American
Petroleum
Institute

Groundwater Sensitivity
TOOLKIT

Users Guide
Version 1.0

AMERICAN PETROLEUM INSTITUTE
CALIFORNIA MTBE RESEARCH PARTNERSHIP

REGULATORY ANALYSIS AND SCIENTIFIC AFFAIRS
PUBLICATION NUMBER 4722
AUGUST 2002

DEVELOPED BY:
GROUNDWATER SERVICES, INC.

GROUNDWATER SENSITIVITY TOOLKIT

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FOREWORD

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Comments and suggested revisions are invited and should be submitted to:

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ABOUT THE GROUNDWATER SENSITIVITY TOOLKIT

The Groundwater Sensitivity Toolkit was designed to help site managers, water purveyors and regulators evaluate the sensitivity of a groundwater resource to a potential release at a particular site. This screening tool cannot anticipate all factors that may affect groundwater sensitivity at a given site. Therefore managers, purveyors, and regulators may need to consider other factors as well.

The toolkit examines three aspects of sensitivity:

- Natural Sensitivity
- Receptor Vulnerability
- Resource Value

The user enters in site-specific information about the site, and the Toolkit returns a three-section "scorecard" addressing the three aspects of sensitivity. This scorecard may be used to prioritize and categorize the sites in a catalog.

The Groundwater Sensitivity Toolkit was developed for the American Petroleum Institute and the California MTBE Research Partnership by Groundwater Services, Inc.

QUICK START

MINIMUM SYSTEM REQUIREMENTS

The Groundwater Sensitivity Toolkit may be used on a computer system running Windows 98/NT/2000/XP and Microsoft Excel™ 97SR-1/2000/XP. A minimum of 64 MB of system memory, 25 MB of free disk space and virtual memory is required.

INSTALLATION

The Groundwater Sensitivity Toolkit is distributed as a self-extracting ZIP file, *Setup.exe*, containing the following files:

Sensitivity.xls	Sensitivity toolkit
Sensitivity.chm	Help file
Readme.txt	Readme
CaseStudy.xls	Case Study example file

The user will be prompted to specify the directory into which to extract the files. By default, the zip file will extract to c:\Sensitivity. Extracting the program into another folder should not cause any problems, although the user may want to check with the network administrator before attempting to install it on a central server. *It is necessary to keep the help file and the Microsoft™ Excel file together, and to maintain the original names.* In addition, the user may also want to set the Sensitivity.xls file to read-only, to minimize the chance of corrupting the macros during use.

DATA INPUT AND OUTPUT

The toolkit was designed to run under Microsoft Excel™ with Visual Basic for Applications (VBA). Input values are entered into spreadsheets, and navigation among the cells on each individual input screen can be performed using the arrow keys or the mouse, just as with any spreadsheet. The individual screens of the toolkit may be printed using the buttons provided or by using the "Print" command (Ctrl+P) command in Microsoft Excel™'s "File" menu.

ON-LINE HELP

Each input and output screen is described in further detail in this manual and in the on-line Help text. To access on-line help for a particular input section, click on the help buttons located throughout the software.

TECHNICAL SUPPORT

Limited technical support related to compatibility issues for the Groundwater Sensitivity Toolkit is available from GSI via phone at 713-522-6300, fax via 713-522-8010, or email at gwsensitivitytoolkit@listserve.api.org. Please be sure to include contact information, the version of the toolkit, and the version of Microsoft Windows/Office that you are using.

INTRODUCTION

PURPOSE

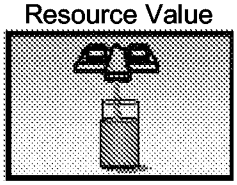
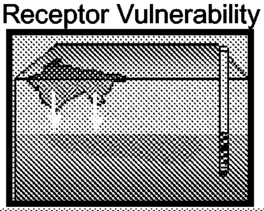
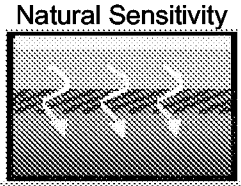
Groundwater sensitivity is a key consideration in the development and implementation of appropriate corrective actions at potential release sites, such as leaking underground storage tanks, landfills, and other sources. Experience shows that actual impacts on critical water supply resources have occurred at a relatively small number of sites. Due to the risk of potential exposure, these high-sensitivity sites should warrant a large percentage of the available public and private resources for release prevention, assessment, and remediation.

However, practical, site-specific measures of groundwater sensitivity may not be sufficiently considered in release prevention efforts and the development of remediation goals. As a result, low sensitivity and high sensitivity sites may be frequently treated as equivalent concerns. This results in an inefficient allocation of available remediation/prevention dollars.

The Groundwater Sensitivity Toolkit is a decision support expert system that allows a user to enter site-specific parameters to generate a scorecard for that site. This scorecard, when compared to the scores for other sites in a portfolio, gives the decision-maker insight into how resources should be allocated amongst the portfolio.

METHOD

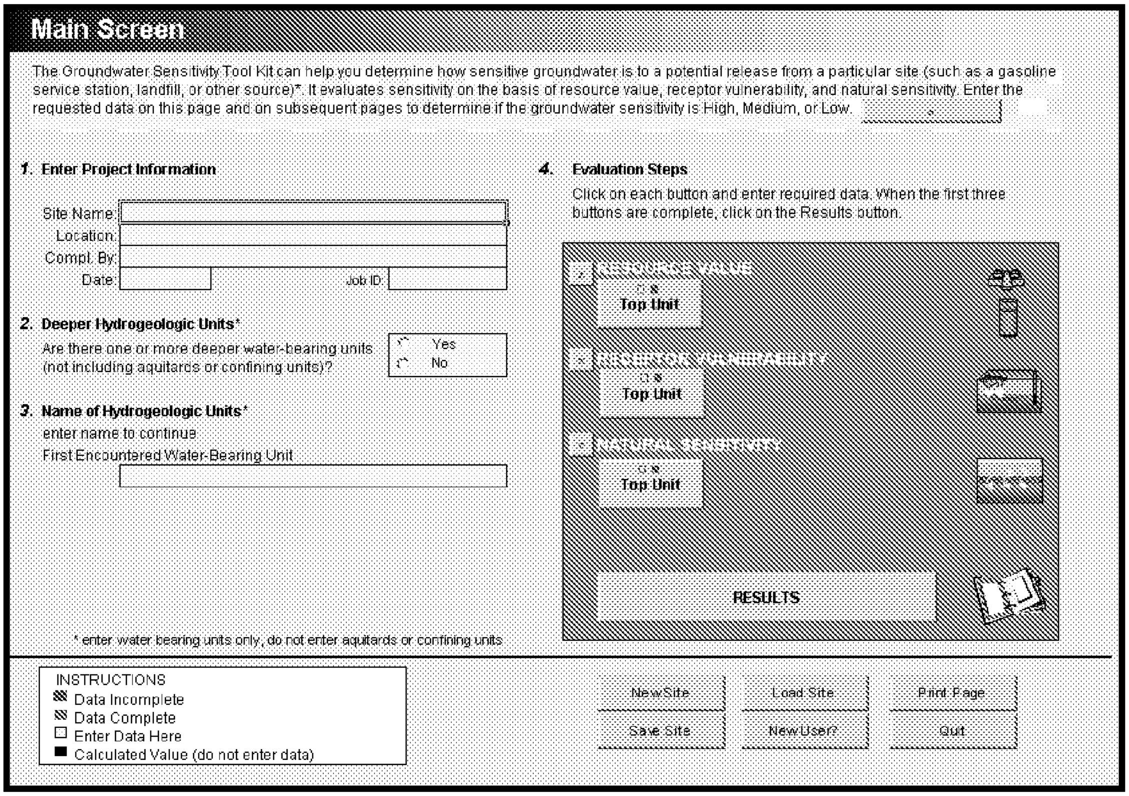
This scorecard is based on three separate but related issues for a site:

Resource Value 	Importance of the groundwater to water purveyors, municipalities, domestic groundwater users, or natural systems.
Receptor Vulnerability 	Impact of a release to groundwater to existing (not potential) receptors who are using groundwater from any hydrogeological unit.
Natural Sensitivity 	Effectiveness of natural factors (such as the depth to water, soil type, etc.) in preventing a release at this location from impacting groundwater.

A user may enter data for up to three aquifers for a site. For each aquifer, a HIGH, MEDIUM, or LOW score is determined for each of the three issues. The results may be printed out, and the project may be saved to a data file for later revision.

MAIN SCREEN

The main screen serves as the central point for the toolkit. It is the launch point to all other sections of the toolkit and is the place where general information about the project, such as name, location, date, and aquifer names is entered. The main screen is also the place in the toolkit where the user may create, load, and save data input files.



PROJECT INFORMATION

Basic site and project information is entered here and will be displayed on all input and output screens for easy identification and recordkeeping.

DEEPER HYDROGEOLOGIC UNITS

This question asks if there are multiple units under consideration. Click yes if there are multiple units, or if the unit under consideration has overlying hydrogeologic units.

NAME OF HYDROGEOLOGIC UNITS

The toolkit permits the user to enter information for up to three hydrogeologic units. This is where you may enter a name for the unit. For sites where there is only one unit of interest, the user can enter information for the Top Unit only. Entering a name into either the Middle or Bottom Unit spaces will display the buttons for that unit in the Evaluation Steps section.

EVALUATION STEPS

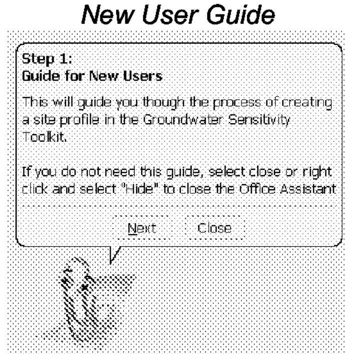
The buttons located on the Evaluation Steps screen provide a gateway for all other input pages in the project. By default, the buttons for the middle and bottom units are hidden. To display the other two units, a name must be entered in the Hydrogeologic Units section.

COMMANDS

- **New Site:** Clears all input values, resets options for the current project, and restores any default values. If the current data set is not saved, a message will prompt the user to either save or discard any changes.
- **Load Site:** Loads the input values and options for a previously saved project data set. If the current project data set is not saved, a message will prompt the user to either save or discard any changes.
- **Save Site:** Saves all input vales and options for the current data set as a separate Microsoft Excel™ workbook (a .xls file). Saved data files do not have to be in the same directory as application files for the Groundwater Sensitivity Toolkit.

Note: Workbooks created by this method are formatted for use with the Sensitivity Toolkit. Editing the files should only be done with the Sensitivity Toolkit, and attempting to change the files manually in Microsoft Excel™ may corrupt the file.

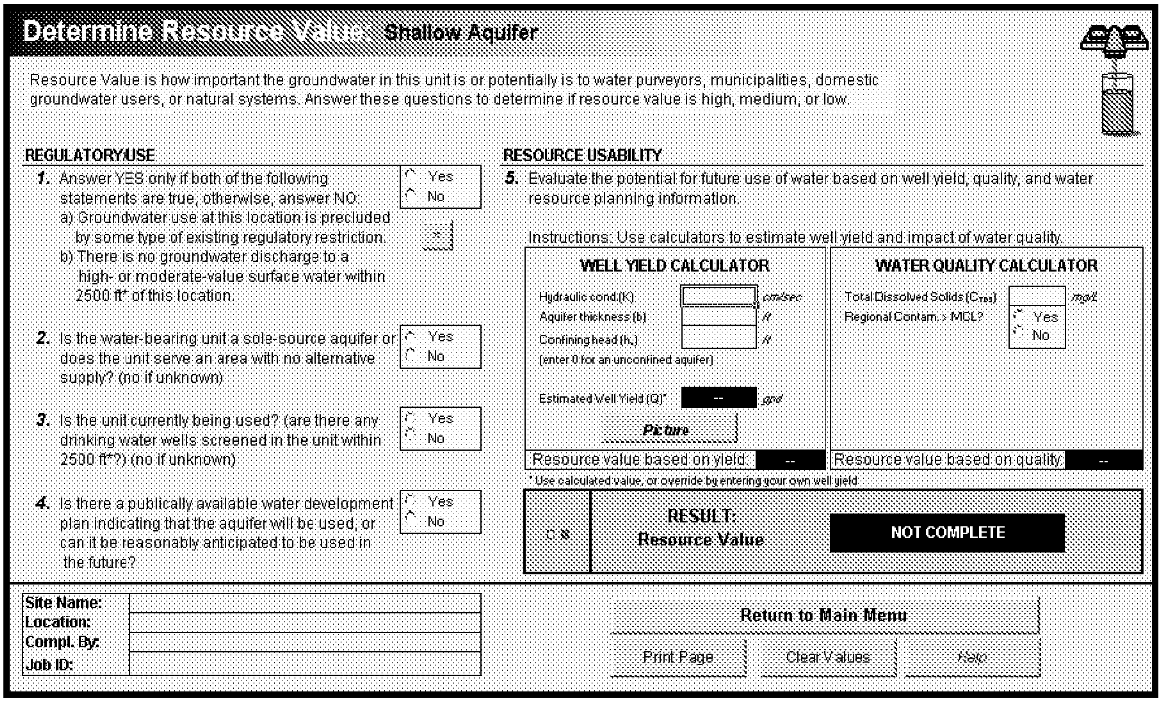
New User Guide



- **Quit:** Quits the Groundwater Sensitivity Toolkit.
- **Print Page:** Opens the Print Preview for the sheet, and allows the user to print the sheet.
- **New User**: Opens the Office Assistant to guide first-time users. This option only works for users of Office 2000 and XP.

RESOURCE VALUE

The Resource Value is an indication of the potential a water-bearing unit has for becoming a usable water supply or a resource to support natural systems.



The first four questions address any policy-based usage of this aquifer. In the toolkit, policy-based considerations override the engineering considerations when determining resource value for an aquifer. The fifth question, in two parts, addresses the two major limitations on water production from an aquifer.

POLICY QUESTIONS

1. If groundwater use is precluded by some type of regulation or law (such as a no-pumping rule) then the Resource Value is defined as LOW as it is not usable as a resource for water-supply purposes.

2. If the water-bearing unit is a sole-source aquifer as defined by federal or state regulations, then the Resource Value is defined as HIGH as the water-bearing unit is a vital water supply resource.

3. If the water-bearing unit is currently being used in the vicinity of the site of interest, then the Resource Value is considered to be HIGH as it is a usable water supply resource. For the purposes of this software, the software development committee used a distance of 2500 ft to determine if water supply wells (either domestic, municipal, irrigation, or industrial) that are screened in the water-bearing unit have the potential for being affected by the site of interest. This distance was based on general experience about the potential conservative (high-end) length of contaminant plumes.

4. If there is a formally adopted water supply plan (adopted by regulatory body such as a city, county, regional planning board, state, etc.) that indicates that the unit may be used as a

drinking water supply in the near future (i.e., within a few years), then the Resource Value is automatically upgraded to MEDIUM.

RESOURCE USABILITY: Well Yield

Determination of well yield addresses the ability of a unit to produce water and is a primary concern when deciding if a water-bearing unit with no production or policy information has the potential to become a water supply resource. The well yield is determined from calculations based on hydraulic conductivity, aquifer thickness, and confining head. The software development committee developed the following rules to define Resource Value as a function of well yield based on regulatory approaches used in several states:

Well Yield	Resource Value Rating
above 144000 gpd (100 gpm)	HIGH
between 200 and 144000 gpd	MEDIUM
less than 200 gpd	LOW

RESOURCE USABILITY: Water Quality

The quality of water in an aquifer is another primary concern that determines resource value. Total dissolved solids (TDS) adversely affect aquifer quality, and any water produced from a high TDS aquifer often precludes use of a groundwater resource as a water supply.

Water Quality	Resource Value Rating
TDS below 500 mg/L	HIGH
TDS between 500 and 3000 mg/L	MEDIUM
TDS above 3000 mg/L	LOW

In addition, the software asks the user if a regional contaminant (such as nitrate) is above the MCL (either secondary or primary). If it is, then the Resource Value is defined as being LOW. Examples of regional contaminants include nitrate, radium, coliform, and some wide-scale man-made contaminants (wide-scale means not from a particular site of interest). In many cases, the regional contaminant will come from diffuse non-point sources rather than from a particular site.

The Resource Value addresses the potential of usage for that aquifer, and considerations regarding the aquifer proximity to surface water bodies or other discharge points to another unit are addressed in other sections of the toolkit.

The final Resource Value is the lower of the two usability criteria unless the answer to question 4 is "yes," in which case the software automatically upgrades the value to at least a MEDIUM.

RESOURCE TO SUPPORT NATURAL SYSTEMS

Many of the criteria above are related to drinking water supply issues. For the purposes of this general planning software, the software development committee is assuming that resource value related to water supply issues will be a good estimate in most cases for the value of a water-bearing unit to natural systems.

RECEPTOR VULNERABILITY

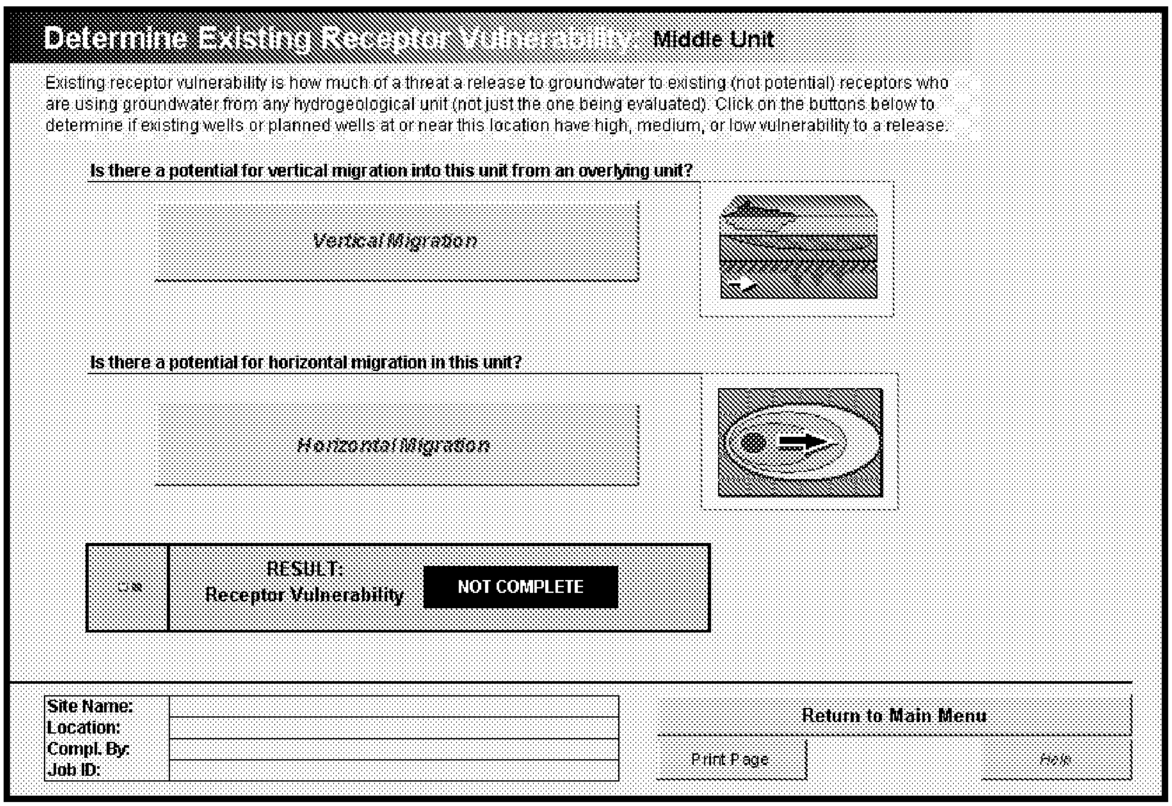
The Receptor Vulnerability section addresses the impact of a release to groundwater to existing (not potential) receptors that are using groundwater from any hydrogeological unit. An aquifer may be affected by horizontal migration of a contaminant to the extraction point, or by vertical migration from a shallower unit.

Two key points are:

1. Analysis of vertical vulnerability will not be needed for the shallowest water-bearing unit, as there is no water-bearing unit above it.

2. The main receptor vulnerability screen allows the user to start with either vertical or horizontal vulnerability, but it is recommended that the user begin by addressing vertical vulnerability first, if there is an upper water-bearing unit above the water-bearing unit of interest.

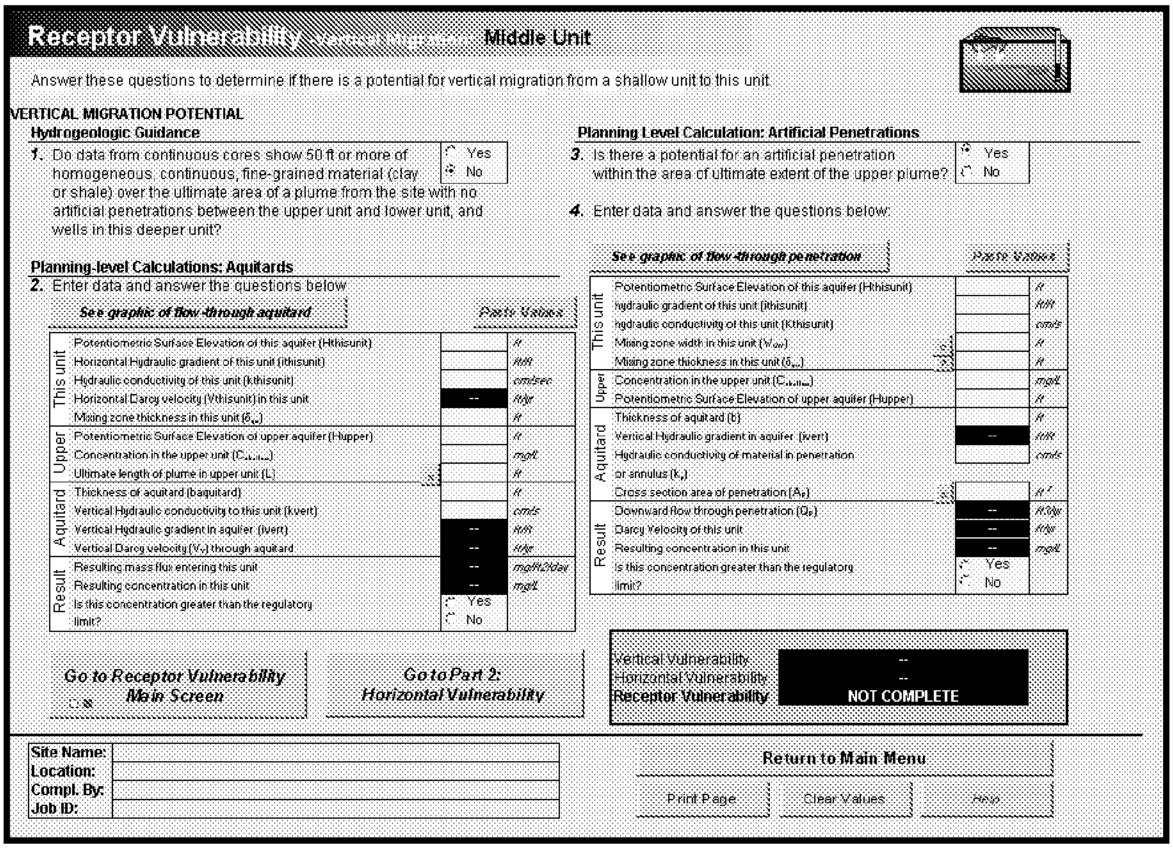
Note that this has been designed by the software development committee to be a conservative analysis and will tend to over predict the risk to existing receptors from an actual or potential release from the site of interest.



VERTICAL VULNERABILITY

The Vertical Vulnerability section addresses the potential for the vertical migration of contaminants from a shallower water-bearing unit to the unit of interest. The toolkit addresses the case in which groundwater from an upper aquifer can seep through an aquitard (confining layer) or an artificial penetration to affect the water-bearing unit of interest. Factors that are related to how easily contaminants can travel through the vadose (unsaturated) zone are handled in the Natural Sensitivity section of the software.

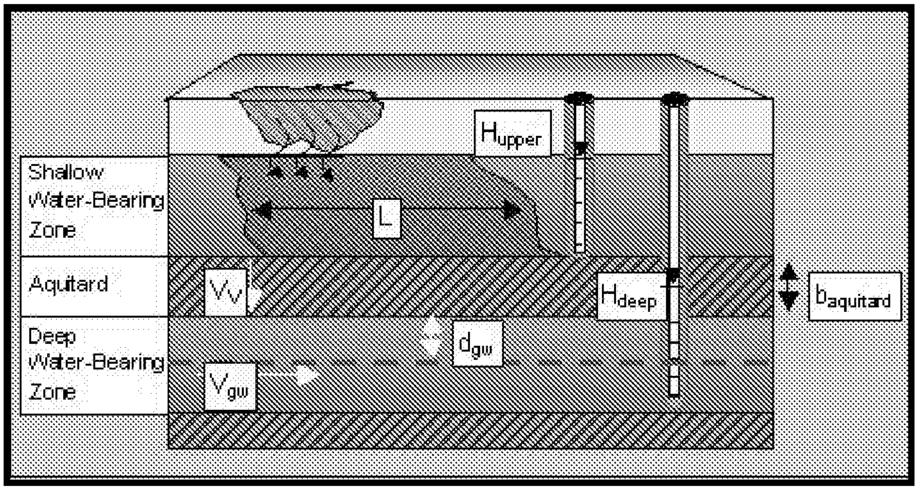
The vertical transport section examines transport occurring in the following scenario: The unit of interest may receive contaminated groundwater from an upper water-bearing unit by either: 1) groundwater flow through an aquitard or through an artificial penetration (such as an inadequately sealed well or a well that has been screened across multiple units).



Four main questions are asked in this section. Questions 1 and 3 are general questions regarding the possibility of transport via aquitard transport or artificial penetration, respectively. Questions 2 and 4 provide the user with supporting calculations to determine if the aquifer could be negatively impacted by a release to an upper unit through aquitard transport or artificial penetration. The user should understand that a "no" answer for either 1 or 3 determine if the calculations in 2 or 4, respectively, are performed.

Aquitards

A contaminant in an upper water-bearing unit may reach a lower water-bearing unit by transport through an aquitard.

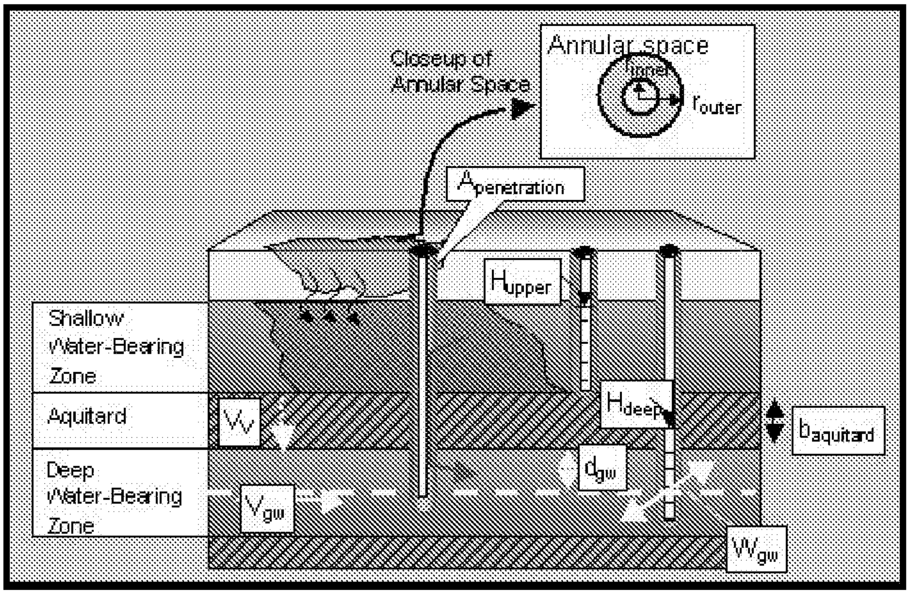


The first question is designed to rule out potential transport through aquitards if there is strong hydrogeologic/stratigraphic information that the aquitard is likely to prevent vertical transport to this water-bearing unit. The second question provides a quantitative tool to estimate the resulting concentration in this water-bearing unit after groundwater migrating from the upper water-bearing unit through the aquitard mixes with groundwater in this water-bearing unit. This calculation is based on potentiometric level, aquifer thickness, concentration in the contaminated unit, mixing layer thickness, and ultimate length of plume in the upper unit. The equations used in this calculation may be viewed by clicking the "See graphic of flow-through aquitard" button.

Once the concentration has been calculated, the user may compare the lower unit concentration to the MCL or other relevant regulatory standard to answer Question 2. Mass flux information associated with transport through the aquitard is also provided.

Artificial Penetrations

A contaminant in an upper water-bearing unit may reach this water-bearing unit by flowing through an artificial penetration. Examples of artificial penetrations include poorly sealed wells or wells screened across units.

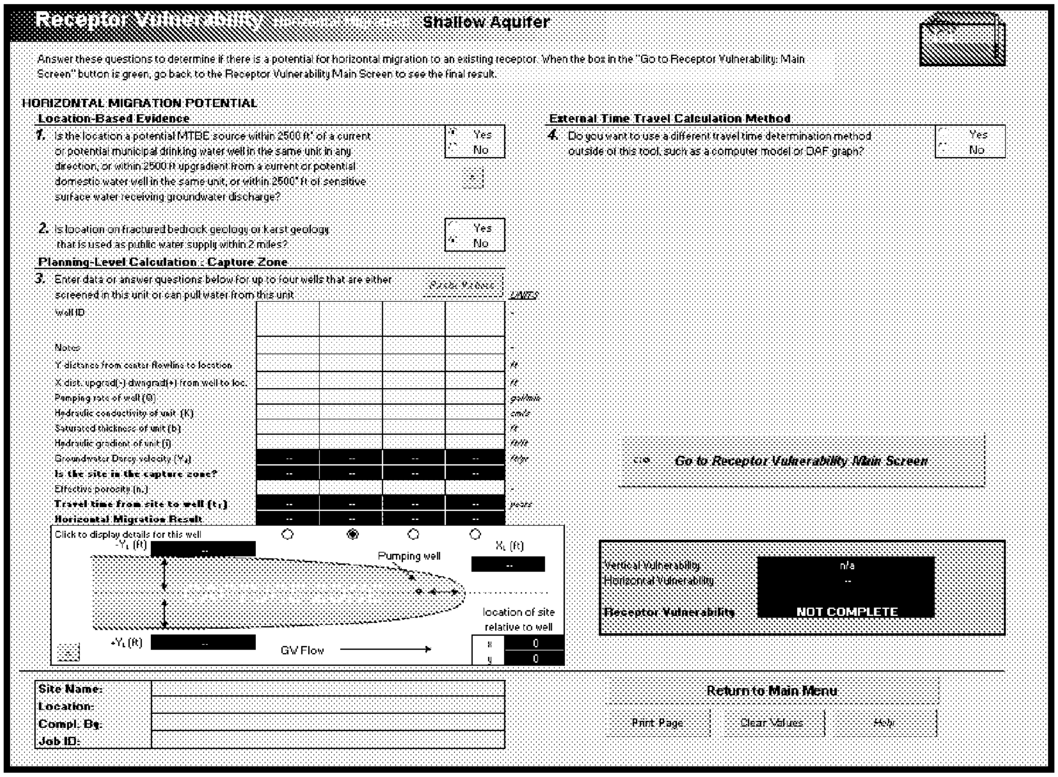


The third and fourth equations address the potential for contamination to flow through an artificial penetration to a lower unit. The fourth question calculates the concentration in the lower unit based on penetration cross sectional area, mixing zone, concentration, potentiometric level, and hydraulic conductivity. The equations used in this calculation may be viewed by clicking the "See graphic of flow-through penetration" button.

Once the concentration has been calculated, the user may compare the lower unit concentration to the MCL or other relevant regulatory standard to answer Question 4. Mass flux information associated with transport through the artificial penetration is also provided.

HORIZONTAL VULNERABILITY

Horizontal Vulnerability addresses the potential for horizontal migration from a site of interest to a well. The first two questions address the possibility of transport to a public water supply, while the remaining questions determine the capture zone and travel time to a water supply well in the vicinity of the site.



For Question 1, the software development committee has utilized a distance of 2500 ft to help users decide if there is a municipal water supply well or discharge point close enough to the site of interest that the well might be threatened by a potential release. To answer "yes" to Question 1, the well must be screened in the water-bearing unit that is being analyzed. If a discharge point is being considered, then the site of interest must be located upgradient of the discharge point. Note that 2500 ft is used as an example plume length for a recalcitrant compound. The user may elect to use 1200 ft if the constituent of concern is known to degrade significantly in groundwater or otherwise use a distance that represents the longest plume length for the constituent in concern in that area, assuming that the plume used for reference has stabilized.

For Question 2, the user should indicate if the site of interest is located near a fractured bedrock or karst water-bearing unit that is being used for a water supply. This question was adapted from California's "Guidelines for Investigation and Cleanup of MTBE and Other Oxygenates, 2001."

Question 3 permits the user to enter data for up to four wells to determine if a plume emanating from the site of interest lies within the capture zone of the well. The capture zone is determined individually for each well, and collective drawdown from a group of wells is not considered in this calculator. The user may view the capture zone for an individual well by clicking the radio buttons below the input column for that well.

Based on a methodology developed by the State of California (California EPA, Guidelines for Investigation and Cleanup of MTBE and Other Oxygenates, 2001), the software development committee developed the following table relating Receptor Vulnerability to travel time:

Travel Time from Release Location to Well	Horizontal Receptor Vulnerability
less than 5 years	HIGH
between 5 and 20 years	MEDIUM
more than 20 years	LOW

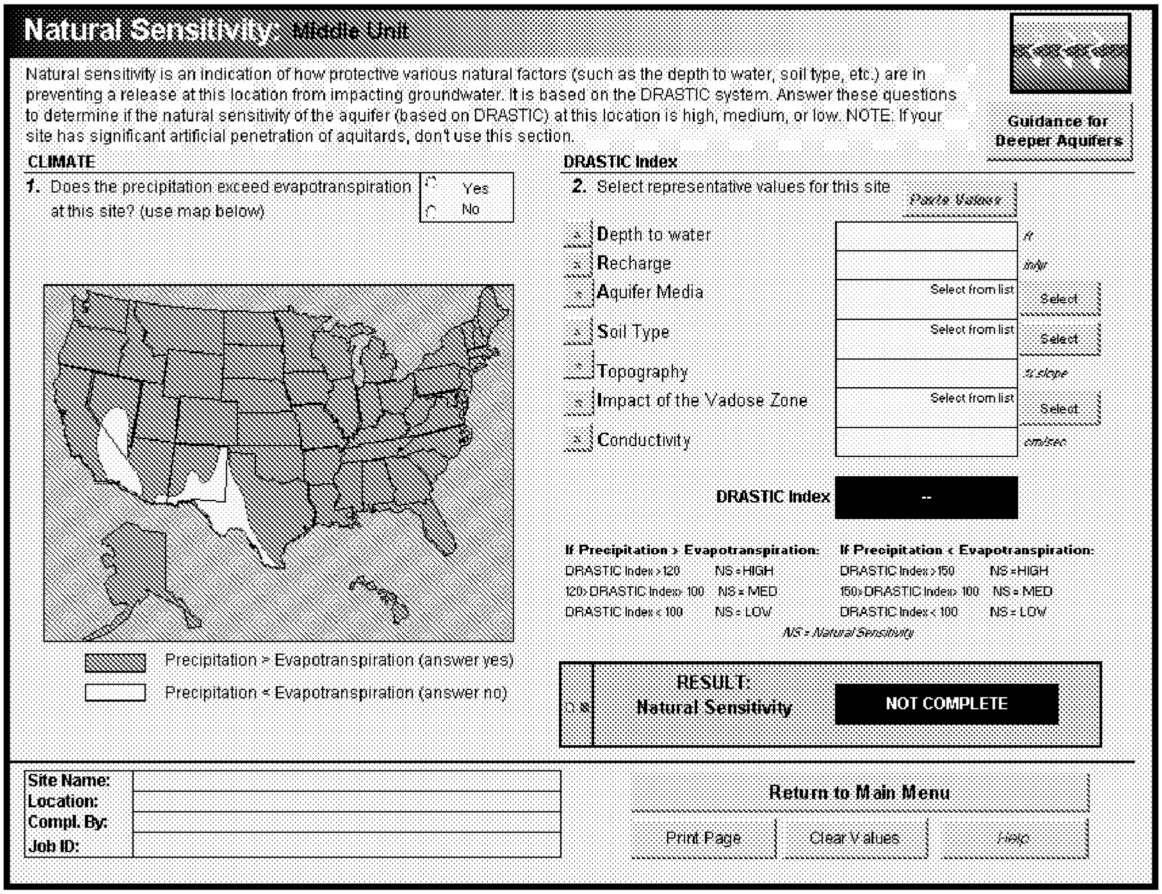
Users with more complex sites (interacting wells, complex hydrogeology, etc) may wish to use their own method outside of this toolkit to determine travel time. For these users, answer "yes" to Question 4, fill in the name of the method, and answer Question 5. Inputs to this section override the travel time calculator in Question 3.

CALCULATING RECEPTOR VULNERABILITY SCORE

The Receptor Vulnerability score is determined by the combination of the vertical and horizontal vulnerability. For the shallow layer, the receptor vulnerability is equal to the horizontal vulnerability. For deeper units, the receptor vulnerability is equal to the horizontal vulnerability only if the vertical vulnerability is either MEDIUM or HIGH. For an aquifer with a LOW vertical vulnerability, the overall receptor vulnerability is also LOW.

NATURAL SENSITIVITY

Natural Sensitivity addresses the effectiveness of natural factors (such as the depth to water, soil type, etc.) in preventing a release at this location from impacting groundwater. The Natural Sensitivity value is based on the DRASTIC Index, which is a system developed by the EPA to "create a standardized system which can be used to evaluate groundwater pollution potential." The definitions and descriptions used in this section, as well as the calculation method, were obtained from *DRASTIC: A Standardized System for Evaluating Ground Water Pollution Potential Using Hydrogeologic Settings*, EPA-600/2-87-035, April 1987.



DRASTIC was developed with four major assumptions:

1. The contaminant is introduced at the ground surface.
2. The contaminant is flushed into the groundwater by precipitation.
3. The contaminant has mobility equal to water.
4. The area being evaluated is 100 acres or larger.

The first question asks if the precipitation exceeds transpiration at the site. This question can be answered either through historical knowledge regarding rainfall and vegetative cover, or by looking at the provided map that gives general regions of precipitation/evapotranspiration ratios.

The second question, in seven parts, asks for various site parameters to calculate a DRASTIC index for the site. The DRASTIC index is calculated by assigning a weight to each site parameter, then multiplying the DRASTIC rating for that parameter by its weight. The final score is calculated by adding all the weighted ratings. Several parameters have a "Select" button located to the right of the input cell. The user should click the Select button for that parameter to choose the correct input from a list of options.

DEPTH TO WATER

Depth to water determines the depth of material through which a contaminant must pass prior to reaching the water-bearing unit. Greater depth of material allows more opportunities for attenuation factors, such as biodegradation or adsorption, to prevent a contaminant from entering the aquifer. For confined water-bearing units, this depth corresponds to the depth of the base of confining unit. The developers of DRASTIC derived the following ranking system for depth to water:

Depth to Water (feet)	Rating
0-5	10
5-15	9
15-30	7
30-50	5
50-75	3
75-100	2
100+	1
Weight	5

RECHARGE

Net recharge represents the amount of water per unit area of land that penetrates the ground surface at the location of the potential release (not at a recharge zone that is miles away). Recharge water is available to transport a contaminant vertically. The DRASTIC system does not take into account any dilution effects of recharge and assumes that the greater the recharge, the greater the potential for groundwater pollution. For confined units, recharge is assumed to represent the amount of recharge entering the confined unit from above, (i.e., through the confining unit) and will in most cases be very low (in other words do not use the recharge from a distant recharge zone). The developers of DRASTIC derived the following ranking system for recharge:

Recharge (inches per year)	Rating
0-2	1
2-4	3
4-7	6
7-10	8
10+	9
Weight	4

AQUIFER MEDIA

Aquifer media refers to the type of material that comprises the water-bearing unit. In general, the larger the grain size and/or the more fractures or openings within the water-bearing unit, the higher the permeability and the higher the potential for contaminant transport. The developers of DRASTIC defined and rated the following aquifer media types as follows:

Aquifer Media	Rating
Massive Shale	3
Metamorphic/Igneous	3
Weathered Metamorphic/Igneous	4
Glacial Till	5
Bedded Sandstone, Limestone and Shale Sequences	6
Massive Sandstone	6
Massive Limestone	6
Sand and Gravel	8
Basalt	9
Karst Limestone	10
Weight	3

The user may select the soil type by clicking the Select button next to the Aquifer Media input cell.

SOIL TYPE

Soil media refers to the uppermost part of the vadose zone characterized by significant biological activity. This is generally considered to be the upper six feet of the strata. This zone can have a significant impact on the vertical transport from the surface to the aquifer. In DRASTIC, the pollution potential is largely affected by the amount of clay present. The developers of DRASTIC defined and rated the following soil types:

Soil Type (top 5 feet)	Rating
Thin or Absent	10
Gravel	10
Sand	9
Peat	8
Shrinking and/or Aggregated Clay	7
Sandy Loam	6
Loam	5
Silty Loam	5
Clay Loam	3
Muck	2
Nonshrinking and Nonaggregated Clay	1
Weight	2

The user may select the soil type by clicking the Select button next to the Soil Type input cell.

TOPOGRAPHY

Topography refers to the slope of the land surface. Topographies that permit a pollutant to run off and prevent infiltration are associated with a lower pollution potential. The developers of DRASTIC derived the following ranking system for topography:

Topography (percent slope)	Rating
0-2	10
2-6	9
6-12	5
12-18	3
18+	1
Weight	1

IMPACT OF THE VADOSE ZONE

The vadose zone is defined as the zone above the water table that is either unsaturated or discontinuously saturated. The type of media in this vadose zone has a significant impact on the various processes (such as attenuation, neutralization, filtration, and dispersion) that occur in the vadose zone. The developers of DRASTIC defined and rated the following vadose zone types:

Vadose Zone	Rating
Confining Layer	1
Silt/Clay	3
Shale	3
Limestone	6
Sandstone	6
Bedded Limestone, Sandstone, Shale	6
Sand and Gravel with significant silt and clay	6
Metamorphic/Igneous	4
Sand and Gravel	8
Basalt	9
Karst Limestone	10
Weight	5

The user may select the soil type by clicking the Select button next to the Vadose Zone input cell.

CONDUCTIVITY

Hydraulic conductivity refers to one factor that controls the ability of the aquifer materials to transmit water. In DRASTIC, high hydraulic conductivities are associated with higher pollution potential. The developers of DRASTIC derived the following ranking system for hydraulic conductivity:

Conductivity (gpd/ft^2)	Conductivity (cm/s)	Rating
1-100	$5*10^{-5}$ to $5*10^{-3}$	1
100-300	$5*10^{-3}$ to $1*10^{-2}$	2
300-700	$1*10^{-2}$ to $3*10^{-2}$	4
700-1000	$3*10^{-2}$ to $5*10^{-2}$	6
1000-2000	$5*10^{-2}$ to $9*10^{-2}$	8
2000+	$9*10^{-2}$ +	10
Weight		3

DRASTIC SCORE AND NATURAL SENSITIVITY RATING

The DRASTIC score is calculated by the formula:

$$\text{DRASTIC score} = (\text{rating}_{DTW} * \text{weight}_{DTW}) + (\text{rating}_{Recharge} * \text{weight}_{Recharge}) + (\text{rating}_{Aquifer\ Media} * \text{weight}_{Aquifer\ Media}) + (\text{rating}_{Soil\ Type} * \text{weight}_{Soil\ Type}) + (\text{rating}_{Topography} * \text{weight}_{Topography}) + (\text{rating}_{Vadose\ Zone} * \text{weight}_{Vadose\ Zone}) + (\text{rating}_{Conductivity} * \text{weight}_{Conductivity})$$

The software development committee for the Groundwater Sensitivity Toolkit assigns its own rating on top of the DRASTIC index for HIGH, MEDIUM, and LOW Natural Sensitivity, as shown below. This classification system was based on an EPA document that indicates in a summary of DRASTIC that aquifers with DRASTIC ratings > 150 are considered "highly vulnerable" by the EPA (U.S. EPA, Handbook of Groundwater and Wellhead Protection, EPA/625/R-94/001, Sept. 1994, pg. 112).

DRASTIC Index when precipitation is greater than evapotranspiration	DRASTIC Index when precipitation is less than evapotranspiration	Natural Sensitivity Rating
> 120	> 150	HIGH
100 - 120	100 - 150	MEDIUM
< 100	< 100	LOW

NATURAL SENSITIVITY RATING FOR DEEPER AQUIFERS

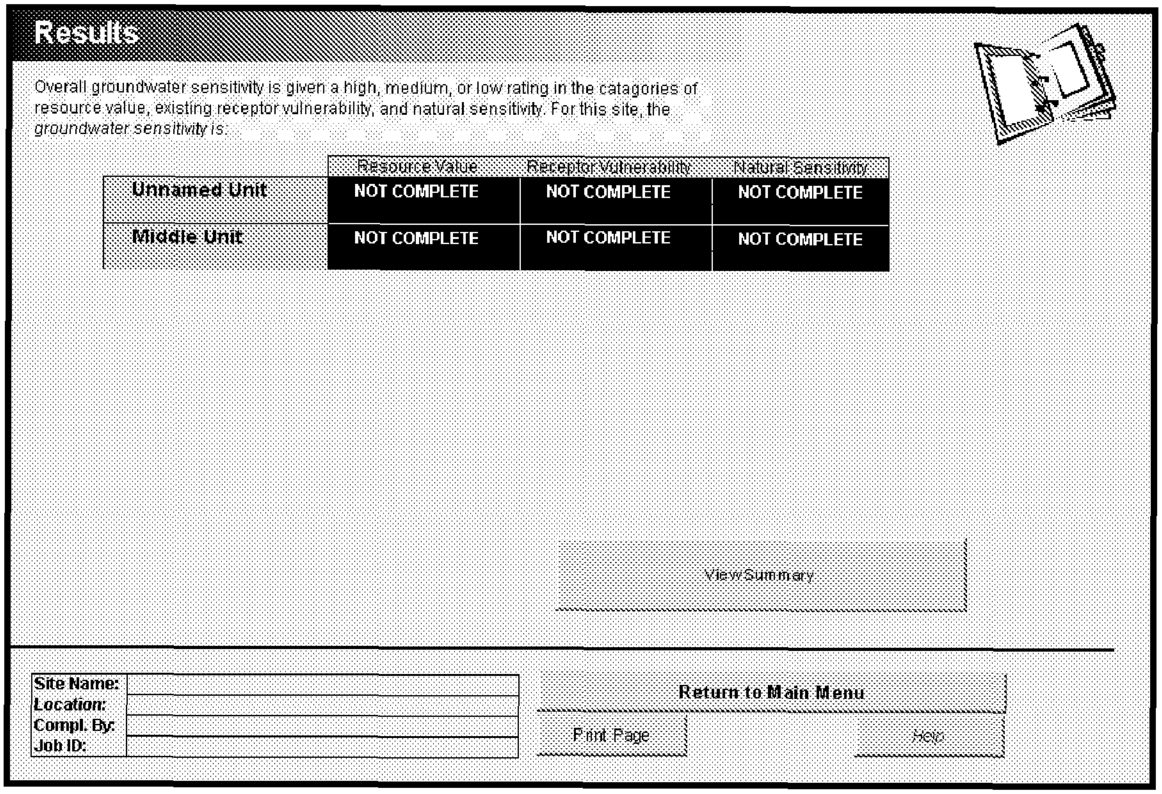
Natural sensitivity can be determined for deeper aquifers, but some additional considerations should be made for the following properties:

Recharge: A deeper aquifer may not receive as much recharge from surface precipitation.

Vadose Zone: A confined aquifer should use the "confined" vadose zone soil type.

SUMMARY

The results page shows the current ratings of all the units for the site. The user may visit the results page at any time during the process to view the site profile. The results values may be used to assist in determining potential use, evaluating risk, and allocating resources.



Clicking on the "View Summary" button will take the user to the summary page, where all of the input and output values are summarized. The summary displays the values for only one unit at a time, and the unit of interest may be switched by using the numbered buttons on the right hand side. The summary can be printed out for reference, but the values are for display only. To change the values, go to the appropriate section of the toolkit to change it.

CASE STUDY

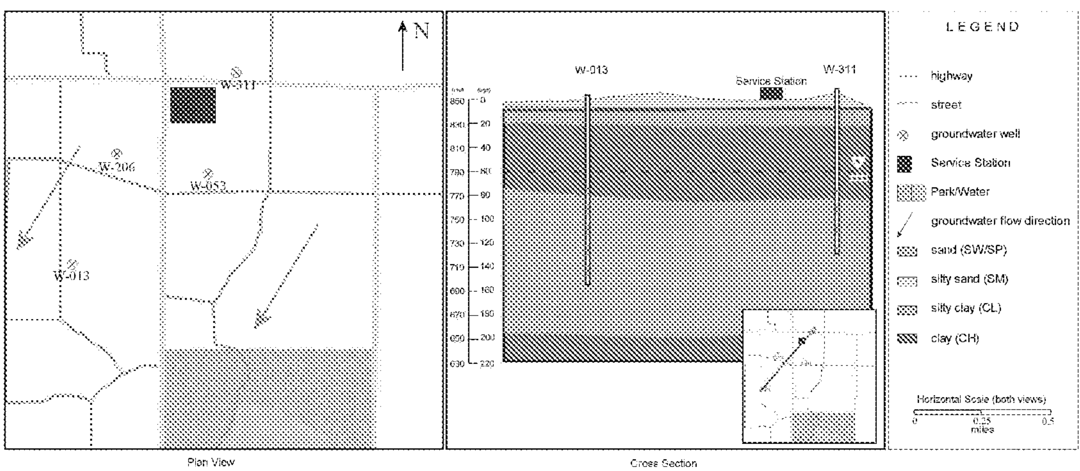
In this example, we will describe a site that can be classified using the Groundwater Sensitivity Toolkit. The data file for this case study is distributed with the toolkit and may be loaded for review. The name of the file is "casestudy.xls"

SITE DESCRIPTION

This site was originally established in 1972. It is a local service station located in a light suburban residential area. The residents of the city rely primarily on the municipal supply, although some maintain private wells.

Located in a region with two water bearing units, the first unit is located near the surface (between 845 and 820 msl or 5-30 feet bgs), while the second is located between 770 and 650 feet msl (80 and 200 feet bgs) and is separated from the upper unit by a silty clay unit. Groundwater flow in both aquifers is to the southwest.

In 1996, a storage tank leak occurred and a quantity of fuel was released. The affected soil was excavated, and there are no indications of a continuing source zone. Recent sampling of the upper sand aquifer measured the MTBE in the affected zone at 1.1 mg/L. Groundwater sampling indicates that the private wells in the area have not been affected by the release.



There are four private wells of concern in the neighborhood of the service station. All the private wells are drilled into the lower unit, and are owned by individuals who resided there prior to the existence of a municipal supply.

	Well 1	Well 2	Well 3	Well 4
Well ID	W-013	W-311	W-053	W-206
Notes	Private	Private	Private	Private
Y distance from site (ft)	100	250	500	500
X distance from site (ft)	4000	-50	500	1000
Pumping rate (gpm)	2	5	5	10
Well Diameter (in)	4	4	4	4
Borehole Diameter (in)	8	8	8	8
Fill material hydraulic conductivity (cm/s)	0.003	0.003	0.003	0.003

The *X* and *Y* well distances listed in the table are relative to the affected zone boundaries using the groundwater streamline as the *X* axis, and the distance perpendicular to the streamline as the *Y* distance. A negative *X* distance indicates that the well is upgradient of the site.

Here is a summary of the hydrogeologic characteristics of the site that will be used in the evaluation.

Upper Unit

Hydraulic conductivity	0.0005	cm/s
Aquifer thickness	25	Ft
Confining head	None. This is an unconfined unit	
Porosity	0.35	
Hydraulic Gradient	0.003	ft/ft
Depth to Water	5	Ft
Soil Type	Sand	
Aquifer Media Soil Type	Sand and Gravel	
Overlying Unit Soil Type	Sand and Gravel	
Recharge	8	in/yr
Topography	0	% slope
Aquifer Elevation	845 - 820	ft msl
Potentiometric Surface Elevation	845	ft msl
Total Dissolved Solids	2000	mg/L
Concentration in upper unit	1.1	mg/L
Ultimate plume length	1000	Ft

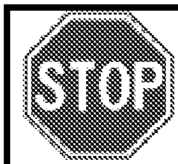
Aquitard

Hydraulic conductivity	0.0000005	cm/s
Aquifer thickness	50	Ft
Soil Type	Silty Clay	

Lower Unit

Hydraulic conductivity	0.005	cm/s
Aquifer thickness	120	Ft
Confining head	20	Ft
Porosity	0.35	
Hydraulic Gradient	0.001	ft/ft
Depth to Water	80	Ft
Soil Type	Sand	
Aquifer Media Soil Type	Sand and Gravel	
Overlying Unit Soil Type	Confining Layer	
Recharge	0	in/yr
Topography	1	% slope
Aquifer Elevation	770 - 650	ft msl
Potentiometric Surface Elevation	790	ft msl
Total Dissolved Solids	450	mg/L
Mixing Zone Width	50	Ft
Mixing Zone Thickness	10	Ft
Concentration in lower unit	0	mg/L

Having established the important features of the site, we can now begin our evaluation...



In the next section, we will describe the steps to follow to create a profile of this site in the Groundwater Sensitivity Toolkit. You can follow along with the discussion, or stop here and work on your own. You may then use the discussion to compare your answers.

CASE STUDY DISCUSSION

MAIN PAGE

In our case, we have two aquifer units, so answer "yes" to Question 2 and enter a name for the top unit and the deep unit in part 3. Upon naming the deep unit, several new buttons appear in the grey box in part 4. The subsequent sections of this chapter follow the six trails (represented by the six buttons that appear in part 4 that must be completed to develop a Sensitivity Profile for the site.

UPPER UNIT: Resource Value

Question 1) *Answer YES only if both of the following statements are true, otherwise, answer NO:*

a) Groundwater use at this location is precluded by some type of existing regulatory restriction.
b) There is no groundwater discharge to a high- or moderate-value surface water within 2500 ft of this location.

Answer: NO. This answer may be found by searching through public records.

Question 2) *Is the water-bearing unit a sole-source aquifer or does the unit serve an area with no alternative supply?*

Answer: NO. This is simply because the upper unit is not classified by EPA to be a sole-source aquifer.

Question 3) *Is the unit currently being used? (Are there any drinking water wells screened in the unit within 2500 ft?)(No if unknown)*

Answer: NO. All wells are screened into the lower unit, so there are no wells in the upper unit.

Question 4) *Is there a publicly available water development plan indicating that the aquifer will be used, or can it be reasonably anticipated to be used in the future?*

Answer: NO. This answer may be found by searching through public records.

Question 5)

Well Yield Calc□ulator□: U□pper Unit

Hydraulic conductivity	0.0005	cm/s
Aquifer thickness	25	ft
Confining head	0*	ft
WELL YIELD	3417	gpd
Resource value based on yield	**MEDIUM**	

*(this is an unconfined aquifer)

Water Quality Calculator

Total Dissolved Solids	2000	mg/L
Regional Contamination > MCL	NO	
Resource value based on quality	**MEDIUM**	

RESOURCE VALUE: MEDIUM

LOWER UNIT: Resource Value

Question 1) *Answer YES only if both of the following statements are true, otherwise, answer NO:*

a) Groundwater use at this location is precluded by some type of existing regulatory restriction.
b) There is no groundwater discharge to a high- or moderate-value surface water within 2500 ft of this location.

Answer: NO. This answer may be found by searching through public records.

Question 2) *Is the water-bearing unit a sole-source aquifer or does the unit serve an area with no alternative supply?*

Answer: NO, the unit is not classified by EPA as a "sole source" aquifer and there is an alternative supply.

Question 3) *Is the unit currently being used? (Are there any drinking water wells screened in the unit within 2500 ft?)(No if unknown)*

Answer: YES, the aquifer is being used.

RESOURCE VALUE: HIGH

UPPER UNIT: Receptor Vulnerability: Vertical Vulnerability

Vertical migration potential is not calculated for the uppermost unit.

UPPER UNIT: Receptor Vulnerability: Horizontal Vulnerability

Question 1) *Is the location a potential MTBE source within 2500 ft of a current or potential municipal drinking water well in the same unit in any direction, or within 2500 ft upgradient from a current or potential domestic water well in the same unit, or within 2500 ft of sensitive surface water receiving groundwater discharge?*

Answer: NO. This location is not a potential MTBE source, as there are no groundwater wells screened in this unit.

HORIZONTAL VULNERABILITY: LOW

In the uppermost unit, the receptor vulnerability is determined completely by the horizontal vulnerability.

RECEPTOR VULNERABILITY: LOW

LOWER UNIT: Receptor Vulnerability: Vertical Vulnerability

Question 1) *Do data from continuous cores show 50 ft or more of homogenous, continuous, fine-grained material (clay or shale) over the ultimate area of a plume from the site with no artificial penetrations between the upper unit and lower unit, and wells in this deeper unit?*

Answer: NO

Question 2) *Aquitard calculation*

Potentiometric level of this aquifer (H_{lower})	790	ft
Horizontal Hydraulic gradient of this unit	0.001	ft/ft
Hydraulic conductivity of this unit	0.005	cm/sec
Horizontal Darcy velocity in this unit	5.2	ft/yr
Mixing zone thickness in this unit	10	ft
Potentiometric level of upper aquifer	845	ft
Concentration in the upper unit	1.1	mg/L
Ultimate length of plume in upper unit	1000	ft
Thickness of aquitard	50	ft
Vertical Hydraulic conductivity to this unit	0.0000005	cm/s
Vertical Hydraulic gradient in aquifer	1.100	ft/ft
Vertical Darcy velocity through aquitard	0.57	ft/yr
Resulting mass flux entering this unit	0.04856	mg/L
Resulting concentration in this unit	1.00833	mg/ft^2/day
Is this concentration greater than the regulatory limit?	YES	

Question 3) *Is there a potential for an artificial penetration within the area of ultimate extent of the upper plume?*

Answer: YES

Question 4) *Artificial Penetration Calculation*

Potentiometric level of this aquifer	790	ft
Hydraulic gradient of this unit	0.001	ft/ft
Hydraulic conductivity of this unit	0.005	cm/s
Mixing zone width in this unit	50	ft
Mixing zone thickness in this unit	10	ft
Concentration in the upper unit	1.1	mg/L
Potentiometric level of upper aquifer	845	ft
Thickness of aquitard	50	ft
Vertical Hydraulic gradient in aquifer	1.100	ft/ft
Hydraulic conductivity of material in penetration or annulus	0.003	cm/s
Cross sectional area of penetration	0.262	ft^2
Downward flow through penetration	894	ft^3/yr
Darcy velocity of this unit	5.17	ft/yr
Resulting concentration in this unit	0.282	mg/L
Is this concentration greater than the regulatory limit?	YES	

VERTICAL VULNERABILITY: HIGH

Because the vertical vulnerability for this unit is HIGH, we must also calculate the horizontal vulnerability for this unit to determine the receptor vulnerability.

LOWER UNIT: Receptor Vulnerability: Horizontal Vulnerability

Question 1) *Is the location a potential MTBE source within 2500 ft of a current or potential municipal drinking water well in the same unit in any direction, or within 2500 ft upgradient from a current or potential domestic water well in the same unit, or within 2500 ft of sensitive surface water receiving groundwater discharge?*

Answer: YES. This site is a potential MTBE source.

Question 2) *Is location on fractured bedrock geology or karst geology that is used as public water supply within 2 miles?*

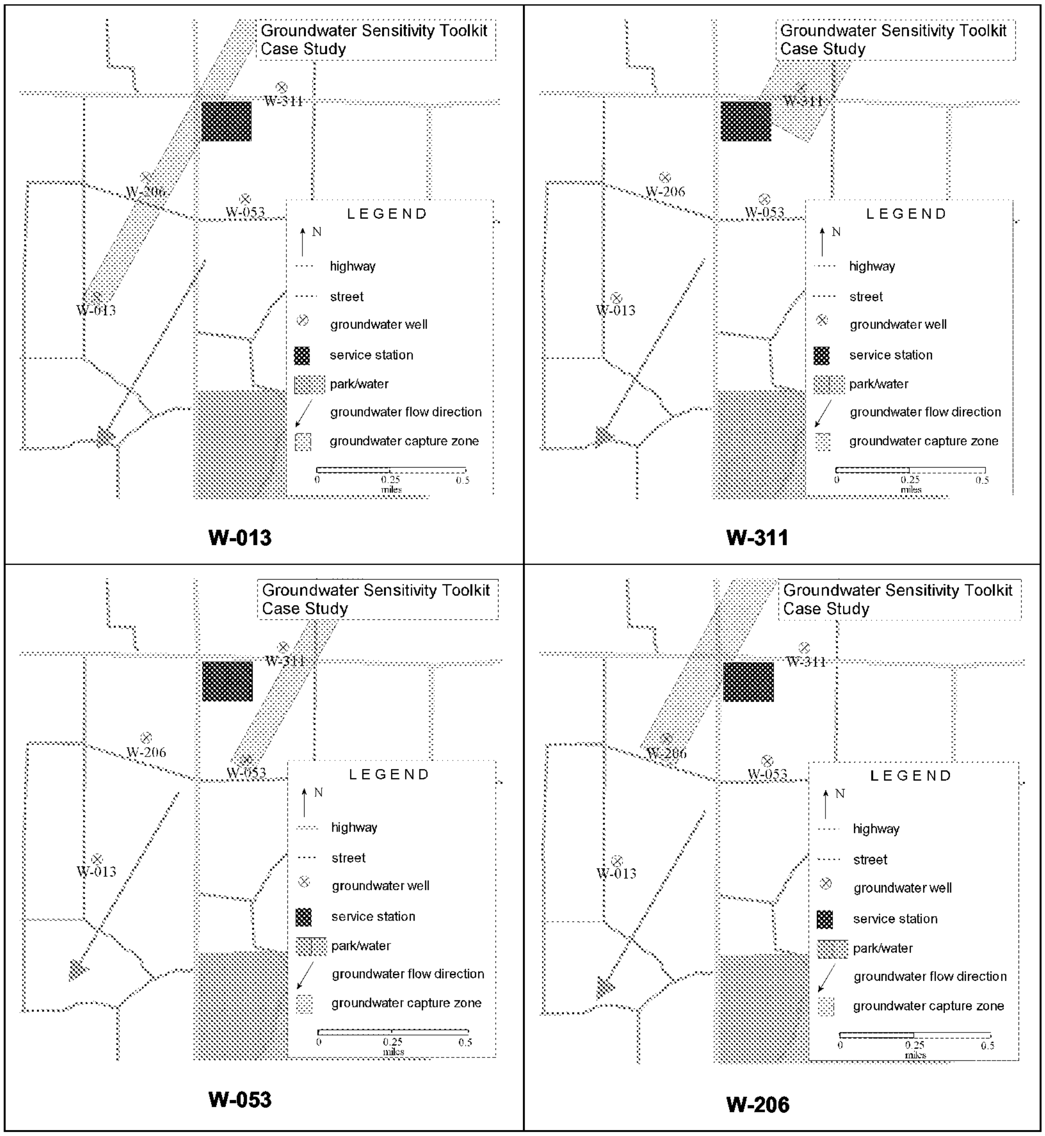
Answer: NO

Question 3) *Enter data for up to 4 wells.*

	Well 1	Well 2	Well 3	Well 4
Well ID	W-013	W-311	W-053	W-206
Notes	Private	Private	Private	Private
Y distance	100	250	500	500
X distance	4000	-50	500	1000
Pumping rate	2	5	5	10
Hydraulic conductivity of unit	0.005	0.005	0.005	0.005
Saturated thickness of unit	120	120	120	120
Hydraulic gradient of unit	0.001	0.001	0.001	0.001
Groundwater Darcy Velocity	5.2	5.2	5.2	5.2
Is the site in the capture zone	YES	YES	NO	YES
Effective porosity	0.35	0.35	0.35	0.35
Est. travel time from site to well	271.9	5.6	--	54.0
Horizontal Migration Result	LOW	MEDIUM	--	LOW
Capture Zone X*	36	90	90	180
Capture Zone Y*	113	283	283	566

* Click on the radio buttons to view the Capture Zone results.

The calculated capture zones are shown on the next figure. The capture zone is bound on three sides by the capture zone constraints, and extends infinitely upgradient of the well along the groundwater flow streamline.



Question 4) *Do you want to use a different travel time determination method outside this tool, such as a computer model or a DAF graph?*

Answer: NO

HORIZONTAL VULNERABILITY: MEDIUM

In this unit, the receptor vulnerability is completely determined by the horizontal vulnerability.

RECEPTOR VULNERABILITY: MEDIUM

UPPER UNIT: Natural Sensitivity

Question 1) *Does the precipitation exceed evapotranspiration at this site?*

Answer: YES

Question 2) *Selecting representative values for this site.*

Depth to water	5	ft
Recharge	8	in/yr
Aquifer Media	Sand and Gravel	
Soil Type	Sand	
Topography	0	% slope
Impact of Vadose Zone	Sand and Gravel	
Conductivity	0.0005	cm/sec
DRASTIC index	**177**	

NATURAL SENSITIVITY: HIGH

LOWER UNIT: Natural Sensitivity

Question 1) *Does the precipitation exceed evapotranspiration at this site?*

Answer: YES

Question 2) *Selecting representative values for this site.*

Depth to water	80	ft
Recharge	0	in/yr
Aquifer Media	Sand and Gravel	
Soil Type	Sand	
Topography	1	% slope
Impact of Vadose Zone	Confining Layer	
Conductivity	0.005	cm/sec
DRASTIC index	**74**	

NATURAL SENSITIVITY: LOW

RESULTS AND SUMMARY

The following table summarizes the results from the Groundwater Sensitivity Toolkit

	Resource Value	Receptor Vulnerability	Natural Sensitivity
Shallow Unit	MEDIUM	LOW	HIGH
Main Aquifer	HIGH	MEDIUM	LOW

GLOSSARY

These terms are used throughout the Groundwater Sensitivity Toolkit:

Aquifer	A water-bearing stratum consisting of either permeable rock, sand, or gravel.
Aquifer Thickness	Thickness of the zone of high hydraulic conductivity.
Aquitard	A zone of low hydraulic conductivity.
Artificial Penetration	A man-made opening through an aquitard, such as a well with an ungrouted or poorly grouted annulus or a well screened across two units.
Capture Zone	The area of a water-bearing unit where water will eventually be drawn into and extracted by a particular pumping well. The dimensions of the capture zone are determined by the pumping rate in combination with aquifer characteristics, such as hydraulic conductivity, gradient, and the screened interval for the well. In this software, the capture zone is assumed to be rectangular in shape.
Darcy Velocity	The velocity of a liquid through a porous media. The product of the hydraulic conductivity and the hydraulic gradient.
DRASTIC	A standard system developed by EPA to evaluate groundwater pollution potential.
DTW	Depth to water, measured as below ground surface (BGS).
Evapotranspiration	Transport of water from liquid to vapor phase due to evaporation, or by the respiratory action of plants (transpiration).
Horizontal Hydraulic Gradient	Measure of slope of the water table or piezometric surface. Hydraulic gradients can have significant seasonal variations, which should be considered when evaluating the receptor vulnerability for a site.
Hydraulic Conductivity	A measure of the permeability of a water-bearing unit.
MCL	Maximum Contaminant Level. Generally refers to a federal drinking water standard.
Mixing Zone Width	The width of the aquifer where water from the clean aquifer mixes with affected water coming down vertically from an artificial penetration. One approach is to use either 1) the capture zone width of a water supply well in the aquifer, or 2) a default value of 20 to 50 ft.

Mixing Zone Thickness	For Evaluating Transport Through Aquitards: The depth that recharge water from an overlying aquitard penetrates into an aquifer. One approach to estimating this value is to use the length of typical water supply well screens (10 to 50 ft). A second approach is use values used for mixing of leachate in Risk-Based Corrective Action models (typically 6 ft). For Evaluating Transport Through Artificial Penetrations: The depth that water moving vertically downward through an artificial penetration will mix with water in the clean aquifer. A typical value is to assume that the mixing depth is equivalent to either the length of typical water supply well screens (10 to 50 ft) or the length of the artificial penetration in the clean aquifer.
Natural Sensitivity	Effectiveness of natural factors (such as the depth to water, soil type, etc.) in preventing a release from impacting groundwater.
Porosity (effective)	The ratio of the pore volume where the water can circulate to the total volume of a representative sample of the medium.
Publicly Available	A plan developed by a planning agency, regulatory agency, or private water development company for the future use of a groundwater resource.
Receptor Vulnerability	The vulnerability of an existing groundwater receptor (including surface water bodies) to a potential contaminant source.
Recharge	In this application, the rate of infiltration from the surface directly above the potential source of contamination.
Regional Contamination	A chemical consistently found in groundwater in that region, typically due to a non-point source. Examples are nitrate, naturally occurring radioactive materials (NORM) and regional chlorinated solvent plumes.
Regulatory Restriction	An official restriction, such as an ordinance prohibiting pumping of groundwater.
Resource Value	Potential an aquifer has for becoming a usable water supply for people or ecological receptors.
Saturated Thickness	The average depth interval of the water that is saturated with water.
TDS	Total Dissolved Solids.
Ultimate Length of Plume	The maximum length that the plume can be anticipated to reach.
Vadose Zone	The unsaturated region above the groundwater level.

Vertical Hydraulic Gradient The hydraulic gradient is the vertical direction across an aquitard.

Well Yield Maximum rate that groundwater can be produced from a well.

EQUATIONS

These following calculations are performed in the toolkit.

Well Yield (from TNRCC, 2001)

Confined Aquifers

$$\text{Well Yield} = \frac{115846 * K * b * H_c}{10.2 + \text{Log}(K*b)}$$

Unconfined Aquifers

$$\text{Well Yield} = \frac{57923 * K * b^2}{7.2 + \text{Log}(K*b)}$$

Where:

Well Yield = Well Yield (gpd)

H_c = Confining head (ft)

K = Hydraulic conductivity of water-bearing unit (cm/s)

b = Saturated thickness of water-bearing unit (ft)

Capture Zone

$$Y_L = \frac{X_L * 2 * 3.14}{2}$$

$$X_L = \frac{Q * 12 * 2.54}{2 * 7.48 * 60 * 3.141 * K * b * i}$$

Where:

Y_L = Upper-range estimate for distance perpendicular to groundwater flow from pumping well to farthest point that will be captured (ft)

X_L = Upper-range estimate for downgradient distance from pumping well to farthest point that will be captured (ft)

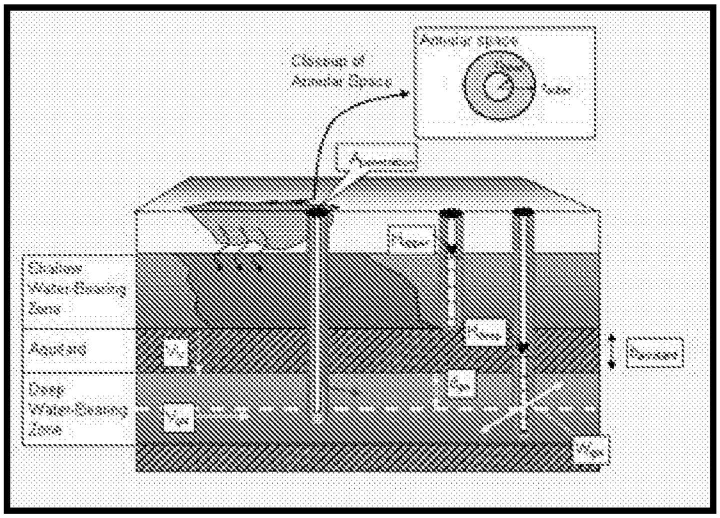
Q = Pumping rate from water supply well (gal/min)

K = Hydraulic conductivity of water-bearing unit (cm/s)

b = Saturated thickness of water-bearing unit (ft)

i = Hydraulic gradient of water-bearing unit (ft/ft)

Artificial Penetration Calculations



Calculated Concentration in the Deep Aquifer

$$C_{deep} = C_{shallow}\,[Q_{penetration}/((V_{gw})(\delta_{gw})(W_{gw})+Q_{penetration})]$$

Where:

C_{deep}	=	Calculated concentration in deeper unit (mg/L)
$C_{shallow}$	=	Representative concentration in upper unit (use typical or average concentration for entire plume) (mg/L)
V_{gw}	=	Groundwater Darcy velocity in deeper unit (ft/yr)
δ_{gw}	=	Groundwater mixing zone thickness in deep unit (ft)
W_{gw}	=	Mixing zone width perpendicular to groundwater flow in deeper unit (ft)
$Q_{penetration}$	=	Flowrate through penetration (ft^3/yr)

Flow Through Artificial Penetration

$$Q_{penetration} = (K_{penetration})(i_{vert})(A_{penetration})*1035354$$

Where:

$Q_{penetration}$	=	Flowrate through penetration (ft^3/yr)
$K_{penetration}$	=	Hydraulic conductivity of material in artificial penetration (cm/s)
i_{vert}	=	Vertical hydraulic gradient in aquitard (ft/ft)
$A_{penetration}$	=	Cross-sectional area of penetration (ft^2)

Vertical Gradient

$$i_{vert} = [(H_{upper} - H_{lower})/b_{aquitard}]$$

Where:

i_{vert}	=	Vertical hydraulic gradient in aquitard (ft/ft)
H_{upper}	=	Potentiometric elevation of upper unit (ft)
H_{lower}	=	Potentiometric elevation of lower unit (ft)
$b_{aquitard}$	=	Thickness of aquitard (ft)

Area of Artificial Penetration

$$A_{penetration} = \pi r^2$$

Where

$A_{penetration}$	=	Cross sectional area of artificial penetration (ft^2)
r	=	Radius of artificial penetration (ft)

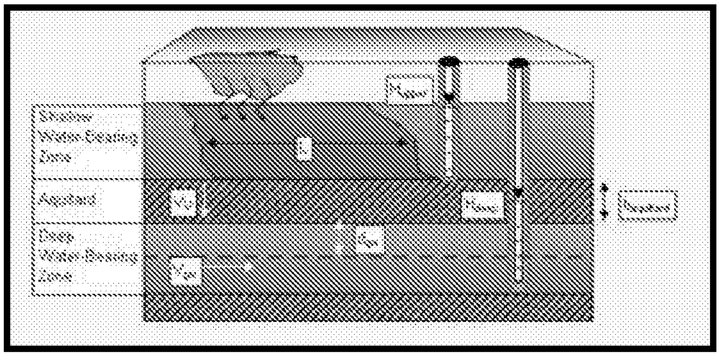
If annulus

$$A_{penetration} = \pi(r_{outer}^2) - \pi(r_{inner}^2)$$

Where:

$A_{penetration}$	=	Cross sectional area of artificial penetration (ft^2)
r_{outer}	=	Radius to outside of annular space (ft)
r_{inner}	=	Radius to inside of annular space (ft)

Aquitard Calculations



Calculated Concentration in the Deep Aquifer

$$C_{deep} = C_{shallow}\ [(V_v{*}L)/((V_{gw}{*}\delta_{gw})+(V_v{*}L)]$$

Where:

C_{deep}	=	Calculated concentration in deeper unit (mg/L)
$C_{shallow}$	=	Representative concentration in upper unit (mg/L)
V_{gw}	=	Groundwater Darcy velocity in deeper unit (ft/yr)
V_v	=	Groundwater Darcy velocity in aquitard (ft/yr)
δ_{gw}	=	Groundwater mixing zone thickness in deep unit
L	=	Ultimate length of plume in upper unit parallel to groundwater flow (ft)

Vertical and Horizontal Groundwater Velocity

$$V_{gw} = (K_{deep})(i_{deep})$$

$$V_v = (K_{vert})(i_{vert})$$

Where:

V_{gw}	=	Groundwater Darcy velocity in deeper unit (ft/yr)
V_v	=	Groundwater Darcy velocity in aquitard (ft/yr)
K_{deep}	=	Horizontal hydraulic conductivity in deep unit (cm/sec)
K_{vert}	=	Vertical hydraulic conductivity of aquitard (cm/sec)
i_{deep}	=	Horizontal hydraulic gradient in deep unit (ft/ft)
i_{vert}	=	Vertical hydraulic gradient in aquitard (ft/ft)

Vertical Hydraulic Gradient

$$i_{vert} = (H_{upper} - H_{deep})/b_{aquitard}$$

Where:

i_{vert}	=	Vertical hydraulic gradient in aquitard (ft/ft)
H_{upper}	=	Potentiometric surface of upper water-bearing unit (ft)
H_{deep}	=	Potentiometric surface of deep water-bearing unit (ft)
$b_{aquitard}$	=	Thickness of aquitard (ft)

Mass Flux Through an Aquitard to a Lower Unit

$$\text{flux} = (V_v * C_{shallow}) * (28.31 / 365.25)$$

Where:

flux	=	mass flux into the lower unit (mg/(ft^2 day))
V_v	=	Vertical Darcy Velocity (ft/yr)
$C_{shallow}$	=	Concentration in the upper unit (mg/L)

Estimated Resource Value

If C_{deep} < regulatory limit, then $ERV_{vert\text{-}aqtd}$ = LOW

If C_{deep} > regulatory limit, then $ERV_{vert\text{-}aqtd}$ = HIGH

Where:

ERV	=	Estimated Resource Value
regulatory limit	=	Acceptable level of constituent in groundwater, such as an MCL or a risk-based concentration.
C_{deep}	=	Calculated concentration in deeper unit (mg/L)

Travel Time

$$T = \frac{(Y_l^{\,2} + X_l^{\,2})^{.5}}{K*1.03*10^6*i/\eta}$$

Where:

T	=	Travel time (years)
Y_L	=	Upper-range estimate for distance perpendicular to groundwater flow from pumping well to farthest point that will be captured (ft)
X_L	=	Upper-range estimate for downgradient distance from pumping well to farthest point that will be captured (ft)
K	=	Hydraulic conductivity (cm/s)
η	=	Porosity
i	=	Hydraulic gradient, calculated as the maximum value of either

1. The natural hydraulic gradient
2. The following calculated gradient, as defined by the artificial gradient between site and pumping well, accounting for the drawdown in pumping well

(Equations for drawdown in pumping well are from Groundwater and Wells, 1986, pg 1021.)

$$i = \frac{Q*2000/(K*21189*b)}{(Y_L^{\,2} + X_L^{\,2})^{.5}}$$

Where:

i	=	Hydraulic gradient (ft)
Q	=	Well pumping rate (gpm)
K	=	Hydraulic conductivity (cm/s)
b	=	Saturated thickness (ft)
Y_L	=	Upper-range estimate for distance perpendicular to groundwater flow from pumping well to farthest point that will be captured (ft)
X_L	=	Upper-range estimate for downgradient distance from pumping well to farthest point that will be captured (ft)

Approach: Use the seepage velocity and the distance between the site and the pumping well to estimate time. Use the maximum of these two estimates for seepage velocity:

1. Naturally occurring seepage velocity with no pumping (i = natural hydraulic gradient)
2. Seepage velocity based on hydraulic gradient between site and well

NOTATION

These terms are used throughout the Groundwater Sensitivity Toolkit.

Resource Value

Name	Units	Description
k	cm/s	Hydraulic conductivity
b	ft	Thickness
h_c	ft	Confining head
C_{TDS}	mg/L	Total Dissolved Solids concentration

Receptor Vulnerability - Vertical Migration

Name	Units	Description
$H_{this\ unit}$	ft	Potentiometric surface elevation of the current working unit
$i_{this\ unit}$	ft/ft	Hydraulic gradient of the current working unit
$k_{this\ unit}$	cm/s	Hydraulic conductivity of the current working unit
$V_{this\ unit}$	-	Darcy velocity of the current working unit
δ_{gw}	ft	Mixing zone thickness of the unit
H_{upper}	ft	Potentiometric surface elevation of the overlying water-bearing unit
$C_{shallow}$	mg/L	Average concentration in the shallow unit
L	ft	Ultimate length of plume in upper unit
$b_{aquitard}$	ft	Thickness of aquitard
k_{vert}	cm/s	Vertical hydraulic conductivity of unit
i_{vert}	ft/ft	Vertical hydraulic gradient in aquifer
V_v	ft/yr	Vertical Darcy velocity through aquitard
W_{gw}	ft	Mixing zone width in the unit
K_p	cm/s	Hydraulic conductivity of material in penetration or annulus
A_p	ft^2	Cross-sectional area of artificial penetration
Q_p	ft^3/yr	Well pumping rate

Receptor Vulnerability - Horizontal Migration

Name	Units	Description
k	cm/s	Hydraulic conductivity of the current working unit
i	ft/ft	Hydraulic gradient of the current working unit
Q	ft^3/yr	Well pumping rate
V_d	ft/yr	Groundwater Darcy velocity
n_e	-	Effective porosity
t_t	yr	Estimated travel time

Natural Sensitivity

Name	Units	Description
Depth to Water	ft	Depth to water determines the depth of material through which a contaminant must pass before reaching the water-bearing unit. Greater depth of material allows more opportunities for attenuation factors, such as biodegradation or adsorption, to prevent contaminant from entering the aquifer. For confined water-bearing units, this depth corresponds to the depth of the base of confining unit.
Recharge	in/yr	Net recharge represents the amount of water per unit area of land that penetrates the ground surface and reaches the water table. Recharge water is available to transport a contaminant vertically. The DRASTIC system does not take into account any dilution effects of recharge and assumes that the greater the recharge, the greater the potential for groundwater pollution. For confined units, recharge is assumed to represent the amount of recharge entering the confined unit from above, (i.e., through the confining unit) and will, in most cases, be very low (in other words do not use the recharge from a distant recharge zone).
Aquifer Media		Aquifer media refers to the type of material that comprises the water-bearing unit. In general, the larger the grain size and the more fractures or openings within the water-bearing unit, the higher the permeability and the higher the potential for contaminant transport.

Soil Type		Soil media refers to the uppermost part of the vadose zone characterized by significant biological activity. This is generally considered to be the upper six feet of the strata. This zone can have a significant impact on the vertical transport from the surface to the aquifer. In DRASTIC, the pollution potential is largely affected by the amount of clay present.
Topography	% slope	Topography refers to the slope of the land surface. Topographies that permit a pollutant to run off and prevent infiltration are associated with a lower pollution potential.
Impact of the Vadose Zone		The vadose zone is defined as the zone above the water table that is either unsaturated or discontinuously saturated. The type of media in this vadose zone has a significant impact on the various processes (such as attenuation, neutralization, filtration, and dispersion) that occur in the vadose zone.
Conductivity	cm/sec	Hydraulic conductivity refers to one factor that controls the ability of the aquifer materials to transmit water. In DRASTIC, high hydraulic conductivities are associated with higher pollution potential.

REFERENCES

Allen, L., et al., *DRASTIC: A Standardized System for Evaluating Ground Water Pollution Potential Using Hydrogeologic Settings*, EPA-600/2-87-035, April 1987.

Driscoll, F., *Ground Water and Wells*, 2nd Ed., Johnson Division, St. Paul, Minnesota. 1986.

California State Water Resources Control Board, "Guidelines for Investigation and Cleanup of MTBE and Other Ether-Based Oxygenates," FINAL DRAFT, www.swrcb.ca.gov/cwphome/ust/mtbe_finaldraft.pdf, 2000.

Texas Natural Resource Conservation Commission, "Procedures for Determination of Groundwater Resource Classification," RG-366/TRRP-8, TNRCC Regulatory Guidance Texas Risk Reduction Program (TRRP), Texas Natural Resource Conservation Commission, Austin, Texas, DRAFT, July 2001.

Johnson, P.C., R.J. Charbeneau, D. Abranovic, T. Hemstreet, *Graphical Approach for Determining Site-Specific Dilution-Attenuation Factors (DAFs): Technical Background and User's Guide*, API Publication 4659, American Petroleum Institute, Washington, D.C., 1998.

TROUBLESHOOTING

1) The buttons are out of proportion on the screen and seem to change size when I click them.

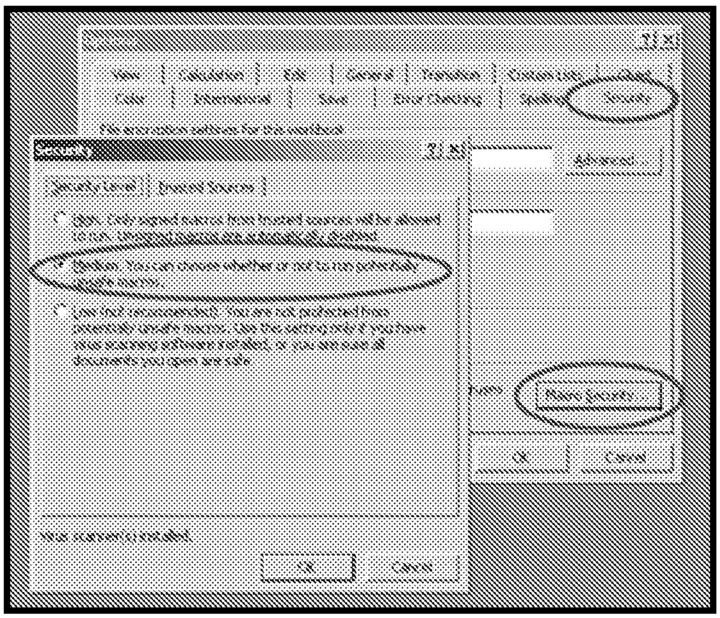
This problem occurs when the screen resolution is changed without restarting the computer. Try restarting the computer and starting the toolkit again.

2) None of the buttons work.

The toolkit was created using custom macros in Visual Basic for Applications (VBA). In order for the toolkit to work, you must have macros enabled. Microsoft Excel™ generally prompts this at startup.

The user should select "Enable macros."

Additionally, some users may have Excel™ set to High security, which disables the ability to run unsigned macros. The user may change the security setting by going to the selecting Tools > Options in Excel™ and then selecting the "Macro Security" button under the "Security" tab. It is suggested that the user select Medium security.



3) I cannot see the entire page. Can I resize the page?

The toolkit was optimized for use with a monitor set to 1024 x 786 or higher. For users with lower resolution monitors, the page may be resized by going to the View > Zoom.

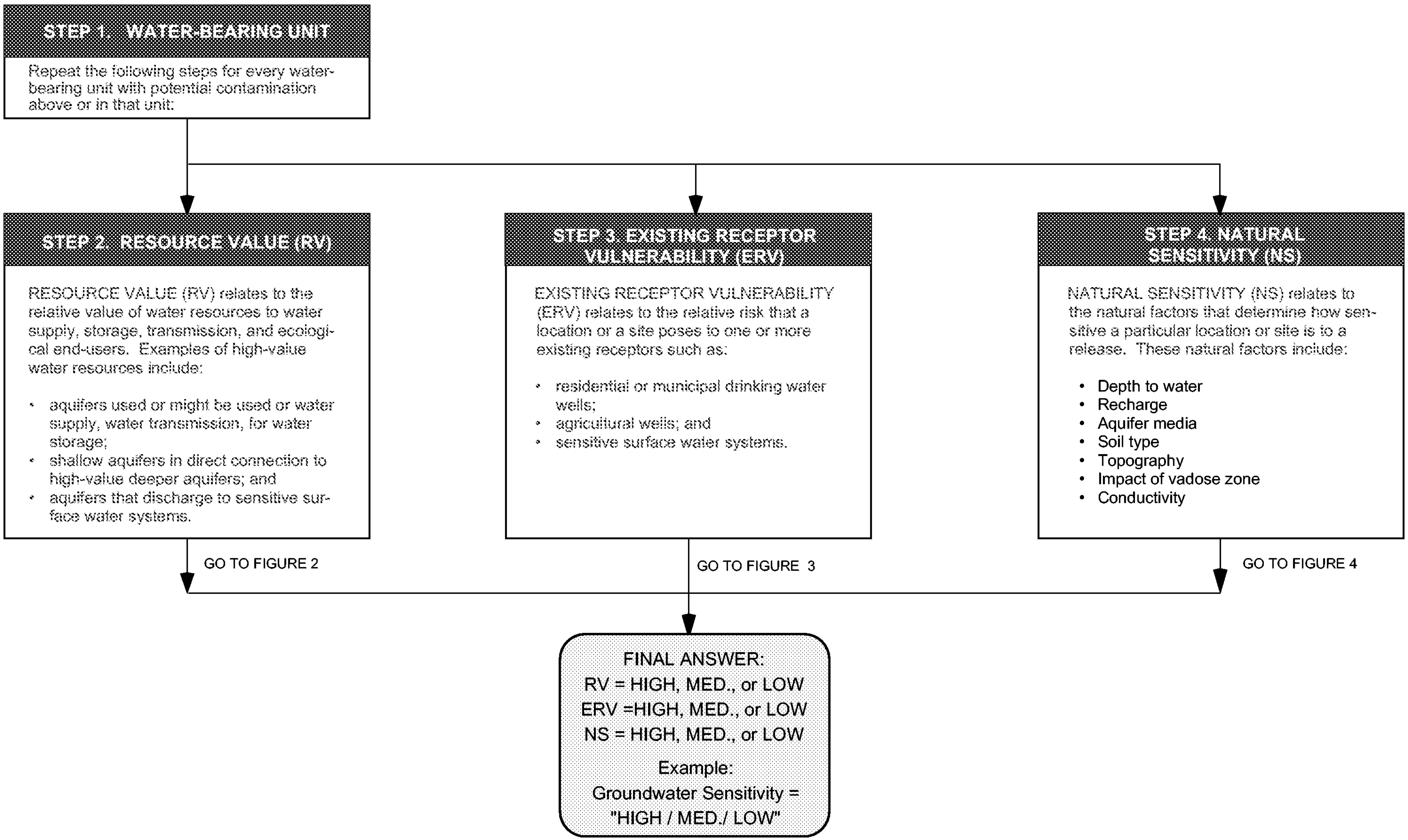
4) I cannot click on some cells. What is happening?

Not all cells in the toolkit are available for writing or selecting. This should not interfere with using the toolkit. If you are trying to enter a value into a cell that is available for writing, click into the cell, enter your value, then press "Enter" or "Tab" to go to the next cell.

APPENDIX A:

GROUNDWATER SENSITIVITY LOGIC DESIGN

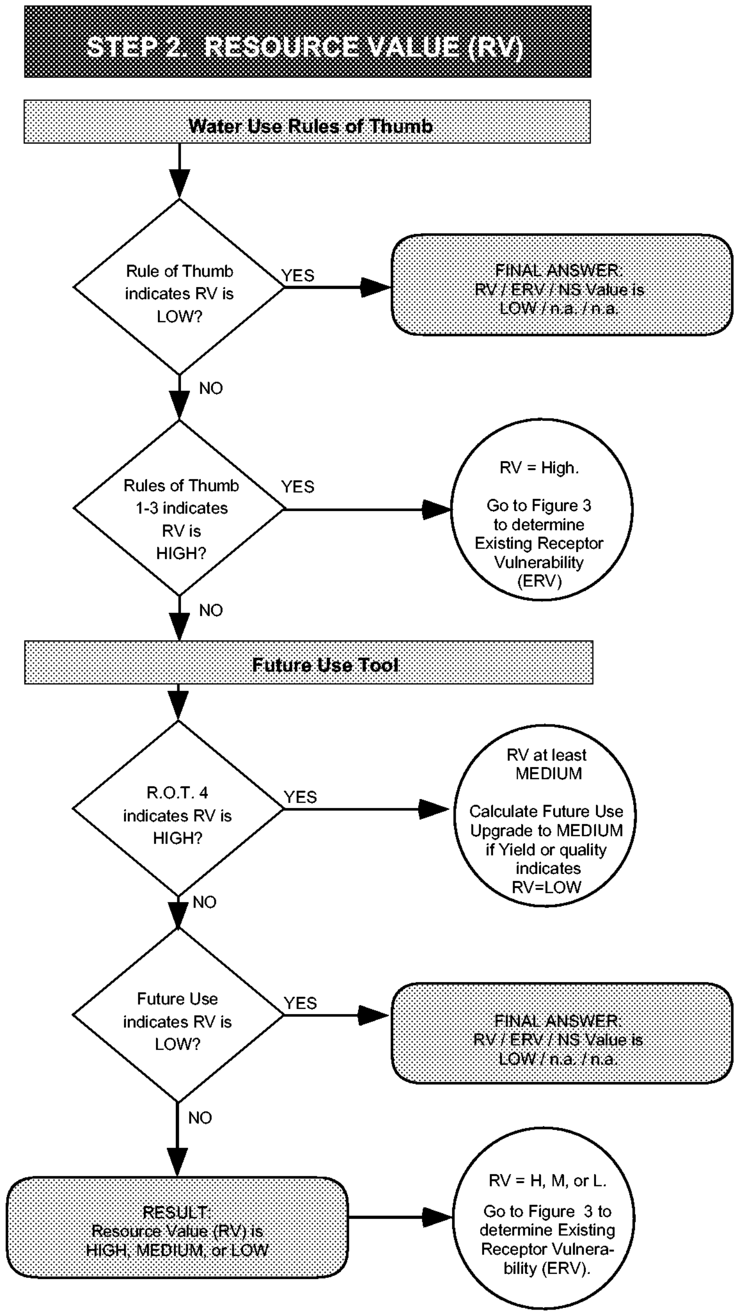
FIGURE 1
GROUNDWATER SENSITIVITY TOOLKIT FLOWCHART
API / California MTBE Research Partnership



Note: If Resource Value is LOW, Steps 3 and 4 default to "Not Applicable" (N.A.)

FIGURE 2
RESOURCE VALUE FLOWCHART FOR GROUNDWATER SENSITIVITY TOOLKIT

API / California MTBE Research Partnership



DETAILS

Water Use Rules of Thumb: DETAILS

Apply simple screening rules to identify Low or High RV.

R.O.T. 1:
Answer YES only if both of the following statements are true, otherwise, answer NO:
a) Groundwater use at this location is precluded by some type of existing regulatory restriction.
b) There is no groundwater discharge to a high- or moderate-value surface water within 2500 ft of this location.

R.O.T. 2:
Is the water-bearing unit a sole-source aquifer or does the unit serve an area with no alternative supply? (no, if unknown)

R.O.T. 3:
Is the unit currently being used? (Are there any drinking water wells screened in the unit within 2500 ft?) (no, if unknown)

Future Use Tool: DETAILS

R.O.T. 4:
Is there a publically available water development plan indicating that the aquifer will be used, or can it be reasonably anticipated to be used in the future?

Evaluate potential for future use of water based on well yield, quality, and water resource planning info.

Step 1.1: Determine Yield using simple well yield formulas based on hydr. conductivity, thickness, confining head of aquifer at location:

- Yield ^{2} 200 gpd*: *RVY*=LOW.
- 200 gpd* < Yield <144,000 gpd**: *RVY* = MED.
- Yield ^{3} 144,000 gpd**: *RVY* =HIGH.

Source of numerical values:
*** In Calif. GW Classification**
**** In TRRP GW Classification**

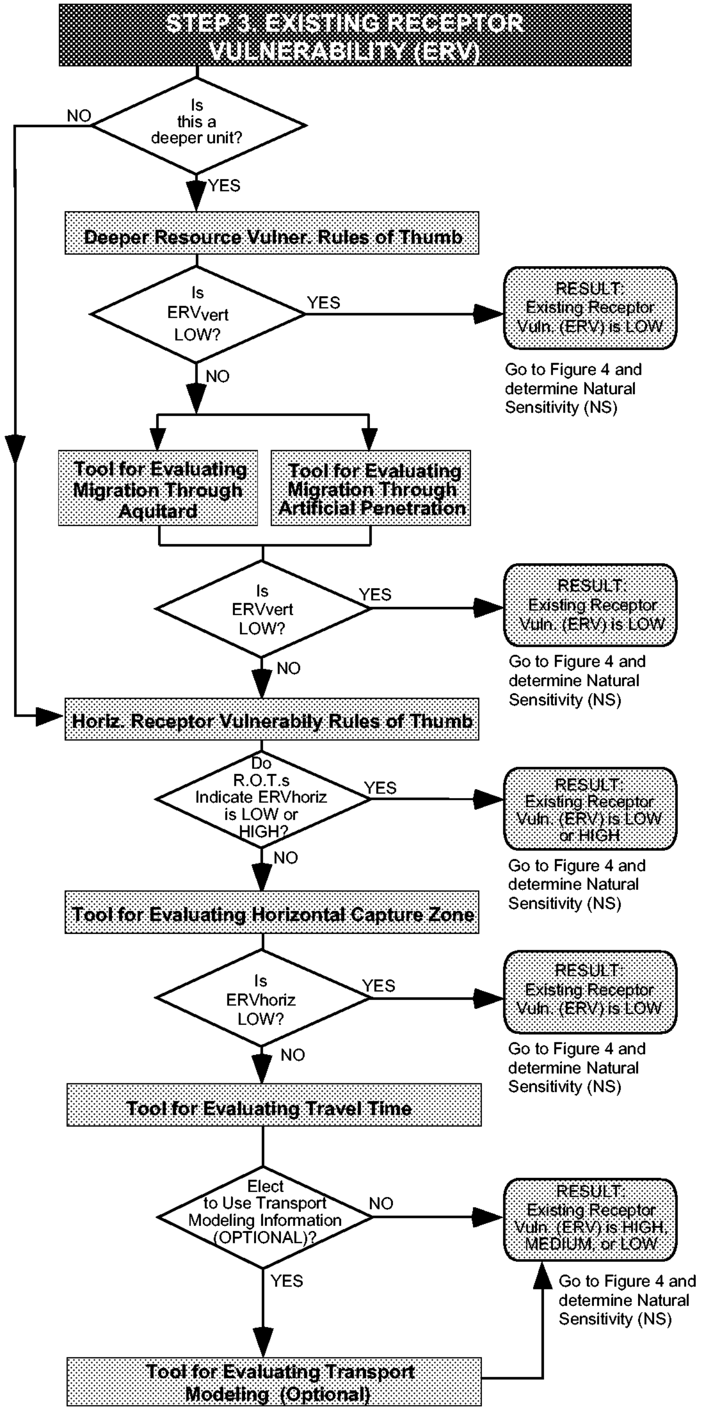
Step 1.2: Determine Water Quality using simple rules regarding TDS, other contaminants of groundwater at location:

- If TDS ^{3} 3,000*, RV_{wq}=LOW
- 500** < TDS<3,000*, RV_{wq}=MED.
- TDS ^{2} 500** mg/L, RV_{wq}=HIGH
  If other natural contaminants>MCL or secondary MCL, RV_{wq}=LOW

Step 1.3: Use lowest rank from Steps 1.1 and 1.2 for answer. For example, if RV_{wq} is HIGH, but RV_{Y} is LOW, final RV is LOW.

Step 1.4: (Must perform if Step 1.3 result is MED). Evaluate potential for future utilization of aquifer based on information/resources regarding: local, regional, and state waterplanning, water demand, replacement value for groundwater, treatment cost, alternative supplies. This module will discuss each item, and provide links/sources of information. Based on information, the user can designate can increase a MED ranking to HIGH if future utilization of the aquifer is planned or likely. (System will provide examples.)

FIGURE 3
EXISTING RECEPTOR VULNERABILITY FLOWCHART FOR GROUNDWATER SENSITIVITY TOOLKIT
API / California MTBE Research Partnership



DETAILS

Deeper Resource Vulner. Rules of Thumb: DETAILS

Use simple rule of thumb to estimate if vertical migration is possible.

Do data from continuous cores show 50 ft or more of homogeneous, continuous, fine-grained material (clay or shale) over the ultimate area of a plume from the site with no artificial penetrations between the upper unit and lower unit, and wells in this deeper unit? If yes, ERV_{vert} = LOW

Tool for Evaluating Migration Through Aquitard and/or Artificial Penetration: DETAILS

Use simple mixing algorithms to determine potential concentrations in deeper unit after mixing with groundwater from shallow unit.

Step 2.1: Estimate concentration of deeper unit after mixing with contaminants migrating through aquitard. Required parameters:
- Effective vert. *K*, thickness of aquitard, vert. gradient
- Velocity of deeper groundwater, mixing zone thickness
- Ultimate size, representative conc. of plume in upper zone,

If conc. in deeper unit < STD, $ERV_{vert\text{-}aqtd}$ = LOW.
If conc. in deeper unit > STD, $ERV_{vert\text{-}aqtd}$ = HIGH.
STD = MCLs or other water quality criteria

Step 2.2: Estimate concentration of deeper unit after mixing with contaminants migrating through an annulus or open well. Required parameters:
- Diameter, screened interval of well, or dimensions of annulus
- Downward gradient
- Velocity of deeper groundwater
- Size of plume in upper zone

If conc. in deeper unit < STD, $ERV_{vert\text{-}hole}$ = LOW.
If conc. in deeper unit > STD, $ERV_{vert\text{-}hole}$ = HIGH.

Step 2.3: Use highest rank from Steps 2.1 & 2.2 for answer.
For example, if $ERV_{vert\text{-}hole}$ is LOW but $ERV_{vert\text{-}aqtd}$ is HIGH, ERV_{vert}= HIGH.

Horiz. Receptor Vulnerabil. Rules of Thumb: DETAILS

Use two simple rules of thumb to determine horizontal receptor vulnerability.

1) Is the location a potential MTBE source, or within 2500 ft* of a current or potential municipal drinking water well in the same unit in any direction, or within 2500 ft upgradient from a current or potential domestic water well in the same unit, or within 2500 ft* of sensitive surface water receiving groundwater discharge? If no, ERV=LOW. *(*2500 ft or other locally established plume length)*

2) Is location on fractured bedrock geology or karst geology that is used as public water supply within 2 miles? If yes, ERV = HIGH. *Note: California MTBE guidelines state: "Located on near-surface fractured bedrock geology that is a water supply source for a community." 2 mile limit was added to this flowchart to make this rule more practical to implement.*

Tool for Evaluating Horizontal Capture Zone : DETAILS

Use simple capture zone relationships to determine if location is within capture zone of well or surface water discharge. Required parameters: hydraulic conductivity, aquifer thickness, well pumping rate, width of potential plume from location, hydraulic gradient, fluctuation in flow direction, number and type of wells in area.

If location is not in capture zone, ERV = LOW.

Tool for Evaluating Travel Time : DETAILS

Use simple travel time relationships to determine if location can have near-term impact to receptors (either drinking water wells or surface water discharge). Required parameters:
- Hydraulic conductivity
- Hydraulic gradient
- Pumping rate of well (used to adjust gradient)
- Distance from location to well

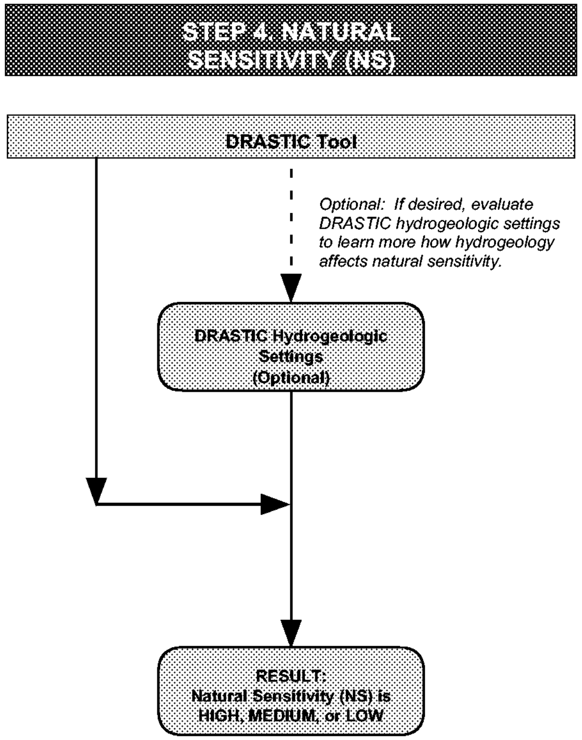
If travel time from location to well is 5 years* or less, ERV=HIGH. If travel time from location to well is between 5 and 20 years*, ERV=MED. If travel time from location to receptor is greater than 20 years*, ERV= LOW.

Source of values:
* In Calif. MTBE Guidelines

Tool for Evaluating Transport Modeling (Optional): DETAILS

Show links to commonly-used models (including DAFgraph). Provides BTEX and MTBE-specific data for use in models. If travel time from location to well is 5 years* or less, ERV=HIGH. If travel time from location to well is between 5 and 20 years*, ERV=MED. If travel time from location to receptor is greater than 20 years*, ERV= LOW.

FIGURE 4
NATURAL SENSITIVITY FLOWCHART FOR GROUNDWATER SENSITIVITY TOOLKIT
API / California MTBE Research Partnership



DETAILS

DRASTIC Tool: DETAILS

Use DRASTIC hydrogeologic settings as an optional educational resource for users wishing to learn more about how hydrogeology affects natural sensitivity.

DRASTIC Hydrogeologic Settings (Optional): DETAILS

Use site-specific DRASTIC methodology to estimate if Natural Sensitivity is HIGH, MEDIUM, or LOW.

Required parameters:

Use site-specific DRASTIC methodology to estimate if Natural Sensitivity is HIGH, MEDIUM, or LOW.

Required parameters:

- Depth to water
- Recharge*
- Aquifer media
- Soil type
- Topography
- Impact of vadose zone
- Conductivity

*(will put more detail about corrective recharge value to use for confined aquifers)

Potential Rules for This System:

If Precipitation > Evapotranspiration:
DRASTIC Index ^{3} 120,.................. NS = HIGH
120 > DRASTIC Index > 100........ NS = MED.
DRASTIC Index ^{2} 100................. NS = LOW

If Precipitation < Evapotranspiration:
DRASTIC Index ^{3} 150,................. NS = HIGH
150 > DRASTIC Index > 100........ NS = MED.
DRASTIC Index ^{2} 100................. NS = LOW

Definition of HIGH from EPA Groundwater Classification Guidance, 1988 *(this is the original reference cited in the EPA's Handbook of Ground Water and Wells, 1994 to support a DRASTIC Index cut-off of 150 for "highly vulnerable" aquifers).*
Definition of LOW (DRASTIC Index ^{2} 100) from our experience with DRASTIC.

As a point of reference, with this approach ~47 of the 111 DRASTIC settings (42%) are HIGH, ~47 settings (42% are MED.), and 17 settings (15%) are LOW. The 17 LOW settings are described as:

Mountain Slopes Facing East; Mountain Slopes Facing West; Mountain Flanks in Western Mountain Ranges
Mountain Slopes; Continental Deposits in Alluvial Basins
Mountain Slopes in Columbia Lava Plateau
Consolidated Sedimentary Rock; Resistant Ridges in Colorado Plateau/Wyoming Basin
Alternating Sandstone, Limestone, and Shale Sequences in High Plains
Metamorphic/Igneous Domes and Fault Blocks; Uncons. & Semicons. Aquifers in Nonglaciated Central Region
Glacial Till Over Shale in Glaciated Central Region
Regolith; Mountain Slopes;Mountain Slopes in Piedmont and Blue Ridge
Mountain Slopes in Northeast and Superior Uplands
Regional Aquifers in Atlantic and Gulf Coastal Plain
Bedrock of the Uplands and Mountains in Alaska

Note that the software will not use DRASTIC hydrogeologic settings system directly, but will rely on site-specific data to calculate the DRASTIC Index for a particular site. This discussion of DRASTIC settings is provided only to give a point of reference for potential DRASTIC cutoff for LOW Natural Sensitivty (DRASTIC Index ^{2} 100).

08/02

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