

## How Far? How Long? The BIOSCREEN Natural Attenuation Decision Support System

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### ABSTRACT

BIOSCREEN is an easy-to-use screening tool for simulating the natural attenuation of dissolved hydrocarbons at petroleum fuel release sites. The software, programmed in the Microsoft Excel spreadsheet environment and based on the Domenico analytical solute transport model, has the ability to simulate solute transport and estimate source zone decay. BIOSCREEN attempts to answer two fundamental questions regarding intrinsic remediation projects:

#### 1. How far will the plume extend if no engineered controls or further source zone reduction measures are implemented?

BIOSCREEN uses the Domenico analytical solute transport model to simulate advection, dispersion, adsorption, and aerobic decay as well as anaerobic reactions, which have been shown to be the dominant biodegradation processes at many petroleum release sites. Three different biodegradation models are provided: a) solute transport without decay, b) solute transport with biodegradation modeled as a first order decay process (lumped-process approach), and c) solute transport with biodegradation modeled as an "instantaneous" biodegradation reaction (approach used by the BIOPLUME model). Each biodegradation model will predict the maximum extent of plume migration, which may then be compared to the location of potential points of exposure (e.g. drinking water wells, groundwater discharge areas, or property boundaries).

#### 2. How long will the plume persist until natural attenuation processes cause it to dissipate?

BIOSCREEN uses a simple mass balance approach to estimate the decline in source zone concentration vs. time. The mass balance is based on a) the mass of dissolvable hydrocarbons in source zone soils and NAPL, b) the rate of hydrocarbons leaving the source zone, and c) an assumed exponential decay relationship for source concentration over time. While this relationship is unverified (there are little data showing source concentrations vs. long time periods), it should provide a relative estimate of the time required for the source to completely dissipate.

The Air Force Center for Environmental Excellence (AFCEE) is distributing BIOSCREEN software and manuals (Newell et al. 1996) via the EPA's Center for Subsurface Modeling Support (CSMoS) at the National Risk Management Research Laboratory in Ada, Oklahoma (Phone: 405 436-8594; Fax: (405) 436-8718; Web: <http://www.epa.gov/ada/bioscreen.html>. Electronic manuals will be in pdf format; users must download Adobe Acrobat Reader to read and print pdf files). The following sections are adapted from the BIOSCREEN User's Manual (Newell et al., 1996). An example application of BIOSCREEN is provided as Appendix 1.

## INTRODUCTION

### The Air Force Natural Attenuation Initiative

Over the past several years, the high cost and poor performance of many pump-and-treat remediation systems have led many researchers to consider remediation by natural attenuation (RNA) as an alternative technology for groundwater remediation. A detailed understanding of natural attenuation processes is needed to support the development of this remediation approach. Researchers associated with the U.S. EPA's R.S. Kerr Environmental Research Laboratory (now the Subsurface Protection and Remediation Division of the National Risk Management Laboratory) have suggested that anaerobic pathways could be a significant, or even the dominant, degradation mechanism at many petroleum fuel sites (Wilson, 1994). The Natural Attenuation Initiative, developed by the AFCEE Technology Transfer Division, was designed to investigate how natural attenuation processes affect the migration of plumes at petroleum release sites. Under the guidance of Lt. Col. Ross Miller, a three-pronged technology development effort was launched in 1993 which will ultimately consist of the following elements:

- 1) *Field data collected at over 30 sites around the country (Wiedemeier, Miller, et al., 1995) analyzing aerobic and anaerobic processes.*
- 2) *A Technical Protocol, outlining the approach, data collection techniques, and data analysis methods required for conducting an Air Force RNA Study (Wiedemeier, Wilson, et al., 1995).*
- 3) *Two RNA modeling tools: the BIOPLUME III model being developed by Dr. Hanadi Rifai at Rice University (Rifai et al., 1995), and the BIOSCREEN model developed by Groundwater Services, Inc. (BIOPLUME III, a more sophisticated biodegradation model than BIOSCREEN, employs particle tracking of both hydrocarbon and alternate electron acceptors using a numerical solver. The model employs sequential degradation of the biodegradation reactions based on zero order, first order, instantaneous, or Monod kinetics).*

## BIOSCREEN CONCEPTS

The BIOSCREEN Natural Attenuation software is based on the Domenico (1987) three-dimensional analytical solute transport model. The original model assumes a fully-penetrating vertical plane source oriented perpendicular to groundwater flow to simulate the release of organics to moving groundwater. In addition, the Domenico solution accounts for the effects of advective transport, three-dimensional dispersion, adsorption, and first-order decay. In BIOSCREEN, the Domenico solution has been adapted to provide three different model types representing i) transport with no decay, ii) transport with first-order decay, and iii) transport with "instantaneous" biodegradation reaction.

### BIOSCREEN Model Types

The software allows the user to see results from three different types of groundwater transport models, all based on the Domenico solution:

1. **Solute transport with no decay.** This model is appropriate for predicting the movement of conservative (non-degrading) solutes such as chloride. The only attenuation mechanisms are dispersion in the longitudinal, transverse, and vertical directions, and adsorption of contaminants to the soil matrix.

- 2. Solute transport with first-order decay.** With this model, the solute degradation rate is proportional to the solute concentration. The higher the concentration, the higher the degradation rate. This method is conventional for simulating biodegradation in dissolved hydrocarbon plumes. Modelers using the first-order decay model typically use the first-order decay coefficient as a calibration parameter, and adjust the decay coefficient until the model results match field data. With this approach, uncertainties in a number of parameters (e.g., dispersion, sorption, biodegradation) are lumped together in a single calibration parameter.

Literature values for the half-life of benzene, a readily biodegradable dissolved hydrocarbon, range from 10 to 730 days while the half-life for TCE, a more recalcitrant constituent, is 10.7 months to 4.5 years (Howard *et al.*, 1991). Other applications of the first-order decay approach include radioactive solutes and abiotic hydrolysis of selected organics, such as dissolved chlorinated solvents. One of the best sources for first-order decay coefficients in groundwater systems is *The Handbook of Environmental Degradation Rates* (Howard *et al.*, 1991).

The first-order decay model does not account for site-specific information such as the availability of electron acceptors. In addition, it does not assume any biodegradation of dissolved constituents in the source zone. The model assumes biodegradation starts immediately downgradient of the source.

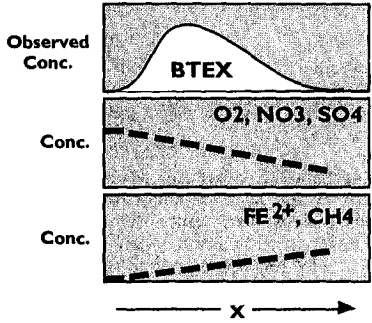
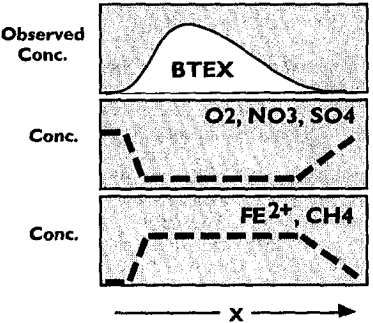
- 3. Solute transport with "instantaneous" biodegradation reaction.** Modeling work conducted by GSI indicate first-order expressions may not be as accurate for describing natural attenuation processes as the instantaneous reaction assumption (Connor *et al.*, 1994). Biodegradation of organic contaminants in groundwater is more difficult to quantify using a first-order decay equation because electron acceptor limitations are not considered. A more accurate prediction of biodegradation effects may be realized by incorporating the instantaneous reaction equation into a transport model. This approach forms the basis for the BIOSCREEN instantaneous reaction model.

To incorporate the instantaneous reaction in BIOSCREEN, a superposition method was used. Using this method, contaminant mass concentrations at any location and time within the flow field are corrected by subtracting 1 mg/L organic mass for each mg/L of biodegradation capacity provided by all of the available electron acceptors, in accordance with the instantaneous reaction assumption. Borden *et al.* (1986) concluded that this simple superposition technique was an exact replacement for more sophisticated oxygen-limited expressions, as long as the oxygen and hydrocarbon exhibited the same transport rates (e.g., retardation factor,  $R = 1$ ). Connor *et al.* (1994) revived this approach for use in spreadsheets and compared the results to those from more sophisticated but difficult to use numerical models. Since this approach works well, even for retardation factors greater than 1, it was incorporated into the BIOSCREEN model.

### Which Biodegradation Model?

Recent results from the AFCEE Natural Attenuation Initiative indicate that the anaerobic reactions, which were originally thought to be too slow to be of significance in groundwater, can also be simulated as instantaneous reactions (Newell *et al.*, 1995). For example, Davis *et al.* (1994) ran microcosm studies with sulfate reducers and methanogens that indicated that benzene could be degraded in a period of a few weeks (after acclimation). Considering the time required to replenish electron acceptors in a plume, it appears appropriate to simulate both aerobic and anaerobic biodegradation of dissolved hydrocarbons with an instantaneous reaction. This conclusion is

supported by observing the pattern of anaerobic electron acceptors and metabolic by-products along the plume at RNA research sites:

If microbial kinetics were limiting the rate of biodegradation:	If microbial kinetics were relatively fast (instantaneous):
<ul style="list-style-type: none"> <li>Anaerobic electron acceptors (nitrate and sulfate) would be constantly <b>decreasing</b> in concentration, moving downgradient from the source zone, and</li> </ul>	<ul style="list-style-type: none"> <li>Anaerobic electron acceptors (nitrate and sulfate) would be mostly or totally <b>consumed in the source zone</b>, and</li> </ul>
<ul style="list-style-type: none"> <li>Anaerobic by-products (ferrous iron and methane) would be constantly <b>increasing</b> in concentration, moving downgradient from the source zone.</li> </ul>	<ul style="list-style-type: none"> <li>Anaerobic by-products (ferrous iron and methane) would be <b>found in the highest concentrations in the source zone</b>.</li> </ul>
<p><b>Observed Conc.</b></p> 	<p><b>Observed Conc.</b></p> 

The second pattern is observed at RNA demonstration sites (see Figure 1), supporting the hypothesis that anaerobic reactions can be considered to be relatively instantaneous at most or almost all petroleum release sites. From a theoretical basis, the only sites where the instantaneous reaction assumption may not apply are sites with very low hydraulic residence times (very high groundwater velocities and short source zone lengths).

Kinetic-limited sites, however, appear to be relatively rare as the instantaneous reaction pattern is observed even at sites such as Site 870 at Hill AFB, with residence times of a month or less. As shown in Figure 1, this site has an active sulfate reducing and methane production zone within 100 ft of the upgradient edge of the plume. When a 1600 ft/yr seepage velocity is considered, this highly anaerobic zone has an effective residence time of 23 days. Despite this very short residence time, significant sulfate depletion and methane production were observed in this zone (see Figure 1). If the anaerobic reactions were significantly constrained by microbial kinetics, the amount of sulfate depletion and methane production would be much less pronounced. Therefore this site supports the conclusion that the instantaneous reaction assumption is applicable to almost all petroleum release sites.

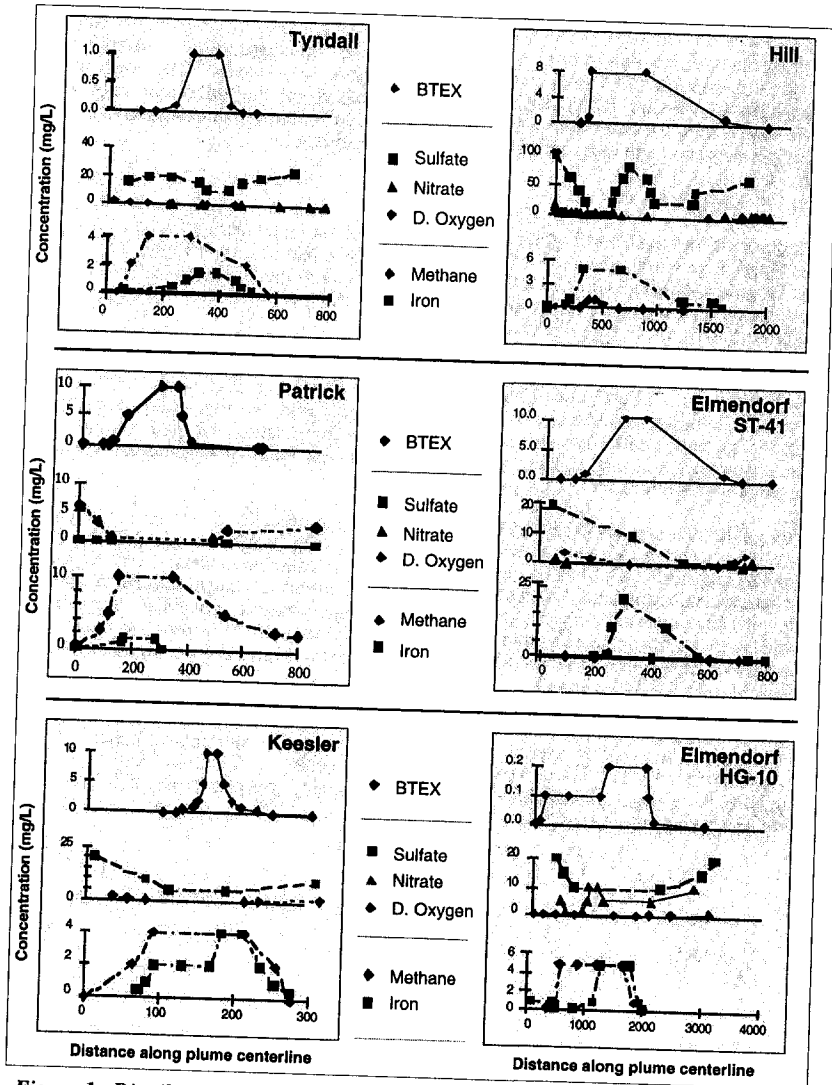


Figure 1. Distribution of BTEX, Electron Acceptors, and Metabolic By-Products vs. Distance Along Centerline of Plume.

Sampling Date and Source of Data: Tyndall 3/95, Keesler 4/95 (Groundwater Services, Inc.), Patrick 3/94 (note: one NO<sub>3</sub> outlier removed, sulfate not plotted), Hill 7/93, Elmendorf Site ST41 6/94, Elmendorf Site HG 10 6/94, (Parsons Engineering Science).

### Using the Instantaneous Reaction Model

To use the instantaneous reaction model, an estimate of the "biodegradation capacity" of groundwater flowing through the source zone and the plume area is needed. The suggested calculation approach to develop BIOSCREEN input data, based on the difference between background and source zone concentrations and a "utilization factor" based on stoichiometry (e.g., 3.14 gms of oxygen degrade 1 gm of hydrocarbon), is summarized below:

Biodegradation Capacity (mg/L) =

$$\begin{aligned} & \{ (\text{Average Upgradient Oxygen Conc.}) - (\text{Minimum Source Zone Oxygen Conc.}) \} / 3.14 \\ + & \{ (\text{Average Upgradient Nitrate Conc.}) - (\text{Minimum Source Zone Nitrate Conc.}) \} / 4.9 \\ + & \{ (\text{Average Upgradient Sulfate Conc.}) - (\text{Minimum Source Zone Sulfate Conc.}) \} / 4.7 \\ + & \{ \text{Average Observed Ferrous Iron Conc. in Source Area} \} / 21.8 \\ + & \{ \text{Average Observed Methane Conc. in Source Area} \} / 0.78 \end{aligned}$$

Note that at some sites the instantaneous reaction model will appear to overpredict the amount of biodegradation that occurs, and will underpredict at others. As with the case of the first-order decay model, some calibration to actual site conditions is required. With the first-order decay, the decay coefficient is adjusted arbitrarily until the predicted values match observed field conditions. With the instantaneous reaction model, there is no first-order decay coefficient to adjust, so the following procedure is recommended:

- a) The primary calibration step (if necessary) is to manipulate the model's dispersivity. Values for dispersivity are related to aquifer scale (defined as the plume length or distance to the measurement point) and simple relationships are usually applied to estimate dispersivities. Gelhar *et al.* (1992) cautions that dispersivity values vary between 2-3 orders of magnitude for a given scale (plume length) due to natural variation in hydraulic conductivity at a particular site. Therefore dispersivity values can be manipulated within a large range and may still be within the range of values observed at field test sites. In BIOSCREEN, adjusting the transverse dispersivity alone will usually be sufficient to calibrate the model.
- b) As a secondary calibration step, the biodegradation capacity calculation may be reevaluated. There is some judgment involved in averaging the electron acceptor concentrations observed in upgradient wells; determining the minimum oxygen, nitrate and sulfate concentrations in the source zone; and estimating the average observed ferrous iron and methane concentrations in the source zone. These values may be adjusted as a final level of calibration.

## ESTIMATION OF SOURCE LIFETIME

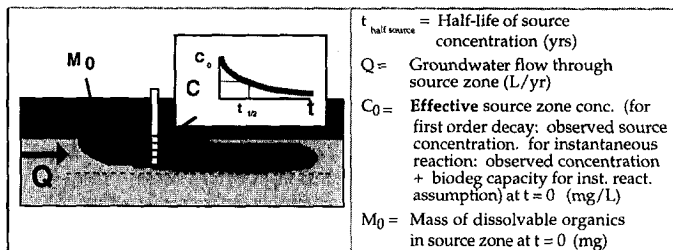
The Domenico (1987) model assumes the source is infinite (i.e. the source concentrations are constant). In BIOSCREEN, however, an approximation for a declining source concentration has been added. Note that this is an experimental relationship, and it should be applied with caution. The declining source term is based on the following assumptions:

- There is a finite mass of organics in the source zone present as a free-phase or residual NAPL. The NAPL in the source zone dissolves slowly as fresh groundwater passes through.
- The change in source zone concentration can be approximated as a first-order decay process. For example, if the source zone concentration "half-life" is 10 years and the initial source zone concentration is 1 mg/L, then the source zone concentration will be 0.5 mg/L after 10 years, and 0.25 mg/L after 20 years.

Note that the assumption that dissolution is a first-order process is only an approximation, and that source attenuation is best described by first-order decay when concentrations are relatively low (< 1 mg/L). For more information on dissolution, see Newell *et al.*, (1994). The source half-life **IS NOT** related to lambda, the biodegradation half-life for dissolved constituents. Lambda is used to calculate the amount of biodegradation of dissolved organics *after* they leave the source zone and travel through the plume area. The source half-life is related to the rate of dissolution occurring in the source zone, and describes the change in source concentrations over time.

- The BIOSCREEN software automatically calculates the source zone concentration half-life if the user enters a best estimate for the mass of dissolvable organics zone (soluble organic constituents sorbed on the soil, residual NAPLs, and free product) in the source. The half-life of the dissolution process can be approximated given the mass of dissolvable organics in the source zone (in mg or kg), the flow rate through the source zone, and the average concentration of dissolved organics that leave the source zone. The equation is based on integrating the concentration vs. time relationship (first-order decay) and using the relationship that the mass in the source zone over time is proportional to the source concentration over time. This yields the following expression for the half-life of the concentration of dissolved organics in the source zone (see Newell *et al.*, 1996 for complete derivation):

$$t_{\text{half source}} = (0.693 * M_0) / (Q * C_0) \quad \text{where:}$$



### Why are two source half-lives reported?

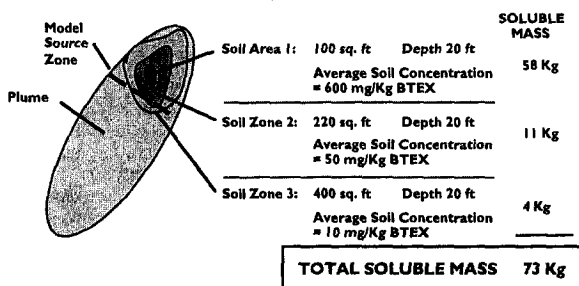
Note that BIOSCREEN automatically selects the correct source half-life value depending on which kinetic model is being used, first order decay vs. instantaneous reaction. Two source half-lives are reported by the model in the source half-life cell: the smaller number will be the source half-life

from dissolution if Instantaneous Reaction kinetics are used, and the larger value will be for No Degradation or First-order Decay kinetics. The first-order decay model assumes biodegradation starts immediately downgradient of the source, and that the rate of dissolution is reflected by the concentration of dissolved organics actually measured in monitoring wells. In other words, the first-order decay model assumes  $C_0$  is equal to the observed source concentration.

The instantaneous reaction model assumes biodegradation is occurring directly in the source zone, and that the **effective** source zone concentration  $C_0$  is equal to the measured concentration in the source zone plus any "missing" concentration due to biodegradation. For example, if the source zone concentration in monitoring wells is 5 mg/L, and the biodegradation capacity is 10 mg/L, the effective source concentration  $C_0$  (concentration before biodegradation) is 15 mg/L. This means use of the instantaneous reaction assumption will result in higher dissolution rates/shorter source lifetimes (see Newell *et al.*, 1995).

### How Is the Source Mass Estimated?

The best estimate of dissolvable organics in the source zone is obtained by adding the mass of dissolvable organics on soils, free-phase NAPLs, and residual NAPLs. This quantity is used to estimate the rate that the source zone concentration declines. For gasoline or JP-4 spills, BTEX is usually assumed to comprise the bulk of dissolvable organics in the source zone. This information will most likely come from integrating maps showing contaminated soil zones (data in mg/kg) and/or NAPL zones (usually product thickness). The user should estimate the volume of contaminated soil, convert to mass of contaminated soil, and multiply by the average soil concentration. To make the estimate more accurate, the soil may be divided into different zones of soil concentrations, into unsaturated vs. saturated soil, and/or into different depths. One standard approach is to divide the soil into a vertically averaged unsaturated zone map and a vertically averaged saturated zone map. If estimates are made from NAPL data, remember that the thickness of product in a aquifer is only 10-50% of the actual product thickness in the well (Bedient *et al.*, 1994). Note that the data is to be entered in kg, and the model will convert the results to estimate the source half-life. An example is shown below using bulk density of 1.7 kg/L (e.g.,  $100 \text{ ft}^2 \times 20 \text{ ft} \times 28.3 \text{ L/ft}^3 \times 1.7 \text{ kg/L} \times 600 \text{ mg/kg} \times 10^{-6} \text{ kg/mg} = 58 \text{ kg}$ ):



### BIOSCREEN EXAMPLE

An example application of BIOSCREEN is shown in Appendix 1.

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## BIOGRAPHICAL SKETCHES:

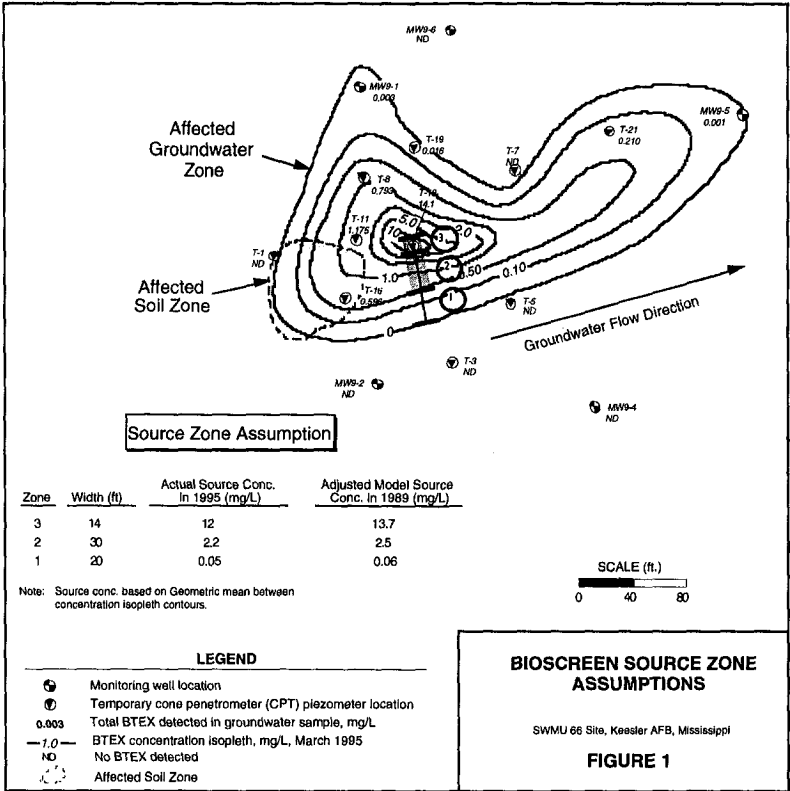
**Charles J. Newell** is Vice President and Environmental Engineer with Groundwater Services, Inc. and an Adjunct Professor of Environmental Engineering at Rice University. He is a co-Principal Investigator for GSI's Natural Attenuation project and co-author of the Prentice-Hall textbook Groundwater Contamination: Transport and Remediation. Groundwater Services, Inc., 5252 Westchester, Suite 270, Houston, Texas 77005. Phone: (713) 663-6600 fax: (713) 663-6546 e-mail: cjenewell@gsi-net.com

**R. Kevin McLeod** is a regulatory specialist with Groundwater Services Inc. His experience includes the negotiation and litigation of state water quality, hazardous waste and radioactive materials permitting cases. Mr. McLeod has extensive experience in developing computer software for the Windows environment, including BIOSCREEN and HYPER335, a hypertext version of the Texas Industrial Solid Waste Rules.

**James R. Gonzales** is an Environmental Engineer with the Technology Transfer Division for the Air Force Center for Environmental Excellence. He is currently involved in projects investigating natural attenuation, bioventing, and vapor phase treatment technologies. 3207 North Road, Bldg 532, Brooks AFB, San Antonio, Texas 78235-5363.

**APPENDIX 1 - BIOSCREEN EXAMPLE**  
**Keesler Air Force Base, SWMU 66, Mississippi**

Hydrogeology	<ul style="list-style-type: none"> <li>Hydraulic Conductivity:</li> <li>Hydraulic Gradient:</li> <li>Porosity:</li> </ul>	1.1 x 10 <sup>-2</sup> (cm/sec) 0.003 (ft/ft) 0.3	<ul style="list-style-type: none"> <li>Slug-tests results</li> <li>Static water level measurements</li> <li>Estimated</li> </ul>																								
Dispersion	Original: <ul style="list-style-type: none"> <li>Longitudinal Dispersivity:</li> <li>Transverse Dispersivity:</li> <li>Vertical Dispersivity:</li> </ul> After Calibration: <ul style="list-style-type: none"> <li>Longitudinal Dispersivity:</li> <li>Transverse Dispersivity:</li> <li>Vertical Dispersivity:</li> </ul>	13.3 (ft) 1.3 (ft) 0 (ft) 32.5 (ft) 3.25 (ft) 0 (ft)	<ul style="list-style-type: none"> <li>Based on estimated plume length of 280 ft and Xu/Eckstein relationship</li> <li>Based on calibration to plume length (Note this is well within the observed range for longitudinal dispersivity).</li> </ul>																								
Adsorption	<ul style="list-style-type: none"> <li>Retardation Factor:</li> <li>Soil Bulk Density rb:</li> <li>foc:</li> <li>Koc:</li> </ul>	1.0 1.7 (kg/L) 0.0057% B: 38                      T: 135 E: 95                        X: 240	<ul style="list-style-type: none"> <li>Calculated from R = 1+Koc x foc x rb/n</li> <li>Estimated</li> <li>Lab analysis</li> <li>Literature: use Koc = 38</li> </ul>																								
Biodegradation	Electron Acceptor: Background Conc. (mg/L): Minimum Conc. (mg/L): Change in Conc. (mg/L):  Electron Acceptor: Max. Conc. (mg/L): Avg. Conc. (mg/L):	<table border="0"> <tr> <td><u>O<sub>2</sub></u></td> <td><u>NO<sub>3</sub></u></td> <td><u>SO<sub>4</sub></u></td> </tr> <tr> <td>2.05</td> <td>0.7</td> <td>26.2</td> </tr> <tr> <td>- 0.4</td> <td>- 0</td> <td>- 3.8</td> </tr> <tr> <td><b>1.65</b></td> <td><b>0.7</b></td> <td><b>22.4</b></td> </tr> <tr> <td colspan="3"> </td> </tr> <tr> <td><u>Fe</u></td> <td><u>CH<sub>4</sub></u></td> <td></td> </tr> <tr> <td>36.1</td> <td>7.4</td> <td></td> </tr> <tr> <td><b>16.6</b></td> <td><b>6.6</b></td> <td></td> </tr> </table> Note: Boxed values are BIOSCREEN input values.	<u>O<sub>2</sub></u>	<u>NO<sub>3</sub></u>	<u>SO<sub>4</sub></u>	2.05	0.7	26.2	- 0.4	- 0	- 3.8	<b>1.65</b>	<b>0.7</b>	<b>22.4</b>				<u>Fe</u>	<u>CH<sub>4</sub></u>		36.1	7.4		<b>16.6</b>	<b>6.6</b>		<ul style="list-style-type: none"> <li>Based on March 1995 groundwater sampling program conducted by Groundwater Services, Inc.</li> </ul>
<u>O<sub>2</sub></u>	<u>NO<sub>3</sub></u>	<u>SO<sub>4</sub></u>																									
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36.1	7.4																										
<b>16.6</b>	<b>6.6</b>																										
General	<ul style="list-style-type: none"> <li>Modeled Area Length:</li> <li>Modeled Area Width:</li> <li>Simulation Time:</li> </ul>	320 (ft) 200 (ft) 6 (yrs)	<ul style="list-style-type: none"> <li>Based on area of affected groundwater plume</li> <li>Steady-state flow</li> </ul>																								
Source Data	<ul style="list-style-type: none"> <li>Source Thickness:</li> <li>Source Concentration:</li> </ul>	10 (ft) (See Figure 1)	<ul style="list-style-type: none"> <li>Based on geologic logs and lumped BTEX monitoring data</li> </ul>																								
Actual Data	<ul style="list-style-type: none"> <li>Distance From Source (ft):</li> <li>BTEX Conc. (mg/L):</li> </ul>	<table border="0"> <tr> <td><del>30</del></td> <td><del>60</del></td> <td><del>180</del></td> <td><del>280</del></td> </tr> <tr> <td>5.0</td> <td>1.0</td> <td>0.5</td> <td>0.001</td> </tr> </table>	<del>30</del>	<del>60</del>	<del>180</del>	<del>280</del>	5.0	1.0	0.5	0.001	<ul style="list-style-type: none"> <li>Based on observed concentrations at site</li> </ul>																
<del>30</del>	<del>60</del>	<del>180</del>	<del>280</del>																								
5.0	1.0	0.5	0.001																								
OUTPUT	Centerline Concentration:	See Figure 3	<ul style="list-style-type: none"> <li>BIOSCREEN Centerline Output</li> </ul>																								
	Array Concentration:	See Figure 4	<ul style="list-style-type: none"> <li>BIOSCREEN Array Concentration Output</li> </ul>																								



## **BIOSCREEN Modeling Summary, Keesler Air Force Base, SWMU 66, Mississippi:**

- BIOSCREEN was used to try to reproduce the movement of the plume from 1989 (the best guess for when the release occurred) to 1995.
- The soluble mass in soil and NAPL was estimated by integrating BTEX soil concentration contours mapped as part of the site soil delineation program. An estimated 2000 kg of BTEX was estimated to be present at the site based on GC/MS analysis of soil samples collected from both the vadose and saturated zone. This value represented a source half-life of 60 years with the instantaneous reaction model (the first value shown in the source half-life box in Figure 2), a relatively long half-life, so the 2000 kg measured in 1995 was assumed to be representative of 1989 conditions.
- The instantaneous reaction model was used as the primary model to try to reproduce the plume length (~ 280 ft).
- Because a decaying source was used, the source concentration on the input screen (representing concentrations 6 yrs ago) were adjusted so the source concentration on the centerline output screen (representing current concentrations) were equal to 12 mg/L. Because the source decay term is different for the first order decay and instantaneous reaction models, this simulation focused on matching the instantaneous reaction model. The final result was a source concentration of 13.68 mg/L in the center of the source zone (note on the centerline output the source concentration is 12.021 mg/L).
- The initial run of the instantaneous reaction model indicated that the plume was too long. This indicates that there is more mixing of hydrocarbon and electron acceptors at the site than is predicted by the model. Therefore the longitudinal dispersivity was adjusted upwards (more mixing) until BIOSCREEN matched the observed plume length. The final longitudinal dispersivity was 32.5 ft.
- As a check, the first-order decay model was used with the BIOSCREEN default value of 2 yrs. This run greatly overestimated the plume length, so the amount of biodegradation was increased by decreasing the solute half-life. A good match of the plume was reached with a solute half-life of 0.15 years. This is within observed ranges reported in the literature.
- As shown in Figure 3, BIOSCREEN matches the observed plume fairly well. The instantaneous model is more accurate near the source while the first order decay model is more accurate near the middle of the plume. Both models reproduce the actual plume length relatively well.
- As shown in Figure 4, the current plume is estimated to contain 7.8 kg of BTEX. BIOSCREEN indicates that the plume under a no-degradation scenario would contain 126.3 kg BTEX. In other words BIOSCREEN indicates that 94% of the BTEX mass that has left the source since 1989 has biodegraded.
- Most of the source mass postulated to be in place in 1989 is still there in 1996 (2000 kg vs. 1837 kg, or 92% left).
- The current plume contains 1.0 ac-ft of contaminated water, with 1.019 acre-ft/yr of water being contaminated as it flows through the source. Because the plume is almost at steady state, 1.019 ac-ft of water become contaminated per year with the same amount being remediated every year due to in-situ biodegradation and other attenuation processes. This indicates that a long-term monitoring approach would probably be more appropriate for this site than active remediation, as the plume is no longer growing in size.



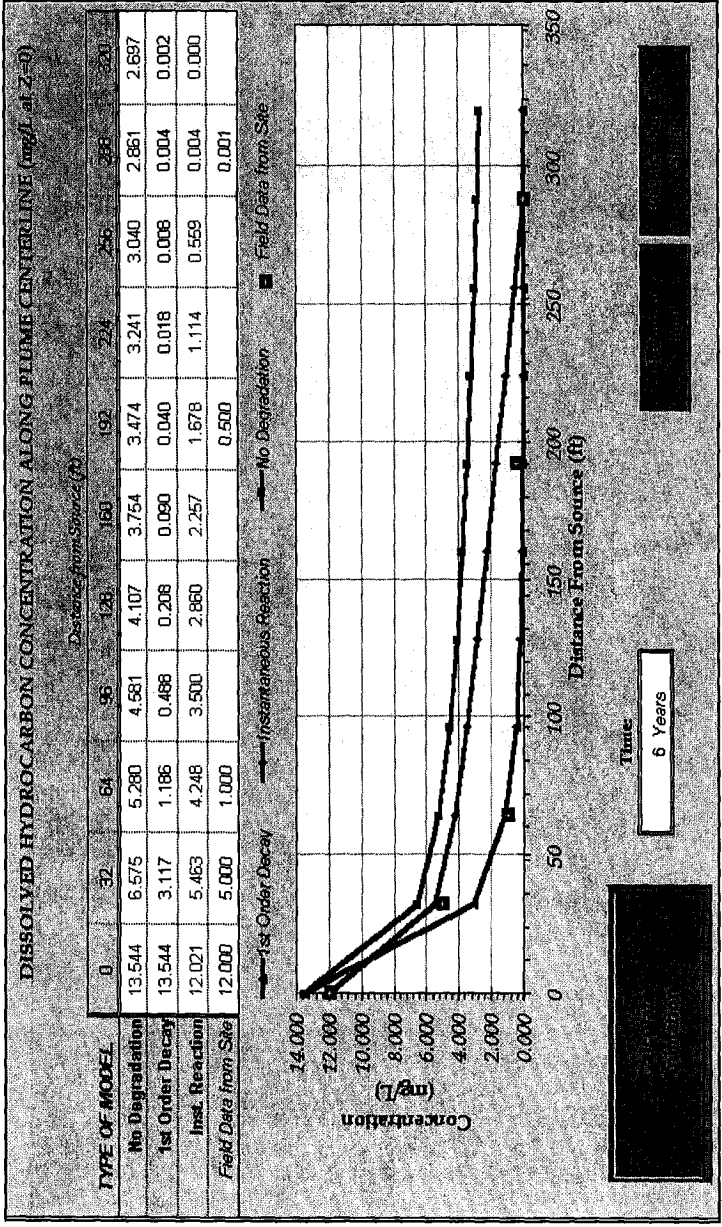


Figure 3. Centerline Output. Keesler Air Force Base, Mississippi.

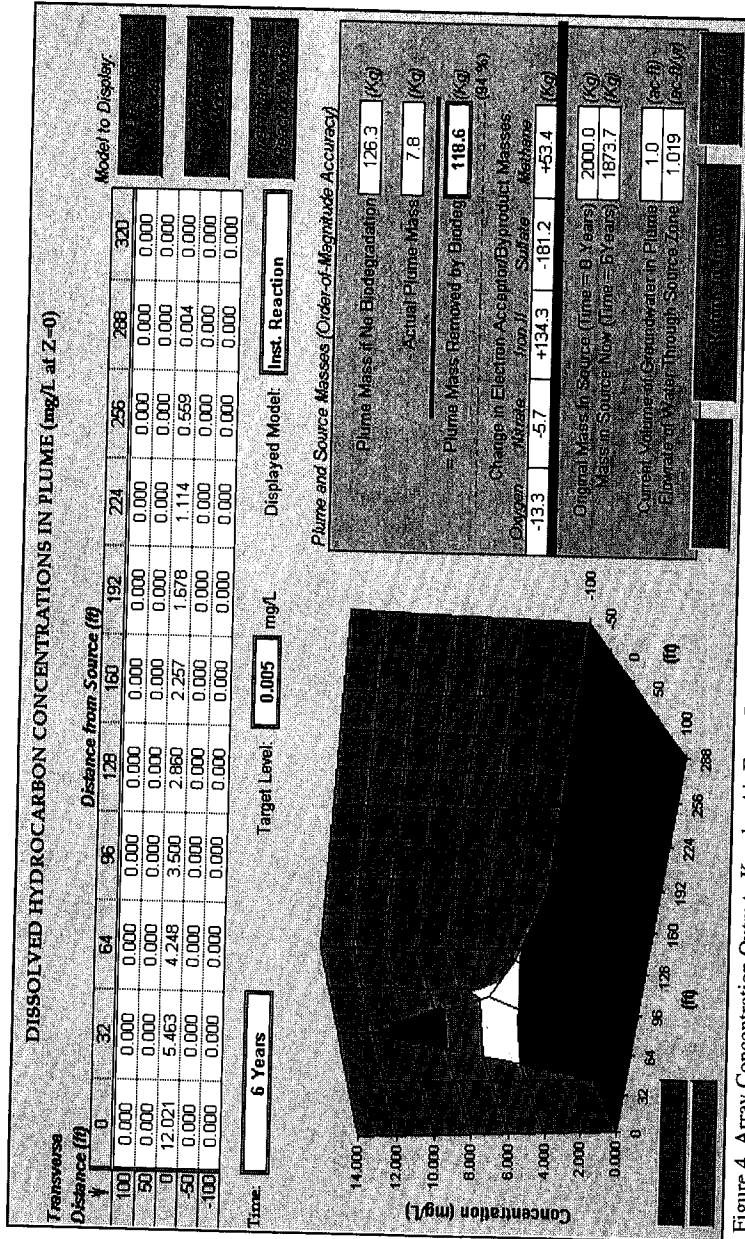


Figure 4. Array Concentration Output. Keesler Air Force Base, Mississippi.