

SOIL CONTAMINATION AS A GROUNDWATER CONTAMINATION INDICATOR

Prepared for

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1 Introduction

This report documents research performed for the New Jersey Department of Environmental Protection and Energy under NJDEPE Contract P30120. The goal of the project is to develop a defensible method to trigger groundwater monitoring at sites at which contaminants have been released to soil. The project is in response to a desire to improve the existing groundwater monitoring trigger. Such an improved trigger would enable NJDEPE to allocate resources more efficiently and to preserve public health more effectively.

To make the trigger more defensible, we have attempted to avoid the flaws that plague similar decision tools developed in the past. We have avoided arbitrary scoring of site parameters, relying on a statistical analysis of data taken from a randomly selected sample of closed NJDEPE case files. We have avoided reliance on a single indicator variable such as a fate and transport model, instead considering a wide spectrum of possible explanatory variables. We have also attempted to verify the results of the trigger by application to other NJDEPE case files.

Application of the trigger would occur at a relatively early stage of site investigation. Therefore, data available for the trigger are expected to be limited. For this reason, we have developed a relatively simple trigger that is based on a few easily-characterized parameters judged to be good indicators of groundwater contamination. The trigger is also expected to be applied to a large number of sites by a wide range of NJDEPE case managers. This planned use of the trigger has suggested a straightforward approach. We have stressed ease of implementation to ensure correct use of the trigger and consistency of results.

Based on these considerations, we have identified five discrete project tasks:

- 1) identify potential indicator variables,
- 2) identify and analyze NJDEPE sites,
- 3) evaluate potential indicator variables and develop the trigger,
- 4) develop and document user-friendly software for implementation of the trigger, and
- 5) assess performance of the trigger.

We begin by identification of variables that affect the fate and transport of contaminants in the vadose zone. Variables are identified based on a review of the professional literature and professional judgement. The ability of these variables to provide an indication of groundwater contamination is evaluated as part of Task 3.

The case files of NJDEPE are randomly sampled to obtain a set of sites for analysis. Potential indicator variables are characterized at these sites.

Evaluation of potential indicator variables is based on data obtained from NJDEPE case files. A simple statistical test is applied to each variable. Only those variables that exhibit a statistically significant ability to indicate groundwater contamination are selected for inclusion in the trigger. The trigger is developed based on the selected indicator variables.

The trigger is incorporated into a user-friendly, menu-driven piece of software. The software is based on Quattro® Pro and allows easy, consistent implementation of the trigger. A user's guide is provided that explains operation of the trigger.

The performance of the trigger is assessed by application to the set of sites identified in Task 2 as well as additional sites provided by NJDEPE. Strengths and weaknesses of the trigger are identified and discussed.

We describe each of these tasks in the sections that follow.

We conclude the report with a summary of our results, a discussion of some implications of our results, and recommendations for further research.

2 Identification of potential indicator variables

Fate and transport parameters relevant to the behavior of contaminants in the subsurface soil environment are identified based on the experience of the project investigators and a review of the pertinent literature. In this section, we limit our analysis to a description of processes and parameters that may prove important.

Loague, *et al.* (1990) address a problem similar to that under consideration here. They provide a convenient scheme for grouping parameters. We use a modified version: 1) chemical parameters, 2) soil parameters, 3) climatic parameters, and 4) site characteristics. We add an additional category: 5) derived parameters. We employ this convention in the discussion that follows.

2.1 Chemical parameters

This category of potential indicator variables includes parameters that define relationships between and within phases. Most contaminants are introduced to the vadose zone in the non-aqueous phase. Although many contaminants are relatively insoluble, some dissolution occurs as contaminants come into contact with water in the soil. Volatilization can also occur from both the non-aqueous and aqueous phases. Contaminants can sorb to soils and organic matter in soils. Contaminants can also degrade as a result of several mechanisms.

We consider four chemical parameters that define relationships between phases: solubility, vapor pressure, Henry's Law constant, and organic carbon coefficient. Solubility is the maximum aqueous concentration of a chemical. The vapor pressure is the pressure exerted by the vapor phase of a chemical in equilibrium with its liquid phase. The vapor pressure can be converted to a vapor phase concentration with the Ideal Gas Law. The Henry's Law constant is a constant of proportionality that relates the aqueous concentration of a chemical to the vapor phase concentration in air above the aqueous phase. It is defined to be the ratio of the vapor pressure and the solubility of the chemical. Solubility, vapor pressure, and Henry's Law constant vary with temperature. The organic carbon coefficient is a constant of proportionality that relates the aqueous concentration of a chemical to concentration of the chemical adsorbed to carbon matter in contact with the aqueous phase.

In addition to the phase relationships, degradation within phases must also be taken into account. Degradation occurs due to a number of processes, including redox reactions, hydrolysis, and biodegradation.

Biodegradation is an exceedingly complex process that is not well understood. For any given chemical, biodegradation involves the properties and concentration of the chemical, the availability of trace nutrients, and the complex dynamics of a variety of microbial populations

(Mackay, *et al.*, 1992). All of these characteristics are known to vary widely from site to site (Gelhar, *et al.*, 1989). In addition, experimental studies have demonstrated that biodegradation is dominated by the availability of oxygen (Borden and Bedient, 1986). For chemical mixtures, these difficulties are multiplied. Degradation may result in the formation of some contaminants such as vinyl chloride.

Given the complexity of the biodegradation processes and the goal of the project to develop a relatively simple system that can be applied at a variety of sites, we assume chemical transformations to be limited to biodegradation. We recognize that biodegradation is a site-specific process. However, we also recognize it to be a process that is not well understood and about which little site-specific information is usually available. For these reasons, we assume that biodegradation is likewise independent of site conditions and can be described by a single parameter, the half-life of a chemical. Since it is reasonable to assume the vadose zone is well-aerated so that oxygen is easily available, aerobic half-life values will be used.

Chemical parameter values are reported in Table 2.1. The vapor pressure and Henry's Law constant are calculated based on the mean annual temperature in Atlantic City, New Jersey of 11.5°C (U.S. Department of Commerce, 1987) and the Antoine expression parameters reported in Ohe (1976).

2.2 Soil parameters

The soil parameters category of potential indicator variables consists of those parameters that describe a soil's ability to retain and conduct water and contaminants. These parameter values can vary significantly in space and, under some circumstances, time.

The moisture retention curve is a parameterization of a soil's ability to retain water with respect to the influences of gravity and capillary pressure. For given conditions of pressure, the moisture retention curve yields the moisture content of the soil. The moisture retention curve of a soil depends on the particle size distribution and the geometry of the particles.

The unsaturated hydraulic conductivity curve is a parameterization of the soil's ability to conduct water with respect to its moisture content. For a given moisture content, the unsaturated hydraulic conductivity curve yields a specific value of hydraulic conductivity. Hydraulic conductivity is dependent on a variety of factors, including soil particle distribution, chemical makeup of the soil and impurities in the water, and the geometry of the soil particles at the pore scale.

Field capacity is the moisture content of the soil after gravity drainage is complete (Linsley, *et al.*, 1982). It is measured more frequently than either the moisture retention curves or the unsaturated hydraulic conductivity curves and is frequently used as a surrogate for them.

It is important to note that sharp changes in soil characteristics, such as is caused by stratification of soils or fractures in the soils, have been observed to dominate the movement of water and the migration of non-aqueous phase contaminants in the vadose zone. These effects can produce unexpected behavior of moisture and contaminants such as strongly enhanced or inhibited vertical movement (Mantoglou and Gelhar, 1987; Schwille, 1988). The study of the effects of changes in soil characteristics is an area of active research. Consideration of such effects will influence assessment of trigger performance in Section 6.

Soils often contain plant matter, especially in the upper soil horizon. This organic matter can result in retardation of the rate of migration of most organic chemicals as a result of adsorption of the chemical. The soil organic content or organic fraction is the fraction of the soil that is organic matter. In clean sands and gravels, the organic fraction can be zero. In organic-rich soils such as peats or agricultural soils, organic fractions can be several percent.

The rate at which ionic contaminants such as metals migrate in soils having very small particles is affected by the process of ion exchange. Ion exchange is, in turn, affected by pH. Thus, knowledge of pH is critical in determining the mobility of ionic contaminants such as metal cations in soil.

In addition to those parameters listed above, it is also useful to have estimates of bulk density, the density of soil including volume occupied by pores, and soil particle density, the density of the soil particles alone. Since the variability of these quantities and their effect on moisture and contaminant movement is relatively small, especially in comparison to the other properties, it may be possible to rely on values reported in the scientific literature.

Most of the parameters listed above are not typically measured at a site. In these cases, either surrogate parameters must be used, or values of the parameters of interest must be obtained from the scientific literature.

At most sites, soil texture is usually classified. Soil texture categories are based on soil particle analyses which, in turn, can be correlated with moisture retention and hydraulic conductivity curves. Although such correlations are less than perfect, their use is strongly encouraged by the lack of alternatives. Freeze and Cherry (1979) and de Marsily (1986) provide ranges of saturated hydraulic conductivity associated with various soil types. Bear (1972), van Genuchten (1980), and Korfiatis, *et al.* (1990) report moisture retention curves and unsaturated hydraulic conductivity curves for some soils.

2.3 Climatic parameters

We consider climatic parameters that affect subsurface conditions. These parameters are not site-specific but are specific to relatively local regions. In addition, they vary with time.

There are two critical climatic parameters: precipitation and evapotranspiration. Precipitation is that water that falls to the ground. Evapotranspiration is a parameter that combines two linked processes: evaporation and transpiration. These parameters, combined with features of ground cover and topography, govern the rate at which water infiltrates into the soil. Since the rate of precipitation can vary greatly with time, a time sequence of precipitation that reflects local conditions should be used. In practice, it is more convenient to use annual averages. Evapotranspiration also varies with time. Since it is very seldom measured, an annual average is typically used.

Temperature is also of interest since several of the chemical parameters are dependent on temperature. Like precipitation, temperature varies with time, though to a smaller degree than precipitation. Again, annual averages are used.

2.4 Site characteristics

Site characteristics are aspects of the site that affect the behavior of contaminants in the vadose zone. These characteristics can be expected to vary from site to site in an unpredictable way and should be assessed for each site.

The most important site characteristic is the nature of the contamination. The nature of contamination must first be characterized before assessing fate and transport characteristics. Also, NJDEPE groundwater standards are chemical-specific. If a meaningful comparison with standards is to be made, the individual contaminants must be identified. The extent of contamination should also be characterized. Doing so helps eliminate the possibility of undetected contributions to site contamination from sources other than the site. Since downward migration is of primary concern, characterization of the depth of the release (or at least of relevant soil samples) may be sufficient.

The nature of the release should also be characterized. Such characterization includes knowledge of the history of the site and activities that may have contributed to contamination. Ideally, the quantity and time of release should be estimated.

Topography and ground cover exert a strong influence on the rate of infiltration (Linsley, *et al.*, 1982). These characteristics are highly site-specific and can vary widely across a single site, especially in urban areas where the ground surface has been modified extensively.

The other important site characteristic that exerts a strong influence on the rate of infiltration is the moisture content of the soil during infiltration. The moisture content is dependent on soil properties such as the moisture retention and hydraulic conductivity curves. Since soil properties vary both across a site and with depth, moisture content and hence infiltration characteristics, can

also be expected to vary. In addition, moisture content is dependent on recent precipitation history, changing in response to infiltration and evapotranspiration.

The depth of the water table gives an indication of the ability of the vadose zone to provide a buffer against migration of contaminants downward to the saturated zone. It can vary substantially with time. This depth should be determined.

2.5 Derived parameters

Derived parameters cannot be measured directly. They are estimated or derived from combinations of parameters that are measured. Although these parameters are not measured directly, they can be treated in the same manner as parameters that are. Furthermore, since the behavior of contaminants in the vadose zone is complex, it is possible that individual parameters may be incapable of accurately indicating groundwater contamination. By applying our understanding of contaminant behavior in the vadose zone, we may be able to combine parameters in a meaningful way via derived parameters.

The derived parameters we consider are estimated transport time and attenuation of contaminants. These estimates are based on the assumption that if contaminants are held in the vadose zone for long enough, they will cease to be a threat to groundwater as a result of volatilization or degradation. The models used to make these estimates are described in Section 4.1.

2.6 Summary of potential indicator variables

Potential indicator variables discussed in the preceding sections are summarized in Table 2.2. The variables have been abbreviated in some of the sections that follow to simplify spreadsheet formatting. These abbreviations are listed in Table 2.3. This set of variables can be compared with variables compiled by others for similar purposes. Table 2.4 reproduces Table 1 in U.S. Environmental Protection Agency (1989). Allowing for differences in terminology, comparison of the variables reported in Table 2.2 and Table 2.4 shows the two sets to be very similar.

2.7 Tables

Table 2.1 Chemical parameter values

Chemical	solubility (mg/L)	See Note	Vapor pressure (atm)	See Note	Henry's Law Constant (dim'les)	See Note	half-life (hours)	See Note	organic carbon adsorption coefficient K_{oc} (mL/g)	See Note
benzene	1805	a	0.065	b	0.121	c	384	d	100	e
toluene	564	a	0.018	b	0.117	c	528	d	200	e
ethyl benzene	170	a	0.0055	b	0.125	c	240	d	380	f
xylenes	178	a	0.0051	b	0.121	c	672	d	300	g
trichloroethene	1050	a	0.044	b	0.236	c	8640	d	100	e
tetrachloroethene	260	a	0.011	b	0.211	c	8640	d	302	e

Notes

a Mackay and Shiu (1981)

b Ohe (1976), at a temperature of 11.5 C (as referenced in text)

c Calculated from solubility and vapor pressure, at a temperature of 11.5 C (as referenced in text)

d Howard, et al. (1991). Reported values are maximum half-lives in soil.

e Korfiatis and Talimcioglu (1991)

f U.S. EPA (1986)

g Roy and Griffith (1985)

The chemical parameter values for p-xylenes are assumed to be representative of all xylenes.

Table 2.2 Potential indicator variables

chemical parameters	soil parameters
solubility vapor pressure Henry's Law Constant organic carbon coefficient half-life/biodegradation rate	moisture retention curve hydraulic conductivity curve organic fraction pH porosity bulk density
climatic parameters	site characteristics
precipitation evapotranspiration temperature	type of contaminant depth of release history of site/release quantity of release soil moisture content depth of water table presence of pavement
derived parameters	
transport time contaminant attenuation	

Table 2.3 Potential indicator variable abbreviations

Variable	Abbreviations
detection of contaminant in soil	det
non-detection of contaminant in soil	ND
exceedence of soil standard	exc, exceed
non-exceedence of contaminant in soil	NE
finest soil texture	fin, fine, f
coarsest soil texture	coa, coarse
clay	c
silt	si
sand	s
gravel	g
transport distance	d
ground cover	cov, cover
transport time	t_{tr} , tr
retarded transport time	t_{tr} , rtr
retarded transport time threshold	thresh _{tr}
attenuation factor	af
solubility	S
vapor pressure	P_v
half-life	$t_{1/2}$
organic carbon coefficient	K_{oc}
chemical property	prop

Table 2.4 Fate and transport processes affecting subsurface migration identified by U.S. EPA (1989)

Category	Process	Factor Affecting Process
Physical	advection dispersion flow in fractures diffusion precipitation dissolution	topography climate precipitation soil type vegetative cover depth to groundwater soil permeability soil void ratio soil-moisture characteristics geology hydrology morphology
Chemical	partitioning - sorption/desorption - ion exchange - volatilization equilibrium speciation - acid/base equilibration - organic complexation - inorganic complexation abiotic transformation - hydrolysis - oxidation/reduction	physical, chemical properties of contaminants geology
Microbial	oxidation/reduction and hydrolysis	geology contaminants microbial environment

3 Reviews of NJDEPE case files

This section documents the case file reviews and reports results. The reviews of NJDEPE case files are intended to serve two purposes. First, the reviews are intended to reveal site characteristics that dominate the behavior of contaminants in the vadose zone, as typically found in New Jersey. Second, the reviews are intended to provide a set of files that can be used to assess the performance of the completed trigger.

Two reviews were conducted. The first consists of a random search of closed cases from the files of NJDEPE Bureau of Underground Storage Tanks (BUST). This search was performed by the Principal Investigator. The second review was performed by members of NJDEPE staff. The second file review was not random; only files that met predefined criteria were selected.

3.1 Random search

The Principal Investigator performed a review of a set of closed BUST case files during the period October 19 to November 15, 1993. The random review of case files was conducted in two phases. First, a preliminary review was performed to gain a broad understanding of the information available. In conjunction with the parameters identified in Section 2, the results of the preliminary survey were used to identify information of interest in the case files. This information was gathered during the course of the second phase. In the process of gathering information, many of the files were discarded for a variety of reasons.

File selection was intended to be random. However, some potential biases are apparent in the file selection process. This section summarizes information obtained from the random search and summarizes possible biases in the file selection process.

3.1.1 Case selection procedure

Thirteen storage boxes containing approximately 200 BUST case files were set aside for review. At the outset of the review, it was decided that only those case files in which both soil and groundwater data were reported for the same contaminants would be acceptable for use. It was also decided that a preliminary review was necessary to gain an overview of the type and quality of information included in BUST case files.

For these reasons, the first step of the random search consisted of a preliminary review. This review located 88 files in which groundwater analyses were reported. Each of the 88 sites is briefly described in Appendix A. The following information was consistently available in these files: the name and BUST case number or UST number for the site, the city or county in which the site was located, the date of case closure or site assessment report, the capacity of the tank, the depth to the water table, the depth of the monitoring well, and visual soil texture analysis.

The contents of the tank were usually reported or could easily be inferred. In some instances, however, the contents of the tank were not reported. Also, the type of ground cover, if any, in the vicinity of the tank was usually reported.

The second review focussed on these 88 case files. This review consisted of a thorough assessment of the adequacy of each case file for purposes of this project. As a result of this second review, many files were judged unsuitable for purposes of this project. These files were rejected. The most common reason for rejection is that soil samples were analyzed for different contaminants than were groundwater samples. Typically, soil samples were collected following excavation (post-excavation or post-ex samples) and were analyzed for total petroleum hydrocarbons (TPH). Groundwater samples were typically analyzed by a modified version of U.S. EPA method 624, which includes volatile organic compounds. The modification to method 624 consists of expanding the list of compounds to include xylenes and other compounds.

The second most common reason for rejection is that the tank or tanks at a given site were situated in the saturated zone. Since groundwater sampling would be required in such cases regardless of other factors, these sites were not relevant to this project.

Other cases were rejected because of incomplete case files or insufficient documentation. At a small number of sites, the source of groundwater contamination was contested. Since it is impossible for us to resolve issues of source identification, these cases were rejected.

Multiple USTs were reported at some sites. The USTs were treated as individual cases if contamination from different USTs could be clearly distinguished.

Of the 88 case files that have been examined, 18 were judged suitable for purposes of this project. Four of these cases include more than one site, for a total of 22 cases. All of these cases include analyses for benzene, toluene, ethylbenzene, and xylenes (BTEX). Some also include analyses for TPH, methyl tertiary butyl ether (MTBE), and tertiary butyl alcohol (TBA).

Data obtained from each of the 22 cases used in this project are summarized in Appendix B.

3.1.2 Potential biases in selection procedure

Although we are reasonably confident that the review was random, we have observed at least three potential sources of bias in the selection procedure of BUST case files. Recognition of such biases is important since, if significant, they could compromise our results. We discuss the potential sources of bias in this section.

We reviewed closed case files. These case files were selected to facilitate access to the files and to minimize disruption to normal BUST operations. Our review of BUST case files indicates

that case files are opened upon notification of a leaking UST. Our review also suggests that such notification occurs only upon on-site observation of contaminated soil or tanks that are not intact. If so, case files may be opened only at sites that have a relatively high degree of contamination. If a trigger based on these files were applied only to sites for which a case file had been opened for a particular site, this matter would be of no consequence. However, if the trigger were applied to sites for which case files had not been opened, the likelihood of groundwater impacts would be overestimated and groundwater monitoring would be triggered at more sites than necessary.

The second potential bias concerns the duration of BUST cases. NJDEPE has acknowledged that cases in which contamination was minimal, those that require no active cleanup, are more easily brought to closure than cases requiring active remediation. Ideally, the BUST program would have been underway much longer than the typical closure time of cases requiring active remediation. Since the BUST program is relatively young, it is possible that many of the cases requiring active remediation have not yet been closed. If this were the case, the sample would be biased toward cases in which the level of contamination was relatively low. This bias would result in a trigger that indicated groundwater monitoring at fewer sites than necessary.

This potential bias can easily be assessed, at least qualitatively. We recommend that NJDEPE personnel familiar with the BUST program compare the duration of cases with the program with the duration of the program itself. If the duration is substantially less than the duration of the existence of the BUST program, it can probably be concluded that the magnitude of this bias is negligible.

The third potential bias is introduced by the selection procedure. As described in Section 3.1.1, cases were included only if both soil and groundwater were sampled for the same compounds. Sampling groundwater is required if conditions of the existing trigger are met.¹ This requirement reflects the judgement of NJDEPE that existing trigger conditions are indicative of a groundwater impact. Assuming these conditions to be effective to some degree, it is likely that groundwater contamination is more likely in the set of cases in which both soil and groundwater were sampled. Therefore, a trigger based on these results would indicate groundwater monitoring at more sites than necessary.

¹ Until June, 1992, provisions of the trigger included a requirement to monitor groundwater if the UST contained gasoline. After June, 1992, groundwater monitoring was required if applicable soil standards were exceeded.

3.1.3 Observations

In this section we summarize observations made during the review of BUST case files. Most BUST cases and the manner in which they were treated under the BUST program share several important characteristics. In some instances, these characteristics aid our analysis. In others, these characteristics limit our analysis and its applicability to other types of sites.

Most sites were relatively small and often consisted of single USTs or sets of USTs grouped together. Values of many potential indicator variables fall within a narrow range. Distance from sample location to water table ranged from 5 to 10 feet in almost all cases. The soil texture was typically silt and sand, with layering frequently observed. As a result of these limited ranges, extension of the trigger to sites with larger transport distances and different soil types may be difficult.

The source of contamination was well-defined in almost all cases. However, characterization of most sites was limited. In many cases, fewer than five soil samples and three groundwater samples were analyzed. In some cases (for example, Firestone Retail Outlet) soil or groundwater samples were taken several months after UST removal. Such samples may not adequately characterize the site.

Boring logs were consistently reported and soil texture analyses appeared to be relatively complete. In almost all instances, borings were placed within 10 to 20 feet of the UST.

3.2 Directed search

In addition to UST sites, the directed search included a wide range of hazardous waste disposal sites. These sites exhibited different characteristics than those identified through random search.

25 case files were identified by directed search. These files were selected by NJDEPE personnel based on exceedence of the applicable standard for at least one chemical despite indication to the contrary by the existing groundwater monitoring trigger. Thus, at least one groundwater standard is exceeded at all 25 of the directed search sites.

Since files obtained from directed search efforts were not randomly selected, they are not amenable to rigorous statistical treatment. In the present section, we briefly summarize relevant information in each case file obtained from directed search. Application of the trigger to these sites is discussed in Section 6.2.

3.2.1 Summaries of files obtained from directed search

We briefly summarize relevant details of sites located in the directed search.² We also include the bureau and case number, if reported.

Adhesives & Chemicals

Bureau and case number: BEECRA #89-332

Toluene was detected at maximum concentrations of 50 ppm in soil and 51000 ppb in groundwater. The water table is located approximately 25 to 30 feet below ground surface. Soil texture analysis was not provided.

Allied Signal, Inc.

Bureau and case number: BGWPA, #NR

Carbon tetrachloride was not detected in soil but was detected in groundwater at a maximum concentration of 32 ppb. The depth to the water table is 175 feet. The source of contamination has not been determined. Soil is fine to medium sand with some gravel.

Apache Building Products

Bureau and case number: BGWPA #NR

Several chlorinated solvents, including tetrachloroethene and trichloroethene, were detected in groundwater at maximum concentrations of 9.6 and 7.3 ppb, respectively. Tetrachloroethene was also detected in soil at ppb levels. Boring logs indicate soil to be silt with a trace of sand (>15% fines). The water table is located between 6 and 8 feet below ground surface.

Asco Electronics

Bureau and case number: BGWPA #85185

Tetrachloroethene, trichloroethene, and t-1,2-dichloroethene were detected in soil and groundwater. The maximum soil and groundwater concentrations of tetrachloroethene are 5.9 ppm and 110 ppm, respectively. The maximum concentrations of trichloroethene are 0.110 ppm and 5200 ppb, respectively. The maximum concentrations of t-1,2-dichloroethene are 0.12 ppm and 31000 ppb. In addition, vinyl chloride was detected in groundwater at a maximum concentration of 5900 ppb but was not detected in soil. The water table is located between 8.5 and 9 feet below ground surface. Boring logs indicate the soil to be fill, with clayey sand and gravel and cobbles.

² These descriptions are based on summary reports provided by NJDEPE. For this reason, the descriptions may not include all important aspects of each site. Detection limits were not reported in most cases.

Atlantic Plastic Container**Bureau and case number: BGWPA #84407**

Several chemicals were detected in soil and groundwater. Maximum concentrations are as follows:

contaminant	soil conc. (ppm)	groundwater conc. (ppb)
1,1-dichloroethane	NR	7.6
1,1-dichloroethene	6.5	12
tetrachloroethene	150	26
toluene	110	5400
1,1,1-trichloroethane	350	130
trichloroethene	0.79	ND

The water table is 27 feet below ground surface. The soil was classified as sand with some gravel.

Boxal**Bureau and case number: BGWDC #NR**

Tetrachloroethene was detected in soil at a concentration of 2.6 ppm and in groundwater at 610 ppb. Trichloroethene, vinyl chloride, and t-1,2-dichloroethene were also detected in groundwater at maximum concentrations of 390, 14, and 350 ppb, respectively, but were not detected in soil. The water table is located 4 feet below the ground surface. Soil was characterized as sand with some silt and fine gravel.

Cenco Petroleum**Bureau and case number: BGWPA #90062**

Petroleum product contamination was detected in surface soils adjacent to above-ground storage tanks. No contaminants were detected in deeper soils, although odor was observed upon boring. Floating product was detected on the water table at a depth of 10 feet. Soil borings indicate soil to be sand and gravel.

Eco Pump - Zone 4**Bureau and case number: BGWPA #84409**

Volatile organics were detected in soil at a depth of 6". The maximum concentration is 298 ppm. An uncontaminated zone was detected at a depth of 36". Trichloroethene and other chlorinated solvents were detected in groundwater. The maximum concentration of trichloroethene in groundwater is 591 ppm. The water table is located 8 to 15 feet below ground surface. Soil consists of shale fragments and shale bedrock.

Eco-Pump - Zone 1**Bureau and case number: BGWPA #84409**

The source of contamination has not been identified.

Electrical Industries**Bureau and case number: BEECRA #88-717**

The summary report is unclear.

Essex Chemical**Bureau and case number: BGWPA #84357**

Tetrachloroethene was detected at maximum concentrations of 15 ppb in near-surface soil and 24000 ppb in groundwater. Toluene was also detected in groundwater at a maximum concentration 590 ppb. Weathered bedrock is present near the surface. The water table is approximately 12 feet below the ground surface.

Garden State Motors**Bureau and case number: BGWPA #85585**

Trichloroethene was detected in groundwater at a maximum concentration of 1400 ppb but was not detected in the soil. The water table is located 28 feet below grade. Soil texture is characterized as sand with a few clay lenses.

Inmont - Belvidere**Bureau and case number: BGWPA #85559**

Ethylbenzene was detected at maximum concentrations of 266 ppm in soil and 8800 ppb in groundwater. Toluene was detected at maximum concentrations of 62 ppm in soil and 15000 ppb in groundwater. Xylenes were detected in groundwater at a maximum concentration of 41450 ppb but were not detected in soil. The water table is 17 feet below ground surface. Soil texture is silt grading to a fine gravel.

J.B. Moore**Bureau and case number: BGWPA #87356**

BTEX and several chlorinated solvents were detected in surface soils and were observed to decrease with depth to non-detect levels at 20 to 30 feet below ground surface. Total volatile organics were detected in groundwater in excess of applicable groundwater standards. Maximum soil concentrations are as follows:

contaminant	soil conc. (ppm)
benzene	0.342
1,1-dichloroethane	7.01
1,1-dichloroethene	2.66
1,2-dichloroethene (total)	1.81
ethylbenzene	57.5
tetrachloroethene	114
toluene	212.0
trichloroethene	61.7
xylenes	177.9

The water table is located 25 to 30 feet below ground surface. Soil was classified as sand and perched water tables were observed.

Keystone Camera

Bureau and case number: BGWPA #85761

Tetrachloroethene was detected in soil at a maximum concentration of 470 ppm at a depth of 5 to 7 feet. Trichloroethene was also detected at a concentration of 0.090 ppm at the same depth. Tetrachloroethene and trichloroethene were detected in groundwater at maximum concentrations of 2826 and 12157 ppb, respectively. Xylenes were also detected in soil (3.1 ppm) but not in groundwater. The water table is 19-20 feet below ground surface. Soil is a mixture of gravel, sand and silt.

Kramer Chemical

Bureau and case number: BGWPA #90397

Free phase 1,2,4-trichlorobenzene was detected in groundwater at a maximum concentration of 228 ppm. Other organic chemicals were also detected but not reported. No contamination was detected in soil. The water table is approximately 14 feet below ground surface and the soil is sand with a clay layer.

Lenox China

Bureau and case number: BGWPA #NR

Trichloroethene was not detected in soil (detection limit 0.005 ppm) but was detected in groundwater at a maximum concentration of 68 ppb. The water table is located approximately 10 feet below ground surface. The soil was characterized as sand.

McGraw-Edison**Bureau and case number: BGWPA #85034**

Tetrachloroethene and trichloroethene concentrations in soil were observed to decrease with depth. An uncontaminated zone was detected in soil. Maximum groundwater concentrations of tetrachloroethene and trichloroethene were reported to be 15000 and 1100 ppb, respectively. The water table is located at a depth of 20 feet. Soil is a sandy silt.

McKesson Chemical**Bureau and case number: GWDC #86817**

Several contaminants were detected in soil and in groundwater. Maximum concentrations were reported as follows:

contaminant	soil conc. (ppm)	groundwater conc. (ppb)
1,1-dichloroethane	6.9	6600
1,1-dichloroethene	15	37000
t-1,2-dichloroethene	3.4	17000
tetrachloroethene	47	13000
1,1,1-trichloroethane	80	540000
toluene	8.3	8
trichloroethene	74	130000

The depth to groundwater is reported to be 10 to 12 feet. Soil was characterized as silt, clay, and fine sand.

Metramatic**Bureau and case number: BGWPA #88529**

Trace levels of tetrachloroethene were detected in soil. The maximum groundwater concentration was 3068 ppb. The water table is approximately 17 feet below ground surface. Soil texture was characterized as poorly sorted glacial till.

Puratex Company, Inc.**Bureau and case number: NR**

Tetrachloroethene was detected in soil at a maximum concentration of 27.6 ppm and in groundwater at a maximum concentration of 28 ppb. The water table is located approximately 95 feet below ground surface. Soil is sand with traces of silt and gravel.

Rockaway Borough Wellfield**Bureau and case number: BGWPA #NR**

Trichloroethene was detected in groundwater at 56 ppb but was not detected in soil at a depth of 22 to 24 feet. Soil concentrations at other locations were not reported. The water table is 24 feet below ground surface. Soil texture was classified as sand.

Schaible Oil Company**Bureau and case number: BGWPA #91183**

Benzene, toluene, ethylbenzene, and xylenes were detected in groundwater at maximum concentrations of 5700, 20000, 4000, and 18100 ppb, respectively. Floating product was also observed. Soil samples taken at a depth of 10 feet exhibited no detectable contamination. Concentrations of soil samples taken from elsewhere were not reported. The depth to the water table is 18 feet. Characterization of soil texture is not reported.

Shieldalloy**Bureau and case number: BFCM #NR**

Trichloroethene and 1,2-dichloroethene were detected in surface soils at maximum concentrations of 2 and 3 ppb, respectively. They were detected in groundwater at maximum concentrations of 840 and 270 ppb, respectively. 1,1-dichloroethene and 1,1,1-trichloroethane were also detected in groundwater at maximum concentrations of 1 and 3 ppb, respectively. The water table is approximately 8 to 10 feet below ground surface and the soil was classified as sand.

Shoreco**Bureau and case number: BGWPA #NR**

Xylenes were detected in soil at a maximum concentration of 1700 ppm. Benzene was also detected in soil at a maximum concentration of 2.6 ppm. Toluene and ethylbenzene were also detected in soil at trace levels. Maximum groundwater concentrations of benzene, toluene, ethylbenzene, and xylenes are 590, 12, 130, and 85 ppb, respectively. The water table is 6.4 feet below ground surface. The source of contamination is a group of USTs. Due to the shallow water table, these USTs were probably situated in the saturated zone.

3.2.2 Observations

Overall, characteristics of the sites located in the directed search differ from those of the sites located in the random search. First, unlike the BUST sites that make up the majority of the random search files, source characteristics of the directed search files vary widely and include short-term spills at well-defined locations, long term releases at relatively dispersed locations, as well as unknown releases. These sites involve a wide range of contaminants, not just BTEX. It is difficult to evaluate the degree of site investigation due to the variable quality of the summaries received from NJDEPE, but it appears site investigations are more extensive than those conducted under BUST. Due to the wide variety of site characteristics, however, it is not clear the nature and extent of contamination is defined better than in the BUST program. Finally, as for BUST sites, our review suggests soil texture does not appear to indicate groundwater standard exceedences or the lack thereof.

In addition, review of these sites suggests anticipation of contaminant behavior can be exceedingly difficult. Despite evidence of limited soil contamination at some sites, extensive groundwater contamination was observed. At some sites, groundwater contamination was observed despite failure to detect contaminants at some depths. These findings suggest characterization of soil contamination is often incomplete or that contaminants behave in a way that is more complex than anticipated by site investigators and case managers.

Soil texture was characterized as sand at the majority of the directed search sites, though in many cases heterogeneities were noted.

The transport distance at most directed search sites falls within the same range as the random search sites, 10 to 20 feet. However, at two of the directed search sites (Allied Signal and Puratex), transport distances are substantially larger than any reported for the random search sites.

4 Evaluation of potential indicator variables and development of trigger

In this section, we use NJDEPE data to identify potential indicator variables that dominate fate and transport of contaminants in the vadose zone. We evaluate the potential indicator variables qualitatively and quantitatively. The variables that are effective indicators of groundwater contamination are incorporated into the groundwater monitoring trigger.

4.1 Comparison of potential indicator variables with case file data

Potential indicator variables are introduced in Section 2 and are listed in Table 2.2. Review of case reports suggests that some of the variables listed in Table 2.2 are readily available to case managers. Other variables are seldom available. If variables are unavailable to case managers, they cannot readily be used as indicator variables. Alternatively, it may be possible to use literature-derived values or surrogates for some variables that are not available.

Review of NJDEPE case files indicates the variables usually available to the case manager are the following: type of contaminant(s), soil concentrations in samples taken at some discrete points in the immediate vicinity of the UST, observations of soil texture from ground surface to the water table, the depth of the water table, and the nature and extent of ground cover. In BUST cases, the depth of release can usually be inferred, at least roughly, by the location of the bottom of the tank. Surface sources (*e.g.*, spills, leaks in above ground storage tanks) can often be identified when present. It is also likely the case manager will have some knowledge of local precipitation and temperature or regional values for the State of New Jersey.

NJDEPE has indicated we are to consider the maximum measured soil concentration as a potential indicator variable. Since the number of soil samples taken at many BUST sites is often limited to three or four, this approach is probably adequate. At sites with more extensive soil sample collection programs, however, it may be appropriate to consider an estimate of the mean as a potential indicator variable.

Detailed history of the site and release is seldom available. Even when available, it is limited. Most of the site's history must be inferred from information gathered during the site investigation. The volume of the release is rarely, if ever, known with any certainty. Soil moisture content is seldom measured. Instead, soil moisture content values are usually inferred from soil texture analyses or taken from the literature (the list provided in Linsley *et al.*, 1982, is typical).

Precipitation, temperature, and evapotranspiration are rarely, if ever, evaluated for a site. Regional values are available, however (annual precipitation and temperature for regions throughout the U.S. are reported in U.S. Bureau of the Census, 1987; Thornthwaite, 1948, reports regional potential evapotranspiration). Variation of temperature, precipitation, and evapotranspiration across the State of New Jersey is not large and is not expected to indicate

groundwater contamination. For this reason, these variables are not considered as potential indicator variables.

Measurements of soil parameters (moisture retention curve, hydraulic conductivity, organic fraction, pH, porosity, and bulk density) are seldom available. Even when they are available, they are based on a limited number of soil samples. Spatial heterogeneity of soil properties may severely restrict the utility of such estimates. In practice, soil parameters are obtained from the literature. Typically, they are based on analysis of the texture of the soil at the site. Values of porosity and bulk density are widely reported (see Linsley *et al.*, 1982, Korfiatis *et al.*, 1990, and Ladwig and Hensel, 1993, for examples). Moisture retention and hydraulic conductivity curves are reported for a limited number of soils. Usually, however, moisture content, porosity, and bulk density are used to infer moisture retention and hydraulic conductivity curves. Korfiatis *et al.* (1990) report inferred curves. Mantoglou and Gelhar (1987) and Yeh *et al.* (1985) report inferred as well as measured curves. A third alternative is to rely on porosity and moisture content alone.

The organic fraction of soil is rarely measured. The organic fraction in surface soils is usually less than 5% and decreases rapidly with depth. pH is seldom measured but can be expected to vary substantially. However, pH is not known to strongly affect migration of the BTEX and other organic compounds under consideration in this project.

Given knowledge of the contaminant, chemical parameters can be obtained from standard references or a database compiled expressly for this purpose. The parameters reported in Table 2.1 represent a modest start for such a database, one that is sufficient for the limited number of contaminants of concern at most UST sites. For each chemical, we have estimated vapor pressure and Henry's Law coefficient for the mean annual temperature in New Jersey, 11.5°C (U.S. Bureau of the Census, 1987). As has been noted in Section 2.1, biodegradation is acknowledged to be dependent on both chemical- and site-specific characteristics. However, as discussed in Section 2.1 we assume biodegradation to be independent of site conditions and rely on chemical-specific values reported in Howard *et al.* (1991). The chemical parameter values listed in Table 2.1 are evaluated as potential indicator variables.

It is widely acknowledged in the literature that the migration of contaminants in the vadose zone is a complex process that is influenced by a wide variety of factors (Schwille, 1988; Freeze and Cherry, 1979; de Marsily 1986). For this reason, considering indicator variables in isolation may not give a good indication of the vulnerability of a site to groundwater contamination.

One way to account for the influence of more than one variable is to consider variables in combination. For example, we could evaluate the effect of soil texture and soil concentration or soil texture and transport distance on the frequency of groundwater contamination. Regression techniques provide a widely used framework for performing this type of analysis. The chief disadvantage of this approach is that, to be meaningful, it requires a database larger than that

available. Such techniques are further constrained by the requirement of linear relationships between variables.

An alternative approach is to consider combinations of the relevant variables via variables such as soil texture or the presence of ground cover and derived variables such as estimated groundwater concentration, transport time, or degree of contaminant degradation. We have elected to take this approach.

We consider soil texture as a surrogate for soil hydraulic properties. Our approach is similar to that employed in similar projects such as those reported in Korfiatis *et al.* (1990) and Ladwig and Hensel (1993). In these studies, soil properties are assumed for each soil type. We also assume soil properties as required. Soil properties are based on soil textures reported in boring logs.

We consider the presence of pavement as a surrogate for the rate of infiltration at a site. As Linsley *et al.* (1992) report, the presence of asphalt or cement pavement can reduce the rate of infiltration by more than 90%. Other factors are also known to affect the rate of infiltration: presence and type of vegetation, topography, and surface soil type as well as soil types at greater depths. If ground cover is not present, these factors can dominate the infiltration process. However, these factors appear to be relatively unimportant if ground cover is present. Since information concerning variables such as the presence of vegetation and topography were not consistently reported in the BUST files, we restrict consideration of infiltration surrogates to ground cover.

Various models are available for estimation of groundwater concentrations and transport times from the source to the water table. Computer models available include SESOIL, IMPACT (Korfiatis *et al.*, 1990), and SWMS-2D (International Ground Water Modeling Center). Analytical solutions such as those presented by Kalinski *et al.* (1994) and El-Kadi (1992) are also available. Loague (1991) and Loague *et al.* (1990), who are concerned with evaluating the vulnerability of aquifers to pesticide contamination, rely on two variables, a retardation factor and an attenuation factor.¹

All of these models describe fate and transport of contaminants dissolved in infiltrating water.² However, non-aqueous phase and vapor phase transport can play important, if not dominant,

¹ The attenuation factor essentially compares biodegradation rates with transport times in an exponential decay model.

² Some, such as SESOIL, consider volatilization. However, volatilization is treated only as a depletion mechanism and does not affect groundwater impacts.

roles in groundwater contamination under some circumstances (Schwille, 1988). We do not mean to suggest that these mechanisms are unimportant. However, the mechanisms are not well understood and models that describe these processes are not generally available. Furthermore, they are considerably more complex than models describing fate and transport of the dissolved phase. For these reasons, we restrict our attention to fate and transport of dissolved contaminants.

Under ideal circumstances, estimation of groundwater concentrations would be the best derived variable since it provides a direct estimate of the variable of interest. However, accurate estimation of contaminant concentrations in groundwater for each site is a demanding task, one that requires accurate characterization of the source, soil, and rate of infiltration. Dilution in the saturated zone between the point of impact and the monitoring well must also be taken into account. The case files contain data insufficient to adequately characterize these variables. Routine characterization of each site to such a degree would probably be prohibitively expensive. In addition, application of the relatively complex models required to estimate groundwater concentrations would demand a high level of expertise.

Estimation of dissolved phase transport time is considerably less demanding than estimation of groundwater contaminant concentrations. Extensive characterization of the source and dilution in the saturated zone is not required. The primary requirement is accurate estimation of the rate of infiltration and downward movement of water and contaminants.

Based on the foregoing considerations, estimation of dissolved phase travel time was selected as the primary derived variable of interest.

We have selected a transport-time screening model based on those reported by Kalinski *et al.* (1994) and Haith and Laden (1989). The model accounts for the effect of layered soils in a straightforward manner. Since we have no information concerning infiltration rates at the site, we use a slightly modified version based on an estimate of the infiltration rate:

$$t_{tr} = \frac{1}{q} \sum_{i=1}^n h_i \theta_i \quad (4.1)$$

where

t_{tr} = transport time, year,
 q = infiltration rate, ft/year,
 h_i = thickness of soil layer i , ft,
 θ_i = moisture content in soil layer i , dimensionless, and
 n = total number of soil layers.

We use Equation (4.1) to estimate time of transport from soil sample location to water table. For a given site, we obtain some model parameters from NJDEPE case files and rely on literature values for the remainder.

The infiltration rate is estimated as described below. Soil texture characterization and layer thicknesses are available from boring logs reported for each site (summarized in Appendix B). Moisture content in Equation (4.1) is assumed to be field capacity.

Estimates of field capacity for clay, silt, and sand are available in Linsley *et al.* (1982). They are

soil type	field capacity
sand	0.05
silt	0.22
clay	0.36

The field capacity of gravel is assumed to equal that of sand.

Estimation of the rate of infiltration is based on regional precipitation data and the SCS method for estimating runoff and infiltration. U.S. Bureau of the Census (1987) reports annual precipitation at Atlantic City to be 41.93 inches. We assume this value to be representative of the State of New Jersey.

Assuming evapotranspiration to be negligible, we divide precipitation into two components (after Chow *et al.*, 1988):

$$P = P_e + I \quad (4.2)$$

where

P = precipitation, inches,
 P_e = rainfall excess (runoff), inches,
 I = infiltration, inches.

Rainfall runoff can be expressed as a fraction, f_i , of total precipitation. Substituting f_i and solving for infiltration yields:

$$I = (1 - f_i)P \quad (4.3)$$

Rainfall runoff is estimated for two cases, sites with asphalt or concrete ground cover, and those without. Assuming the soil to be a sandy loam (Soil Conservation Service (SCS) Group B), the

corresponding SCS Curve Numbers are 98 and 82 for paved and unpaved areas, respectively (Linsley, *et al.*, 1982). These curve numbers yield estimates for infiltrating fraction of total precipitation of 0.07 and 0.8 for paved and unpaved areas, respectively. Substituting these values into Equation (4.3) yields estimates of annual infiltration of 2.9 and 34 inches/year.

Loague (1991) and Loague *et al.* (1990) define a retardation factor as follows:

$$RF = 1 + \frac{\rho_b f_{oc} K_{oc}}{\theta_{fc}} C + \frac{H}{\theta_{fc}} - \frac{\rho_b H}{\rho_s \theta_{fc}} - H \quad (4.4)$$

where

ρ_b = bulk density of the soil, kg/m³,
 f_{oc} = soil organic carbon fraction, dimensionless,
 K_{oc} = organic carbon coefficient, mL/g,
 θ_{fc} = soil moisture content at field capacity,
 ρ_s = soil particle density, kg/m³,
 H = Henry's Law coefficient, dimensionless, and
 C = conversion factor, 0.001 g-m³/kg-mL.

We evaluate retarded transport time from sample location to water table by combining the retardation factor of Equation (4.4) with the transport-time screening model of Equation (4.1). Since Equation (4.4) depends on soil characteristics that vary with texture, it is applied to each soil layer:

$$t_{rr} = \frac{1}{q} \sum_{i=1}^n h_i \theta_i RF_i \quad (4.5)$$

where RF_i is the retardation factor calculated for layer i .

The soil organic fraction was assumed to be 0.01 and the particle density to be 2650 kg/m³ for all soil types. The organic carbon coefficient and Henry's Law coefficient are chemical-specific and are reported in Table 2.1. Assumed bulk densities of soil types are as follows:

soil type	bulk density kg/m ³
sand	1520
silt	1280
clay	1200

Loague (1991) and Loague *et al.* (1990) use a pesticide mobility index to estimate land use impacts on groundwater. The index can be readily adopted for use as a potential indicator variable. The index, referred to as an attenuation factor (AF), simply compares an estimate of transport time with the half-life of the contaminant, yielding the fraction of contaminant remaining. The attenuation factor is expressed

$$AF = \exp \left[-\frac{\ln 2}{t_{1/2}} t_{tr} \right] \quad (4.6)$$

where

$t_{1/2}$ = half-life of the contaminant, 1/year, and

We evaluate the attenuation factor, Equation (4.6), as a potential indicator variable. Estimates of contaminant half-lives are included in Table 2.1.

Groundwater and soil contamination, as well as potential indicator variable data obtained from the case files are summarized in Table 4.1, Table 4.2, and Table 4.3, respectively. Estimated values of derived variables are listed in Table 4.4.

Evaluation of potential indicator variables is discussed in Sections 4.3 and 4.4.

4.2 Treatment of data

Data were obtained from two sources. The first is the set of case files selected randomly by the Principal Investigator from BUST case files. The second source is the set of case files selected by NJDEPE case managers. These files were selected because groundwater contamination was observed despite the failure of the existing trigger to indicate groundwater monitoring. Both sources of data are discussed in detail in Section 3. Here, treatment of information obtained from both sources is described.

Two aspects of the treatment of randomly selected site data should be noted. First, it is not possible to use some statistical techniques because the data and variables of interest are not continuous. These considerations suggest grouping the data into categories and analyzing them

with statistical techniques designed for treating discrete data. The second aspect of data treatment is that some indicator variable data were unavailable or otherwise unusable for some sites. These sites were excluded from evaluation of the indicator variable.

4.2.1 Categorization of data

Contaminants were detected in groundwater with relatively low frequency. The majority of the data are non-detects. In addition, the variable of interest, exceedence of the groundwater standard, not groundwater concentration as such, is not a continuous variable, but one consisting of a threshold. NJDEPE desires a second threshold, exceedence of the soil standard, to be considered as part of the groundwater monitoring trigger. These considerations make the use of standard techniques (for example, linear regression and ANOVA) to evaluate potential indicator variables difficult at best. In addition, some of the potential indicator variables are best treated as discrete data. Potential indicator variables that fall into this category are ground cover and soil type.

One way to overcome these constraints is to use maximum-likelihood techniques to estimate the distribution of groundwater concentrations. However, the high degree of censoring precludes use of these techniques: no single BTEX compound was detected in groundwater at more than four of the 22 sites considered.

Buxton and Stedfast (1994) consider the problem of using censored data to identify indicator variables. They apply the Kruskal-Wallis test to their data set (Conover, 1971). Conover indicates the test is well-suited to situations in which many ties are found in the data. Non-detects cannot be treated as ties, however, since the true concentration lies at an unknown point between zero and the detection limit. Therefore, the Kruskal-Wallis test is inappropriate for this application. Another test commonly used in similar situations, the Mann-Whitney test, is inappropriate for the same reason.

An alternative is available. It consists of dividing the groundwater data and potential indicator variables into two discrete populations. Grouping data this way enables us to treat the data as if drawn from discrete distributions. Statistical methods for the treatment of discrete distributions have been developed (Benjamin and Cornell, 1970; Conover, 1971; Hollander and Wolfe, 1973; Rothman, 1986). Dividing groundwater data and potential indicator variables into discrete populations is consistent with the goal of this project: establishment of two categories of site information, one corresponding to a high probability of groundwater standard exceedence, the other to a low probability. For these reasons, we take this approach.

To evaluate each potential indicator variable, data are divided into two populations corresponding to the presence or absence of the variable in question. Within each population, the sites are divided into two categories corresponding to exceedence or non-exceedence of the groundwater

standard. Four categories result: 1) those sites at which the indicator variable in question is present and the groundwater standard is exceeded, 2) those sites at which the indicator variable is present and the groundwater standard is not exceeded, 3) those sites at which the indicator variable is not present and the groundwater standard is exceeded, and 4) those sites at which the indicator variable is not present and the groundwater standard is not exceeded.

The categories are represented in tabular form in Table 4.5. In Table 4.5, O_{11} is the number of observations of Population 1, presence of potential indicator variable, falling in Category 1, exceedence of the groundwater standard. Similarly, O_{12} is the number of observations of Population 1 falling in Category 2, etc.

These categories are mutually exclusive and collectively exhaust the range of possible values. For some variables, more than two categories are defined. For any given variable, the categories are divided by threshold values.

The categorization of a variable can be expressed in general, with N thresholds and $N + 1$ categories, as follows:

Category 1	$V < V_{T1}$
Category 2	$V_{T1} \leq V < V_{T2}$
.	
.	
.	
Category $N + 1$	$V_{TN} \leq V$

where

V = variable of interest,
 V_{T1} = category threshold 1,
 V_{T2} = category threshold 2, ..., and
 V_{TN} = category threshold N .

Category thresholds are defined based on two considerations. First, the thresholds are defined to provide the best indication of groundwater standard exceedence. This is accomplished in part by a trial and error process of selecting thresholds such that the test statistic is maximized. However, it is not enough to simply maximize the threshold since doing so would result in a

trigger that indicates groundwater contamination under circumstances in which evidence is overwhelming. As a result, an unacceptably large fraction of sites with contaminated groundwater could go undetected. Therefore, professional judgement is used to adjust the thresholds to give a high value of the test statistic but also allows few sites with contaminated groundwater to go undetected. Second, thresholds are defined to span the range of variables observed so that the number of samples in each category is adequate.

Potential indicator variables are categorized as follows. Soil concentrations are categorized as non-detect, detection without exceedence of the existing soil standard, and exceedence of the soil standard. Soil textures are grouped based on the finest and coarsest layer observed. Four soil texture categories are used: clay, silt, sand, and gravel. The majority of transport distances are less than 10 feet (see Table 4.3). Therefore, transport distance categories are defined as follows: distance less than or equal to 5 feet, between 5 and 7 feet, between 7 and 9 feet, and greater than 9 feet. In the case of ground cover, sites are grouped according to the existence or absence of concrete or asphalt ground cover. Transport times are divided into two categories: less than or equal to 2 years and greater than 2 years. Chemical-specific thresholds are defined for retarded transport time estimates. The thresholds are 5, 9, 18, and 14.5 years for benzene, toluene, ethylbenzene, and xylenes, respectively. The attenuation factor threshold is 0.01 for all chemicals. The threshold values for solubility, vapor pressure, half-life, and organic carbon coefficient are 500 mg/L, 0.02 atm, 336 hours (two weeks), and 250 mL/g, respectively.

When necessary, categories are aggregated to ensure an adequate number of samples in each category.³ For this reason, soil textures are aggregated into two categories: soils characterized as clay or silt (silt or finer) and those characterized as sand or gravel (sand or coarser). Transport distances are aggregated into two sets of categories one with a threshold of 5 feet, the other with a threshold of 7 feet.

The variables of interest, groundwater concentrations, are divided into two categories: non-exceedence of the existing groundwater standard, and exceedence of the standard.

Since soil and groundwater standards are used as category thresholds, they are listed in Table 4.6.

³ As will be shown below, uncertainty increases rapidly when few data are available.

4.2.2 Other data considerations

Random selection of case files is intended to characterize conditions most often encountered in the BUST program. Since the number of BUST cases is in the tens of thousands, it is unlikely that the sample of 22 sites completely represents the population of BUST cases. The limitations of this small data set are complicated by the fact that data for some potential indicator variables are not available at all sites. In some cases these data limitations affect our analysis method.

Many BUST case files involve more than one UST. At many of these sites, all USTs were treated as a single potential source and sampling was undertaken accordingly. For most of those sites at which the USTs were separated by considerable distances, sampling programs were undertaken to characterize USTs individually or in small groups. When the potential for cross-contamination is small, we treat individual or small groups of USTs as distinct sites. Four BUST cases fall in the multiple-site category: Mobil Retail Facility #15-J9N, Pohatcong Township Municipal Building, Leo & Ray's Sunoco, and NJAWC Short Hills Station. Data for two UST sites were taken from each of these BUST case files.

Review of the data reveals that at some sites, samples were not analyzed for all four of the compounds of interest. This was frequently the case for soil samples. In these cases comparison of contamination levels in soil and groundwater is not possible. Data from these sites are therefore excluded from evaluation of soil data as an indicator variable.

It should be noted that in the case of ethylbenzene, Highland High School and Spiniello Construction are excluded from evaluation of soil contamination as an indicator variable. These sites exhibit the highest groundwater concentrations of ethylbenzene found in the survey. As a result, our ability to evaluate soil contamination as an indicator variable for ethylbenzene contamination of groundwater is lost. Sites with missing data have been organized by compound and are reported in Table 4.7.

When evaluating chemical parameters as potential indicator variables, we use only sites with data for all four chemicals. Sites excluded from this group (the union of the sites for which soil or groundwater data for any chemical are not reported) are also listed in Table 4.7.

In addition to sites that are excluded because of lack of soil or groundwater contaminant data, some sites are excluded from our analysis because data concerning a potential indicator variable were not reported or are inappropriate for use. Only one site is excluded because a potential indicator variable is not reported: Johnson & Towers. The presence or absence of ground cover was not reported for this site. We exclude the site from evaluation of ground cover and derived variables that depend on ground cover such as transport time.

Sites excluded because of inappropriate data are limited to those taken from the same BUST case file. As stated above, we limit consideration of multiple sites in the same BUST file to those at which contaminant data collected can clearly be attributed to the UST specified. Independent contaminant data do not ensure independence of other characteristics of the site. Of four multiple-site cases (Mobil Retail Facility #15-J9N, Pohatcong Township Municipal Building, Leo & Ray's Sunoco, and NJAWC Short Hills Station), depth to groundwater and soil texture were found to be nearly identical in three (Mobil Retail Facility #15-J9N, Pohatcong Township Municipal Building, and Leo & Ray's Sunoco). To treat these data as independent would be inappropriate. Therefore, only one UST site from each of these cases is used to evaluate potential indicator variables other than soil data.

A final issue concerning the data should be noted. Most of the detection limits are below the corresponding groundwater or soil standard. In these cases non-detects can be interpreted as non-exceedence of the standard. When detection limits are above the soil or groundwater standard, non-detects cannot be so interpreted. Instead, the possibility of undetected exceedence of the standard must be acknowledged. An example of a site at which the soil detection limit is elevated above the soil standard is AT&T Totowa Road. The benzene detection limit is reported to be 6 ppm, the soil standard for benzene, 1 ppm. We have chosen not to evaluate the benzene soil concentration as a potential indicator variable for this site and included the site in Table 4.7. A similar situation exists at Spiniello construction (method detection limit 3 ppm). In this instance, since the detection limit is closer to the soil standard, we do consider the soil concentration as a potential indicator variable.

The detection limit of benzene in water is typically reported to be 5 ppb whereas the groundwater standard is 1 ppb. We treat these non-detects as non-exceedences of the groundwater standard.

4.3 Summary statistics

The estimated probabilities of groundwater standard exceedence for each BTEX compound are reported in Table 4.8. If a variable is a significant indicator of groundwater exceedence, we expect the probability estimates of groundwater standard exceedence conditioned on the presence of that variable to be significantly different from estimates conditioned on the absence of that variable. This probability estimate should also differ from the unconditioned estimate of probability of groundwater exceedence.

Benzene exceeds the groundwater standard most frequently. The unconditioned probability of exceedence is 0.19. Ethylbenzene exceeds the standard least frequently, with a frequency of 0.05. This range is not inconsistent with that reported by Kalinski *et al.* (1994). The corresponding probabilities of soil standard exceedence are 0.05 and 0.11 for benzene and ethylbenzene, respectively. Since the probability of exceedence of the benzene groundwater standard is larger than the probability of exceedence of the soil standard, groundwater standard

exceedence must also occur at sites at which the soil standard has not been exceeded. These probabilities suggest that, even under ideal circumstances, soil standard exceedence cannot always indicate exceedence of the groundwater standard.

The remainder of Table 4.8 consists of probabilities conditioned according to the method in Section 4.2.1. The use of additional information to modify a probability estimate is known as conditioning. The notation is as follows: if $P(A)$ represents the probability of the occurrence of event A, $P(A|B)$ represents the probability of event A given that B has occurred. Thus, the probability that the groundwater standard is not exceeded given that the contaminant has not been detected in soil is represented by $P(\text{no groundwater exceedence}|\text{non-detect in soil})$. This can be expressed in abbreviated notation $P(\text{no exceed}|\text{ND})$.

The probabilities in Table 4.8 are based on the number of sites falling into the category indicated. These numbers are reported in Appendix C. The conditioned probabilities are defined by Bayes' Theorem to be (Benjamin and Cornell, 1970):

$$P(A|B) = \frac{P(A \cap B)}{P(B)} \quad (4.7)$$

Equation (4.7) states that the probability of event A conditioned on event B is equal to the probability of event A and B occurring, divided by the probability of event B.

Calculation of conditioned probabilities is straightforward. Since the samples are independent and each trial from each population falls into one of two mutually exclusive and collectively exhaustive categories, the probabilities are binomially distributed (Benjamin and Cornell, 1970). One possible outcome of any given trial is typically referred to as a success and occurs with probability P. The alternate outcome of each trial is referred to as a failure and occurs with probability 1 - P. For a given population, say Population 1 shown in Table 4.5, the estimated probability of success is expressed:

$$\hat{P}(O_{11}|\text{Population 1}) = \frac{O_{11}}{O_{11} + O_{12}} \quad (4.8)$$

where the symbol $\hat{}$ denotes an estimated quantity. Equation (4.8) is used to calculate the probabilities reported in Table 4.8 based on the numbers of sites reported in Appendix C as falling into each category.

Of the four chemical parameters considered as potential indicator variables, the results for K_{oc} and S are identical. For this reason, they are combined in Table 4.8.

4.4 Qualitative observations

In this section, we make qualitative observations concerning the estimated probabilities of exceedence of the groundwater standards. We present a rigorous treatment of the results in Section 4.5.

Table 4.8 indicates the baseline probability of exceedence of the groundwater standard to be 0.19, 0.09, 0.05, and 0.14 for benzene, toluene, ethylbenzene, and xylenes, respectively. Conditioning on detection of contamination in the soil actually appears to decrease the probability estimate for benzene ($P(\text{exceed}|\text{detect}) = 0.17$) and ethylbenzene ($P(\text{exceed}|\text{detect}) = 0.00$). The decrease for ethylbenzene can be attributed to elimination of sites at which soil samples were not analyzed for ethylbenzene, as pointed out in Section 4.2.2. Corresponding estimates for toluene and xylenes are higher than the unconditioned estimates. However, the increase is relatively small.

These results suggest that detection of soil contamination is not a useful indicator variable. Since levels of soil contamination are low at most sites, we can conclude that the existence of low levels of contamination fails to indicate groundwater standard exceedence.

Following similar reasoning, Table 4.8 suggests exceedence of the existing soil standard to be a good indicator of the exceedence of the groundwater standard. For benzene, toluene, and xylenes, the probability of groundwater exceedence is increased to 1.00, 0.67, and 0.67, respectively. Conversely, the probabilities of groundwater standard exceedence given no exceedence of the soil standard are relatively low. These results suggest that detection of relatively high levels of soil contamination (concentrations at least as great as the soil standard) indicates groundwater standard exceedence.

Finest and coarsest soil textures appear to have limited value as indicators of groundwater standard exceedence. If the finest layer of soil is clay, the estimate of the conditioned probability of exceedence appears to be considerably higher for benzene, increasing to 0.50. If the coarsest soil layer is clay or silt, the estimated probability of groundwater exceedence for benzene, toluene, ethylbenzene, and xylenes are 1.00, 0.00, 0.00, and 1.00, respectively. Unless there is some reason to expect soil texture to affect the migration of toluene and ethylbenzene differently, these data are inconsistent. Aside from these results, soil texture appears to have no discernable ability to indicate groundwater exceedence.

The situation is similar for transport distance. Any increases in the probability of groundwater standard exceedence are relatively small and can probably be attributed to uncertainty in the estimates.

For all four chemicals, Table 4.8 indicates the estimated probabilities of groundwater exceedence are higher in the absence of ground cover. The largest difference between conditioned and unconditioned probability estimates is 0.3 for benzene.

With the possible exception of toluene, travel time does not appear to provide a strong indication of groundwater standard exceedence. Retarded travel time, however, does. The differences between probability estimates conditioned on retarded travel times less than 5, 9, 18, and 14.5 years for benzene, toluene, ethylbenzene, and xylenes respectively, range from a minimum of 0.25 for ethylbenzene to a maximum of 0.44 for toluene. These differences are greater than those for any other potential indicator variable except exceedence of the soil standard. The only difference between estimates of retarded travel time and unretarded travel time is the retardation factor defined in Equation (4.5).

The attenuation factor appears to be a very poor indicator of groundwater exceedence. This is not surprising. The values of the attenuation factor listed in Table 4.4 all indicate complete biodegradation of contamination, contradicting the observation that contamination is present at many sites. For this reason, the attenuation factor is not analyzed further and is not included in summary Table 4.8.

Probabilities of groundwater standard exceedence conditioned on combinations of indicator variables are also reported in Table 4.8. We emphasize non-exceedence of the soil standard because the results for single variables and review of the data suggests that no combination of variables will provide better indication than exceedence of the soil standard alone. In addition, it may be useful to be able to identify sites at which, despite non-exceedence of the soil standard, groundwater standard exceedence is likely. Assuming non-exceedence,⁴ we ask which of the following variables provide a good indication of groundwater standard exceedence: 1) finest soil texture of clay or silt, 2) the presence of ground cover, 3) transport time, and 4) retarded transport time.

The only potential indicator variable in combination with non-exceedence of the soil standard that provides any indication of exceedence of the groundwater standard is retarded transport time. This is not surprising since retarded transport time alone appears to provide a good indication of groundwater standard exceedence.

In summary, review of the data suggest the following potential indicator variables may provide some indication of exceedence of the groundwater standard: exceedence of the existing soil standard, estimates of retarded travel times less than 5, 9, 18, and 14.5 years for benzene,

⁴ There are too few data to ask the related and perhaps more interesting question of sites at which contaminants are detected in soil.

toluene, ethylbenzene, and xylenes, respectively, and the presence of concrete or asphalt pavement on the ground surface above contaminated soil.

4.5 Statistical comparison

Although useful for an overview of the results of the analysis, the observations of Section 4.4 are insufficient for drawing conclusions because they do not take into account uncertainty in the probability estimates. In this section, uncertainty is treated in a more rigorous fashion. We present confidence intervals around the probability estimates and perform a simple statistical test to determine whether differences observed in the probability estimates are significant. If they are significant, we conclude the variable in question indicates exceedence of the groundwater standard. If they are not, we conclude the variable provides is not a good indicator of groundwater standard exceedence.

Before proceeding, it is useful to elaborate on our approach to sample categorization. For two populations and two categories, Conover (1971) defines the matrix shown in Table 4.9. It is similar to that shown in Table 4.5. Here, n_1 is the number of samples drawn from population 1 and n_2 is the number of samples drawn from population 2. C_1 and C_2 are the number of samples falling into categories 1 and 2, respectively. N is the total number of samples and can be expressed as shown or as $C_1 + C_2$. O_{ij} is the number of observations from population i that fall into category j . These variables are used in the calculations that follow.

4.5.1 Confidence intervals

To give an indication of uncertainty for each estimated probability, we report 90% confidence intervals. These intervals have been taken from Table 21 of Crow *et al.* (1960) and are plotted, together with corresponding probability estimates, in Figure 1 to Figure 13. In the figures, the cross-bar corresponds to the estimate of the mean probability and the vertical line represents the 90% confidence interval on the estimate of the mean. The upper (P_U) and lower (P_L) limits of the intervals are reported in Appendix D, along with probability estimates and values of the test statistic (introduced in Section 4.5.2).

In most cases, the confidence intervals are relatively wide. This is a result of the limited number of data available. As can be seen in Appendix C, the number of data seldom exceeds 10 for any given category. The effect of the number of data on uncertainty can be seen by considering the Clopper-Pearson expression⁵ for calculating confidence intervals (Hollander and Wolfe, 1973).

⁵ Crow *et al.* (1960) indicate the Clopper-Pearson expression to be appropriate only for data sets larger than 30. For smaller data sets, they recommend the tabulated values used herein.

The upper and lower confidence intervals for the estimate of the mean probability of success for Population 1 can be expressed:

$$\hat{P}_{1U}(\alpha) \approx \hat{P}_1 + z_{\alpha/2} \left[\frac{\hat{P}_1(1 - \hat{P}_1)}{n_1} \right]^{1/2} \quad (4.9)$$

$$\hat{P}_{1L}(\alpha) \approx \hat{P}_1 - z_{\alpha/2} \left[\frac{\hat{P}_1(1 - \hat{P}_1)}{n_1} \right]^{1/2} \quad (4.10)$$

where $z_{\alpha/2}$ is the standard normal variable corresponding to the α significance level (significance levels are discussed in greater detail in Section 4.5.2). Equations (4.9) and (4.10) show that, for a given α , the upper and lower bounds of the confidence interval vary at a rate of $n^{-1/2}$.

Figure 1 shows estimates of the probability of groundwater exceedence conditioned on detection of each contaminant in soil. For benzene, the complete overlap of the intervals for $P(\text{exceedence}|\text{detection})$ and $P(\text{exceedence}|\text{no detection})$ (designated 1 and 3 on the x-axis in the figure) for benzene strongly suggests that detection of contamination in soil does not provide indication of groundwater standard exceedence. The situation is similar, though the overlap of confidence intervals is not as pronounced, for toluene and xylenes. In no case was ethylbenzene detected in soil and found to exceed the groundwater standard. This is reflected in the identical probability estimates and confidence intervals shown.

Figure 2 shows estimates of the probability of groundwater exceedence conditioned on exceedence of the soil standard. As in Figure 1, there is overlap of the intervals of groundwater exceedence conditioned on exceedence of the soil standard and those conditioned on non-exceedence. However, the overlap is less than that in Figure 1, suggesting a difference between the probability estimates. In addition, the estimated probabilities (indicated by the cross bars) can be seen to differ in accordance with the presence or absence of soil contaminated in exceedence of the standard.

Figure 3 and Figure 4 show large overlap in the confidence intervals, suggesting little, if any, ability of the finest and coarsest soil textures to indicate exceedence of the groundwater standard. Figure 5 shows the situation is similar for transport distance.

Figure 6 shows considerable overlap, but not to the same degree as the previous three figures. This confirms our observation that the presence or absence of ground cover may provide a good indication of groundwater standard exceedence. Confidence intervals overlap to an even smaller degree in Figure 8, suggesting retarded transport time may be a useful indicator variable, again agreeing with observations reported in Section 4.4. The intervals overlap to a large degree in Figure 7, Figure 9 to Figure 11, and Figure 13, suggesting these variables and variable combinations provide little indication of groundwater standard exceedence. Figure 12 shows the intervals for the estimated probabilities of groundwater exceedence conditioned on non-exceedence of the soil standard and retarded transport time. These intervals overlap to a smaller degree than Figure 9 to Figure 13.

4.5.2 Approximate χ^2 test statistic

A number of methods exist for comparing samples that have been classified into two or more categories to determine whether or not they have been selected from the same population. Fisher's Exact Test is one such method (Rothman, 1986). It is commonly used by epidemiologists to identify characteristics that are associated with the incidence or prevalence of disease in a population. It is also useful for evaluating the significance of a treatment on a subset of a population. If a chosen characteristic of the treated subset of the population can be distinguished from the larger population, it can be concluded that the treatment has some effect. In our case, the method could be used to evaluate potential indicator variables.

Conover (1971) provides an alternate method based on an approximation of the χ^2 variable. In elementary statistical textbooks, hypotheses concerning sample data are often tested with the χ^2 variable. Since it is based on an approximation of a relatively familiar test statistic and the commonly used hypothesis-testing framework, the approach of Conover is probably more familiar to those working outside the field of epidemiology. Therefore, we have elected to employ it here.

If we define P_1 to be the true probability (that is, not estimated) that a sample selected randomly from population 1 will be in category 1 and P_2 to be the true probability that a sample selected randomly from population 2 will be in category 1, we can write the two-sided hypothesis test as follows:

$$H_0: P_1 = P_2$$

$$H_1: P_1 \neq P_2$$

where H_0 and H_1 are the Null and Alternate hypotheses, respectively.

Using the notation of Table 4.9, the test statistic is defined:

$$T = \frac{N(O_{11}O_{22} - O_{12}O_{21})^2}{n_1n_2C_1C_2} \quad (4.11)$$

The test statistic T is approximately a χ^2 variable with 1 degree of freedom. Tabulations of χ^2 are widely available in standard statistics texts such as Benjamin and Cornell (1970), Crow *et al.* (1960), Conover (1971), and Hollander and Wolfe (1973).

For the two-sided test, H_0 is rejected (and H_1 accepted) at the significance level α if T exceeds the $1-\alpha$ quantile of the χ^2 random variable with 1 degree of freedom. The significance level of the test, and the associated value of the χ^2 variable, can be specified prior to the test. If the resulting test statistic exceeds the value of the specified χ^2 , H_0 is rejected. This approach suffers from the shortcoming that there is no rigorous way to define α . α typically is defined by convention to be 0.1, 0.05, or 0.01. An alternative is to simply determine the value of α associated with the highest quantile exceeded by the value of T . Doing so provides a relative indication of confidence (smaller values are associated with greater confidence) in the rejection of the null hypothesis and α can be used to compare the importance of different variables of interest. A simplification of this approach is to simply compare values of the test statistic T . Since the first approach suffers from a significant shortcoming and since we are interested in evaluating the relative importance of potential indicator variables, we feel the latter approach to be more appropriate. As a point of reference, however, it is useful to note that for values of α commonly employed in hypothesis testing, 0.1 and 0.05, the corresponding value of χ^2 is 2.706 and 3.841, respectively.

The test statistics are reported in Table 4.10. Test statistics that are 2.706 or higher have been underlined. If α were 0.1, these variables would be accepted as significant. Review of Table 4.10 shows the potential indicator variables corresponding to relatively high test statistics are exceedence of the soil standard, coarsest texture of the soil, the presence of ground cover, and retarded transport time.

With the possible exception of soil standard exceedence, the variables are not significant for all chemicals. The only variables that appear to be significant for benzene are exceedence of the soil standard and the coarsest soil texture. For toluene, the most important variables are soil exceedence, ground cover, and retarded transport time. Although ground cover and retarded transport time appear to be important for benzene, they are not statistically significant given $\alpha = 0.1$. The test statistic indicates ground cover to be a significant indicator variable only for toluene. However, values of the test statistic for ground cover are relatively high for all chemicals. The consistency is reassuring. Such consistency is not found in the test statistic values for coarsest soil texture; in that case, the variable is either significant or completely

insignificant. Retarded transport time is significant for three of the four chemicals. In the fourth case (benzene), the test statistic is relatively high.

As expected, the lack of data indicating exceedence of the ethylbenzene soil and groundwater standards greatly reduces our ability to identify significant indicator variables. However, it is probably safe to assume the behavior of ethylbenzene is similar to that of the other BTEX compounds.

4.6 Discussion

With the exception of exceedence of the soil standard, our results give only limited indication that any potential indicator variable provides a reliable indication of exceedence of the groundwater standard for all BTEX compounds. Retarded transport time and the existence of ground cover give some indication of exceedence of the groundwater standard, though the evidence is not compelling. In this section we suggest possible explanations for these results and discuss some implications.

Soils at most sites were comprised of silts and sands, with occasional layers of clay and gravel. As a result, it is difficult to detect an effect that soil textures might have on the frequency of groundwater standard exceedence. Finest soil texture appears to be unimportant in most cases. However, there appears to be some indication that coarser soils are associated with fewer groundwater standard exceedences for benzene and xylenes. This result contradicts expectations since finer soils are usually considered to be barriers to water movement and contaminant migration. Since the uncertainty is very large for the probability estimates for groundwater exceedence conditioned on a coarsest soil of clay or silt, and since the statistics for toluene and ethylbenzene do not give the same results, we cannot draw any conclusions from this evidence.

Our results suggest transport distance is unimportant, a finding that agrees with the conclusions of Ladwig and Hensel (1993). One possible explanation for this result is the relatively limited range of transport distances in the case files. We can infer a similar limited range of variation for the BUST program as a whole. It is of interest to note that benzene groundwater standard was exceeded at AT&T Totowa Road, the site with the largest transport distance of all sites considered (54 feet).

Our results also indicate chemical properties provide little indication of groundwater standard exceedence. This is not surprising. The chemical properties of the BTEX compounds span a narrow range. If the contaminants of concern exhibited substantially different chemical properties, we could expect a more significant effect.

The existence of ground cover appears give some indication of exceedence of the groundwater standard. This result is probably due to ground cover limiting infiltration. Ground cover is also relatively easy for the case manager to evaluate, a quality that would encourage its use as an indicator variable.

The retarded transport time prediction of appears to be a reasonably good indicator variable. Predictions of transport time and attenuation factor do not appear to be good indicator variables. The ease of estimation of retarded transport time would encourage its use as an indicator variable.

It should be kept in mind that the transport times and attenuation factors estimated here should not be interpreted as accurate predictions of actual transport times and attenuation factors, even if the predictions do provide good indications of groundwater standard exceedence. Without field verification, screening model predictions used in this study should only be compared with one another to give relative measures of transport times.

None of the combinations of potential indicator variables considered provide an indication of groundwater exceedence. This result may be due to the limited number of BUST cases available at which soil standards were not exceeded.

As stated above, exceedence of soil standards appears to give the best indication of groundwater standard exceedence. It is useful to consider this conclusion in some detail. Data reported in Appendix C indicate that, in the case of benzene, there is one site at which the soil standard is exceeded. The concentration of benzene in groundwater at this site exceeds the groundwater standard. However, the groundwater standard is also exceeded at 2 of the 11 sites at which the soil standard is not exceeded. These data indicate that reliance on exceedence of the soil standard alone to trigger groundwater sampling would ensure a high success rate: exceedence of the soil standard appears to be a good indicator of exceedence of the groundwater standard. However, relying *only* on the exceedence of the benzene soil standard to trigger groundwater sampling at these 19 sites would allow 2 sites with contaminated groundwater to go undetected. Thus, considering benzene alone, the trigger would allow approximately two-thirds of the sites with groundwater standard exceedences to go undetected.

The data reported in Appendix C indicate that for toluene, reliance on the soil standard to trigger groundwater sampling would result detection of almost all of the sites at which groundwater concentrations exceed the standard. For xylenes, 2/3 of the cases of groundwater exceedence would be detected.

As discussed in Section 6, in practice a trigger is applied to all contaminants at a site. Therefore, a more realistic evaluation of the performance of a trigger is on a site-by-site basis rather than for

specific chemicals. As is shown in Section 6, such an evaluation yields results substantially different from those reported in this section.

Due to the low frequency of groundwater standard exceedences, we believe our data base is too small to effectively evaluate combinations of potential indicator variables. However, our results suggest that ground cover and retarded transport time alone are good indicators of groundwater exceedence. Therefore, despite our inconclusive findings, it would probably be useful to use these variables in conjunction with exceedence of the existing soil standard.

The files reviewed as part of the directed search exhibit widely varying characteristics and complex contaminant behavior. In contrast to BUST cases, sources at BEECRA and BGWPA sites tend to be complex and relatively difficult to characterize. These findings suggest that identification of indicator variables may be more difficult for these sites than for the relatively uniform set under the BUST program. This finding agrees with the results of the random search.

4.7 Uncertainties

The analysis is subject to a wide variety of uncertainties. Some uncertainties may significantly affect the reliability of the analysis, some probably do not. In this section we describe the sources of uncertainty and make some qualitative remarks concerning the importance of each type. We also note measures taken to reduce uncertainty where appropriate.

The most important source of uncertainty in soil and groundwater data is probably the location of sample collection. Groundwater investigation at most BUST sites consisted of placement and sampling of three monitoring wells. At least one well was located downgradient of the UST at each site. Maximum groundwater contamination would be expected directly downgradient of the well. However, the downgradient well(s) was not always placed directly downgradient of the UST. Thus, it is possible the sample obtained from the downgradient well does not represent the maximum groundwater contamination. Most monitoring wells installed at BUST sites are within 10 feet of the UST(s), so the effect of dilution is probably limited.

Soil samples were usually collected in a regular pattern from within the pit dug to remove the UST. In some cases, composite samples were taken from excavated soil. In other cases, samples were taken from areas in the excavation pit that appeared to be stained. As in the case of monitoring well placement, it is not clear that locations of maximum soil contamination were sampled.

In some cases, soil and/or groundwater samples were collected well after removal of the UST. The most noteworthy example is the Firestone Retail Outlet. At this site, soil samples collected one year after UST removal did not contain contaminants in detectable quantities, despite the

observation, reported elsewhere in the case file, of free-phase product upon removal as well as exceedence of applicable groundwater standards.

Sample collection methods may also introduce uncertainty. Since the contaminants of interest are highly volatile, care must be taken during sample collection to minimize volatilization and escape to the atmosphere. Although cases of significant losses to the atmosphere have been documented (University of Wisconsin-Madison, 1993), we have no basis from which to evaluate the methods used at the BUST sites we have considered.

Uncertainty is introduced by all types of chemical analysis. Since we seldom had access to laboratory reports during the course of reviewing BUST case files, it is impossible to evaluate the quality assurance and quality control methods used by the reporting laboratories. Based on our experience, however, we believe such uncertainties to be relatively small (tens of percent) for analyses of volatile organic compounds in soil and water.

Soil texture characterization is typically performed in the field. Visual inspection is the usual method employed and we found no exceptions to this practice. Although standard soil classification systems have been developed (for example, USCS and USDA), it is impossible to determine the accuracy of any given soil texture characterization. Since the characterization is performed visually, it seems appropriate to consider such characterizations as rough estimates only. Assigning each texture characterization to one of four broad categories probably helps to minimize the uncertainty of these characterizations.

Measurement of the depth of the water table is relatively straightforward. However, in almost all BUST cases considered, only one measurement was reported. The location of the water table at a given site can be expected to vary seasonally, however, and one measurement cannot capture this variation. Furthermore, the depth of the water table has been measured at different sites during different seasons. Thus, two sources of water table depth uncertainty exist: seasonal variability at a given site and seasonal variability between sites.

Evaluation of soil cover is relatively straightforward. On-site visual inspection reveals the existence of concrete or asphalt paving. Other types of ground cover are not always indicated and no indication is provided of the condition of the cover. The simple classification system used in this project (cover/no cover) reflects these data limitations. However, as a result, differences between badly cracked and intact cover, cover extending over a large area and cover limited to the immediate vicinity of the UST, as well as differences between grass and dirt are ignored. These differences can have substantial impact on infiltration rates. In addition, this classification system ignores other factors that can strongly influence infiltration rates. Topography is a factor that falls in this category, since steep slopes tend to limit infiltration and uneven ground surfaces can increase ponding and infiltration. Since relief at the 22 sites considered in this project appears to be mild, this may be a relatively unimportant source of uncertainty. The ability of the

soil, especially the surface soil, to convey water also falls into this category. Unlike topography, soil properties can dominate infiltration, especially when ground cover is absent. However, soil texture is considered as a separate potential indicator variable, so its influence is not ignored altogether.

Estimation of travel time is highly uncertain for several reasons. First, the screening models used here are relatively simple. Ground cover is the primary control of infiltration rates in the model. Variations in soil moisture content and hydraulic conductivity are accounted for by means of relatively crude parameterizations based on reported soil texture characterizations. Despite these drawbacks, the use of simple infiltration models under similar circumstances persists in the field of hydrology. This suggests reasonable predictive ability. To minimize the impact of model prediction uncertainty, we treat our screening model predictions only as relative estimates of travel time, comparing the estimates with each other only.

Estimation of the retarded transport time and the attenuation factor are subject to the same sources of uncertainties as the estimate of transport time. The retarded transport time is subject to uncertainty in the assumed soil organic fraction and chemical parameter values. The attenuation factor is also subject to uncertainty in the estimates of biodegradation rates. Our results suggest the half-lives reported by Howard *et al.* (1991) are gross overestimates of rates of biodegradation actually occurring in the field. The results also suggest that our simple treatment of retardation is effective.

Information taken from the files obtained as a result of directed search are also subject to considerable uncertainty. In particular, conditions at most of these sites appear to vary over a much wider range than those obtained as a result of random search of BUST files. Sources are often incompletely characterized and contamination widespread. Instead of discrete USTs, contamination is often attributed to spills and leaks and other activities of an unknown nature. This site-to-site variability makes it much more difficult to identify potential indicator variables.

4.8 Development of trigger

In consultation with NJDEPE, it was decided to develop a tiered trigger. This approach offers the advantage of requiring only the information needed for the current tier: if groundwater monitoring were triggered by a tier, there would be no need to continue to the next tier.

According to the statistical test results in Section 4.5.2, the existing soil standard is the best indicator of groundwater contamination. This is true both for individual chemicals as well as for the set of BTEX chemicals. Furthermore, soil samples are routinely analyzed as part of site investigations. For these reasons, the existing soil standard was selected as the first tier of the trigger.

Selection of the second tier is not as straightforward. The presence of ground cover and the retarded transport time are the next best indicators of groundwater contamination. Both appear to be good indicator variables for most chemicals, but neither is a good indicator variable for all BTEX chemicals. Ground cover has the advantage of requiring no additional effort on the part of the case manager; the presence or absence of pavement is readily evident. It has a significant disadvantage, however. Since no pavement was present at almost half of the files reviewed as part of the random search, use of ground cover as an indicator variable could result in unnecessary sampling at a large fraction of sites. Retarded transport time requires more extensive characterization of site parameters, including ground cover and texture of soil beneath the site, as well as implementation of the transport time screening model. However, retarded transport time appears to be a better indicator of groundwater contamination than the presence of ground cover. Furthermore, it accounts for the presence or absence of ground cover in the estimation of infiltration rate.

The potential difficulties associated with using retarded transport time as the second tier are not overwhelming, however. Borings appear to be installed and soil texture beneath a site characterized as a matter of routine. The implementation of the transport model can be automated to a large degree. These considerations, combined with the observation that retarded transport time is a better indicator, recommend retarded transport time as the second tier of the trigger.

Thus, the potential indicator variables included in the trigger are the maximum soil concentration and the estimated retarded transport time. All other potential indicator variables are excluded from the trigger.

These indicator variables have been incorporated into the trigger software. The trigger software is discussed in Section 5.

4.9 Tables

Table 4.1 Summary of maximum groundwater concentrations

	benzene (ppb)	toluene (ppb)	ethyl- benzene (ppb)	xylenes (ppb)
Rebco Realty	ND 5	ND 5	ND 5	ND 5
NJAWC Baltasrol Station	ND	ND	ND	ND
Potamkin Chrysler Plymouth	ND 1	ND 1	ND 1	ND 1
Firestone Retail Outlet		ND 5	ND 5	ND 5
Mobil Retail Facility #15-J9N	ND 5	ND 5	ND 5	ND 5
Mobil Retail Facility #15-J9N	ND 5	ND 5	ND 5	ND 5
McKee City Distributors, Inc.	ND 5	ND 5	ND 5	ND 5
Pohatcong Township Municipal Bldg. West	ND 5	ND 5	ND 5	ND 5
Pohatcong Township Municipal Bldg. East	ND 5	ND 5	ND 5	ND 5
C.C.L.P. Associates	ND 5	ND 5	ND 5	ND 5
Exxon Service Station #3-8238	61	ND	13	69
Sandoz Pharmaceuticals Corp - Tank E24	ND 5	ND 5	ND 5	ND 5
Highland High School	1125	18750	4700	45000
Spiniello Construction	7000	19000	560	11000
Leo & Ray's Sunoco - gasoline USTs	ND 5	ND 5	ND 5	ND 15
Leo & Ray's Sunoco - waste oil USTs	ND 5	ND 5	ND 5	ND 15
Hackensack Cemetery Company	ND 5	ND 5	ND 5	ND 5
NJAWC Short Hills Station - Pit A3	ND 5	ND 5	ND 5	ND 5
NJAWC Short Hills Station - Pit C5	ND 5	ND 5	ND 5	ND 5
Johnson & Towers	ND	ND	ND	ND
Vineland Post Office	ND 5	ND 5	ND 5	
AT&T Totowa Rd.	17	ND 6	ND 7	

ND indicates non-detect; the number following ND is the detection limit. Blanks indicate data that are not reported in the case files.

Table 4.2 Summary of maximum soil concentrations

	benzene (ppm)	toluene (ppm)	ethyl- benzene (ppm)	xylenes (ppm)
Rebco Realty	ND 0.0068	ND 0.0107		ND 0.0124
NJAWC Baltasrol Station	ND 0.025	ND 0.025	ND 0.025	ND 0.025
Potamkin Chrysler Plymouth	ND 0.005	ND 0.005	ND 0.005	ND 0.005
Firestone Retail Outlet	ND 0.020	0.020	0.060	0.360
Mobil Retail Facility #15-J9N	0.13	0.110	0.195	0.075
Mobil Retail Facility #15-J9N	0.75	0.700	0.915	0.500
McKee City Distributors, Inc.	ND 0.005	ND 0.005	ND 0.005	ND 0.005
Pohatcong Township Municipal Bldg. West	ND 0.005	ND 0.005	ND 0.005	ND 0.005
Pohatcong Township Municipal Bldg. East	ND 0.005	ND 0.005	ND 0.005	ND 0.005
C.C.L.P. Associates	ND 0.005	0.012	ND 0.005	ND 0.005
Exxon Service Station #3-8238	ND	ND	ND	ND
Sandoz Pharmaceuticals Corp - Tank E24	0.011	0.029	0.083	0.684
Highland High School	94	1000		1250
Spiniello Construction	ND 3	255		900
Leo & Ray's Sunoco - gasoline USTs	ND 0.0052	0.0043	ND 0.0052	ND 0.0156
Leo & Ray's Sunoco - waste oil USTs	ND 0.0052	ND 0.0052	ND 0.0052	ND 0.0156
Hackensack Cemetery Company	ND 0.005	ND 0.005	0.0009	0.0099
NJAWC Short Hills Station - Pit A3	0.030	ND	ND	ND
NJAWC Short Hills Station - Pit C5	0.100	2.000	10.800	52.100
Johnson & Towers			0.131	0.563
Vineland Post Office	ND 0.005	0.027	0.012	0.113
AT&T Totowa Rd.			33.000	360.000

ND indicates non-detect; the number following ND is the detection limit. Blanks indicate data that are not reported in the case files.

Table 4.3 Summary of potential indicator variables

	finest soil	coarsest soil	transport distance (feet)	ground cover
Rebco Realty	sand	sand	4.9	asphalt
NJAWC Baltasrol Station	sand	sand	8.4	none
Potamkin Chrysler Plymouth	sand	sand	5.8	asphalt
Firestone Retail Outlet	silt	sand	9	asphalt
Mobil Retail Facility #15-J9N	silt	sand	5	concrete
Mobil Retail Facility #15-J9N				concrete
McKee City Distributors, Inc.	silt	sand	8.8	none
Pohatcong Township Municipal Bldg. West	silt	sand	30.2	none
Pohatcong Township Municipal Bldg. East				none
C.C.L.P. Associates	sand	sand	8.1	asphalt
Exxon Service Station #3-8238	silt	silt	6.1	asphalt
Sandoz Pharmaceuticals Corp - Tank E24	silt	gravel	6.7	concrete
Highland High School	sand	sand	8.5	none
Spiniello Construction	sand	sand	4.4	none
Leo & Ray's Sunoco - gasoline USTs	sand	sand	5.6	asphalt
Leo & Ray's Sunoco - waste oil USTs				asphalt
Hackensack Cemetery Company	sand	sand	7.9	asphalt
NJAWC Short Hills Station - Pit A3	silt	sand	8.4	none
NJAWC Short Hills Station - Pit C5	gravel	gravel	5.4	paved
Johnson & Towers	sand	sand	0.1	
Vineland Post Office	clay	sand	40	asphalt
AT&T Totowa Rd.	clay	gravel	54	none

Blanks indicate variables not evaluated as potential indicator variables.

Table 4.4 Summary of derived variables

	transport time (years)	retarded transport time (years) benzene	retarded transport time (years) toluene	retarded transport time (years) ethylbenzene	retarded transport time (years) xylenes
Rebco Realty	1	33	63	119	94
NJAWC Baltasrol Station	0.2	5	9	18	14
Potamkin Chrysler Plymouth	1	39	75	140	111
Firestone Retail Outlet	8	57	104	188	151
Mobil Retail Facility #15-J9N	3	32	60	111	88
Mobil Retail Facility #15-J9N					
McKee City Distributors, Inc.	0.2	5	10	18	15
Pohatcong Township Municipal Bldg W.	2	17	30	55	44
Pohatcong Township Municipal Bldg E.					
C.C.L.P. Associates	2	54	104	194	154
Exxon Service Station #3-8238	5	38	70	128	102
Sandoz Pharmaceuticals Corp - Tank E24	4	43	81	150	119
Highland High School	0.2	5	10	18	14
Spiniello Construction	0.1	3	5	9	7
Leo & Ray's Sunoco - gasoline USTs	1	37	72	134	107
Leo & Ray's Sunoco - waste oil USTs					
Hackensack Cemetery Company	2	52	101	190	150
NJAWC Short Hills Station - Pit A3	1	5	8	15	12
NJAWC Short Hills Station - Pit C5	1	36	69	130	103
Johnson & Towers					
Vineland Post Office	16	263	504	938	745
AT&T Totowa Rd.	2	31	59	110	88

Blanks indicate variables were not evaluated as potential indicator variables.

Table 4.4 Summary of derived variables (continued)

	attenuation factor	attenuation factor	attenuation factor	attenuation factor
	benzene	toluene	ethyl- benzene	xylene
Rebco Realty	0	0	0	0
NJAWC Baltasrol Station	4e-34	8e-48	0	1e-55
Potamkin Chrysler Plymouth	0	0	0	0
Firestone Retail Outlet	0	0	0	0
Mobil Retail Facility #15-J9N	0	0	0	0
Mobil Retail Facility #15-J9N				
McKee City Distributors, Inc.	2e-35	1e-49	0	7e-58
Pohatcong Township Municipal Bldg W.	0	0	0	0
Pohatcong Township Municipal Bldg E.				
C.C.L.P. Associates	0	0	0	0
Exxon Service Station #3-8238	0	0	0	0
Sandoz Pharmaceuticals Corp - Tank E24	0	0	0	0
Highland High School	2e-34	3e-48	0	3e-56
Spiniello Construction	3e-18	2e-25	0	2e-29
Leo & Ray's Sunoco - gasoline USTs	0	0	0	0
Leo & Ray's Sunoco - waste oil USTs				
Hackensack Cemetery Company	0	0	0	0
NJAWC Short Hills Station - Pit A3	2e-32	6e-43	0	5e-49
NJAWC Short Hills Station - Pit C5	0	0	0	0
Johnson & Towers				
Vineland Post Office	0	0	0	0
AT&T Totowa Rd.	0	0	0	0

Blanks indicate variables were not evaluated as potential indicator variables.

Table 4.5 Categories of population and indicator variables

	Exceedence of GW standard	No exceedence of GW standard
Presence of potential indicator variable	O_{11}	O_{12}
Absence of potential indicator variable	O_{21}	O_{22}

Table 4.6 Soil and groundwater standards

	soil (ppm)	groundwater (ppb)
benzene	1	1
toluene	500	1000
ethylbenzene	100	700
xylene	10	40
1,1-dichloroethane	1	70
1,1-dichloroethene	10	2
1,2-dichloroethene	50	100
tetrachloroethene	1	1
1,1,1-trichloroethane	50	30
trichloroethene	1	1

Table 4.7 Sites for which chemical data in soil or groundwater are not available

one or more chemicals in soil or groundwater

Johnson & Towers
AT&T Totowa Road
Rebco Realty
Highland High School
Spiniello Construction
Vineland Post Office

benzene

Johnson & Towers - soil
AT&T Totowa Road - soil
Firestone Retail Outlet - groundwater

ethylbenzene

Rebco Realty - soil
Highland High School - soil
Spiniello Construction - soil

toluene

Johnson & Towers - soil
AT&T Totowa Road - soil

xylenes

Vineland Post Office - groundwater
AT&T Totowa Road - groundwater

Table 4.8 Summary statistics (see Table 2.3 for abbreviations)

	benzene	toluene	ethyl- benzene	xylene
P(GW exceed)(sites w/ soil data)	0.16	0.10	0.00	0.16
P(GW exceed)(all GW data)	0.19	0.09	0.05	0.14
P(soil exceed)	0.05	0.15	0.11	0.00
P(exceed detect)	0.17	0.20	0.00	0.22
P(no exceed detect)	0.83	0.80	1.00	0.78
P(exceed ND)	0.15	0.00	0.00	0.09
P(no exceed ND)	0.85	1.00	1.00	0.91
P(exceed exceed)	1.00	0.67	0.00	0.67
P(no exceed exceed)	0.00	0.33	1.00	0.33
P(exceed no exceed)	0.11	0.00	0.00	0.06
P(no exceed no exceed)	0.89	1.00	1.00	0.94
P(exclfine=c)	0.50	0.00	0.00	NA
P(no exclfine=c)	0.50	1.00	1.00	NA
P(exclfine=s)	0.17	0.00	0.00	0.14
P(no exclfine=s)	0.83	1.00	1.00	0.86
P(exclfine=sa)	0.22	0.22	0.11	0.22
P(no exclfine=sa)	0.78	0.78	0.89	0.78
P(exclfine=g)	0.00	0.00	0.00	0.00
P(no exclfine=g)	1.00	1.00	1.00	1.00
P(exclcoarse=c)	NA	NA	NA	NA
P(no exclcoarse=c)	NA	NA	NA	NA
P(exclcoarse=s)	1.00	0.00	0.00	1.00
P(no exclcoarse=s)	0.00	1.00	1.00	0.00
P(exclcoarse=sa)	0.14	0.13	0.07	0.14
P(no exclcoarse=sa)	0.86	0.87	0.93	0.86
P(exclcoarse=g)	0.33	0.00	0.00	0.00
P(no exclcoarse=g)	0.67	1.00	1.00	1.00
P(exclfine≤silt)	0.25	0.00	0.00	0.14
P(no exclfine≤silt)	0.75	1.00	1.00	0.86
P(exclfine>silt)	0.20	0.20	0.10	0.20
P(no exclfine>silt)	0.80	0.80	0.90	0.80

Table 4.8 Summary statistics (continued)

	benzene	toluene	ethyl- benzene	xylenes
P(exclcoa≤silt)	1.00	0.00	0.00	1.00
P(no exclcoa≤silt)	0.00	1.00	1.00	0.00
P(exclcoa>silt)	0.18	0.11	0.06	0.13
P(no exclcoa>silt)	0.82	0.89	0.94	0.88
P(excl≤5)	0.25	0.25	0.00	0.25
P(no excl≤5)	0.75	0.75	1.00	0.75
P(excl5<d≤7)	0.20	0.00	0.00	0.20
P(no excl5<d≤7)	0.80	1.00	1.00	0.80
P(excl7<d≤9)	0.17	0.14	0.14	0.14
P(no excl7<d≤9)	0.83	0.86	0.86	0.86
P(excl>9)	0.33	0.00	0.00	0.00
P(no excl>9)	0.67	1.00	1.00	1.00
P(excl≤7)	0.22	0.11	0.00	0.22
P(no excl≤7)	0.78	0.89	1.00	0.78
P(excl>7)	0.22	0.10	0.10	0.13
P(no excl>7)	0.78	0.90	0.90	0.88
P(excl≤5)	0.25	0.25	0.00	0.25
P(no excl≤5)	0.75	0.75	1.00	0.75
P(excl>5)	0.21	0.07	0.07	0.15
P(no excl>5)	0.79	0.93	0.93	0.85
P(exclcov)	0.08	0.00	0.00	0.08
P(no exclcov)	0.92	1.00	1.00	0.92
P(exclno cover)	0.38	0.25	0.13	0.29
P(no exclno cov)	0.63	0.75	0.88	0.71

Table 4.8 Summary statistics (continued)

	benzene	toluene	ethyl- benzene	xylene
P(excltr $\leq$ 2)	0.25	0.17	0.08	0.18
P(no excltr $\leq$ 2)	0.75	0.83	0.92	0.82
P(excltr $>$ 2)	0.20	0.00	0.00	0.17
P(no excltr $>$ 2)	0.80	1.00	1.00	0.83
P(excltr $\leq$ thresh _{tr})	0.50	0.50	0.25	0.50
P(no excltr $\leq$ thresh _{tr})	0.50	0.50	0.75	0.50
P(excltr $>$ thresh _{tr})	0.15	0.06	0.00	0.08
P(no excltr $>$ thresh _{tr})	0.85	0.94	1.00	0.92
P(exclNE&f $\leq$ silt)	0.14	0.00	0.00	0.14
P(no exclNE&f $\leq$ silt)	0.86	1.00	1.00	0.86
P(exclNE&f $>$ silt)	0.13	0.00	0.00	0.00
P(no exclNE&f $>$ silt)	0.88	1.00	1.00	1.00
P(exclNE&cov)	0.08	0.00	0.00	0.09
P(no exclNE&cov)	0.92	1.00	1.00	0.91
P(exclNE&no cov)	0.17	0.00	0.00	0.00
P(no exclNE&no cov)	0.83	1.00	1.00	1.00
P(exclNE&tr $\leq$ 2)	0.10	0.00	0.00	0.00
P(no exclNE&tr $\leq$ 2)	0.90	1.00	1.00	1.00
P(exclNE&tr $>$ 2)	0.20	0.00	0.00	0.20
P(no exclNE&tr $>$ 2)	0.80	1.00	1.00	0.80
P(exclNE&rtr $\leq$ thresh _{tr})	0.33	0.00	0.00	0.00
P(no exclNE&rtr $\leq$ thresh _{tr})	0.67	1.00	1.00	1.00
P(exclNE&rtr $>$ thresh _{tr})	0.08	0.00	0.00	0.09
P(no exclNE&rtr $>$ thresh _{tr})	0.92	1.00	1.00	0.91
	S/K_{oc}	P_v	t_{1/2}	
P(exclprop $<$ prop _T)	0.11	0.11	0.05	
P(no exclprop $<$ prop _T)	0.89	0.89	0.95	
P(exclprop $>$ prop _T)	0.13	0.16	0.14	
P(no exclprop $>$ prop _T)	0.87	0.84	0.86	

Table 4.9 Summary of population and indicator variables

	Category 1	Category 2	Total
Population 1	O_{11}	O_{12}	n_1
Population 2	O_{21}	O_{22}	n_2
Total	C_1	C_2	$N = n_1 + n_2$

Table 4.10 Test statistics

Variable of interest	benzene	toluene	ethyl- benzene	xylenes	all chemicals
soil detect	0.005	2.222	NA	0.669	
soil exceed	<u>5.630</u>	<u>12.593</u>	NA	<u>7.389</u>	
finest $\leq$ silt	0.064	2.012	0.950	0.093	
coarsest $\leq$ silt	<u>3.706</u>	0.124	0.059	<u>4.958</u>	
transport dist. $\leq$ 7'	0.000	0.006	0.950	0.275	
transport dist. $\leq$ 5'	0.023	1.127	0.281	0.195	
ground cover	2.552	<u>3.592</u>	1.706	1.362	
transport time $\leq$ 2yr	0.049	1.125	0.529	0.007	
retarded trans. time $\leq$ thresh _{tr}	2.037	<u>3.445</u>	<u>3.706</u>	<u>3.419</u>	
NE & finest $\leq$ silt	0.010	NA	NA	1.077	
NE & cover	0.281	NA	NA	0.485	
NE & trans. time $\leq$ 2yr	0.288	NA	NA	1.733	
NE & ret. trans. time $\leq$ thresh _{tr}	1.298	NA	NA	NA	
solubility/organic carbon coefficient					0.126
vapor pressure					0.378
half-life					1.050

4.10 Figures

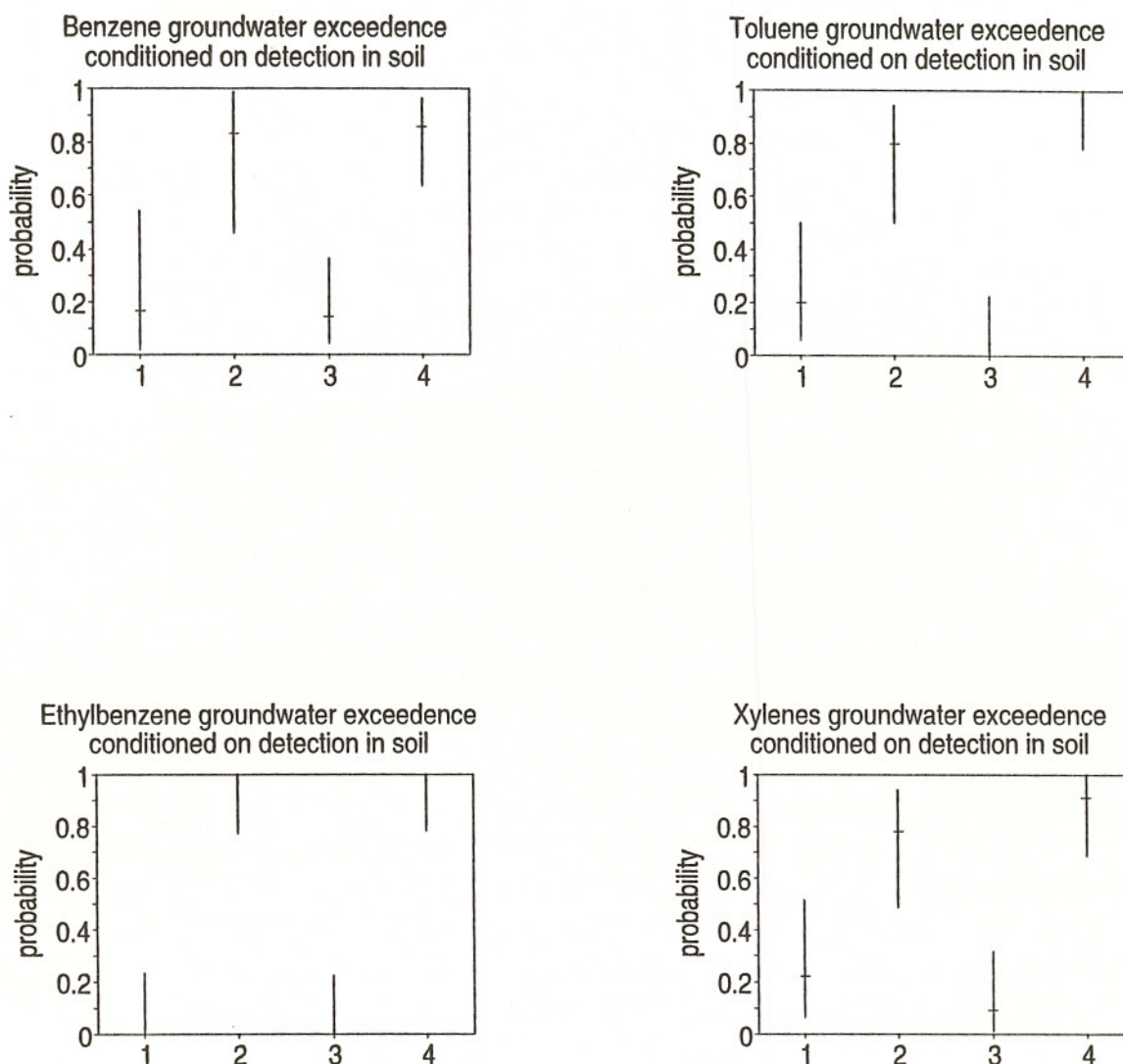


Figure 1 1 – P(GW exceedence|soil detection), 2 – P(no GW exceedence|soil detection), 3 – P(GW exceedence|no soil detection), 4 – P(no GW exceedence|no soil detection)

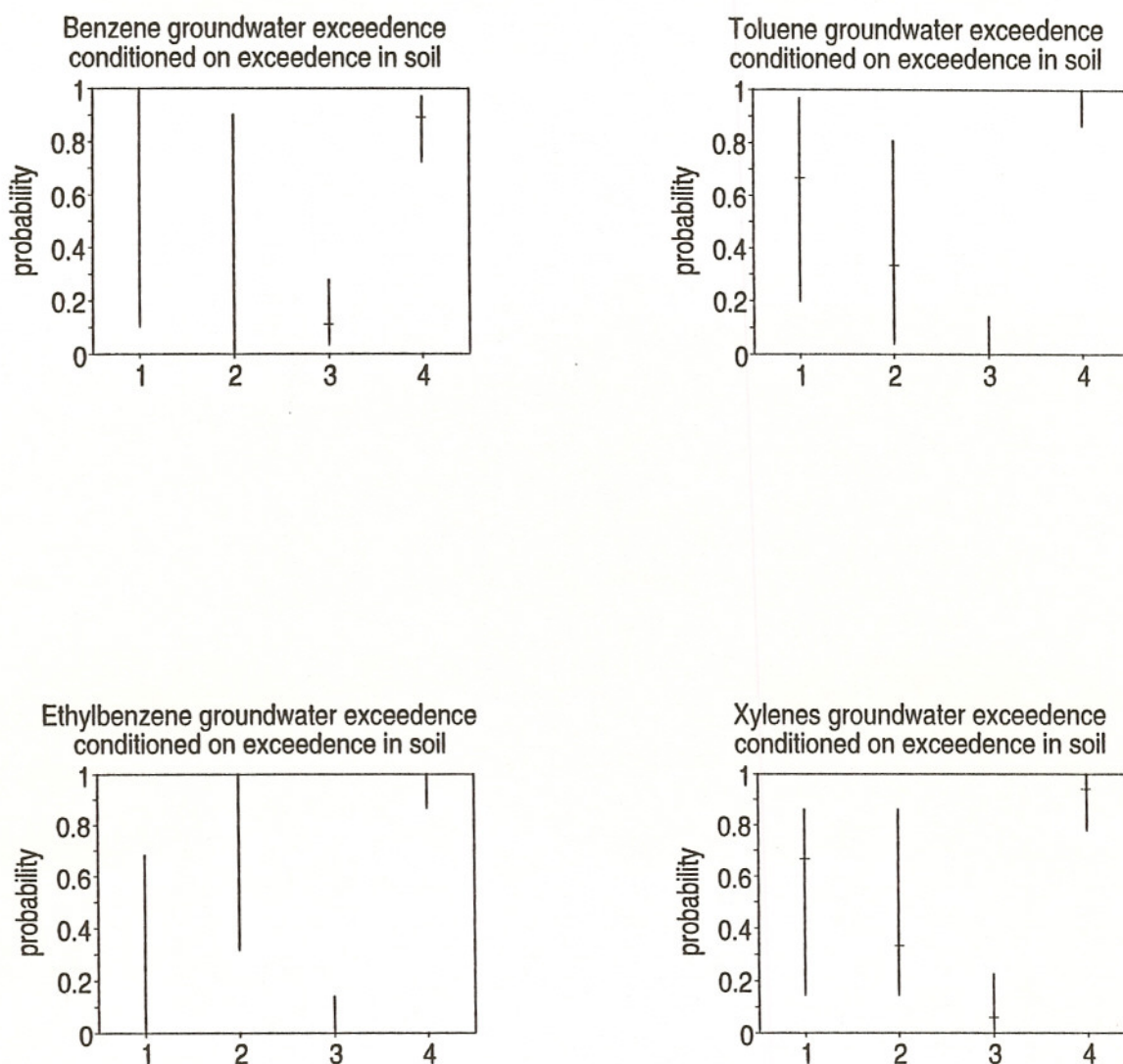


Figure 2 1 – P(GW exceedence|soil exceedence), 2 – P(no GW exceedence|soil exceedence), 3 – P(GW exceedence|no soil exceedence), 4 – P(no GW exceedence|no soil exceedence)

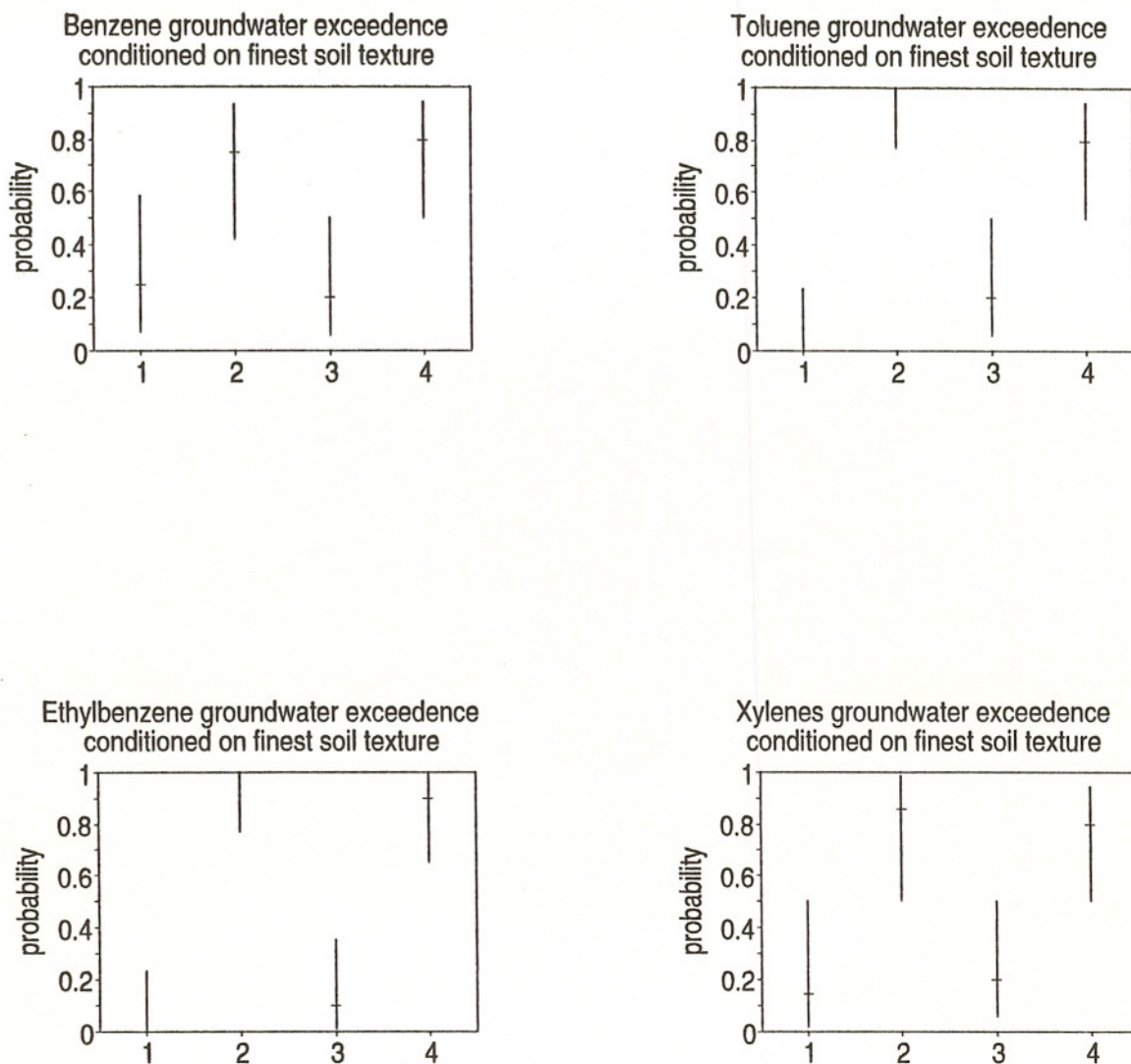


Figure 3 1 – $P(\text{GW exceedence} | \text{finest} \leq \text{silt})$, 2 – $P(\text{no GW exceedence} | \text{finest} \leq \text{silt})$, 3 – $P(\text{GW exceedence} | \text{finest} > \text{silt})$, 4 – $P(\text{no GW exceedence} | \text{finest} > \text{silt})$

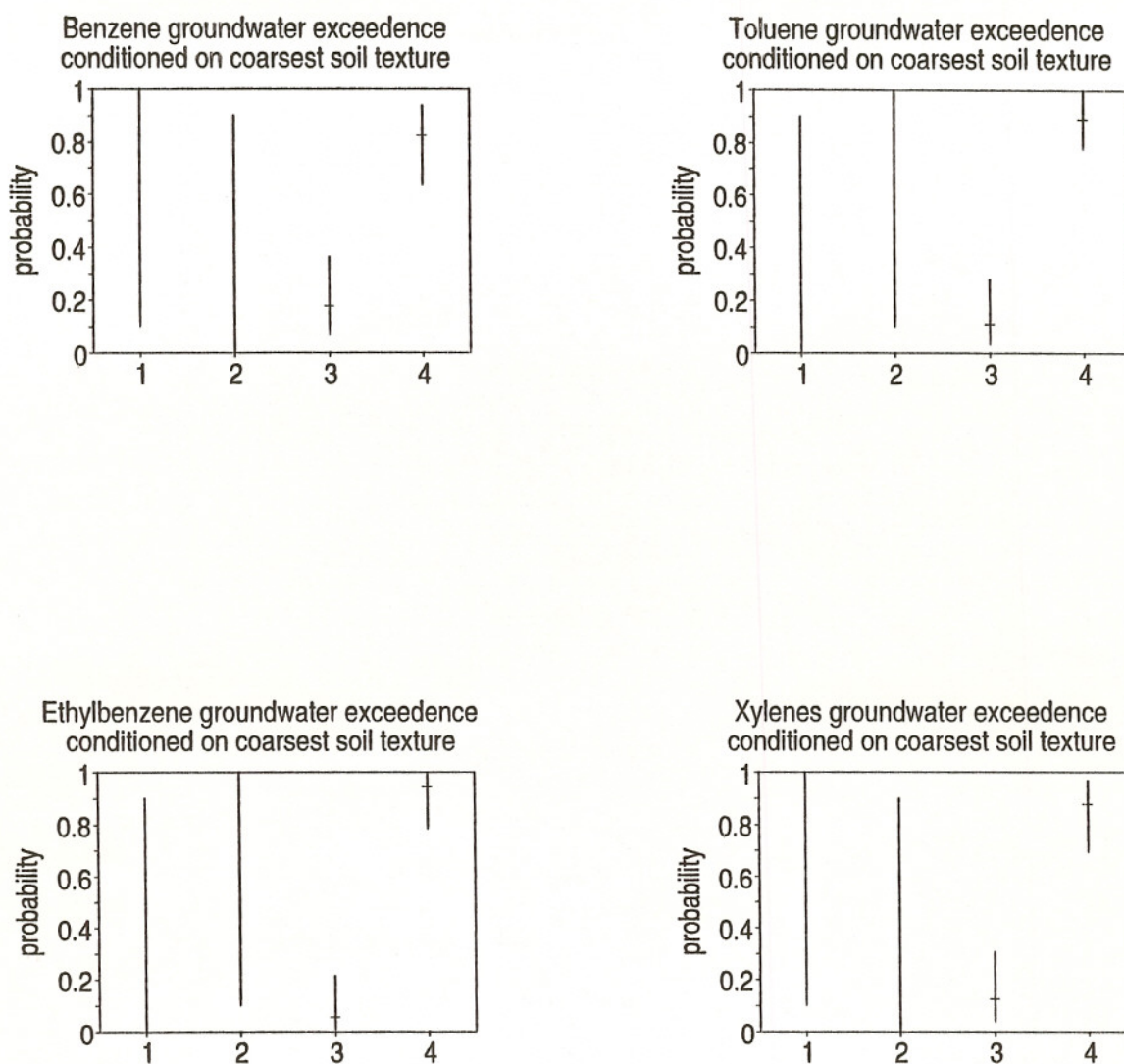


Figure 4 1 – $P(\text{GW exceedence} | \text{coarsest} \leq \text{silt})$, 2 – $P(\text{no GW exceedence} | \text{coarsest} \leq \text{silt})$,
3 – $P(\text{GW exceedence} | \text{coarsest} > \text{silt})$, 4 – $P(\text{no GW exceedence} | \text{coarsest} > \text{silt})$

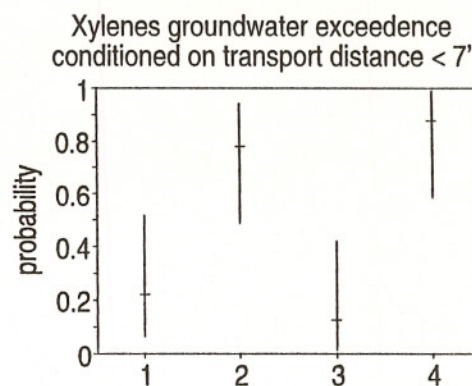
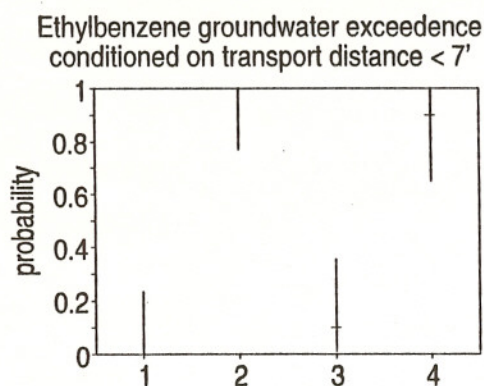
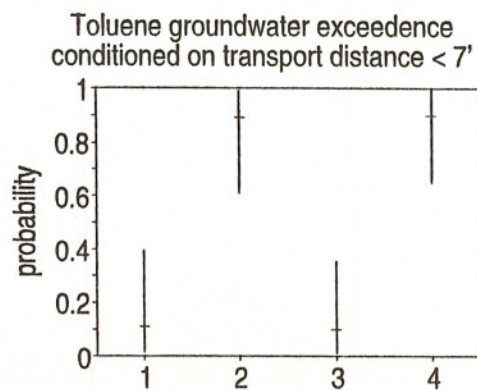
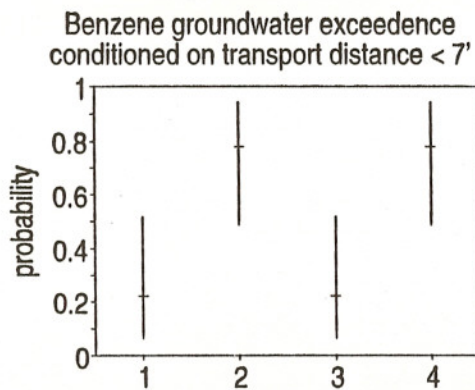


Figure 5 1 – $P(\text{GW exceedence} | \text{distance} \leq 7')$, 2 – $P(\text{no GW exceedence} | \text{distance} \leq 7')$, 3 – $P(\text{GW exceedence} | \text{distance} > 7')$, 4 – $P(\text{no GW exceedence} | \text{distance} > 7')$

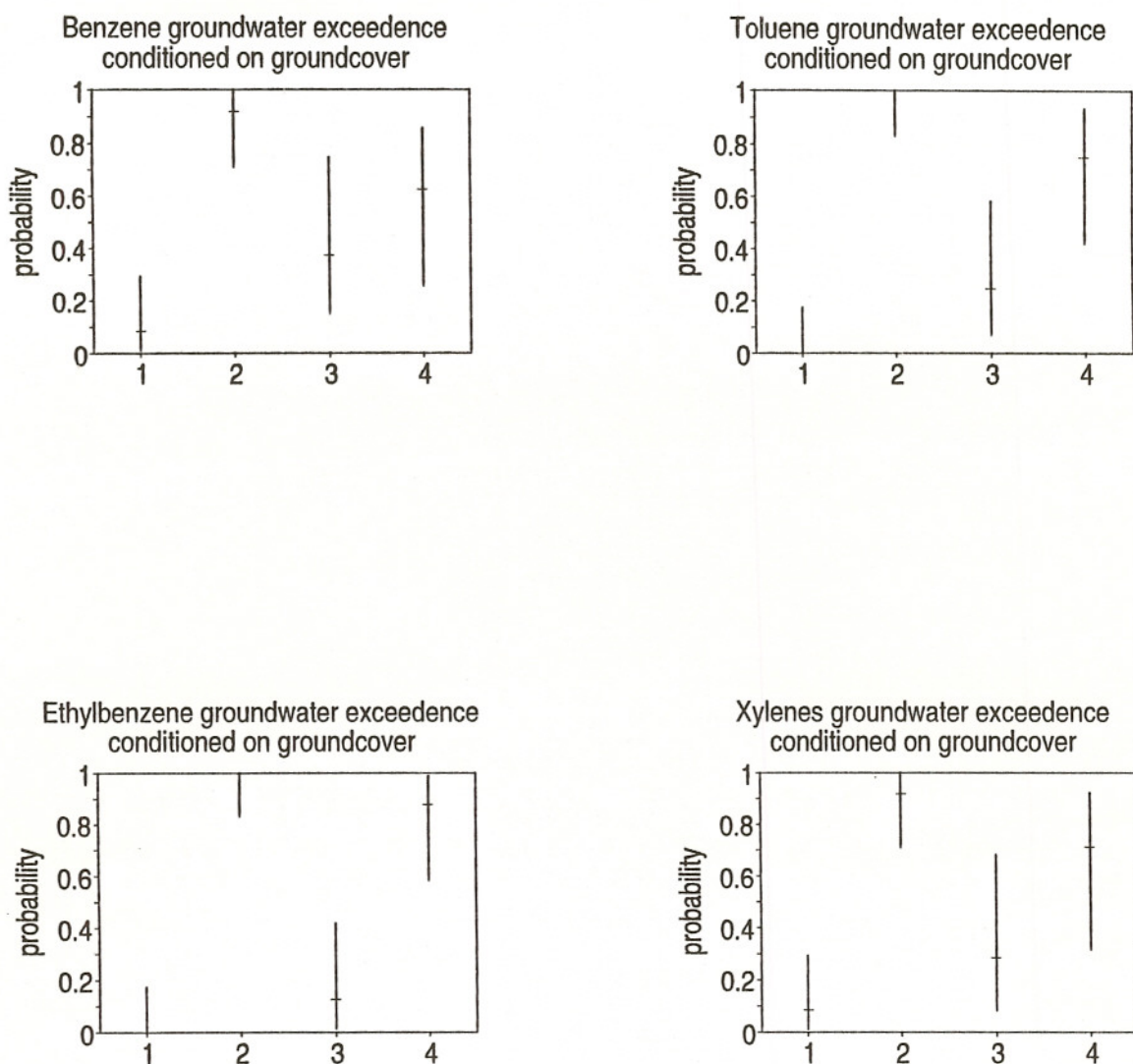


Figure 6 1 – P(GW exceedence|ground cover), 2 – P(no GW exceedence|ground cover),
3 – P(GW exceedence|no ground cover), 4 – P(no GW exceedence|no ground cover)

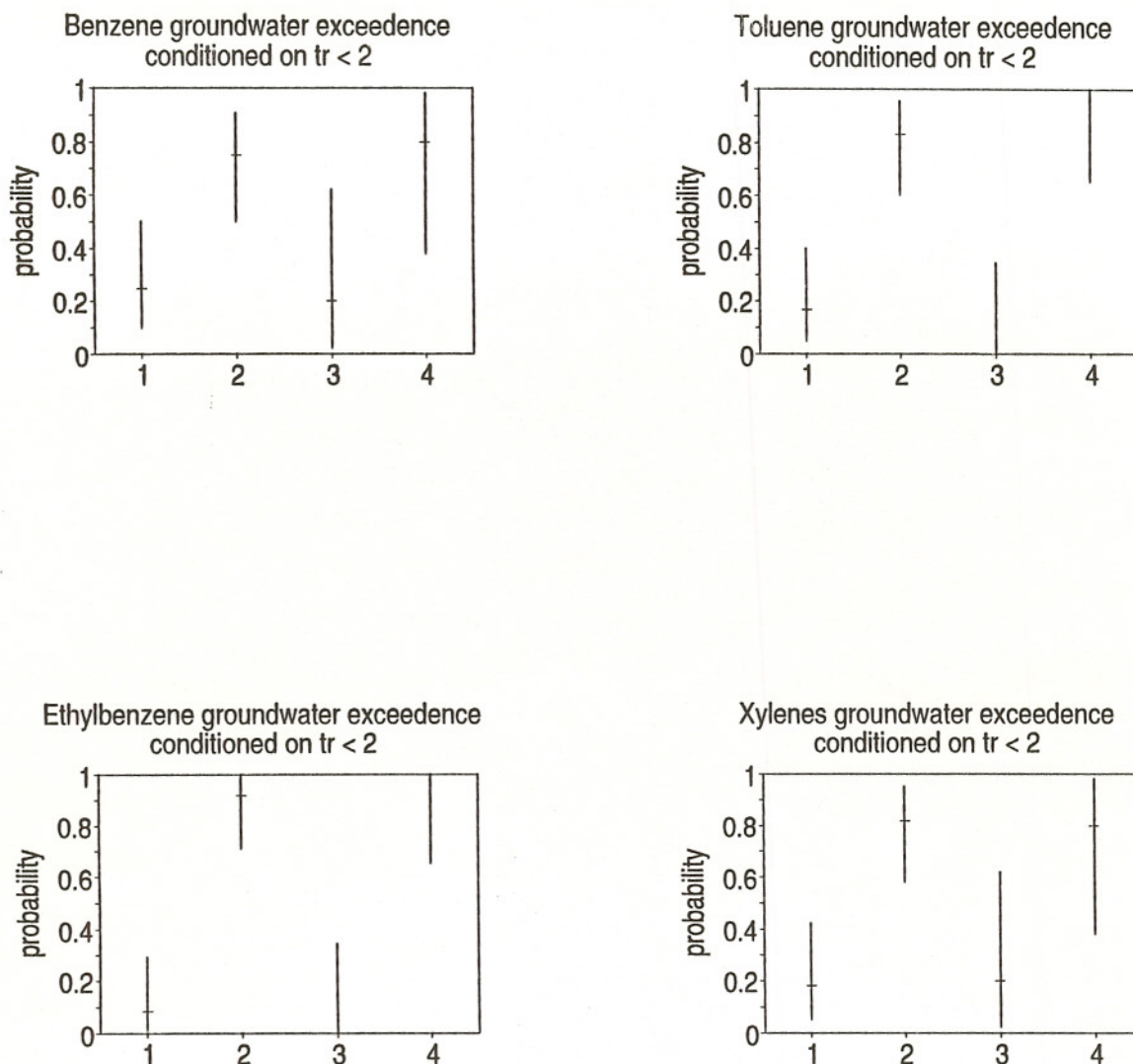


Figure 7 1 – $P(\text{GW exceedence} | t_r \leq 2 \text{ years})$, 2 – $P(\text{no GW exceedence} | t_r \leq 2 \text{ years})$, 3 – $P(\text{GW exceedence} | t_r > 2 \text{ years})$, 4 – $P(\text{no GW exceedence} | t_r > 2 \text{ years})$

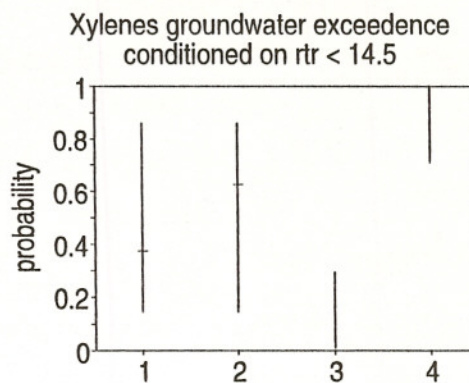
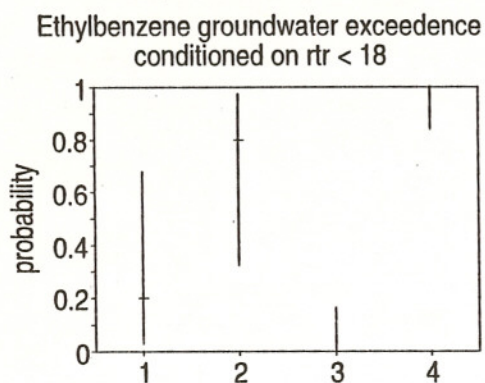
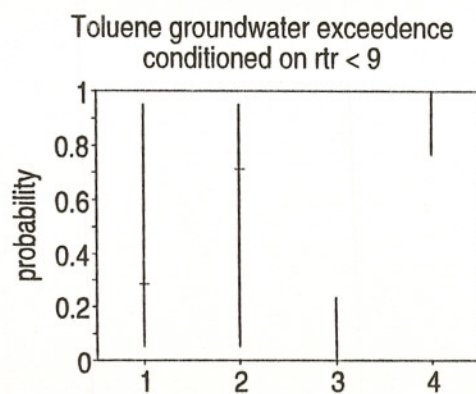
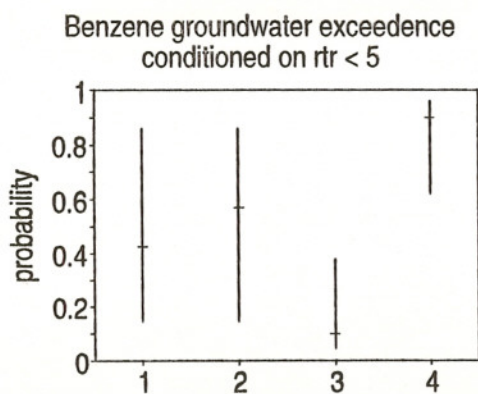


Figure 8 1 – $P(\text{GW exceedence} | t_{tr} \leq 5 \text{ yr})$, 2 – $P(\text{no GW exceedence} | t_{tr} \leq 9 \text{ yr})$, 3 – $P(\text{GW exceedence} | t_{tr} > 18 \text{ yr})$, 4 – $P(\text{no GW exceedence} | t_{tr} > 14.5 \text{ yr})$

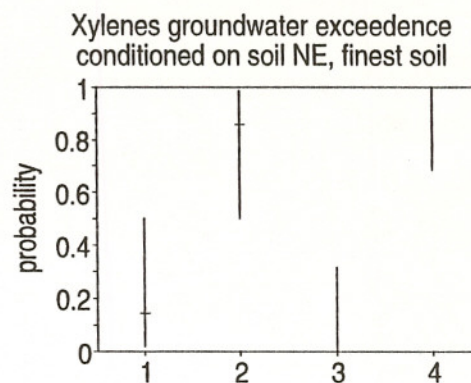
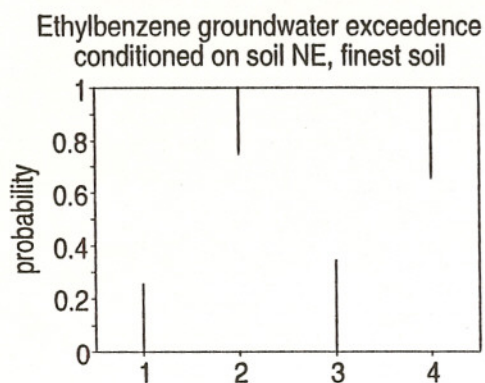
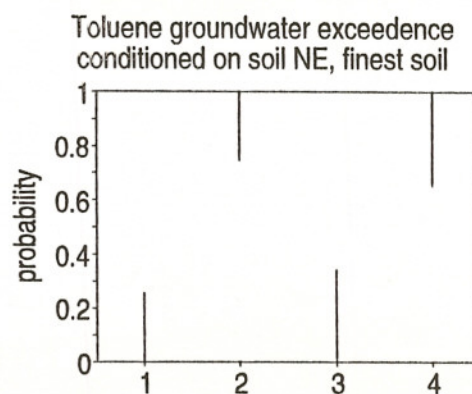
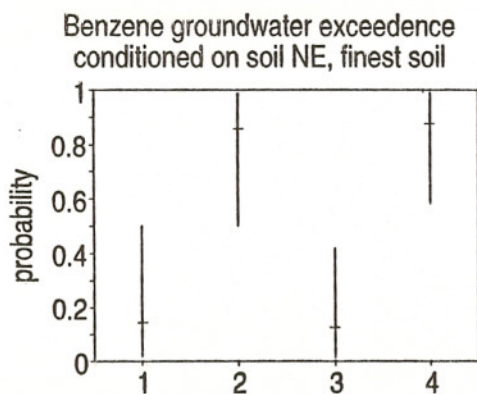


Figure 9 1 – $P(\text{GW exceedence} | \text{NE, finest} \leq \text{silt})$, 2 – $P(\text{no GW exceedence} | \text{NE, finest} \leq \text{silt})$, 3 – $P(\text{GW exceedence} | \text{NE, finest} > \text{silt})$, 4 – $P(\text{no GW exceedence} | \text{NE, finest} > \text{silt})$

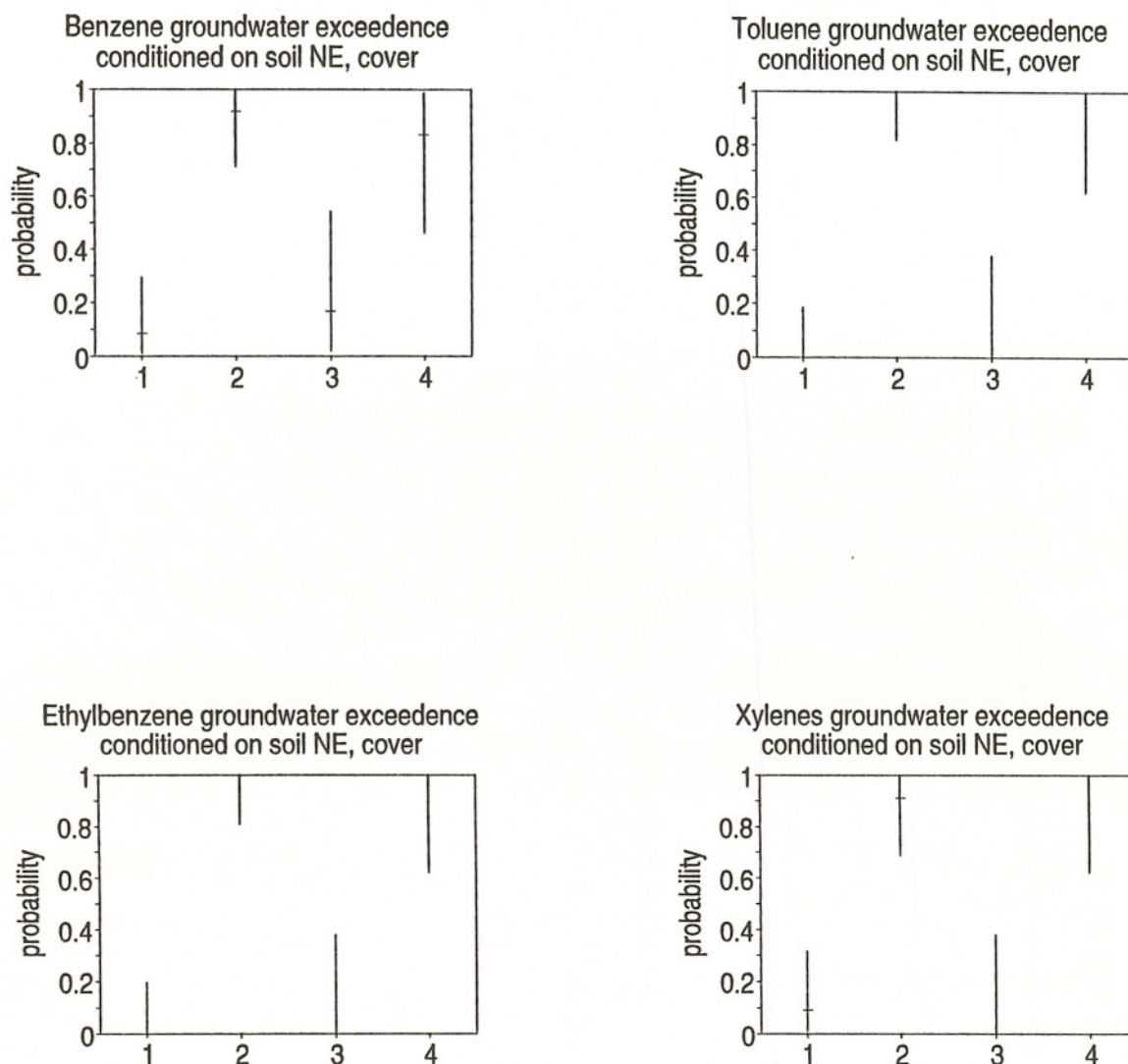


Figure 10 1 – P(GW exceedence|NE, ground cover), 2 – P(no GW exceedence|NE, ground cover), 3 – P(GW exceedence|NE, no ground cover), 4 – P(no GW exceedence|NE, no ground cover)

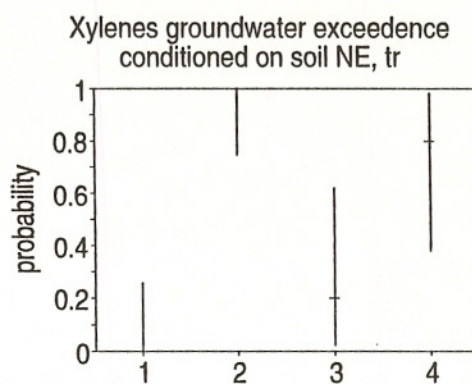
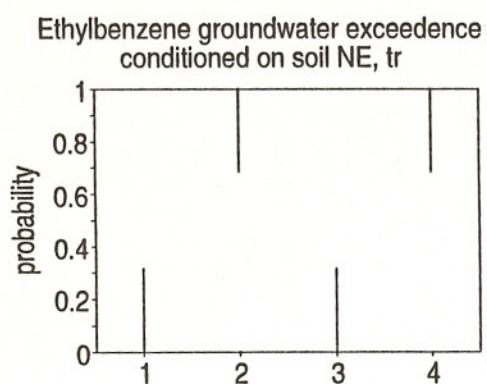
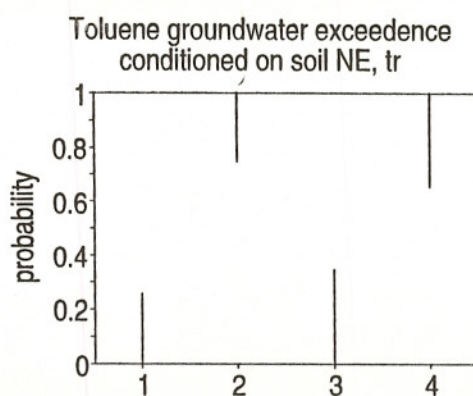
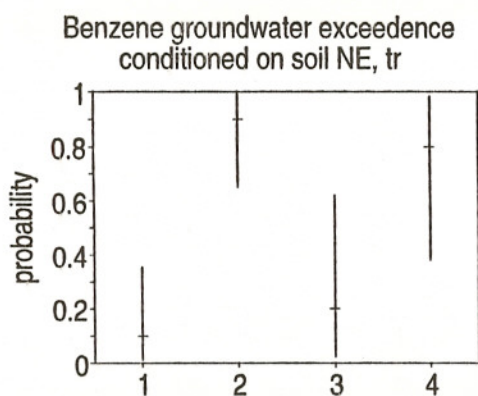


Figure 11 1 – $P(\text{GW exceedence}|\text{NE}, t_r \leq 2 \text{ yr})$, 2 – $P(\text{no GW exceedence}|\text{NE}, t_r \leq 2 \text{ yr})$, 3 – $P(\text{GW exceedence}|\text{NE}, t_r > 2 \text{ yr})$, 4 – $P(\text{no GW exceedence}|\text{NE}, t_r > 2 \text{ yr})$

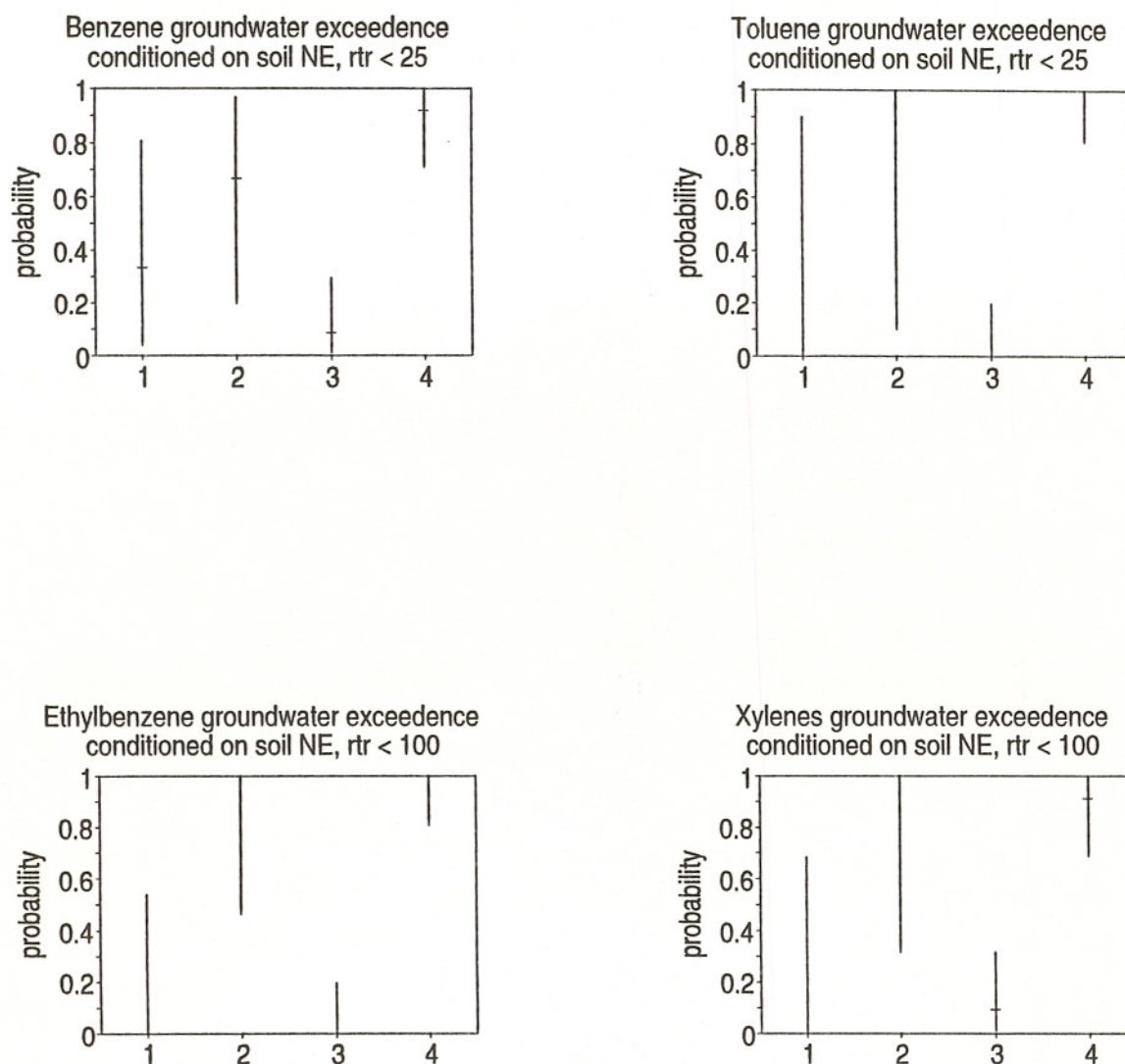


Figure 12 1 – P(GW exceedINE, $t_{tr} \leq 5$ yr), 2 – P(no GW exceedINE, $t_{tr} \leq 9$ yr), 3 – P(GW exceedINE, $t_{tr} > 18$ yr), 4 – P(no GW exceedINE, $t_{tr} > 14.5$ yr)

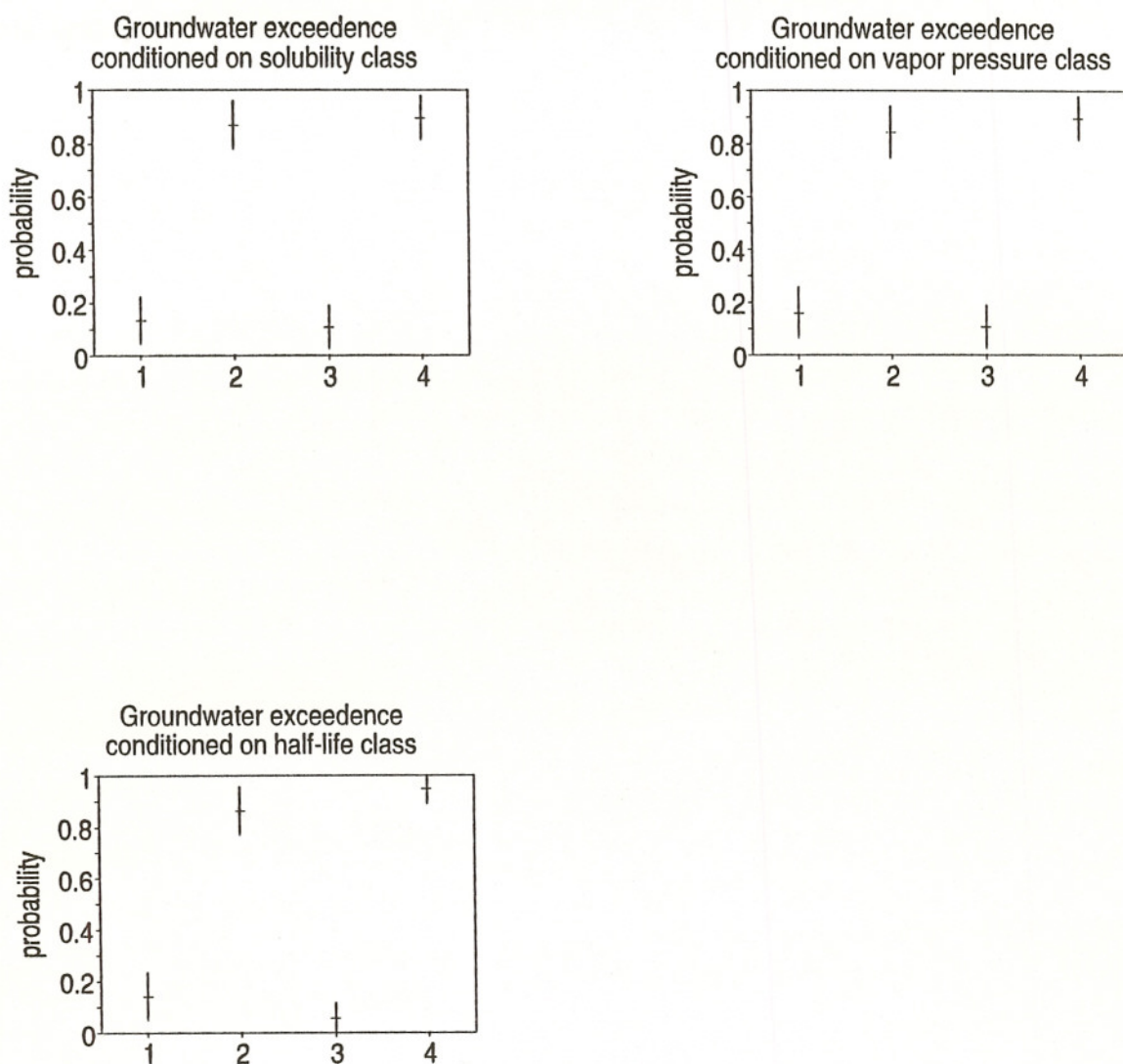


Figure 13 1 – P(GW exceedence|chem. param. $\leq$ threshold), 2 – P(no GW exceedence|chem. param. $\leq$ threshold), 3 – P(GW exceedence|chem. param. $>$ threshold), 4 – P(no GW exceedence|chem. param. $>$ threshold)

5 Development of trigger software

This section describes operation of the trigger software. The software version of the trigger is based on the spreadsheet Quattro® Pro and has been written in the Quattro® Pro macro programming language. Although not necessary, the user should be familiar with basic Quattro® Pro features. We do not discuss these features in any detail. For further information concerning Quattro® Pro features, we refer the user to the Quattro® Pro *User's Guide*.

In this section, an overview of the trigger is provided. We describe operation of the trigger, including data requirements and reporting capabilities. We conclude with an illustrative example.

5.1 Overview of trigger software

The trigger is designed with the user in mind. It is menu-driven for easy use, prompting the user for keyboard input or selection from a menu. It also checks inputs, rejecting those found to be unacceptable (negative concentrations, for example) and prompting the user with a range of acceptable inputs.

The trigger consists of five modules: 1) introduction, 2) general site information, 3) Tier 1, 4) Tier 2, and 5) quitting the trigger and saving results. These modules are shown in Figure 5.1. The first module introduces the user to the trigger and its operation. The second module prompts the user for general information concerning the site such as its name, case number, etc. The third module consists of the first tier. The user is prompted to select the contaminants of concern from a menu and to enter the soil concentrations. The trigger then reports the result of the first tier. If Tier 1 indicates groundwater monitoring, the trigger proceeds to the fifth module where the user can quit or save the results to a file (see below). If Tier 1 fails to indicate groundwater monitoring, the trigger proceeds to the next module, the second tier. In Tier 2, the user is prompted for the site data required by the transport time screening model and the model is run for each contaminant entered in the first tier. If the second tier indicates groundwater monitoring, the user is informed of the result and the trigger proceeds to the fifth module. The fifth module gives the user the option of starting the trigger again and analyzing another site as well as quitting the trigger.

The trigger software contains two databases. The first is a database of chemicals and their properties. The database also includes soil standards and retarded transport time thresholds. These threshold values are used by the trigger to assess the likelihood of groundwater contamination. The second database contains soil textures and parameters for use by the transport time screening model.

The trigger has been provided with safeguards to prevent unauthorized modification. For this reason, the only way that the user can quit without using the trigger software's help menus is to reboot the computer.

5.2 Operation of the trigger software

The trigger software uses Quattro® Pro menu and command features to interact with the user. In most cases, the trigger communicates with the user via Quattro® Pro-style messages that appear in the middle of the screen. These messages are supplemented by prompts at the Quattro® Pro command line, from which most data are entered by the user. The user is also prompted to select items from menu lists. The menu lists appear at the upper left-hand corner of the screen.

When the trigger is started, the main menu is shown on-screen. The main menu gives the user three options: quit the trigger, go through the introduction, or continue with the trigger.

If the user selects the introduction, the trigger displays the first of three introduction messages. Each message summarizes part of the trigger and its operation. The user moves through the introduction messages by pressing any key besides Q. Q can be pressed to return to the main menu at any time. At the conclusion of the introduction, the user is returned to the main menu.

If the user elects to continue the trigger from the main menu, the trigger displays a message requesting general site information: the site name, the responsible NJDEPE bureau, the case number, the name of the user, and the current date. The user should press any key to continue. The user is then prompted for each piece of information at the Quattro® Pro command line. Each input should also be entered at the Quattro® Pro command line. Upon receiving all requested information, the trigger advances to Tier 1.

Tier 1 begins by prompting the user to enter the number of contaminants of concern at the site. This tier requires the name and the maximum concentration (in units of ppm) of each of the contaminants of concern for the site. A list of chemical names is provided in a Quattro® Pro menu. In addition to chemicals detected at sites identified through the random search, the list includes chemicals detected at sites identified through the directed search. These chemicals can be assessed by the first tier only.¹ Selection of a chemical is identical to selection of any item in a Quattro® Pro menu. To select a chemical, the user moves the cursor to highlight the name of the chemical of concern and presses Enter. Alternatively, the user can press the first letter of the chemical of concern. Following selection of a chemical, the user is prompted for the maximum concentration. The concentration should be entered at the Quattro® Pro command line. Non-

¹ Since no transport time thresholds have been established for these chemicals, Tier 2 cannot be applied.

detects² are entered as zero. Following selection of a chemical of concern and entry of the maximum concentration, the trigger repeats until the names and maximum concentrations of all chemicals of concern have been entered. Applicable soil standards are not required inputs since they are included in the trigger's internal database.

Upon completion of chemical name and concentration input, the trigger compares the maximum concentrations with the applicable soil standards listed in Table 4.6. If the applicable soil standard for any chemical is exceeded, the trigger reports that groundwater monitoring is indicated. If groundwater monitoring is indicated, the trigger advances to the Quit module (see below). If groundwater monitoring is not indicated, the trigger advances to the second tier.

Tier 2 begins by prompting the user to indicate whether or not asphalt or concrete pavement is present (or was before site investigation) on the ground surface. The user need simply press Y for yes or N for no. The user is then prompted for the distance from the sample to the water table. The distance (in units of feet) should be entered at the Quattro[®] Pro command line. The user is then prompted for the number of soil layers. The number of soil layers should also be entered at the Quattro[®] Pro command line. A maximum of 10 soil layers is allowed. The trigger then prompts the user for information concerning each of the soil layers. First, the user is prompted to select the soil type from a Quattro[®] Pro menu. Similar to selecting a chemical name, the user should move the cursor to highlight the name of the desired soil type and press Enter. The user is then prompted to enter the thickness of that soil layer. The thickness of the layer (in units of feet) should be entered at the Quattro[®] Pro command line. The process of selecting a soil type and thickness is repeated for each soil layer specified.

Upon completion of required parameter input, the trigger runs the transport time screening model for each contaminant for which transport time thresholds are available. The trigger compares estimated transport times with corresponding transport time thresholds. If the threshold for any chemical is exceeded, the trigger reports groundwater monitoring is indicated.³

If no thresholds are exceeded in either the first or second tiers, the trigger reports groundwater monitoring is not indicated.

² Non-detects are reasonable maximum concentrations if there are other indications of the presence of the chemical such as knowledge of the contents of a leaking UST. Non-detects with elevated detection limits should not be interpreted as indicating the absence of a chemical.

³ The trigger reports "NA" (non-applicable) for those chemicals having no transport time thresholds.

No other parameters are needed since they are all contained within the trigger software's database. Figure 5.2 shows required inputs of the General Site Information, Tier 1, and Tier 2 modules of the groundwater monitoring trigger.

Upon completing the site assessment, the trigger displays a message with three options for the user: quit the trigger and save the results to a spreadsheet file, quit the trigger without saving the results, and restart the trigger without saving the results. If the user elects to restart the trigger without saving the results, the current results are erased, the user is returned to the beginning of the trigger, and the main menu is displayed on-screen. If the user elects to save the results to an output file, the user is prompted for the name of the output file. Details of output are provided in Section 5.3. Following output, the user has the choice of either quitting or restarting the trigger.

Although the software automates application of the trigger, care should be taken to ensure the trigger is applied in a way consistent with its development. Soil texture should be characterized as it is herein, directly from boring logs. The transport distance should be measured from the soil sample location, not from the ground surface. Non-detects with detection limits elevated above applicable soil standards should not be treated as non-exceedence of the standards. Units should be consistent with those specified by the trigger.

Ease of trigger use does not obviate the need for good judgement on the part of the user. Input parameters must be derived from all site information available. Evidence of release such as badly corroded USTs should be taken under consideration, even if no contaminants are detected in soil. Site features that can dominate contaminant migration should be identified. Such features include fractures, macropores, drainage and utility conduits, large variations in water table elevation, and extreme topography (*e.g.*, large depressions) that can concentrate infiltration. Such features can be particularly important if they are not accounted for by the trigger.

5.3 Description of trigger software output

The trigger software has provision for saving results to a spreadsheet file. The default results file is results.wq1. However, the user has the option of specifying the name of the file. If the user specifies the name of a file that already exists in the current directory, the existing file is overwritten.

The output consists of the summary of general site information and the results of each tier. The summary of site information includes the name of the site, the case number and responsible bureau, the name of the trigger user and the date of its use. The results of Tier 1 consist of the contaminant names, soil concentrations, and applicable soil standards. The results of Tier 2 consist of estimates of travel time and the associated travel time thresholds. Whether or not groundwater monitoring is indicated is also reported.

An example output file has been prepared. It is based on a hypothetical site that can be summarized:

A gasoline-storage UST is removed from the property of Acme, Inc. The contaminants of concern are benzene, toluene, ethylbenzene, and xylenes. Soil samples exhibit the following maximum concentrations: non-detect of benzene, 100 ppm of toluene, 20 ppm of ethylbenzene, and 7 ppm of xylenes. The surface of the site consists of a layer of gravel. The distance to the water table is 9 feet, the soil consisting of a layer of silt 5 feet thick and a layer of sand 4 feet thick.

The output of the trigger software for this site is reported in Table 5.1. The output clearly indicates none of the applicable soil standards are exceeded. However, the trigger indicates groundwater monitoring based on estimated transport times of ethylbenzene and xylenes.

5.4 Tables

Table 5.1 Results for Acme, Inc. site.

Site name: Acme, Inc.
 Bureau: BUST
 Case number: 1234
 User: Steve Luis
 Date: May 5, 1994

Tier 1:

chemical	maximum conc. (ppm)	soil standard (ppm)	exceed?
benzene	ND	1	no
toluene	100	500	no
ethylbenzene	20	100	no
xylene	7	10	no

Tier 1 result: Groundwater contamination is unlikely.

Tier 2:

chemical	estimated transport time (yrs)	transport time threshold (yrs)	exceed?
benzene	5	5	no
toluene	10	9	no
ethylbenzene	18	18	yes
xylene	14	14.5	yes

Tier 2 result: Groundwater contamination is likely.

5.5 Figures

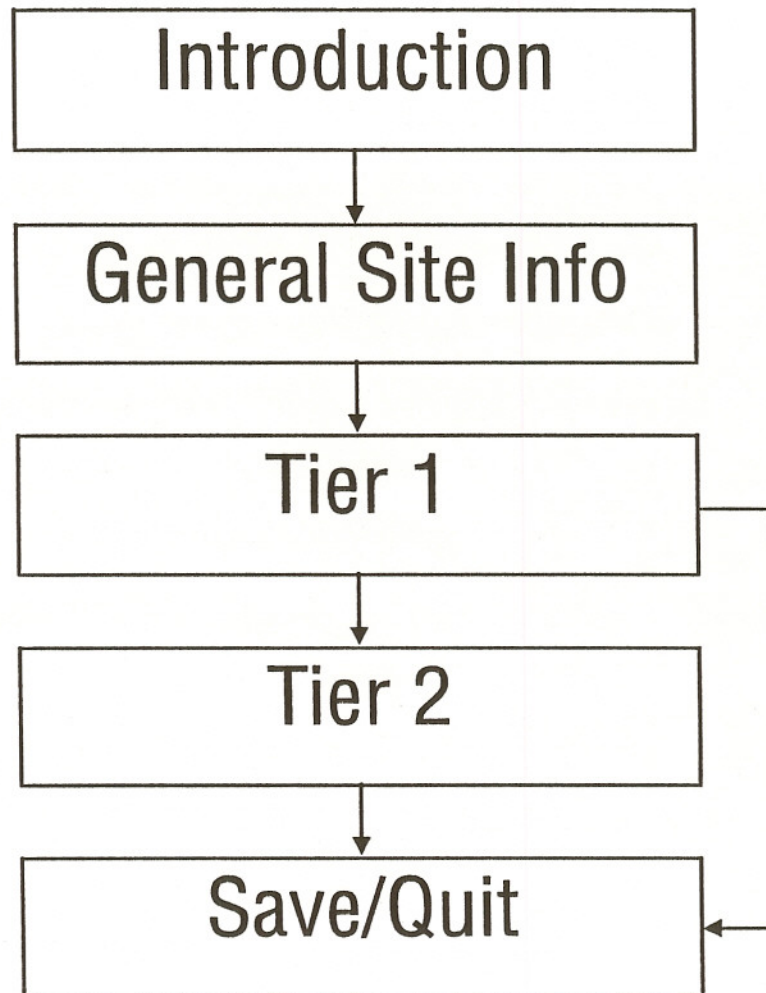


Figure 5.1 Schematic of groundwater monitoring trigger

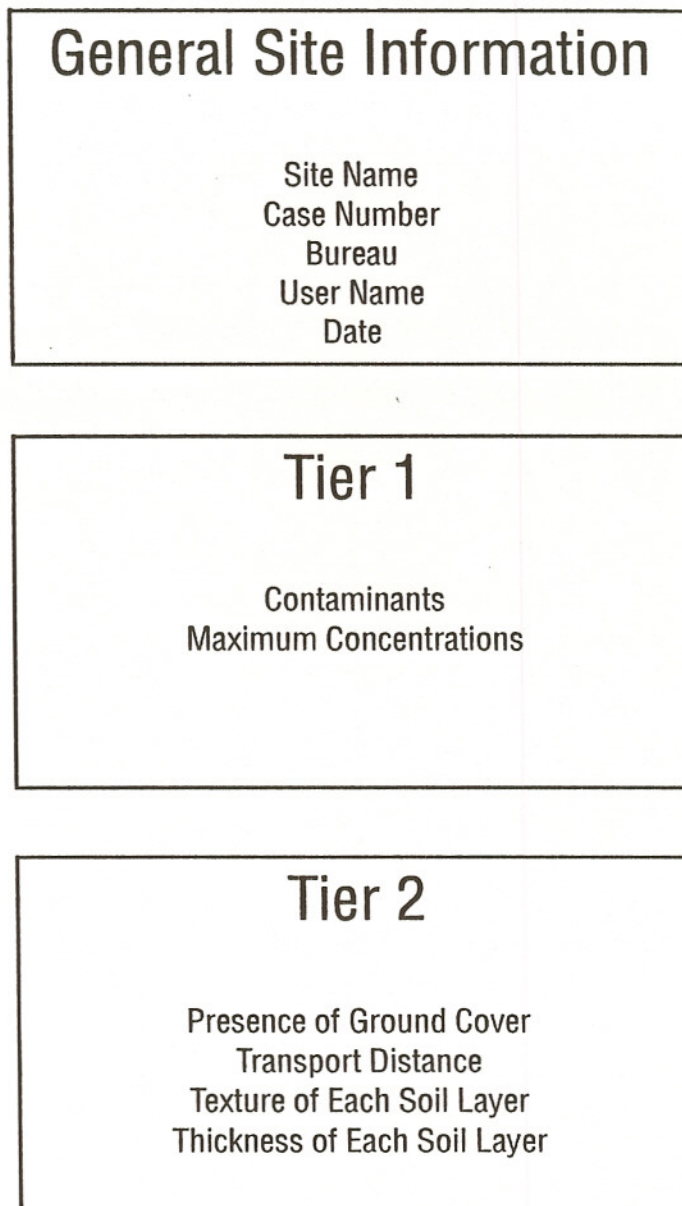


Figure 5.2 Input requirements of groundwater monitoring trigger

6 Assessment of trigger performance

In this section, we assess the performance of the trigger. The performance of the trigger is assessed in two ways. First, the trigger is assessed using conventional definitions of accuracy. Performance is also assessed by applying the trigger to two sets of files. The first set is that obtained as a result of the random search. Since these files were used to develop the trigger, we expect it to perform relatively well on them. The trigger is also applied to the set of cases obtained from the directed search. Since these files were selected because they represent unusual site conditions, the trigger is not expected to perform as well.

6.1 Accuracy of the trigger

Each application of the trigger can have one of four outcomes. Two of the possible outcomes are true and two are false. These outcomes can be schematized as in Table 6.1.

The accuracy of a general diagnostic procedure is defined in four ways by the U.S. Preventive Services Task Force (1989). These definitions can easily be adapted to the groundwater monitoring trigger developed here. The modified definitions are:

1. sensitivity (true positive) — the probability of indication of groundwater contamination in exceedence of the groundwater standard, given the existence of groundwater contamination in exceedence of the standard,
2. specificity (true negative) — the probability of indication of no groundwater contamination, given no groundwater contamination in exceedence of the standard,
3. positive predictive value — the probability of groundwater contamination, given indication of groundwater contamination, and
4. negative predictive value — the probability of no groundwater contamination, given indication of no contamination.

Ideally, all four measures of accuracy would be high. However, as the analysis in Section 4.5 shows, uncertainties in the data used to develop the trigger are relatively large. These uncertainties can be expected to adversely affect the accuracy of the trigger and to be reflected in the four measures of accuracy defined above.

The four measures of accuracy have been calculated for each tier of the trigger and for the trigger as a whole. They are reported in Table 6.2. Since triggering groundwater monitoring for any individual contaminant would effectively result in monitoring for all contaminants, the last column probably best indicates how the trigger would perform in actual use.

Table 6.2 shows the overall sensitivity or true positive rate of the trigger is 0.75. This means that the trigger could be expected to identify approximately 75% of the sites at which groundwater contamination has occurred. It also means the trigger would fail to identify 25% of the UST sites at which contamination of groundwater has occurred. The specificity or true negative rate of the trigger is 0.79. The trigger could be expected to correctly identify approximately 79% of the sites at which no contamination has occurred. The trigger could also be expected to incorrectly indicate groundwater monitoring at 21% of the sites at which no contamination has occurred.

As desired, the sensitivity and specificity appear to be relatively high. However, there are no objective criteria against which the values can be compared.

Since our analysis in Section 4.3 shows that groundwater standards are exceeded at approximately 18% of the UST sites included in the survey,¹ we would expect application of the trigger to correctly indicate monitoring for 75% of these, or 14% of all UST sites. By the same reasoning, we would also expect the trigger to incorrectly indicate monitoring at 17% of UST sites (*i.e.*, sites at which groundwater standards were not exceeded). Altogether then, the trigger would identify 31% of UST sites for groundwater monitoring.

The positive predictive value of the trigger is 50%. This means that contamination in excess of the groundwater standard would be detected in about 50% of the monitoring wells installed. The negative predictive value is 92%. This indicates that in 92% of the instances in which the trigger indicates no exceedence of applicable groundwater standards, no exceedence of applicable groundwater standards would occur.

A strict interpretation of the results for all chemicals reported in Table 6.2 leads to the conclusion that application of the full trigger provides no improvement over use of the soil standard alone. However, Table 6.2 shows that addition of the second tier improves the sensitivity of the trigger from 0.33 to 0.67 for benzene and from 0.5 to 1.0 for toluene. However, for xylenes, use of the second tier results in a decrease of the specificity and positive and negative predictive values of the trigger. Thus, our measures of accuracy give some indication that the second tier improves the effectiveness of the trigger, but the evidence is not overwhelming.

Some case file data suggest the need for a second tier, however. There are cases in which concentrations of contaminants in soils do not exceed the soil standard but in which groundwater contamination occurs. Exxon Service Station #3-8238 is the best example in the set of cases

¹ This is the fraction of sites at which any one or more BTEX groundwater standards are exceeded, or 4 out of 22 sites.

discovered by random search. No contaminants were detected in soil² at this site, but groundwater concentrations of benzene and xylenes exceeded their respective standards. In this case, the storage tank may have been in the groundwater, with overlying soil uncontaminated. The second tier is intended to identify sites at which soil contamination is negligible but groundwater contamination is not. This situation could occur at sites in which the storage tank lies (in part or in whole) beneath the groundwater table (which was potentially the case at the Exxon Service Station site). Before the trigger is applied in these cases, however, there should be circumstantial evidence of a release to groundwater, such as the presence of a visible sheen on the groundwater table or indication of a breach in the integrity of the storage tank. Application of the trigger to the directed search files may give further indication of the usefulness of the second tier of the trigger.

6.1.1 Discussion of trigger performance with respect to specific sites

The trigger was applied to the case files obtained from the random search. The first tier, the soil standard for at least one of the BTEX contaminants, would have triggered groundwater sampling at four sites: Highland High School, Spiniello Construction, NJAWC Short Hills Station - Pit C5, and AT&T Totowa Road. The groundwater standard was exceeded at three of these sites: Highland High School, Spiniello Construction, and AT&T Totowa Road. No contaminants were detected in groundwater at NJAWC Short Hills Station - Pit C5.

At some sites for which groundwater monitoring is triggered by the first tier, groundwater standards were exceeded for different chemicals. For example, groundwater monitoring is indicated at AT&T Totowa Road for xylenes (soil concentration 360 ppm). However, benzene was detected in groundwater in excess of the standard (17 ppb).³ Similarly, groundwater monitoring is indicated at Spiniello construction by exceedence of the xylenes soil standard, but benzene and toluene groundwater standards were exceeded in addition to that for xylenes.

The second tier of the trigger, the retarded transport time, would have triggered groundwater sampling at Highland High School and Spiniello Construction as well as two additional sites, NJAWC Baltasrol Station and McKee City Distributors. No contaminants were detected in groundwater at these two additional sites, nor were contaminants detected in soil.

If the presence of ground cover were used as an additional tier, groundwater monitoring would have been triggered at three additional sites (in addition to five sites at which monitoring would

² Detection limits were not reported in the case file. Therefore, it is possible the detection limits were elevated.

³ Groundwater samples were not analyzed for xylenes. Therefore, it is possible the xylenes groundwater standard was exceeded as well.

have been triggered by the other two tiers). The three sites are Pohatcong Township Municipal Building - West UST, Pohatcong Township Municipal Building - East UST, and NJAWC Short Hills Station - Pit A3.

After application of the first tier, 3 of 4 sites at which groundwater contamination in exceedence of the standard would have been detected. After application of the second tier, two additional sites would have been sampled, but no additional groundwater exceedences detected. After application of a hypothetical additional tier, groundwater at three additional sites would have been sampled, but the fourth site at which groundwater contamination exceeded the standard would have remained undetected.

All three of the sites at which groundwater monitoring would have been triggered share similar characteristics: relatively coarse soils (mostly sands and gravels), an absence of pavement, and relatively high levels of soil contamination. The sites do not share distance to the water table as one of the common characteristics, however. At two of the sites, the distance to the groundwater is less than 10 feet. However, at AT&T Totowa Road, the transport distance is approximately 54 feet.

Groundwater monitoring would not have been triggered by any of the triggers at the fourth site, Exxon Service Station #3-8238. Examination of the data reported for the site reveals that no contaminants were detected in soil samples. Furthermore, soil texture at the site was characterized as a relatively fine soil (silt), the transport distance was estimated to be only 6.1 feet, and the site was covered with asphalt paving. Given these site characteristics, it is not surprising no groundwater monitoring was indicated.

Overall then, the groundwater monitoring would have been triggered at 3/4 sites at which groundwater was observed to be contaminated in excess of the standard. In addition to these three sites, the two tiers would have resulted in groundwater monitoring at three additional sites, for a total of six sets of monitoring wells. This is slightly more than 1/4 of the 22 sites for which data are available. In contrast to this, monitoring wells were actually installed at all 22 of these sites. Thus, application of the trigger would have reduced monitoring costs by almost 75%.

It is not surprising these results agree with the trigger accuracy assessed in Section 6.1. Both sections are based on the same set of case files.

Also, it should be noted that at NJAWC Baltasrol Station and McKee City Distributors, no contaminants were detected in soils. Before applying the trigger (which, given ND in soil, would entail application of the second tier), there should be some evidence of a spill or leakage. If there is none, it may not be sensible to apply the trigger.

6.2 Application of trigger to directed search files

The trigger was applied to sites identified through directed search. As stated in Section 3.2, these case files were selected by NJDEPE personnel because they involve exceedence of at least one groundwater standard despite indication to the contrary by the current trigger. Since these sites were not selected randomly, the measures of performance defined in Section 6.1 cannot be applied. The sites also involve a wider range of chemicals than the BTEX chemicals encountered at UST sites. These additional chemicals are listed in Table 6.3. These sites are drawn from a more diverse set of sites than the random search sites and therefore exhibit a more diverse set of characteristics. Thus, these sites are expected to pose greater difficulties for the trigger.

A subset of the files listed in Section 3.2.1 was used for trigger verification. Nine sites were excluded from trigger verification. Foremost among reasons for exclusion is contamination by a chemical that was detected at less than two sites. These sites are excluded because use of them for verification would give results having little meaning. Sites at which a source was not clearly identified are also excluded. Some sites are also excluded because summary reports are incomplete or insufficiently detailed.

Since development of the second tier of the trigger is limited to BTEX chemicals, this tier cannot be applied to the chemicals listed in Table 6.3. Therefore, application of the trigger to the directed search sites is limited to the first tier, the existing soil standard. This condition has been included in the trigger software described in Section 5.

Of the 25 sites listed in Section 3.2.1, the following 16 were used for trigger verification:

Apache Building Products	Keystone Camera
Asco Electronics	Lenox China
Atlantic Plastic Container	McKesson Chemical
Boxal	Metramatic
Essex Chemical	Puratex
Garden State Motors	Rockaway Borough Wellfield
Inmont-Belvidere	Schaible Oil Company
J.B. Moore	Shieldalloy

The trigger indicated groundwater monitoring at the following eight sites:

Asco Electronics	J.B. Moore
Atlantic Plastic Container	Keystone Camera
Boxal	McKesson Chemical
Inmont-Belvidere	Puratex

The trigger indicated groundwater monitoring for 8 of 16 of the directed search sites. Since groundwater is contaminated in excess of applicable standards at all 16 sites, a perfect trigger would indicate groundwater monitoring for all 16 sites. Clearly, the trigger fails to achieve this success rate. However, since these sites are regarded by case managers as difficult for the existing trigger (*i.e.*, these sites exhibited conditions that did not obviously suggest groundwater contamination), a 50% success rate suggests that the first tier is reasonably successful. If soil standards are exceeded at any location of the site, groundwater should be sampled. This finding is in agreement with the results for randomly selected sites.

Table 6.4 summarizes the results of applying the trigger to sites identified as a result of directed search. If the soil standard were a sufficient trigger, Table 6.4 would show soil standard exceedences associated with groundwater standard exceedences and failure to exceed soil standards with failure to exceed groundwater standards (*i.e.*, values greater than zero in the first and fourth columns and values of zero in the second and third columns). Since there are more non-zero values in the first rather than the second column, it can be concluded that soil standard exceedences are associated with groundwater standard exceedences. However, for most chemicals, failure to exceed the applicable soil standard is not associated with failure to exceed the applicable groundwater standard, as indicated by the relatively large number of non-zero values in the third column rather than the fourth. It is these cases the second tier is intended to detect.

Table 6.4 also shows that the ability of the first tier of the trigger to detect sites at which groundwater standards are exceeded varies with chemical. This can be seen by comparing the values in the first and third columns for a given chemical. If Tier 1 of the trigger performs well for a given chemical, the value reported in the first column should be greater than that in the third, indicating a stronger association between soil standard exceedence and groundwater standard exceedence than between a lack of soil standard exceedence and groundwater standard exceedence. Values in the third column greater than those in the first is evidence that the soil standard is not a very good indicator variable.

This argument can be illustrated by an example. The two compounds detected most frequently in soil and groundwater are tetrachloroethene and trichloroethene. Table 6.4 shows tetrachloroethene was detected in excess of the applicable soil standard at seven of ten sites. The groundwater standard was exceeded at all of these sites. In contrast to this, trichloroethene was detected in excess of the soil standard at only two of 11 sites, whereas the groundwater standard was exceeded at ten of the 11 sites. This result suggests the existing tetrachloroethene soil standard is a better groundwater contamination indicator than the trichloroethene standard. It also suggests alteration of the trichloroethene soil standard or development of additional tiers may be appropriate. Also, given that trichloroethene is more mobile than tetrachloroethene, additional tiers might help distinguish between the behavior of these two compounds.

Multiple chemicals were detected at many sites. Most chemicals at sites with multiple chemicals were present at levels below the relevant soil standards. However, even if only one chemical exceeds the soil standard, groundwater monitoring would be triggered. This characteristic of the trigger is largely responsible for the trigger indicating groundwater monitoring at half the directed search sites.

As in the case of the sites identified through random search, the trigger appears to perform better for sites than for individual contaminants. This can be illustrated by again considering tetrachloroethene and trichloroethene, two contaminants that were frequently detected at the same sites. Five of ten occurrences of groundwater contamination by trichloroethene were accompanied by soil concentrations of tetrachloroethene in excess of the standard. At only two of these sites was trichloroethene detected in excess of the soil standard. Thus, tetrachloroethene appears to give some indication of exceedence of the trichloroethene groundwater standard. Groundwater contamination by contaminants different from those detected at high levels in soil occurs at other sites as well. Aside from tetrachloroethene and trichloroethene, however, there appears to be no trend.

6.3 Tables

Table 6.1 Possible outcomes of the groundwater monitoring trigger

Indicated state	True state	
	groundwater contamination	no groundwater contamination
groundwater contamination	True positive	False positive
no groundwater contamination	False negative	True negative

Table 6.2 Measures of accuracy for the groundwater monitoring trigger

	benzene	toluene	ethyl- benzene	xylenes	all chemicals
trigger (both tiers)					
sensitivity	0.67	1.00	1.00	0.67	0.75
specificity	0.85	0.86	0.87	0.69	0.79
positive pv	0.50	0.50	0.25	0.33	0.50
negative pv	0.92	1.00	1.00	0.91	0.92
soil standard (alone)					
sensitivity	0.33	0.50	NA	0.67	0.75
specificity	0.94	1.00	1.00	0.94	0.94
positive pv	1.00	0.67	NA	0.67	0.75
negative pv	0.89	1.00	1.00	0.94	0.94
t_{tr} threshold (alone)					
sensitivity	0.50	1.00	1.00	0.67	0.50
specificity	0.85	0.88	0.82	0.85	0.89
positive pv	0.50	0.50	0.25	0.50	0.50
negative pv	0.85	0.94	1.00	0.92	0.86

See Section 6.1 for definitions of the terms listed in this table. The terms can be explained as follows:

A sensitivity of the trigger (both tiers) of 0.75 means that the trigger can be expected to identify 75% of the sites at which applicable groundwater standards have been exceeded. A specificity of 0.79 means that the trigger can be expected to identify 79% of the sites at which applicable groundwater standards have not been exceeded. A positive predictive value of 0.50 means that exceedence of the groundwater standard would be detected at about 50% of the sites at which groundwater monitoring is triggered. A negative predictive value of 0.92 means that 92% of the instances in which the trigger indicates no groundwater exceedence, no exceedence would have occurred.

Table 6.3 Additional chemicals considered for directed search sites

tetrachloroethene
trichloroethene
t-1,2-dichloroethene
vinyl chloride
1,1-dichloroethane
1,1-dichloroethene
1,1,1-trichloroethane

Table 6.4 Trigger performance on sites identified through directed search				
	soil standard exceedence		no soil standard exceedence	
chemical	GW exceed.	no GW exceed.	GW exceed.	no GW exceed.
benzene	0	0	2	0
toluene	0	0	4	2
ethylbenzene	1	0	2	0
xylene	1	0	2	0
tetrachloroethene	7	0	3	0
trichloroethene	2	0	8	1
t-1,2-dichloroethene	0	0	4	0
vinyl chloride	0	0	2	0
1,1-dichloroethane	2	0	0	1
1,1-dichloroethene	1	0	2	1
1,1,1-trichloroethane	2	0	0	1

Since this table reports that all instances of soil standard exceedence are associated with groundwater standard exceedence, it can be concluded that when the soil standard is exceeded, the groundwater standard is also exceeded. However, this table also indicates the converse is not true: failure to exceed the soil standard is not consistently associated with uncontaminated groundwater.

7 Summary and conclusions

The goal of the project is to develop a groundwater monitoring trigger that is defensible, consistent, and easily used. We have attempted to achieve defensibility and consistency by relying on a statistical analysis of data taken from NJDEPE BUST case files. The case files were used to identify variables that are good indicators of groundwater contamination by benzene, toluene, ethylbenzene, and xylenes. They were also used in preliminary verification of the trigger.

Three variables have been identified as good indicator variables: the existing soil standard, an estimate of retarded transport time from the location of the soil sample exhibiting the maximum concentration to the water table, and the presence of asphalt or concrete pavement on the ground surface above the UST. These variables consistently performed well when evaluated by statistical test, a result that is in agreement with professional judgement.

Transport distance and soil texture, indicator variables used by others in similar applications, are found to be poor indicator variables. This result may be due to the limited range of transport distances and soil types in the data set. Estimates of unretarded transport time appear to be poor indicator variables as well. Single chemical properties of contaminants also appear to be poor indicator variables.

To make the trigger easy to use, the first two indicator variables have been incorporated into a user-friendly piece of software that automates implementation of the trigger. The two indicator variables make up two tiers. If the first tier, the current soil standard, is not exceeded, the second tier, estimated retarded transport time, can still trigger groundwater monitoring. The software is based on the familiar spreadsheet Quattro® Pro. The trigger is menu driven and a user's manual is provided as part of this report.

Ease of trigger use does not obviate the need for good judgement on the part of the user. Input parameters must be derived from all site information available. Dominant site features should be accounted for, even if the features are not required trigger inputs.

The sensitivity of the trigger is estimated to be 75%. This can be interpreted as meaning that the trigger would indicate groundwater monitoring in approximately 75% of the instances in which groundwater standards had actually been exceeded. The specificity of the trigger is estimated to be 79%; the trigger would correctly indicate no exceedence of groundwater standards in approximately 79% of the cases.

The trigger also exhibited reasonably good performance when applied to the directed search files. At these sites, groundwater was contaminated in excess of applicable standards despite

indications to the contrary. Despite the difficult nature of the sites, the trigger achieved a success rate of 50%.

The most important constraint in trigger development has been the lack of site data. As a result, our ability to identify effective indicator variables has been reduced. The lack of data has also limited our ability to verify the trigger. However, we feel reasonably confident that the variables identified provide good indication of groundwater contamination. Another result of the data constraints is that the trigger is relatively simple and can be applied to a limited in range of sites. Nevertheless, verification of the trigger carried out in Section 6 suggests the trigger will be effective in its intended role.

The results of the project support continued use of existing BTEX soil standards as part of a comprehensive groundwater monitoring trigger. Application of the trigger to sites identified both through the random search and the directed search indicates compelling evidence that a failure to exceed existing soil standards does not preclude exceedence of groundwater standards. We believe this evidence suggests the need for separate tiers such as those we have developed. Unfortunately, there are too few data to allow refinement of the existing standards or development of additional tiers.

The statistical approach used in this research may be useful for refining soil standards. Although relatively simple, the approach relies on actual site data. If conducted properly, site data can be treated in a manner similar to a Monte Carlo analysis (each site representing a single realization). This approach has the additional benefit of relying on samples from actual sites instead of synthetic sites and derived distributions. Altogether, these factors could contribute to more defensible soil standards just as they have contributed to a more defensible groundwater monitoring trigger.

We found Quattro® Pro adequate for this project. It offers several useful features: a familiar, user-friendly, menu-driven interface, relational database capabilities, and the ability to run simple models. Programming in the Quattro® Pro macro language is relatively straightforward. The language is similar to widely-used programming languages such as Fortran. As a result, the Quattro® Pro macro language can readily be learned.

8 Recommendations for further research

Development of the trigger relied exclusively on closed case files taken from the files of the NJDEPE BUST program. All of these sites involve USTs and the primary contaminants are BTEX. Application of the trigger should be limited to similar sites. The trigger should be evaluated further before applying it to other types of sites, such as those identified through the directed search portion of this project. In particular, additional tiers should be developed for these sites. If necessary, these tiers should include different indicator variables appropriate for these types of sites.

Consideration of potential indicator variables has necessarily been limited. Other potential indicator variables should be evaluated. Of particular interest are variables that can dominate the transport characteristics of a site. Fractures and macropores can provide conduits for very rapid transport of contaminants to the water table. In cases of large releases, gravity-driven migration of the non-aqueous phase could dominate the potential for groundwater contamination. It may be possible to identify site features (*e.g.*, fractures observed at the ground surface) that provide good indication that such mechanisms are important. Also, it may be possible that some soil contaminants could indicate groundwater contamination by contaminants not detected in soil. As discussed in Section 6.1.1 and 6.2, trigger by one chemical and detection of another in groundwater appears to result in a more effective trigger. In this study, we have not considered total petroleum hydrocarbons (TPH), a contaminant for which soil samples are routinely analyzed. We recommend TPH be evaluated as a separate component of the trigger.

Improved statistical methods should be developed. The thresholds used in the trigger were arrived at largely by trial and error because the test statistic measures only the trigger's ability to correctly identify sites at which groundwater contamination has occurred. The test statistic does not directly measure the trigger's ability to correctly identify sites at which groundwater contamination has *not* occurred. Since it is important for the trigger to correctly identify both types of sites, we used best professional judgement to select thresholds that give adequate performance for both types of site. We recommend an additional statistical measure of performance be defined, one that directly accounts for the trigger's ability to correctly identify sites at which groundwater contamination has not occurred. Ideally, the process of establishing optimal trigger thresholds could be automated so that they are determined automatically.

Verification of the trigger carried out in Section 6 suggests the trigger will be effective in its intended role. However, the verification should be extended to include a second, randomly selected set of sites. Only by application to a second set of randomly selected sites can the trigger be verified in a rigorous manner and uncertainties assessed. The second set of verification sites should reflect a wider range of site conditions than the set used in this project.

Uncertainties in the trigger are probably relatively large as a result of the small data set used for development and the difficult role of the trigger. The largest sources of uncertainty have been identified. The magnitude of these uncertainties should be evaluated.

At present, there does not appear to be a mechanism for case managers to accumulate knowledge in a department-wide database. We recommend that NJDEPE develop and implement a program to compile data collected as part of its day-to-day operation. Information collected as a matter of routine by NJDEPE case managers would be useful to develop the trigger further, just as case data were used to develop the trigger described herein. Such data could also be used to develop and/or refine soil clean-up and similar standards, as well as evaluate overall program effectiveness.

It may also be useful to accumulate information concerning specific types of sites and regions of New Jersey. Doing so could effectively reduce the uncertainty that would result if all sites across the entire state were considered together.

It may be desirable to link the trigger to New Jersey's Geographic Information System (GIS). Information concerning local soil type, topography, ground cover such as vegetation, and other important parameters could thereby be input directly into the trigger by simply specifying the location of the site. Such a combination would enhance the trigger's effectiveness without complicating its use.

The screening model used for estimation of retarded transport time is very simple and has not been extensively evaluated elsewhere to our knowledge. To increase confidence in the model, more rigorous verification should be carried out. Alternative models should also be considered.

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Appendix A: Random search case file summaries

Cape May Court House Shell Station

Case #87-11-09-10s

Floating product was observed in the vicinity of the site. Three tanks were removed, two of which appeared to have been leaking. Approximately 40 wells were installed. The water table is reported to be 5 to 11 feet below grade. This case appears to have no contaminant data. The file is limited to boring logs, water level, and floating product data.

McKee City Distributors

TMS#C91-1658

A 2000 gallon gasoline and 6000 gallon diesel fuel UST were removed. Ten soil samples were taken and one monitoring well installed. Maximum soil detect was 77.4 ppm TPH. No BTEX contaminants were detected in groundwater. Boring log indicates no sign of contamination. The water table is 16.5 feet below grade.

Cape May Post Office

C-91-0039, C-91-0419

A 10000 gallon gasoline and a 6000 gallon fuel oil UST were removed. Three monitoring wells were installed in the vicinity of the gasoline tank. Maximum soil contamination is reported to be 150 mg/kg TPH, with trace levels of VOCs. Groundwater samples exhibited BTEX contamination, with constituents in the hundreds of ppb range. TBA was also detected. The levels of contaminants reported are below drinking water standards, with the exception of benzene. It is noted that no visible signs of leakage were observed upon removal of the USTs.

South Jersey Fuel

Case #87-03-25-04S

Documentation of this file appears to be incomplete or at least insufficient to get a complete overview. Apparently there are several USTs at the site and several monitoring wells. There are soil sample data. There is no indication the case has been closed other than its presence in the box.

Apex Trucking

Case #89-08-24-1519

One 10000 gallon UST was used to store #2 fuel oil. Stained soil was observed upon removal of the tank. Six soil samples were taken from 5.5 feet below grade and 6 inches above the water table, which is located at a depth of 6 feet. No sheen was observed during groundwater sampling. Soil pH is reported to be 9.9. Although TPH was found in soil, no BTEX were detected in groundwater.

National Sign Company

Case #90-08-16-1625

The site consisted of 1000 gallon UST with unleaded gas. The tank had been abandoned seven years previously, following flushing. The water table is reported four feet below grade and four soil samples were taken 6 inches above water table. TPH were detected in all samples, but no BTEX. One monitoring well was installed at the former location of the UST. BTEX were detected in groundwater, with benzene and xylenes above NJDEPE standards.

NJAWC Short Hills Station

Case #89-12-29-1442

One 5000, three 1000, and one 550 gallon gasoline USTs were removed. The area of the site is on the order of two acres. Two soil samples were collected from the bottom of each tank excavation pit. BTEX levels in all samples were less than soil standards. TPH levels were in the hundreds of ppm range. Soil stains were evident in one of the pits. This pit showed relatively high levels of TPH contamination. A sixth tank, a kerosene storage tank, was also discovered and removed. This tank showed signs of leakage. Three monitoring wells were installed. The water table is located approximately 15 feet below grade. On-site production wells (the site is used for municipal water supply) are routinely sampled and show no sign of contamination.

NJAWC Baltusrol Station

UST #264521/Case #90-03-30-1120

Two 4000 gallon diesel fuel USTs were removed. Stained soils were observed during removal. The tanks had not been in service since the late 1960s. Two monitoring wells were installed. The water table is located approximately 12 feet below grade. No petroleum-related compounds were detected in the groundwater.

Profleet Services

Case #90-02-13-1629

One 3000 gallon #2 fuel oil, one 3000 gallon gasoline, one 6000 gallon #2 fuel oil, and one 10000 gallon diesel fuel UST were removed. 18 soil samples were collected. TPH contamination was detected in soil samples. Two monitoring wells were installed. In one, trace levels of petroleum-related organics were detected. A composite soil sample was analyzed for BTEX for purposes of waste characterization. The wellscreen extends from a depth of 7 to 17 feet, so the water table is probably less than 10' below grade.

Rebco Realty

Case #90-01-09-1156

Three USTs were removed: 10000 gallon #2 fuel oil, 2000 gallon gasoline, and 2500 gallon #2 fuel oil. Soil staining was observed only in the vicinity of the gas tank filler cap. Soil samples showed limited TPH, but no BTEX. One monitoring well was installed. The water table is located approximately 14' below grade. No fuel-related compounds were detected in groundwater.

Swedish Imports, Inc.

Case #89-12-06-1630

A 275 gallon waste oil tank was removed. Analysis of soil samples revealed contamination above NJDEPE standards, at levels up to 17000 ppm. One monitoring well was installed. The water table is at 8 to 12 feet depth and appears to be highly variable. Toluene was detected in groundwater at a level of 1.4 ppb. TPH were not detected in groundwater. It is noted in the report that a clay layer (at 6 feet depth) may impede the downward migration of contaminants.

Potamkin Chrysler/Plymouth

Case #89-06-26-1538

Four USTs were removed: one 550 gallon waste oil, one 1000 gallon motor oil, one 550 gallon automatic transmission fluid (ATF), and one 4000 gallon gasoline. TPH were detected at high levels. Two tanks were judged to be leaking. The water table is located approx. 16 feet below grade. Low levels of MTBE were detected in groundwater.

Bell Holding Company/Abandoned Service Station

Case #89-04-13-1111

Four 2000 gallon gasoline USTs were removed along with an abandoned dry well that was used for waste oil disposal and 250 tons of contaminated soil. Two groundwater monitoring wells were installed. One round of sampling was conducted. No BTEX compounds were detected. Soil boring logs show the soil to be clay with some gravel from a depth of about 2 to at least 20 feet. The water table is 11 feet below grade.

Fedco Steel

Case #89-08-29-1334

Four 5000 gallon heating fuel oil tanks were removed. A clay layer was detected at between 8 and 15 feet below grade upon installation of three monitoring wells. Soil contamination was evident. Water table is 9 to 11 feet below grade, and is influenced by tidal fluctuations. No petroleum-associated organics were detected. However, chlorinated solvents were detected, probably originating offsite. Also, there appears to be the possibility of perched water tables.

Former Mobil Station #15-A9R

Case #90-09-28-1220

I don't believe the tanks were actually removed. Subsurface conditions were evaluated by means of four boreholes. The water table is approx. 10 feet below grade. TPH and BTEX were detected in soils at up to 32200 and 1 ppm, respectively. Four monitoring wells were installed, as were further boreholes and a test pit. Levels of BTEX and MTBE in groundwater were higher than NJDEPE standards.

The PQ Corporation, Avenue L

Case #90-01-05-1012

One 1500 gallon spilled fuel oil sump UST was removed. One groundwater monitoring well was installed. The water table is approximately 5 feet below grade. Contaminated soil was removed without sampling. Groundwater sampling revealed "non-detectable levels" of VOCs, indicating, presumably, no contamination.

Highland Park - Gasoline Spill

Case #90-11-09-1614

This is an old case, dating from 1980. Floating product was observed on the water table but almost no other information is provided.

Block 4702 Lot 2 (McDonald's)

Case # - is not reported

Three 4000 and two 2000 USTs were removed. Stained soils were observed. 24 soil samples were taken. BTEX were detected at levels in the 10s of ppm range (mostly xylenes, no benzene). Four monitoring wells were installed. BTEX were elevated in groundwater above standards levels. Benzene was detected in groundwater (at 1300 ppb at MW-4) but not in soil. Water table is 9-10 feet below grade, so tanks are probably just in groundwater.

New Jersey Bell Telephone Westfield Central Office

Case #90-01-29-1500

A 3000 gallon diesel fuel and 7500 gallon fuel oil UST were removed. The small report indicates TPH-contaminated soils were detected during tank removal. No other information concerning soil contamination is available. One monitoring well was installed. Samples indicate no groundwater contamination. Soils are clay and silt and ground cover is asphalt paving. The water table is at 18.5 feet below grade, so tanks are above water.

Kleppers Auto Parts

Case #90-07-25-1056

Three 4000 gallon gasoline and one 550 gallon fuel oil USTs were removed. The report indicates gasoline-contaminated soils were removed. BTEX contamination of soil is limited to the ppb range. One monitoring well was installed and sampled. No contaminants were detected in groundwater. The top of the well screen is at a depth of 22 feet.

Attanasio's Garage

Case #90-01-19-1650

Three multiple-hundred gallon gasoline USTs were removed. Contaminated soil was detected and holes in all three tanks observed. BTEX were detected in groundwater at low (ppb range) levels. MTBE and TBA were detected at higher levels that exceeded NJDEPE standards. Water supply wells approximately 1400 feet away show water table at 7 feet below grade. There is no water table elevation information for monitoring wells. The tanks are small enough so that they are probably above the water table. Boring logs show mostly sand, with some clay and silt. Ground cover is concrete.

Merck & Company Research Farm

Case #90-06-26-1022, 89-10-26-1353 (site straddles two counties)

One 275 gallon gasoline, one 2000 gallon #2 fuel oil, and one 5000 gallon #2 fuel oil UST were removed. Stained soil was observed upon excavation. Several monitoring wells were installed. Leaked oil appears to have migrated along gravel fill of nearby storm drain. Analysis of groundwater samples indicates trace amounts of petroleum-related compounds. Groundwater is at least 18 feet below grade.

Pennco Enterprises

Case #90-04-13-1514

Five gasoline and fuel oil USTs were removed, ranging in size from 1000 to 4000 gallons. Contaminated soils were detected, with TPH up to 890 ppm, though BTEX were detected at trace levels. Two monitoring wells were installed. Analysis of samples indicate minor lead

contamination (one tank had lead gasoline) and only traces of other contaminants. Borings were only about 8 feet deep, so tanks are in groundwater.

Firestone Retail Outlet

Case #90-02-28-1445

One 550 gallon waste oil tank was removed. Stained soil and floating product were observed in the excavation pit. Four soil borings were made and one well installed. Soil samples from boreholes exhibited TPH contamination at less than action levels and only trace levels of other contaminants. Boring samples were taken just above the water table at a depth of 10 to 12 feet. Soil samples taken at the time of tank removal exhibit relatively high levels of contamination (hundreds of ppm TPH and hundreds ppb BTEX). Water table is located at approximately 11 feet below grade. The tank extended to approximately 6 feet below grade, based on deepest soil sample during removal process. Groundwater samples did not contain petroleum-related contaminants. The existence of a perched water table is reported. Boring logs indicate mostly sand and a layer of sandy silt and the ground cover is asphalt.

Mayfair Exxon #3-4255

Case #81-03-04-02M

This is an old case, originating in the early 1980s. Documentation is very poor. Apparently two USTs were involved. They were removed when they were discovered to be leaking. Several monitoring wells were installed and remediation efforts undertaken to remove floating product. Depth to water table is approximately 20 feet. No analytical data are available.

Angostura International, Ltd.

Case #90-10-15-1118

One 5000 gallon #2 fuel oil UST was removed. TPH soil contamination was NJDEPE standards. Three monitoring wells were installed. BTEX were detected in two of the wells at detectable levels. The Peer Review file indicates the wells were installed upgradient of the tank, but the DICAR contradicts this, arguing that contamination is due to another UST at the site. It's difficult to determine what's going on with this site.

Mobil Service Station #15-J4A

Case #89-09-11-1614

A 550 gallon waste oil and 550 gallon fuel oil UST were removed. The site is an operating service station. Four monitoring wells were installed. The water table is located 7 to 10 feet deep, so tank is in groundwater. BTEX were detected in groundwater at 10s of ppb levels.

General Instruments Company

Case #89-06-21-1437

A 1000 gallon and 10000 gallon fuel oil UST were removed. Soil TPH levels were up to 9900 ppm, but mostly much lower. One monitoring well was installed. No BTEX were detected in groundwater. The water table is located 60 feet below grade.

Pohatcong Township Municipal Building

TMS # C-91-1857/C-91-1574

Two 1000 gallon gasoline USTs were removed. Soil exhibited no signs of contamination. No contaminants were detected in soil except for lead. No contaminants were detected in groundwater except for MTBE, at tens of ppb levels. The water table is located about 30 to 50 feet below grade.

C.C.L.P. Associates

TMS # C91-4503/UST #023161

One UST was removed. Soil sampling revealed PCE and toluene below NJDEPE standards. A monitoring well was installed 4 feet downgradient. Depth to groundwater is about 15 feet. Toluene was detected, as were other VOCs and lead, but all at less than NJDEPE standards.

Institute for Advanced Studies

Case #90-05-21-1202

One 5000 gallon heating oil UST was removed. Nine soil samples exhibited TPH contamination ranging from <50 to 380 ppm. Three monitoring wells were installed. No target compounds were above NJDEPE standards. The water table is approximately 11' deep. Soil appears to be clayey.

U.S. Post Office, Marlton, Burlington County

Case #91-05-23-1005

A 5000 gallon gasoline and a 2000 gallon heating fuel UST were removed. Stained soils were observed in excavation. BTEX were detected in soil samples, mostly at detection limits. One sample exhibited BTEX contamination in the 1000 ppb range. Benzene and xylene were detected in groundwater at detection limit levels. Groundwater is located approximately 1-2 feet below grade.

Johnson & Towers, Inc.

Case #91-014-15-1406

Three 2000 gallon heating oil, one 2000 gallon diesel, one 2000 gallon gasoline USTs were removed. Most TPH levels were less than 100 ppm. Samples from gasoline tank showed hundreds of ppb of BTEX. No petroleum-related compounds were detected in groundwater. Wellscreens are from 5 to 15 feet deep.

Eighths Holding Company

Case #90-014-27-1258

A 4000 gallon diesel fuel UST was removed. Borehole soil samples exhibited TPH contamination at levels ranging from 180 to 7700 ppm. No VOCs were detected. Monitoring wells were installed. Depth to water is about 3 feet. No target compounds were detected.

New Jersey Bell

A-10



Cambridge Environmental Inc.

58 Charles Street Cambridge, Massachusetts 02141
617-225-0810 617-225-0813 FAX

Case #89-12-12-0955

A 6000 gallon #2 fuel oil UST was removed. Soil samples revealed TPH contamination at up to 140 ppm. One monitoring well was installed. No contaminants were detected in groundwater samples except 1 ppb of toluene.

Exxon Service Station, Location # 39789**Case # 88-11-02-1354**

The site consists of four USTs, three of which were removed. Soil samples from six monitoring well boreholes exhibit BTEX levels up to 1980 ppb. Groundwater levels of BTEX are in the thousands of ppb range. Groundwater is about 3 feet below grade.

Former Boy Scout Reservation**Case # 89-08-05-1537**

Five USTs containing gasoline, fuel oil, or kerosene, were removed. TPH in soils were measured at less than 100 ppm. Three monitoring wells were installed. No petroleum-related contamination was detected. Low permeability of soil at the site was noted. Documentation is poor.

Mobil Retail Facility #15-J9N**Case #89-10-13-1143 (89-12-28-1756) (90-09-28-1218)**

Soil borings revealed TPH as high as 9000 ppm. Consequently, one 1000 gallon heating oil and one 550 gallon waste oil UST were removed. Nine additional gasoline USTs were removed. Post-excavation soil samples exhibited concentrations up to 2.395 ppm BTEX (waste oil tank excavation). Monitoring wells were installed. No contaminants were detected in groundwater. The water table is approximately 24 feet below grade. Soils are fine to medium sands with gravel and cobbles.

United Telephone company of NJ, Inc - Franklin Facility

Case #90-07-06-1325

A 550 gallon diesel fuel UST was removed. The maximum level of soil contamination was 187 ppm TPH. Three monitoring wells were installed. Groundwater samples exhibited no contamination. Depth to groundwater ranged from 19 to 43 feet.

H. Resiman Corporation

Case #89-10-17-1053

A 5000 gallon heating oil UST was removed. Three monitoring wells were installed. The water table is located 20 feet below grade. Some TPH were detected in soil, but none in groundwater.

Exxon Service Station # 3-2210

Case # 89-05-26-1120

Three USTs were removed of size 6000, 8000, and 10000 gallons. Soils exhibited BTEX contamination in the thousands (one in the tens of thousands) of ppb range. Five monitoring wells were installed. BTEX concentrations in groundwater ranged up to 701 ppb. Also MTBE and TBA were present. Water table is located between 7 and 8 feet below grade.

Irvington Fidelco Association

Case #89-01-06-1034

A 20000 gallon No. 6 fuel tank was abandoned in place. Soil samples were taken by cutting holes in the bottom of the tank. The samples revealed TPH contamination up to 211 ppm. One monitoring well was installed. No contaminants were detected in groundwater. The top of well screen is within 2 feet of grade.

Gould School/Mountain Avenue School

Case #89-05-24-1431

A 3000 gallon No. 2 fuel oil UST was abandoned in place. The water table is 6.75 feet below grade. Floating product was observed. Soil samples were taken from 7 feet depth and the maximum TPH level was 76 ppm. Groundwater samples taken several months later show no contamination. The well screen beginning at a depth of 10 feet. The groundwater report states that there is no groundwater impact and the case was closed on that basis.

Witco-Humko Chemical Division

Case #89-08-11-1455

One 1000 gallon gasoline UST was removed. Six soil samples and one groundwater sample were taken. Lead was present in soil at levels up to 1790 ppm, xylenes at up to 1690 ppb. Benzene and toluene were not detected in soil. Benzene was detected in groundwater, but other BTEX were not. Water table is located 3 to 6 feet below grade.

Washington Elementary School

Case #90-06-06-1056

A 10000 gallon No. 2 fuel oil UST was removed. The water table is approximately 18 feet below grade. Up to 8310 ppm TPH was detected in soil. No petroleum-related compounds were detected in groundwater.

Johnson & Johnson

TMS #C-90-0433, UST# 0008679

One 7500 gallon ammonia UST was removed. The highest level of soil concentration was 79.9 ppm of ammonia. No ammonia was detected in groundwater. Water table is approximately just below tank.

Hackensack Cemetery Co.

Case #C91-2684

One 550 gallon gasoline UST was removed. No contaminants were detected in either soil or groundwater samples.

Sandoz Pharmaceuticals Corporation

Case #91-12-31-1605-26

A 250 gallon gasoline UST was removed (several other tanks were also removed, but groundwater not sampled). Soil sampling revealed the presence of TPH at up to 300 ppm. BTEX compounds were present in the hundreds of ppb range. No petroleum-related compounds were detected in groundwater. The depth to groundwater is reported as 13.72 feet.

Smith Transfer Facility

Case # 88-10-19-1409

A 1000 gallon gas UST was removed (a 10000 gallon diesel UST was left in service). Two monitoring wells were installed. MTBE was detected in groundwater at 12 ppb. The existence of low-permeability soils at the site was noted. The cover is asphalt, sandy layer, then clayey silt to bottom of borehole. The water table about 2 feet below grade. A soil-gas survey revealed the presence of BTEX compounds.

Hewlett-Packard Company

Case #88-11-23-0919

Two 4000 gallon gasoline USTs were removed. TBA was detected in groundwater at up to 25 ppb, which is below the NJDEPE standard. The water table is about 6 feet below grade. Soil samples were taken. No BTEX were detected in soil and the maximum TPH level was 35 ppm.

Exxon Service Station 30-37

Case #90-09-07-1106

Three gasoline (8000, 10000, 12000 gallon) and one 1000 gallon heating oil and one 1000 gallon waste oil USTs were removed. Perched groundwater was encountered at as little as 1 foot below grade. The water table is about 10 feet below grade. The soil is clay/silt. The only contaminant found in groundwater is TCE, putatively from another source. No soil data are reported.

Pantone Inc.

Case #89-11-20-1511

Two 2000 gallon USTs containing xylene and isopropyl alcohol were removed. Post-excavation soil sampling revealed the presence of xylene, toluene, TPH and 4-methyl-2-pentanone. Water table is very close to surface, judging from screening intervals of local wells. No contaminants were detected in groundwater.

Mondry

Case#90-03-01-1514

No soil data is reported, only groundwater. BTEX were detected at concentrations above NJDEPE standards.

AT&T Totowa Road

Case #98-07-23-1510

One 6000 gallon gasoline, one 275 gallon waste oil, and one abandoned 2000 gallon gasoline UST were removed from the site. Another No. 2 fuel oil tank was also present but not part of this project. A perched water table was encountered from 1-1/2 to 4 feet below ground. The soil is a glacial till and TPH contamination was evident. Benzene was detected in groundwater at up to 150 ppb, as well as other BTEX in the same range. Depth to groundwater is reported in EPA documents to be 6-10 feet.

Alpha Wire Corporation

Case #88-12-14-1420

A 10000 gallon gasoline UST was removed. Soil TPH contamination levels ranged from 193-797 ppm. No contaminants were detected in groundwater. The water table is about 5.5 feet below grade.

PPG Industries, Inc.

Case # 88-08-04-1557

Two 4000 gallon USTs were removed. One soil sample exhibited TPH contamination of 358 ppm, but most samples were in the 10s of ppm. The top of the well screen is 3.5 feet below grade. No contaminants were detected in groundwater.

Rolls Offset Group Inc.

Case #88-014-28-1638

One 550 gallon gasoline and one 3000 gallon diesel fuel UST were removed. Saturated sand layers were encountered overlying a 2 feet thick clay zone located at 10 feet below grade. The water table is 2 feet below grade. No soil sampling appears to have been performed.

Leo and Ray's Sunoco Gas Station

Case #91-01-14-1040

One 6000 gallon gas, three 3000 gallon gas and one 550 gallon waste oil UST were removed. The water table is located 24 feet below grade. The soil consists of sand with some gravel. Soil samples exhibited up to 176 ppm TPH. No VOCs were detected in groundwater samples.

Colorama Tank Removal

ECRA Case #86346

One methyl ether ketone and one methyl isobutyl ketone UST were removed. The maximum soil contamination detected was 343 ppm TPH. 7 ppb, 89 ppb non-targeted VOC and B/N, respectively, were detected in groundwater. No other information is available.

AT&T Easy Link Services

Case #91-10-04-1054

One 500 gallon waste oil and two 10000 gallon diesel fuel USTs were removed. Soil samples revealed TPH levels up to 56.7 ppm. Wells were installed but, apparently, not sampled. Wells were screened about 4 feet below grade, so it's likely the tanks were in the groundwater.

IBM Corporation

Case #89-08-24-0916

One 2000 gallon diesel UST was removed. Post excavation sampling revealed TPH contamination up to 6100 ppm. Contaminated soil was removed. Two monitoring wells were installed. Sampling revealed no contaminants. No BTEX were detected in soils.

Power Industrial Products

Case #89-11-13-1552

A 2000 gallon gasoline UST was removed. TBA, MTBE, xylenes, ethylbenzene were detected in groundwater at levels higher than NJDEPE standards. The water table is 4 feet below grade. The area is paved. The report indicates 87 cubic yards of contaminated soil were removed. Only TPH data are provided.

Exxon Service Station #3-8238

Case #91-03-12-0854-51

A 6000, 8000, and 10000 gallon gasoline UST were removed. BTEX were detected in groundwater at levels up to 143 ppb and TBA at 740 ppb, MTBE at 330 ppb. Water table is at a depth of from 9 to 12 feet depth and groundwater was observed in the excavation. Soil samples were analyzed for VOCs, but none were detected.

Former Exxon Service Station #31995

Case#88-08-04-1425

Three gasoline storage tanks were removed. Total BTEX were detected in groundwater at levels up to 529 ppb. MTBE and TBA were also present in groundwater. Wellscreens begin at a depth of 3-4 feet. A strong hydrocarbon odor was noted in the excavation pit during tank removal, but apparently samples were not taken.

C&C Metal Products Corporation

Case #90-05-07-1615

Two 4000 gallon No. 2 heating fuel oil USTs were removed. TPH in levels in soil ranged up to 63 ppm. The water table is located at 5 feet below grade. No petroleum-related compounds were detected in groundwater.

Finest Car Service Center

Case #89-06-20-1511

A 1000 gallon waste oil and 1000 gallon transmission oil UST were removed. The water table is 5 feet below grade. Only non-target B/N compounds were detected at 10s ppb range. The report indicates disposal of contaminated soils, but no soil data are provided. Presumably classification as contaminated was based on visual and/or olfactory inspection.

CPC-Best Foods

Case#89-11-09-0920

A 2000 gallon gasoline and 10000 gallon diesel UST were removed. The water table is 3 to 3.5 feet below grade. TBA was detected in groundwater at up to 44000 ppb. BTEX were also detected at levels exceeding the NJDEPE standard. Soil sampling revealed high levels of TPH and BTEX contamination.

Evans Road Corporation

Case #91-03-01-1643

Two 2000, one 3000, one 20000 gallon gasoline USTs were removed. The water table is located 6 to 8 feet below grade. Petroleum-related volatiles were not detected in groundwater. Soil sample photoionization detector results indicate TPH in excess of NJDEPE standards in the upper few feet of soil, but most of the concentrations were than the standard.

Jewish Community Center of Central Jersey

Case #91-05-09-1533

A 10000 gallon No. 2 fuel oil UST was removed. Soil contamination ranged up to 439 ppm TPH. Groundwater was observed in the trench, so the water table is not more than about 12 feet deep. 1.9 ppb BTEX were detected in groundwater.

Plochman Inc.

Case #91-5-14-0834-24

A 8000 gallon No. 2 fuel oil UST was removed. TPH in soil were greater than NJDEPE standards. No petroleum-related contaminants were detected in groundwater. The maximum level of soil contamination is 2030 ppm TPH. The well screen begins at a depth of 15 feet. Soil is clayey sand with some gravel.

Big Timber Lake Campground

Case #91-5010-1739-15

Two 5000 gallon and two 2000 gallon gasoline and diesel fuel USTs were removed. The maximum soil contamination is 5.4 ppm BTEX, and 5285 ppm TPH. The maximum groundwater contamination is 3.8 ppb BTEX. The top of screen is 1 feet below grade.

Stu Lord Properties

Case #90-07-05-1108

Three USTs were removed: 1000 gallon leaded gasoline, 1000 gallon unleaded gasoline, and 1000 gallon diesel. The water table is about 4 feet below grade. The maximum total VOCs is 707 ppb. The Site Assessment Summary indicates no soil samples were taken.

World Lafayette Hotel

Case #91-01-23-1731

Two 4000 gallon No. 2 fuel oil USTs were removed. TPH contamination in soil samples were as high as 30000 ppm. Groundwater was encountered at a depth of 6 feet. No petroleum-related contaminants were detected in groundwater.

Vineland Post Office, Landis Avenue

Case #91-6-28-1528

One 8000 gallon heating fuel oil and one 5000 gallon unleaded gasoline UST were removed. The ground surface above the tanks was paved with concrete. The highest soil TPH level was 140 ppm. BTEX were detected in the low ppb range, exceeding NJDEPE standards. The screened intervals of the wells were 35-45 feet below ground surface.

Hershey Creamery

Case #90-01-05-1612

A gasoline UST was removed. No contaminants were detected in groundwater. The water table is located 11 to 12 feet below grade. No soil data are reported.

Ogden Allied Maintenance Building

Case #90-09-11-1622

Boreholes exhibited hydrocarbon contamination exceeding NJDEPE standards. The water table is located at 7 feet depth. Groundwater sampling revealed contamination up to 32 ppb of benzene as well as ethylbenzene.

Highland High School

Case #90-02-16-1009

A 2000 gallon gasoline UST was removed. Toluene and xylenes were detected at levels in excess of 1000 ppm in a composite soil sample. Soil is sandy clay and loam. The top of the well screens are located 17 to 18 feet below grade. BTEX contamination is present at levels exceeding NJDEPE standards.

Organon

Case #88-08-03-1113

A feeder line to a 15000 gal No. 4 fuel oil UST was removed. Soil contamination was observed at the ground surface. Groundwater is about 6 feet below grade, so tank is in groundwater but the feeder line is probably not. Trace levels of toluene were detected in groundwater.

Adamucci Oil Co.

Case #90-05-24-1148

Eight USTs were removed from the site. BTEX compounds were detected in groundwater above NJDEPE standards. The wellscreen begins 4 feet below ground surface (water table at 5 feet depth), so tanks were probably in groundwater. The summary indicates the existence of contaminated soil, but the data aren't reported.

Enterprise Investments

Case #89-11-22-1317

Four 4000 gallon fuel oil USTs were removed. Groundwater contamination was detected, with a maximum BTEX concentration of 216 ppb. Soil sampling revealed TPH contamination in the hundreds of ppm range. Clay and weathered mudstone were present to a depth of 8-11 feet. The depth to groundwater is about 7-9 feet. BTEX levels in groundwater exceed NJDEPE standards.

Atlantic City Medical Center

Case #89-7-10-1457

A 15000 gallon #2 fuel oil UST was removed. Product loss was documented as 350 gallons. Naphthalene is the only compound detected in groundwater at 15 ppb. Most monitoring wells are not downgradient. A nested well was proposed. The water table is located approximately 12-14 feet below ground surface. No soil data are provided, contamination being visually confirmed.

I&B Builders Inc.

Case #90-01-30-1047

Three USTs were removed. BTEX were detected in groundwater. The depth to groundwater is 1 to 8 feet. The summary indicates soil levels of VOCs were in exceedence of NJDEPE standards, but no data are reported.

JTC Corporation

Case # 89-07-27-1441

A 550 gallon waste oil UST was removed. The well depth is 27 feet, 10 feet of screen, so the water table is about 17 feet below the ground surface. No contaminants were detected in groundwater. There are no soil sample data in the file and no discussion of soil conditions at the site.

Gallo Asphalt

Case #87-12-24-0938

Only laboratory data for groundwater and soil samples are included. I can find no information concerning the site.

Plainfield High School

Case #90-05-06-1706

One 15000 gallon No. 4 heating oil UST was removed. Inspection of tank revealed 2"x3" hole in addition to pencil-size holes. Four other tanks remain in place. Groundwater samples revealed no petroleum-related contamination. Wellscreen is from 15 to 25 feet depth, so the tank is above groundwater. The field log reports depth to groundwater of 19 feet. 127 ppm TPH were detected in soil.

Historical Development Victorian Court

Case #87-09-08-03S

Two USTs were removed. Investigation associated with tank removal revealed TPH levels up to 6160 ppm. No contaminants were detected in groundwater. No information concerning depth to groundwater is available.

Mobil Service Station, Liberty Corner

Case #90-05-231-533 (this format is incorrect; it's probably 90-05-23-1533)

Four 4000 gallon USTs were removed. Fractured shale lies beneath the site. Water table is 14 to 16 feet deep. Groundwater samples reveal gasoline-related contamination in the hundreds of ppb range. The site is covered by asphalt. Soil contamination was apparent upon excavation, but no soil data are included with the report.

Spiniello Construction

Case #89-12-29-1403

Five diesel and gasoline-containing USTs were removed. BTEX levels in soil exceeded 1 ppm. Floating product was observed, so NJDEPE standards were exceeded. The soil is classified as a gravelly loamy sand. Boring logs show sand and gravelly sand. The water table is located at a depth of 11 to 13 feet.

Appendix B: Random search case file data

B-1



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Soil Profile Characterization

Well/borehole: MW-2

	Upper	Lower
	depth (ft)	
silt and sand	0	15
gravel and sand	15	20
sand	20	27

Notes: This case was logged by Brian Sogorka.

Depth to water table measured from top of casing to be 15.4'.

Soil sample depth based on bottom of excavation for 1000 gallon UST.

Monitoring well located within 10' of UST.

Soil detection limits are not available.

NR – not reported for medium indicated

blank – not reported for either medium

Site name: New Jersey American Water Company Short Hills Station - Pit C5
Site location: Springfield Twp/Union City
Report date: 10/90
Bureau: BUST
Case number: 89-12-29-1442
Box: EF-16

25 ft, depth for well
14.44 ft to water table
paved Ground cover/surface

MW-1
MW-1

Maximum contaminant concentrations

contaminant	Soil conc. ppm	Sample ID	Exceed Std. ?	Sample depth (ft)	GW conc. ppb	Sample ID	Exceed Std. ?
TPH	1970	C5B	yes		NR		
benzene	0.100	T2S1	no	9	ND 5	MW-1	no
toluene	2.000	T2S1	yes	9	ND 5	MW-1	no
ethylbenzene	10.800	C5B	yes		ND 5	MW-1	no
xylene	52.100	C5B	yes	9	ND 5	MW-1	no
MTBE	NR				ND 10	MW-1	no
TBA	NR				ND 50	MW-1	no
PCE							
TCE							

B-38


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Soil Profile Characterization

Well/borehole: MW-1

	Upper	Lower
	depth (ft)	
silt, some clay/sand	0	7
sandy gravel	7	26
gravelly sand	26	27

Notes: This case was logged by Brian Sogorka.

Depth to water table measured from top of casing to be 15.4'.

Well is located within 10' of tank.

Post-excavation soil samples taken from gasoline-stained soils.

NR – not reported for medium indicated

blank – not reported for either medium

Site name: Johnson & Towers
Site location: Mt. Laurel
Report date: received by BUST 12/20/91
Bureau: UST
Case number: 91-04-15-1406
Box: EF-121

15.4 ft, depth for well TP-1
 6.55 ft to water table TP-1
 NR Ground cover/surface

Maximum contaminant concentrations

contaminant	Soil conc. ppm	Sample ID	Exceed Std. ?	Sample depth (ft)	GW conc. ppb	Sample ID	Exceed Std. ?
TPH							
benzene	NR				ND	TP-1	no
toluene	NR				ND	TP-1	no
ethylbenzene	0.131	SJTE34	no	8.5	ND	TP-1	no
xlenes	0.563	SJTE34	no	8.5	ND	TP-1	no
MTBE	NR				ND	TP-1	no
TBA	NR				ND	TP-1	no
PCE							
TCE							

B-40

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Soil Profile Characterization

Well/borehole: TP-1

	Upper	Lower
	depth (ft)	
f-m silty sand	0	2
sandy clay	2	4
coarse med sand	4	14
fine-med sand	14	15
clay	15	17

Notes: Well TP-1 is located within 10' of UST.

Well was finished 2' above grade, so depth to water is 6.55' rather than 8.55' as reported.

Detection limits for groundwater analyses were not reported.

This tank is about 3-4' in diameter, based on reported length

Therefore, the tank is probably just above the water table.

Reported purge volume is 20 gallons.

NR – not reported for medium indicated

blank – not reported for either medium

Site name: Vineland Post Office
Site location: Vineland
Report date: 1/92
Bureau: UST
Case number: C-91-0046
Box: EF-100

48.0 ft, depth for well
43.00 ft to water table
asphalt Ground cover/surface

MW-3
MW-3

Maximum contaminant concentrations

contaminant	Soil conc. ppm	Sample ID	Exceed Std. ?	Sample depth (ft)	GW conc. ppb	Sample ID	Exceed Std. ?
TPH							
benzene	ND 0.005	GT-6	no	3	ND 5	MW-3	no
toluene	0.027	GT-6	no	3	ND 5	MW-3	no
ethylbenzene	0.012	GT-6	no	3	ND 5	MW-3	no
xylene	0.113	GT-6	no	3	NR		
MTBE							
TBA							
PCE							
TCE							

Soil profile Characterization

Well/borehole: MW-3

	Upper	Lower
	depth (ft)	
asphalt and concrete	0	1
SANDY CLAY and CLAY, trace	1	6
gravel		
CLAYEY SAND, trace gravel	6	7
CLAY, some sand and gravel	7	10
SANDY CLAY	10	12
CLAYEY SAND	12	34
SAND	34	47

Notes: MW-3 is located approximately 20' from former UST.

Depth to soil sample location is approximate, based on fact that sample GT-6 was taken from area of fill line, not the bottom of the tank.

Depth to water table is smallest value reported.

Depth to GW is 42.02 in MW-1.

NR – not reported for medium indicated

blank – not reported for either medium

B-43


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Site name: AT&T Totowa Rd.
Site location: Totowa
Report date: 6/30/89
Bureau: UST
Case number: 87-07-23-1510
Box: EF-36

75 ft, depth for well MW-1
 55 ft to water table MW-1
 none Ground cover/surface

Maximum contaminant concentrations

contaminant	Soil conc. ppm	Sample ID	Exceed Std. ?	Sample depth (ft)	GW conc. ppb	Sample ID	Exceed Std. ?
TPH	7900	#3	yes	1	NR		
benzene	ND 6.000	#3	no	1	17	MW-1	yes
toluene	ND 8.200	#3	no	1	ND 6	MW-1	no
ethylbenzene	33.000	#3	yes	1	ND 7	MW-1	no
xylene	360.000	#3	yes	1	NR		
MTBE	NR				ND 10	MW-1	no
TBA	NR				ND 10	MW-1	no
PCE							
TCE							

B-44

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Soil profile Characterization

Well/borehole:	MW-1	Upper	Lower
		depth (ft)	
miscellaneous fill		0	6
clay stiff to v. stiff (CL)		6	15
boulders and cobbles		15	24
basalt		24	75

Notes: The aquifer beneath MW-1 appears to be an artesian aquifer at about 55' depth. Later depth to water table measurements are really measurements to head level in artesian aquifer. Two tanks were removed. We limit ourselves to the 275 gallon waste oil tank and oil/water separator. There is no perched water table at this location. Groundwater was encountered at a depth of approximately 55'. Benzene GW data could not be found in report. For purposes of calculating well purging volume, depth to water table due to artesian aquifer pressure is reported to be 10'. NR – not reported for medium indicated blank – not reported for either medium

Appendix C: Categorization of potential indicator variables

C-1



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Table C.1 Summary of potential indicator variables

	benzene	toluene	ethyl- benzene	xylenes
N(sites w/ GW data)	21	22	22	20
N(sites w/ soil data)	20	20	19	22
N(sites w/ soil and GW data)	19	20	19	20
N(GW exceed)	4	2	1	3
N(soil exceed)	1	3	2	4
N(exceed detect)	1	2	0	2
N(no exceed detect)	5	8	9	7
N(exceed ND)	2	0	0	1
N(no exceed ND)	11	10	10	10
N(exceed exceed)	1	2	0	2
N(no exceed exceed)	0	1	2	2
N(exceed no exceed)	2	0	0	1
N(no exceed no exceed)	16	17	17	16
N(exclfine=c)	1	0	0	0
N(no exclfine=c)	1	2	2	0
N(exclfine=s)	1	0	0	1
N(no exclfine=s)	5	7	7	6
N(exclfine=sa)	2	2	1	2
N(no exclfine=sa)	7	7	8	7
N(exclfine=g)	0	0	0	0
N(no exclfine=g)	1	1	1	1
N(exclcoarse=c)	0	0	0	0
N(no exclcoarse=c)	0	0	0	0
N(exclcoarse=s)	1	0	0	1
N(no exclcoarse=s)	0	1	1	0
N(exclcoarse=sa)	2	2	1	2
N(no exclcoarse=sa)	12	13	14	12
N(exclcoarse=g)	1	0	0	0
N(no exclcoarse=g)	2	3	3	2
N(exclfine≤silt)	2	0	0	1
N(no exclfine≤silt)	6	9	9	6
N(exclfine>silt)	2	2	1	2
N(no exclfine>silt)	8	8	9	8

Table C.1 Summary of potential indicator variables (continued)

	benzene	toluene	ethyl- benzene	xylenes
N(exclcoa≤silt)	1	0	0	1
N(no exclcoa≤silt)	0	1	1	0
N(exclcoa>silt)	3	2	1	2
N(no exclcoa>silt)	14	16	17	14
N(excl≤5)	1	1	0	1
N(no excl≤5)	3	3	4	3
N(excl5<d≤7)	1	0	0	1
N(no excl5<d≤7)	4	5	5	4
N(excl7<d≤9)	1	1	1	1
N(no excl7<d≤9)	5	6	6	6
N(excl>9)	1	0	0	0
N(no excl>9)	2	3	3	1
N(excl≤7)	2	1	0	2
N(no excl≤7)	7	8	9	7
N(excl>7)	2	1	1	1
N(no excl>7)	7	9	9	7
N(excl≤5)	1	1	0	1
N(no excl≤5)	3	3	4	3
N(excl>5)	3	1	1	2
N(no excl>5)	11	14	14	11
N(exclcover)	1	0	0	1
N(no exclcover)	11	13	13	11
N(exclno cover)	3	2	1	2
N(no exclno cover)	5	6	7	5
N(excltr<2)	3	2	1	2
N(no excltr<2)	9	10	11	9
N(excltr>2)	1	0	0	1
N(no excltr>2)	4	6	6	4

Table C.1 Summary of potential indicator variables (continued)

	benzene	toluene	ethyl- benzene	xylenes
$N(\text{excltr} \leq \text{thresh}_{\text{tr}})$	2	1	1	2
$N(\text{no excltr} \leq \text{thresh}_{\text{tr}})$	2	1	3	2
$N(\text{excltr} > \text{thresh}_{\text{tr}})$	2	1	0	1
$N(\text{no excltr} > \text{thresh}_{\text{tr}})$	11	15	14	11
$N(\text{exclaf} < 0.01)$	4	2	1	3
$N(\text{no exclaf} < 0.01)$	13	16	17	13
$N(\text{exclraf} < 0.01)$	0	0	0	0
$N(\text{no exclraf} < 0.01)$	0	0	0	0
$N(\text{exclNE} \& \text{f} \leq \text{silt})$	1	0	0	1
$N(\text{no exclNE} \& \text{f} \leq \text{silt})$	6	8	8	6
$N(\text{exclNE} \& \text{f} > \text{silt})$	1	0	0	0
$N(\text{no exclNE} \& \text{f} > \text{silt})$	7	6	6	7
$N(\text{exclNE} \& \text{cover})$	1	0	0	1
$N(\text{no exclNE} \& \text{cover})$	11	12	11	10
$N(\text{exclNE} \& \text{no cover})$	1	0	0	0
$N(\text{no exclNE} \& \text{no cover})$	5	5	5	5
$N(\text{exclNE} \& \text{tr} \leq 2)$	1	0	0	0
$N(\text{no exclNE} \& \text{tr} \leq 2)$	9	8	7	8
$N(\text{exclNE} \& \text{tr} > 2)$	1	0	0	1
$N(\text{no exclNE} \& \text{tr} > 2)$	4	6	7	4
$N(\text{exclNE} \& \text{rtr} < 25)$	1	0	0	0
$N(\text{no exclNE} \& \text{rtr} < 25)$	2	1	3	2
$N(\text{exclNE} \& \text{rtr} > 25)$	1	0	0	1
$N(\text{no exclNE} \& \text{rtr} > 25)$	11	13	11	10
	S/K_{oc}	P_v	$t_{1/2}$	
$N(\text{exclprop} < \text{prop}_T)$	4	6	1	
$N(\text{no exclprop} < \text{prop}_T)$	34	51	18	
$N(\text{exclprop} > \text{prop}_T)$	5	3	8	
$N(\text{no exclprop} > \text{prop}_T)$	33	16	49	

Appendix D: Probability estimates and confidence intervals

D-1



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Table D.1 Summary of estimates of the mean and 90% confidence intervals on estimates of the mean

	benzene			toluene		
	P	P _L	P _U	P	P _L	P _U
P(GW exceed)	0.19	0.086	0.353	0.09	0.024	0.236
P(GW no exceed)	0.81	0.647	0.914	0.91	0.764	0.976
P(exceed detect)	0.17	0.017	0.542	0.20	0.055	0.500
P(no exceed detect)	0.83	0.458	0.983	0.80	0.500	0.945
P(exceed ND)	0.15	0.042	0.379	0.00	0.000	0.222
P(no exceed ND)	0.85	0.621	0.958	1.00	0.778	1.000
P(exceed exceed)	1.00	0.100	1.000	0.67	0.196	0.965
P(no exceed exceed)	0.00	0.000	0.900	0.33	0.035	0.804
P(exceed no exceed)	0.11	0.030	0.277	0.00	0.000	0.140
P(no exceed no exceed)	0.89	0.723	0.970	1.00	0.860	1.000
P(exclfine≤silt)	0.25	0.069	0.582	0.00	0.000	0.232
P(no exclfine≤silt)	0.75	0.418	0.931	1.00	0.768	1.000
P(exclfine>silt)	0.20	0.055	0.500	0.20	0.055	0.500
P(exclfine>silt)	0.80	0.500	0.945	0.80	0.500	0.945
P(exclcoa≤silt)	1.00	0.100	1.000	0.00	0.000	0.900
P(no exclcoa≤silt)	0.00	0.000	0.900	1.00	0.100	1.000
P(exclcoa>silt)	0.18	0.067	0.364	0.11	0.030	0.277
P(no exclcoa>silt)	0.82	0.636	0.933	0.89	0.775	0.994
P(excl≤7)	0.22	0.061	0.515	0.11	0.012	0.391
P(no excl≤7)	0.78	0.485	0.939	0.89	0.609	0.988
P(excl>7)	0.22	0.061	0.515	0.10	0.010	0.352
P(no excl>7)	0.78	0.485	0.939	0.90	0.648	0.990

Table D.1 Summary of estimates of the mean and 90% confidence intervals on estimates of the mean (continued)

	benzene			toluene		
	P	P _L	P _U	P	P _L	P _U
P(excl _d ≤5)	0.25	0.026	0.680	0.25	0.026	0.680
P(no excl _d ≤5)	0.75	0.320	0.974	0.75	0.320	0.974
P(excl _d >5)	0.21	0.081	0.422	0.07	0.007	0.247
P(no excl _d >5)	0.79	0.578	0.919	0.93	0.753	0.993
P(excl _{cover})	0.08	0.009	0.294	0.00	0.000	0.173
P(no excl _{cover})	0.92	0.706	0.991	1.00	0.827	1.000
P(excl _{no cover})	0.38	0.147	0.745	0.25	0.069	0.582
P(no excl _{no cover})	0.63	0.255	0.853	0.75	0.418	0.931
P(excl _{tr} <2)	0.25	0.096	0.500	0.17	0.045	0.398
P(no excl _{tr} <2)	0.75	0.500	0.904	0.83	0.602	0.955
P(excl _{tr} >2)	0.20	0.021	0.621	0.00	0.000	0.345
P(no excl _{tr} >2)	0.80	0.379	0.979	1.00	0.655	1.000
P(excl _{tr} ≤thresh _{tr})	0.50	0.143	0.857	0.50	0.051	0.949
P(no excl _{tr} ≤thresh _{tr})	0.50	0.143	0.857	0.50	0.051	0.949
P(excl _{tr} >thresh _{tr})	0.15	0.042	0.379	0.06	0.007	0.235
P(no excl _{tr} >thresh _{tr})	0.85	0.621	0.958	0.94	0.765	0.993
P(excl _{NE&≤silt})	0.14	0.015	0.500	0.00	0.000	0.255
P(no excl _{NE&≤silt})	0.86	0.500	0.985	1.00	0.745	1.000
P(excl _{NE&>silt})	0.13	0.013	0.418	0.00	0.000	0.345
P(no excl _{NE&>silt})	0.88	0.582	0.987	1.00	0.655	1.000
P(excl _{NE&cover})	0.08	0.009	0.294	0.00	0.000	0.184
P(no excl _{NE&cover})	0.92	0.706	0.991	1.00	0.816	1.000
P(excl _{NE&no cover})	0.17	0.017	0.542	0.00	0.000	0.379
P(no excl _{NE&no cover})	0.83	0.458	0.983	1.00	0.621	1.000

Table D.1 Summary of estimates of the mean and 90% confidence intervals on estimates of the mean (continued)

	benzene			toluene		
	P	P _L	P _U	P	P _L	P _U
P(exclNE&tr<2)	0.10	0.010	0.352	0.00	0.000	0.255
P(no exclNE&tr<2)	0.90	0.648	0.990	1.00	0.745	1.000
P(exclNE&tr>2)	0.20	0.021	0.621	0.00	0.000	0.345
P(no exclNE&tr>2)	0.80	0.379	0.979	1.00	0.655	1.000
P(exclNE&rtr<thresh _{rtr})	0.33	0.035	0.804	0.00	0.000	0.900
P(no exclNE&rtr<thresh _{rtr})	0.67	0.196	0.965	1.00	0.100	1.000
P(exclNE&rtr>thresh _{rtr})	0.08	0.009	0.294	0.00	0.000	0.197
P(no exclNE&rtr>thresh _{rtr})	0.92	0.706	0.991	1.00	0.803	1.000

Table D.1 Summary of estimates of the mean and 90% confidence intervals on estimates of the mean (continued)

	ethyl- benzene			xylenes		
	P	P _L	P _U	P	P _L	P _U
P(GW exceed)	0.05	0.005	0.182	0.15	0.056	0.328
P(GW no exceed)	0.95	0.818	0.995	0.85	0.672	0.944
P(exceed detect)	0.00	0.000	0.232	0.22	0.061	0.515
P(no exceed detect)	1.00	0.768	1.000	0.78	0.485	0.939
P(exceed ND)	0.00	0.000	0.222	0.09	0.010	0.315
P(no exceed ND)	1.00	0.778	1.000	0.91	0.685	0.990
P(exceed exceed)	0.00	0.000	0.684	0.67	0.196	0.965
P(no exceed exceed)	1.00	0.316	1.000	0.33	0.035	0.804
P(exceed no exceed)	0.00	0.000	0.140	0.06	0.006	0.225
P(no exceed no exceed)	1.00	0.860	1.000	0.94	0.775	0.994
P(exclfine≤silt)	0.00	0.000	0.232	0.14	0.015	0.500
P(no exclfine≤silt)	1.00	0.768	1.000	0.86	0.500	0.985
P(exclfine>silt)	0.10	0.010	0.352	0.20	0.055	0.500
P(exclfine>silt)	0.90	0.648	0.990	0.80	0.500	0.945
P(exclcoa≤silt)	0.00	0.000	0.900	1.00	0.100	1.000
P(no exclcoa≤silt)	1.00	0.100	1.000	0.00	0.000	0.900
P(exclcoa>silt)	0.06	0.006	0.216	0.13	0.034	0.305
P(no exclcoa>silt)	0.94	0.784	0.994	0.88	0.695	0.966
P(excl≤7)	0.00	0.000	0.232	0.22	0.061	0.515
P(no excl≤7)	1.00	0.768	1.000	0.78	0.485	0.939
P(excl>7)	0.10	0.010	0.352	0.13	0.013	0.418
P(no excl>7)	0.90	0.648	0.990	0.88	0.582	0.987

Table D.1 Summary of estimates of the mean and 90% confidence intervals on estimates of the mean (continued)

	ethyl- benzene			xylenes		
	P	P _L	P _U	P	P _L	P _U
P(excl _d ≤5)	0.00	0.000	0.500	0.25	0.026	0.680
P(no excl _d ≤5)	1.00	0.500	1.000	0.75	0.320	0.974
P(excl _d >5)	0.07	0.007	0.247	0.15	0.042	0.379
P(no excl _d >5)	0.93	0.753	0.993	0.85	0.621	0.958
P(excl _{cover})	0.00	0.000	0.173	0.08	0.009	0.294
P(no excl _{cover})	1.00	0.827	1.000	0.92	0.706	0.991
P(excl _{no cover})	0.13	0.013	0.418	0.29	0.079	0.684
P(no excl _{no cover})	0.88	0.582	0.987	0.71	0.316	0.921
P(excl _{tr} <2)	0.08	0.009	0.294	0.18	0.049	0.423
P(no excl _{tr} <2)	0.92	0.706	0.991	0.82	0.577	0.951
P(excl _{tr} >2)	0.00	0.000	0.345	0.17	0.017	0.542
P(no excl _{tr} >2)	1.00	0.655	1.000	0.83	0.458	0.983
P(excl _{tr} ≤thresh _{tr})	0.25	0.026	0.680	0.50	0.143	0.857
P(no excl _{tr} ≤thresh _{tr})	0.75	0.320	0.974	0.50	0.143	0.857
P(excl _{tr} >thresh _{tr})	0.00	0.000	0.163	0.08	0.009	0.294
P(no excl _{tr} >thresh _{tr})	1.00	0.837	1.000	0.92	0.706	0.991
P(excl _{NE&≤silt})	0.00	0.000	0.255	0.14	0.015	0.500
P(no excl _{NE&≤silt})	1.00	0.745	1.000	0.86	0.500	0.985
P(excl _{NE&>silt})	0.00	0.000	0.345	0.00	0.000	0.316
P(no excl _{NE&>silt})	1.00	0.655	1.000	1.00	0.684	1.000
P(excl _{NE&cover})	0.00	0.000	0.197	0.09	0.010	0.315
P(no excl _{NE&cover})	1.00	0.803	1.000	0.91	0.685	0.990
P(excl _{NE&no cover})	0.00	0.000	0.379	0.00	0.000	0.379
P(no excl _{NE&no cover})	1.00	0.621	1.000	1.00	0.621	1.000

Table D.1 Summary of estimates of the mean and 90% confidence intervals on estimates of the mean (continued)

	ethyl- benzene			xylenes		
	P	P _L	P _U	P	P _L	P _U
P(exclNE&tr<2)	0.00	0.000	0.316	0.00	0.000	0.255
P(no exclNE&tr<2)	1.00	0.684	1.000	1.00	0.745	1.000
P(exclNE&tr>2)	0.00	0.000	0.316	0.20	0.021	0.621
P(no exclNE&tr>2)	1.00	0.684	1.000	0.80	0.379	0.979
P(exclNE&rtr<thresh _{rtr})	0.00	0.000	0.536	0.00	0.000	0.684
P(no exclNE&rtr<thresh _{rtr})	1.00	0.464	1.000	1.00	0.316	1.000
P(exclNE&rtr>thresh _{rtr})	0.00	0.000	0.197	0.09	0.010	0.315
P(no exclNE&rtr>thresh _{rtr})	1.00	0.803	1.000	0.91	0.685	0.990

	S/K _{oc}			P _v		
	P	P _L	P _U	P	P _L	P _U
P(exclprop<prop _T)	0.11	0.02	0.19	0.11	0.02	0.19
P(no exclprop<prop _T)	0.89	0.81	0.98	0.89	0.81	0.98
P(exclprop>prop _T)	0.13	0.04	0.22	0.16	0.06	0.26
P(no exclprop>prop _T)	0.87	0.78	0.96	0.84	0.74	0.94

	t _{1/2}		
	P	P _L	P _U
P(exclprop<prop _T)	0.05	0.00	0.11
P(no exclprop<prop _T)	0.95	0.89	1.00
P(exclprop>prop _T)	0.14	0.05	0.23
P(no exclprop>prop _T)	0.86	0.77	0.95