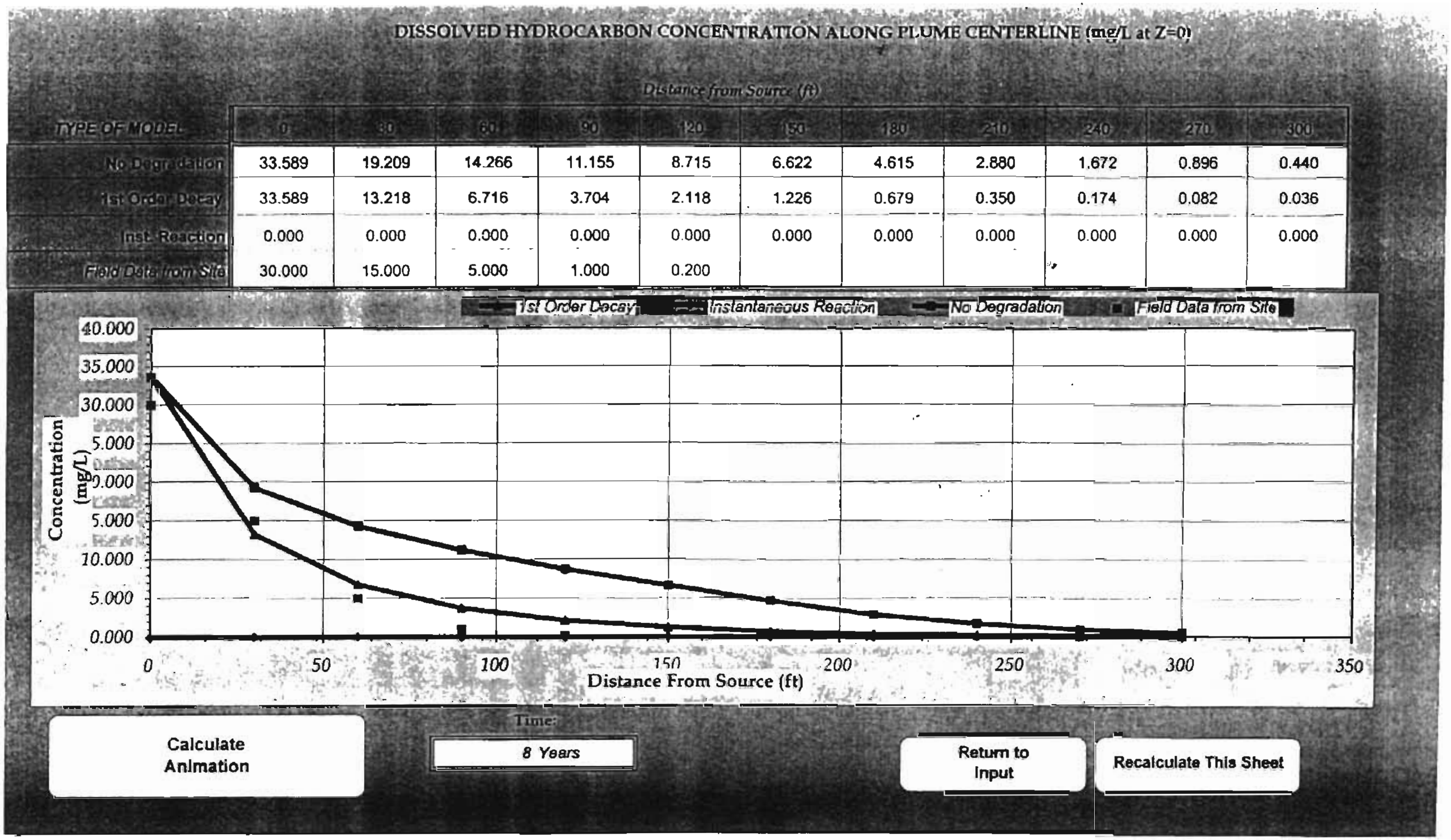
View of Plume Looking Down

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Concentration (mg/L)	30.0	15.0	5.0	1.0	.2	0					
Dist. from Source (ft)	*0*	*30*	*60*	*90*	*120*	*150*	*180*	*210*	*240*	*270*	*300*

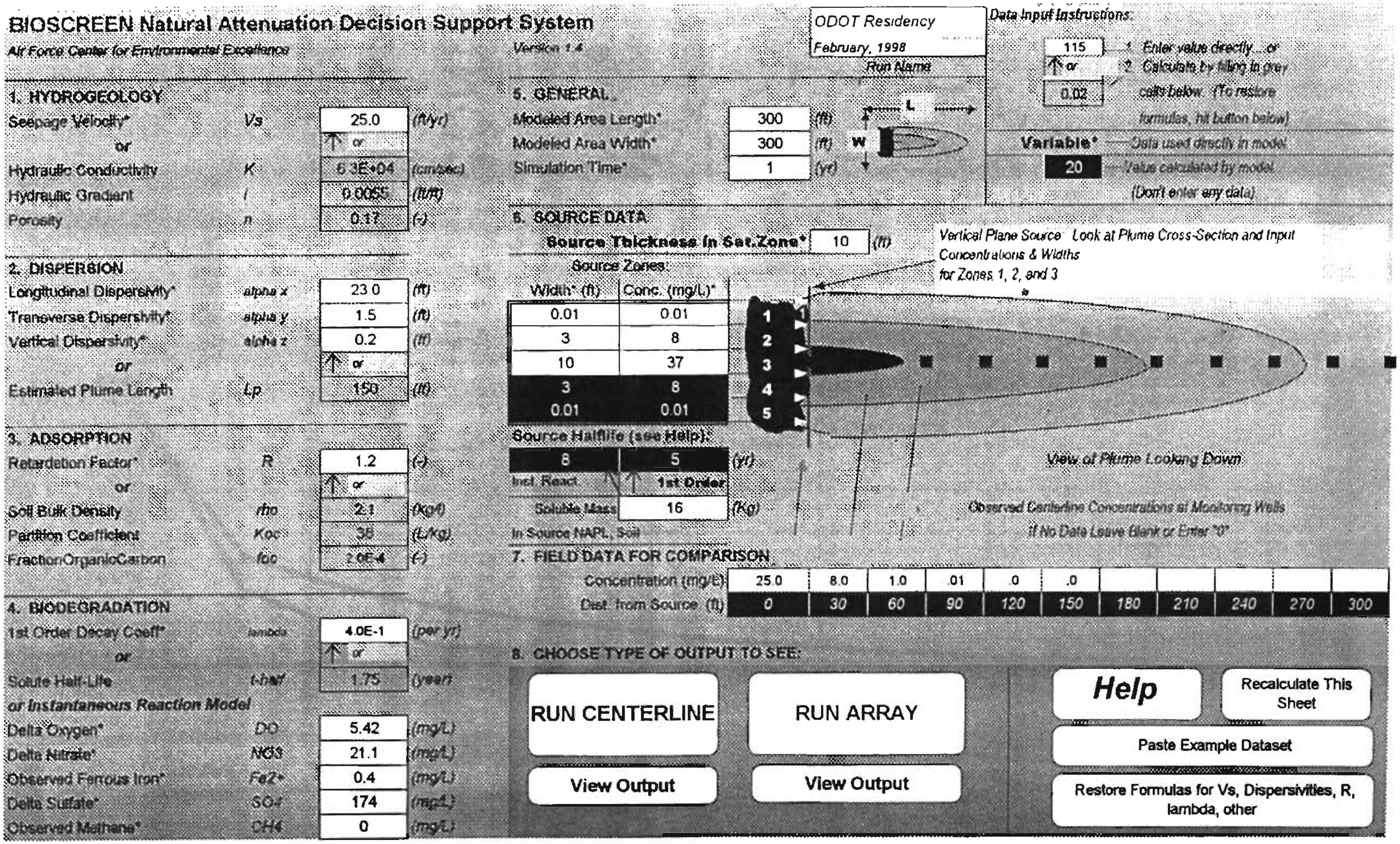
8. CHOOSE TYPE OF OUTPUT TO SEE:



DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	33.589	19.209	14.266	11.155	8.715	6.622	4.615	2.880	1.672	0.896	0.440
1st Order Decay	33.589	13.218	6.716	3.704	2.118	1.226	0.679	0.350	0.174	0.082	0.036
Inst. Reaction	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	30.000	15.000	5.000	1.000	0.200						



BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence

Version 1.4

ODOT Residency
February, 1998
Run Name

Data Input Instructions:

115 — 1. Enter value directly ...or
↑ or
0.02 — 2. Calculate by filling in grey cells below. (To restore formulas, hit button below)

Variable* — Data used directly in model
20 — Value calculated by model (Don't enter any data)

1. HYDROGEOLOGY

Seepage Velocity*	Vs	25.0	(ft/yr)
or		↑ or	
Hydraulic Conductivity	K	6.3E+04	(cm/sec)
Hydraulic Gradient	i	0.0055	(ft/ft)
Porosity	n	0.17	(-)

2. DISPERSION

Longitudinal Dispersivity*	alpha x	23.0	(ft)
Transverse Dispersivity*	alpha y	1.5	(ft)
Vertical Dispersivity*	alpha z	0.2	(ft)
or		↑ or	
Estimated Plume Length	Lp	150	(ft)

3. ADSORPTION

Retardation Factor*	R	1.2	(-)
or		↑ or	
Soil Bulk Density	rho	2.1	(kg/l)
Partition Coefficient	Koc	38	(L/kg)
FractionOrganicCarbon	foc	2.0E-4	(-)

4. BIODEGRADATION

1st Order Decay Coeff*	lambda	4.0E-1	(per yr)
or		↑ or	
Solute Half-Life	t-half	1.75	(year)
or Instantaneous Reaction Model			
Delta Oxygen*	DO	5.42	(mg/L)
Delta Nitrate*	NO3	21.1	(mg/L)
Observed Ferrous Iron*	Fe2+	0.4	(mg/L)
Delta Sulfate*	SO4	174	(mg/L)
Observed Methane*	CH4	0	(mg/L)

5. GENERAL

Modeled Area Length*	300	(ft)
Modeled Area Width*	300	(ft)
Simulation Time*	1	(yr)

6. SOURCE DATA

Source Thickness in Sat.Zone* 10 (ft)

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths for Zones 1, 2, and 3

Source Zones:

Width* (ft)	Conc. (mg/L)*
0.01	0.01
3	8
10	37
3	8
0.01	0.01

Source Halflife (see Help):

Inst. React.	1st Order	
8	5	(yr)

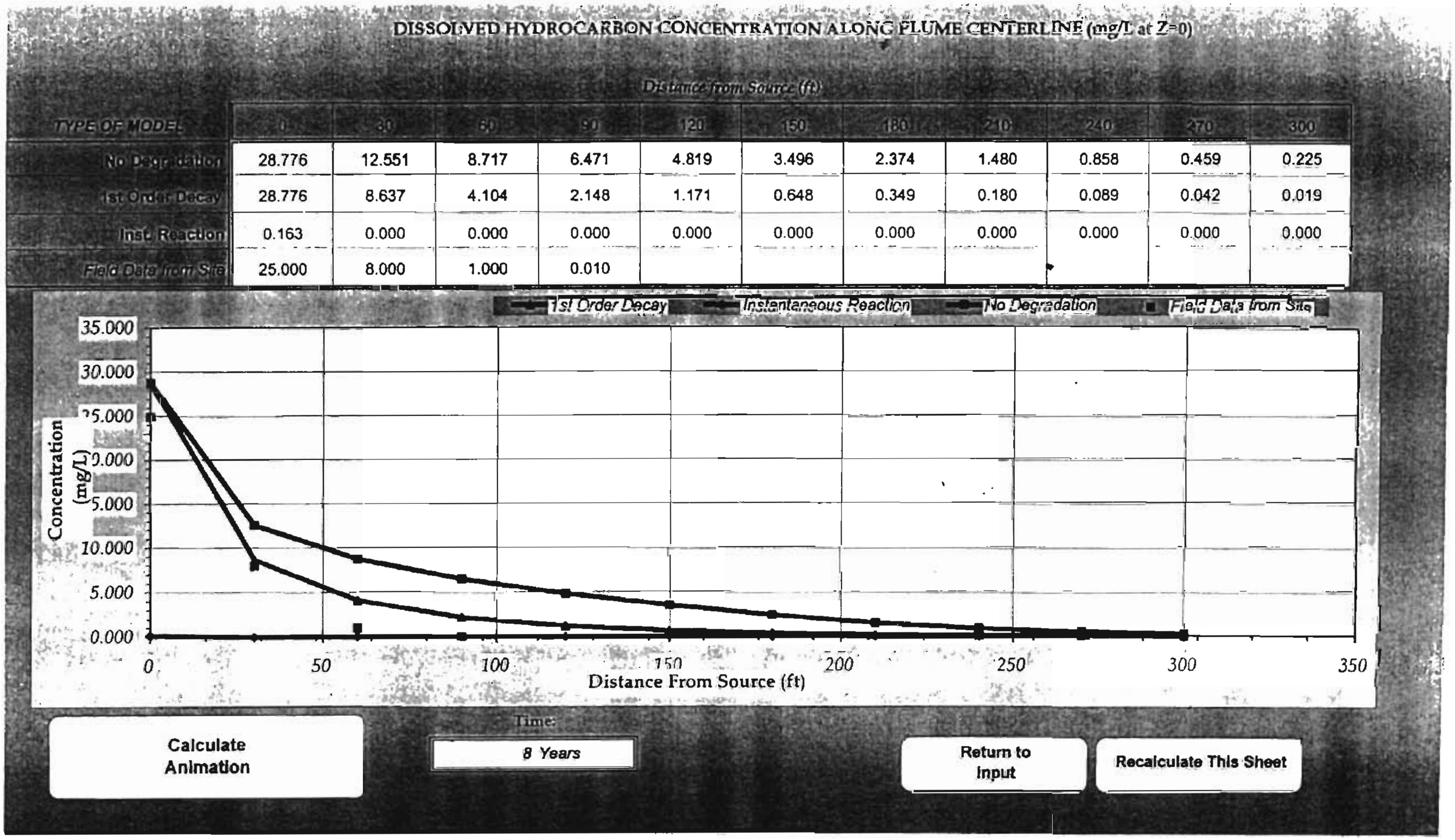
Soluble Mass 16 (Kg)
In Source NAPL, Soil

7. FIELD DATA FOR COMPARISON

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

Concentration (mg/L)	25.0	8.0	1.0	.01	.0	.0					
Dist. from Source (ft)	0	30	60	90	120	150	180	210	240	270	300

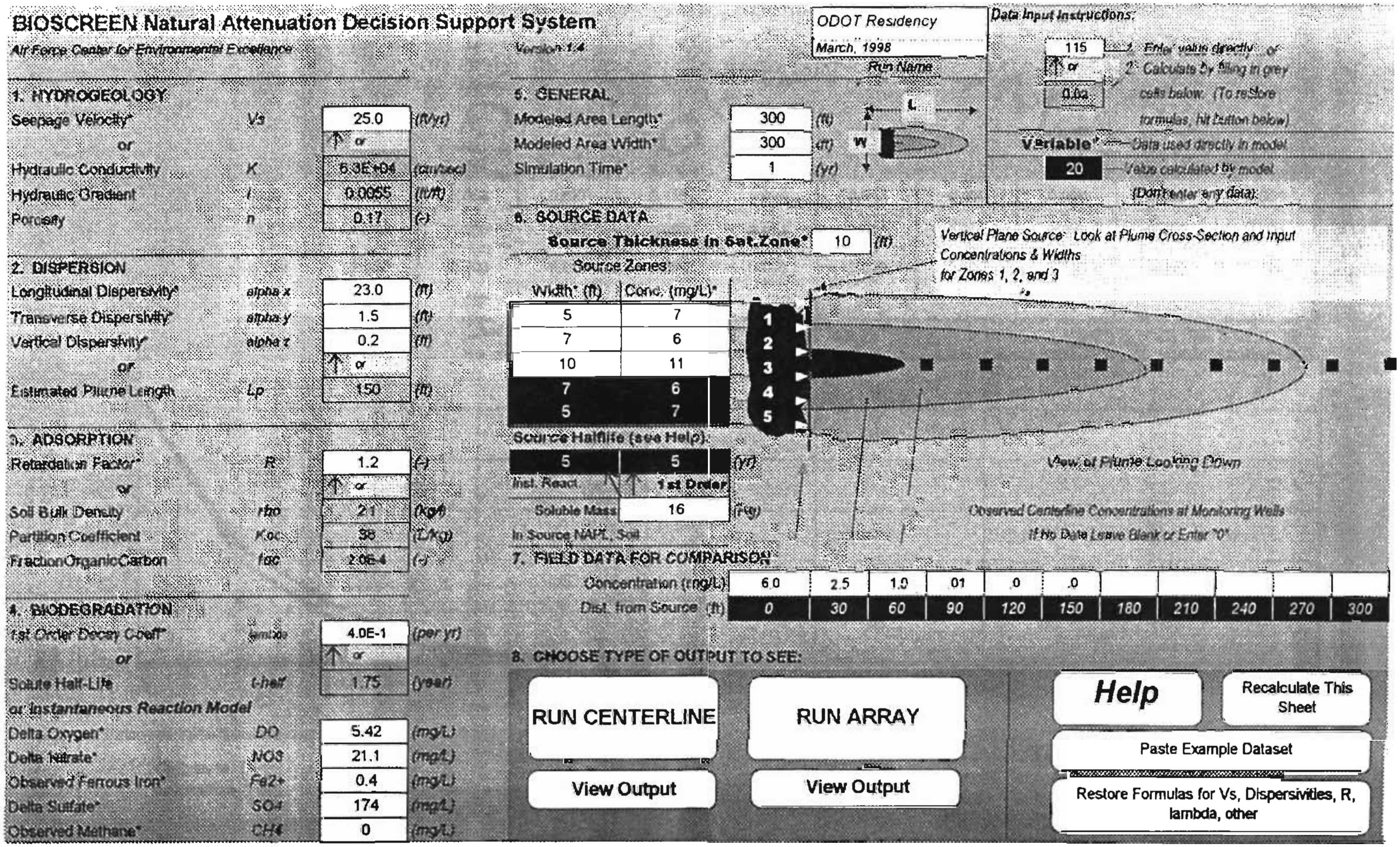
8. CHOOSE TYPE OF OUTPUT TO SEE:



DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

	Distance from Source (ft)										
TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	28.776	12.551	8.717	6.471	4.819	3.496	2.374	1.480	0.858	0.459	0.225
1st Order Decay	28.776	8.637	4.104	2.148	1.171	0.648	0.349	0.180	0.089	0.042	0.019
Inst. Reaction	0.163	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	25.000	8.000	1.000	0.010							

Time: 8 Years



BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence

Version 1.4

ODOT Residency

March, 1998

Run Name

Data Input Instructions:

115 — 1. Enter value directly ...or

↑ or — 2. Calculate by filling in grey cells below. (To restore formulas, hit button below)

0.02

Variable* — Data used directly in model.

20 — Value calculated by model. (Don't enter any data).

1. HYDROGEOLOGY

Seepage Velocity*	Vs	25.0	(ft/yr)
or		↑ or	
Hydraulic Conductivity	K	5.3E+04	(cm/sec)
Hydraulic Gradient	i	0.0055	(ft/ft)
Porosity	n	0.17	(-)

2. DISPERSION

Longitudinal Dispersivity*	alpha x	23.0	(ft)
Transverse Dispersivity*	alpha y	1.5	(ft)
Vertical Dispersivity*	alpha z	0.2	(ft)
or		↑ or	
Estimated Plume Length	Lp	150	(ft)

3. ADSORPTION

Retardation Factor*	R	1.2	(-)
or		↑ or	
Soil Bulk Density	rho	2.1	(kg/l)
Partition Coefficient	Koc	38	(L/kg)
FractionOrganicCarbon	foc	2.0E-4	(-)

4. BIODEGRADATION

1st Order Decay Coeff*	lambda	4.0E-1	(per yr)
or		↑ or	
Solute Half-Life	t-half	1.75	(year)
or Instantaneous Reaction Model			
Delta Oxygen*	DO	5.42	(mg/L)
Delta Nitrate*	NO3	21.1	(mg/L)
Observed Ferrous Iron*	Fe2+	0.4	(mg/L)
Delta Sulfate*	SO4	174	(mg/L)
Observed Methane*	CH4	0	(mg/L)

5. GENERAL

Modeled Area Length*	300	(ft)
Modeled Area Width*	300	(ft)
Simulation Time*	1	(yr)

6. SOURCE DATA

Source Thickness in Sat.Zone* 10 (ft)

Source Zones:

Width* (ft)	Conc. (mg/L)*
5	7
7	6
10	11
7	6
5	7

Source Halflife (see Help):

5	5	(yr)
Inst. React.	1st Order	

Soluble Mass 16 (Kg)

In Source NAPL, Soil

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths for Zones 1, 2, and 3

View of Plume Looking Down

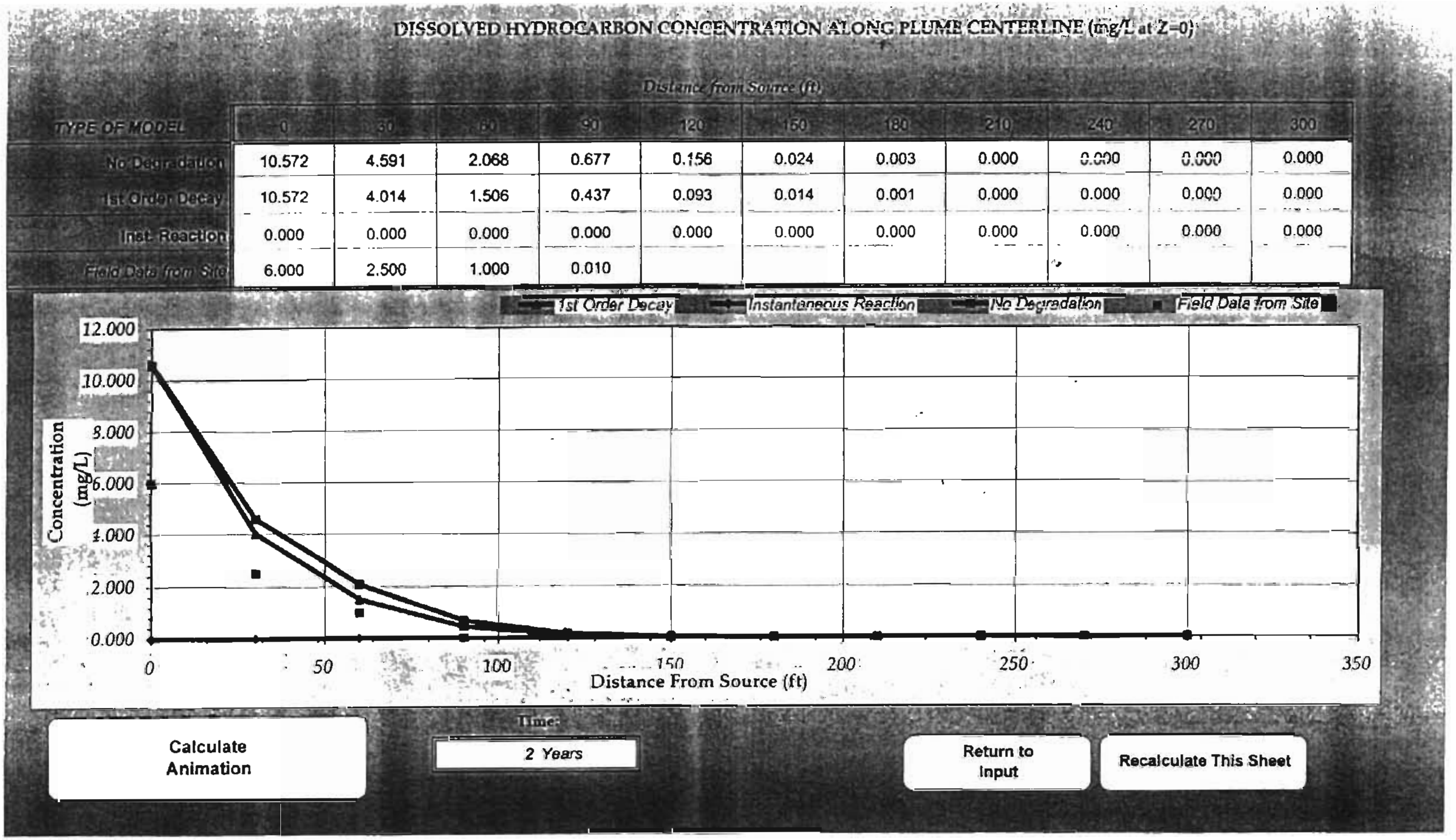
Observed Centerline Concentrations at Monitoring Wells

If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

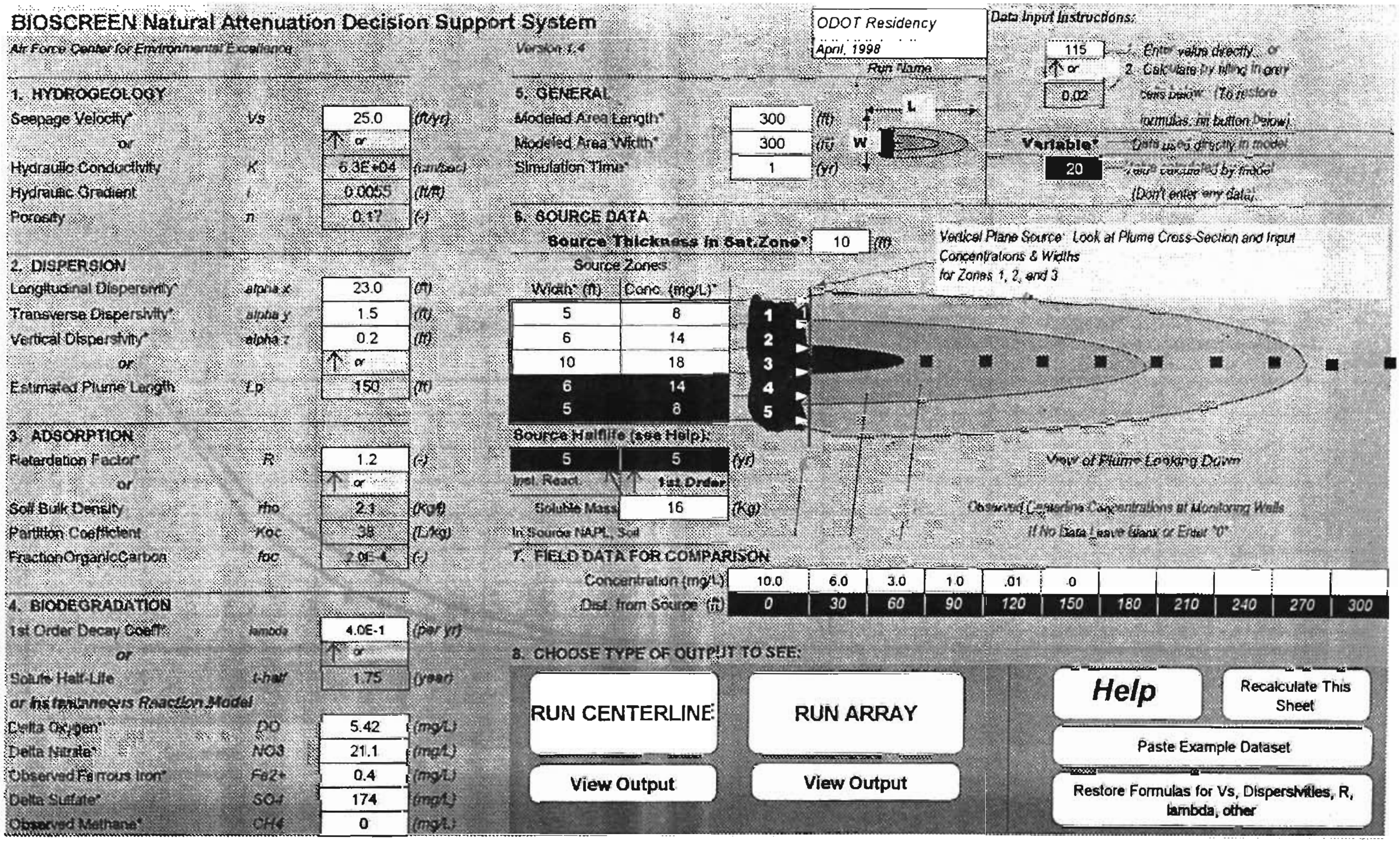
Concentration (mg/L)	6.0	2.5	1.0	.01	.0	.0					
Dist. from Source (ft)	0	30	60	90	120	150	180	210	240	270	300

8. CHOOSE TYPE OF OUTPUT TO SEE:



DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	10.572	4.591	2.068	0.677	0.156	0.024	0.003	0.000	0.000	0.000	0.000
1st Order Decay	10.572	4.014	1.506	0.437	0.093	0.014	0.001	0.000	0.000	0.000	0.000
Inst. Reaction	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	6.000	2.500	1.000	0.010							



BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence

Version 1.4

Run Name: *ODOT Residency*, *April, 1998*

1. HYDROGEOLOGY

Seepage Velocity* Vs 25.0 (ft/yr)
or
Hydraulic Conductivity K 6.3E+04 (cm/sec)
Hydraulic Gradient i 0.0055 (ft/ft)
Porosity n 0.17 (-)

2. DISPERSION

Longitudinal Dispersivity* alpha x 23.0 (ft)
Transverse Dispersivity* alpha y 1.5 (ft)
Vertical Dispersivity* alpha z 0.2 (ft)
or
Estimated Plume Length Lp 150 (ft)

3. ADSORPTION

Retardation Factor* R 1.2 (-)
or
Soil Bulk Density rho 2.1 (Kg/l)
Partition Coefficient Koc 38 (L/kg)
FractionOrganicCarbon foc 2.0E-4 (-)

4. BIODEGRADATION

1st Order Decay Coeff* lambda 4.0E-1 (per yr)
or
Solute Half-Life t-half 1.75 (year)
or Instantaneous Reaction Model
Delta Oxygen* DO 5.42 (mg/L)
Delta Nitrate* NO3 21.1 (mg/L)
Observed Ferrous Iron* Fe2+ 0.4 (mg/L)
Delta Sulfate* SO4 174 (mg/L)
Observed Methane* CH4 0 (mg/L)

5. GENERAL

Modeled Area Length* 300 (ft)
Modeled Area Width* 300 (ft)
Simulation Time* 1 (yr)

Data Input Instructions:

115 1. Enter value directly... or
or 2. Calculate by filling in grey
0.02 cells below. (To restore formulas, hit button below).

Variable* Data used directly in model.
20 Value calculated by model. (Don't enter any data).

6. SOURCE DATA

Source Thickness in Sat.Zone* 10 (ft)

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths for Zones 1, 2, and 3

Source Zones:

Zone	Width* (ft)	Conc. (mg/L)*
1	5	8
2	6	14
3	10	18
4	6	14
5	5	8

Source Halflife (see Help):

Inst. React.	1st Order	
5	5	(yr)

Soluble Mass 16 (Kg)
In Source NAPL, Soil

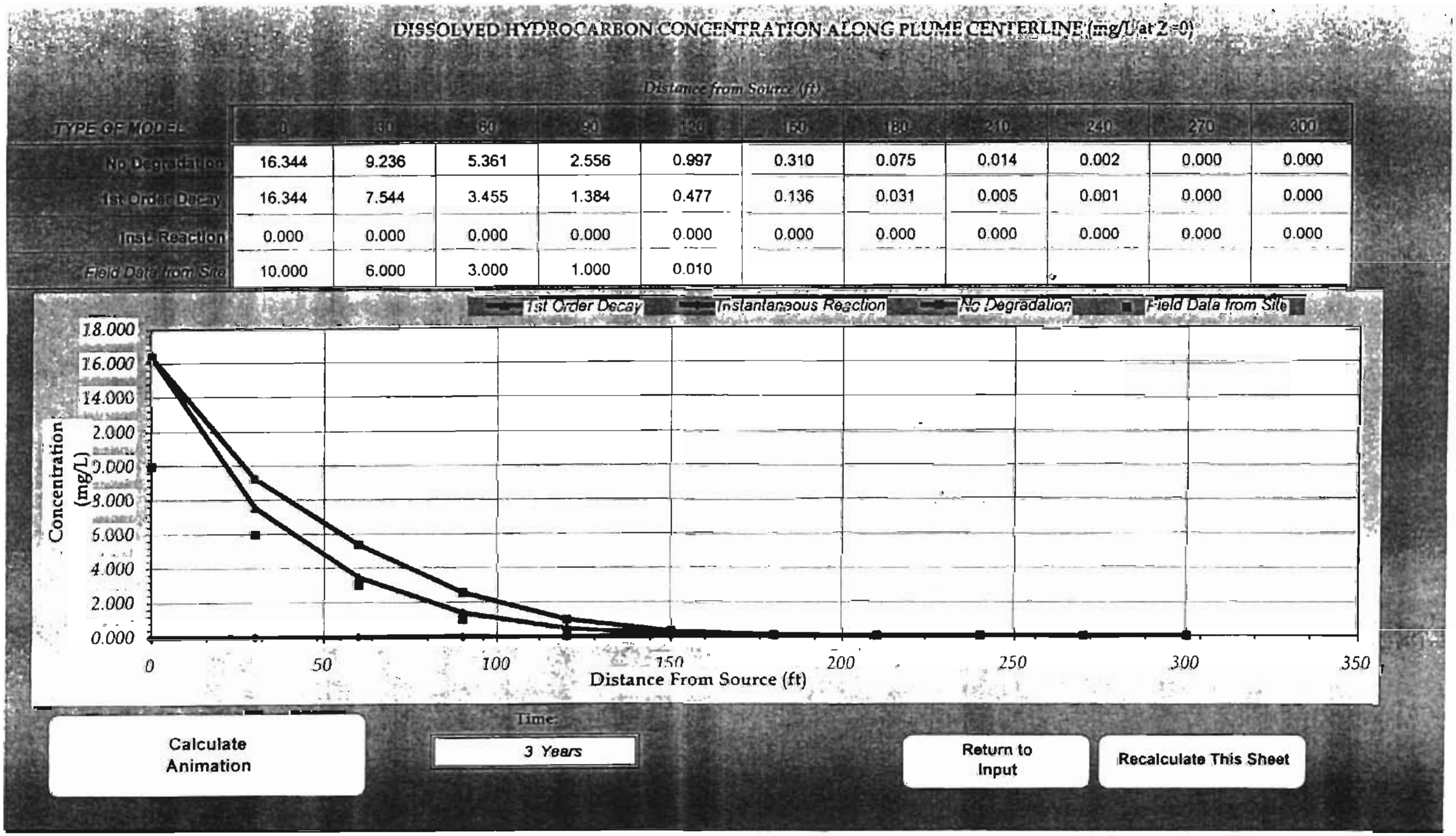
View of Plume Looking Down

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Concentration (mg/L)	10.0	6.0	3.0	1.0	.01	0					
Dist. from Source (ft)	0	30	60	90	120	150	180	210	240	270	300

8. CHOOSE TYPE OF OUTPUT TO SEE:

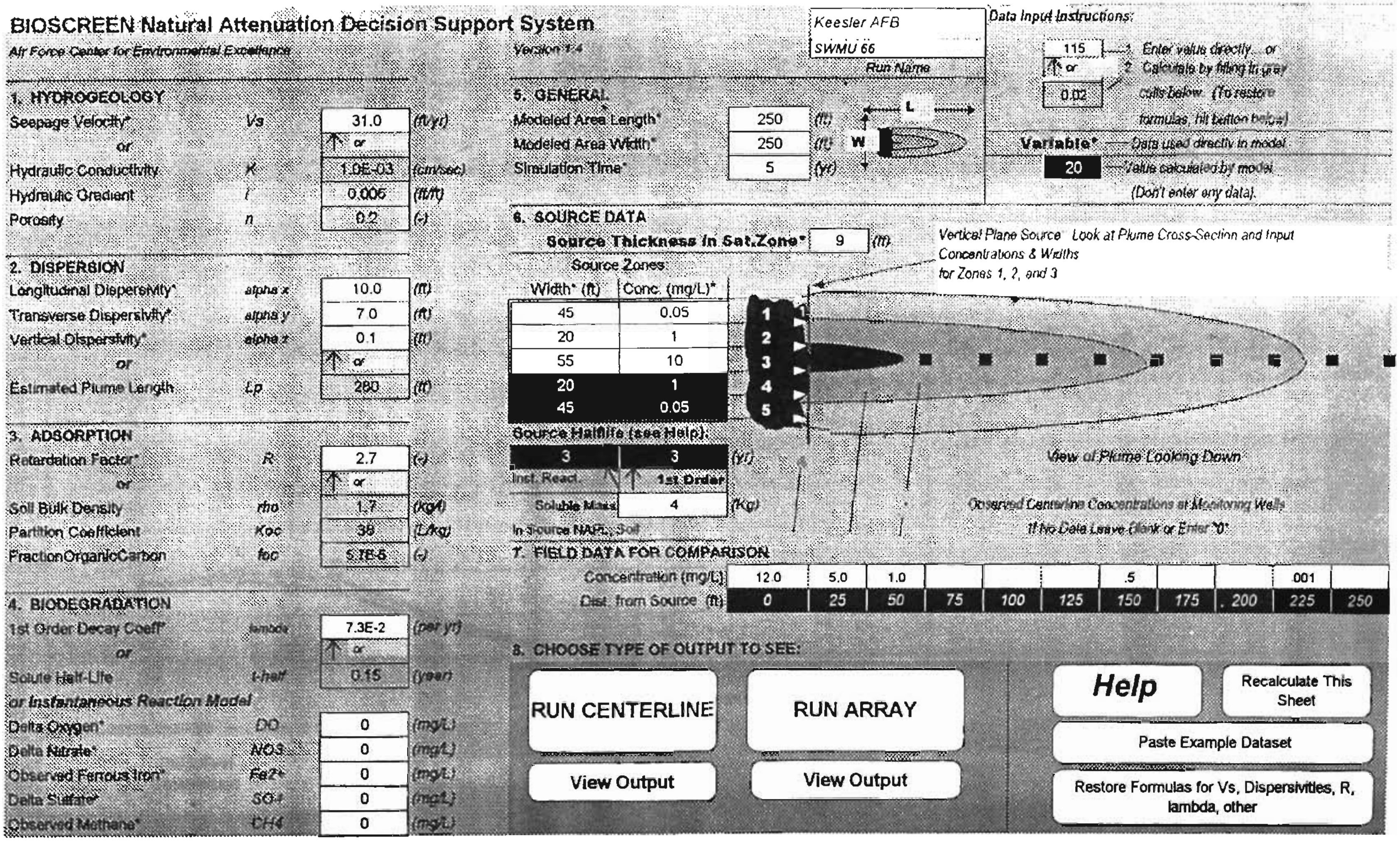


DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z =0)

	Distance from Source (ft)										
TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	16.344	9.236	5.361	2.556	0.997	0.310	0.075	0.014	0.002	0.000	0.000
1st Order Decay	16.344	7.544	3.455	1.384	0.477	0.136	0.031	0.005	0.001	0.000	0.000
Inst. Reaction	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	10.000	6.000	3.000	1.000	0.010						

Time: 3 Years

APPENDIX H
BIOSCREEN OUTPUT – RUN #4



BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence

Version 1.4

Keesler AFB
SWMU 66
Run Name

Data Input Instructions:

115 — 1. *Enter value directly... or*
↑ or — 2. *Calculate by filling in gray*
0.02 — *cells below. (To restore formulas, hit button below)*

Variable* — *Data used directly in model.*
20 — *Value calculated by model. (Don't enter any data).*

1. HYDROGEOLOGY

Seepage Velocity*	*Vs*	31.0	*(ft/yr)*
or		↑ or	
Hydraulic Conductivity	*K*	1.0E-03	*(cm/sec)*
Hydraulic Gradient	*i*	0.005	*(ft/ft)*
Porosity	*n*	0.2	*(-)*

2. DISPERSION

Longitudinal Dispersivity*	*alpha x*	10.0	*(ft)*
Transverse Dispersivity*	*alpha y*	7.0	*(ft)*
Vertical Dispersivity*	*alpha z*	0.1	*(ft)*
or		↑ or	
Estimated Plume Length	*Lp*	280	*(ft)*

3. ADSORPTION

Retardation Factor*	*R*	2.7	*(-)*
or		↑ or	
Soil Bulk Density	*rho*	1.7	*(kg/l)*
Partition Coefficient	*Koc*	38	*(L/kg)*
FractionOrganicCarbon	*foc*	5.7E-5	*(-)*

4. BIODEGRADATION

1st Order Decay Coeff*	*lambda*	7.3E-2	*(per yr)*
or		↑ or	
Solute Half-Life	*t-half*	0.15	*(year)*
or Instantaneous Reaction Model			
Delta Oxygen*	*DO*	0	*(mg/L)*
Delta Nitrate*	*NO3*	0	*(mg/L)*
Observed Ferrous Iron*	*Fe2+*	0	*(mg/L)*
Delta Sulfate*	*SO4*	0	*(mg/L)*
Observed Methane*	*CH4*	0	*(mg/L)*

5. GENERAL

Modeled Area Length*	250	*(ft)*
Modeled Area Width*	250	*(ft)*
Simulation Time*	5	*(yr)*

6. SOURCE DATA

Source Thickness in Sat.Zone* 9 *(ft)*

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths for Zones 1, 2, and 3

Source Zones:

Width* (ft)	Conc. (mg/L)*
45	0.05
20	1
55	10
20	1
45	0.05

Source Halflife (see Help):

3	3	*(yr)*
Inst. React. ↑	↑ **1st Order**	

Soluble Mass 4 *(Kg)*

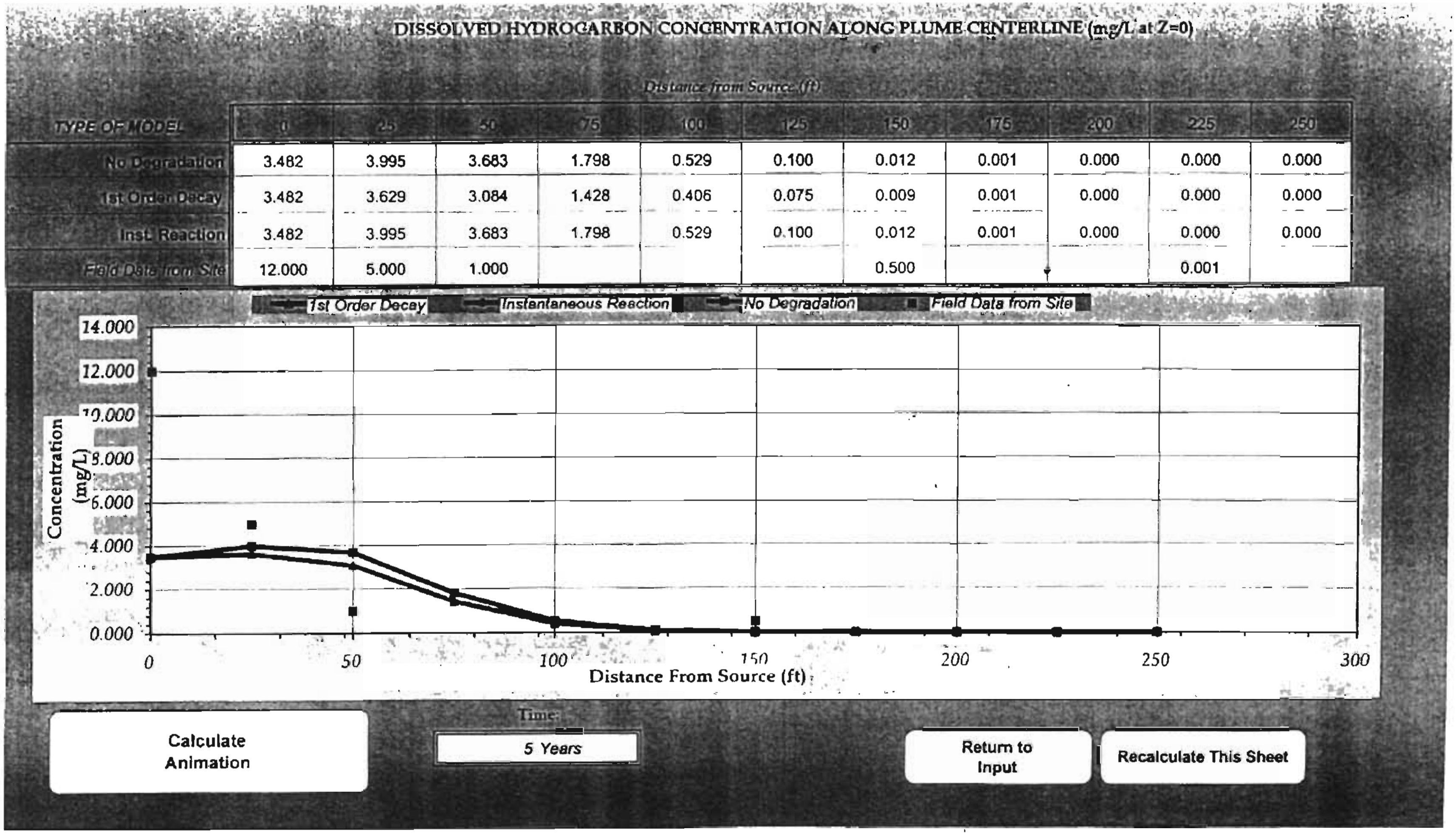
In Source NAPL, Soil

7. FIELD DATA FOR COMPARISON

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

Concentration (mg/L)	12.0	5.0	1.0				.5			.001	
Dist. from Source (ft)	*0*	*25*	*50*	*75*	*100*	*125*	*150*	*175*	*200*	*225*	*250*

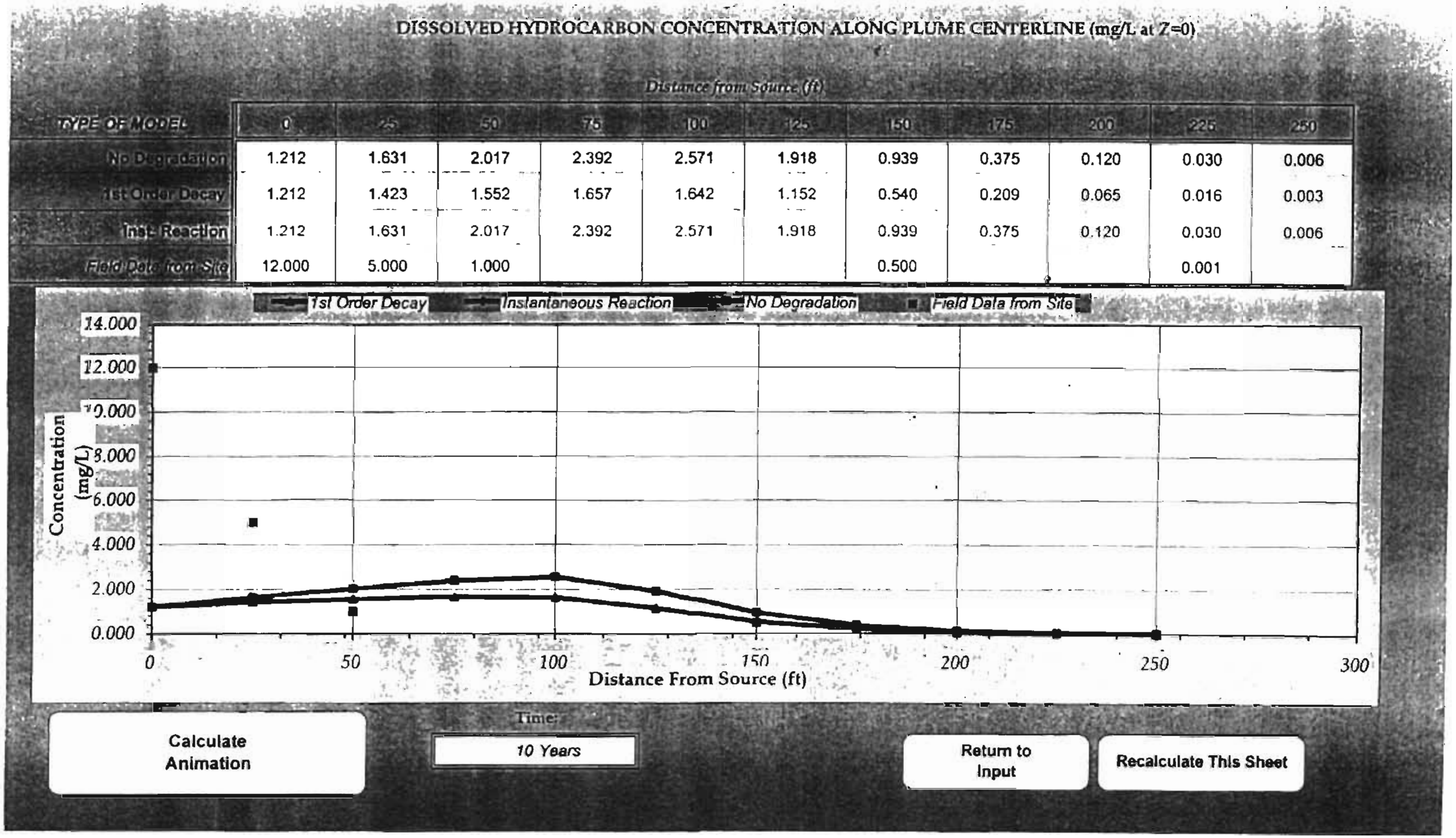
8. CHOOSE TYPE OF OUTPUT TO SEE:



DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

TYPE OF MODEL	0	25	50	75	100	125	150	175	200	225	250
	Distance from Source (ft)										
No Degradation	3.482	3.995	3.683	1.798	0.529	0.100	0.012	0.001	0.000	0.000	0.000
1st Order Decay	3.482	3.629	3.084	1.428	0.406	0.075	0.009	0.001	0.000	0.000	0.000
Inst. Reaction	3.482	3.995	3.683	1.798	0.529	0.100	0.012	0.001	0.000	0.000	0.000
Field Data from Site	12.000	5.000	1.000				0.500			0.001	

Time: 5 Years

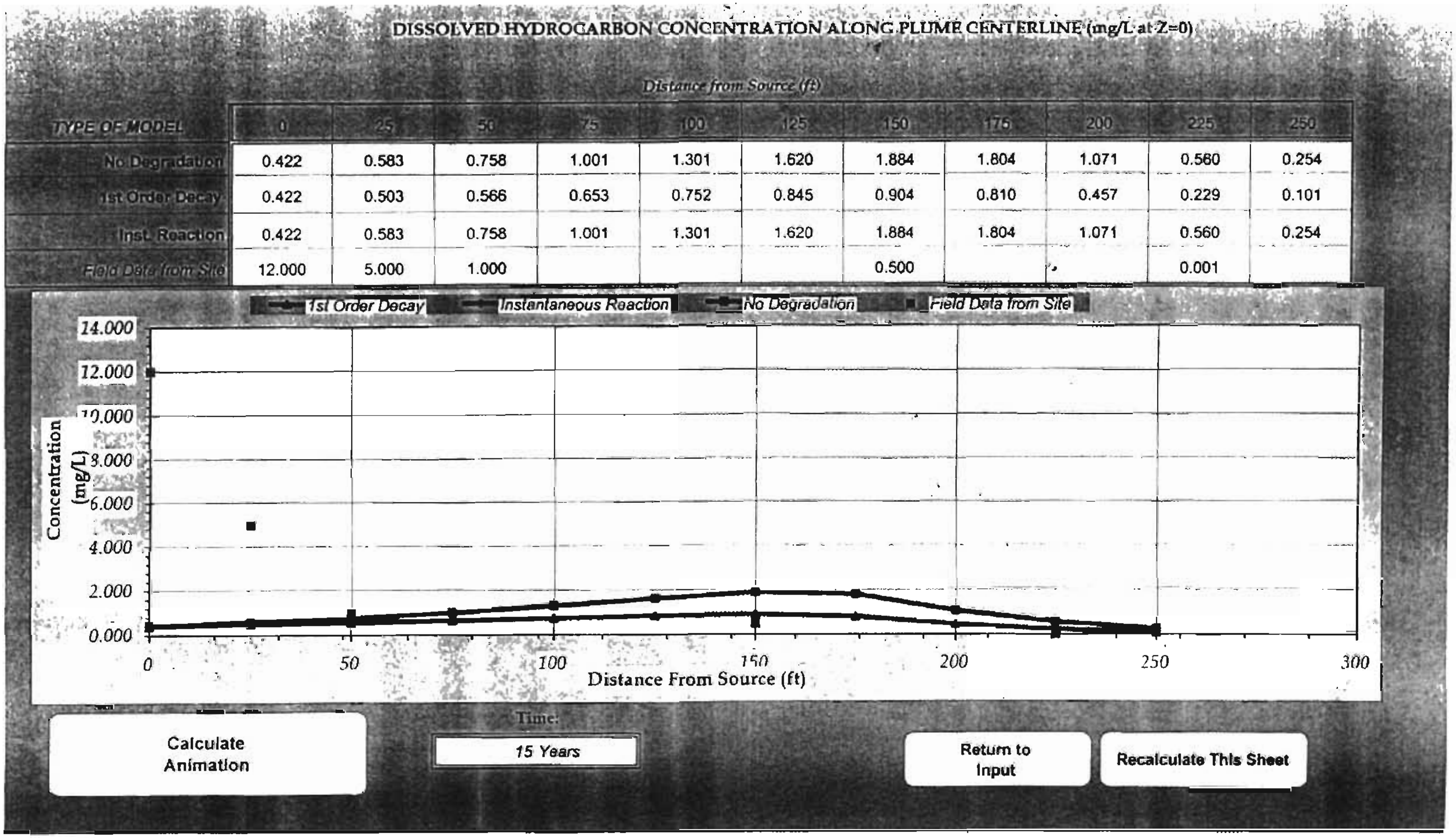


DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

	Distance from Source (ft)										
TYPE OF MODEL	0	25	50	75	100	125	150	175	200	225	250
No Degradation	1.212	1.631	2.017	2.392	2.571	1.918	0.939	0.375	0.120	0.030	0.006
1st Order Decay	1.212	1.423	1.552	1.657	1.642	1.152	0.540	0.209	0.065	0.016	0.003
Inst. Reaction	1.212	1.631	2.017	2.392	2.571	1.918	0.939	0.375	0.120	0.030	0.006
Field Data from Site	12.000	5.000	1.000				0.500			0.001	

Time:

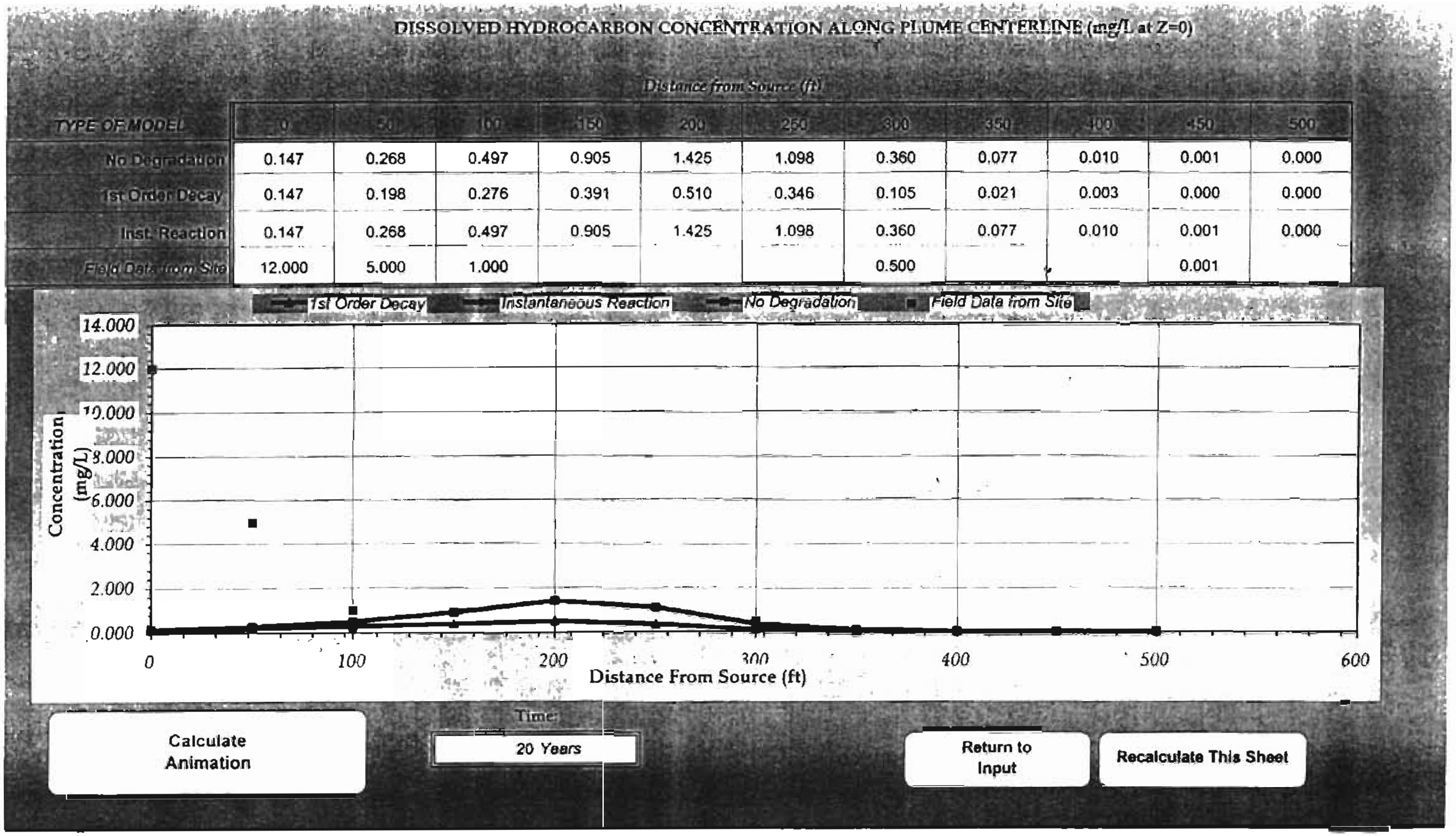
10 Years



DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0	25	50	75	100	125	150	175	200	225	250
No Degradation	0.422	0.583	0.758	1.001	1.301	1.620	1.884	1.804	1.071	0.560	0.254
1st Order Decay	0.422	0.503	0.566	0.653	0.752	0.845	0.904	0.810	0.457	0.229	0.101
Inst. Reaction	0.422	0.583	0.758	1.001	1.301	1.620	1.884	1.804	1.071	0.560	0.254
Field Data from Site	12.000	5.000	1.000				0.500			0.001	

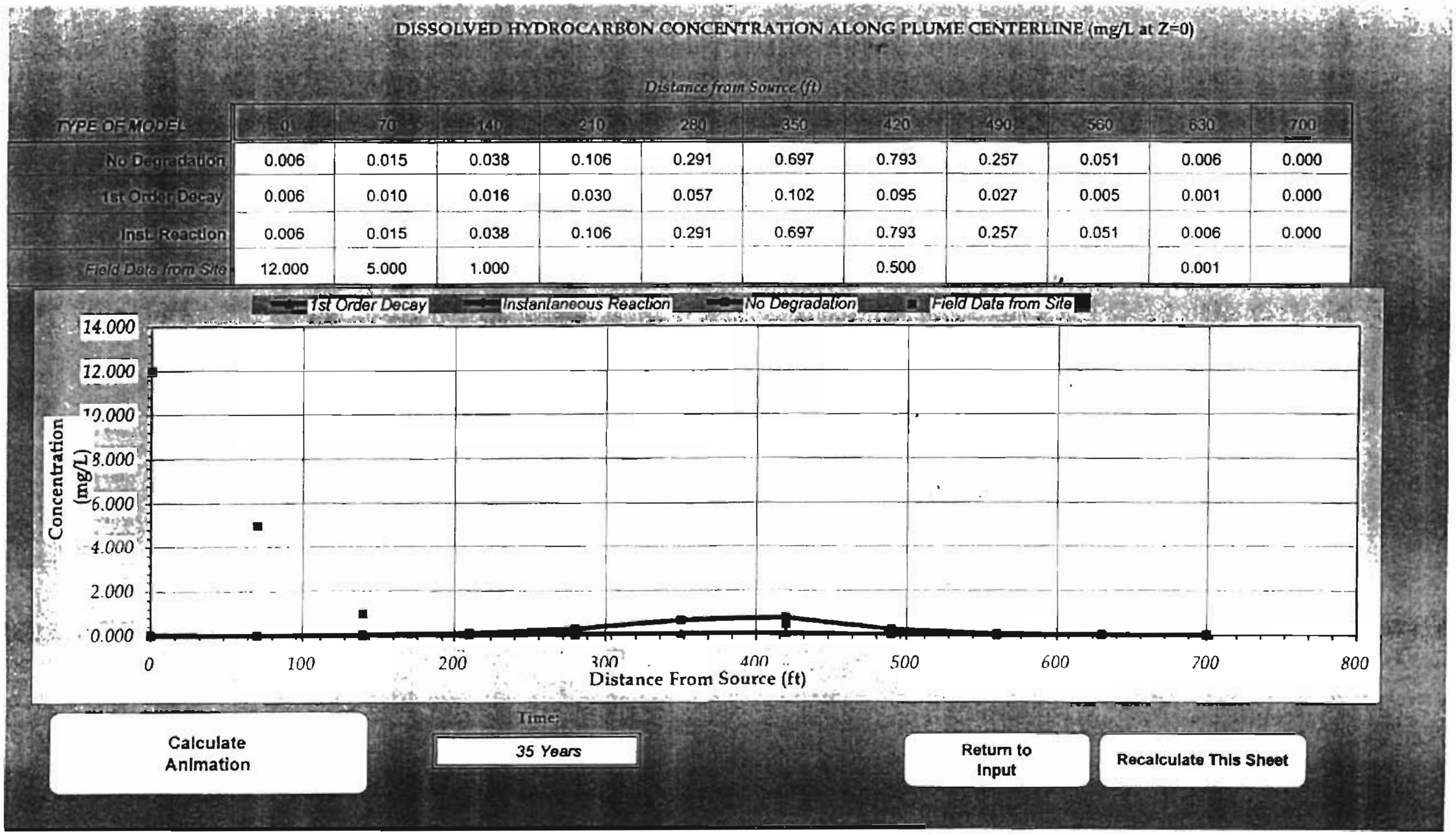


DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0	50	100	150	200	250	300	350	400	450	500
No Degradation	0.147	0.268	0.497	0.905	1.425	1.098	0.360	0.077	0.010	0.001	0.000
1st Order Decay	0.147	0.198	0.276	0.391	0.510	0.346	0.105	0.021	0.003	0.000	0.000
Inst. Reaction	0.147	0.268	0.497	0.905	1.425	1.098	0.360	0.077	0.010	0.001	0.000
Field Data from Site	12.000	5.000	1.000				0.500			0.001	

Time: 20 Years

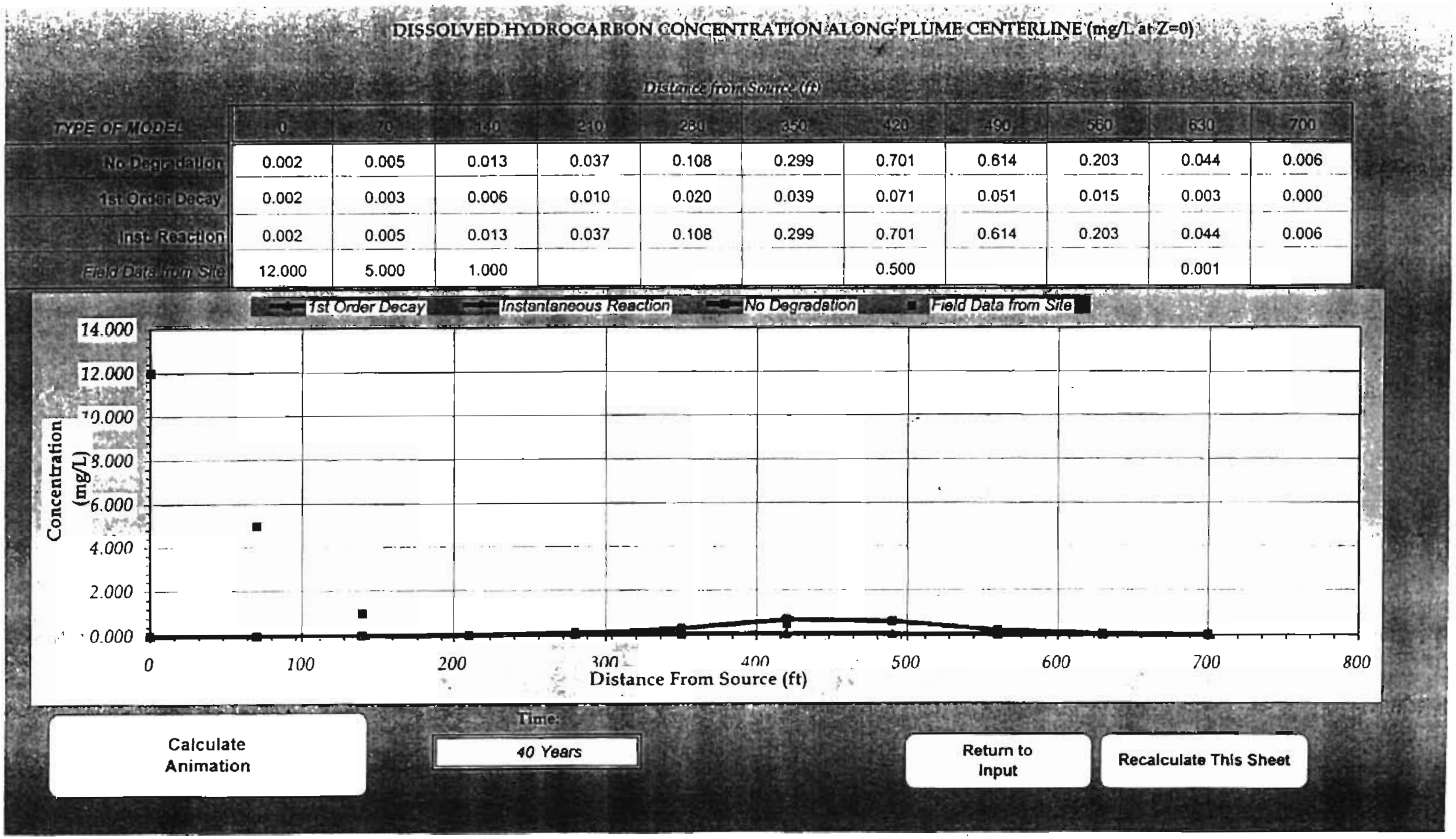


DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0	70	140	210	280	350	420	490	560	630	700
No Degradation	0.006	0.015	0.038	0.106	0.291	0.697	0.793	0.257	0.051	0.006	0.000
1st Order Decay	0.006	0.010	0.016	0.030	0.057	0.102	0.095	0.027	0.005	0.001	0.000
Inst. Reaction	0.006	0.015	0.038	0.106	0.291	0.697	0.793	0.257	0.051	0.006	0.000
Field Data from Site	12.000	5.000	1.000				0.500			0.001	

Time: 35 Years

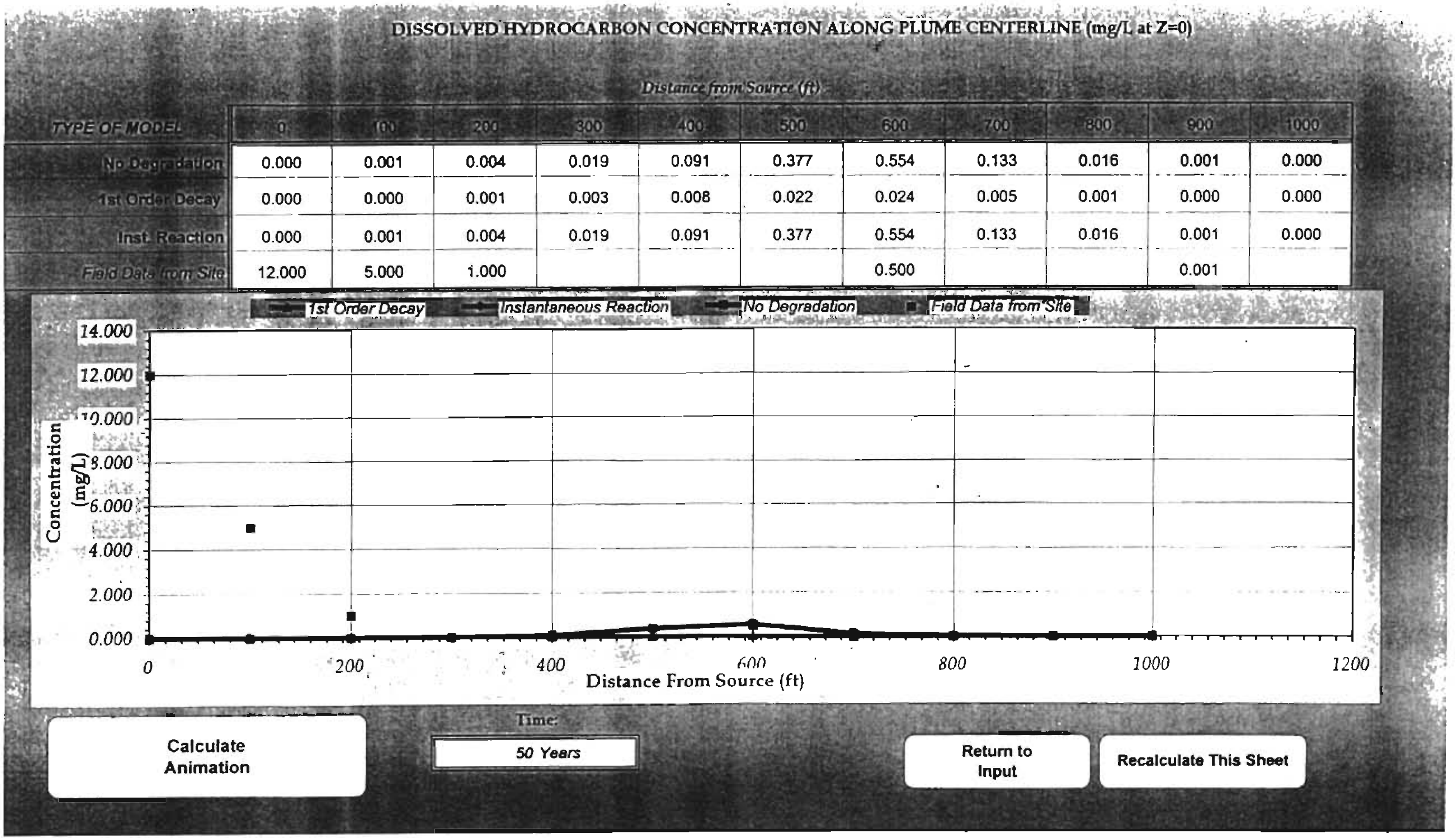


DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

	Distance from Source (ft)										
TYPE OF MODEL	0	70	140	210	280	350	420	490	560	630	700
No Degradation	0.002	0.005	0.013	0.037	0.108	0.299	0.701	0.614	0.203	0.044	0.006
1st Order Decay	0.002	0.003	0.006	0.010	0.020	0.039	0.071	0.051	0.015	0.003	0.000
Inst. Reaction	0.002	0.005	0.013	0.037	0.108	0.299	0.701	0.614	0.203	0.044	0.006
Field Data from Site	12.000	5.000	1.000				0.500			0.001	

Time:

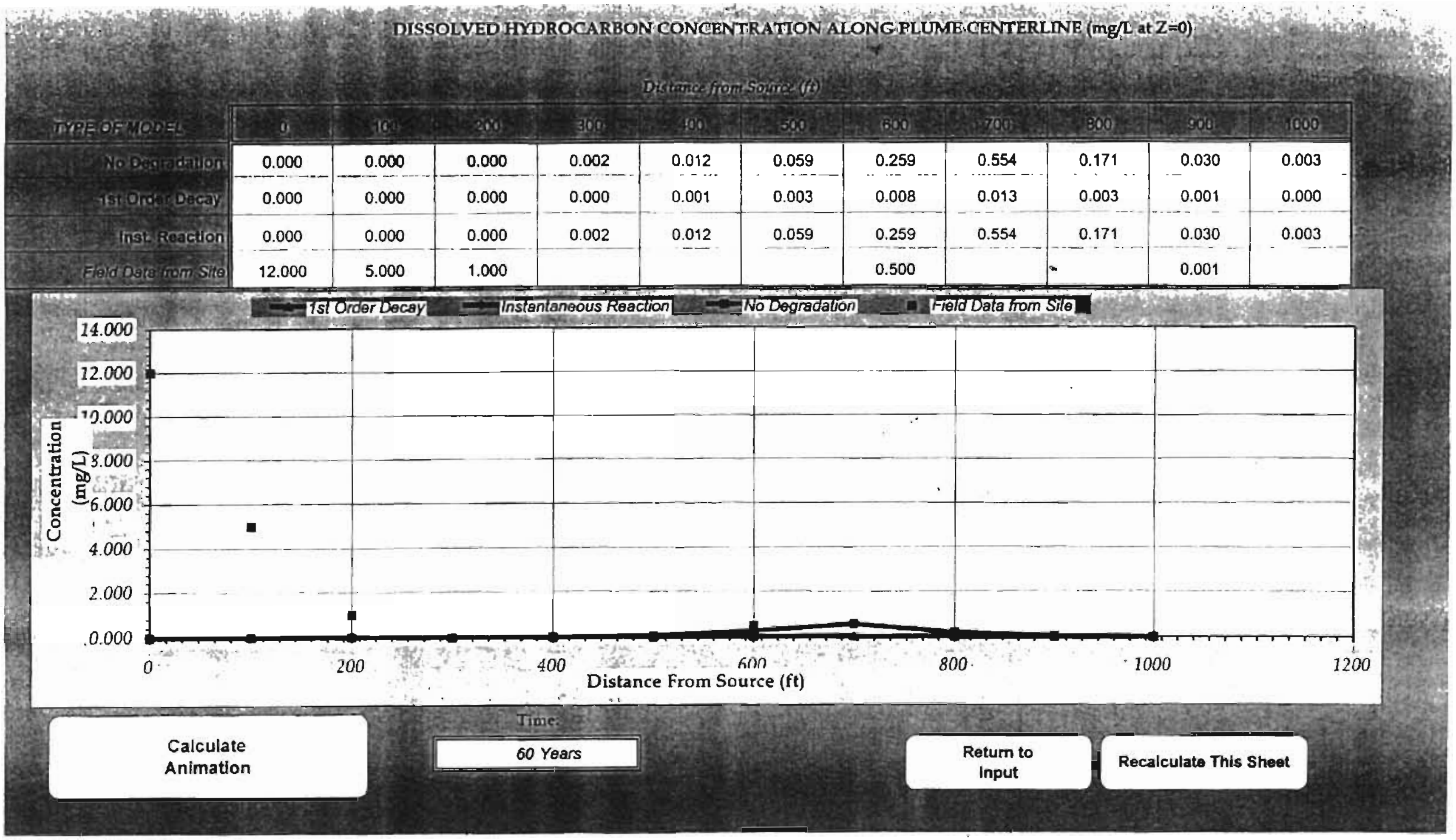
40 Years



DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

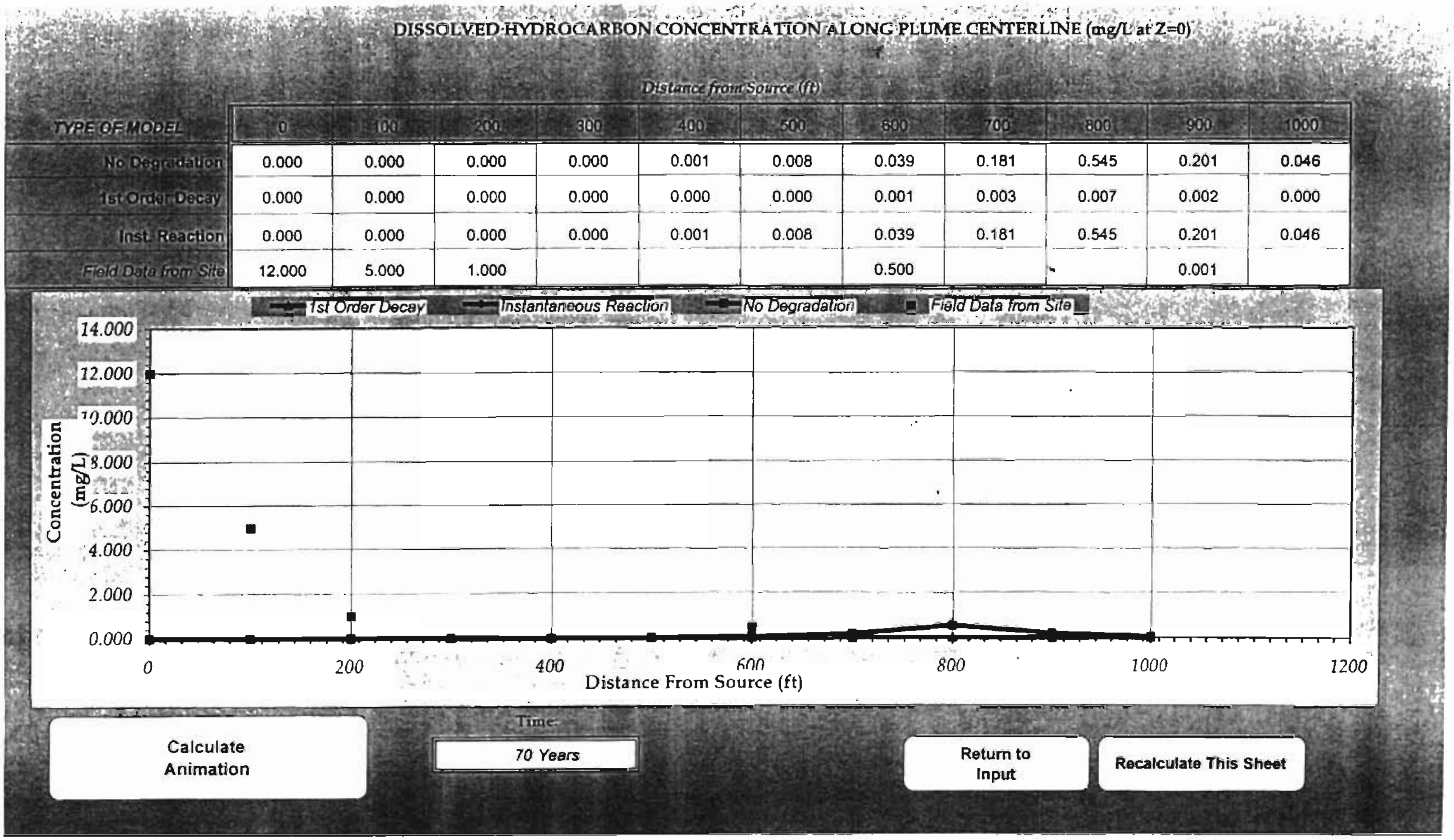
Distance from Source (ft)

TYPE OF MODEL	0	100	200	300	400	500	600	700	800	900	1000
No Degradation	0.000	0.001	0.004	0.019	0.091	0.377	0.554	0.133	0.016	0.001	0.000
1st Order Decay	0.000	0.000	0.001	0.003	0.008	0.022	0.024	0.005	0.001	0.000	0.000
Inst. Reaction	0.000	0.001	0.004	0.019	0.091	0.377	0.554	0.133	0.016	0.001	0.000
Field Data from Site	12.000	5.000	1.000				0.500			0.001	



DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

TYPE OF MODEL	Distance from Source (ft) 0	100	200	300	400	500	600	700	800	900	1000
No Degradation	0.000	0.000	0.000	0.002	0.012	0.059	0.259	0.554	0.171	0.030	0.003
1st Order Decay	0.000	0.000	0.000	0.000	0.001	0.003	0.008	0.013	0.003	0.001	0.000
Inst. Reaction	0.000	0.000	0.000	0.002	0.012	0.059	0.259	0.554	0.171	0.030	0.003
Field Data from Site	12.000	5.000	1.000				0.500			0.001	



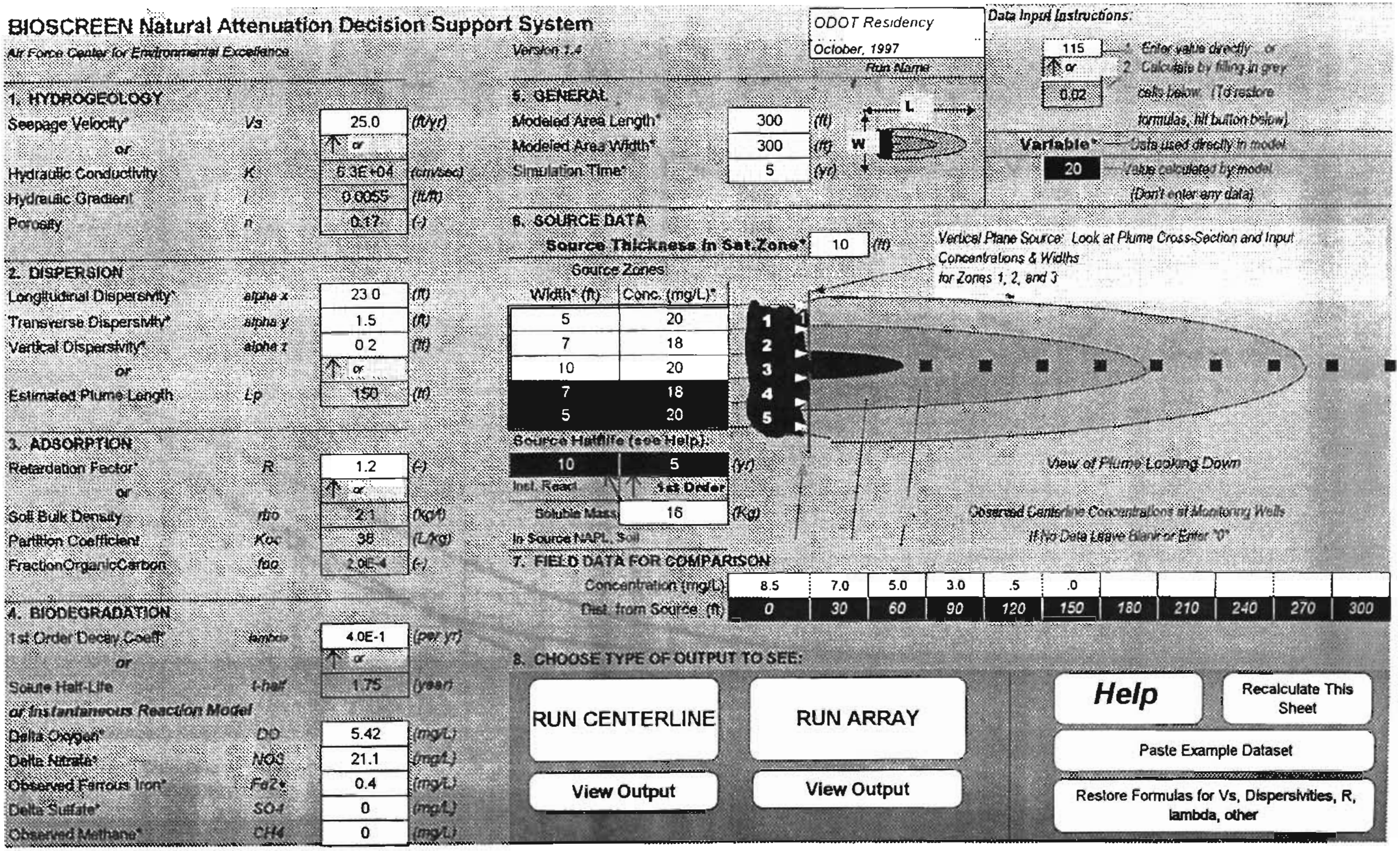
DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0	100	200	300	400	500	600	700	800	900	1000
No Degradation	0.000	0.000	0.000	0.000	0.001	0.008	0.039	0.181	0.545	0.201	0.046
1st Order Decay	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.003	0.007	0.002	0.000
Inst. Reaction	0.000	0.000	0.000	0.000	0.001	0.008	0.039	0.181	0.545	0.201	0.046
Field Data from Site	12.000	5.000	1.000				0.500			0.001	

Time: 70 Years

APPENDIX I
BIOSCREEN OUTPUT – RUN #5



BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence

Version 1.4

ODOT Residency
October, 1997
Run Name

Data Input Instructions:

115 — 1. Enter value directly ... or
or — 2. Calculate by filling in grey cells below. (To restore formulas, hit button below)
0.02

Variable* — Data used directly in model

20 — Value calculated by model (Don't enter any data)

1. HYDROGEOLOGY

Seepage Velocity*	Vs	25.0	(ft/yr)
or		or	
Hydraulic Conductivity	K	6.3E+04	(cm/sec)
Hydraulic Gradient	i	0.0055	(ft/ft)
Porosity	n	0.17	(-)

2. DISPERSION

Longitudinal Dispersivity*	alpha x	23.0	(ft)
Transverse Dispersivity*	alpha y	1.5	(ft)
Vertical Dispersivity*	alpha z	0.2	(ft)
or		or	
Estimated Plume Length	Lp	150	(ft)

3. ADSORPTION

Retardation Factor*	R	1.2	(-)
or		or	
Soil Bulk Density	rho	2.1	(kg/l)
Partition Coefficient	Koc	38	(L/kg)
FractionOrganicCarbon	foc	2.0E-4	(-)

4. BIODEGRADATION

1st Order Decay Coeff*	lambda	4.0E-1	(per yr)
or		or	
Solute Half-Life	t-half	1.75	(year)
or Instantaneous Reaction Model			
Delta Oxygen*	DO	5.42	(mg/L)
Delta Nitrate*	NO3	21.1	(mg/L)
Observed Ferrous Iron*	Fe2+	0.4	(mg/L)
Delta Sulfate*	SO4	0	(mg/L)
Observed Methane*	CH4	0	(mg/L)

5. GENERAL

Modeled Area Length*	300	(ft)
Modeled Area Width*	300	(ft)
Simulation Time*	5	(yr)

6. SOURCE DATA

Source Thickness in Sat.Zone* 10 (ft)

Source Zones

Width* (ft)	Conc. (mg/L)*
5	20
7	18
10	20
7	18
5	20

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths for Zones 1, 2, and 3

Source Halflife (see Help):

10	5	(yr)
Inst. React.	1st Order	

Soluble Mass 16 (Kg)

In Source NAPL, Soil

View of Plume Looking Down

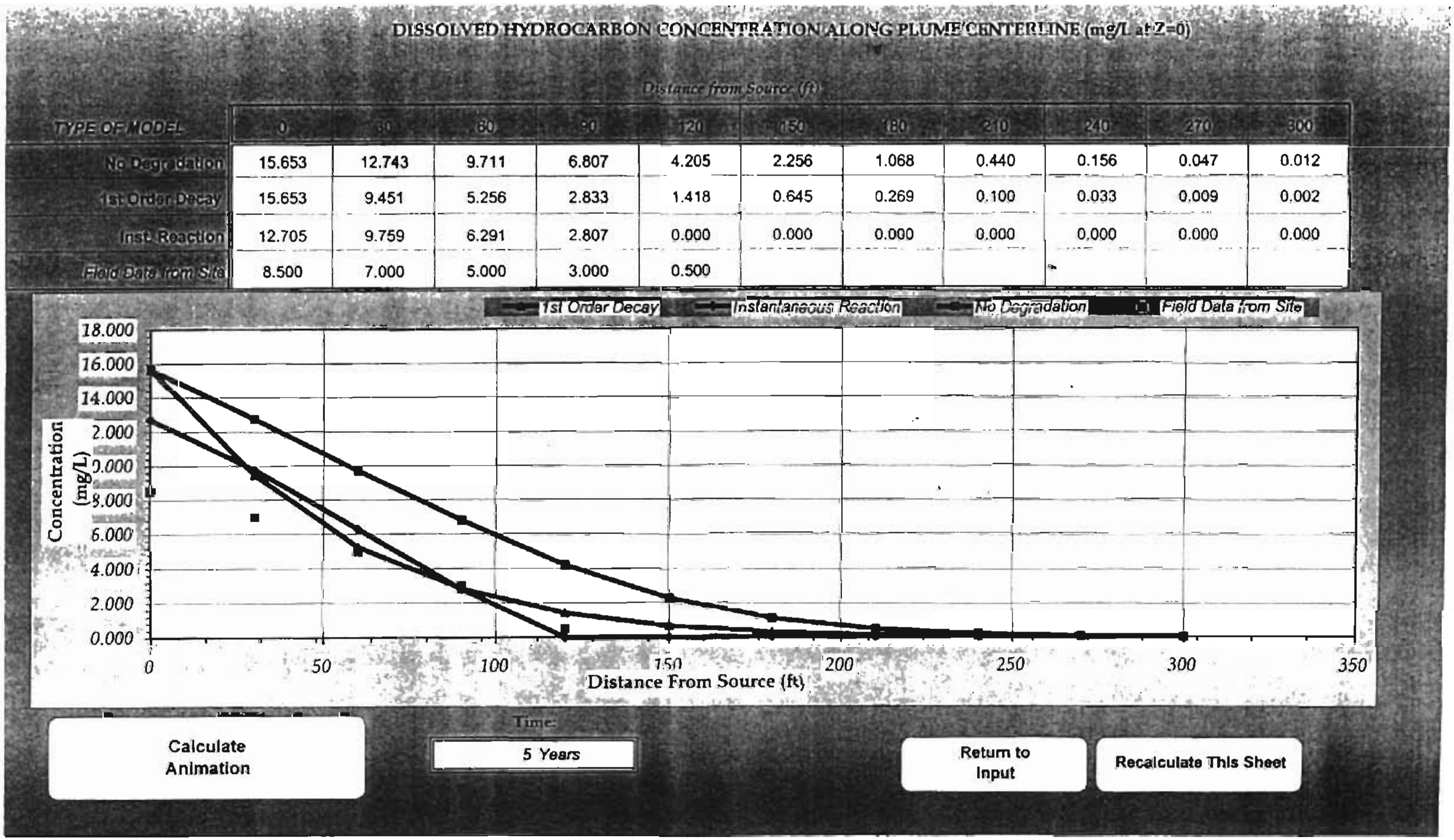
Observed Centerline Concentrations at Monitoring Wells

If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

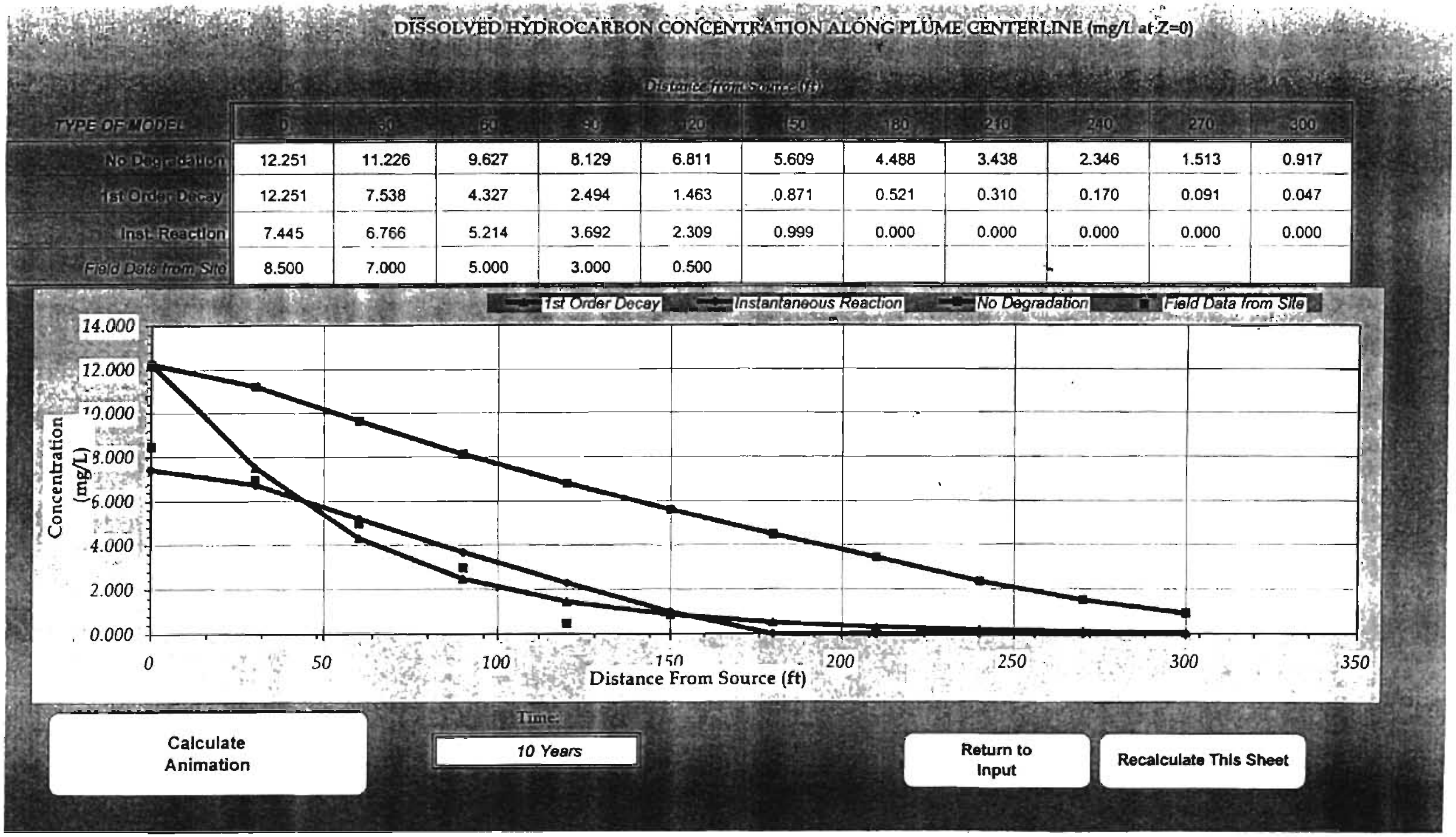
Concentration (mg/L)	8.5	7.0	5.0	3.0	.5	.0					
Dist. from Source (ft)	0	30	60	90	120	150	180	210	240	270	300

8. CHOOSE TYPE OF OUTPUT TO SEE:



DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

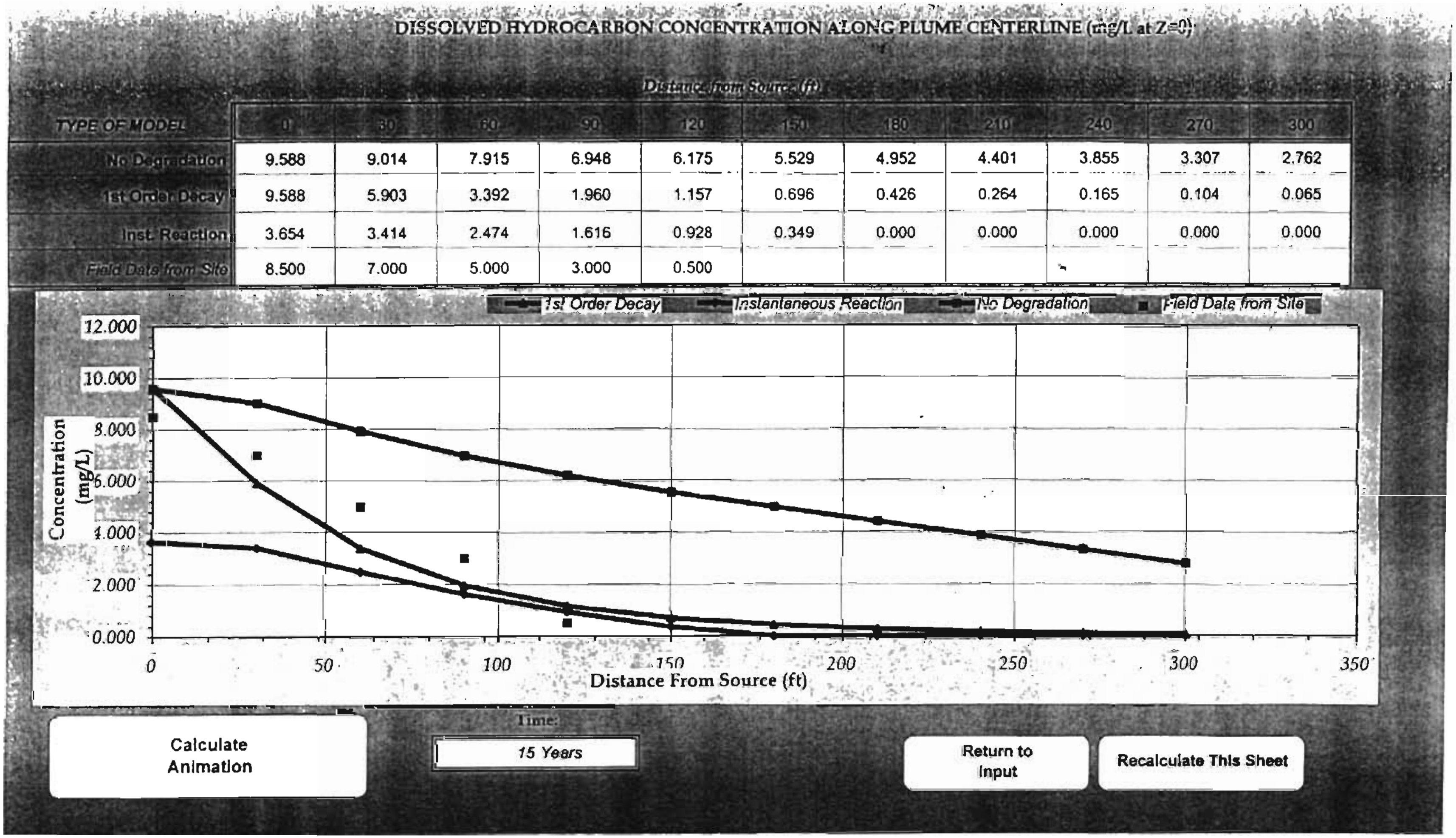
TYPE OF MODEL	Distance from Source (ft)										
	0	30	60	90	120	150	180	210	240	270	300
No Degradation	15.653	12.743	9.711	6.807	4.205	2.256	1.068	0.440	0.156	0.047	0.012
1st Order Decay	15.653	9.451	5.256	2.833	1.418	0.645	0.269	0.100	0.033	0.009	0.002
Inst. Reaction	12.705	9.759	6.291	2.807	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	8.500	7.000	5.000	3.000	0.500						



DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

TYPE OF MODEL	Distance from Source (ft)										
	0	30	60	90	120	150	180	210	240	270	300
No Degradation	12.251	11.226	9.627	8.129	6.811	5.609	4.488	3.438	2.346	1.513	0.917
1st Order Decay	12.251	7.538	4.327	2.494	1.463	0.871	0.521	0.310	0.170	0.091	0.047
Inst. Reaction	7.445	6.766	5.214	3.692	2.309	0.999	0.000	0.000	0.000	0.000	0.000
Field Data from Site	8.500	7.000	5.000	3.000	0.500						

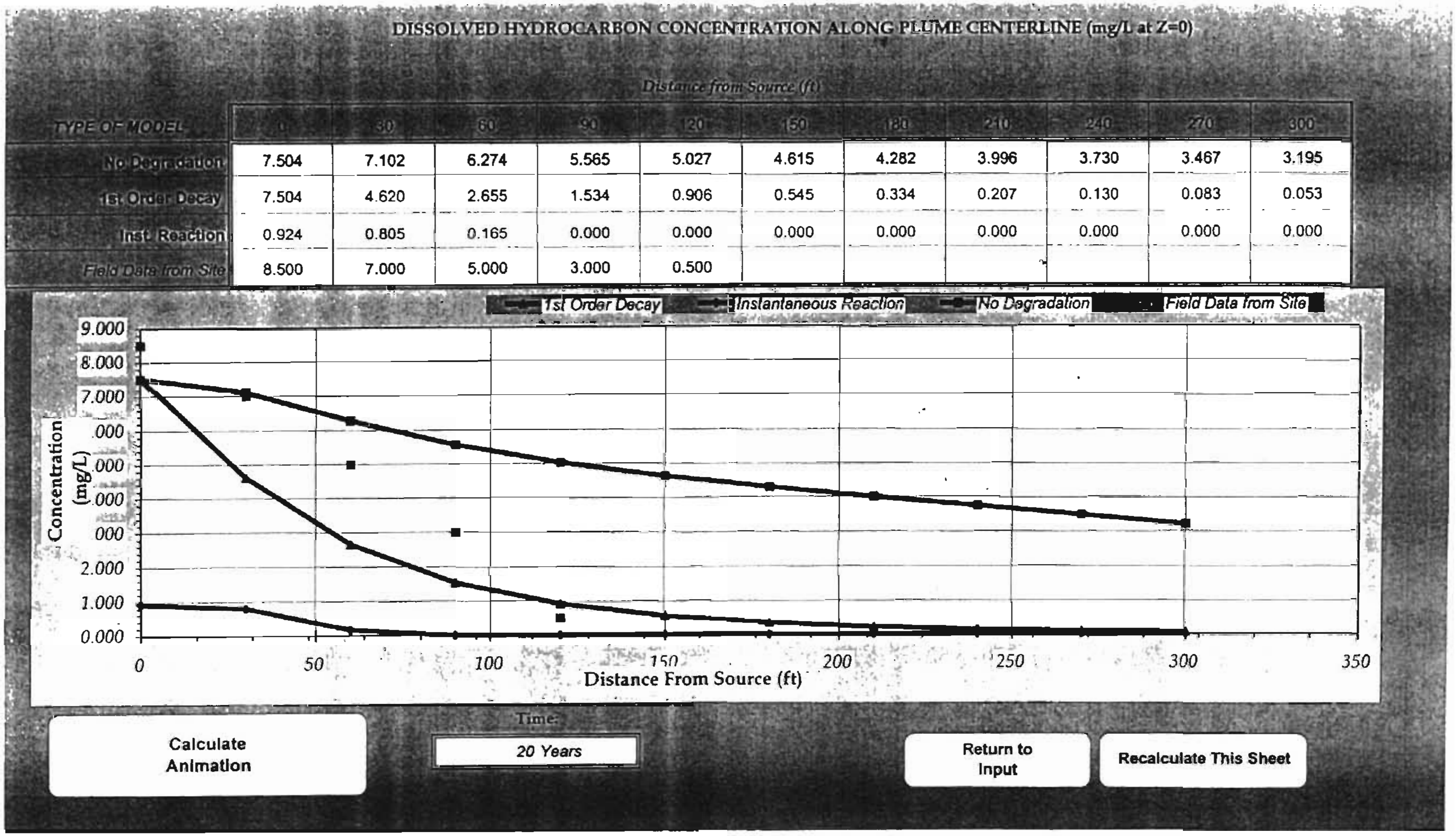
Time: 10 Years



DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

	Distance from Source (ft)										
TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	9.588	9.014	7.915	6.948	6.175	5.529	4.952	4.401	3.855	3.307	2.762
1st Order Decay	9.588	5.903	3.392	1.960	1.157	0.696	0.426	0.264	0.165	0.104	0.065
Inst. Reaction	3.654	3.414	2.474	1.616	0.928	0.349	0.000	0.000	0.000	0.000	0.000
Field Data from Site	8.500	7.000	5.000	3.000	0.500						

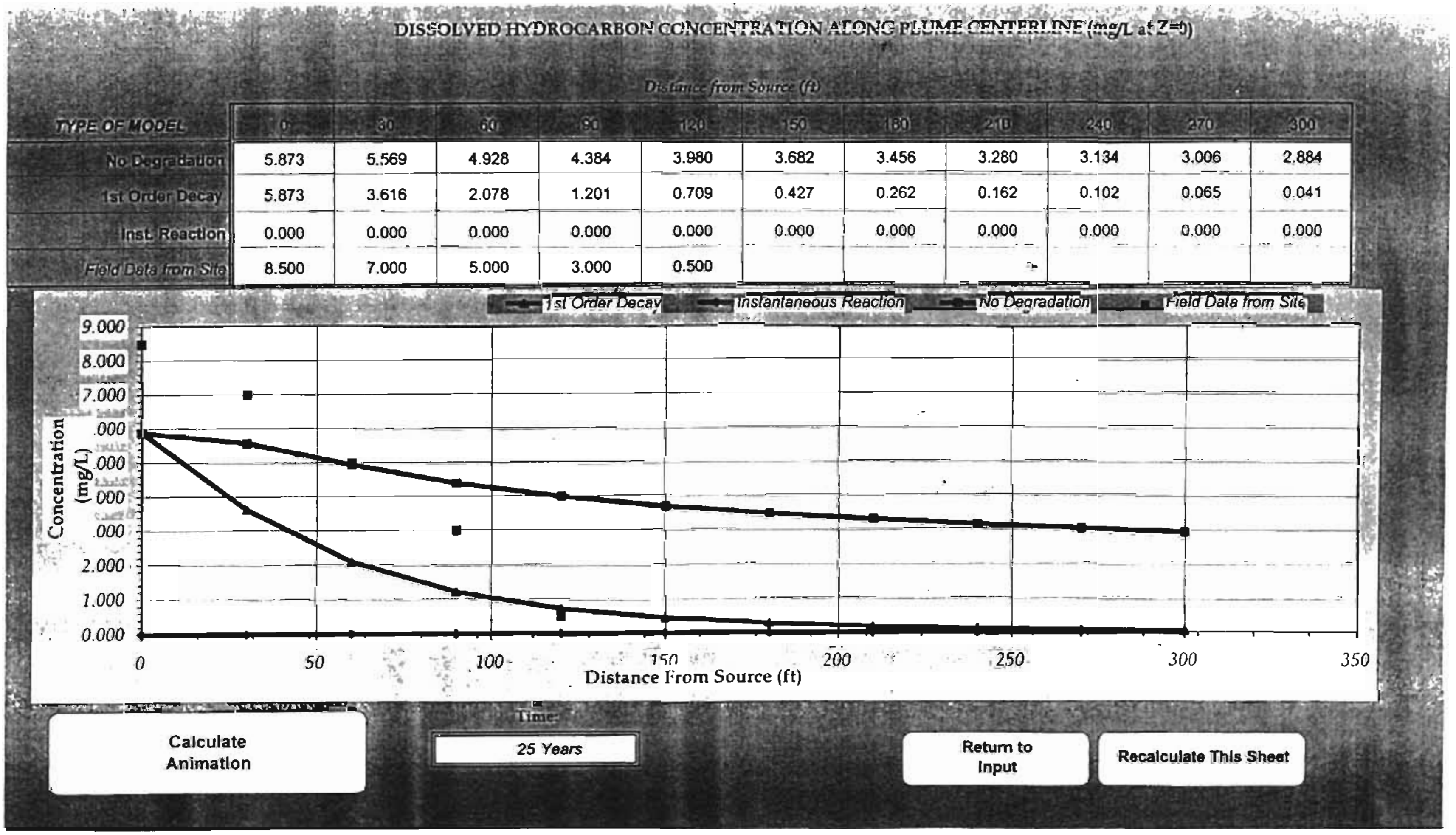
Time: 15 Years



DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

TYPE OF MODEL	Distance from Source (ft)										
	0	30	60	90	120	150	180	210	240	270	300
No Degradation	7.504	7.102	6.274	5.565	5.027	4.615	4.282	3.996	3.730	3.467	3.195
1st Order Decay	7.504	4.620	2.655	1.534	0.906	0.545	0.334	0.207	0.130	0.083	0.053
Inst. Reaction	0.924	0.805	0.165	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	8.500	7.000	5.000	3.000	0.500						

Time: 20 Years



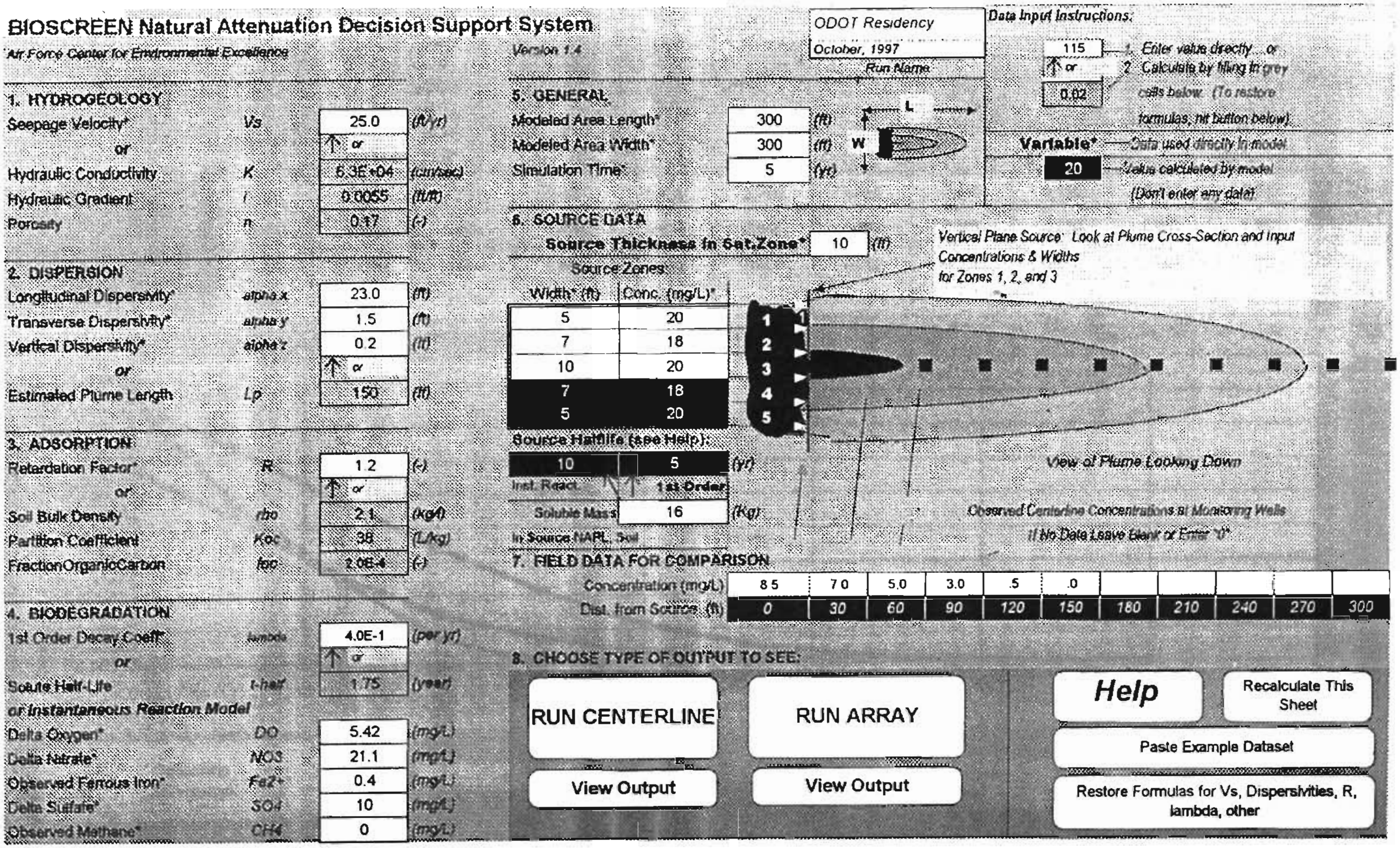
DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	5.873	5.569	4.928	4.384	3.980	3.682	3.456	3.280	3.134	3.006	2.884
1st Order Decay	5.873	3.616	2.078	1.201	0.709	0.427	0.262	0.162	0.102	0.065	0.041
Inst. Reaction	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	8.500	7.000	5.000	3.000	0.500						

Time:

25 Years



BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence

Version 1.4

ODOT Residency
October, 1997
Run Name

Data Input Instructions:

115 — 1. Enter value directly ... or
↑ or
0.02 — 2. Calculate by filling in grey cells below. (To restore formulas, hit button below).

Variable* — Data used directly in model
20 — Value calculated by model (Don't enter any data).

1. HYDROGEOLOGY

Seepage Velocity*	Vs	25.0	(ft/yr)
or		↑ or	
Hydraulic Conductivity	K	6.3E+04	(cm/sec)
Hydraulic Gradient	i	0.0055	(ft/ft)
Porosity	n	0.17	(-)

2. DISPERSION

Longitudinal Dispersivity*	alpha x	23.0	(ft)
Transverse Dispersivity*	alpha y	1.5	(ft)
Vertical Dispersivity*	alpha z	0.2	(ft)
or		↑ or	
Estimated Plume Length	Lp	150	(ft)

3. ADSORPTION

Retardation Factor*	R	1.2	(-)
or		↑ or	
Soil Bulk Density	rho	2.1	(kg/l)
Partition Coefficient	Koc	38	(L/kg)
FractionOrganicCarbon	foc	2.0E-4	(-)

4. BIODEGRADATION

1st Order Decay Coeff*	lambda	4.0E-1	(per yr)
or		↑ or	
Solute Half-Life	t-half	1.75	(year)
or Instantaneous Reaction Model			
Delta Oxygen*	DO	5.42	(mg/L)
Delta Nitrate*	NO3	21.1	(mg/L)
Observed Ferrous Iron*	Fe2+	0.4	(mg/L)
Delta Sulfate*	SO4	10	(mg/L)
Observed Methane*	CH4	0	(mg/L)

5. GENERAL

Modeled Area Length*	300	(ft)
Modeled Area Width*	300	(ft)
Simulation Time*	5	(yr)

6. SOURCE DATA

Source Thickness in Sat.Zone* 10 (ft)

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths for Zones 1, 2, and 3

Source Zones:

Width* (ft)	Conc. (mg/L)*
5	20
7	18
10	20
7	18
5	20

Source Halflife (see Help):

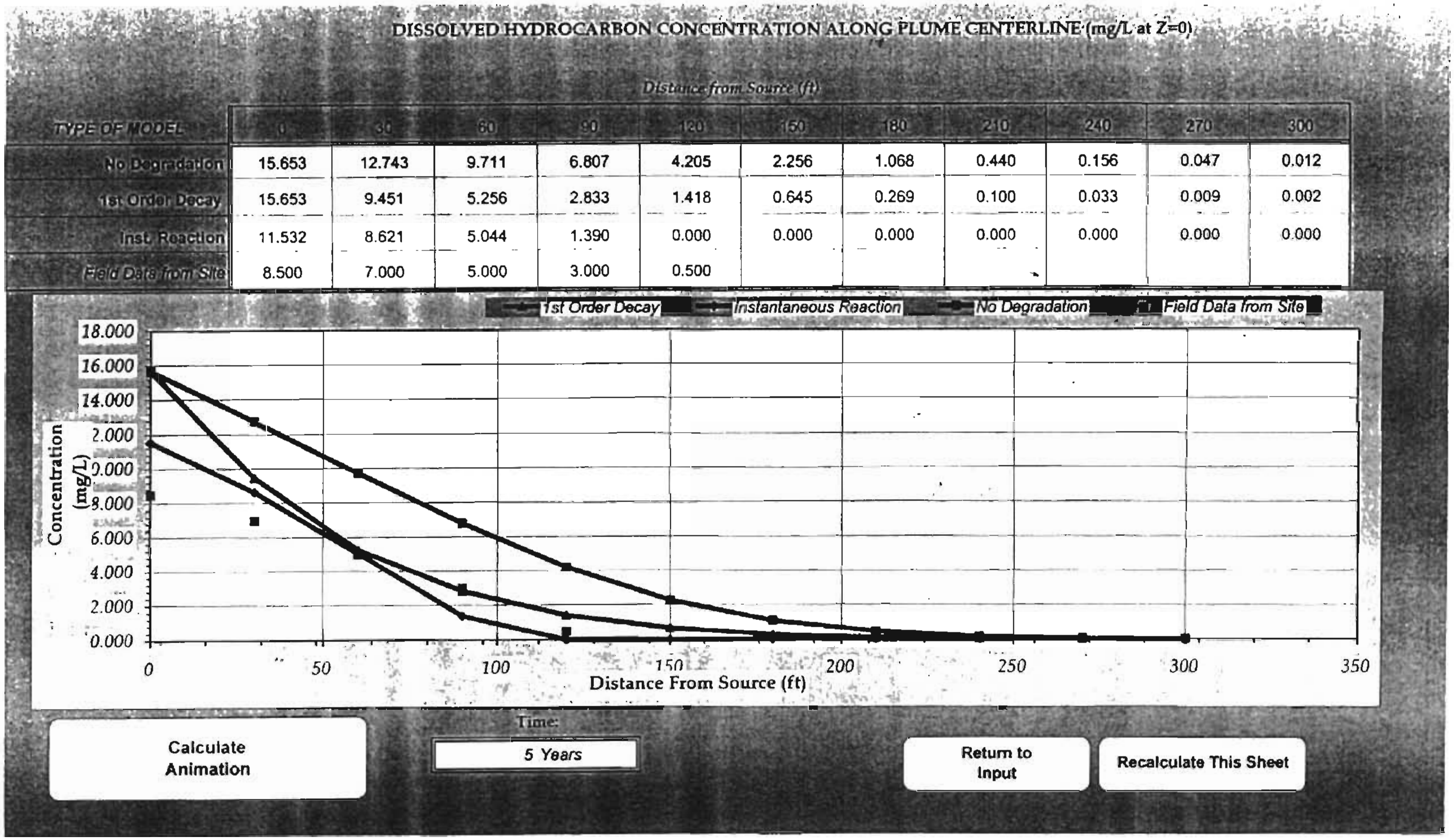
10	5	(yr)
Inst. React.	1st Order	

Soluble Mass 16 (Kg)
In Source NAPL, Soil

7. FIELD DATA FOR COMPARISON

Concentration (mg/L)	8.5	7.0	5.0	3.0	.5	.0					
Dist. from Source (ft)	0	30	60	90	120	150	180	210	240	270	300

8. CHOOSE TYPE OF OUTPUT TO SEE:



DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

	Distance from Source (ft)										
TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	15.653	12.743	9.711	6.807	4.205	2.256	1.068	0.440	0.156	0.047	0.012
1st Order Decay	15.653	9.451	5.256	2.833	1.418	0.645	0.269	0.100	0.033	0.009	0.002
Inst. Reaction	11.532	8.621	5.044	1.390	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	8.500	7.000	5.000	3.000	0.500						

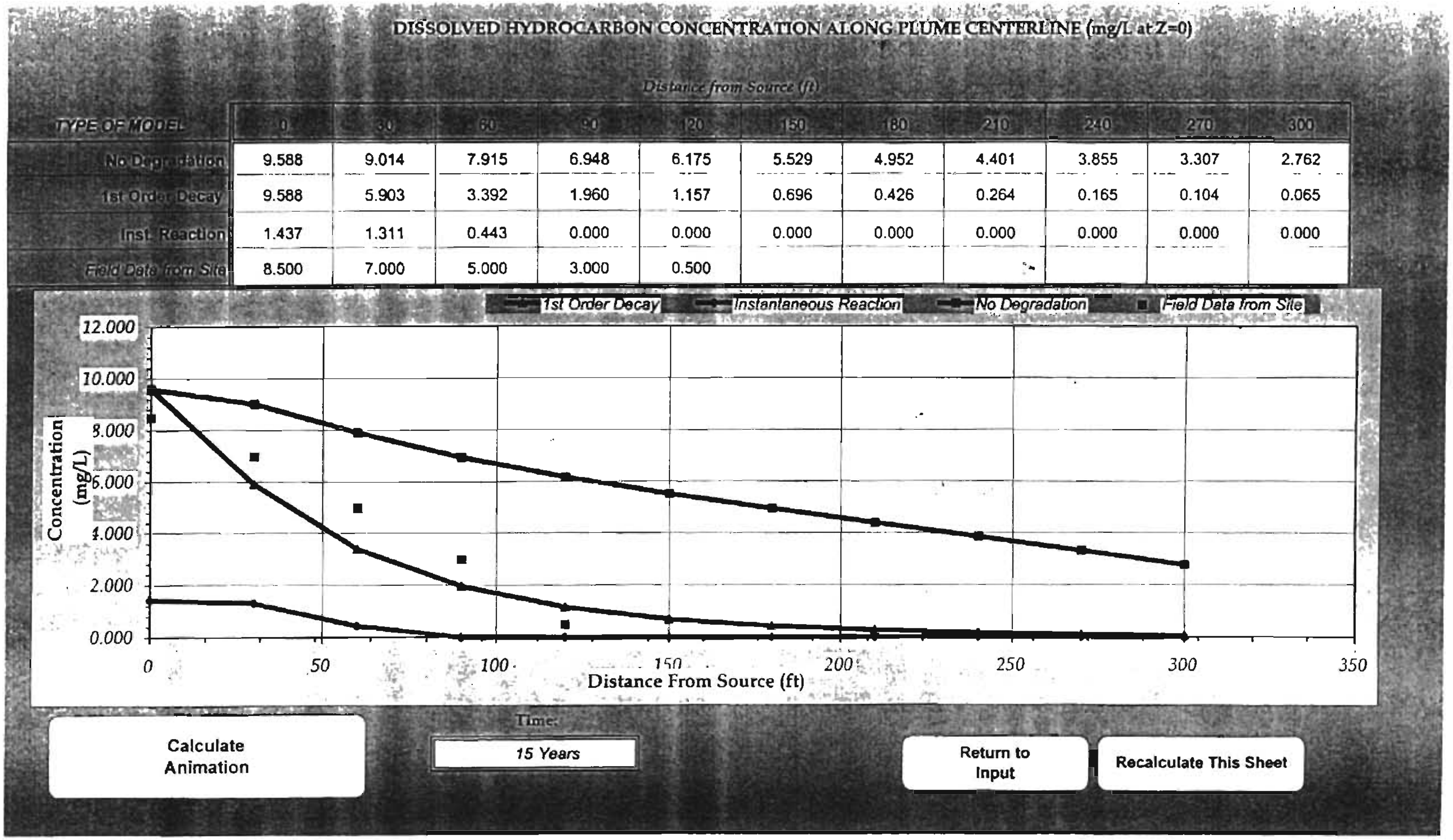
Calculate Animation

Time:

5 Years

Return to Input

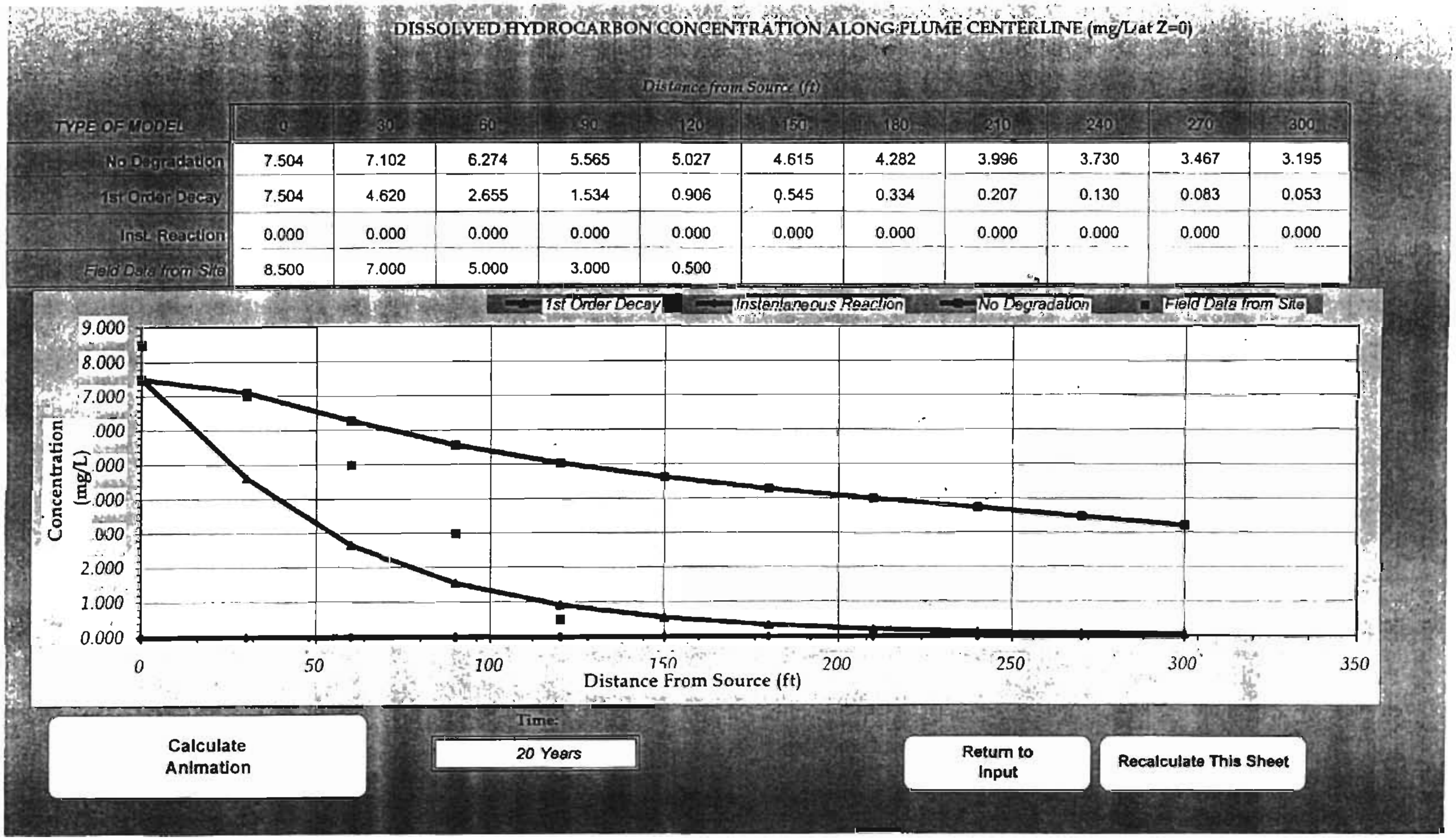
Recalculate This Sheet



DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

	Distance from Source (ft)										
TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	9.588	9.014	7.915	6.948	6.175	5.529	4.952	4.401	3.855	3.307	2.762
1st Order Decay	9.588	5.903	3.392	1.960	1.157	0.696	0.426	0.264	0.165	0.104	0.065
Inst. Reaction	1.437	1.311	0.443	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	8.500	7.000	5.000	3.000	0.500						

Time: 15 Years

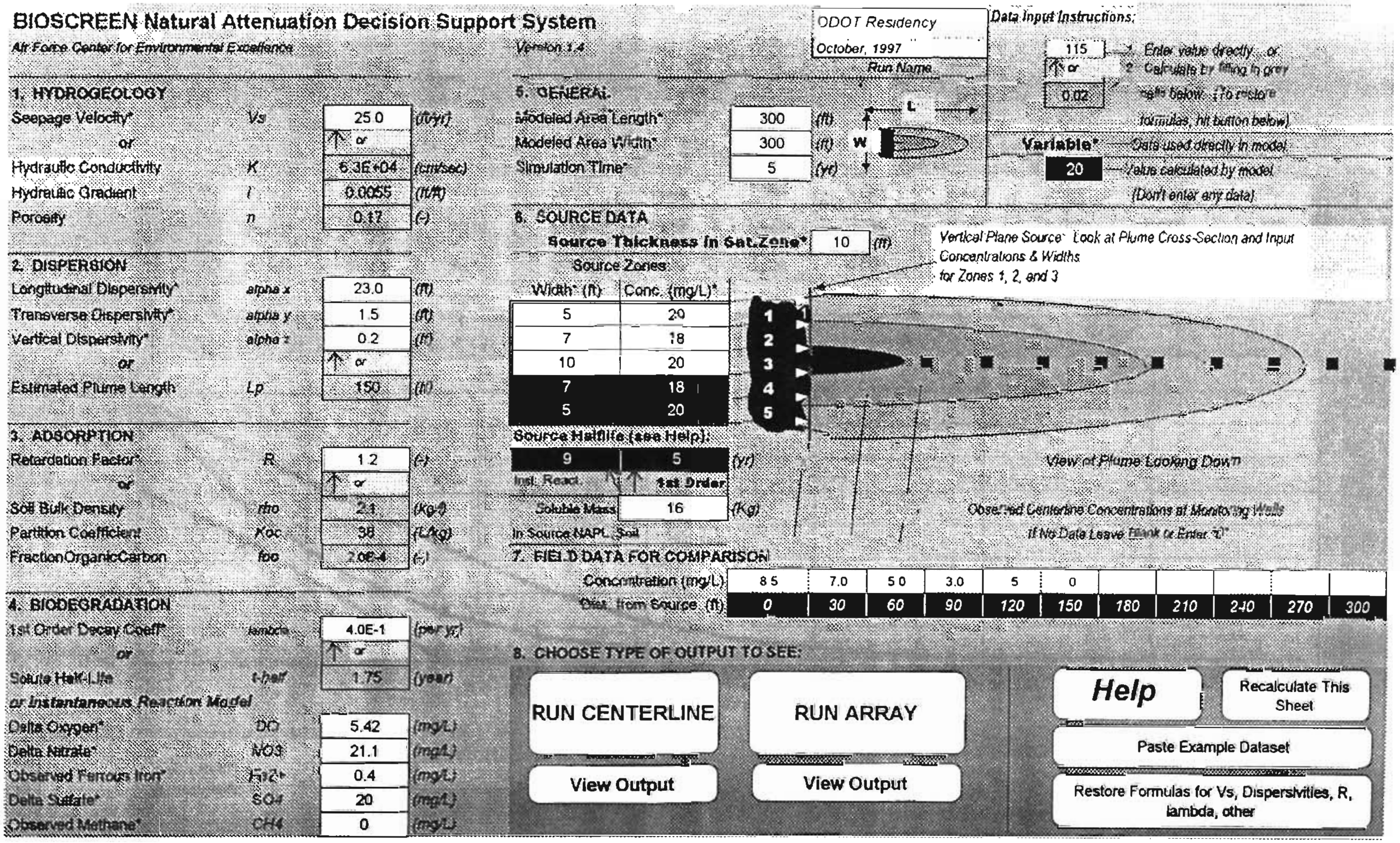


DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	7.504	7.102	6.274	5.565	5.027	4.615	4.282	3.996	3.730	3.467	3.195
1st Order Decay	7.504	4.620	2.655	1.534	0.906	0.545	0.334	0.207	0.130	0.083	0.053
Inst. Reaction	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	8.500	7.000	5.000	3.000	0.500						

Time: 20 Years



BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence *Version 1.4*

ODOT Residency
October, 1997
Run Name

Data Input Instructions:
115 → 1. Enter value directly ... or
↑ or 2. Calculate by filling in grey
0.02 cells below. (To restore formulas, hit button below)
Variable* — Data used directly in model
20 — Value calculated by model (Don't enter any data)

1. HYDROGEOLOGY

Seepage Velocity*	*Vs*	25.0	*(ft/yr)*
or		↑ or	
Hydraulic Conductivity	*K*	6.3E-04	*(cm/sec)*
Hydraulic Gradient	*i*	0.0055	*(ft/ft)*
Porosity	*n*	0.17	*(-)*

2. DISPERSION

Longitudinal Dispersivity*	*alpha x*	23.0	*(ft)*
Transverse Dispersivity*	*alpha y*	1.5	*(ft)*
Vertical Dispersivity*	*alpha z*	0.2	*(ft)*
or		↑ or	
Estimated Plume Length	*Lp*	150	*(ft)*

3. ADSORPTION

Retardation Factor*	*R*	1.2	*(-)*
or		↑ or	
Soil Bulk Density	*rho*	2.1	*(kg/l)*
Partition Coefficient	*Koc*	38	*(L/kg)*
FractionOrganicCarbon	*foc*	2.0E-4	*(-)*

4. BIODEGRADATION

1st Order Decay Coeff*	*lambda*	4.0E-1	*(per yr)*
or		↑ or	
Solute Half-Life	*t-half*	1.75	*(year)*
or Instantaneous Reaction Model			
Delta Oxygen*	DO	5.42	*(mg/L)*
Delta Nitrate*	NO3	21.1	*(mg/L)*
Observed Ferrous Iron*	Fe2+	0.4	*(mg/L)*
Delta Sulfate*	SO4	20	*(mg/L)*
Observed Methane*	CH4	0	*(mg/L)*

5. GENERAL

Modeled Area Length*	300	*(ft)*
Modeled Area Width*	300	*(ft)*
Simulation Time*	5	*(yr)*

6. SOURCE DATA

Source Thickness in Sat.Zone* 10 *(ft)*

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths for Zones 1, 2, and 3

Source Zones:

Zone	Width* (ft)	Conc. (mg/L)*
1	5	20
2	7	18
3	10	20
4	7	18
5	5	20

Source Halflife (see Help):

Inst. React.	1st Order	
9	5	*(yr)*

Soluble Mass 16 *(Kg)*
In Source NAPL, Soil

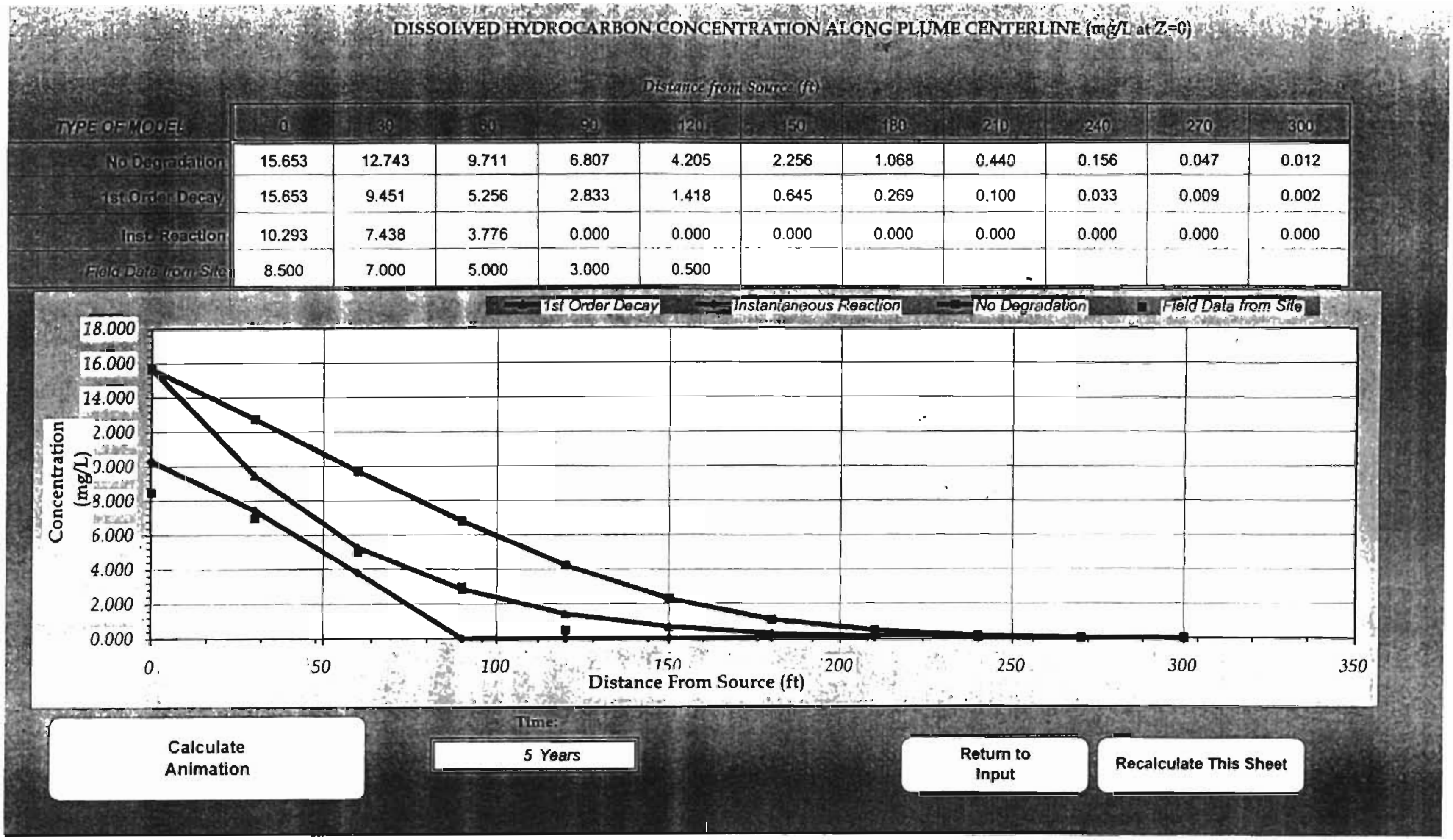
View of Plume Looking Down

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Concentration (mg/L)	8.5	7.0	5.0	3.0	5	0					
Dist. from Source (ft)	*0*	*30*	*60*	*90*	*120*	*150*	*180*	*210*	*240*	*270*	*300*

8. CHOOSE TYPE OF OUTPUT TO SEE:

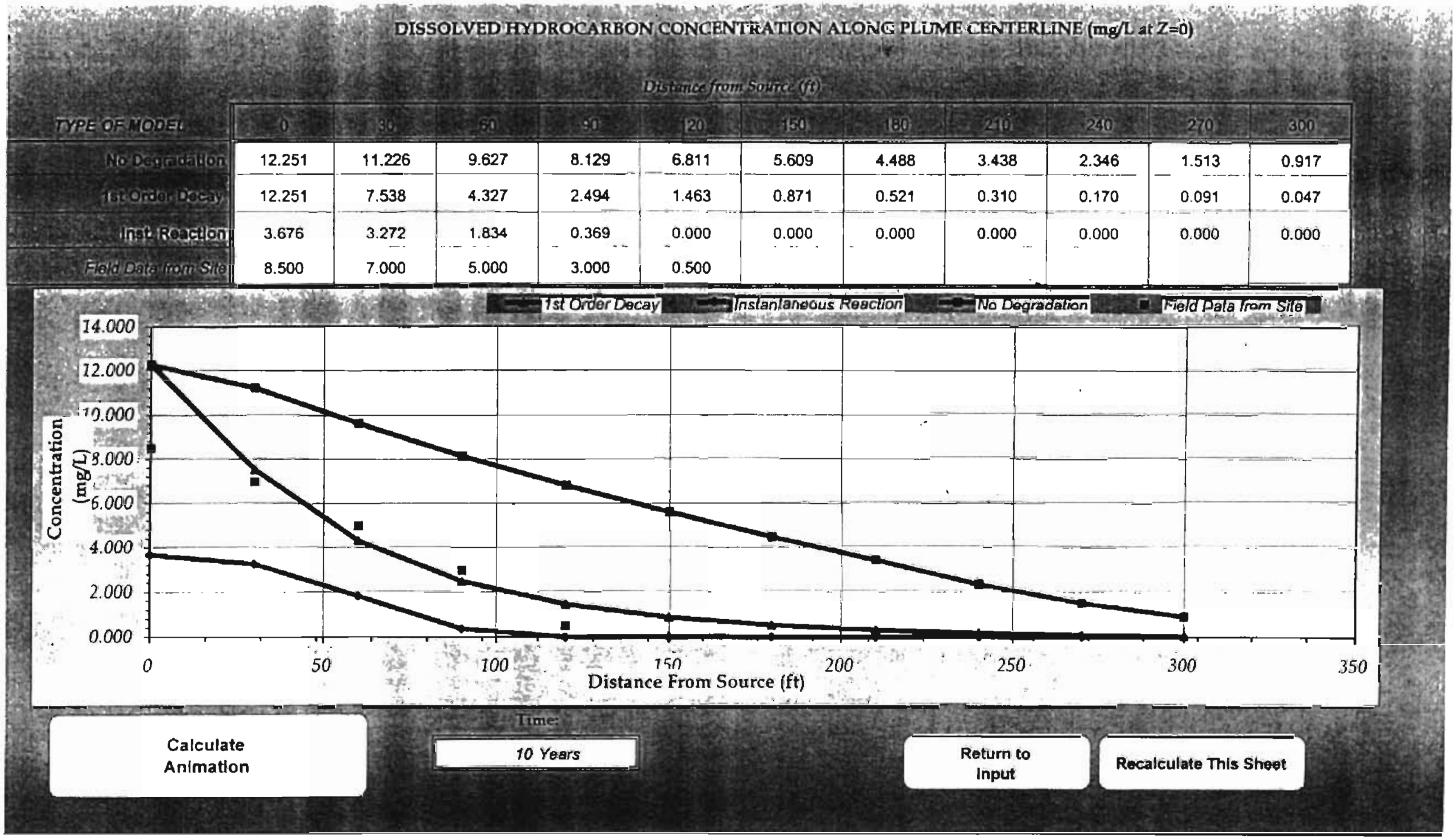


DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	15.653	12.743	9.711	6.807	4.205	2.256	1.068	0.440	0.156	0.047	0.012
1st Order Decay	15.653	9.451	5.256	2.833	1.418	0.645	0.269	0.100	0.033	0.009	0.002
Inst. Reaction	10.293	7.438	3.776	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	8.500	7.000	5.000	3.000	0.500						

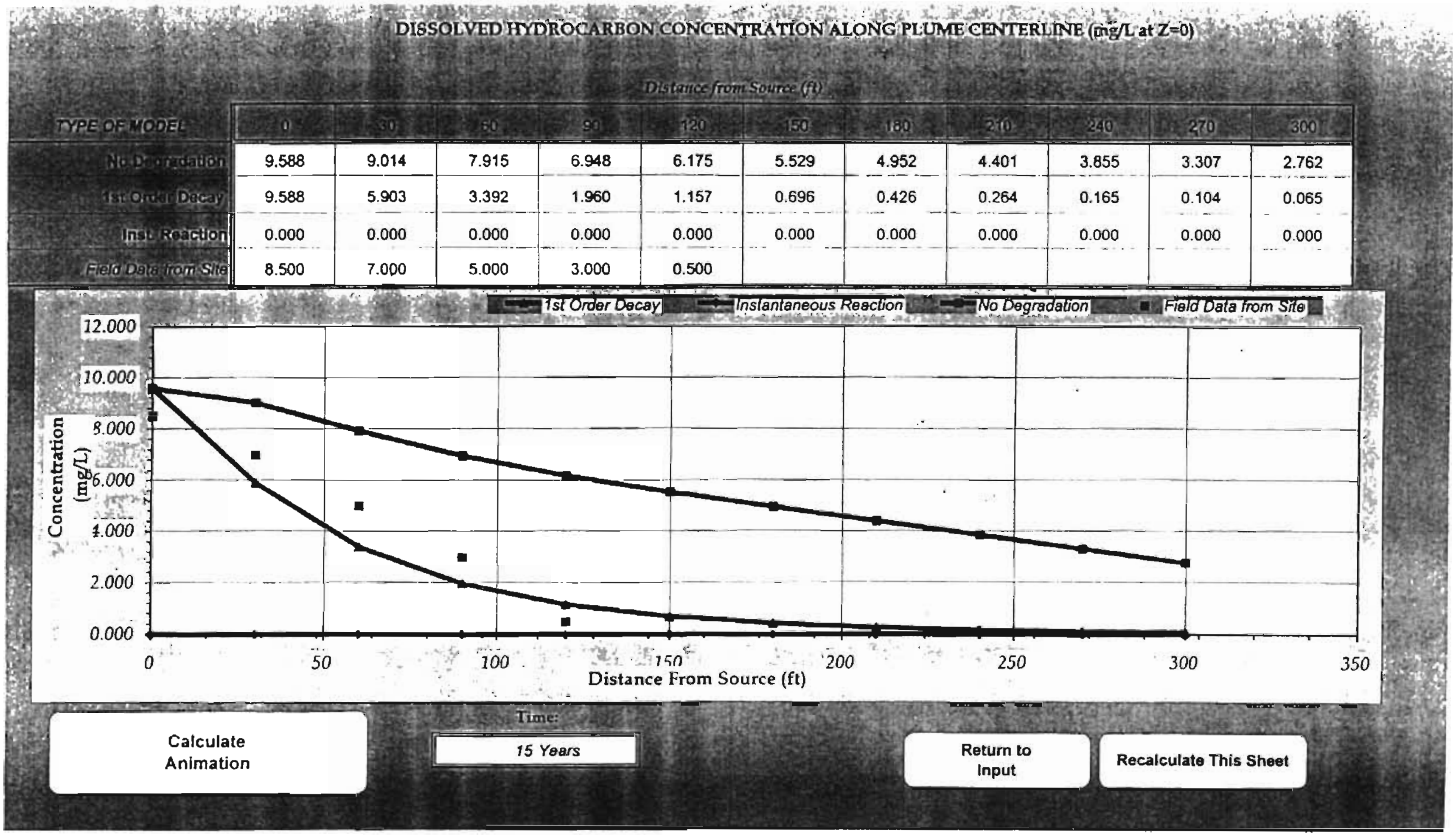
Time: 5 Years



DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	12.251	11.226	9.627	8.129	6.811	5.609	4.488	3.438	2.346	1.513	0.917
1st Order Decay	12.251	7.538	4.327	2.494	1.463	0.871	0.521	0.310	0.170	0.091	0.047
Inst. Reaction	3.676	3.272	1.834	0.369	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	8.500	7.000	5.000	3.000	0.500						

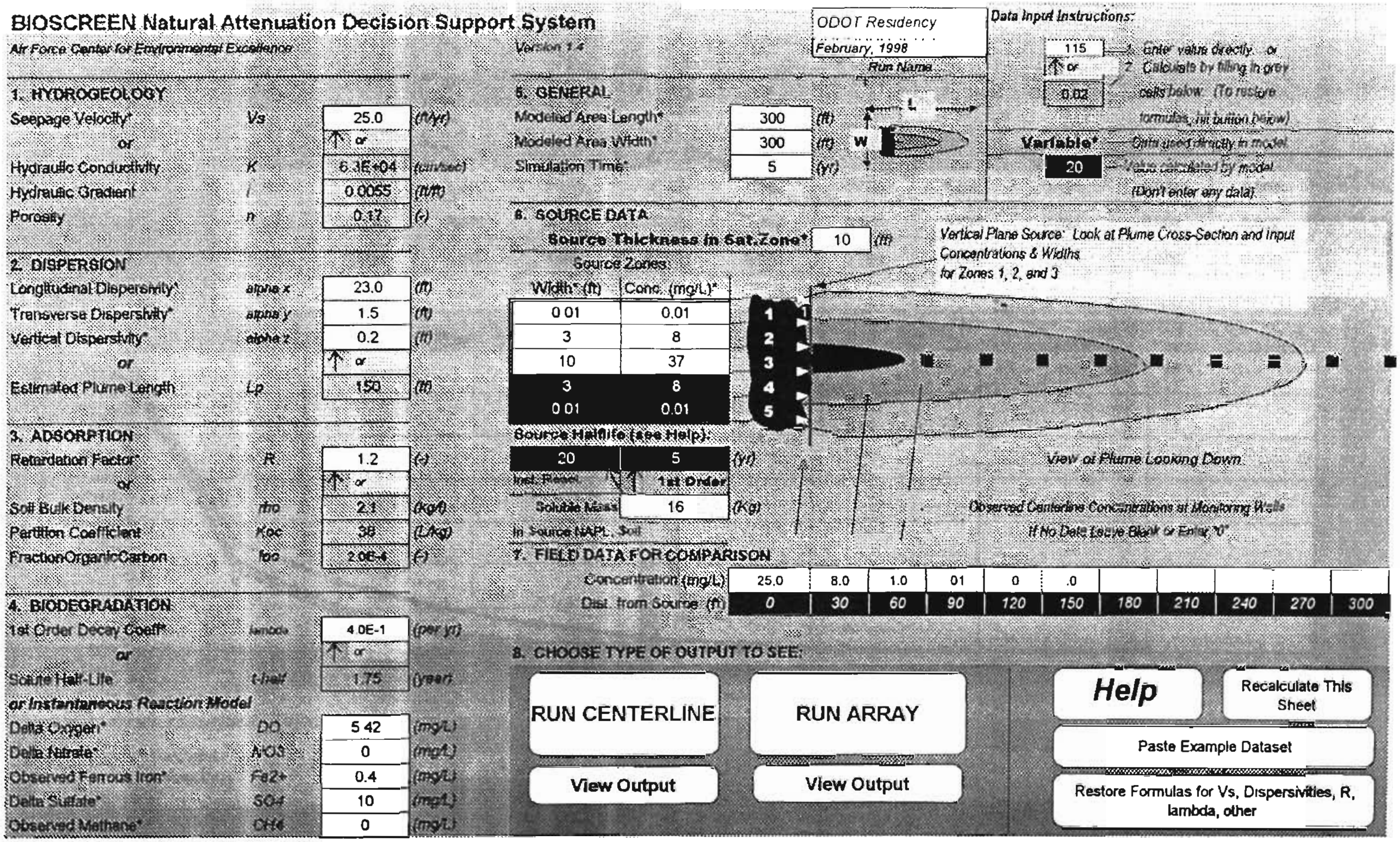


DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	9.588	9.014	7.915	6.948	6.175	5.529	4.952	4.401	3.855	3.307	2.762
1st Order Decay	9.588	5.903	3.392	1.960	1.157	0.696	0.426	0.264	0.165	0.104	0.065
Inst. Reaction	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	8.500	7.000	5.000	3.000	0.500						

APPENDIX J
BIOSCREEN OUTPUT – RUN #6



BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence

Version 1.4

ODOT Residency

February, 1998

Run Name

Data Input Instructions:

115 — 1. Enter value directly ... or

↑ or — 2. Calculate by filling in grey

0.02 — cells below. (To restore formulas, hit button below)

Variable* — Data used directly in model.

20 — Value calculated by model. (Don't enter any data).

1. HYDROGEOLOGY

Seepage Velocity*	Vs	25.0	(ft/yr)
or		↑ or	
Hydraulic Conductivity	K	6.3E+04	(cm/sec)
Hydraulic Gradient	i	0.0055	(ft/ft)
Porosity	n	0.17	(-)

2. DISPERSION

Longitudinal Dispersivity*	alpha x	23.0	(ft)
Transverse Dispersivity*	alpha y	1.5	(ft)
Vertical Dispersivity*	alpha z	0.2	(ft)
or		↑ or	
Estimated Plume Length	Lp	150	(ft)

3. ADSORPTION

Retardation Factor*	R	1.2	(-)
or		↑ or	
Soil Bulk Density	rho	2.1	(kg/l)
Partition Coefficient	Koc	38	(L/kg)
FractionOrganicCarbon	foc	2.0E-4	(-)

4. BIODEGRADATION

1st Order Decay Coeff*	lambda	4.0E-1	(per yr)
or		↑ or	
Solute Half-Life	t-half	1.75	(year)
or Instantaneous Reaction Model			
Delta Oxygen*	DO	5.42	(mg/L)
Delta Nitrate*	NO3	0	(mg/L)
Observed Ferrous Iron*	Fe2+	0.4	(mg/L)
Delta Sulfate*	SO4	10	(mg/L)
Observed Methane*	CH4	0	(mg/L)

5. GENERAL

Modeled Area Length*	300	(ft)
Modeled Area Width*	300	(ft)
Simulation Time*	5	(yr)

6. SOURCE DATA

Source Thickness in Sat.Zone* 10 (ft)

Source Zones:

Zone	Width* (ft)	Conc. (mg/L)*
1	0.01	0.01
2	3	8
3	10	37
4	3	8
5	0.01	0.01

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths for Zones 1, 2, and 3

Source Halflife (see Help): 20 | 5 (yr)

Inst. React. | 1st Order

Soluble Mass 16 (Kg)

In Source NAPL, Soil

View of Plume Looking Down

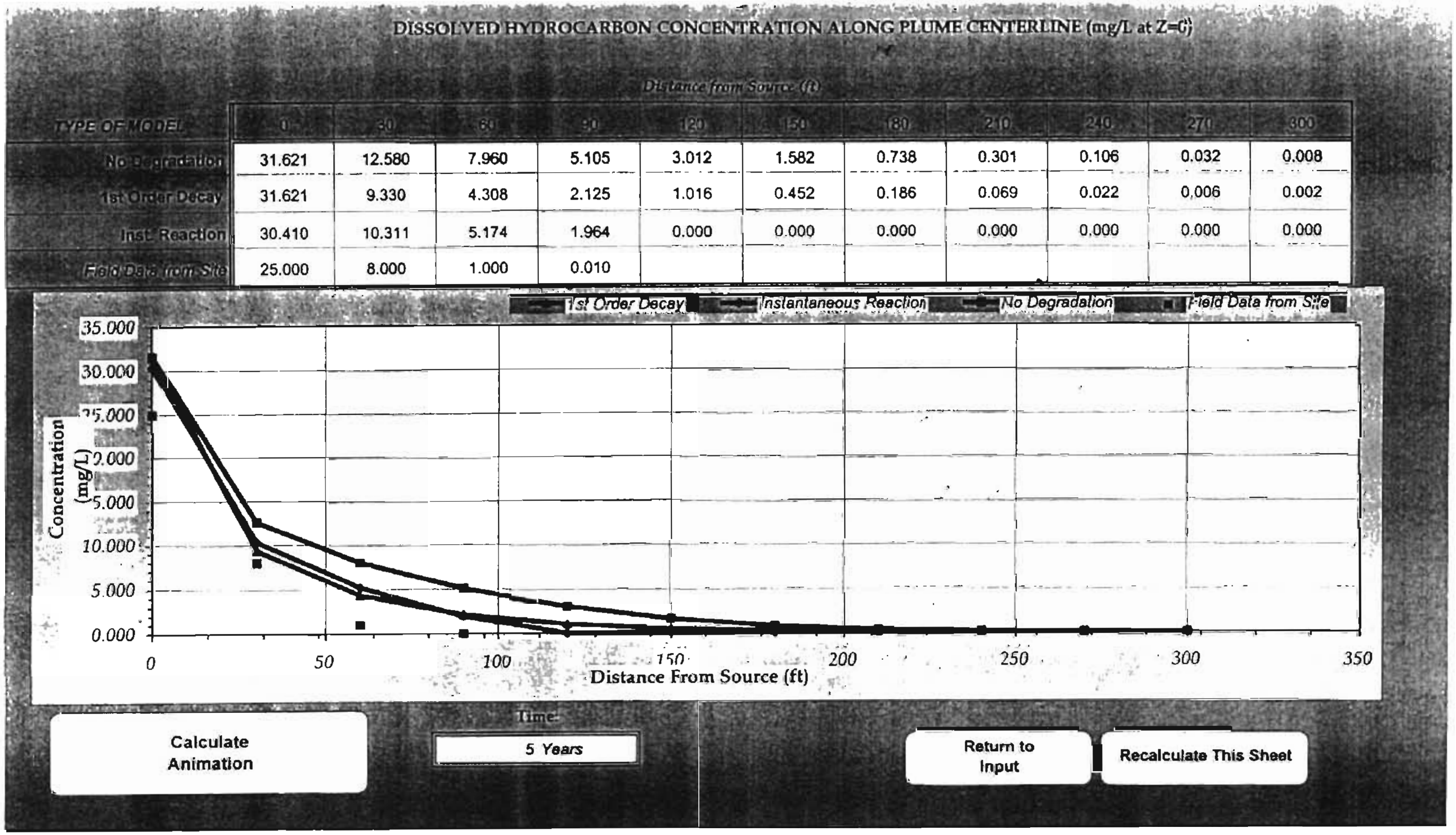
Observed Centerline Concentrations at Monitoring Wells

If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Concentration (mg/L)	25.0	8.0	1.0	01	0	.0					
Dist. from Source (ft)	0	30	60	90	120	150	180	210	240	270	300

8. CHOOSE TYPE OF OUTPUT TO SEE:

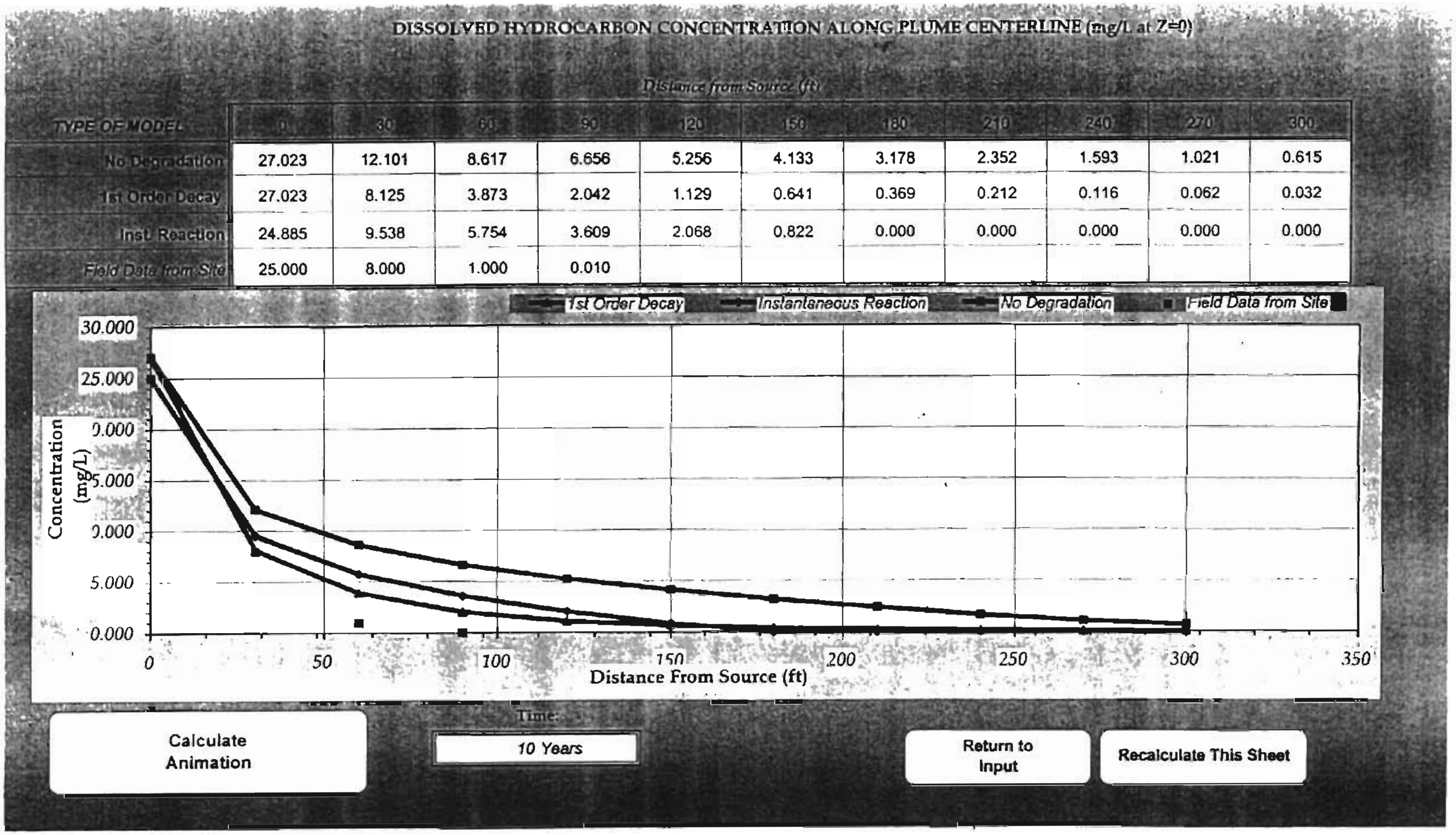


DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	31.621	12.580	7.960	5.105	3.012	1.582	0.738	0.301	0.106	0.032	0.008
1st Order Decay	31.621	9.330	4.308	2.125	1.016	0.452	0.186	0.069	0.022	0.006	0.002
Inst. Reaction	30.410	10.311	5.174	1.964	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	25.000	8.000	1.000	0.010							

Time: 5 Years

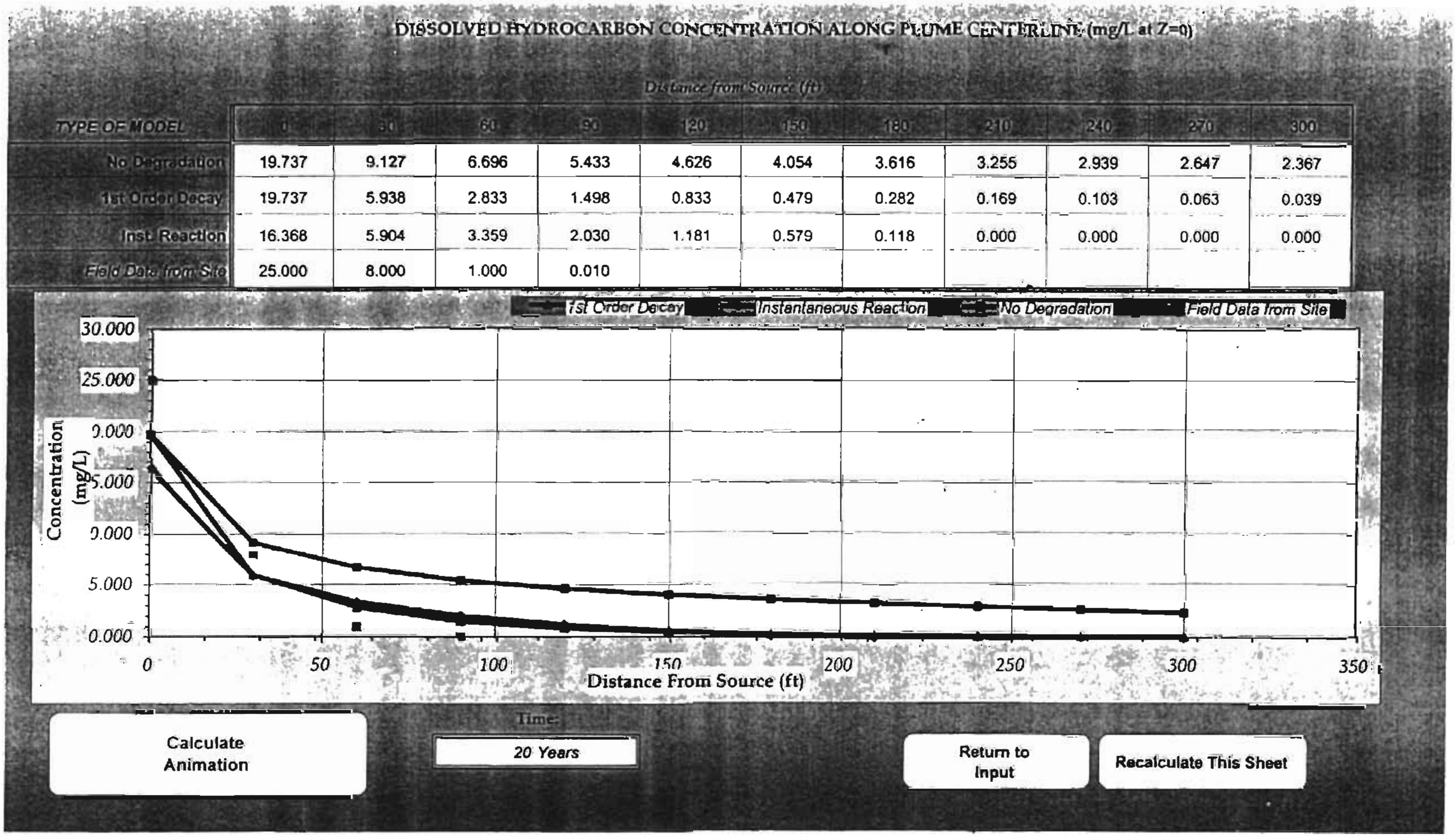


DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	27.023	12.101	8.617	6.656	5.256	4.133	3.178	2.352	1.593	1.021	0.615
1st Order Decay	27.023	8.125	3.873	2.042	1.129	0.641	0.369	0.212	0.116	0.062	0.032
Inst. Reaction	24.885	9.538	5.754	3.609	2.068	0.822	0.000	0.000	0.000	0.000	0.000
Field Data from Site	25.000	8.000	1.000	0.010							

Time: 10 Years

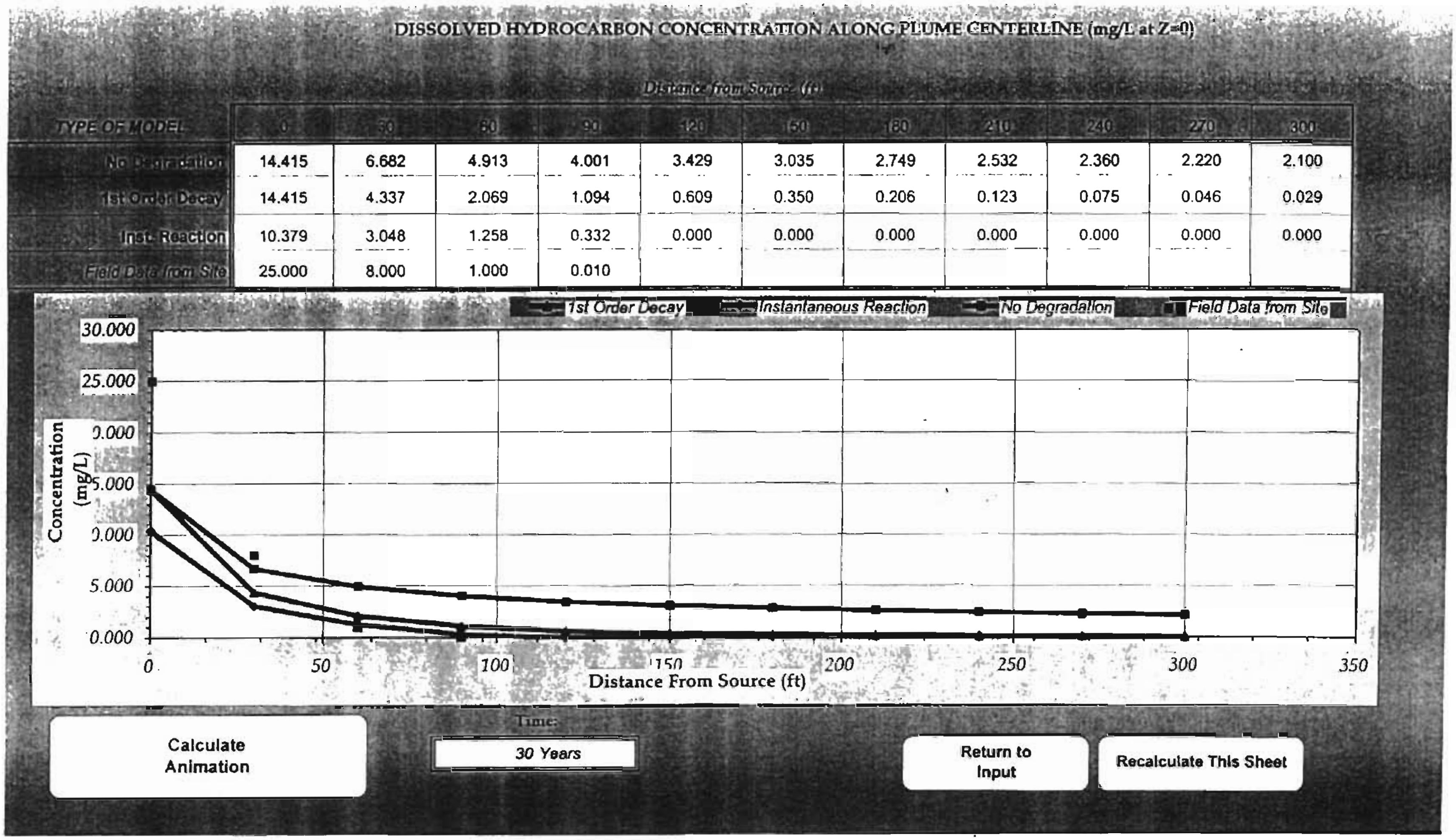


DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	19.737	9.127	6.696	5.433	4.626	4.054	3.616	3.255	2.939	2.647	2.367
1st Order Decay	19.737	5.938	2.833	1.498	0.833	0.479	0.282	0.169	0.103	0.063	0.039
Inst. Reaction	16.368	5.904	3.359	2.030	1.181	0.579	0.118	0.000	0.000	0.000	0.000
Field Data from Site	25.000	8.000	1.000	0.010							

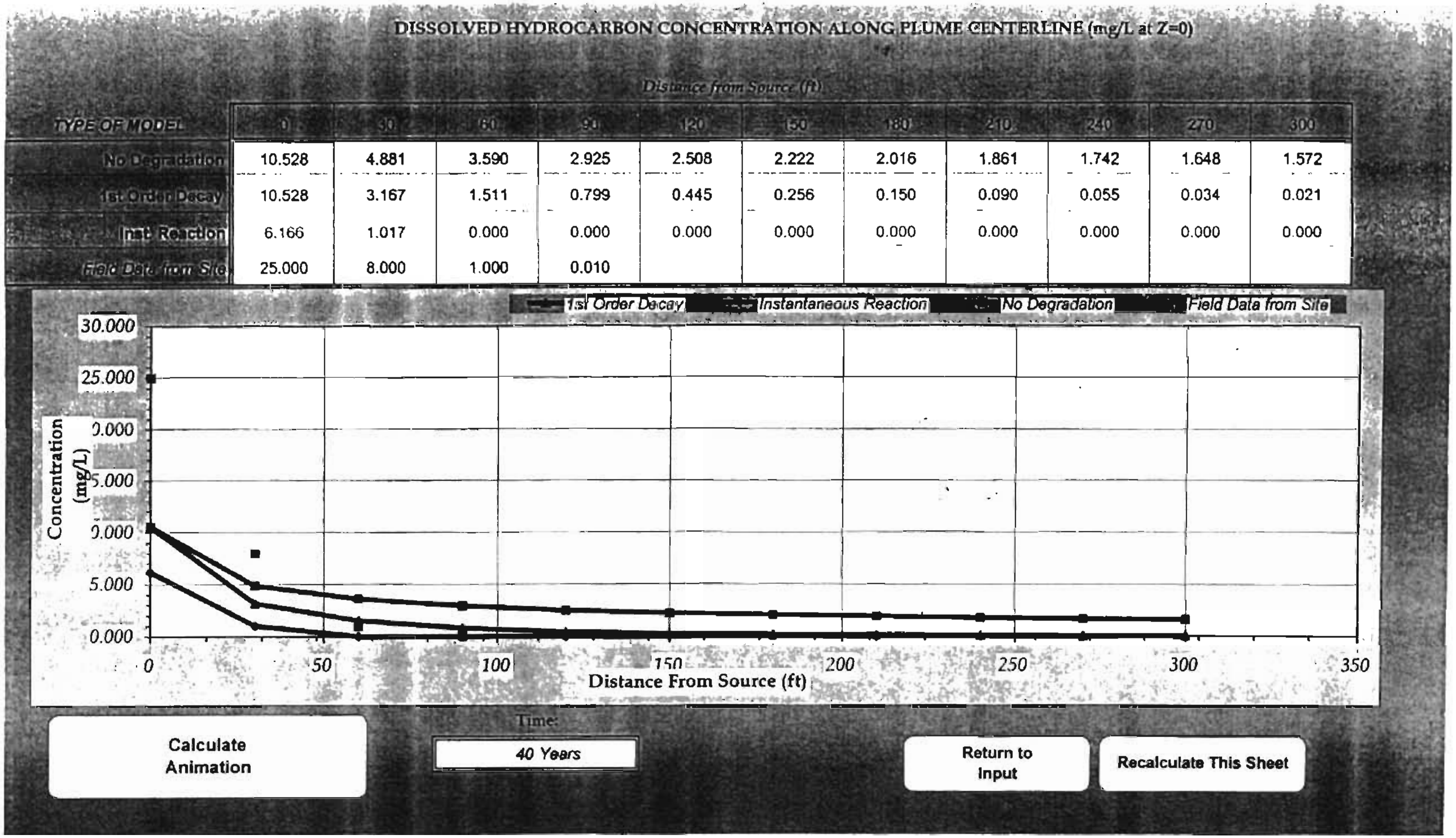
Time: 20 Years



DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

TYPE OF MODEL	Distance from Source (ft) 0	30	60	90	120	150	180	210	240	270	300
No Degradation	14.415	6.682	4.913	4.001	3.429	3.035	2.749	2.532	2.360	2.220	2.100
1st Order Decay	14.415	4.337	2.069	1.094	0.609	0.350	0.206	0.123	0.075	0.046	0.029
Inst. Reaction	10.379	3.048	1.258	0.332	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	25.000	8.000	1.000	0.010							

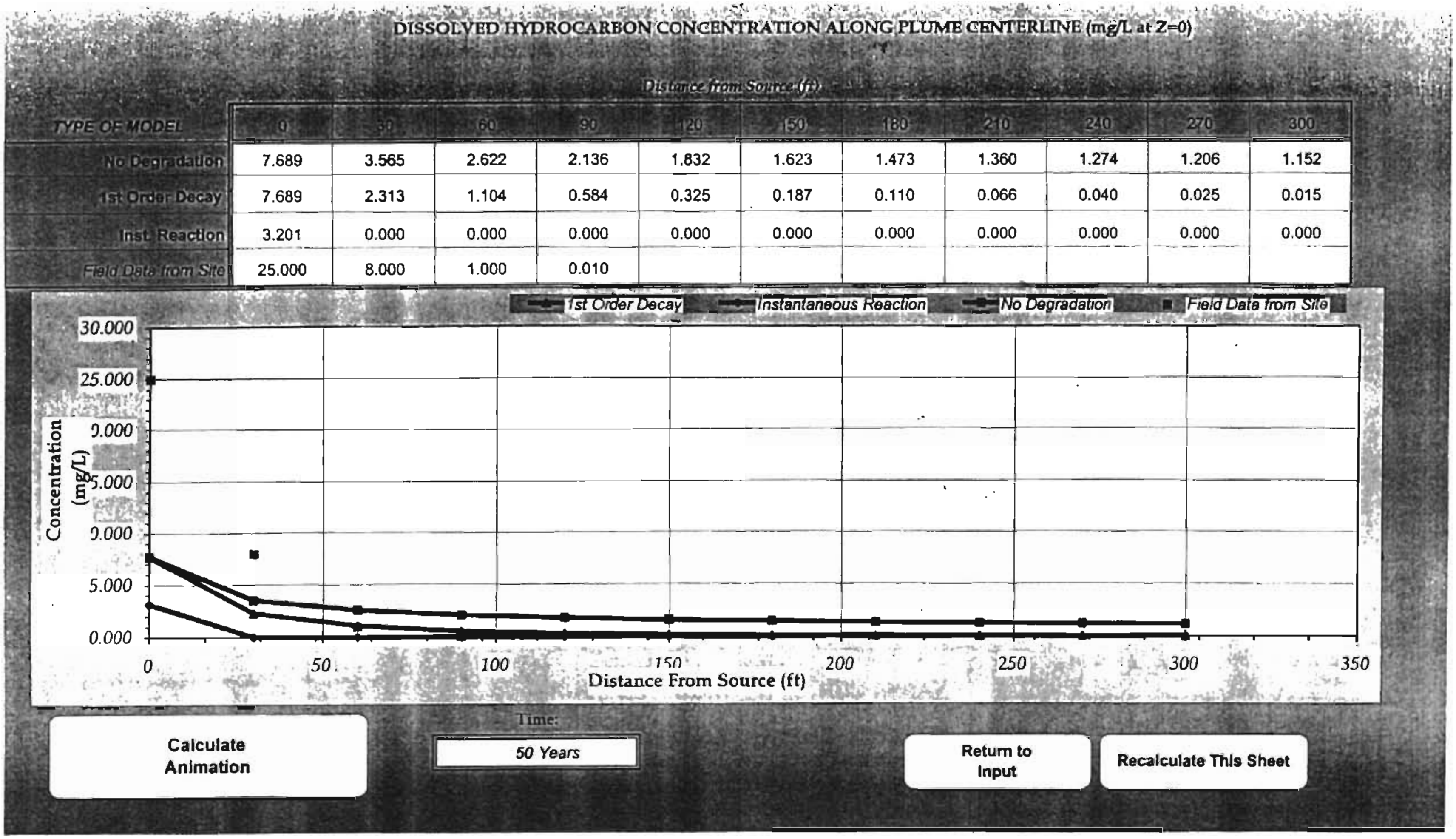
Time: 30 Years



DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

	Distance from Source (ft)										
TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	10.528	4.881	3.590	2.925	2.508	2.222	2.016	1.861	1.742	1.648	1.572
1st Order Decay	10.528	3.167	1.511	0.799	0.445	0.256	0.150	0.090	0.055	0.034	0.021
Inst. Reaction	6.166	1.017	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	25.000	8.000	1.000	0.010							

Time: 40 Years



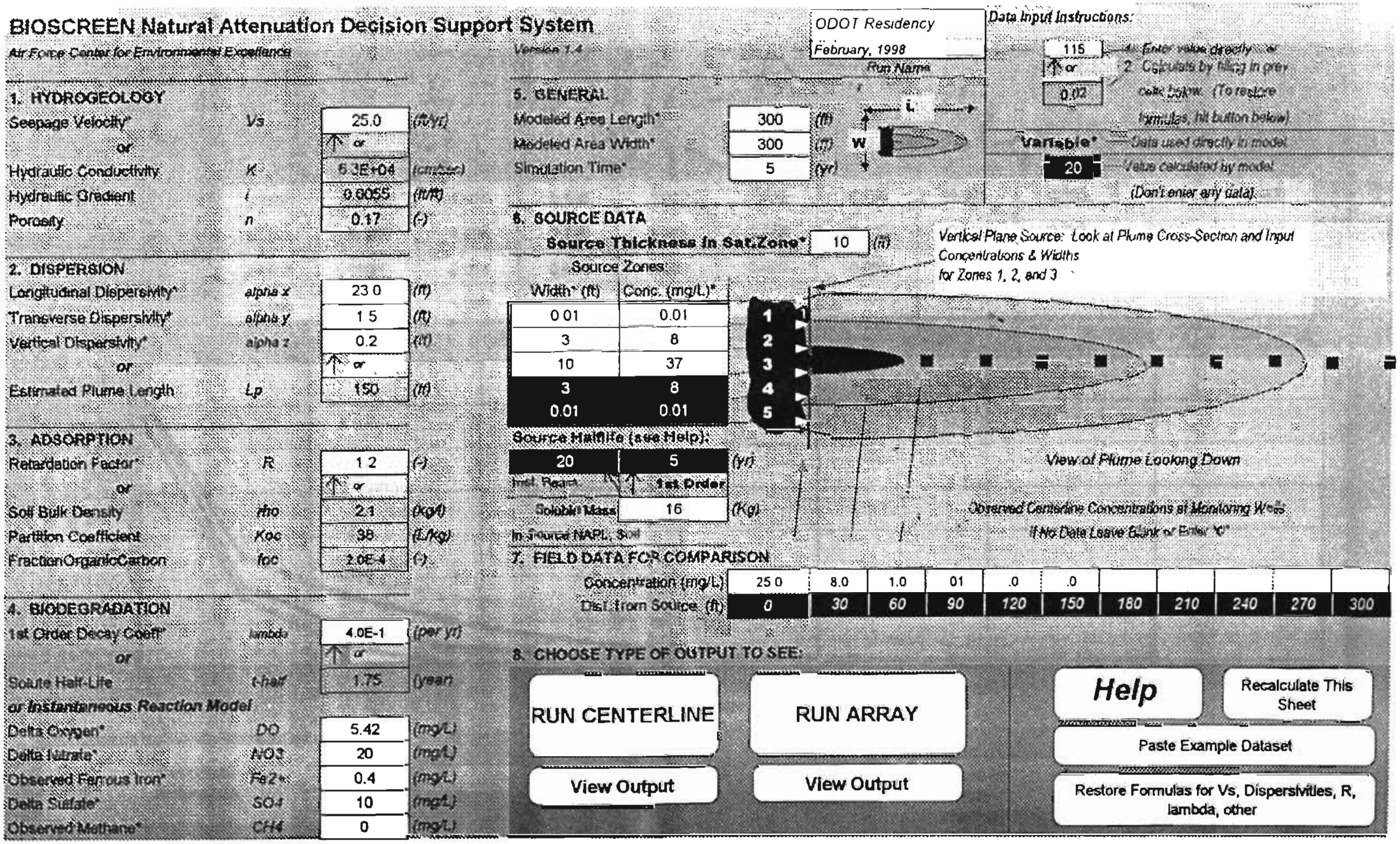
DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	7.689	3.565	2.622	2.136	1.832	1.623	1.473	1.360	1.274	1.206	1.152
1st Order Decay	7.689	2.313	1.104	0.584	0.325	0.187	0.110	0.066	0.040	0.025	0.015
Inst. Reaction	3.201	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	25.000	8.000	1.000	0.010							

Time:

50 Years



BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence

Version 1.4

ODOT Residency
February, 1998
Run Name

Data Input Instructions:
115 ← 1. Enter value directly... or
↑ or 2. Calculate by filling in grey
0.02 cells below. (To restore formulas, hit button below)
Variable* — Data used directly in model
20 — Value calculated by model (Don't enter any data).

1. HYDROGEOLOGY

Seepage Velocity* Vs 25.0 (ft/yr)
or
Hydraulic Conductivity K 6.3E+04 (cm/sec)
Hydraulic Gradient i 0.0055 (ft/ft)
Porosity n 0.17 (-)

2. DISPERSION

Longitudinal Dispersivity* alpha x 23 0 (ft)
Transverse Dispersivity* alpha y 1 5 (ft)
Vertical Dispersivity* alpha z 0.2 (ft)
or
Estimated Plume Length Lp 150 (ft)

3. ADSORPTION

Retardation Factor* R 1 2 (-)
or
Soil Bulk Density rho 2.1 (kg/l)
Partition Coefficient Koc 38 (L/kg)
FractionOrganicCarbon foc 2.0E-4 (-)

4. BIODEGRADATION

1st Order Decay Coeff* lambda 4.0E-1 (per yr)
or
Solute Half-Life t-half 1.75 (year)
or Instantaneous Reaction Model
Delta Oxygen* DO 5.42 (mg/L)
Delta Nitrate* NO3 20 (mg/L)
Observed Ferrous Iron* Fe2+ 0.4 (mg/L)
Delta Sulfate* SO4 10 (mg/L)
Observed Methane* CH4 0 (mg/L)

5. GENERAL

Modeled Area Length* 300 (ft)
Modeled Area Width* 300 (ft)
Simulation Time* 5 (yr)

6. SOURCE DATA

Source Thickness in Sat.Zone* 10 (ft)

Source Zones:

	Width* (ft)	Conc. (mg/L)*
1	0 01	0.01
2	3	8
3	10	37
4	3	8
5	0.01	0.01

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths for Zones 1, 2, and 3

Source Halflife (see Help):
20 5 (yr)
Inst. React. 1st Order
Soluble Mass 16 (Kg)
In Source NAPL, Soil

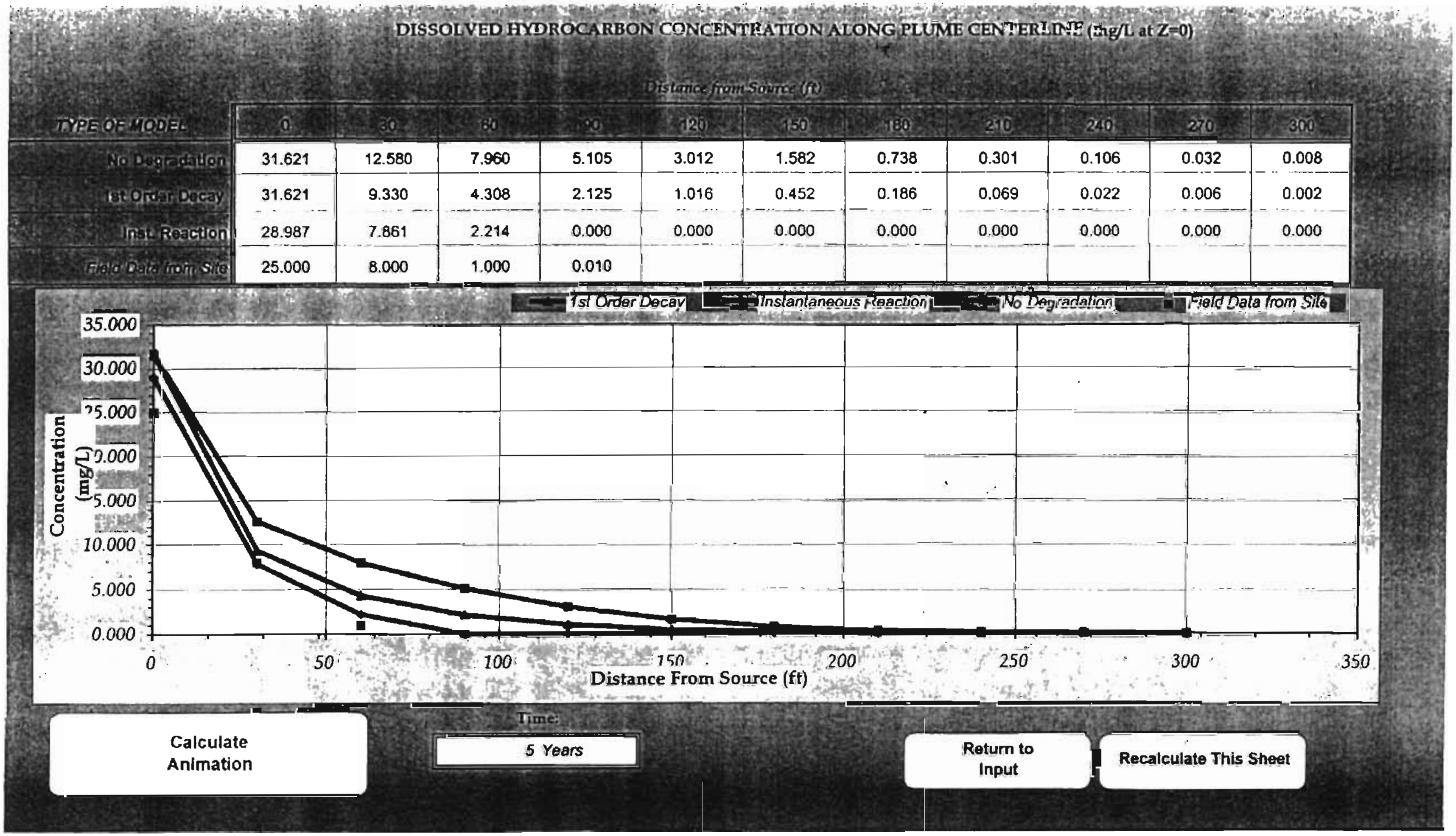
View of Plume Looking Down

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Concentration (mg/L)	25 0	8.0	1.0	01	.0	.0					
Dist. from Source (ft)	0	30	60	90	120	150	180	210	240	270	300

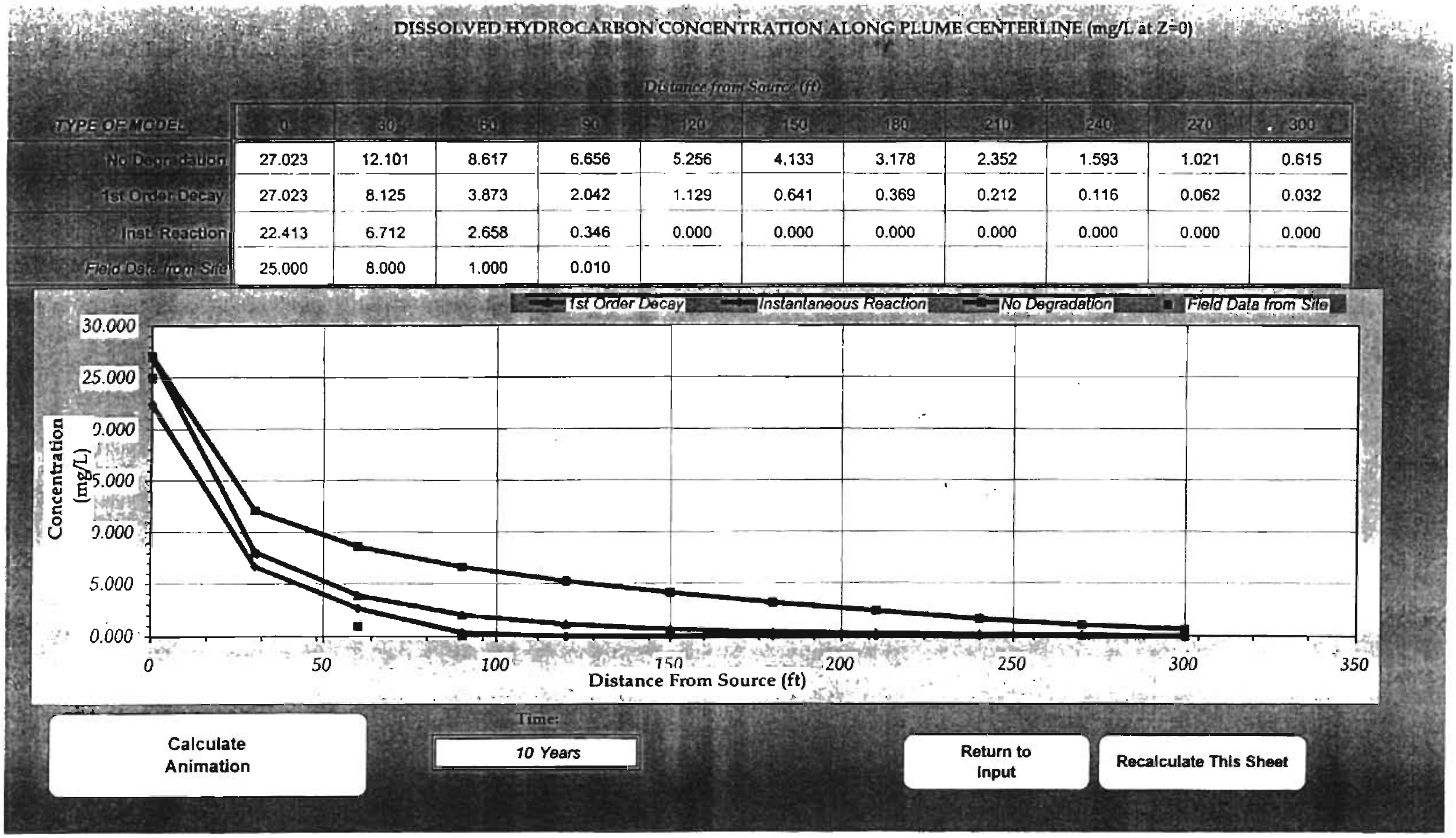
8. CHOOSE TYPE OF OUTPUT TO SEE:



DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

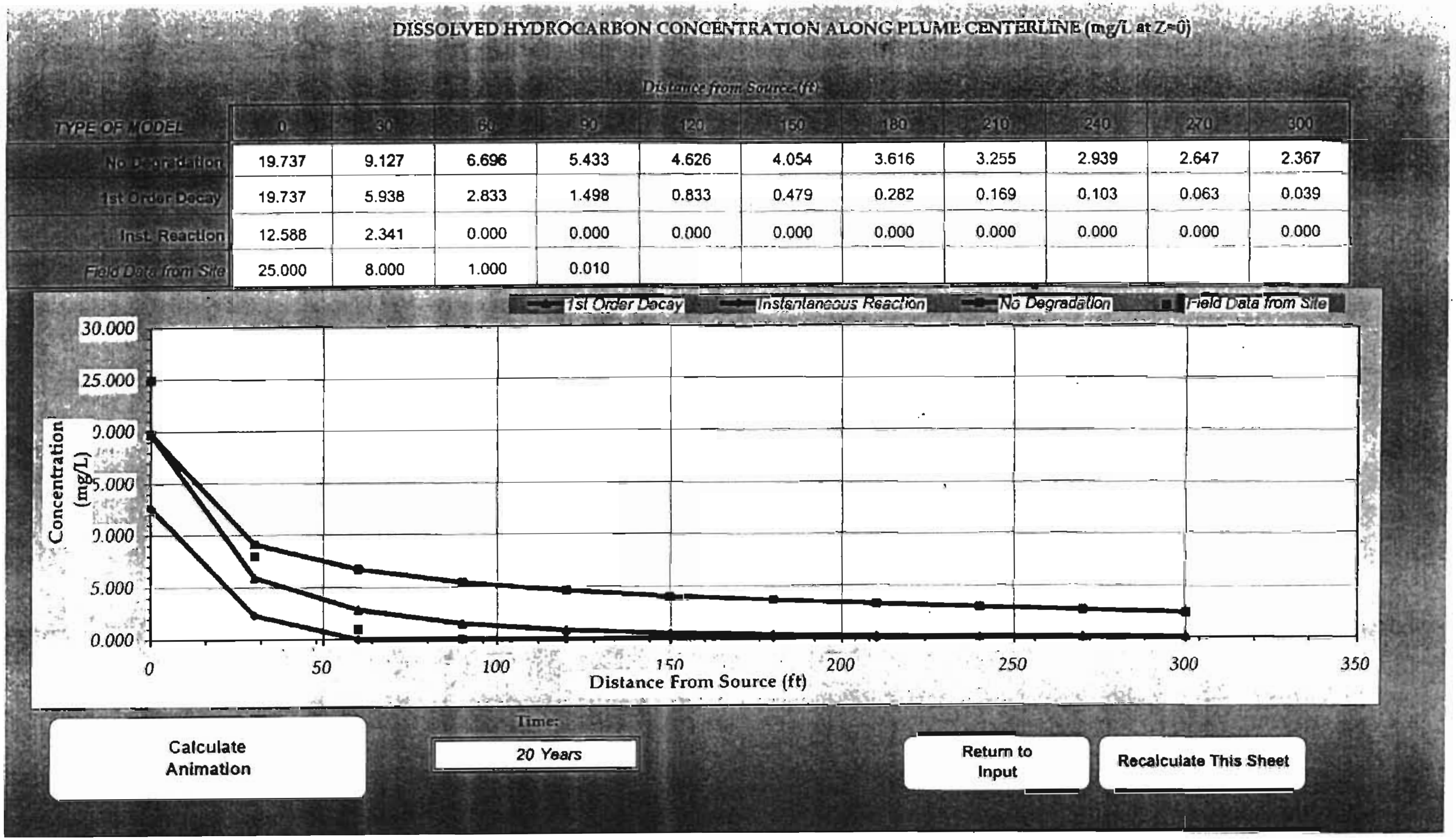
Distance from Source (ft)

TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	31.621	12.580	7.960	5.105	3.012	1.582	0.738	0.301	0.106	0.032	0.008
1st Order Decay	31.621	9.330	4.308	2.125	1.016	0.452	0.186	0.069	0.022	0.006	0.002
Inst. Reaction	28.987	7.861	2.214	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	25.000	8.000	1.000	0.010							



DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

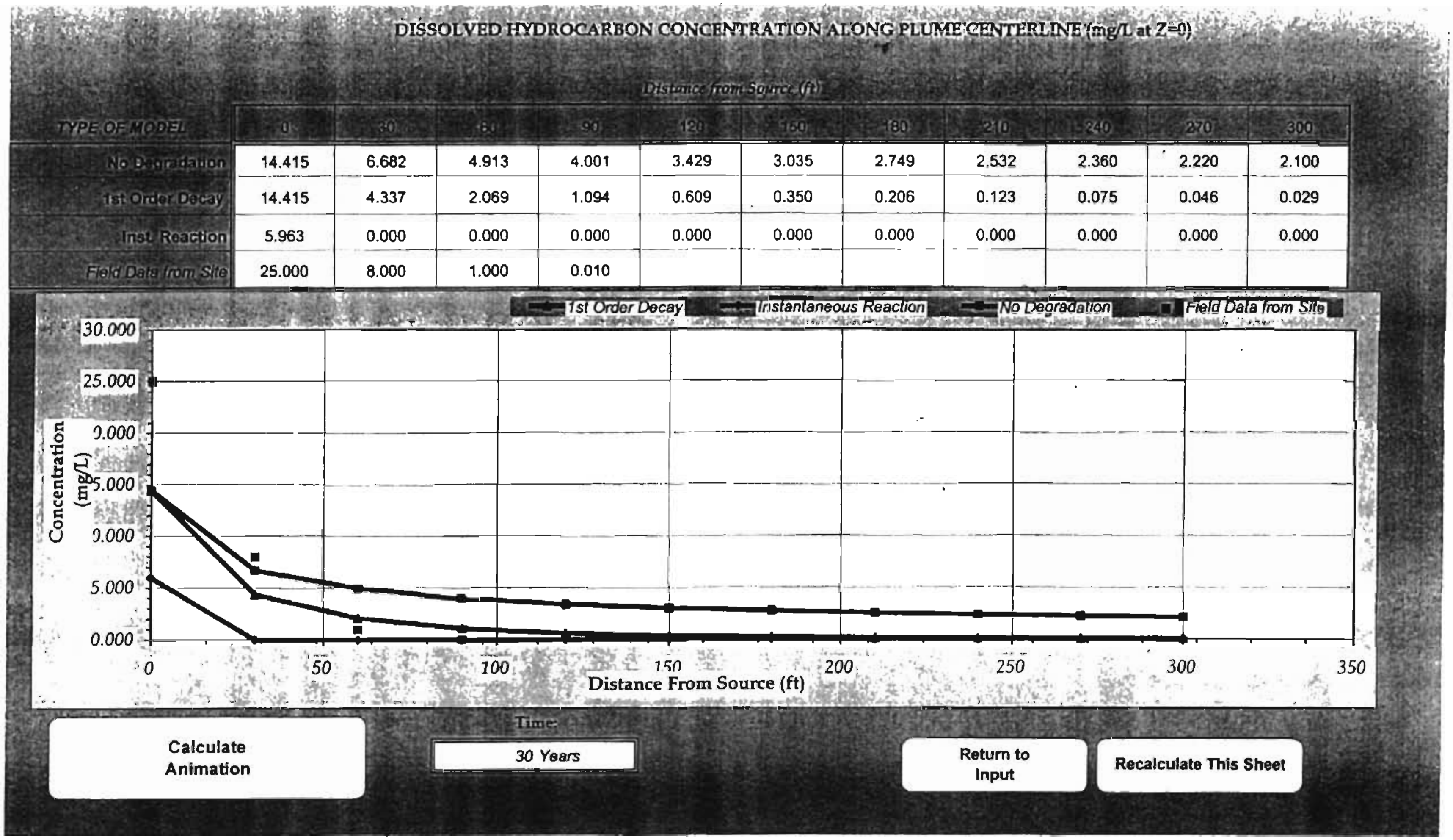
	Distance from Source (ft)										
TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	27.023	12.101	8.617	6.656	5.256	4.133	3.178	2.352	1.593	1.021	0.615
1st Order Decay	27.023	8.125	3.873	2.042	1.129	0.641	0.369	0.212	0.116	0.062	0.032
Inst. Reaction	22.413	6.712	2.658	0.346	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	25.000	8.000	1.000	0.010							



DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

TYPE OF MODEL	Distance from Source (ft)										
	0	30	60	90	120	150	180	210	240	270	300
No Degradation	19.737	9.127	6.696	5.433	4.626	4.054	3.616	3.255	2.939	2.647	2.367
1st Order Decay	19.737	5.938	2.833	1.498	0.833	0.479	0.282	0.169	0.103	0.063	0.039
Inst. Reaction	12.588	2.341	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	25.000	8.000	1.000	0.010							

Time: 20 Years

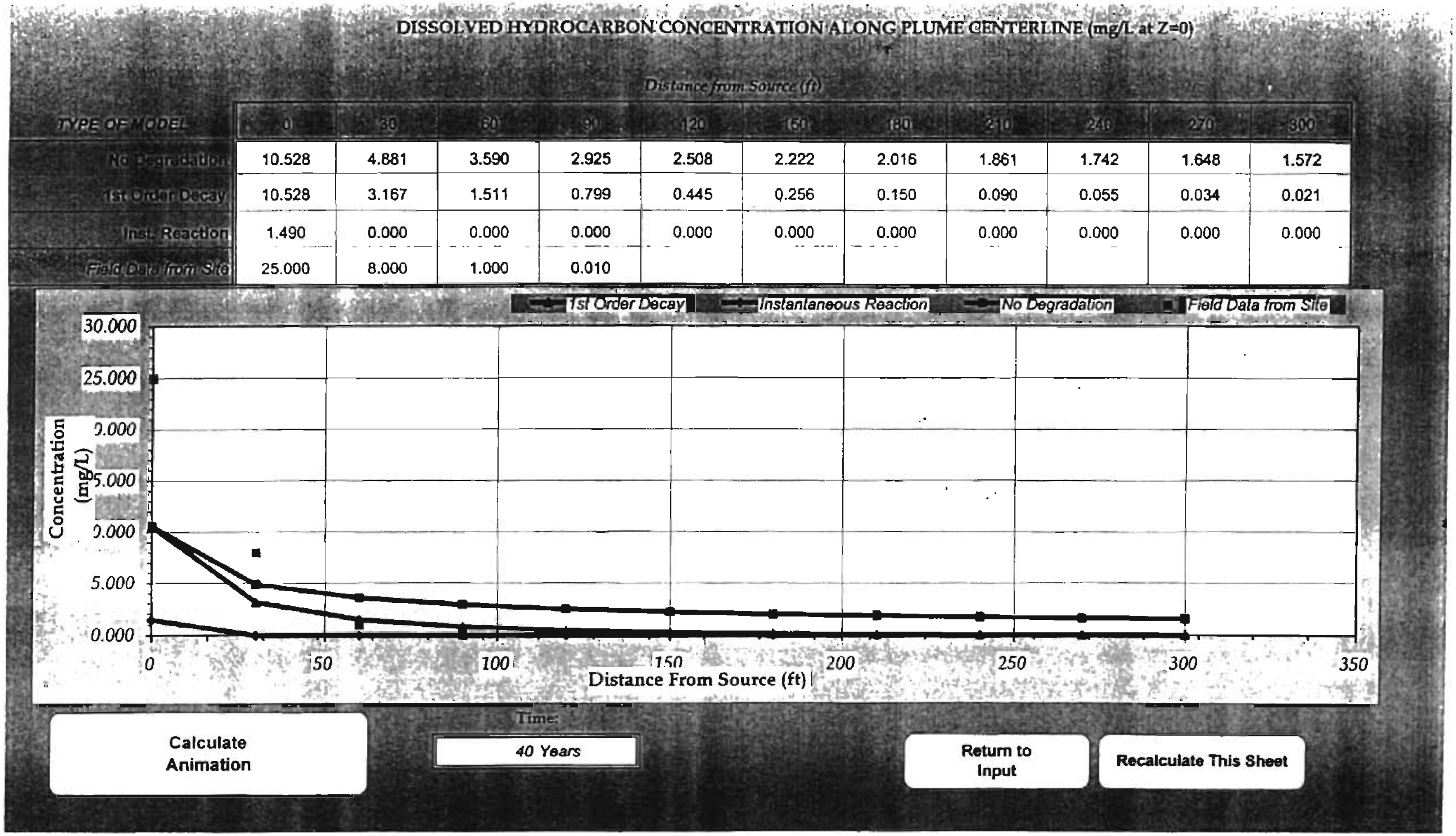


DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	14.415	6.682	4.913	4.001	3.429	3.035	2.749	2.532	2.360	2.220	2.100
1st Order Decay	14.415	4.337	2.069	1.094	0.609	0.350	0.206	0.123	0.075	0.046	0.029
Inst. Reaction	5.963	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	25.000	8.000	1.000	0.010							

Time: 30 Years



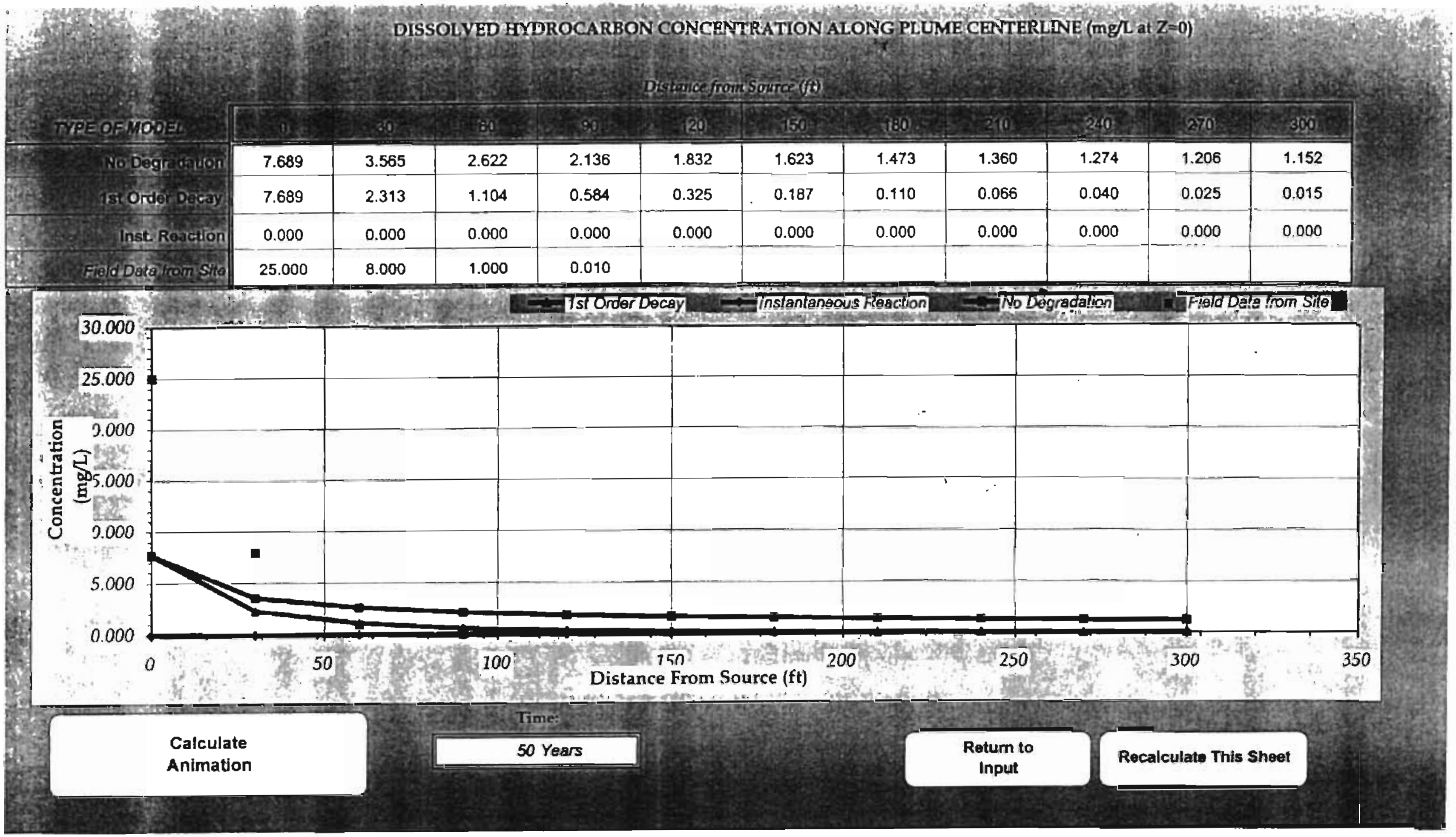
DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	10.528	4.881	3.590	2.925	2.508	2.222	2.016	1.861	1.742	1.648	1.572
1st Order Decay	10.528	3.167	1.511	0.799	0.445	0.256	0.150	0.090	0.055	0.034	0.021
Inst. Reaction	1.490	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	25.000	8.000	1.000	0.010							

Time:

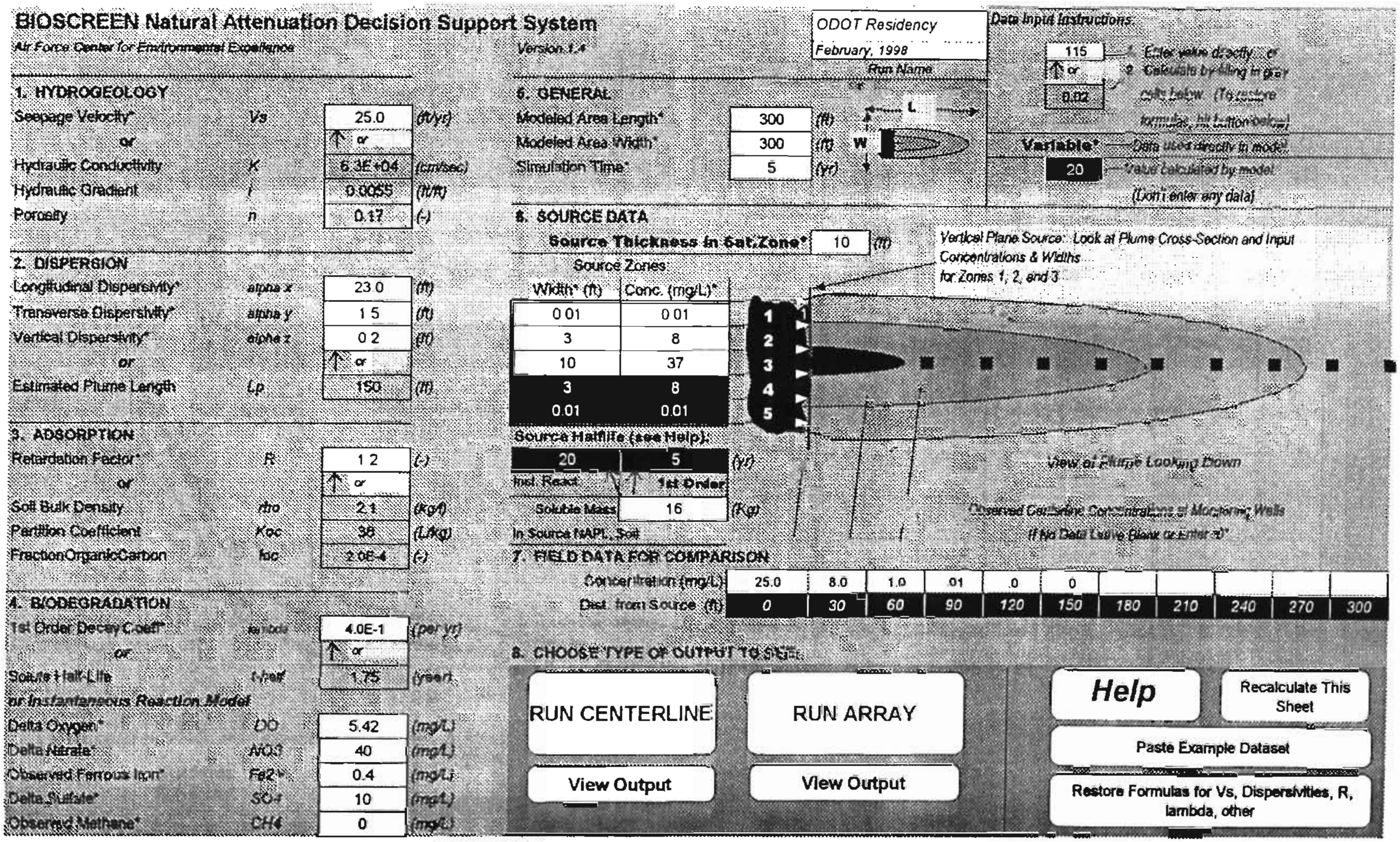
40 Years



DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	7.689	3.565	2.622	2.136	1.832	1.623	1.473	1.360	1.274	1.206	1.152
1st Order Decay	7.689	2.313	1.104	0.584	0.325	0.187	0.110	0.066	0.040	0.025	0.015
Inst. Reaction	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	25.000	8.000	1.000	0.010							



BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence

Version 1.4

Run Name: ODOT Residency, February, 1998

1. HYDROGEOLOGY

Seepage Velocity*	Vs	25.0	(ft/yr)
or			
Hydraulic Conductivity	K	6.3E+04	(cm/sec)
Hydraulic Gradient	i	0.0055	(ft/ft)
Porosity	n	0.17	(-)

2. DISPERSION

Longitudinal Dispersivity*	alpha x	23.0	(ft)
Transverse Dispersivity*	alpha y	1 5	(ft)
Vertical Dispersivity*	alpha z	0 2	(ft)
or			
Estimated Plume Length	Lp	150	(ft)

3. ADSORPTION

Retardation Factor*	R	1 2	(-)
or			
Soil Bulk Density	rho	2.1	(kg/l)
Partition Coefficient	Koc	38	(L/kg)
FractionOrganicCarbon	foc	2.0E-4	(-)

4. BIODEGRADATION

1st Order Decay Coeff*	lambda	4.0E-1	(per yr)
or			
Solute Half-Life	t-half	1.75	(year)
or Instantaneous Reaction Model			
Delta Oxygen*	DO	5.42	(mg/L)
Delta Nitrate*	NO3	40	(mg/L)
Observed Ferrous Iron*	Fe2+	0.4	(mg/L)
Delta Sulfate*	SO4	10	(mg/L)
Observed Methane*	CH4	0	(mg/L)

5. GENERAL

Modeled Area Length*	300	(ft)
Modeled Area Width*	300	(ft)
Simulation Time*	5	(yr)

6. SOURCE DATA

Source Thickness in Sat.Zone* 10 (ft)

Source Zones:

	Width* (ft)	Conc. (mg/L)*
1	0 01	0 01
2	3	8
3	10	37
4	3	8
5	0.01	0.01

Source Halflife (see Help): 20 (Inst. React.), 5 (1st Order) (yr)

Soluble Mass In Source NAPL, Soil: 16 (Kg)

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths for Zones 1, 2, and 3

View of Plume Looking Down

Observed Centerline Concentrations at Monitoring Wells

If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Concentration (mg/L)	25.0	8.0	1.0	.01	.0	0					
Dist. from Source (ft)	0	30	60	90	120	150	180	210	240	270	300

8. CHOOSE TYPE OF OUTPUT TO SEE:

Data Input Instructions:

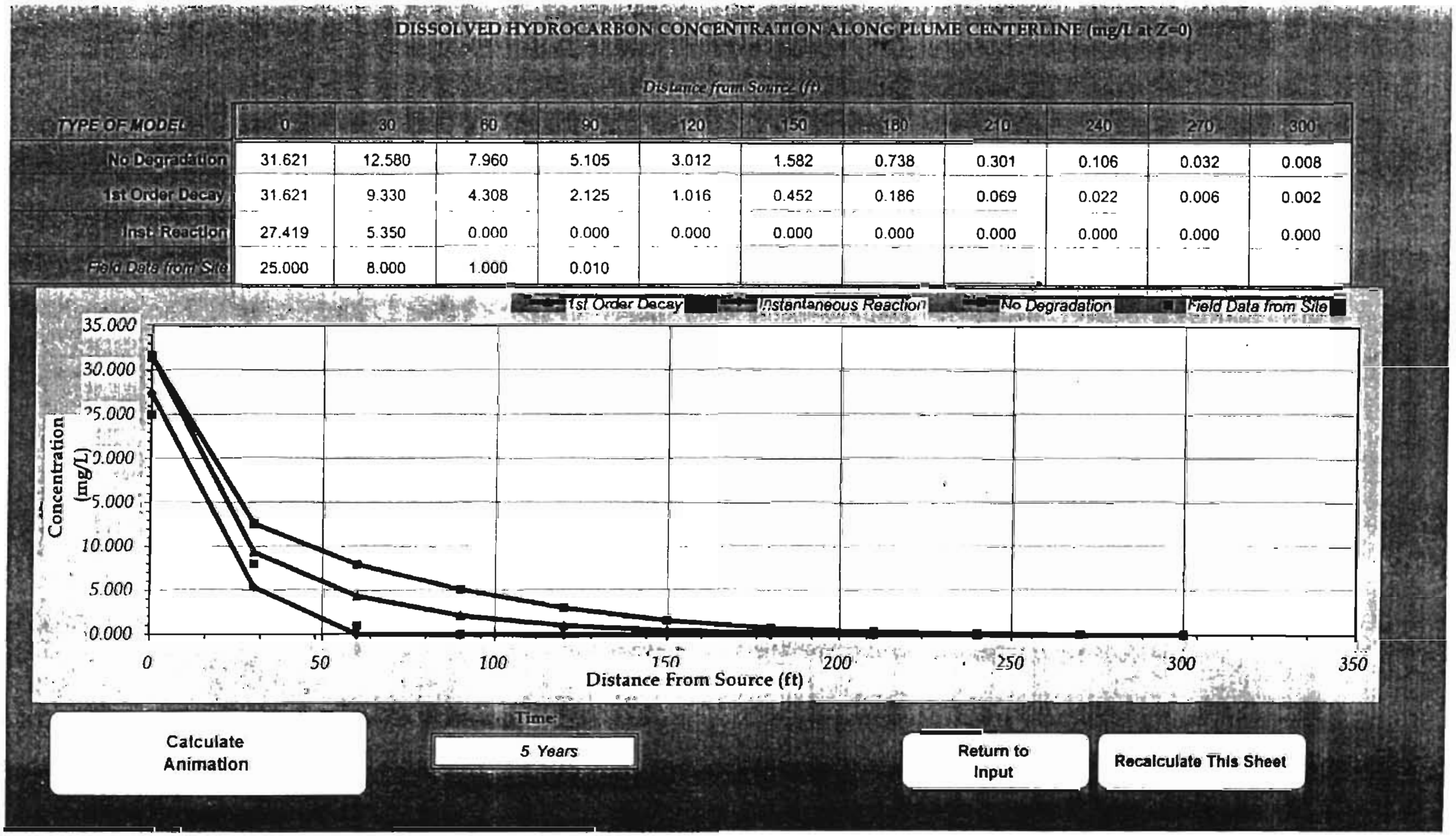
115 — 1. Enter value directly... or

↑ or

0.02 — 2. Calculate by filling in gray cells below. (To restore formulas, hit button below).

Variable* — Data used directly in model.

20 — Value calculated by model (Don't enter any data).

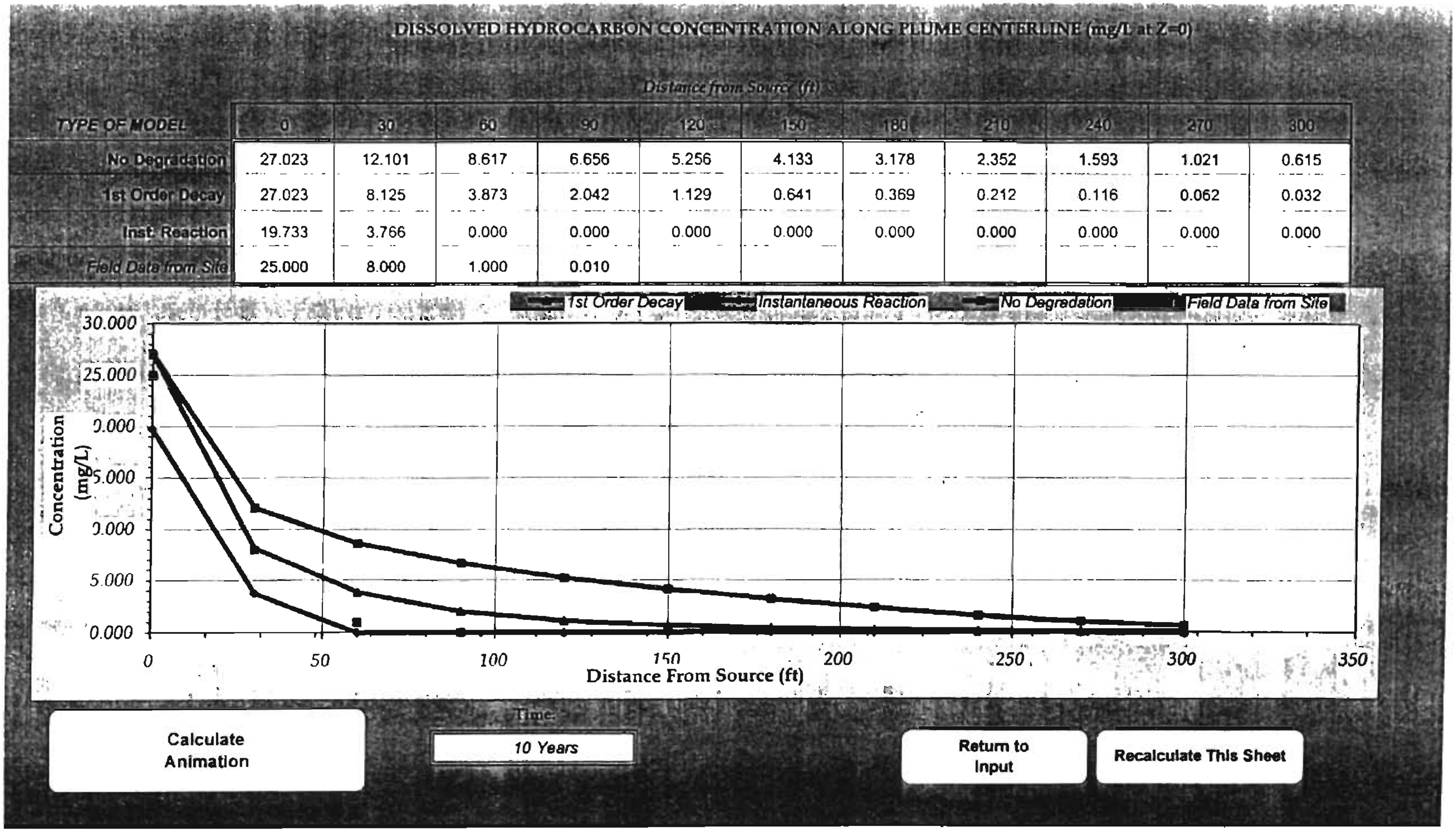


DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	31.621	12.580	7.960	5.105	3.012	1.582	0.738	0.301	0.106	0.032	0.008
1st Order Decay	31.621	9.330	4.308	2.125	1.016	0.452	0.186	0.069	0.022	0.006	0.002
Inst. Reaction	27.419	5.350	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	25.000	8.000	1.000	0.010							

Time: 5 Years

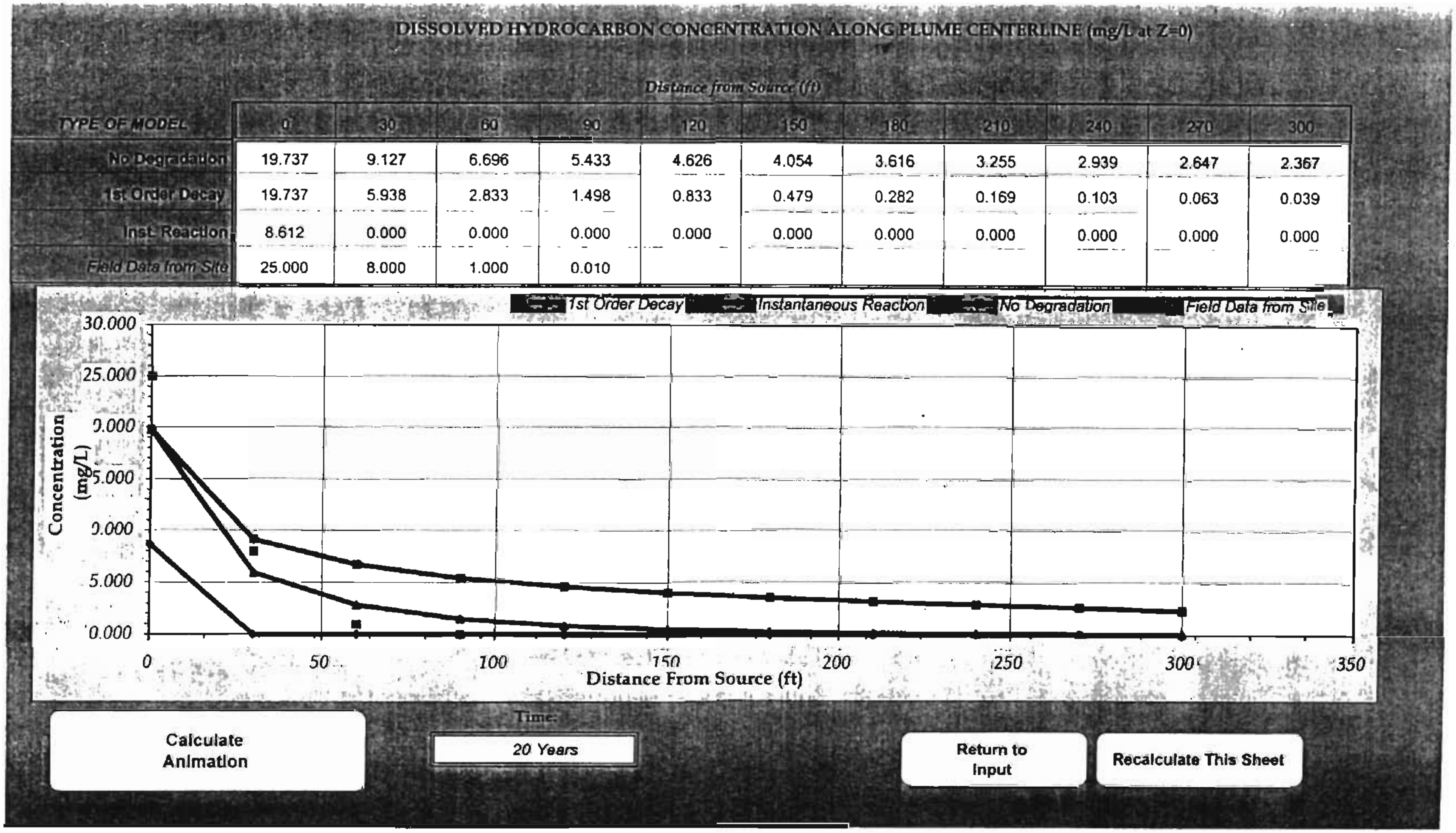


DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	27.023	12.101	8.617	6.656	5.256	4.133	3.178	2.352	1.593	1.021	0.615
1st Order Decay	27.023	8.125	3.873	2.042	1.129	0.641	0.369	0.212	0.116	0.062	0.032
Inst. Reaction	19.733	3.766	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	25.000	8.000	1.000	0.010							

Time: 10 Years



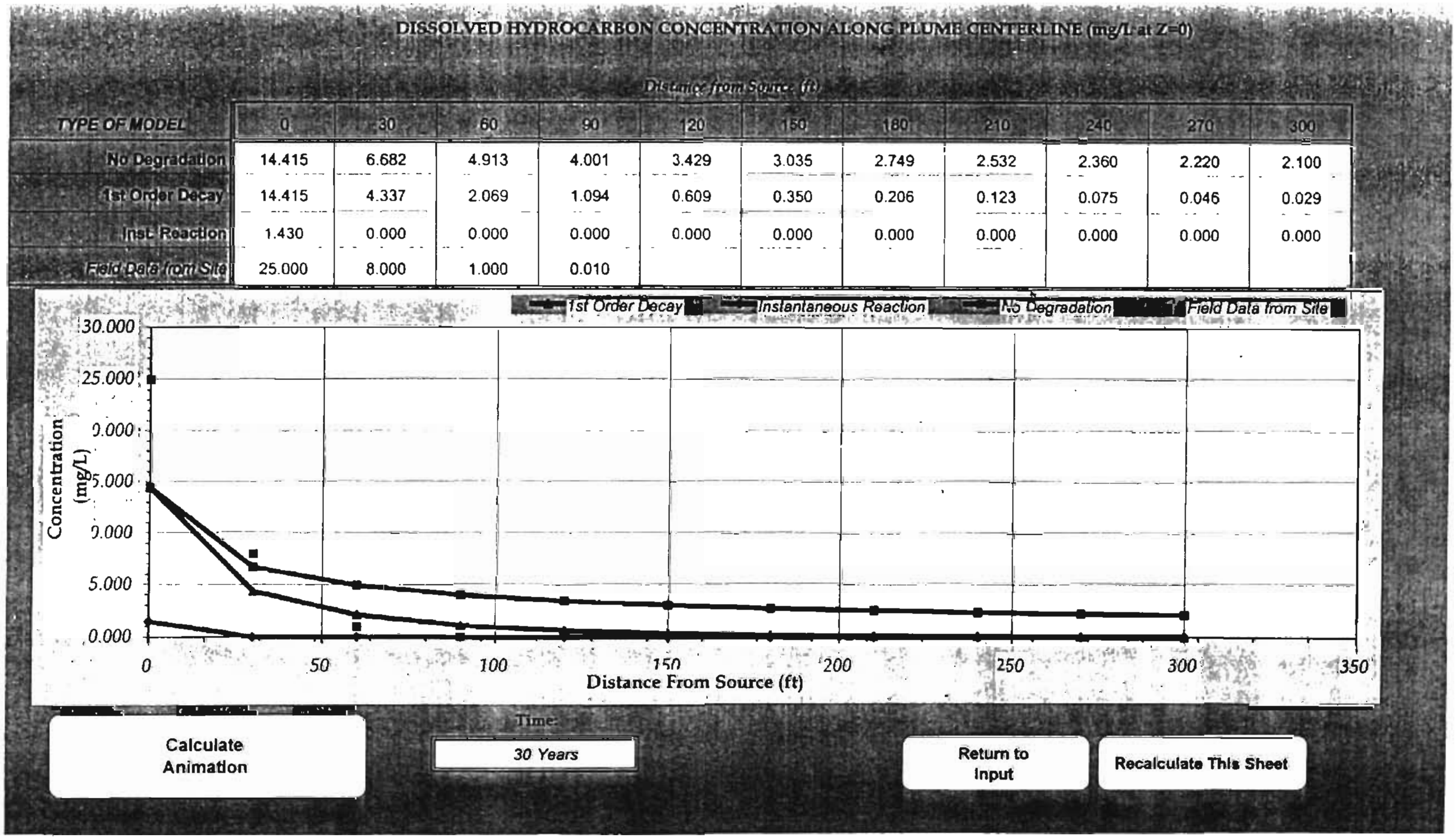
DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	19.737	9.127	6.696	5.433	4.626	4.054	3.616	3.255	2.939	2.647	2.367
1st Order Decay	19.737	5.938	2.833	1.498	0.833	0.479	0.282	0.169	0.103	0.063	0.039
Inst. Reaction	8.612	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	25.000	8.000	1.000	0.010							

Time:

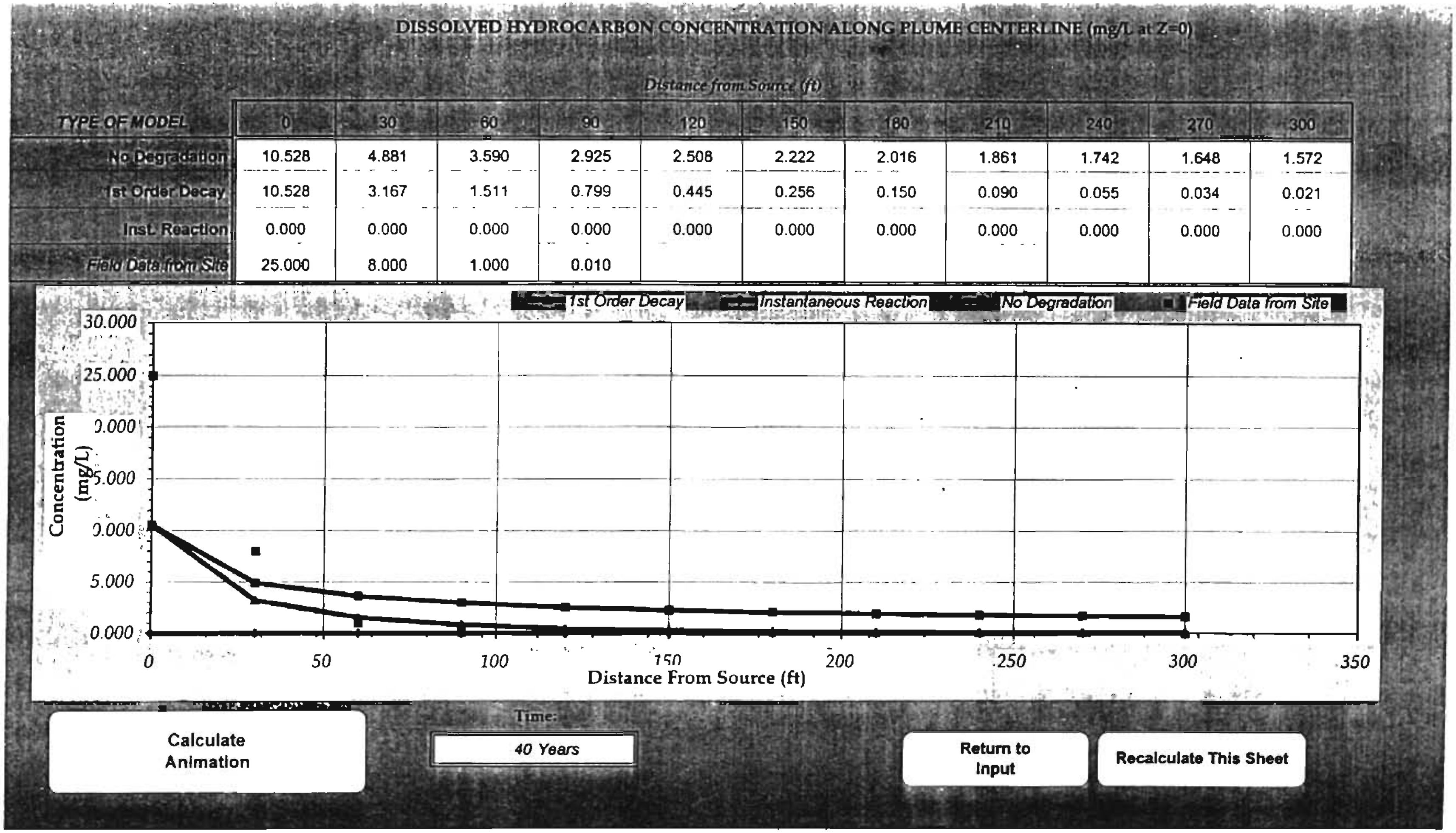
20 Years



DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

TYPE OF MODEL	Distance from Source (ft) 0	30	60	90	120	150	180	210	240	270	300
No Degradation	14.415	6.682	4.913	4.001	3.429	3.035	2.749	2.532	2.360	2.220	2.100
1st Order Decay	14.415	4.337	2.069	1.094	0.609	0.350	0.206	0.123	0.075	0.046	0.029
Inst. Reaction	1.430	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	25.000	8.000	1.000	0.010							

Time: 30 Years

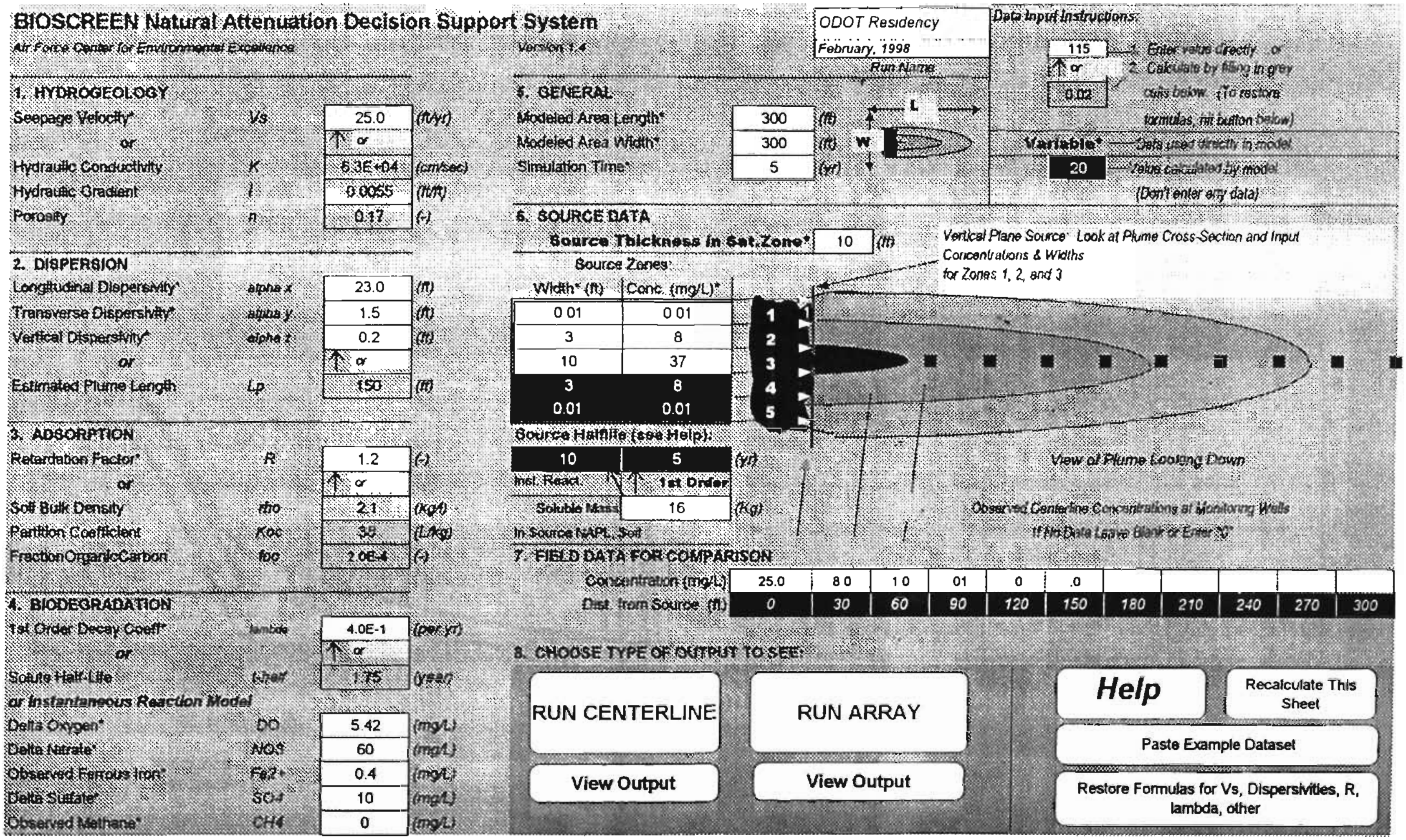


DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	10.528	4.881	3.590	2.925	2.508	2.222	2.016	1.861	1.742	1.648	1.572
1st Order Decay	10.528	3.167	1.511	0.799	0.445	0.256	0.150	0.090	0.055	0.034	0.021
Inst. Reaction	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	25.000	8.000	1.000	0.010							

Time: 40 Years



BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence

Version 1.4

ODOT Residency

February, 1998

Run Name

Data Input Instructions:

115 — 1. Enter value directly ... or

↑ or — 2. Calculate by filling in grey

0.02 — cells below. (To restore formulas, hit button below)

Variable* — Data used directly in model

20 — Value calculated by model (Don't enter any data)

1. HYDROGEOLOGY

Seepage Velocity*	Vs	25.0	(ft/yr)
or		↑ or	
Hydraulic Conductivity	K	6.3E+04	(cm/sec)
Hydraulic Gradient	i	0.0055	(ft/ft)
Porosity	n	0.17	(-)

2. DISPERSION

Longitudinal Dispersivity*	alpha x	23.0	(ft)
Transverse Dispersivity*	alpha y	1.5	(ft)
Vertical Dispersivity*	alpha z	0.2	(ft)
or		↑ or	
Estimated Plume Length	Lp	150	(ft)

3. ADSORPTION

Retardation Factor*	R	1.2	(-)
or		↑ or	
Soil Bulk Density	rho	2.1	(kg/l)
Partition Coefficient	Koc	38	(L/kg)
FractionOrganicCarbon	foc	2.0E-4	(-)

4. BIODEGRADATION

1st Order Decay Coeff*	lambda	4.0E-1	(per yr)
or		↑ or	
Solute Half-Life	t-half	1.75	(year)
or Instantaneous Reaction Model			
Delta Oxygen*	DO	5.42	(mg/L)
Delta Nitrate*	NO3	60	(mg/L)
Observed Ferrous Iron*	Fe2+	0.4	(mg/L)
Delta Sulfate*	SO4	10	(mg/L)
Observed Methane*	CH4	0	(mg/L)

5. GENERAL

Modeled Area Length*	300	(ft)
Modeled Area Width*	300	(ft)
Simulation Time*	5	(yr)

6. SOURCE DATA

Source Thickness in Sat.Zone* 10 (ft)

Source Zones:

Width* (ft)	Conc. (mg/L)*
0.01	0.01
3	8
10	37
3	8
0.01	0.01

Source Halflife (see Help):

10	5	(yr)
Inst. React.	1st Order	

Soluble Mass 16 (Kg)

In Source NAPL, Soil

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths for Zones 1, 2, and 3

View of Plume Looking Down

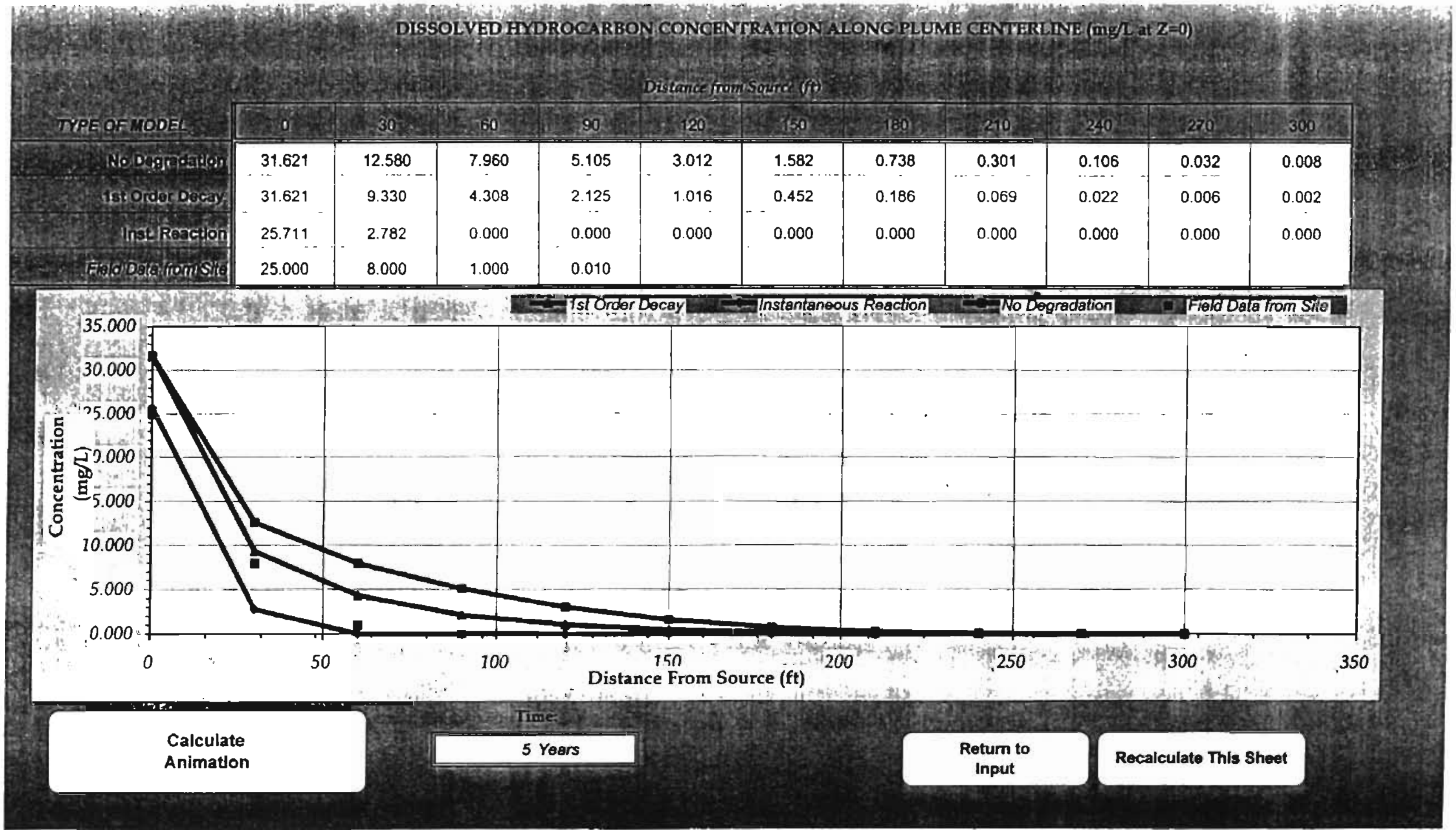
Observed Centerline Concentrations at Monitoring Wells

If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Concentration (mg/L)	25.0	8.0	1.0	.01	0	.0					
Dist. from Source (ft)	0	30	60	90	120	150	180	210	240	270	300

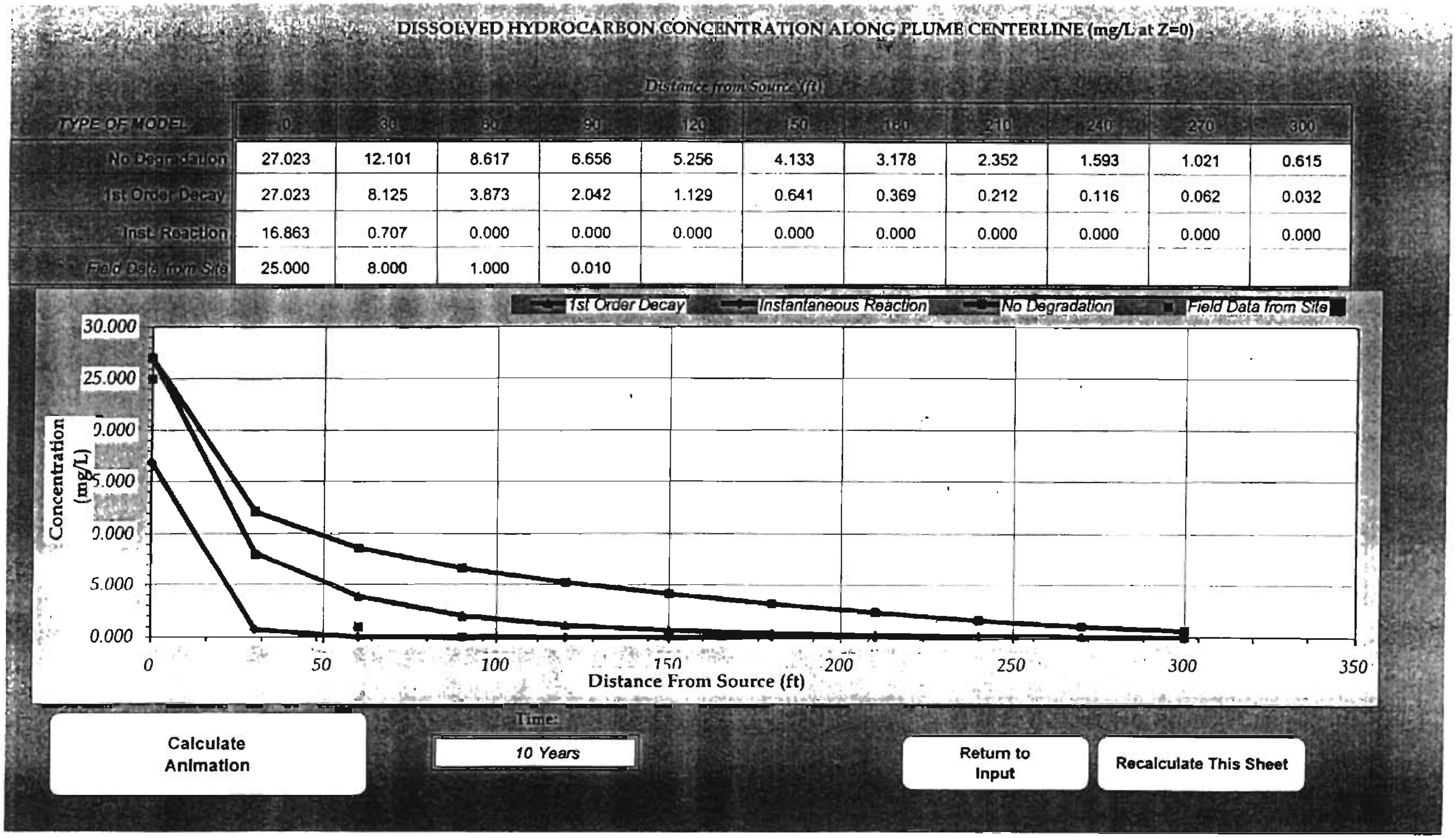
8. CHOOSE TYPE OF OUTPUT TO SEE:



DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

	Distance from Source (ft)										
TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	31.621	12.580	7.960	5.105	3.012	1.582	0.738	0.301	0.106	0.032	0.008
1st Order Decay	31.621	9.330	4.308	2.125	1.016	0.452	0.186	0.069	0.022	0.006	0.002
Inst. Reaction	25.711	2.782	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	25.000	8.000	1.000	0.010							

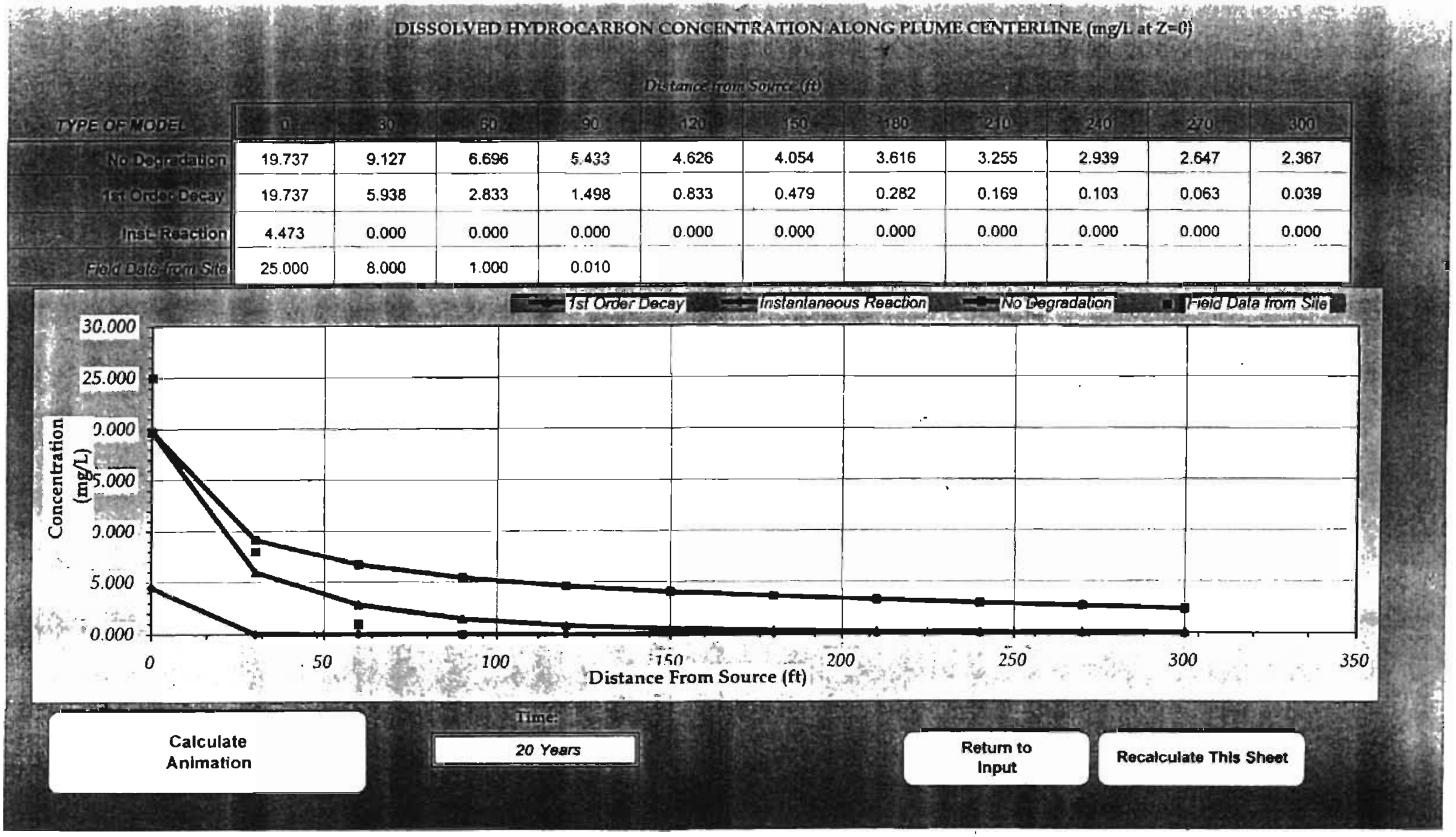
Time: 5 Years



DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

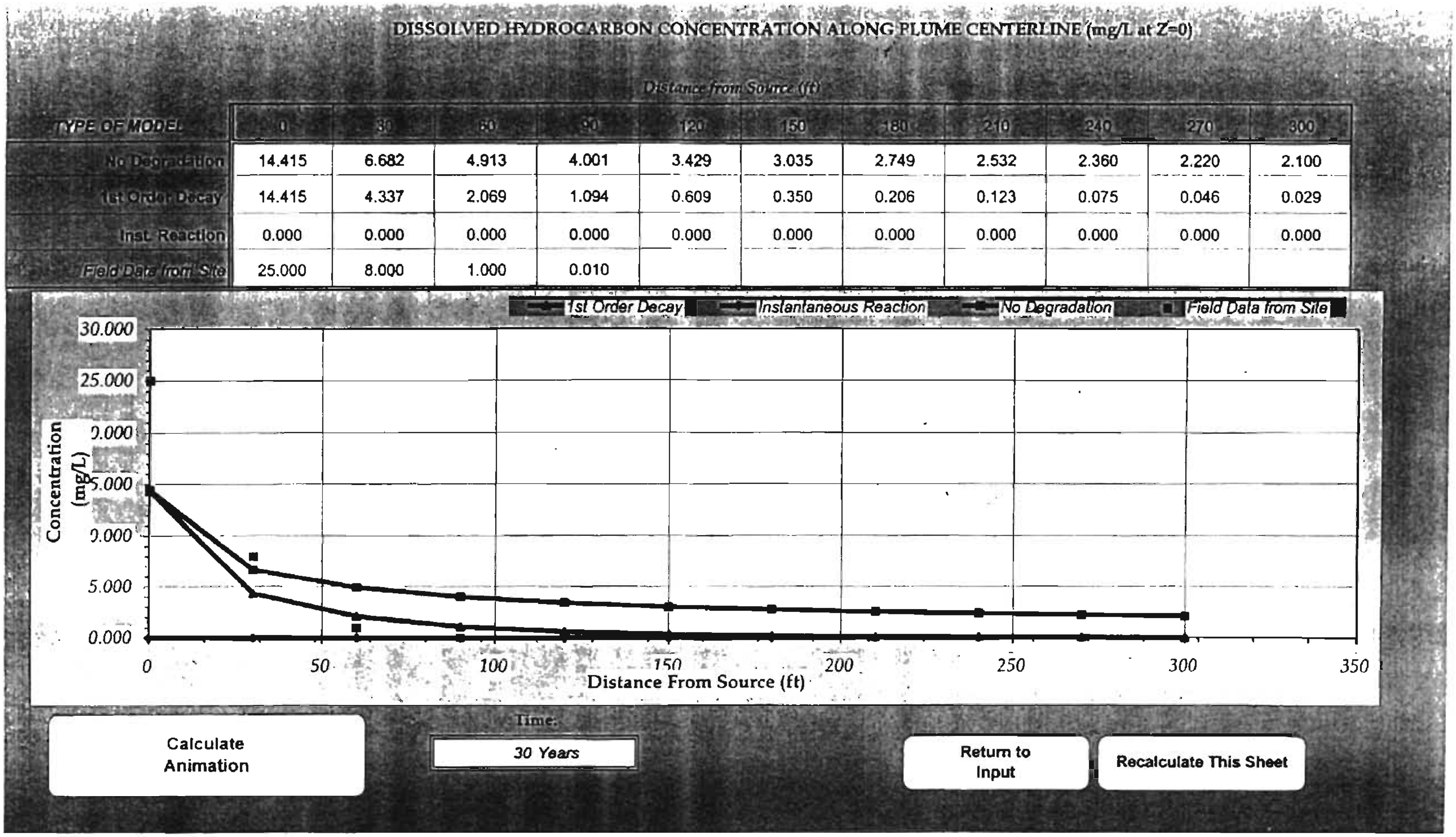
TYPE OF MODEL	Distance from Source (ft) 0	30	60	90	120	150	180	210	240	270	300
No Degradation	27.023	12.101	8.617	6.656	5.256	4.133	3.178	2.352	1.593	1.021	0.615
1st Order Decay	27.023	8.125	3.873	2.042	1.129	0.641	0.369	0.212	0.116	0.062	0.032
Inst. Reaction	16.863	0.707	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	25.000	8.000	1.000	0.010							

Time: 10 Years



DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

TYPE OF MODEL	Distance from Source (ft)										
	0	30	60	90	120	150	180	210	240	270	300
No Degradation	19.737	9.127	6.696	5.433	4.626	4.054	3.616	3.255	2.939	2.647	2.367
1st Order Decay	19.737	5.938	2.833	1.498	0.833	0.479	0.282	0.169	0.103	0.063	0.039
Inst. Reaction	4.473	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	25.000	8.000	1.000	0.010							



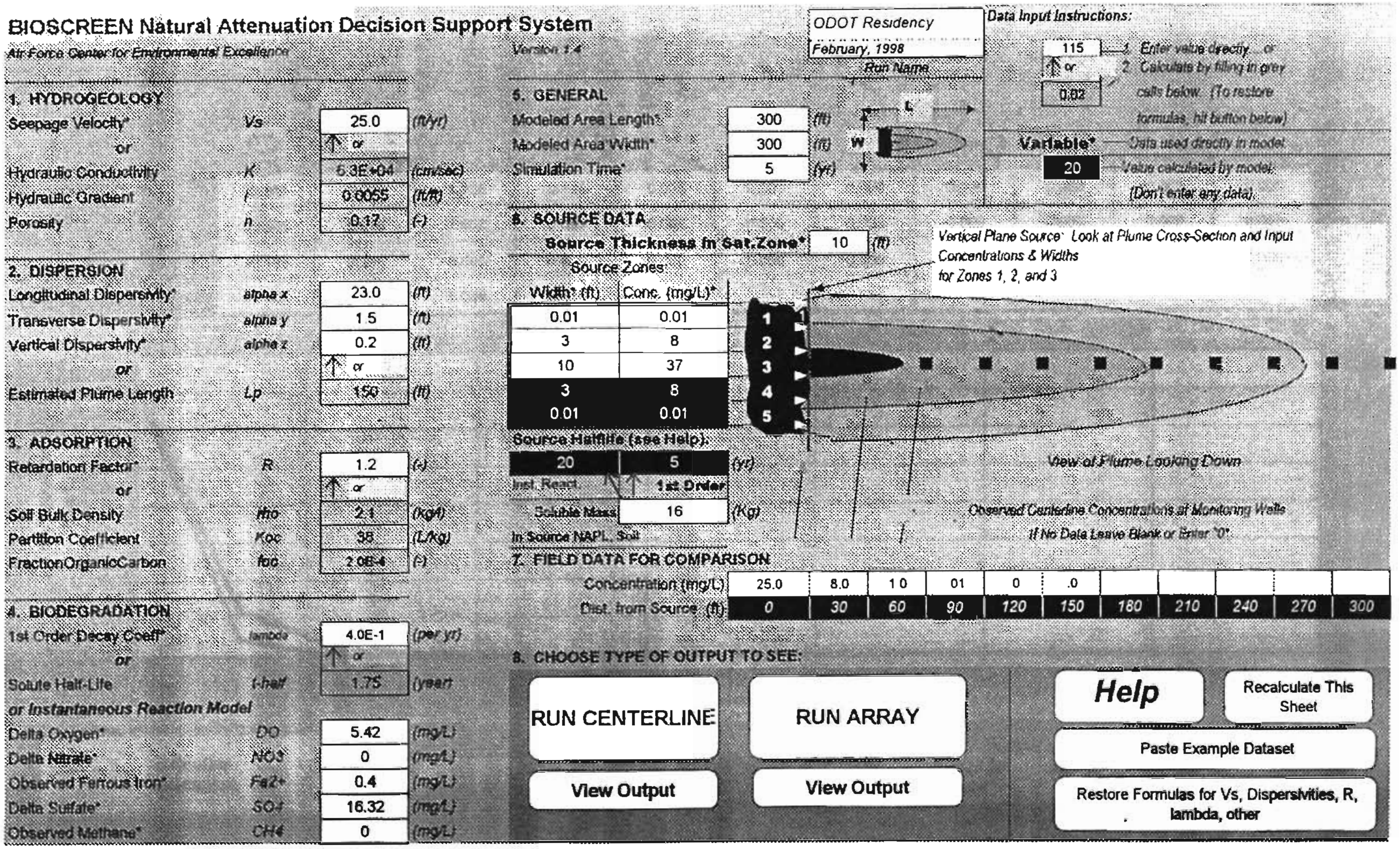
DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	14.415	6.682	4.913	4.001	3.429	3.035	2.749	2.532	2.360	2.220	2.100
1st Order Decay	14.415	4.337	2.069	1.094	0.609	0.350	0.206	0.123	0.075	0.046	0.029
Inst. Reaction	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	25.000	8.000	1.000	0.010							

Time: 30 Years

APPENDIX K
BIOSCREEN OUTPUT – RUN #7



BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence

Version 1.4

ODOT Residency

February, 1998

Run Name

Data Input Instructions:

115 — 1. Enter value directly ... or

↑ or — 2. Calculate by filling in grey cells below. (To restore formulas, hit button below)

0.02

Variable* — Data used directly in model.

20 — Value calculated by model. (Don't enter any data).

1. HYDROGEOLOGY

Seepage Velocity*	Vs	25.0	(ft/yr)
or		↑ or	
Hydraulic Conductivity	K	6.3E+04	(cm/sec)
Hydraulic Gradient	i	0.0055	(ft/ft)
Porosity	n	0.17	(-)

2. DISPERSION

Longitudinal Dispersivity*	alpha x	23.0	(ft)
Transverse Dispersivity*	alpha y	1.5	(ft)
Vertical Dispersivity*	alpha z	0.2	(ft)
or		↑ or	
Estimated Plume Length	Lp	150	(ft)

3. ADSORPTION

Retardation Factor*	R	1.2	(-)
or		↑ or	
Soil Bulk Density	rho	2.1	(kg/l)
Partition Coefficient	Koc	38	(L/kg)
FractionOrganicCarbon	foc	2.0E-4	(-)

4. BIODEGRADATION

1st Order Decay Coeff*	lambda	4.0E-1	(per yr)
or		↑ or	
Solute Half-Life	t-half	1.75	(year)
or Instantaneous Reaction Model			
Delta Oxygen*	DO	5.42	(mg/L)
Delta Nitrate*	NO3	0	(mg/L)
Observed Ferrous Iron*	Fe2+	0.4	(mg/L)
Delta Sulfate*	SO4	16.32	(mg/L)
Observed Methane*	CH4	0	(mg/L)

5. GENERAL

Modeled Area Length*	300	(ft)
Modeled Area Width*	300	(ft)
Simulation Time*	5	(yr)

6. SOURCE DATA

Source Thickness in Sat.Zone* 10 (ft)

Source Zones:

Width* (ft)	Conc. (mg/L)*
0.01	0.01
3	8
10	37
3	8
0.01	0.01

Source Halflife (see Help):

20	5	(yr)
Inst. React.	1st Order	

Soluble Mass 16 (Kg)

In Source NAPL, Soil

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths for Zones 1, 2, and 3

View of Plume Looking Down

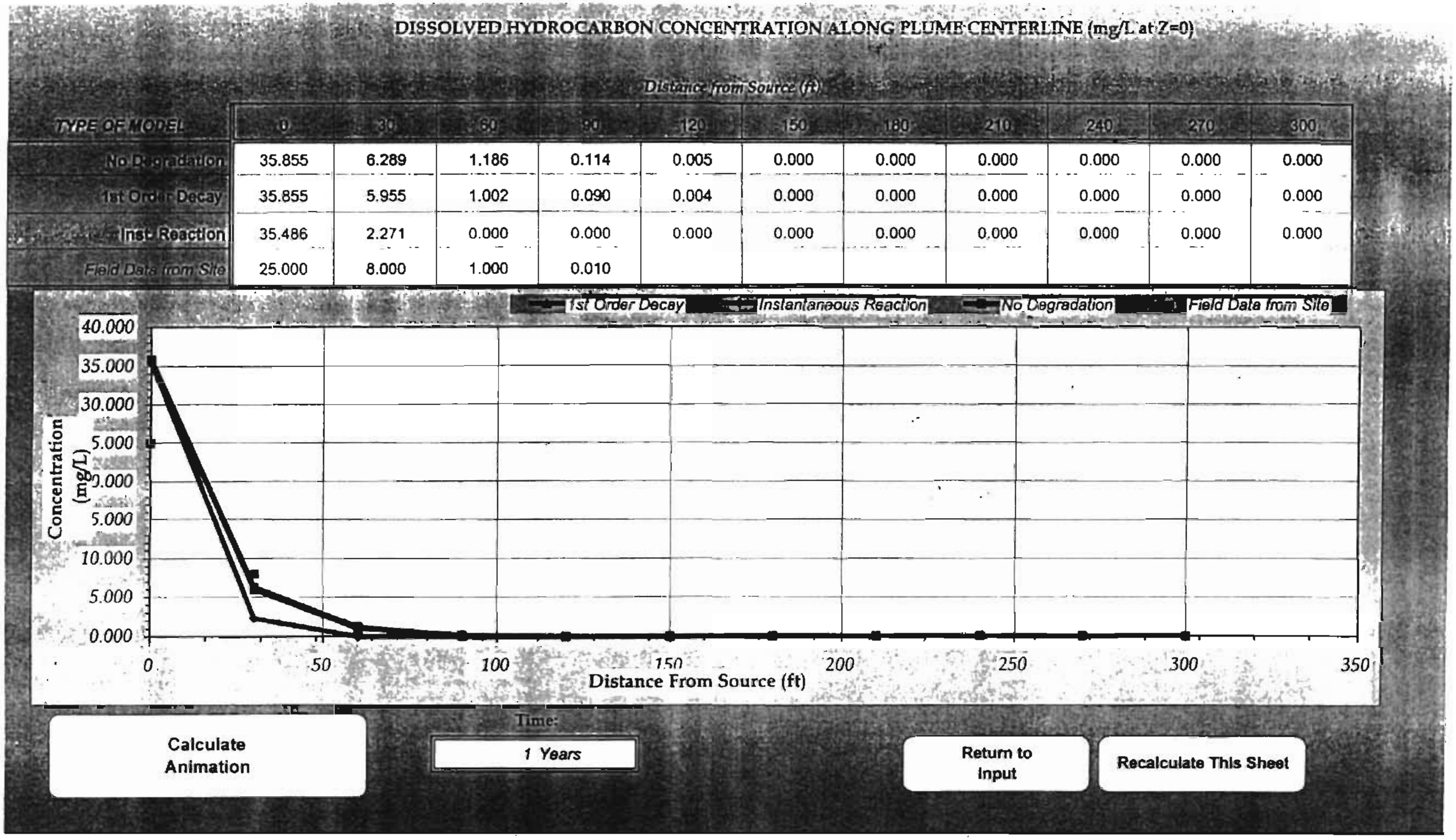
Observed Centerline Concentrations at Monitoring Wells

If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

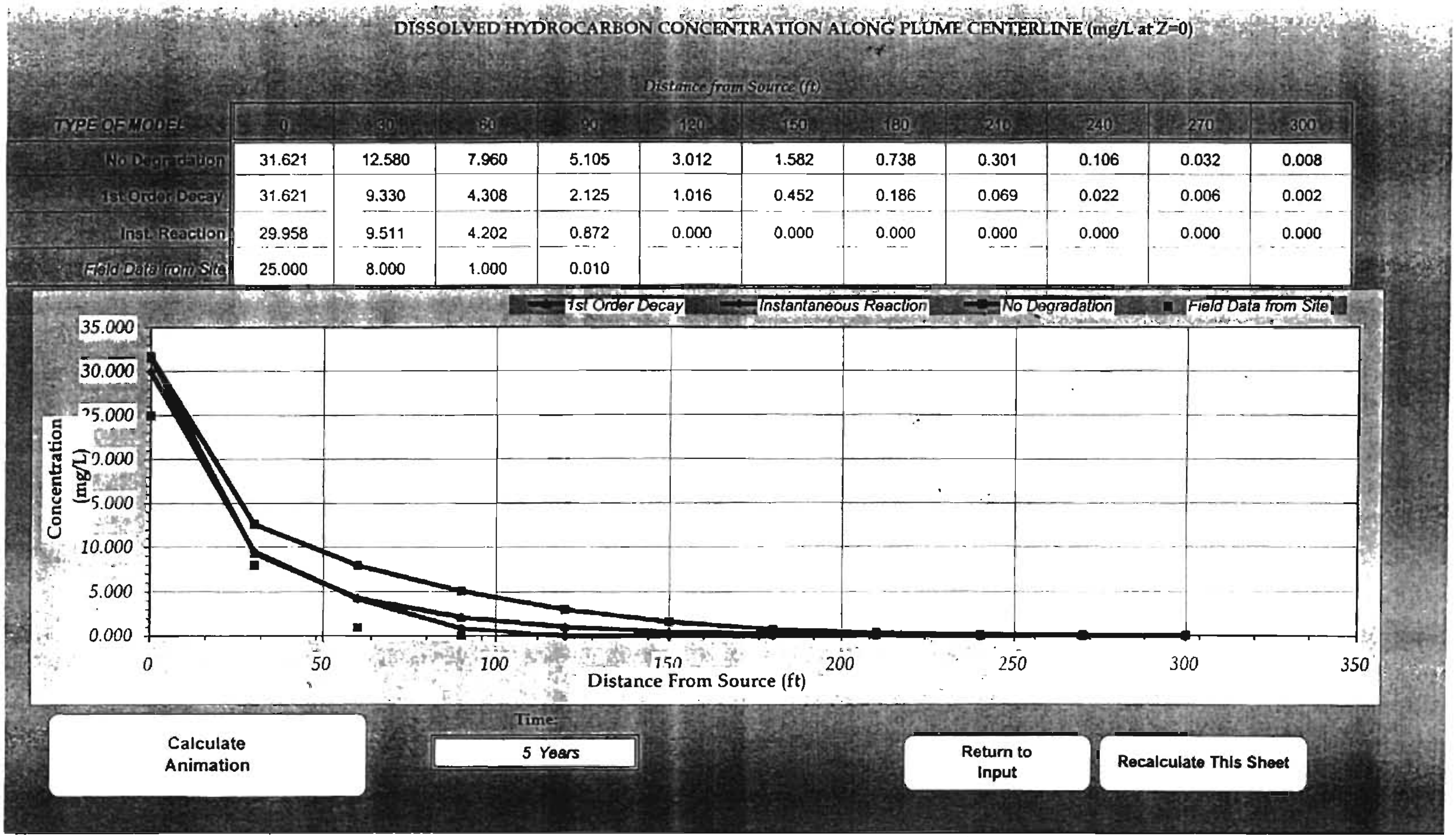
Concentration (mg/L)	25.0	8.0	1 0	01	0	.0					
Dist. from Source (ft)	0	30	60	90	120	150	180	210	240	270	300

8. CHOOSE TYPE OF OUTPUT TO SEE:



DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

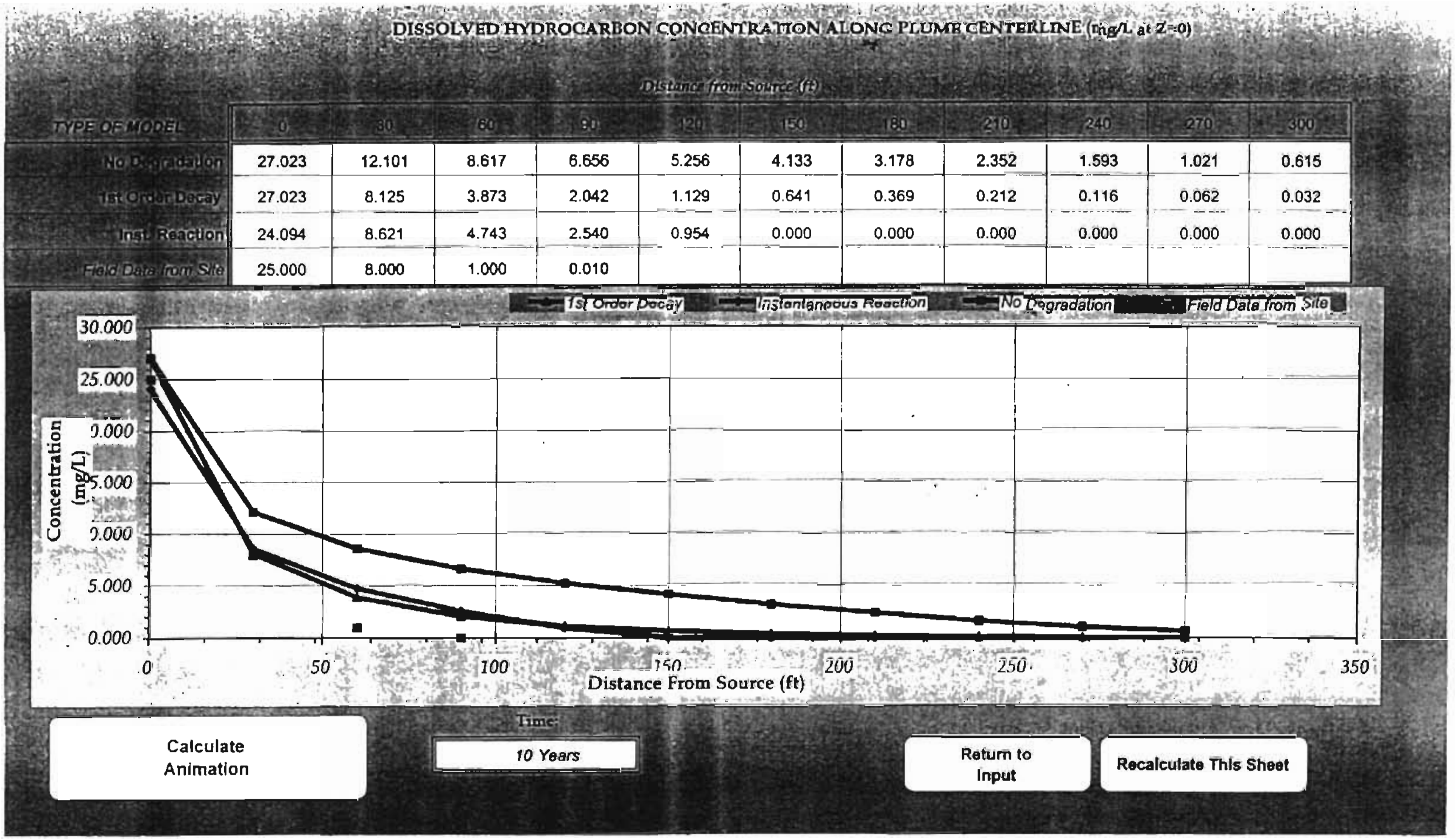
	Distance from Source (ft)										
TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	35.855	6.289	1.186	0.114	0.005	0.000	0.000	0.000	0.000	0.000	0.000
1st Order Decay	35.855	5.955	1.002	0.090	0.004	0.000	0.000	0.000	0.000	0.000	0.000
Inst. Reaction	35.486	2.271	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	25.000	8.000	1.000	0.010							



DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	31.621	12.580	7.960	5.105	3.012	1.582	0.738	0.301	0.106	0.032	0.008
1st Order Decay	31.621	9.330	4.308	2.125	1.016	0.452	0.186	0.069	0.022	0.006	0.002
Inst. Reaction	29.958	9.511	4.202	0.872	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	25.000	8.000	1.000	0.010							

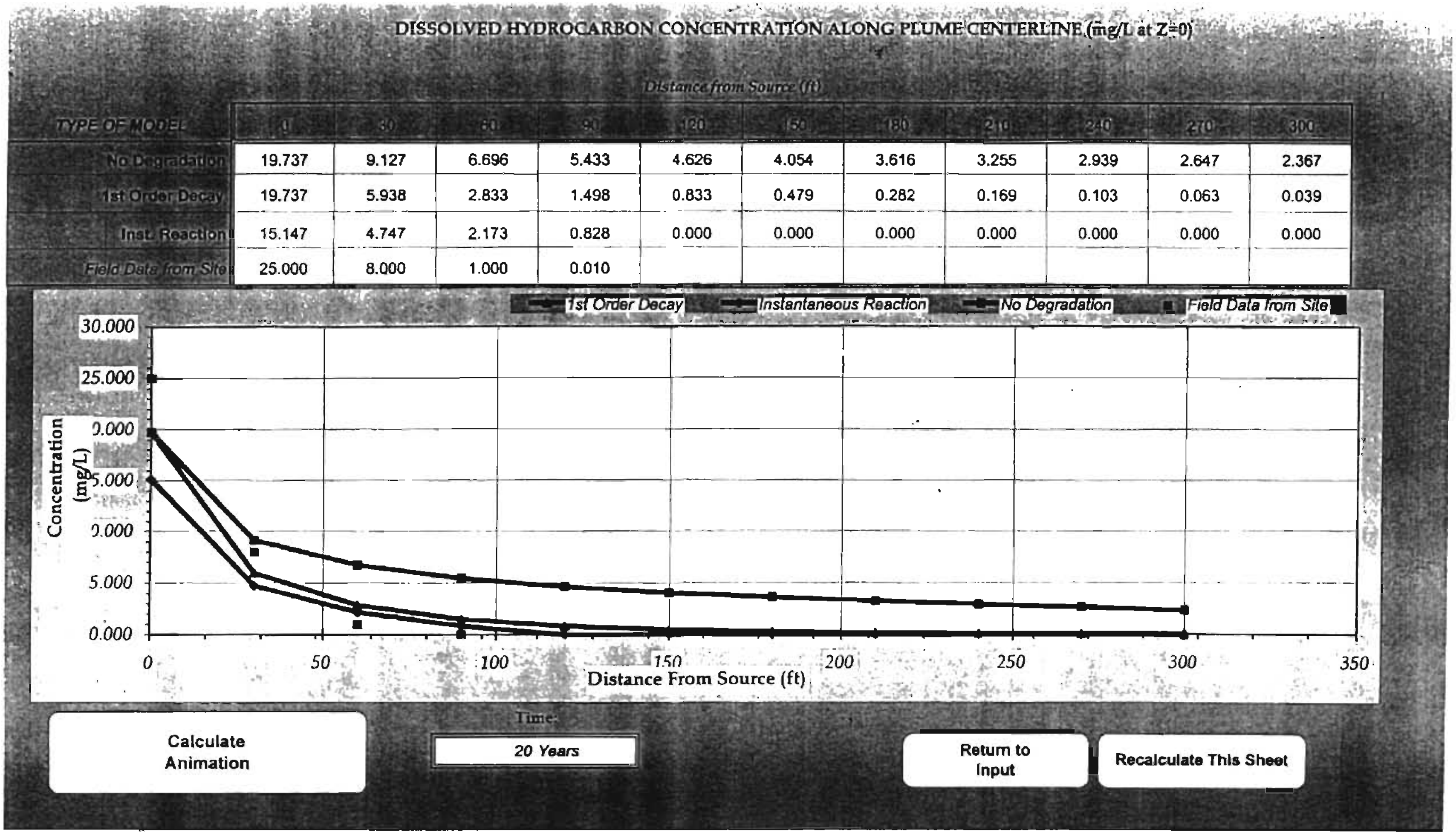


DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	27.023	12.101	8.617	6.656	5.256	4.133	3.178	2.352	1.593	1.021	0.615
1st Order Decay	27.023	8.125	3.873	2.042	1.129	0.641	0.369	0.212	0.116	0.062	0.032
Inst. Reaction	24.094	8.621	4.743	2.540	0.954	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	25.000	8.000	1.000	0.010							

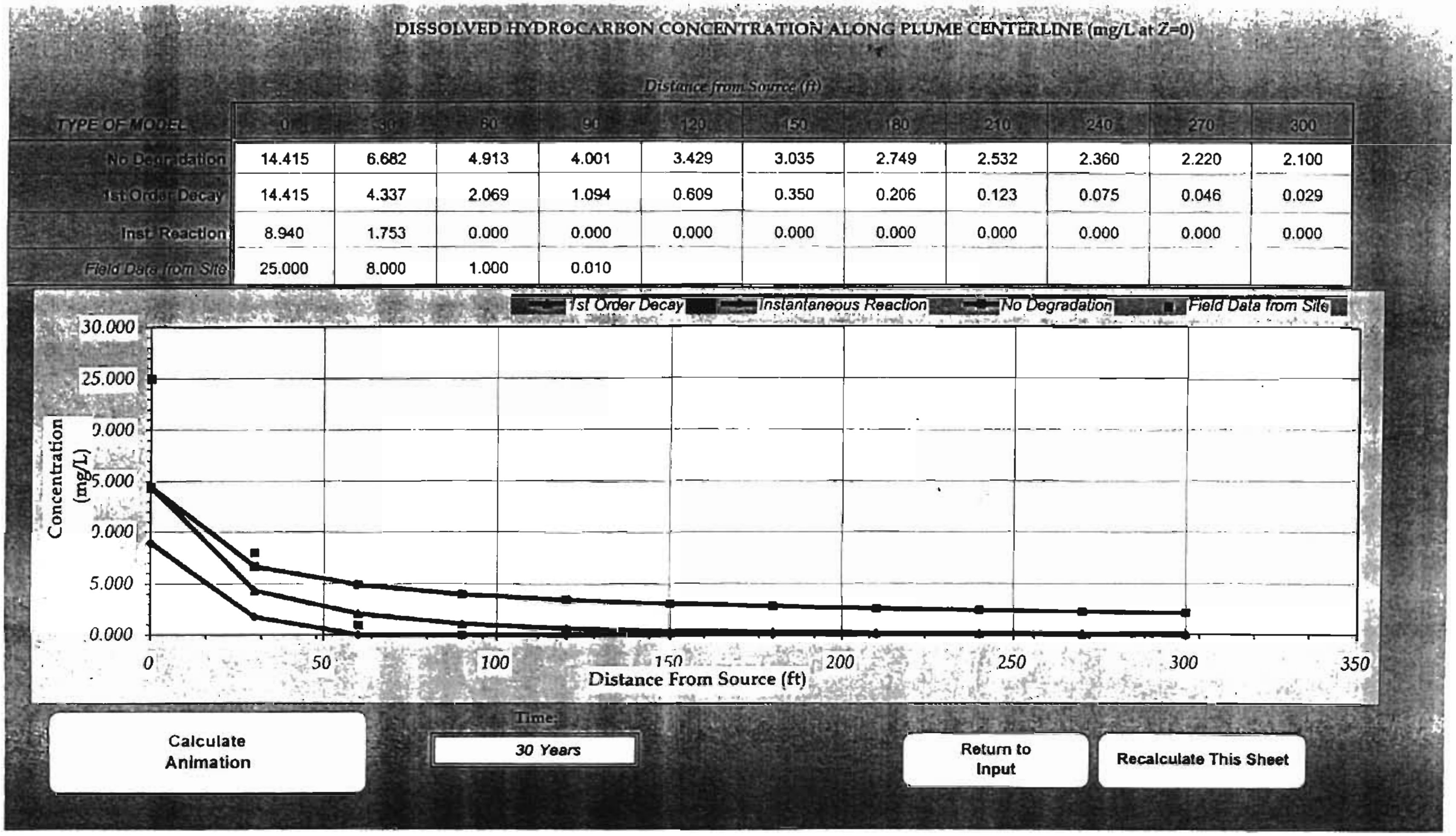
Time: 10 Years



DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

TYPE OF MODEL	Distance from Source (ft) 0	30	60	90	120	150	180	210	240	270	300
No Degradation	19.737	9.127	6.696	5.433	4.626	4.054	3.616	3.255	2.939	2.647	2.367
1st Order Decay	19.737	5.938	2.833	1.498	0.833	0.479	0.282	0.169	0.103	0.063	0.039
Inst. Reaction	15.147	4.747	2.173	0.828	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	25.000	8.000	1.000	0.010							

Time: 20 Years



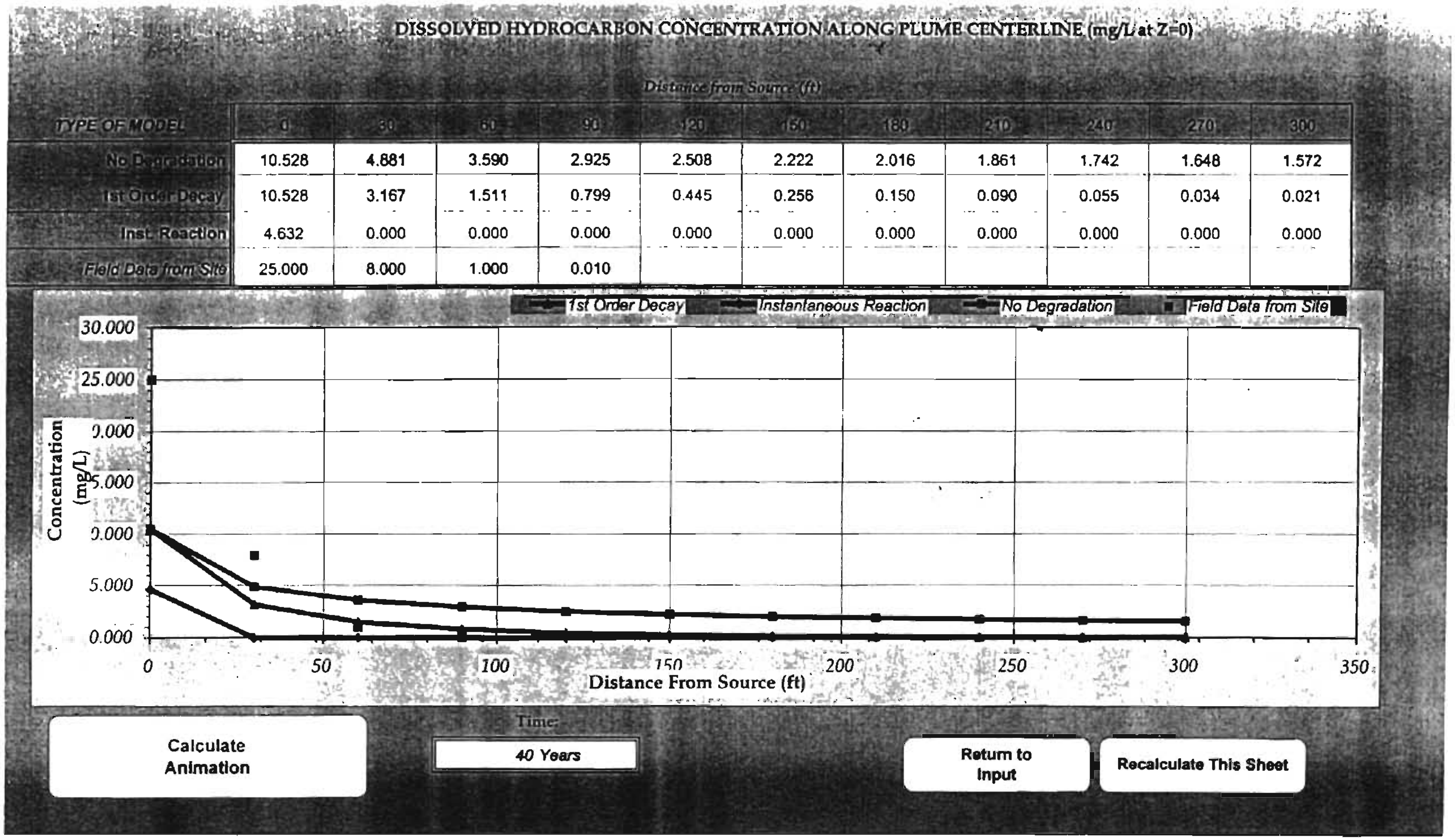
DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	14.415	6.682	4.913	4.001	3.429	3.035	2.749	2.532	2.360	2.220	2.100
1st Order Decay	14.415	4.337	2.069	1.094	0.609	0.350	0.206	0.123	0.075	0.046	0.029
Inst. Reaction	8.940	1.753	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	25.000	8.000	1.000	0.010							

Time:

30 Years

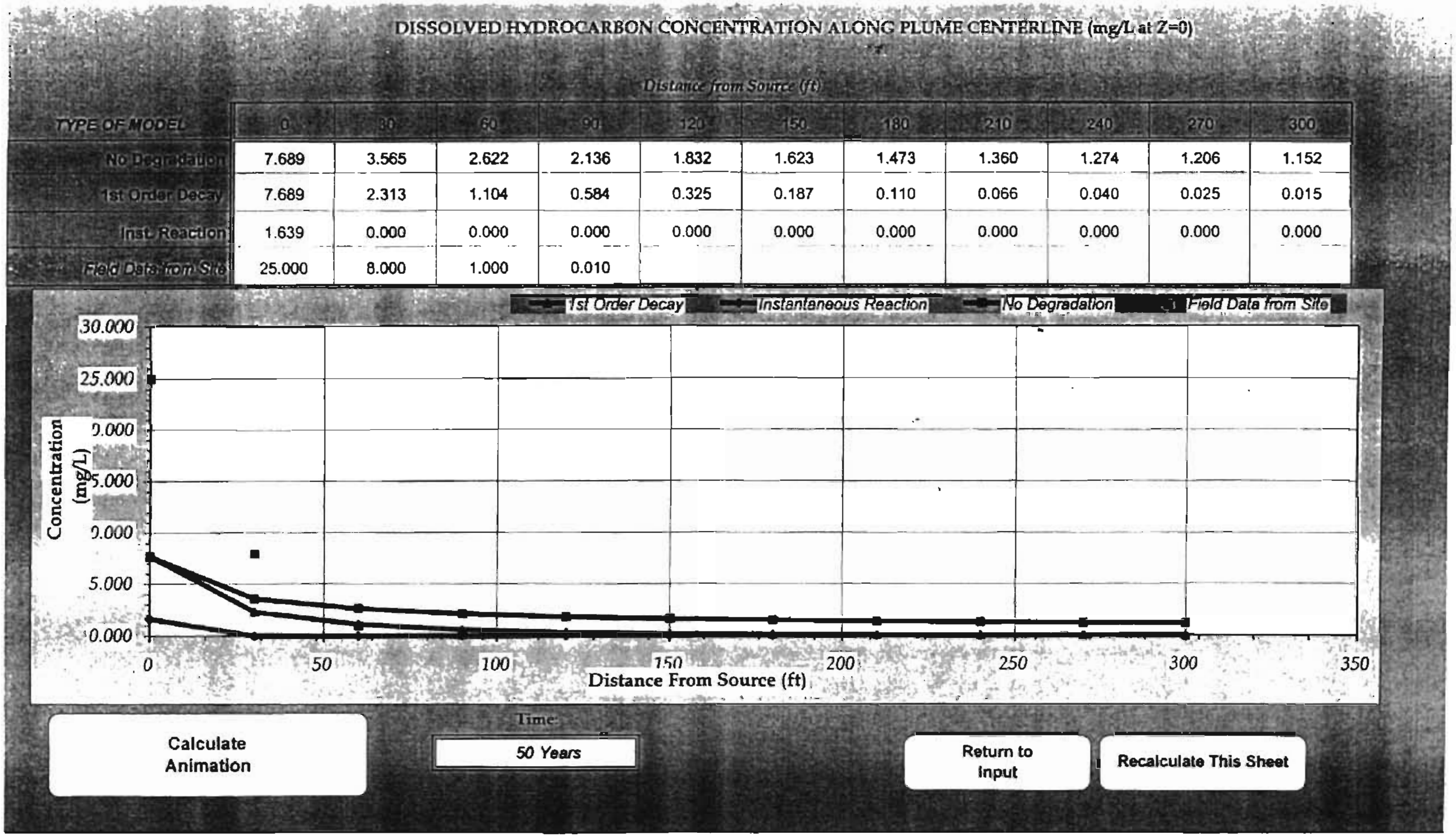


DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	10.528	4.881	3.590	2.925	2.508	2.222	2.016	1.861	1.742	1.648	1.572
1st Order Decay	10.528	3.167	1.511	0.799	0.445	0.256	0.150	0.090	0.055	0.034	0.021
Inst. Reaction	4.632	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	25.000	8.000	1.000	0.010							

Time: 40 Years

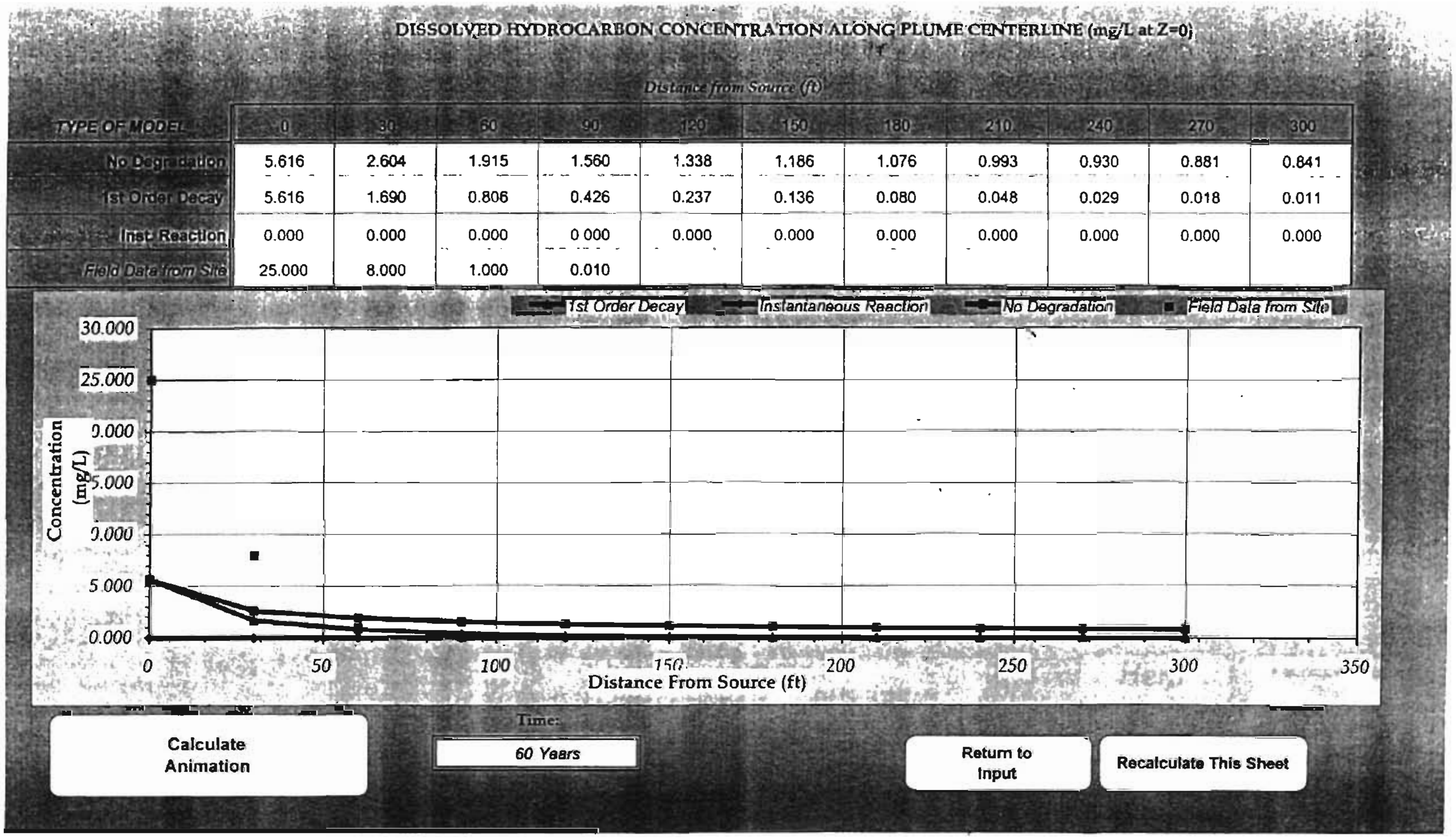


DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	7.689	3.565	2.622	2.136	1.832	1.623	1.473	1.360	1.274	1.206	1.152
1st Order Decay	7.689	2.313	1.104	0.584	0.325	0.187	0.110	0.066	0.040	0.025	0.015
Inst. Reaction	1.639	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	25.000	8.000	1.000	0.010							

Time: 50 Years

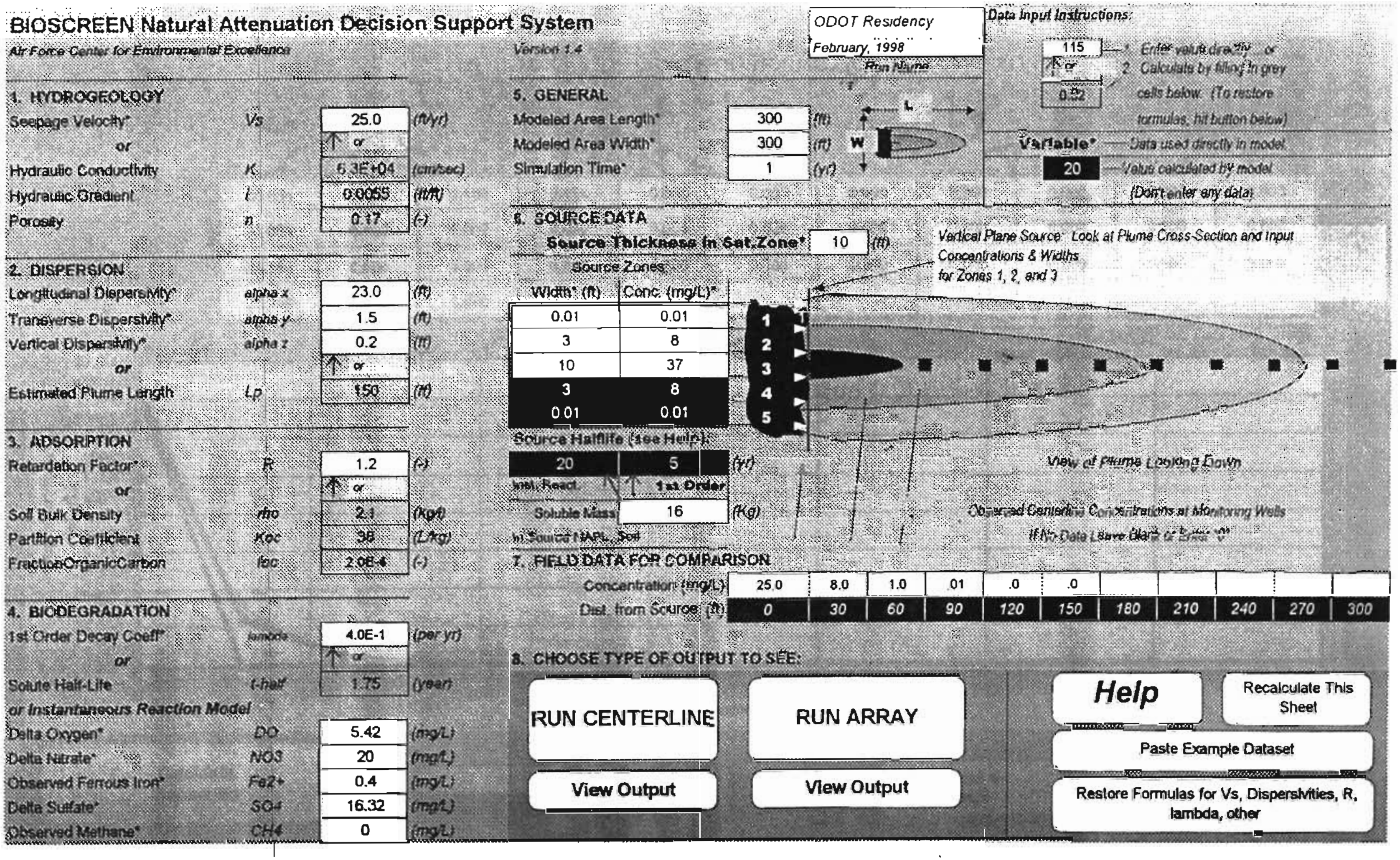


DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

	Distance from Source (ft)										
TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	5.616	2.604	1.915	1.560	1.338	1.186	1.076	0.993	0.930	0.881	0.841
1st Order Decay	5.616	1.690	0.806	0.426	0.237	0.136	0.080	0.048	0.029	0.018	0.011
Inst. Reaction	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	25.000	8.000	1.000	0.010							

Time:

60 Years



BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence

Version 1.4

ODOT Residency
February, 1998
Run Name

Data Input Instructions:

115 — 1. Enter value directly ... or
or
0.52 — 2. Calculate by filling in grey cells below. (To restore formulas, hit button below)

Variable* — Data used directly in model.

20 — Value calculated by model. (Don't enter any data)

1. HYDROGEOLOGY

Seepage Velocity*	Vs	25.0	(ft/yr)
or		or	
Hydraulic Conductivity	K	6.3E+04	(cm/sec)
Hydraulic Gradient	i	0.0055	(ft/ft)
Porosity	n	0.17	(-)

2. DISPERSION

Longitudinal Dispersivity*	alpha x	23.0	(ft)
Transverse Dispersivity*	alpha y	1.5	(ft)
Vertical Dispersivity*	alpha z	0.2	(ft)
or		or	
Estimated Plume Length	Lp	150	(ft)

3. ADSORPTION

Retardation Factor*	R	1.2	(-)
or		or	
Soil Bulk Density	rho	2.1	(kg/l)
Partition Coefficient	Koc	38	(L/kg)
FractionOrganicCarbon	foc	2.0E-4	(-)

4. BIODEGRADATION

1st Order Decay Coeff*	lambda	4.0E-1	(per yr)
or		or	
Solute Half-Life	t-half	1.75	(year)
or Instantaneous Reaction Model			
Delta Oxygen*	DO	5.42	(mg/L)
Delta Nitrate*	NO3	20	(mg/L)
Observed Ferrous Iron*	Fe2+	0.4	(mg/L)
Delta Sulfate*	SO4	16.32	(mg/L)
Observed Methane*	CH4	0	(mg/L)

5. GENERAL

Modeled Area Length*	300	(ft)
Modeled Area Width*	300	(ft)
Simulation Time*	1	(yr)

6. SOURCE DATA

Source Thickness in Sat.Zone* 10 (ft)

Source Zones:

Zone	Width* (ft)	Conc. (mg/L)*
1	0.01	0.01
2	3	8
3	10	37
4	3	8
5	0.01	0.01

Source Halflife (see Help): 20 | 5 (yr)
Inst. React. | 1st Order

Soluble Mass 16 (Kg)
In Source NAPL, Soil

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths for Zones 1, 2, and 3

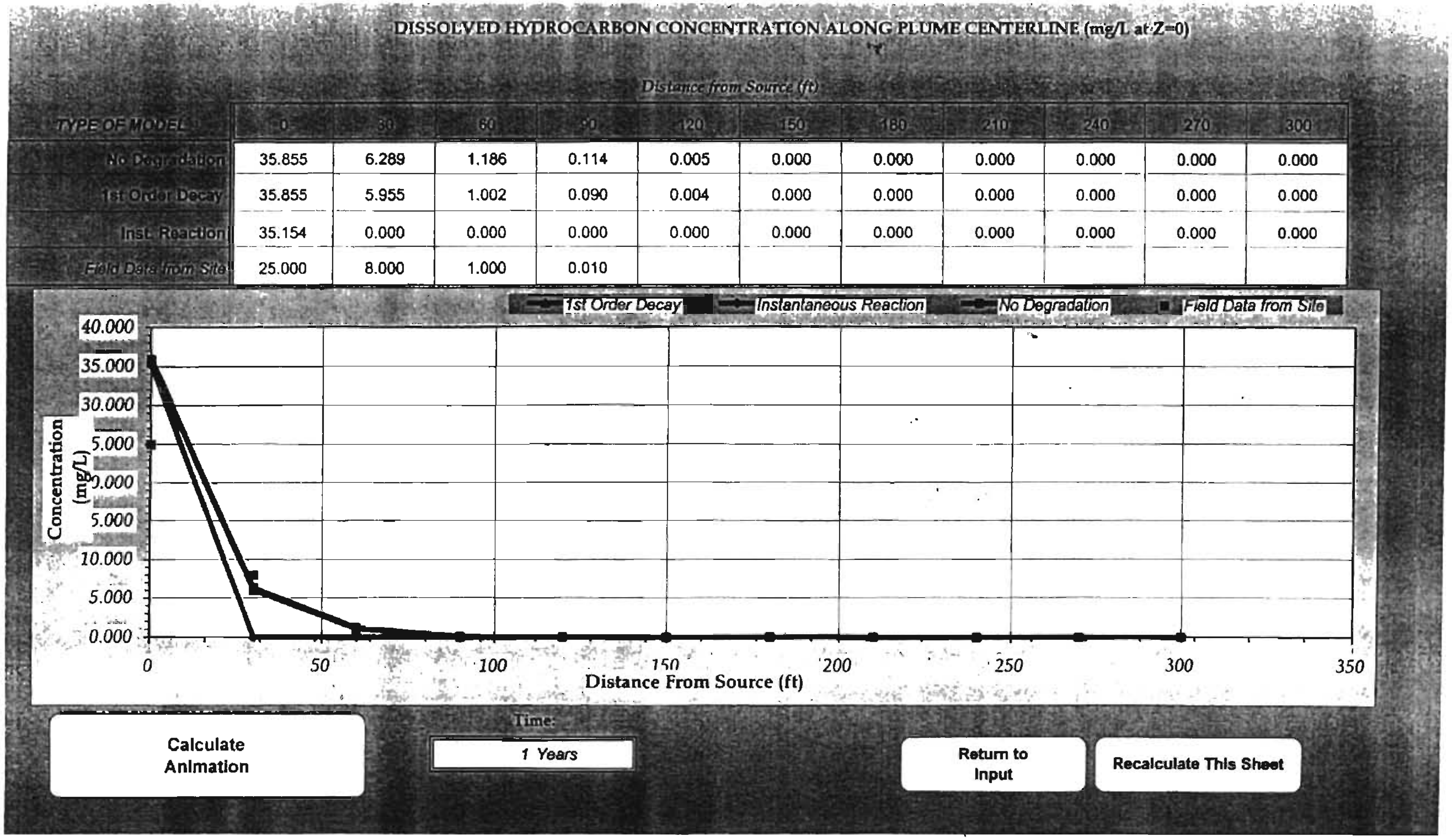
View of Plume Looking Down

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Concentration (mg/L)	25.0	8.0	1.0	.01	.0	.0					
Dist. from Source (ft)	0	30	60	90	120	150	180	210	240	270	300

8. CHOOSE TYPE OF OUTPUT TO SEE:



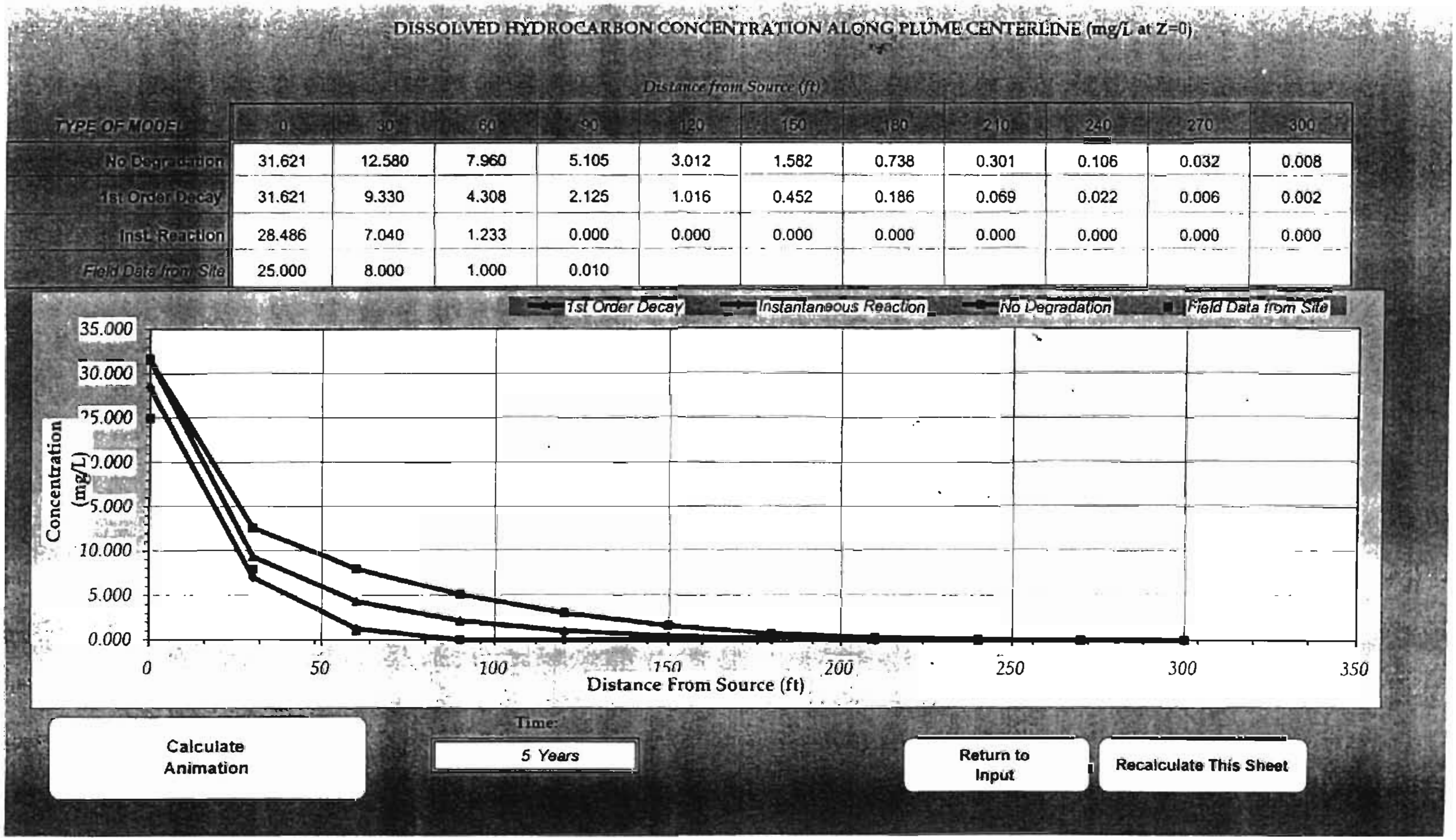
DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	35.855	6.289	1.186	0.114	0.005	0.000	0.000	0.000	0.000	0.000	0.000
1st Order Decay	35.855	5.955	1.002	0.090	0.004	0.000	0.000	0.000	0.000	0.000	0.000
Inst. Reaction	35.154	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	25.000	8.000	1.000	0.010							

Time:

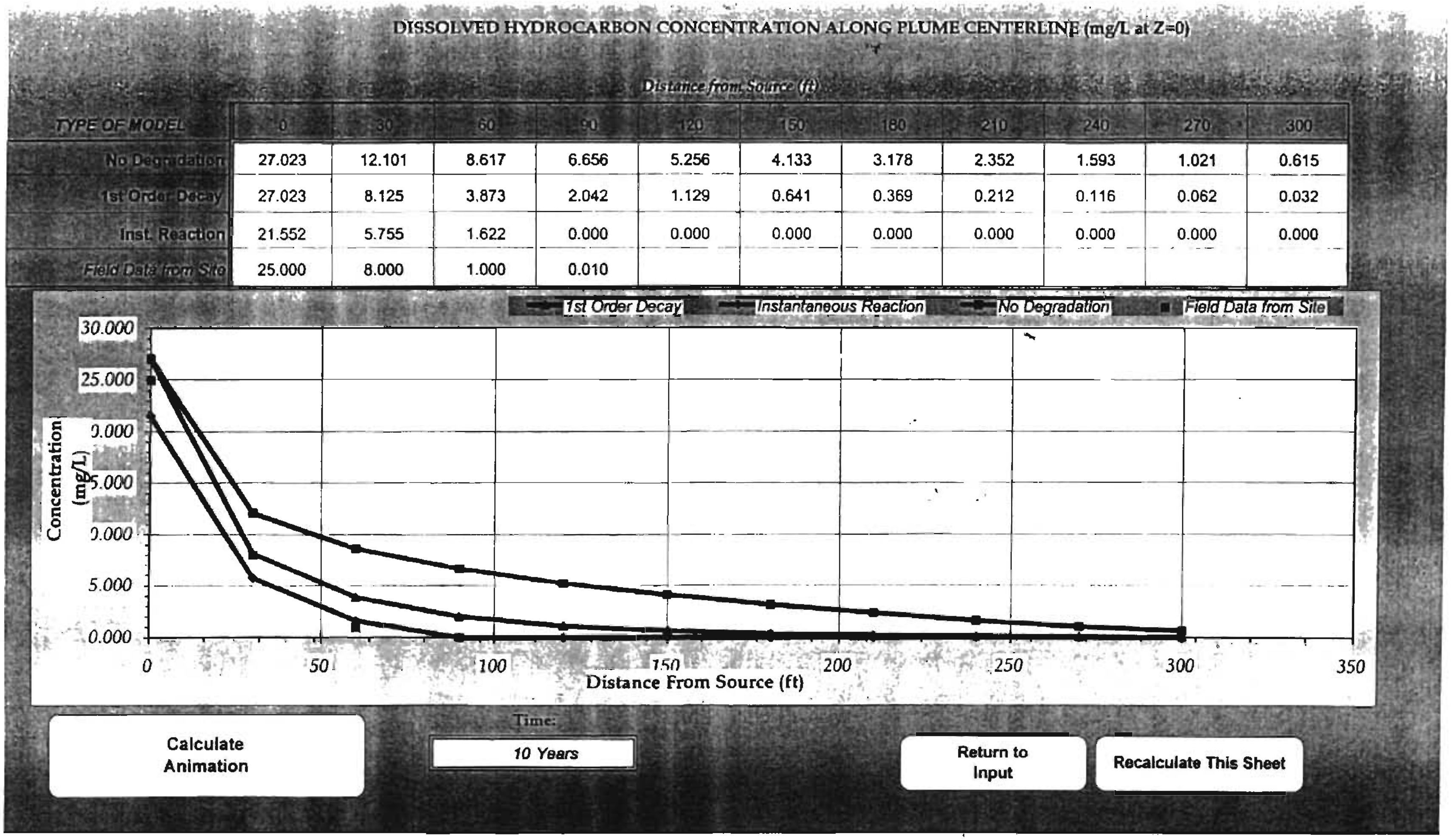
1 Years



DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

Distance from Source (ft)

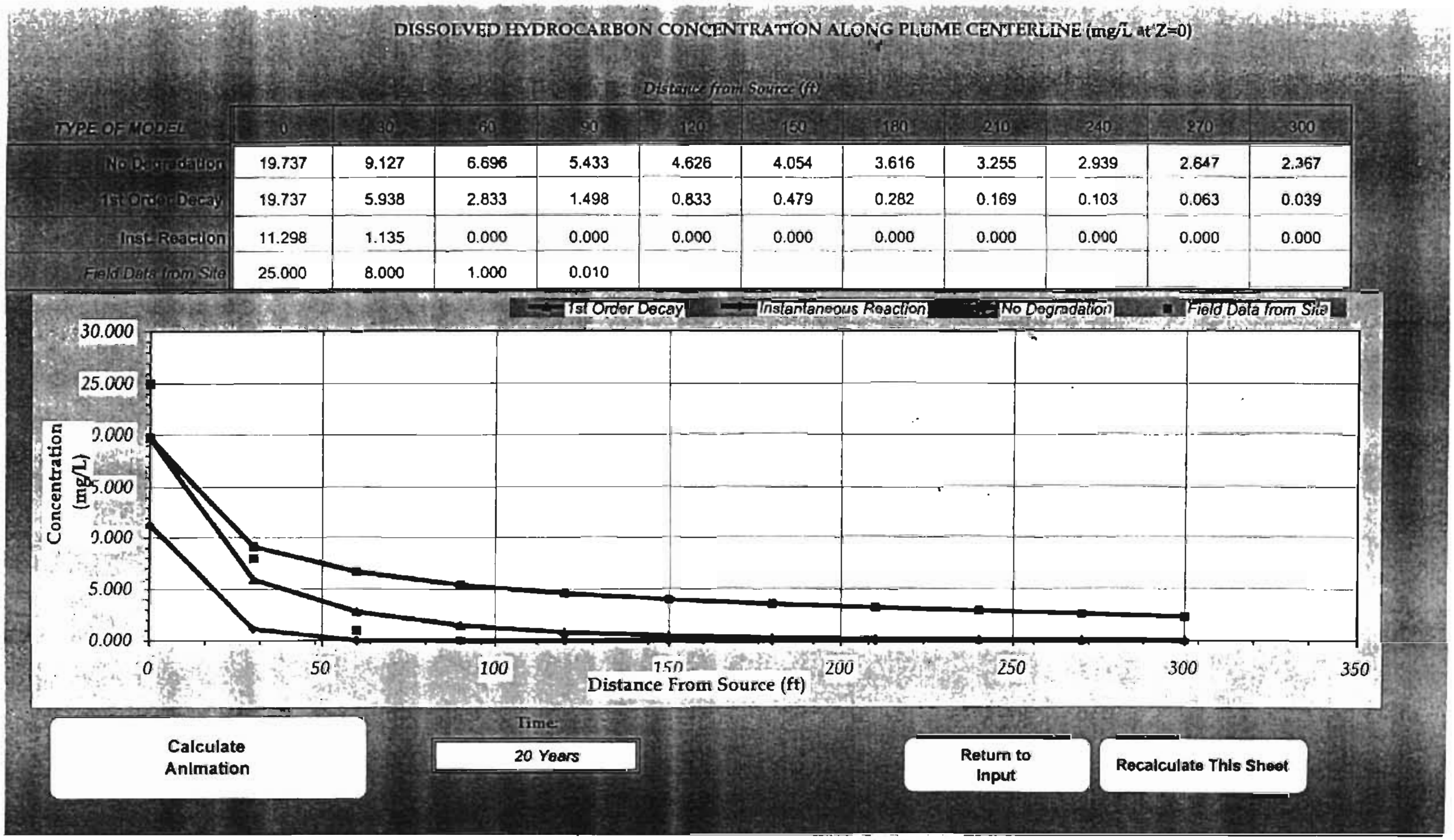
TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	31.621	12.580	7.960	5.105	3.012	1.582	0.738	0.301	0.106	0.032	0.008
1st Order Decay	31.621	9.330	4.308	2.125	1.016	0.452	0.186	0.069	0.022	0.006	0.002
Inst. Reaction	28.486	7.040	1.233	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	25.000	8.000	1.000	0.010							



DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

	Distance from Source (ft)										
TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	27.023	12.101	8.617	6.656	5.256	4.133	3.178	2.352	1.593	1.021	0.615
1st Order Decay	27.023	8.125	3.873	2.042	1.129	0.641	0.369	0.212	0.116	0.062	0.032
Inst. Reaction	21.552	5.755	1.622	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	25.000	8.000	1.000	0.010							

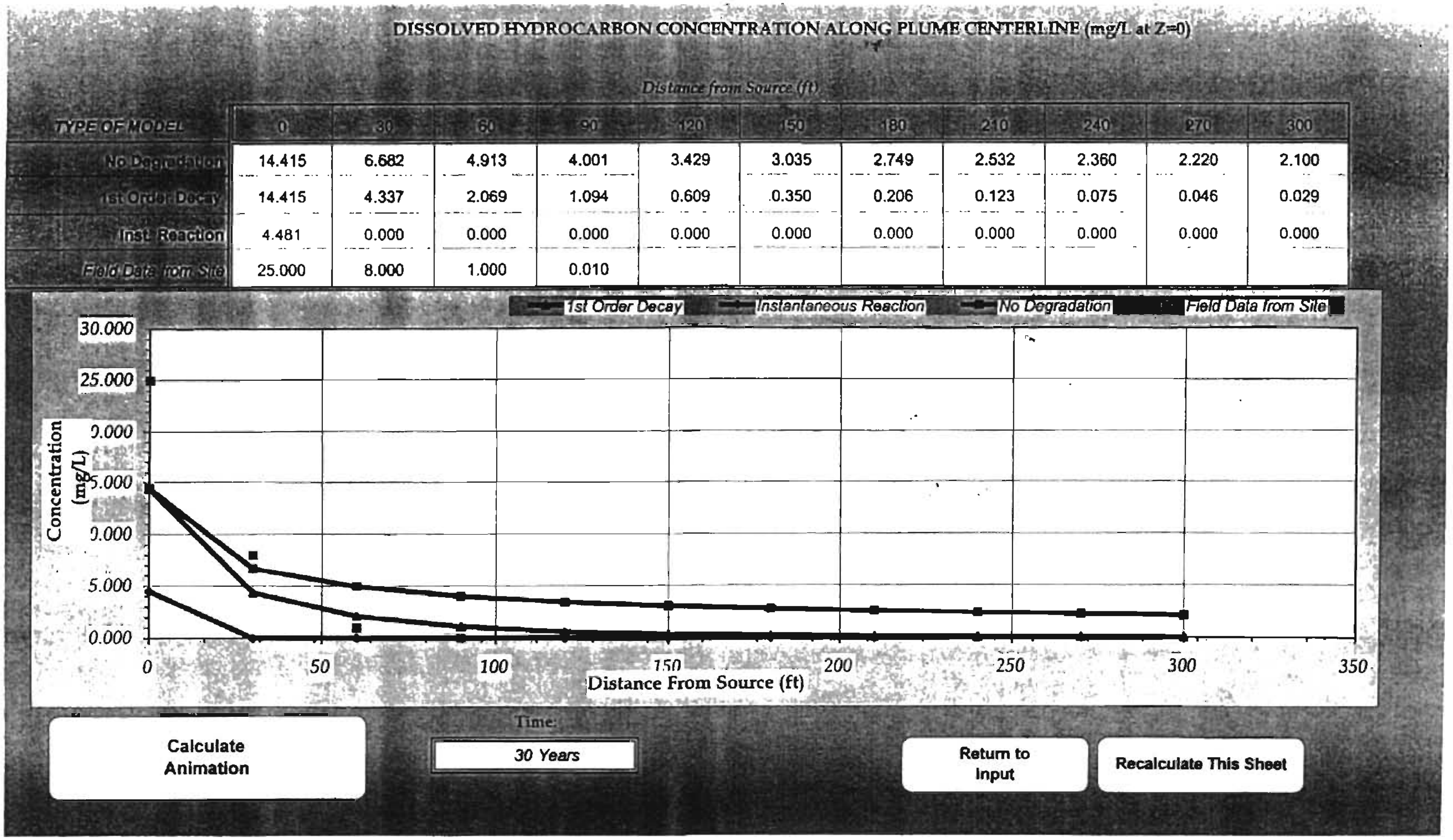
Time: 10 Years



DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

	Distance from Source (ft)										
TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	19.737	9.127	6.696	5.433	4.626	4.054	3.616	3.255	2.939	2.647	2.367
1st Order Decay	19.737	5.938	2.833	1.498	0.833	0.479	0.282	0.169	0.103	0.063	0.039
Inst. Reaction	11.298	1.135	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	25.000	8.000	1.000	0.010							

Time: 20 Years

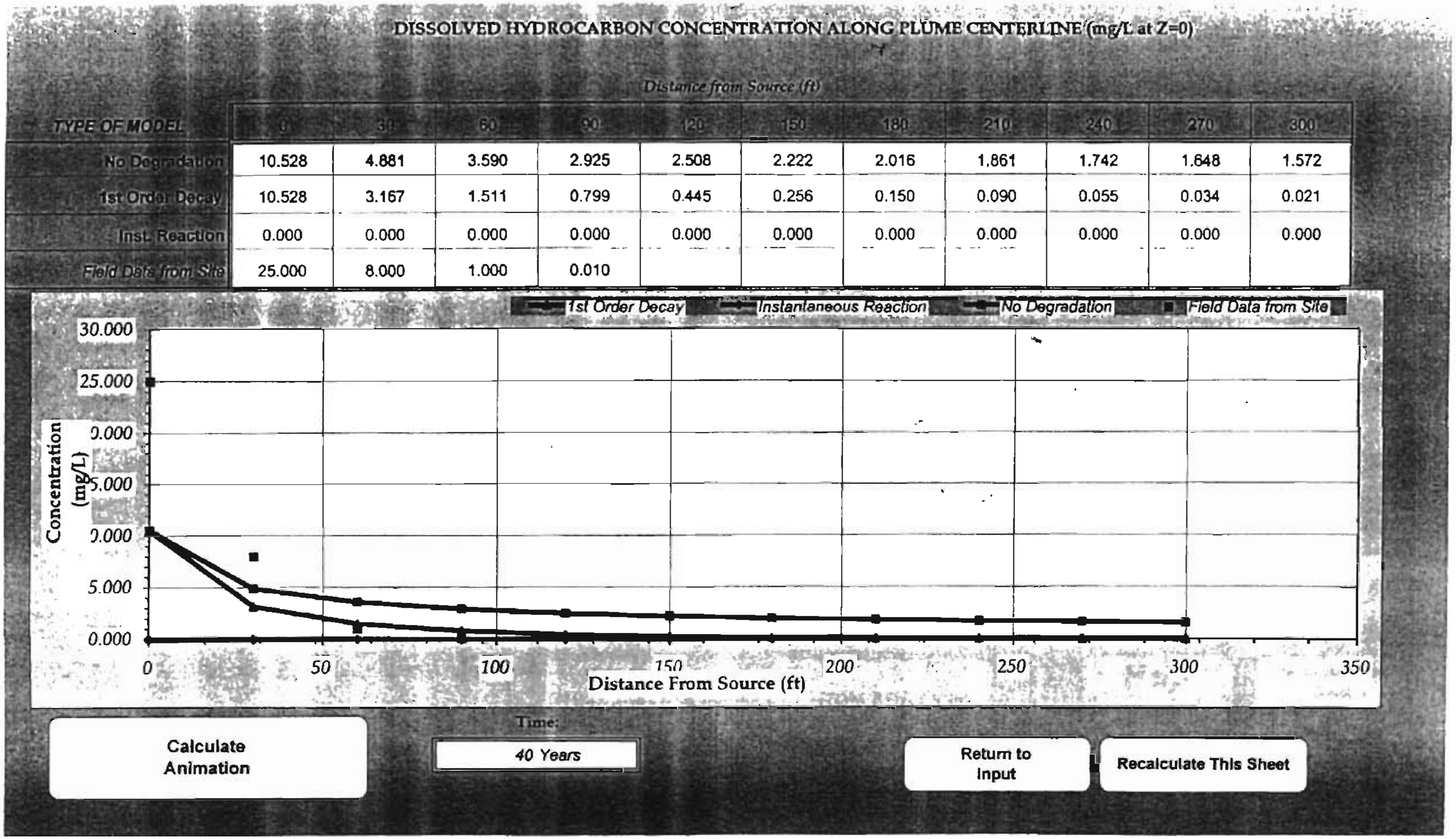


DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	14.415	6.682	4.913	4.001	3.429	3.035	2.749	2.532	2.360	2.220	2.100
1st Order Decay	14.415	4.337	2.069	1.094	0.609	0.350	0.206	0.123	0.075	0.046	0.029
Inst. Reaction	4.481	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	25.000	8.000	1.000	0.010							

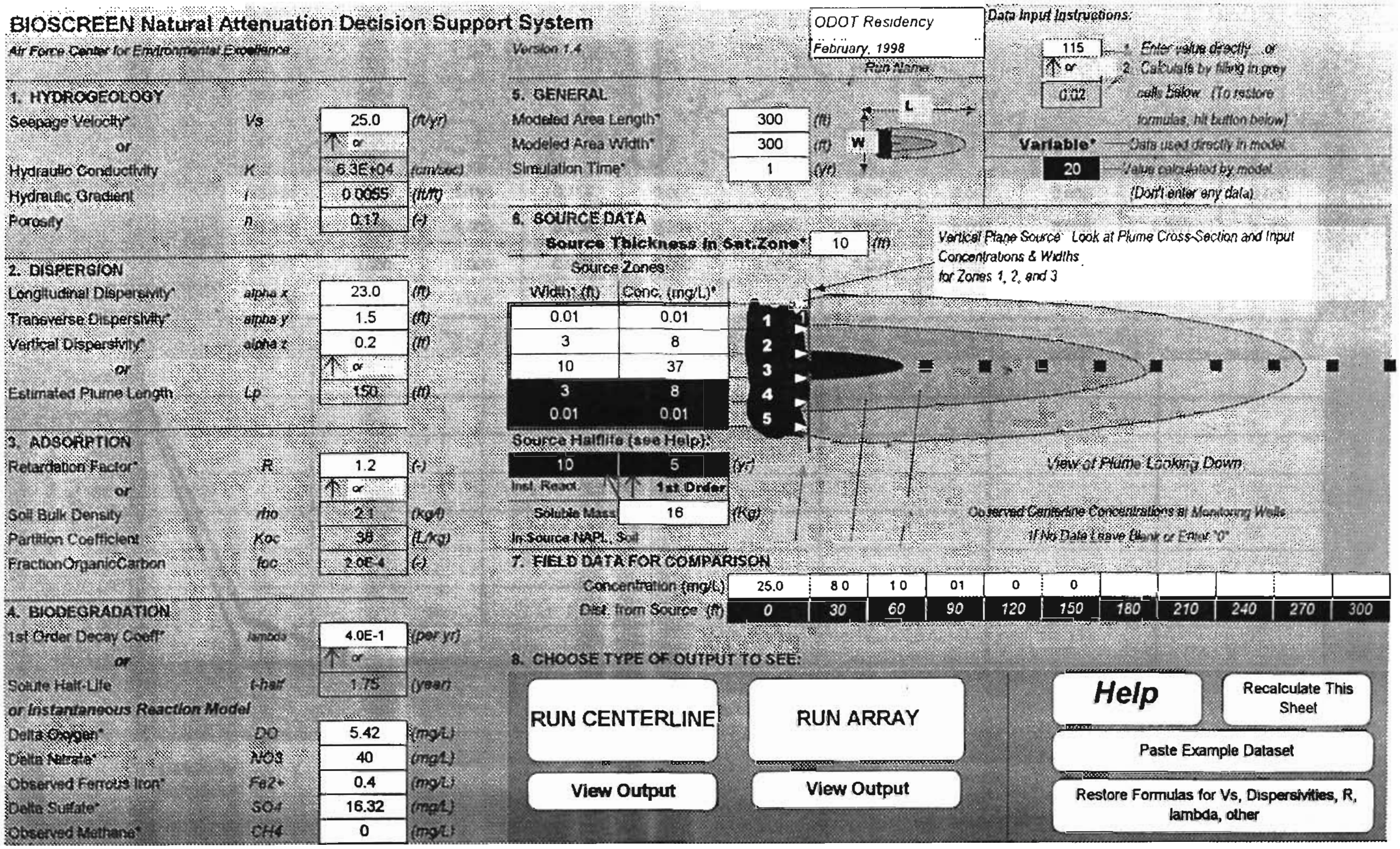
Time: 30 Years



DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
	Distance from Source (ft)										
No Degradation	10.528	4.881	3.590	2.925	2.508	2.222	2.016	1.861	1.742	1.648	1.572
1st Order Decay	10.528	3.167	1.511	0.799	0.445	0.256	0.150	0.090	0.055	0.034	0.021
Inst. Reaction	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	25.000	8.000	1.000	0.010							

Time: 40 Years



BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence

Version 1.4

ODOT Residency
February, 1998
Run Name

Data Input Instructions:

115	1. Enter value directly ... or
↑ or	2. Calculate by filling in grey cells below. (To restore formulas, hit button below)
0.02	
Variable*	Data used directly in model
20	Value calculated by model (Don't enter any data)

1. HYDROGEOLOGY

Seepage Velocity*	Vs	25.0	(ft/yr)
or		↑ or	
Hydraulic Conductivity	K	6.3E+04	(cm/sec)
Hydraulic Gradient	i	0.0055	(ft/ft)
Porosity	n	0.17	(-)

2. DISPERSION

Longitudinal Dispersivity*	alpha x	23.0	(ft)
Transverse Dispersivity*	alpha y	1.5	(ft)
Vertical Dispersivity*	alpha z	0.2	(ft)
or		↑ or	
Estimated Plume Length	Lp	150	(ft)

3. ADSORPTION

Retardation Factor*	R	1.2	(-)
or		↑ or	
Soil Bulk Density	rho	2.1	(kg/l)
Partition Coefficient	Koc	38	(L/kg)
FractionOrganicCarbon	foc	2.0E-4	(-)

4. BIODEGRADATION

1st Order Decay Coeff*	lambda	4.0E-1	(per yr)
or		↑ or	
Solute Half-Life	t-half	1.75	(year)
or Instantaneous Reaction Model			
Delta Oxygen*	DO	5.42	(mg/L)
Delta Nitrate*	NO3	40	(mg/L)
Observed Ferrous Iron*	Fe2+	0.4	(mg/L)
Delta Sulfate*	SO4	16.32	(mg/L)
Observed Methane*	CH4	0	(mg/L)

5. GENERAL

Modeled Area Length*	300	(ft)
Modeled Area Width*	300	(ft)
Simulation Time*	1	(yr)

6. SOURCE DATA

Source Thickness in Sat.Zone* 10 (ft)

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths for Zones 1, 2, and 3

Source Zones:

	Width* (ft)	Conc. (mg/L)*
1	0.01	0.01
2	3	8
3	10	37
4	3	8
5	0.01	0.01

Source Halflife (see Help):

Inst. React.	1st Order	
10	5	(yr)

Soluble Mass 16 (Kg)

In Source NAPL, Soil

View of Plume Looking Down

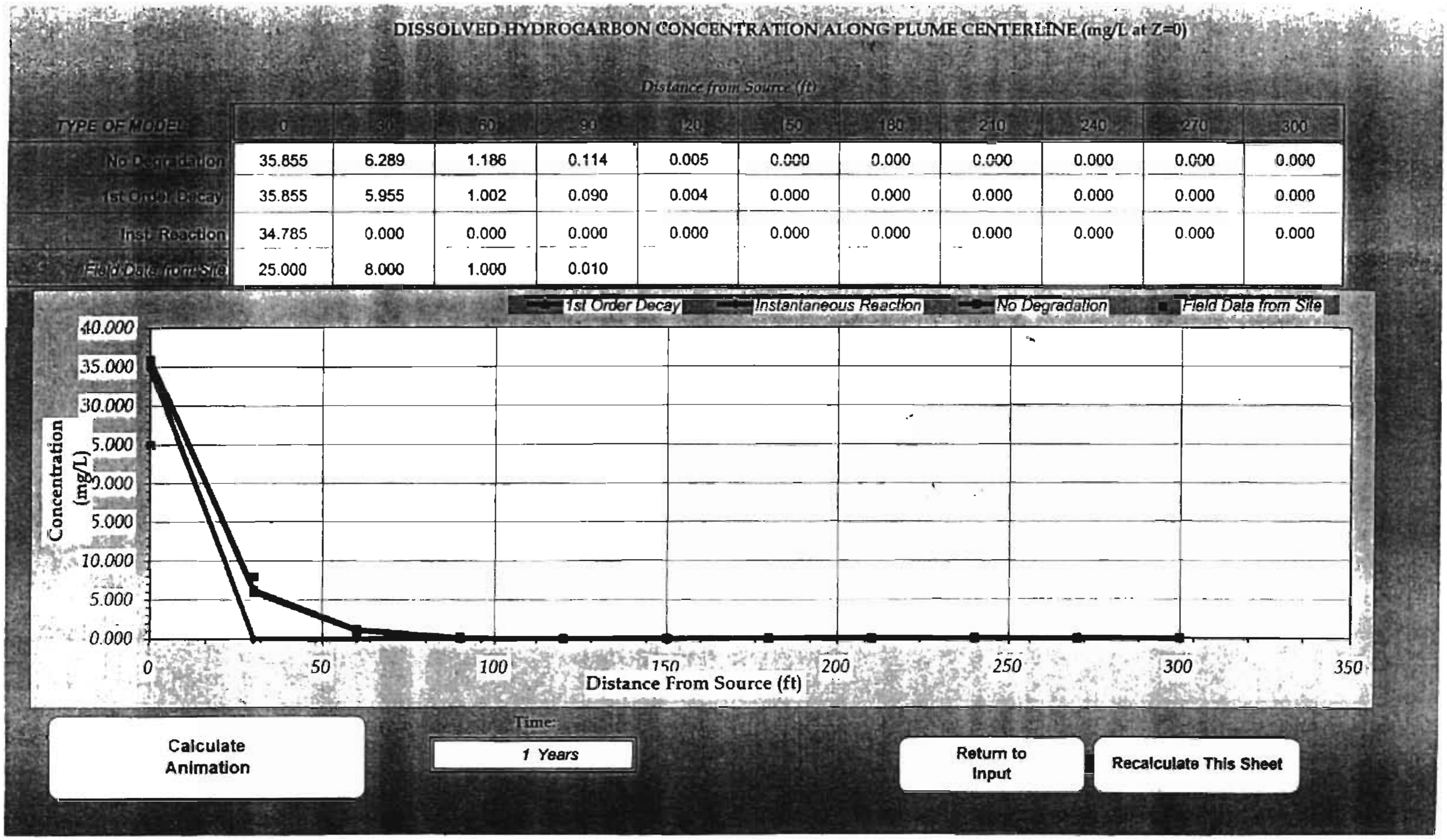
Observed Centerline Concentrations at Monitoring Wells

If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Concentration (mg/L)	25.0	8 0	1 0	01	0	0					
Dist. from Source (ft)	0	30	60	90	120	150	180	210	240	270	300

8. CHOOSE TYPE OF OUTPUT TO SEE:



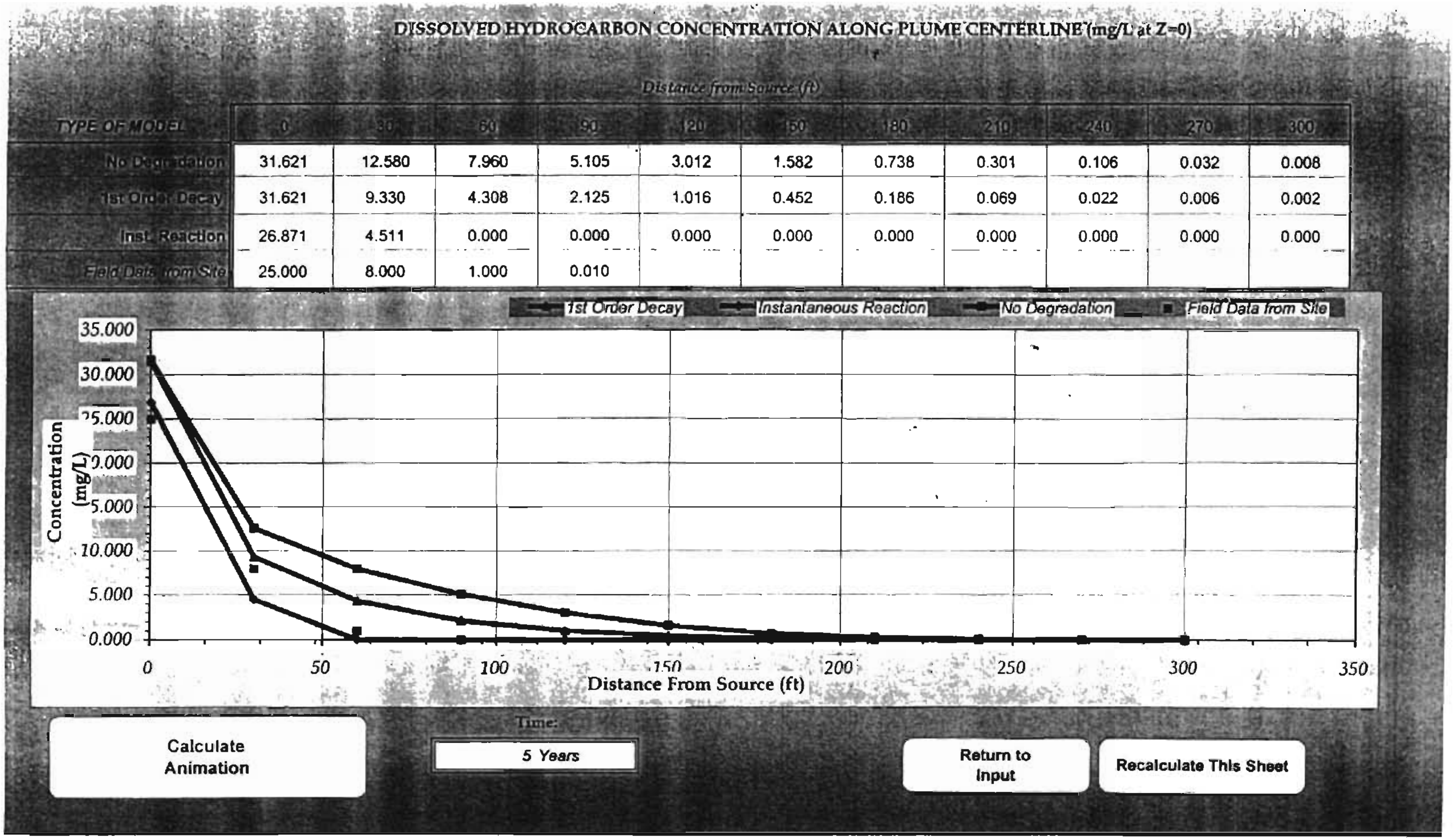
DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	35.855	6.289	1.186	0.114	0.005	0.000	0.000	0.000	0.000	0.000	0.000
1st Order Decay	35.855	5.955	1.002	0.090	0.004	0.000	0.000	0.000	0.000	0.000	0.000
Inst. Reaction	34.785	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	25.000	8.000	1.000	0.010							

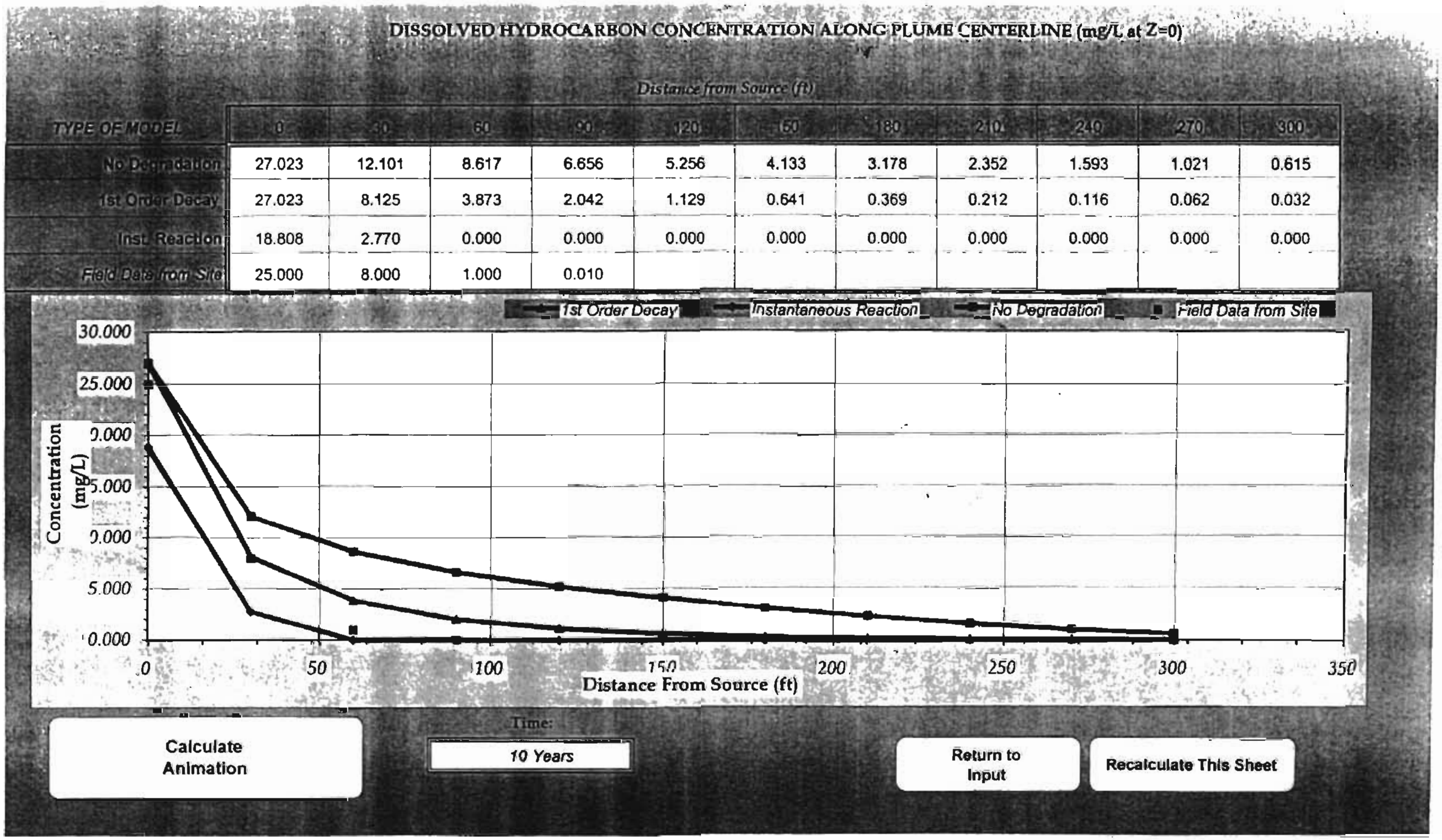
Time:

1 Years



DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

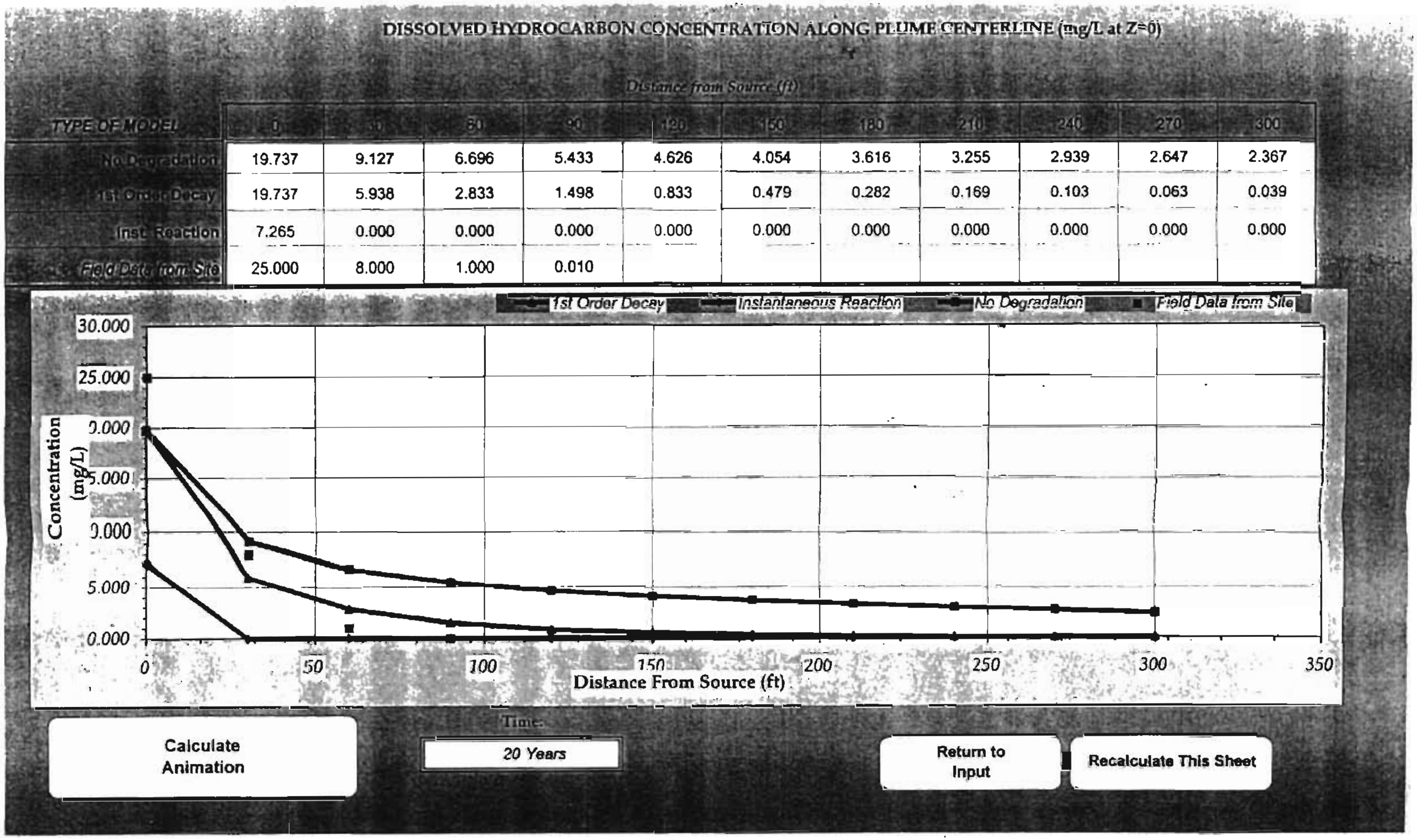
TYPE OF MODEL	Distance from Source (ft) 0	30	60	90	120	150	180	210	240	270	300
No Degradation	31.621	12.580	7.960	5.105	3.012	1.582	0.738	0.301	0.106	0.032	0.008
1st Order Decay	31.621	9.330	4.308	2.125	1.016	0.452	0.186	0.069	0.022	0.006	0.002
Inst. Reaction	26.871	4.511	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	25.000	8.000	1.000	0.010							



DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
No Degradation	27.023	12.101	8.617	6.656	5.256	4.133	3.178	2.352	1.593	1.021	0.615
1st Order Decay	27.023	8.125	3.873	2.042	1.129	0.641	0.369	0.212	0.116	0.062	0.032
Inst. Reaction	18.808	2.770	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	25.000	8.000	1.000	0.010							



DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
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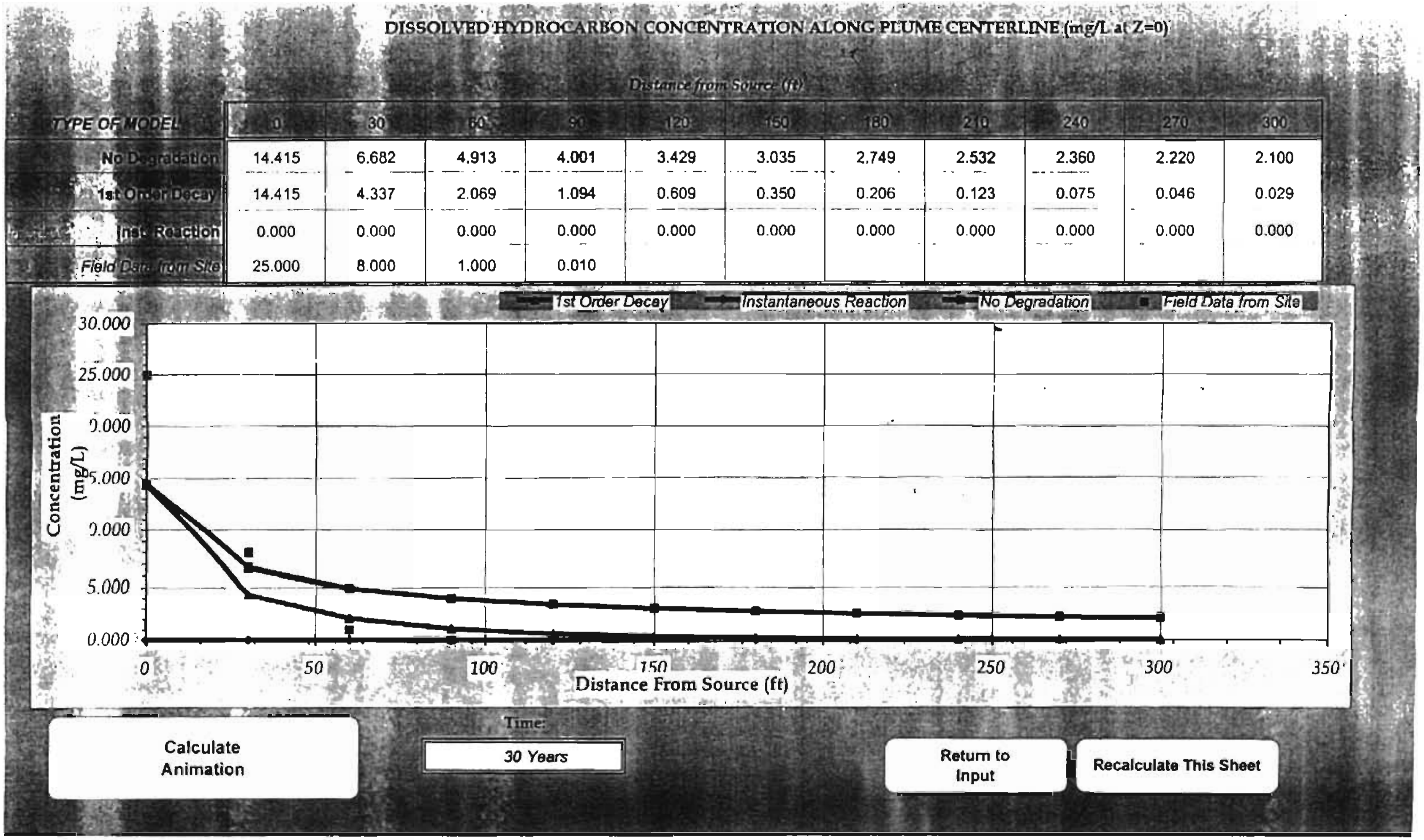
1st Order Decay	19.737	5.938	2.833	1.498	0.833	0.479	0.282	0.169	0.103	0.063	0.039
Inst. Reaction	7.265	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	25.000	8.000	1.000	0.010							

Time: 20 Years



DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0	30	60	90	120	150	180	210	240	270	300
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1st Order Decay	14.415	4.337	2.069	1.094	0.609	0.350	0.206	0.123	0.075	0.046	0.029
Inst. Reaction	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	25.000	8.000	1.000	0.010							

Time: 30 Years

VITA

Candy Rae Akins

Candidate for the Degree of
Master of Science

Thesis: APPLICABILITY OF BIOSCREEN TO A HYDROCARBON CONTAMINATED UNDERGROUND STORAGE TANK SITE

Major Field: Environmental Engineering

Biographical:

Education: Graduated from Guthrie High School, Guthrie, Oklahoma in May 1989; received a Bachelor of Science degree in Civil Engineering from Oklahoma State University, Stillwater, Oklahoma in May 1997. Completed the requirements for the Master of Science degree in Environmental Engineering at Oklahoma State University in May 1999.

Experience: Previously employed as a Civil Engineer Intern by Cobb Engineering Company of Oklahoma City, Oklahoma; previously performed grant-supported graduate research for the Department of Civil and Environmental Engineering at Oklahoma State University; currently employed by Cardinal Engineering, Inc. in the Oklahoma City office as a Project Manager since May 1998.

Professional Memberships: Chi Epsilon, Phi Kappa Phi, Oklahoma Society of Professional Engineers, National Society of Professional Engineers.