

**A TEACHER'S GUIDE TO
THE EXPANDED PLUME BUSTERS SOFTWARE**

By

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Preface

The Expanded Prototype Plume Busters software simulates an environmental problem and engages the student in its resolution under the real-world constraints of time, money, and technological capability.

For the student, adequate directions are provided in the HTML-linked pages to successfully work through the software. For the instructor, the guide provides useful information on software features that will help the student derive maximum benefit from the experience. It is recommended that instructors provide their own introduction to the software based on the material in the guide.

Before Downloading

This guide is designed for use with the Expanded Plume Busters educational software. Instructors are advised to read the Computer System Requirements and the Downloading the Software sections prior to downloading the software from the Kansas Geological Survey website. These sections provide operating system requirements, suggested browsers for viewing the HTML pages, screen resolution control settings, and instructions on downloading the software from the Survey website and the Java run-time environment from the Sun Microsystems website.

Questions, comments, or problems with the software should be directed to Dr. P. Allen Macfarlane at the Kansas Geological Survey by phone at (785) 864-2068 or by e-mail at dowser@kgs.ku.edu

A TEACHER'S GUIDE TO PLUME BUSTERS

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Welcome to the Expanded Plume Busters software!

Computer System Requirements

Currently the Expanded Plume Busters software runs on:

- Windows operating system environments with Windows NT with Microsoft Office 2000 and Windows XP with Microsoft Office 2003 on PCs and
- OS-10 or higher operating systems on Macintosh microcomputers.

File sizes are generally small in the kilobyte size range and the software occupies less than 4 Megabytes on the computer.

The software consists of a set of HTML-linked pages and a Java application. The HTML-linked pages can be displayed with (in order of preference) Explorer, Netscape, Safari, or Mozilla browsers. The main hardware issue is computer screen resolution, which needs to be set as high as possible (1,280 pixels x 1,024 pixels minimum). The software graphics use a fixed number of pixels on the computer screen irrespective of its resolution. Higher resolution allows both the graphics and the text to be displayed such that the text is not wrapped around the graphic due to the smaller total number of pixels available on the screen. The application uses the Java 2 SDK version of the JAVA programming language. This software is intended for use on Microsoft Windows 95, 98 (1st or 2nd 2000 Professional, 2000 Server, 2000 Advanced Server) or XP operating systems. A Pentium 166MHz or faster processor with at least 32 megabytes of physical RAM is required to run graphically based applications. You should have 70 megabytes of free disk space before attempting to install the Java 2 SDK software.

Downloading the Software

The link to the software download is on the Plume Busters page on the Kansas Geological Survey (KGS) website and can be accessed directly by entering the URL, <http://www.kgs.ku.edu/Hydro/GWutor.html>. The link can also be accessed indirectly from the KGS home page (<http://www.kgs.ku.edu>). On the homepage, click on the Education link on left side of the KGS home page, and click on Plume Busters. Under Plume Buster Downloads, click on the Undergraduate Version to download the HTML-linked pages and the Java application onto a local computer.

Software Overview

Using the Expanded Plume Busters software, post-secondary, undergraduate students take on the role of an environmental consultant¹ and apply groundwater flow, chemistry, and well hydraulics principles to solve a simulated chromium contamination problem. The software should be introduced to students following basic instruction in these topics. Follow-up activities can range

¹ Underlined items are defined in the Glossary.

from discussion of environmental policy and ethics to the role of technology in solving societal and environmental problems. An earlier version of the software is described in Macfarlane et al. (2006).

In the role as an environmental consultant, students simulate the cleanup of a chemical spill from a ruptured pipeline that transports CCA liquid to a nearby industrial plant (Figure 1). CCA or

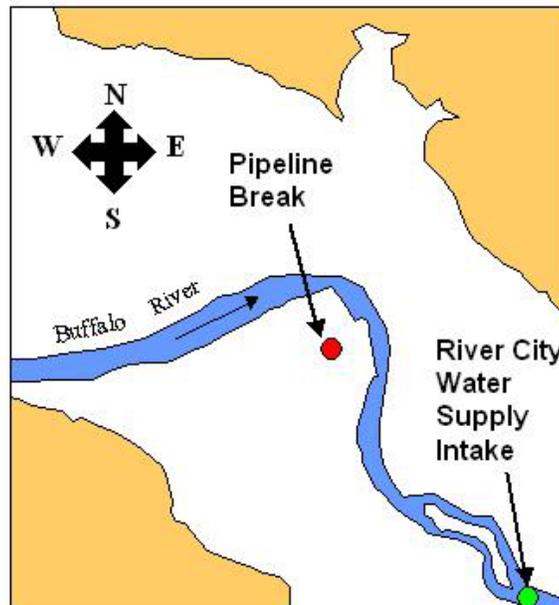


Figure 1. Location of the pipeline break in the Buffalo River valley with respect to the intake for the River City water supply.

copper chromate arsenate is used to protect wood products from attack by biological agents. In these simulations chromium VI (Cr^{+6}) is the contaminant of primary concern. The chemical spill has entered the alluvial aquifer and if unchecked, chromium VI will travel from the pipeline break (spill site), seep into a nearby Buffalo River, and render the downstream River City public water supply unusable. The pipeline owner hires an environmental consultant (the student), whose objective is to eliminate the contamination from the ground water in the shortest amount of time for the least cost. To complete the first simulation (Locate the Plume), the student must find concentrations of the contaminant in 3 monitoring wells. In the second simulation (Remediate the Plume), the student designs and selects the most cost-efficient remediation system based on one of three technologies (pump-and-treat, permeable reactive barrier, and in situ redox manipulation) to remove the contamination threat from the aquifer. In the last section of the software, the student is invited to prepare a 3 to 5-page consultant's letter report with attachments as needed. As part of the role-play, the purpose of the letter report is to inform the state environmental regulatory agency of the work completed to locate the contamination and to identify the most cost-effective remedy for remediation. However, as a tool of instruction the report is a reflection piece that also serves the purpose of summative evaluation of student performance.

Science and Environmental Policy Context

A usable supply of water is the basis of life on the Earth. Issues related to water supply, water quality, and the degradation of aquatic environments are central to modern daily life in many ways. All sources of fresh water are under increasing pressure because of point-source and non-point-source contamination.

Public perception of the issues surrounding the seamless interconnection of surface water and groundwater parts of the hydrologic cycle is lacking (Dickerson and Dawson, 2004; Dickerson et al., 2005). Water in lakes and streams is often thought of as being distinctly separate from water in aquifers. The exchange of water between aquifers and surface water bodies depends on hydraulic head differences between them, which may reverse on both short and long time scales. Thus, contaminants once mobilized have the potential to move freely through the hydrologic cycle and impact drinking water supplies and aquatic ecosystems. The inability to visualize how water flows between aquifers and surface water bodies directly affects the public perception of human impacts on this part of the hydrologic cycle. Public education on the impact of human activities on water and environmental quality is crucial to society's ability to make informed decisions on natural-resource management and environmental quality.

The Expanded Plume Busters software provides instructors with a means to initiate student exploration of a wide range of environmental issues. Listed below are some suggested topics:

- Source-water assessment, and wellhead protection zones, and environmental protection using land-use planning and zoning regulations;
- The impact of human activities and technology on the hydrosphere and biosphere;
- The role of technology in the resolution of environmental issues;
- The social, political, and economic costs of environmental degradation;
- The impacts of environmental laws and regulations on the social, political, and economic systems;
- Assessment of risk to environmental quality from human activities; and
- Assessment of risk to human health from contamination.

What Students Gain from Exposure to the Software

The Expanded Plume Busters software helps students make the transition from novice learner to expert by providing (developing):

- Deeper understanding of the hydrologic cycle.
- Experience in applying concepts from geology, geography, hydrogeology, chemistry, mathematics, and economics to practical problem solution. By drawing on the concepts from these diverse sources, the student can begin to see how they fit together as an integrated body of knowledge.
- Experience in making decisions based on uncertain data.
- Confidence from being able to solve a simulated, real-world problem. In working with Plume Busters, the student must make decisions and deal with their consequences. Students also confront the practical side of environmental consulting as they solve this real-world environmental problem. Decisions made by the student are constrained not only by time and economic and other institutional realities.

- Improved understanding of the application of technology to the solution of environmental problems.
- Insight into environmental policy issues, including the means to achieve environmental protection, topics related to the economic cost of human activities on environmental quality, how clean are our water resources, and setting limits on acceptable levels of contamination in water resources.
- Experience in technical report writing.

Primary Science and Mathematics Concepts Addressed by the Software

The emphasis of the Expanded Plume Busters is on the practical application of science and mathematics concepts to “real-world” problem solution.

To simplify the search in Locate the Plume, it is assumed that the plume, which has well-defined leading and trailing edges, is moving advectively with the groundwater flow. The student must know the groundwater flow direction from the spill site, the average groundwater velocity, and the elapsed time that the plume has been in transit to determine where it is with respect to the spill site. The approximate groundwater flow path from the spill site to the river is provided in the Map View interface to limit the search area for the moving target. The student uses Darcy’s law and aquifer porosity to estimate average groundwater velocity. The student must also estimate how long the leading and trailing edges of the plume have been moving from the spill site toward the river. Monitoring wells are then installed within a target area defined by the approximate groundwater flow path and the estimated distance traveled by the leading and trailing edges of the plume from the spill site.

To make the initial estimate of average groundwater velocity, aquifer porosity must be derived from drillers’ logs of water wells and a table of representative porosity values from all types of alluvial materials. Because the “Main Aquifer” consists of several different lithologies, the average porosity of the “Main Aquifer” must be estimated by weighting the representative porosities of each lithology relative to total thickness of the “Main Aquifer”. Once the weighted average porosity values have been calculated for each of the 6 well sites, the porosity of the alluvial aquifer at the spill site is calculated as the simple arithmetic average of the weighted porosity values.

In the Remediate the Plume simulation the student develops on-site designs for the pump-and-treat (P&T), permeable reactive barrier (PRB), and in situ redox manipulation (ISRM) technologies and selects from these the single most cost-effective design that will eliminate the contamination threat to the Buffalo River. P&T consists of a production-injection well couplet, and a treatment plant. The production-injection well couplet is situated such that the plume is contained entirely within the couplet’s capture zone (Fetter, 1993). Ground water is pumped from the production well installed down gradient of the plume and piped to a treatment plant for removal of contaminants. The treated water is piped to an injection well where it is put back into the aquifer upgradient of the plume. The couplet’s capture zone develops by superposition of the cone of depression created by withdrawing water from the aquifer by pumping and the cone of impression created by the addition of water to the aquifer by injection. The resulting capture

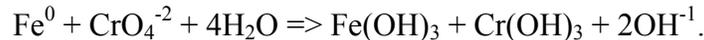
zone is elliptical in shape and oriented such that the long axis of the ellipsoid connects the production and injection wells and parallel to the direction of groundwater flow.

The treatment method in this simulation uses the Forager™ technology, which adsorbs dissolved ions, including chromium onto a sponge or granular surface coated with a polymer (US EPA, 1995). The order of the polymer's affinity for metallic and non-metallic ions in solution is:

(Greatest affinity) $Au^{+3} > Cu^{+2} > Cd^{+2} > Hg^{+2} > Pb^{+2} > Ni^{+2} > Mn^{+2} > Fe^{+3} > Co^{+2} > Zn^{+2} > Au(CN)^{-2} > SeO_4^{-2} > AsO_4^{-3} > CrO_4^{-2} > UO_4^{-2} > Ag^{+1} \gg Al^{+3} > Mg^{+2} > Na^{+1}, K^{+1}, Ca^{+2}, Cl^{-1}$ and SO_4^{-2} (Least affinity).

Water to be treated is passed through columns or beds filled with the Forager™ polymer-coated sponges or granules to produce the desired treatment result.

Unlike the P&T technology, the PRB relies on the passive flow of ground water through a constructed reactive zone containing granular elemental iron to remove contaminants by means of redox chemical reactions (Powell et al., 1998). Elemental iron (Fe^0) removes the highly mobile Cr^{+6} from ground water and transforms it to the immobile Cr^{+3} by donating electrons to it. In the process, elemental iron is oxidized to Fe^{+3} and the Cr^{+6} is reduced to Cr^{+3} . The net chemical reaction is:

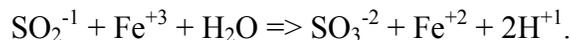


Iron and chromium hydroxides [$Fe(OH)_3$ and $Cr(OH)_3$] are precipitated onto the granular matrix materials that fill the reactive zone and the pH of the water downgradient of the barrier is increased due to the addition of hydroxyl (OH) ions.

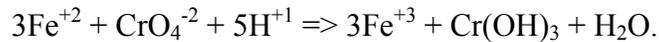
ISRM technology also relies on a similar chemical mechanism to remove the dissolved chromium contamination (Cr^{+6}) from solution (Vermeul et al., 2004). ISRM creates a treatment zone within the aquifer by injecting a buffered sodium dithionite ($Na_2S_2O_4$) solution into the aquifer. Sodium dithionite dissolves in water to eventually produce sodium (Na^{+1}) and sulfoxyl (SO_2^{-1}) ions:



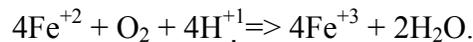
The injected sulfoxyl ions reduce Fe^{+3} to Fe^{+2} in the aquifer materials:



After a predetermined reaction time, the injected solution is recovered from the aquifer by pumping the injection wells. Later, as the Cr^{+6} -contaminated groundwater flows through the treatment zone, the chromium is precipitated as a byproduct of redox chemical reactions with iron-bearing minerals on the aquifer matrix. Fe^{+2} ions donate electrons to Cr^{+6} ions, which causes Cr^{+6} to be reduced to the relatively immobile Cr^{+3} . In the process Fe^{+2} is oxidized to Fe^{+3} . The net chemical reaction is:



The ISRM treatment zone also rapidly depletes the dissolved oxygen (O₂) in the aquifer:



Software Structure and Features

The software consists of: (1) a set of linked HTML pages, and (2) a numerical groundwater flow model and its user interface, Map View as a Java application.

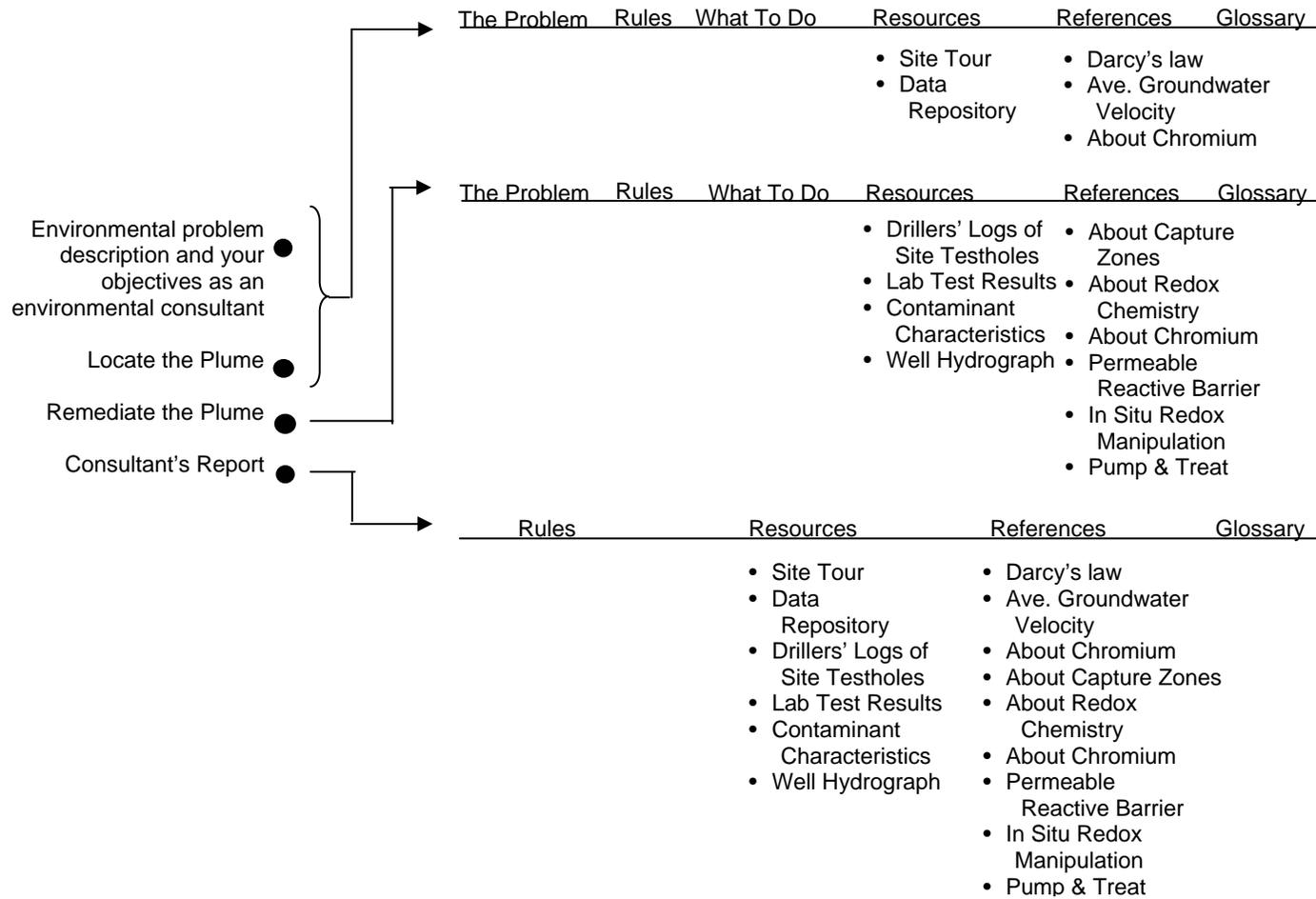
The linked HTML pages are grouped into 4 sections:

- Environmental problem description and your objectives as an environmental consultant,
- Locate the Plume,
- Remediate the Plume, and
- Consultant's Report.

Each section is structured to help guide the student through the simulations and provide site information and reference materials. Navigation bars facilitate movement between sections of linked HTML pages (Figure 2).

The user interacts with a groundwater flow model through the Map View window (Figure 3). At the top of the window, the display lists (1) the current calendar date, (2) the time in days since the contamination was reported, (3) the money remaining in the consultant's project account balance, (4) the total amount of money spent on the project to date, (5) the estimated amount of chromium released to the aquifer from the spill, and (6) the amount of chromium remaining in the aquifer. In the top right corner, an array of buttons allows the student to exit from the simulation, start the simulation over, and access the Observed Data table, and the Calculator. In the middle of the window, a gridded map of the spill site vicinity shows the location of the pipeline, the spill site, and the river. The dimensions of the gridded map are 305 meters by 305 meters (1,000 feet by 1,000 feet) and the map is scaled in northing and easting coordinates. At the bottom of the window, a log automatically tracks actions taken by the student in Map View and their results. Following each entry, the student has the opportunity to comment on what took place as a result of his/her interaction with the computer model or record other pieces of information.

Map View is a Java application that is downloaded and launched using Java WebStart, a technology that provides automatic download and installation of an application on the user's machine. Thus the application runs locally, rather than over the Internet, providing rapid response to user input. The application uses a simple two-dimensional, finite-difference formulation to simulate groundwater flow through a slightly heterogeneous alluvial aquifer to a river. A different problem setting and realization of the aquifer's spatially varying hydraulic conductivity field is generated every time the application is restarted, providing significant variations in the plume trajectory toward the river from one program run to the next. The contaminant plume is represented using 1,000 particles that enter the aquifer over a fixed span of time at the location of the pipeline break. Each particle's movement is tracked over a series of



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Figure 2. Navigation bars for each part of the expanded Plume Busters software.

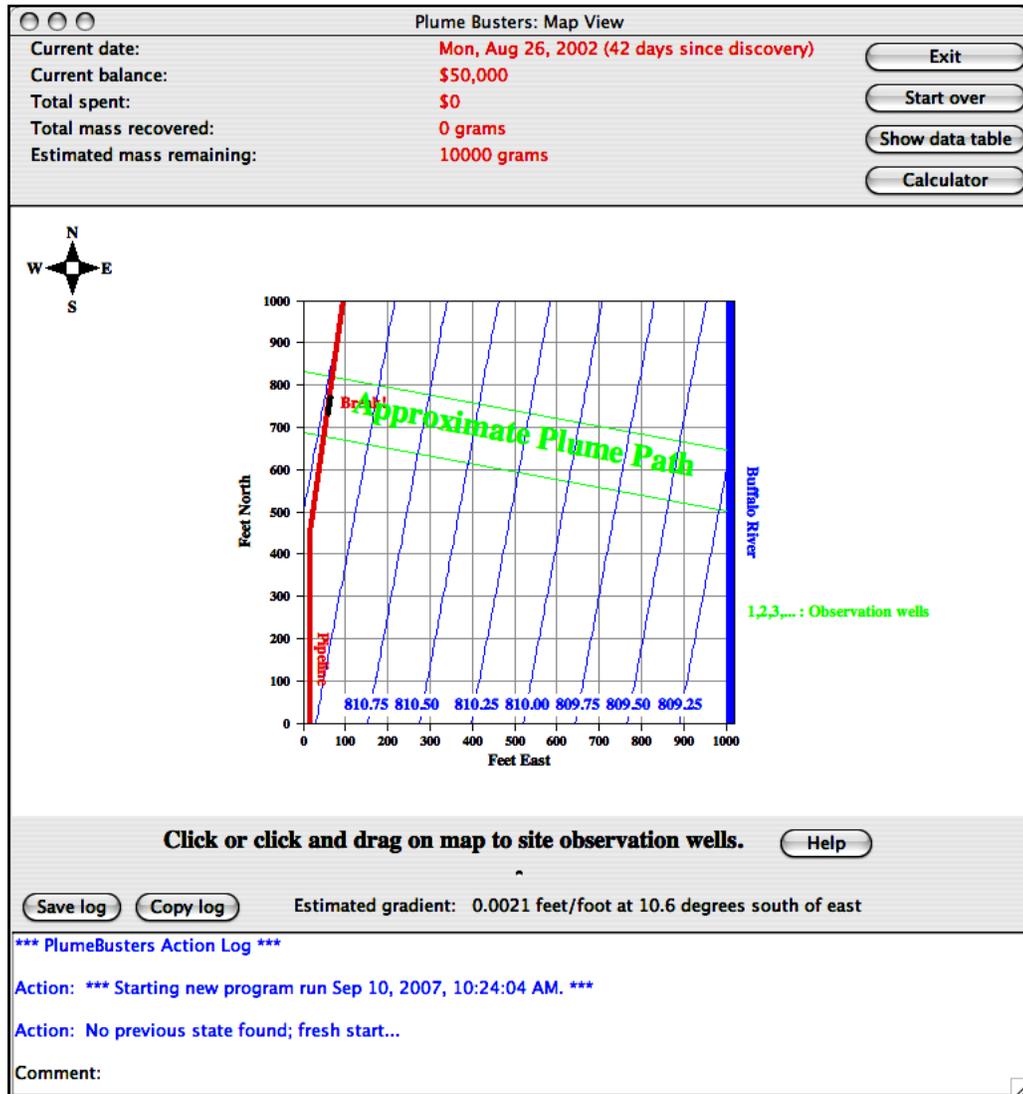


Figure 3. The Map View window during the Locate the Plume simulation. The upper part of the window (in gray) is a status report on the simulation. The middle part of the window contains a gridded map of the site showing the Buffalo River, the pipeline, the pipeline break, contours showing the elevation of the water table in blue and the approximate ground-water flow path based on the water-table contours. The lower part is the tracking log. Text in blue is a program-generated record of actions taken by the student and their results. The comment section is for the student to use as a field book in which to record other observations or the derivation of input data to use in calculating travel distance.

time steps, with the displacement between time steps consisting of an advective component, determined by the average groundwater velocity, and a random component, imparting a small degree of plume dispersion.

Starting the Software

Clicking on the link to the Plume Busters software on the KGS home page (<http://www.kgs.ku.edu>) brings up the Introductory page of the HTML-linked pages. Clicking on the arrow in the lower right corner of the page brings up the next page that describes the role-play the student will be undertaking, the purpose of the HTML-linked pages, and the possibility that once the simulations have been completed, the instructor may want the student to complete a consultant's report. The student is also instructed to set his computer screen to the highest resolution possible (1,280 pixels x 1,024 pixels minimum). At this point the student is free to navigate to any of the 4 major sections of the HTML-linked pages by clicking on the appropriate radio button at the bottom of the screen.

Initially, the student should start with the Environmental problem description ... section.. This section contains a description of the environmental problem and defines the role that student will be taking on and his objectives in the simulations.

Note: If the student is returning to the HTML-linked pages after a break, he may click on any of the other radio buttons to navigate to any of the other sections (Locate the Plume, Remediate the Plume, or the Consultant's Report).

At the end of this section, the student should click on the What to Do tab on the navigation bar to bring up instructions and information for the Locate the Plume simulation. Here, the student will be given the option of starting the software online or downloading the software to his computer.

The student is also prompted to activate the Map View interface to the Java application. Most of the newer Windows and OS-10 or higher operating systems already have Java installed as part of the system software. Check to insure that Java is already installed before trying to run the application. If you are unsure, double click on the Map View icon. If Map View does not start up when you attempt to launch it or if Java is not currently installed do the following:

- Go to java.com
- Click on the Java Software Download button to install the latest version of Java. Near the top of the java.com/en/ page is a box labeled "Java Software Free Download". A new page will appear and will contain instructions for users with Mozilla and Firefox browsers.
- If the student is not using any of these browsers on his machine, look to the right and click on Other Platforms.
- On the next page, click on the appropriate platform download instructions.
- Once you have read the instructions, click on the download button and proceed following the instructions for each part of the download process.

The student launches Map View by double-clicking its icon. With Map View visible on the computer screen adjust its and the browser's window displaying the HTML-linked pages so that both can be viewed simultaneously.

When Map View starts up, the software creates a file (gwStatus.dat) that tracks plume and monitoring well locations and other information and enables the user to stop and restart the application midway through a session without having to start completely over. The gwStatus.dat file is placed by the application on the user's computer Desktop. After the student has completed the entire session with the software, the file can be deleted.

Student Interaction with the Expanded Plume Busters

To successfully accomplish the software educational objectives, it is important for the student to:

- Use the provided information and the Calculator to estimate where the plume is located in the aquifer each time a monitoring well is installed;
- Take advantage of the reference material on each remediation technology that is included as documents in pdf form within the HTML-linked pages;
- Use the tracking log throughout both simulations as a means to self-evaluate progress through the simulations, and plan ahead; and
- Use the information from the tracking log, the Resources tab, and the References tab to complete the consultant's letter report.

Environmental Problem Description And Your Objectives As An Environmental Consultant

This subsection consists of 2 HTML-linked pages. The student is informed that a pipeline transporting a solution of CCA wood preservative has ruptured in a corn field in the Buffalo River valley, just upstream of River City (Figure 1). The source for the River City water supply is the Buffalo River and the water supply intake is located less than 3 miles downstream of the pipeline break. An emergency response team was dispatched to the site to contain and clean up the spill. The team reported that the pipeline had been leaking for some time prior to the break's discovery and that the spilled liquid has reached the water table of the alluvial aquifer. Based on preliminary information, it appears that the contamination is moving toward the river and River City's public water supply is in jeopardy. Of primary concern is the dissolved chromium (Cr^{+6}) in the ground water from the spill, which if it reaches the river, will render the city's water supply unusable.

The student is invited to take on the role of an environmental consultant whose task is to:

- Find where the contamination from the spill is located in the aquifer, and
- Design the most cost-efficient remediation system that will remove the contamination from the ground water before it gets to the river and endangers the public water supply.

The last HTML-page for this section indicates that the student will search for the contamination by installing monitoring wells and collecting water samples to determine the concentration of dissolved chromium. Successful completion of the Locate the Plume simulation occurs when the student finds concentrations of the contaminant in water samples from 3 monitoring wells and completes the project under budget and before the plume reaches the river. To move to the

HTML-linked pages that pertain to the Locate the Plume simulation the student must click on the What to Do tab on the navigation bar.

Locate the Plume Simulation

HTML-linked pages: What to Do (Figure 2): The first 3 HTML-linked pages describe the features of the Map View interface (Figure 3).

HTML-linked pages: What to Do- The Calculator Tutorial: The tutorial shows the student how to use the Calculator by working through an example. The tutorial also directs the student in the use of the information in the Map View window and the timeline of events in the HTML-linked pages under the Resources tab (Figure 2) to make the required calculations.

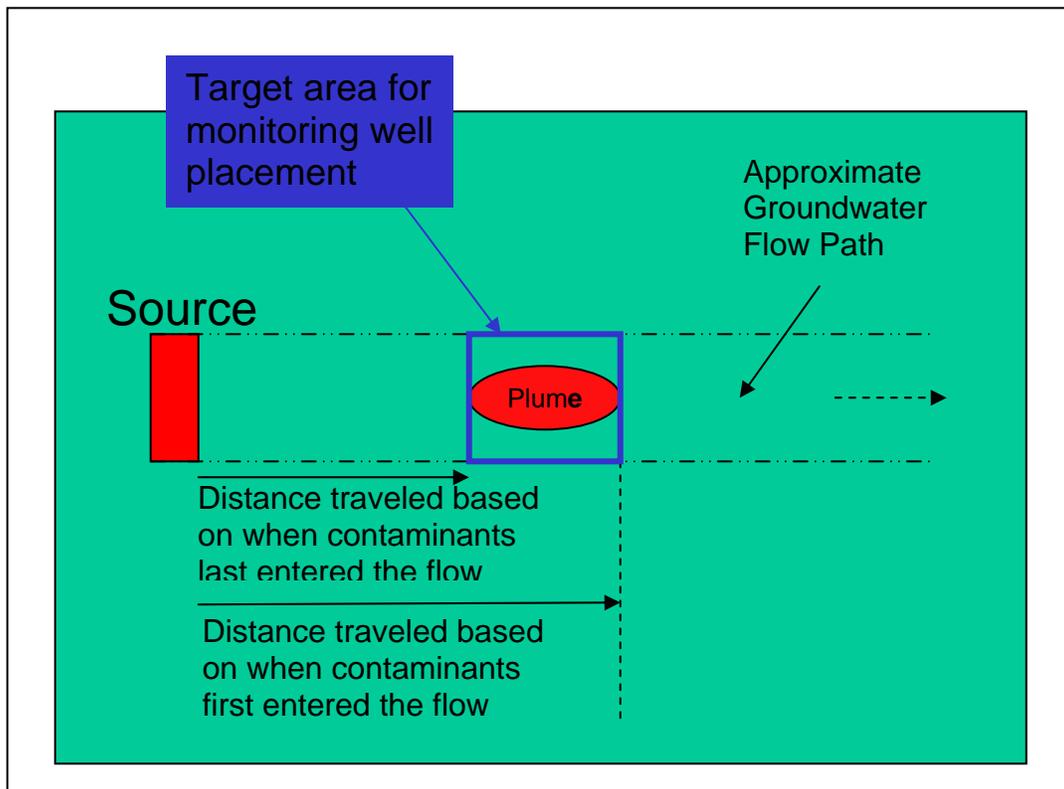


Figure 4. The boundaries of the target area for monitoring well placement.

Under the Resources tab (Figure 2), the Data Repository lists the following Critical Information for Locating the Plume in a table:

- Pipeline break discovery date,
- Estimated pipeline break date,
- Leakage end date,
- Amount of the Chromium leaked, and the
- Aquifer hydraulic conductivity.

To make the calculations for determining the location of the first monitoring well, the student must derive the porosity from drillers' logs of water wells (see HTML-linked pages: What to Do-

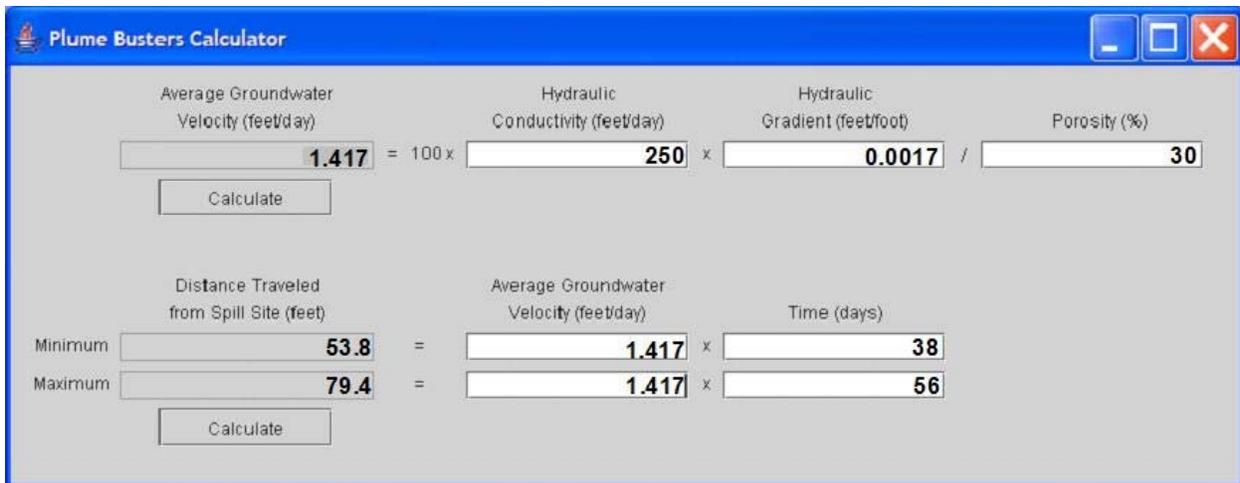


Figure 5. The Calculator used to estimate the average groundwater velocity and the distance traveled by the leading and trailing edges of the plume.

Data Repository). Once all the data have been entered in the appropriate boxes the student clicks the upper Calculate button to estimate the average groundwater velocity and the lower Calculate button to produce an estimate of the distances traveled by the leading and trailing edges of the plume.

Map View: The Calculator: The Calculator is opened by clicking on the button labeled Calculator on the upper right corner of the Map View window (Figure 3). The calculator is used to estimate average ground-water velocity and the distance traveled by the leading and trailing edges of the contaminant plume (Figures 4 and 5).

HTML-linked pages: What to Do- Data Repository: At the end of the tutorial the student is directed to the drillers' logs of nearby water wells located under the Resources tab in the Data Repository.

Under the Estimating Porosity from Drillers' Logs section of the Data Repository, the student will need to use a hand calculator or the calculator provided with the computer system software to estimate the weighted average porosity of what is referred to as the "Main Aquifer" (Figure 6). The logs are provided in tabular and graphical form and for each log there is a table of expected average porosity values for lithologies typical of alluvial deposits. To estimate the average porosity of the aquifer in the vicinity of the spill site, the student is asked to calculate the arithmetic mean of the weighted average porosities of the "Main Aquifer" at each well site.

The calculated weighted average porosity is used by the Calculator to compute an initial estimate of the average groundwater velocity for determining the location of the first monitoring well with respect to the spill site. To install succeeding monitoring wells, the student has as a default the option of using the updated porosity and hydraulic conductivity values contained in the Observed Data pop-up window that appears each time a new monitoring well is installed.

Under the Resources tab the student will find a tour of the site (Figure 1). The Site Tour contains spill site photos, shows the student some of the protective clothing and other gear needed by those working at the site and presents information on the variation of soil texture with depth in a dug pit described in the literature about the site vicinity.

HTML-linked pages: What to Do- Monitoring Well Installation: This tutorial follows the calculator tutorial. The student places monitoring wells on the grid in Map View using the mouse cursor. To install and sample a monitoring well on the map grid in Map View:

- Expand the Map View window as needed to more accurately locate the well.
- Place the mouse cursor over the spill site,
- Depress and hold down the left mouse button (PC) or the mouse button (Mac),
- Drag the mouse cursor the required distance (noting the distance in feet displayed in red) and direction away from the pipeline break to the spot on the gridded map where the monitoring well is to be located (Figure 7),
- Release the mouse(button) to install the monitoring well (Figure 8).

Driller's Log from Well 2

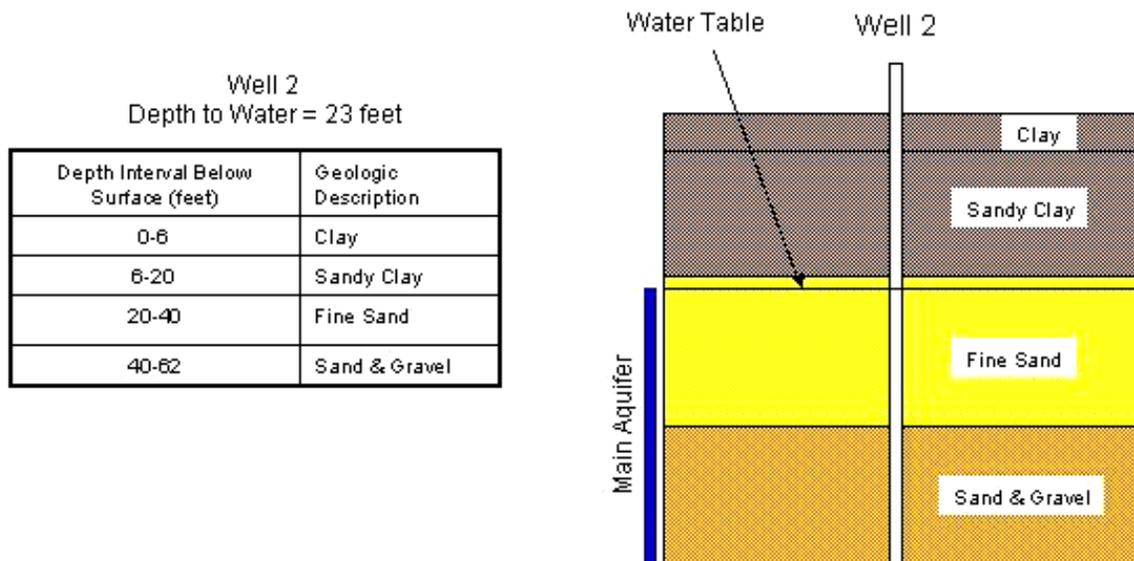


Figure 6. The driller’s log of an offsite water well in graphical and tabular form. The student calculates the weighted average porosity of the interval labeled “Main Aquifer”.

After each monitoring well installation, the student is provided with data on the water-table elevation, the contaminant concentration, the aquifer hydraulic conductivity, and porosity and other data pertinent to the well site in the Observed Data pop-up window (Figure 9).

HTML-linked pages: Rules Tab: The site characterization plan governs actions taken by the student and is designed to provide some real-world constraints on the exploration for the plume. The student is provided with \$50,000 to conduct this part of the role-play. Well installation and the chemical analysis of water samples cost money and time (\$4,000 per well, \$1,000 per chemical analysis, and one week of time to do both). Resampling a previously installed monitoring well also requires a week of time to obtain the chemical analysis results. To complete this simulation, contamination must be found in water samples from 3 monitoring wells.

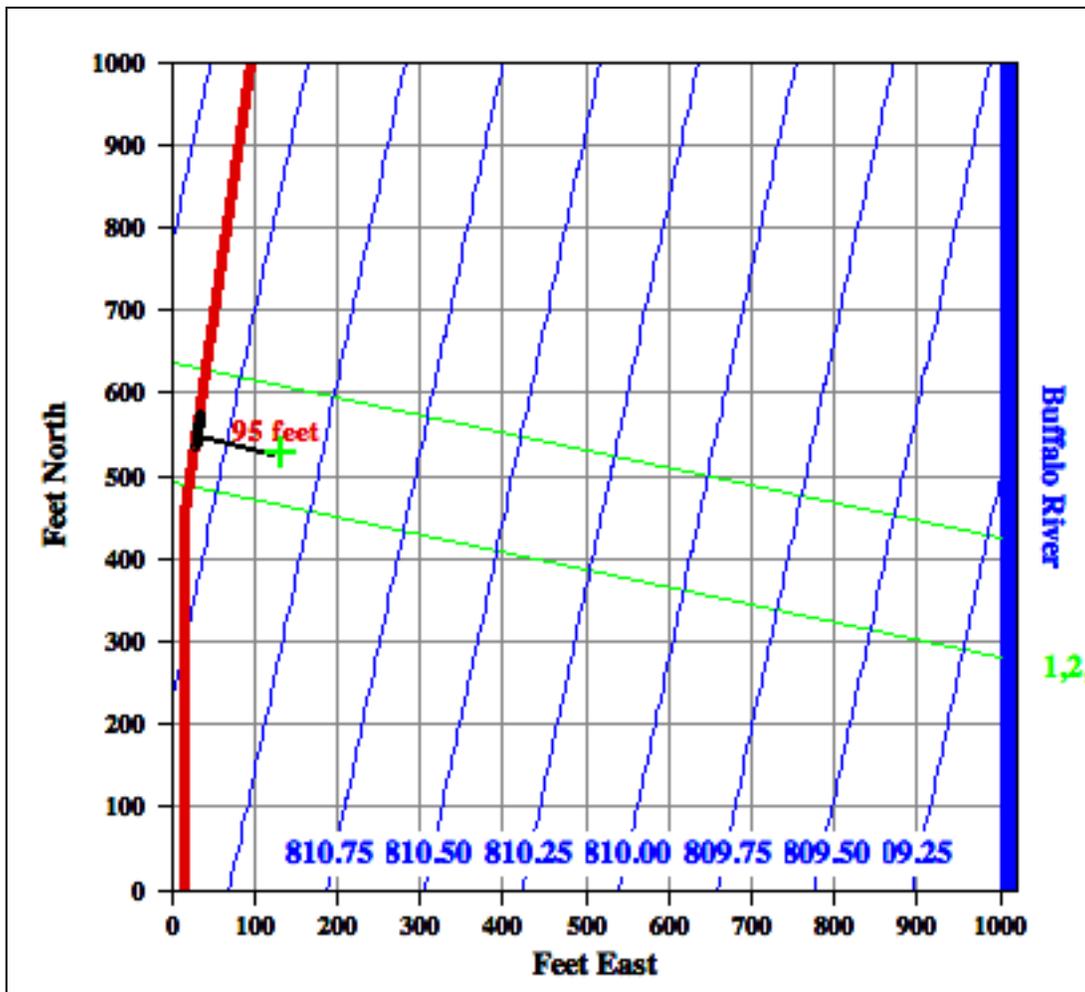


Figure 7. To install a monitoring well click and hold down the mouse over the pipeline break (black) and drag the mouse to the desired location. This activates a ruler that displays in red the distance from the spill site to the monitoring well location in feet.

The end of the Locate the Plume simulation: Map View: The Locate the Plume simulation ends when measurable concentrations of chromium in water samples from 3 monitoring wells have been found. To signify the end of this simulation, a pop-up window appears congratulating the

student on his successful completion of the simulation. The full extent of the simulated plume is also revealed as the total number of particles that were released from the source (Figure 11).

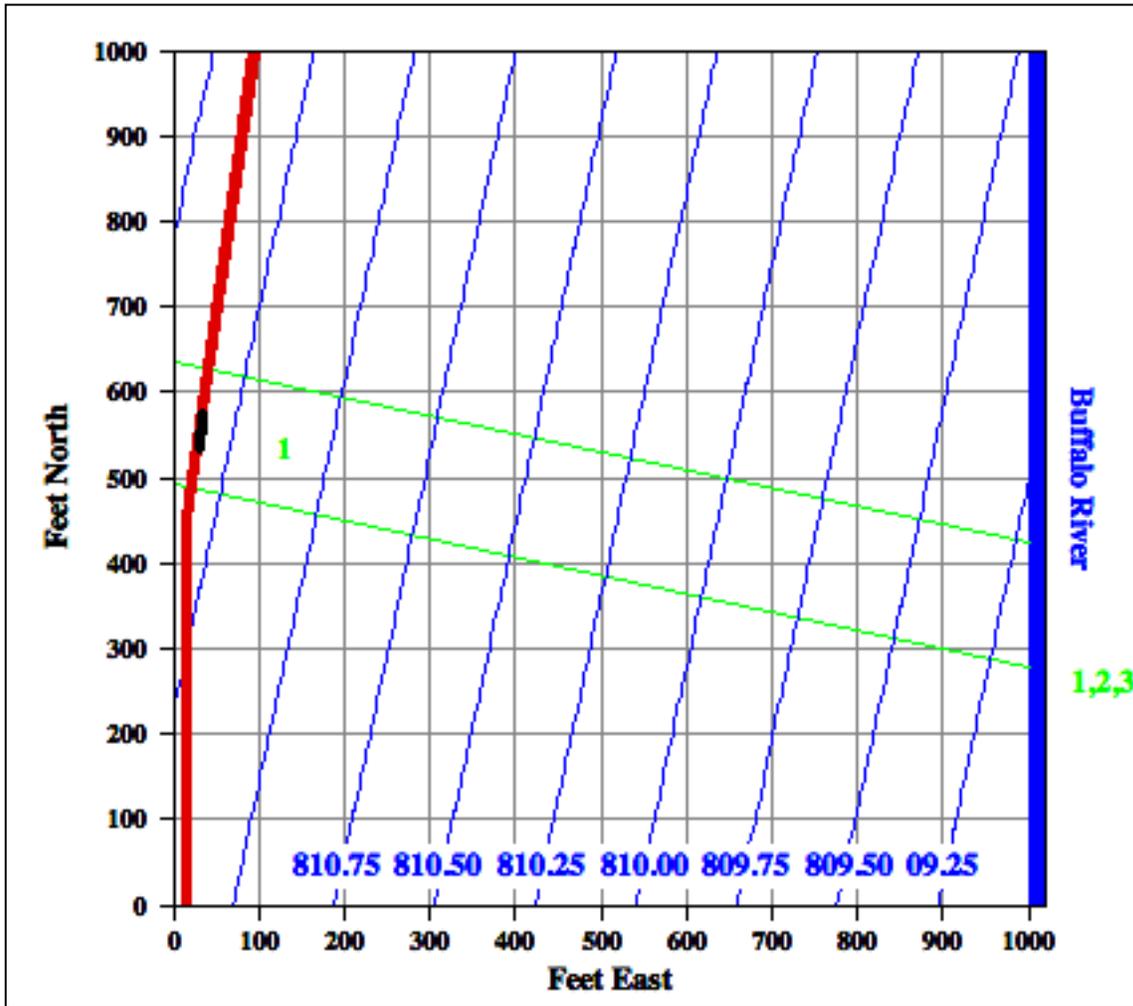


Figure 8. The location of the first monitoring well shown with the number 1 in green and placed 95 feet downgradient of the spill site.

Observed Data									
Obs. Well #	Date	Days Sinc...	X (feet)	Y (feet)	WT Elev. (ft)	Conc. (m...	Hyd. Con...	Porosity (...)	
1	Fri, 8/3...	46.0	130.0	530.0	811.11	9.26	182.44	32.87	

Figure 9. The Observed Data pop-up window.

Remediate the Plume Simulation

On completion of the Locate the Plume simulation the student is instructed on the HTML-linked pages to:

- Use the computer's utility to do a screen capture (print screen) of the Map View window, paste it into a page on a word processor, and save the document for later reference.
- Increase the size of the HTML-linked pages window to make it readable.
- Click on the word “here” to proceed to the Problem for the Remediate the Plume simulation.

Goal of the Remediate the Plume Simulation: The objective is for the student to design the most cost-effective on-site remediation system that will remove the contaminants from the ground-water system based on one of the 3 featured remediation technologies.

HTML-linked pages- What to Do: On the first HTML page the student is informed that he will be evaluating remediation system designs based on the PRB, ISRM, and P&T technologies. There is also a brief listing of what is contained under the Resources and References and Rules tabs in the HTML-linked pages. If the computer being used to run this simulation does not have a pdf reader, a free one should be downloaded from the Adobe website at this time (<http://www.adobe.com/>).

The student should be encouraged to look through the site information contained under the Resources tab and carefully review the write-up on each technology under the References tab. The site information provides data that should be used as a basis for assessing the suitability of using each technology for this environmental problem and includes:

- Drillers' logs of test holes drilled in the vicinity of the spill site,
- Column and batch test results and an analysis to determine reducible iron content of the aquifer materials,
- Contaminant characteristics,
- Native groundwater chemistry, and a
- Hydrograph of a nearby groundwater level monitoring well.

The write-ups for each technology under the References tab follow the same format:

- A short description of the technology
- A summary of the science behind the technology
- How the technology is used in practice (design)
- Advantages/disadvantages associated with use of the technology
- The types of costs associated with the technology
- PDFs of references that pertain to the technology, including reports of actual use.

HTML-linked Pages: What to Do- General Instructions: The General Instructions provide guidance for creating remediation system designs in Map View.

Installation of the PRB in Map View: The PRB in this simulation is continuous with an interior permeable reactive zone filled with a mixture of granular elemental iron and quartz sand (Figure 10; Powell et al., 1998). The barrier extends five feet above the top of the highest water-table

elevation on record and is keyed into the underlying bedrock. In this simulation, the student determines the PRB location, orientation, and length.

To activate this technology in Map View, the student clicks on the PRB button. Using the mouse cursor the student draws the trace of the PRB on the site map using the following procedure:

- Place the mouse cursor at one end of the PRB,
- Depress and hold down the left mouse button (PC) or the mouse button (Mac),
- Drag the cursor to the desired length and end-point location, (Figure 11) and
- Release the mouse(button).

As the orange PRB trace is being drawn, the software displays its footage in red (Figure 11). If the location, extent, and orientation of the PRB are satisfactory, the student clicks the Submit button. If not the student redraws the PRB trace and old trace disappears. Once the submit button is clicked, a dialog box appears indicating the costs associated with the particular design. If the expense is acceptable, the student may proceed with operating the design for one week by clicking the Yes button. Succeeding clicks on the Keep Going button will allow the design to operate a week at a time until the plume is removed from the groundwater system or the available funds for remediation have been exhausted.

To try another design based on this or another technology, click on the Roll Back button. With each new design, the student should perform a screen capture (OS-10 or higher) or print screen (Windows) and paste them into a word processor to document the design process. Roll back is possible because the software creates and places on the computer Desktop a file (gwRollback.dat) that contains the plume location data at the completion of the Locate the Plume simulation.

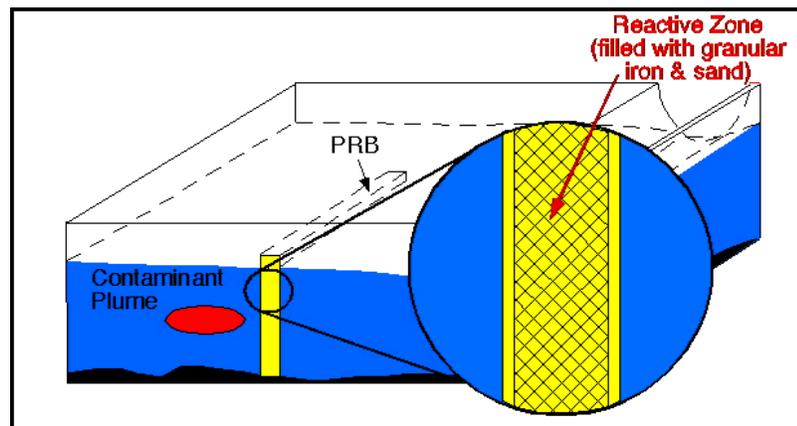


Figure 10. The continuous permeable reactive barrier (PRB) passively treats the contamination in the barrier's reactive zone.

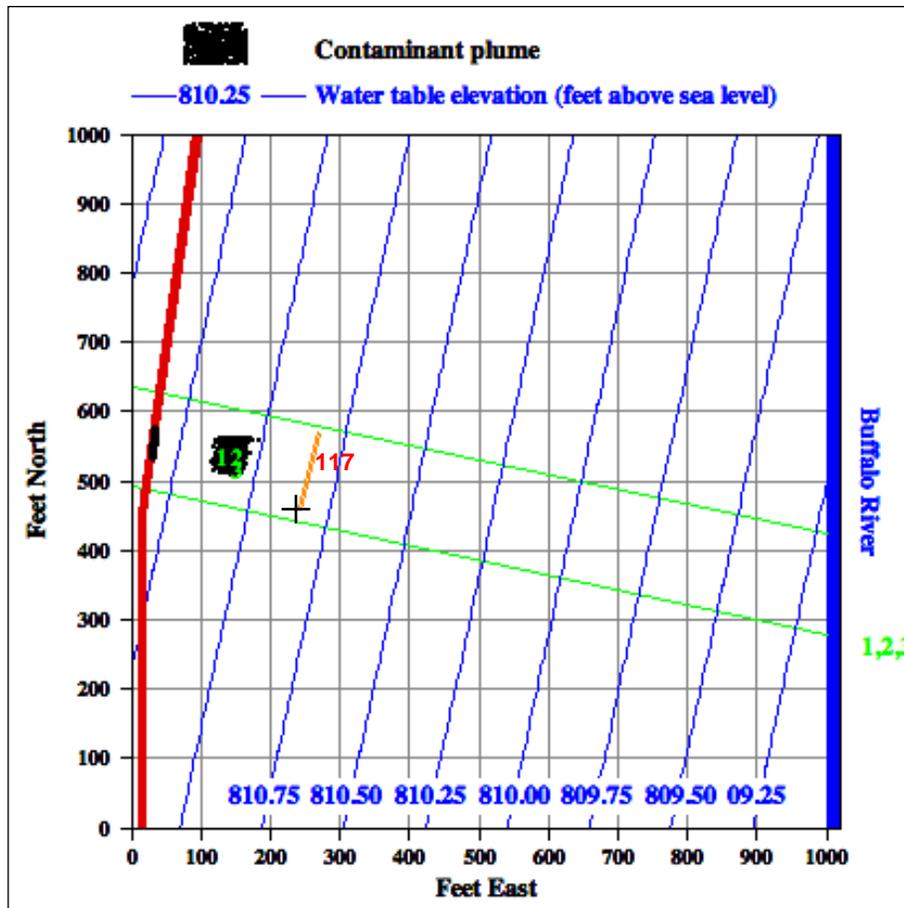


Figure 11. Drawing the trace of the PRB in Map View. The cursor is placed at one end and the mouse is clicked, held down, and dragged to the other end-point. The trace is shown in orange and the total footage is indicated in red numerals.

Installation of the ISRM wellfield in Map View: ISRM is a relatively new remediation technology that relies on chemically treating the sediments that form the aquifer using injection wells to produce a redox treatment zone by reducing ferric iron (Fe^{+3}) in the aquifer materials to ferrous iron (Fe^{+2}) (Figure 12; Vermeul et al., 2004). To implement this technology in a real-world situation (1) a solution contain a reducing agent (such as sodium dithionite) is injected into the aquifer in liquid form, (2) the reducing agent is left in the aquifer for a predetermined amount of time to react with the reducible iron, and finally (3) the injected fluid is pumped out of the aquifer using the injection wells. The amount of time the reducing agent is left in the aquifer is based on the results of batch tests run in a laboratory. To create the treatment zone often requires installation of large numbers of injection wells depending on the extent of the aquifer in need of treatment. For most aquifers with moderate amounts of reducible iron, the treatment zone diameter around an injection well is typically 40 feet. To be cost-effective, the aquifer must contain enough reducible iron to create the treatment zone, but not so much that large volumes of reducing agent need to be injected to achieve the desired treatment zone extent. As the contaminants passively move through the treatment zone, they undergo reduction at the same time that the ferrous iron is oxidized back to ferric iron.

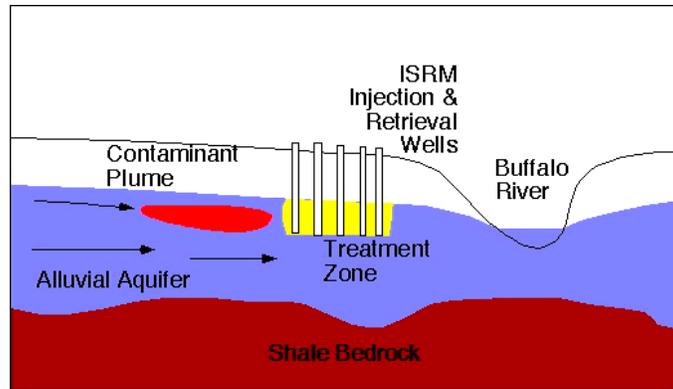


Figure 12. The in situ redox manipulation (ISRMs) technology is used to remediate contaminated groundwater systems by creating treatment zone in which reducible iron is produced by injecting a reducing agent into the aquifer. The reducible iron reacts with Cr^{+6} [Cr (VI)] to produce Cr^{+3} [Cr (III)], which precipitates onto the aquifer materials.

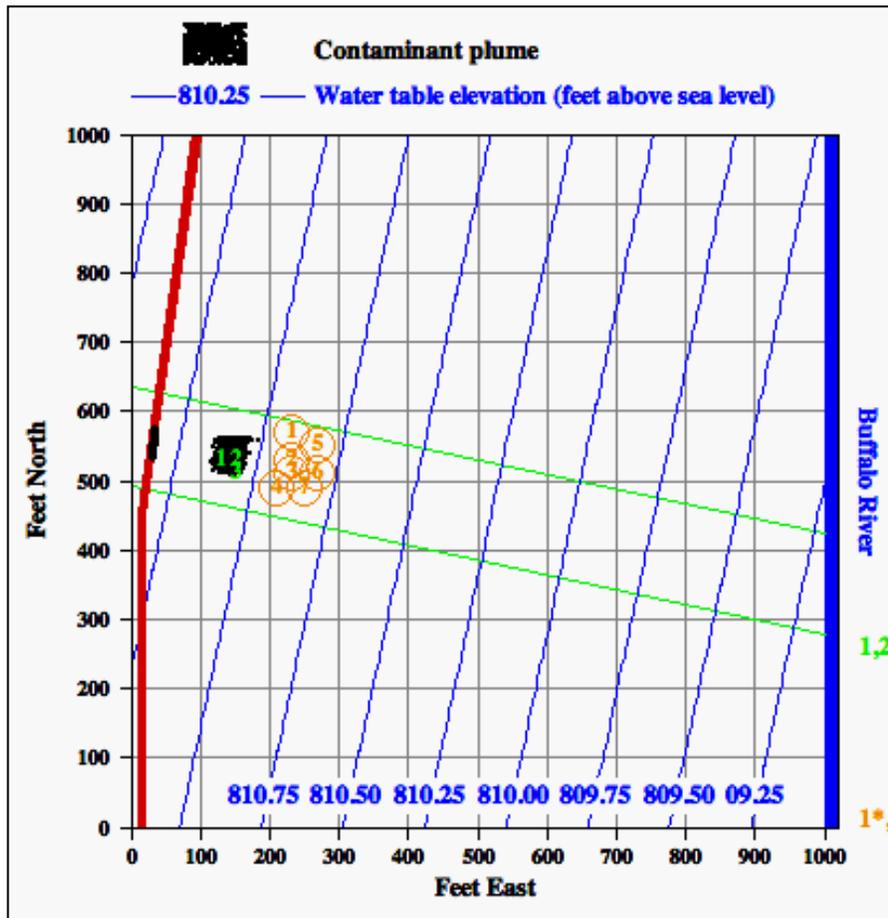


Figure 13. Installation of the treatment zone using the ISRMs technology. The location of each injection well is numbered and the circles represent the extent of the aquifer impacted by injection of the reducing agent at each well to create a circular, redox-treated zone.

To activate this technology, the student must first click on the ISRM button in Map View. The mouse cursor is used to site the injection wells by a single click of the mouse at the desired location. Doing so brings up a dialog box that asks if a well location is correct. Clicking the Yes button cites an ISRM injection well at the chosen location (Figure 13). Each well location is numbered sequentially. The circle around the location is the estimated extent of the aquifer affected by injection of the reducing agent. This operation is repeated until the desired treatment zone extent has been reached. If the extent is acceptable, the student clicks the Submit button and a dialog box will appear. If the expense is acceptable, the student may proceed with operating the design for one week by clicking the Yes button. Succeeding clicks on the Keep Going button will allow the design to operate a week at a time until the plume is removed from the groundwater or the available funds for remediation have been exhausted. To try another design based on this or another technology, click on the Roll Back button.

Installation of the P&T wellfield in Map View: The design offered in this version of the software uses a production well to remove contaminated ground water from the aquifer and an injection well to return the produced water back to the aquifer after it has passed through the treatment plant (Fetter, 1993; Figure 14). The production well is sited downgradient of the plume and the injection well, upgradient of the plume.

To start, the student clicks on the P&T button below the site map. This action prompts him to enter a pumping/injection rate of up to 20 gallons/minute. A mouse click on the Next button prompts the student to locate the production (extraction) well on the site map. A click with the mouse on the map at the desired location installs the production well and displays its parabolically shaped capture zone when it is pumping. The student should check to insure that the plume is entirely contained within the capture zone. If not, the student can click on the Back button to start over. If the plume is entirely within the capture zone, the student should click on the Next button to proceed. The student will be prompted to locate the injection well on the site map. Clicking on the desired location installs the well and changes the shape of the capture zone from parabolic to ellipsoidal (Figure 15). As in the previous step, the student should check

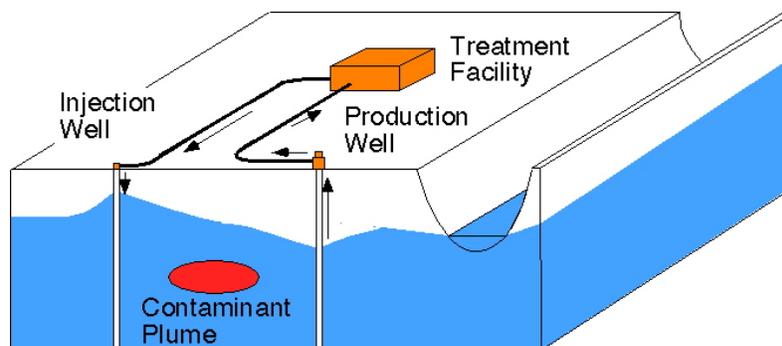


Figure 14. The pump-and-treat remediation system with a treatment plant.

to insure that the plume is entirely within the capture zone. If the resulting production/injection well couplet appears to be properly sited, the student clicks the Submit button and a dialog box will appear. If the expense is acceptable, the student may proceed with operating the design for one week by clicking the Yes button. Succeeding clicks on the Keep Going button will allow the

design to operate a week at a time until the plume is removed from the ground water or the funds available for remediation are exhausted. To try another design based on this or another technology, click on the Roll Back button.

The rules of the simulation: The consultant is provided with a \$1,000,000 budget to install, operate, and maintain a remediation design. Table 1 is a schedule of capital and operation & maintenance costs associated with each technology. It takes 3 weeks to install and begin operation of the remediation design once the student has submitted it to the management team of the consulting company. The management team must approve the design, order and receive all the materials and equipment needed for the project, and obtain approval by the state environmental protection agency.

Map View: Exiting from Map View: Click the Exit button below the site map or in the upper right-hand corner of the Map View window.

Map View: Start Over in Map View: Some students will find it necessary to start the Locate the Plume simulation over because of difficulties in successfully achieving the objective for the simulation.

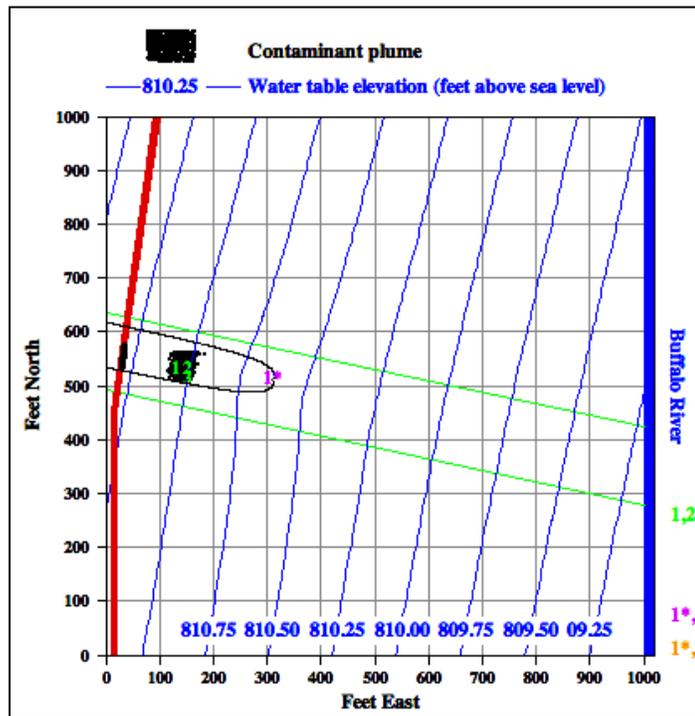
To restart the simulation click on the Start Over button located in the upper right corner of the Map View window with the left mouse button (PC) or the mouse button (Mac). When this button is clicked a new setting for the environmental problem appears in Map View with ground-water flow, hydraulic conductivity, and porosity fields that differ from the previous setting.

What Students Need to Have Been Exposed to Before Using the Plume Busters Software?

The following is a list of the topics that students should be exposed to prior to working with the interactive ground-water tutor:

- Hydrologic cycle,
- Rocks and minerals,
- Porosity of earth materials,
- Hydraulic conductivity of earth materials,
- Hydraulic head,
- Hydraulic gradient,
- Darcy's law,
- Distance, time, and velocity relationships,
- Interpretation of simple water-table elevation maps to determine ground-water flow direction,
- Ground-water flow systems,
- Ground-water quality,
- Cone of depression,
- Cone of impression,
- Capture zone,
- Zone of influence,
- Remediation, and
- Basic chemistry, including redox reactions

A.



B.

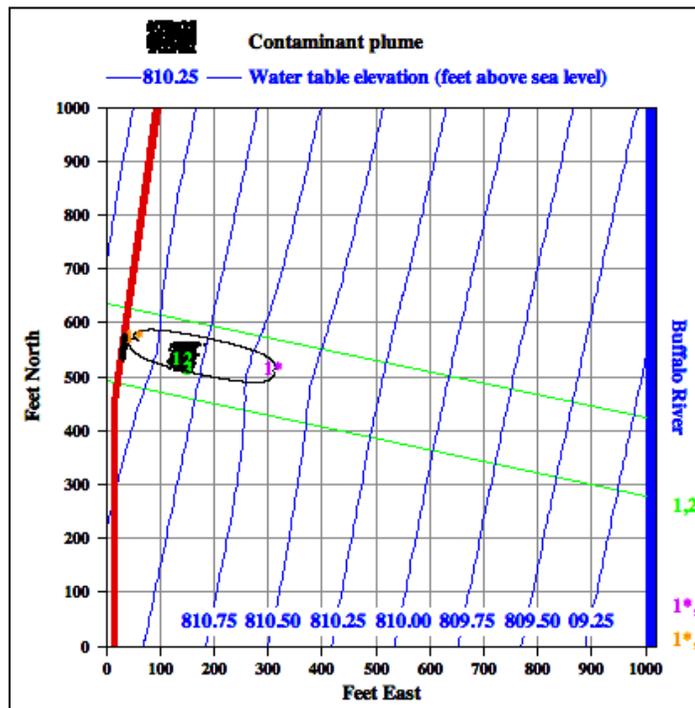


Figure 15. The capture zone that results from installing (A) a production (extraction) well and (B) an injection well couplet.

Table 1. Capital and operation and maintenance costs associated with each technology.

Remediation Technology	Capital Cost (one-time expense)	Operation and Maintenance Cost
Permeable Reactive Barrier	Construction Cost: \$7,143 per linear foot of barrier	Weekly routine monitoring: \$4,500
In Situ Redox Manipulation	\$4,000 per injection well	Sodium Dithionite injection, retrieval, and disposal: \$4,100 per well (one time expense) Weekly routine monitoring: \$4,500
Pump & Treat with the Forager™ Polymer	\$37,000 per pumping/injection well couplet and the treatment plant \$50,000 for equipment	\$29,000 for the treatment building Weekly routine monitoring: \$4,500

Summaries of most of these topics that apply to the simulations are covered in the HTML-linked pages under the References and What to Do tabs.

What Basic Skills Do Students Need to Have before Using the Plume Busters Software?

The following is a list of the skills that should be helpful to students to working with the Plume Busters software:

- Map reading
- Map scales
- Interpretation of x,y-graphs
- Interpretation of time limes
- Estimation based on reference points or standards
- Operation of personal computers with Windows-based operating systems
- Measurement units, English and metric

Helpful Hints for the Instructor

Locate the Plume Simulation

Making decisions based on analysis of uncertain data is a dominant theme in this simulation. To start the search for the plume, the student must decide where to install the first monitoring well in

the Map View map grid. To simplify the problem of monitoring-well placement, the student is informed that the plume moves advectively with the ground water even though there is some built-in dispersion in the model due to heterogeneity of the aquifer properties fields. Retardation and aquifer material/water chemical reactions are not factors in the chromium transport through the aquifer. Thus, the basis for the student's decision is the average groundwater velocity, the estimated time of travel of the leading and trailing edges of the plume, and the path taken by the plume from the pipeline break to the river. The average groundwater velocity is calculated from the hydraulic conductivity, hydraulic gradient, and porosity. A rough estimate of hydraulic conductivity, and the approximate timeline of events related to the spill can be found in the Critical Information for Locating Plume table of the Data Repository. The hydraulic gradient and its direction based on the water table are listed at the bottom of the map grid in Map View. The initial porosity must be derived from off-site information and values representative of the sediments found in alluvial aquifers. The approximate path that the plume will follow is provided in Map View. However, the plume is small target relative to the width of the outlined path and heterogeneity may cause the plume trajectory to deviate slightly from that path.

With each monitoring-well installation, new hydraulic conductivity and porosity information become available presumably from laboratory tests on samples collected during drilling and from single-well hydraulic tests using the newly installed wells. As a default, the write-up in the HTML-linked pages coaches the student to update the average groundwater velocity as new information is developed. However, the student has the option of not using this new information to revise the estimate of average groundwater velocity if he chooses. The hydraulic conductivity and porosity fields are spatially variable and values of these properties will change from one well installation to next. Thus, the student must decide the best use of any new data to reduce uncertainty in the estimated travel distance. As part of the introduction to the software the instructor should feel free to encourage the student to explore the significance of this uncertainty as part of the simulation.

Students need to be reminded that average ground-water velocities are low in comparison to the movement of water in a stream. Average groundwater velocities in sandy aquifers are typically on the order 1-2 feet/day. Use of the Calculator to estimate this parameter and the travel distances should reinforce this generalization.

The student is provided with a \$50,000 budget in the Locate the Plume simulation. Some will use up their allotted budget without achieving their objective in this simulation. In the upper right hand corner of Map View, the student can click on the Start Over button, which resets the entire problem, including the location of the pipeline break and the groundwater flow, hydraulic conductivity and porosity fields.

Remediate the Plume Simulation

When environmental consulting companies plan for the remediation of contaminated aquifers, it is seldom that only one technology is found to be appropriate for aquifer clean up. Each technology will have its advantages, disadvantages, and costs that to be selected for use must be consistent with site conditions and the most cost-effective for the client. This evaluation process is one of the most challenging aspects of environmental consulting because of the need to balance cost against environmental restoration and protection.

The Remediate the Plume simulation is a scoping exercise that involves 3 appropriate technologies that take differing approaches to remediation. The student's task is to use Map View to design the most cost-effective, on-site remediation system for each technology and use the results of their simulated operation and other data contained in the Resources and References tabs to choose the best overall design. In design the student must consider: (1) placement of the production/injection well couplet with respect to the plume and pumping/injection rates for the P&T installations; (2) placement and length of the barrier with respect to the plume in the PRB installation; and (3) placement of the wellfield with respect to the plume and the number of injection wells to be installed in the ISRM installation. Factors to consider for evaluation of cost-effectiveness include capital costs and total cost of operation and maintenance from start to completion of the aquifer remediation.

The Consultant's Letter Report

In the role of environmental consultant, the student must present well-reasoned arguments in the consultant's letter report to support his assessment of the most cost-effective remediation design that will clean up the aquifer. One of the objectives that must be achieved along the way is to determine which of the 3 technologies is the most appropriate for the problem at hand. The acceptability of the featured remediation technologies by environmental regulatory agencies is not specifically addressed in the software, but it is a consideration that the student should keep in mind while completing his report. As a general rule, regulatory bodies must be convinced of a technology's effectiveness to remediate an environmental problem before they will approve its use. P&T uses a treatment plant to remove contaminants from the pumped contaminated ground water and is a well-established technology. Regulatory agencies have more experience with P&T installations than they do with either PRB or ISRM installations. However, the selected treatment process used in P&T relies on the adsorptive properties of a polymer in the Forager™ sponge, which has not been widely used for remediation of contaminated ground water. The ISRM technology is new and has been used in only a few documented instances and use of PRB technology has been more widely reported since the 1990s. The included pdfs of articles in the HTML-linked pages should be used to support any recommendations made by the student based his evaluation of different on-site remediation designs.

Using The Tracking Log and Supporting Graphics

At the bottom of the Map View window a tracking log records all actions taken by the student and their results (Figure 2). Following each action-result set entry there is a Comment section in which the student can make notes about the progress of the simulation or record other information. In parallel, the software records the action-result set entries and any text entered by the student in a text file, gwActionLog.txt. The software places the file on the computer's Desktop where the text can be readily imported into a word processor and combined with screen capture (OS-10 or higher) or print screen (Windows) images.

The student should use the tracking log and the saved screen captures (OS-10 or higher) or print screens (Windows) of each design to document progress through the simulation. If he combines the text from the tracking log with the saved screen captures, this tells a story that can be easily turned into the consultant's letter report.

Assessment

Formative Assessment

In the Locate the Plume simulation, multiple-choice and true-false questions are interspersed throughout the HTML-linked pages to assess the student's understanding of the content in the HTML-linked pages (formative assessment). Failure to select the correct answer takes the student back in the page sequence to a point just before the subject of the incorrectly answered question is discussed. This process is repeated until the student answers correctly.

In the introductory section of Plume Busters one question is posed to assess understanding of why it is important to resolve the pipeline spill problem:

Question 1: It is important that you succeed in removing the contamination from the aquifer because:

- A. River City's water supply is located upstream of the pipeline break and will become contaminated by chromium from seeping into the Buffalo River.
- B. River City's wellfield will be rendered unusable by the chromium contained in the plume and they will have to rely on surface water sources for their supply.
- C. Chromium is harmful to aquatic organisms in the Buffalo River.
- D. River City's water supply is located downstream of the pipeline break and will become contaminated by chromium from the spill seeping into the Buffalo River.
- E. Both C and D

Selection E is the correct answer to the above question.

In the HTML-linked pages for the Locate the Plume simulation 7 formative assessment questions are posed to the student:

Question 2: To roughly estimate the distance traveled by the leading edge of the plume through the aquifer from the pipeline break:

- A. You have to know when the contamination first reached the water table.
- B. You have to know when the aquifer stopped receiving contamination from the source.
- C. It is convenient to assume that the contamination is moving with the same velocity as the ground water.
- D. Both A and C

Selection D is the correct answer to the above question.

Question 3:

Plume Busters Calculator

Average Groundwater Velocity (feet/day) = 100 x Hydraulic Conductivity (feet/day) x Hydraulic Gradient (feet/foot) / Porosity (%)

1.417 = 100 x 250 x 0.0017 / 30

Calculate

Examine the graphic of the Calculator above. If the hydraulic gradient were twice the value indicated, the average groundwater velocity would:

- A. Decrease by a factor of 0.5
- B. Increase by a factor of 2
- C. Remain the same
- D. Decrease by a factor of 2

Selection B is the correct answer to the above question.

Question 4: Suppose the pipeline spill was discovered on September 10, 2006, and from the records it appears that the pipeline break probably happened on July 15, 2006. Your first monitoring well will be installed and sampled on October 15, 2006. What is the maximum length of time that the contaminants have been in transit through the aquifer?

- A. 82 days
- B. 92 days
- C. 87 days
- D. 97 days

Selection B is the correct answer to the above question.

Question 5: Continuing this example, at 300 days following the pipeline break the leading edge of the plume in the example should be approximately:

- A. 458 feet away from the pipeline break
- B. 469 feet away from the pipeline break
- C. 425 feet away from the pipeline break

D. 497 feet away from the pipeline break

Selection C is the correct answer to the above question.

Question 6: If the chromium concentration in the water sample is 0 at the time the monitoring well is installed, later resampling of the well is pointless and will only cost money and time.

A. True

B. False

Selection B is the correct answer to the above question.

Question 7: What is the minimum number of monitoring wells that must be installed and sampled before you can complete the Locate the Plume simulation?

A. 1

B. 2

C. 3

D. 4

Selection C is the correct answer to the above question.

Question 8:

<u>Depth From Surface</u>	<u>Earth Material</u>	<u>Porosity</u>
0 – 20 feet	Clay	50%
20 – 40 feet	Mixed silt, sand, gravel	25%

The table above is a section of a driller's log that contains a description of the different earth materials that the driller encountered while drilling a borehole for a well from the ground down to 40 feet. The third column shows the representative porosity value in percent for the earth materials listed in the log. The calculated weighted average porosity for the earth materials from the ground surface down to 40 feet is:

A. 29.5%

B. 32.5%

C. 33.3%

D. 37.5%

Selection D is the correct answer to the above question.

Because of the nature of the information presented in the Remediate the Plume simulation, the type of assessment was modified and questions of a more general nature were posed that would not be suitable for multiple choice or true-false formats. Here are some examples of the questions posed:

In the Cost section of the description of the PRB technology under the References tab:
What factors determined that the barrier height should be 35 feet?

In the Disadvantages section of the description of the ISRM technology under the References tab: The state environmental protection agency is concerned about possible dithionite contamination of the aquifer after completion of the remediation. Considering the average groundwater velocity and the reaction of the dithionite solution with the iron in the aquifer, is it reasonable to conclude that all of the chemical will be recovered by pumping? What steps would you take to assess the possibility dithionite contamination, or is that necessary?

In the Disadvantages section of the description of the P&T technology under the References tab: Based on your understanding of how the Forager™ polymer removes dissolved constituents from water, including chromium, what strategy would you use to insure that chromium-contaminated water was not being returned to the aquifer in the injection well or is this an issue? This is an issue that the state environmental protection agency will want you to cover in your letter report.

The tracking log in Map View also provides another opportunity for formative assessment because it keeps a running account of what transpired during the student's session with Map View.

Summative Assessment

The last section of the Expanded Plume Busters software invites the student to prepare a 3 to 5-page consultant's letter report with attachments to the state environmental regulatory agency using a suggested outline of what should be presented. The purposes of the report are to:

- Inform the agency of the work completed by the consultant, and
- Recommend an on-site remediation system design based on one of the 3 technologies evaluated in the Remediate the Plume simulation.

For the instructor the consultant's report should be evaluated on the basis of two considerations. The written report is (1) summative assessment, i.e., a reflection piece that allows the student an opportunity to summarize the work completed in the simulations and (2) a piece of technical writing in which the student must use technical information to convince the environmental regulatory agency that the selected design is the most cost-efficient that will clean up the ground water.

It is expected that the student will use the tracking log; the graphics saved in a word processor document; and the References, Resources, and Rules information of the HTML-linked pages to develop the report. The following is a detailed outline of what the letter report could contain:

- Date
- Recipient and address
- Salutation
- Your purpose for writing
- Brief description environmental problem you were hired to resolve
 - Problem description including the results of the work done by the emergency response team.
 - Why is it so important to clean up the chromium contamination?
- Important results
- Brief description of the site
 - Where is the site located?
 - Is there an aquifer at the site and is it used for water supply?
- Brief description of the procedures your company followed
 - How did you locate the plume?
 - How many monitoring wells did you install to locate the plume?
 - What data did you collect from the monitoring wells
 - Which remediation technologies did you evaluate?
 - What procedures did you follow to make your evaluation of the technologies and possible designs?
- Presentation of the analyses you performed and results
 - How did you locate the plume and what problems did you encounter?
 - Make comparisons between the three remediation technologies.
 - What comparisons did you make to determine the most cost-effective technology design?
 - With regard to the P & T technology, what strategy would you adopt to insure that chromium-contaminated water is not being returned to the aquifer after treatment with the Forager™ polymer?
 - With regard to the ISRM technology:
 - What is the volume of sodium dithionite solution to be injected in each well?
 - How much sodium dithionite must be added to make up the solution to be injected?
 - With an injection rate of 50 gallons per minute, how long will it take to inject solution into the aquifer?
 - Will all of the sodium dithionite solution be withdrawn from the aquifer after it has reacted with the reducible iron in the aquifer? What strategy would you use to insure this?
 - With regard to the PRB design you created, what factors determine its dimensions?
 - Where would you place monitoring wells to insure that each of the remediation designs is performing adequately?
- Discussion of the results

- What convinced you that the design you are advocating is the best?
 - Support all conclusions with evidence
- Recommendations
 - Identify the best remediation technology and describe your final design.
 - Concise statement of why these are the best choices (cost, probability of success)
- Signature and position in the company
 - The position you hold in your company is Senior Environmental Scientist or Engineer depending on your preference
- Attachments
 - All calculations
 - Screen shots of the Map View window showing
 - The monitoring well locations at the conclusion of Locate the Plume.
 - The remediation design you are advocating.

Acknowledgements

This work was funded by the National Science Foundation under the grants GEO-0424871 and DUE-CCLI -0443037. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation. We wish to thank the reviewers of this guide and the many instructors and their students for field-testing and commenting on our software.

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Resources

The ground-water part of the hydrologic cycle is difficult for students and adults to visualize and understand. Fortunately, there are many resources available in print and on the Internet to help teachers develop lesson plans and “hands-on” experiments. In this section, we present an annotated list of these resources.

Ground Water Basics

University of Illinois – Meteorologic and hydrologic information – good graphics and explanations. World Weather 2010 program – online guides to a variety of topics
[http://ww2010.atmos.uiuc.edu/\(Gh\)/guides/mtr/hyd/home.rxml](http://ww2010.atmos.uiuc.edu/(Gh)/guides/mtr/hyd/home.rxml)

Ground Water Primer – Online discussion with good graphics about the hydrologic cycle, water use and demand, water quality issues, what you can do section. Developed by:
Agricultural and Biological Engineering, Purdue University:
<http://www.epa.gov/seahome/groundwater/src/ground.htm>

USEPA Fact Flash 5 Groundwater (superfund lesson plan site) – good basic information about ground water and hydrologic cycle
http://www.epa.gov/superfund/students/clas_act/haz-ed/ff_05.htm

USEPA region 1 (New England) groundwater resources – basic ground water information with examples from New England area <http://www.epa.gov/region01/students/pdfs/gwb1.pdf>

Underground water

<http://earthsci.org/geopro/ugwater/ugwater.html> Excellent site from Australia presents graphics on ground-water occurrence, well drilling, groundwater monitoring, ground-water modeling, water quality issues, ground-water remediation, and geophysical exploration for ground water.

About NIH Image

<http://www.isat.jmu.edu/users/klevicca/Image/#Laboratories> Groundwater sand tank flow model demonstration of movement of a plume through an aquifer. Background on ground-water basics, equations for Darcy’s Law, velocity, hydraulic conductivity, and hydraulic gradient. Excellent source of information.

Water Science for Schools: Earth's water

<http://www.ga.usgs.gov/edu/mearth.html> USGS water web site for schools. Good compilation of information, ideas, and graphics to explain the water cycle and different aspects of hydrology.

Plumeflow project, Columbia University Environmental Molecular Sciences Institute, Excellent information source on use of sand tanks to teach hydrogeology concepts. Junior high lesson plan for inclusive study program on use of sand tanks for study of hydrogeology in conjunction with reading various non-fiction and fiction works (such as a Civil Action or Silent Spring)
<http://www.cise.columbia.edu/emsi/edout/sandtanks/curricula/>

Darcy's Law

Teaching Quantitative Skills in a Geoscience Context, "Darcy's Law for multiple levels in Math and Geoscience Courses" Developed by Steve Leonhardi (Math/Stats) and Cathy Summa (Geoscience) Winona State University

<http://dlesecommunity.carleton.edu/quantskills/events/NAGT02/projects/darcyslaw.pdf>

Good reference with ideas and examples for teaching Darcy's Law

Ground-Water Contamination

Groundwater Contamination by Christine McLelland – Discussion articles and questions dealing with groundwater contamination issues

http://www.geosociety.org/educate/LessonPlans/Groundwater_Contamination.pdf

Paper chromatography experiment – uses coffee filters and washable black markers (and other colors if desired) to illustrate the several colors that compose black ink. Experiment illustrates the idea of breakdown products of contaminants, and the presence of breakdown products plus parent product in an aquifer <http://www.kyantec.com/Tips/paperchromatography.htm>

USEPA region 1 (New England) Groundwater contamination pdf – good explanation of contamination issues <http://www.epa.gov/region01/students/pdfs/gwc1.pdf>

US EPA enviromapper – Enter zip code or look at sites provided under map section to see location of waste discharge and disposal sites in your area <http://www.epa.gov/enviro/html/>

USEPA Superfund for teachers and students Fact Flash 8- Information about cleanup methods for remediating aquifers http://www.epa.gov/superfund/students/clas_act/haz-ed/ff_08.htm
Simpler format than the Ground-water remediation technologies analysis center (next)

Ground-Water Remediation Technologies Analysis Center <http://www.gwrtac.org/>
Information on ground-water remediation technologies – good definitions and technical reports on the topics available for downloading.

USEPA Superfund for Students and Teachers – good background information on hazardous waste sites, contaminants, and cleanup; lots of information and lesson plans
http://www.epa.gov/superfund/students/clas_act/haz-ed/hazindex.htm

USEPA reading list on hazardous waste topics
http://www.epa.gov/superfund/students/clas_act/haz-ed/rdlist.htm

The Numbers Game (USEPA superfund for students and teachers site)– gives students insight into the meaning of parts per billion and parts per trillion
http://www.epa.gov/superfund/students/clas_act/haz-ed/numbers.htm

Hazardous waste issues in the news – good information for beginning discussion of contamination issues http://www.epa.gov/superfund/students/clas_act/haz-ed/news.htm

USEPA superfund site Fact Flash 9 – Common Contaminants – Simplified explanation of TCE (trichloroethylene) http://www.epa.gov/superfund/students/clas_act/haz-ed/ff_09.htm

Agency for Toxic Substances and Disease Registry Case Studies in Environmental Medicine
Trichloroethylene Toxicity- exposure information about TCE

<http://www.atsdr.cdc.gov/HEC/CSEM/tce/tce.pdf>

USEPA Sources of common contaminants and their health effects

<http://www.epa.gov/superfund/programs/er/hazsubs/sources.htm>

Mapping Expertise

New England USEPA Region 1 – Predicting ground water flow using contour maps

<http://www.epa.gov/region01/students/pdfs/gwb10.pdf>

USGS online Exploring maps module lesson plans for 7-12. Use of maps, making maps, navigation, information, exploration

<http://interactive2.usgs.gov/learningweb/teachers/exploremaps.htm>

USGS Earthshots: Satellite images of environmental change: photos show a variety of changes over time <http://edcwww.cr.usgs.gov/earthshots/slow/tableofcontents>

Orienteering – making a map of the school grounds in order to understand topography and maps

<http://www.en.eun.org/eun.org2/eun/en/vs-physicaleducation/content.cfm?lang=en&ov=4906>

Mapping lesson 2 – representation of elevation in 2 dimensions

<http://www.en.eun.org/eun.org2/eun/en/vs-physicaleducation/content.cfm?lang=en&ov=4907>

Discussion Topics on Environmental Issues

USEPA Suggested readings about hazardous waste disposal and cleanup

http://www.epa.gov/superfund/students/clas_act/haz-ed/rdlist.htm

Current national or Global “Problem & Solution” worksheet to help students evaluate and critique environmental articles

http://www.pbs.org/newshour/extra/teachers/lessonplans/general/global_problem_and_solution.html

Geological Society of America (GSA) Reaction Paper – help direct students to read critically and evaluate issues http://www.geosociety.org/educate/LessonPlans/s_gen.htm

Articles

Don't Use It All Up – global use and distribution of water resources

<http://www.sd5.k12.mt.us/glaciereft/aquak12.htm>

Decision process for drinking water – how water moves, how to keep it clean, costs involved good discussion questions (USEPA) <http://www.epa.gov/OGWDW/kids/decision.pdf>

USEPA Office of Ground Water and Drinking water – Myths and Realities of Ground Water

<http://www.epa.gov/OGWDW/kids/myths.pdf>

Groundwater and contamination articles written for the Portage County area in Wisconsin. Good discussion of issues and public view points.

<http://www.uwsp.edu/water/portage/teach/pieart.htm#Portage%20County%20Groundwater%20Goals%20Ready%20for%20Public%20Review>

Scientific American: Search on groundwater contamination or ground water to find articles

<http://www.sciam.com/>

Scientific American: Bad Actors rendered harmless, article about bacteria being used to break down TCE.

<http://www.sciam.com/article.cfm?articleID=000E12E6-8481-1C76-9B81809EC588EF21>

Scientific American: A Case of the Vapors – Denver, CO, dry cleaning solvents in groundwater

<http://www.sciam.com/article.cfm?articleID=00096AA4-7891-1D06-8E49809EC588EEDF>

Scientific American: Drinking Without Harm: Arsenic in Bangladesh ground water

http://www.sciam.com/print_version.cfm?articleID=0003DF8E-DABF-1C73-9B81809EC588EF21

Scientific American: In a Dry Land – Southwest US faces a dry future

<http://www.sciam.com/article.cfm?articleID=00045D04-BEA6-1C6F-84A9809EC588EF21&catID=2>

Scientific American: Out of Sight, Out of Mind - an oncoming crisis over misuse of a hidden resource – America's aquifer

<http://www.sciam.com/article.cfm?articleID=000E0D9E-B4FE-1DF7-9733809EC588EEDF&catID=2>

Scientific American: Protecting the Nation's Water Supply

<http://www.sciam.com/article.cfm?articleID=000C7709-A9E6-1C75-9B81809EC588EF21&catID=4>

Scientific American: Toxins on the Firing Range – EPA orders cleanup of unexploded ordinance

<http://www.sciam.com/article.cfm?articleID=0002772B-6643-1C74-9B81809EC588EF21&catID=2>

Smithsonian Magazine: California Scheming, Water wars in Los Angeles area

http://www.smithsonianmag.si.edu/smithsonian/issues02/oct02/water_wars.html

Smithsonian Magazine: Wastewater problem? Just plant a marsh

http://www.smithsonianmag.com/smithsonian/issues97/jul97/phenom_july97.html

Glossary

Advective – In reference to mass transport, movement with the flow unimpeded by dispersion or retardation.

Alluvial – An adjective referring to alluvium.

Alluvial aquifer – An aquifer formed by materials deposited by physical processes in river channels and on floodplains.

Alluvium – Deposits of clay, silt, sand, gravel, or other particulate materials that have been deposited by a stream in a streambed or on a flood plain.

Aquatic – Pertaining to surface water bodies.

Aquifer – A geologic formation, which contains sufficient, saturated permeable material to yield significant quantities of water to wells and springs.

Arithmetic average – the mean of a set of values computed as the sum of the values divided by the number of data values.

Average ground-water velocity – The speed and direction of travel of ground water through an aquifer. The average ground-water velocity is calculated from the specific discharge and the aquifer porosity.

Bedrock – In this case, the consolidated earth material beneath the alluvial aquifer.

Biosphere – The realm of living things on Earth.

CCA – Used as a wood preservative with a chemical composition of copper **chromate arsenate**.

Capture zone -- The area contributing to flow to a well. The shape of the capture zone depends on the average linear ground-water velocity, the rate at which the well is being pumped, and the hydraulic conductivity of the aquifer. The upgradient extent of the capture zone depends on how long the well is being pumped.

Concentration – The amount of contaminant (or other constituent) in a given volume of water, often as milligrams per liter (mg/L).

Cone of depression – The depression, roughly conical in shape, produced in a water table by the extraction of water from a well at a given rate. The size of the cone of depression depends on the duration of pumping, the pumping rate, and the hydraulic conductivity, specific yield, and thickness of the aquifer.

Cone of impression -- A rise, roughly conical in shape, produced in the water table from the addition of water from an injection well at a rate that is faster than the ability of the aquifer to

transmit the water away from the well. The size of the cone of impression depends on the duration of pumping, the pumping rate, and the hydraulic conductivity, specific yield, and thickness of the aquifer.

Contaminants -- Anything found in water (including microorganisms, minerals, chemicals, radionuclides, etc.), which may be harmful to human health.

Contamination – The degradation of natural water quality beyond permissible limits as a result of man's activities. Such limits depend on the potential uses of the water in question.

Contaminant plume – An elongate zone of moving contaminated water in surface or ground water moving away from the contaminant source.

Contour – In this instance, a line along which the elevation of the water table is constant.

Darcy's law – A mathematical equation stating that the flow rate of water through porous materials is proportional to the hydraulic gradient. The constant of proportionality is the hydraulic conductivity.

Discharge – The volume of water that passes a given location within a given period of time. Usually expressed in cubic feet per second or gallons per minute.

Dispersion – A spreading of the plume in three dimensions as it moves through a porous medium.

Downgradient – Toward areas of lower hydraulic head or toward the discharge area or in the direction of ground-water flow.

Drawdown – The lowering of the water table caused by pumping, measured as the difference between the original water table elevation and the current elevation after a period of pumping.

Driller – a person who uses a drilling rig

Driller's log – A log kept at the time of drilling showing the depth, thickness, character of the different rock strata penetrated, and location of water-bearing strata.

Environmental consultant – A professional who directs the clean-up of environmental contamination or pollution for hire.

Finite-Difference Formulation – A method used to produce approximate a numerical solution to a partial differential equation, in this case the equation that describes the flow of ground water through a porous medium.

Formative Assessment– An evaluation of the progress of a process, such as learning.

Flowpath – An underground route for ground-water movement, extending from a recharge (intake) zone to a discharge (output) zone such as a shallow stream.

Ground water – (1) water that flows or seeps downward and saturates soil or rock, supplying springs and wells. The upper surface of the saturate zone is called the water table. (2) Water stored underground in the pores of geologic materials that make up the Earth's crust..

Ground-water flow system – The underground pathways by which ground water moves through several aquifers that are linked together from areas of recharge to areas of discharge.

Heterogeneous – Non uniform or mixed.

Hydraulic conductivity – The capacity of a rock to transmit fresh water, expressed usually as feet per day or meters per second.

Hydraulic gradient – The slope of the water table which determined as the change in hydraulic head per unit distance in a given direction.

Hydraulic head – The elevation of the water level in wells penetrating an aquifer and in this case, it is equivalent to the elevation of the water table. Also, the elevation of the water surface in surface water bodies, such as lakes and streams.

Hydrograph – In this instance, a record of water-level fluctuations in a well over time.

Hydrologic cycle -- The continuous movement of water between the atmosphere, lithosphere, and biosphere.

Hydrosphere -- That part of the earth that contains all of the water reservoirs and the hydrologic cycle on Earth.

ISRM – In situ redox manipulation.

In Situ Redox Manipulation – A process in which a treatment zone is established chemically within an aquifer by the reduction of ferric (Fe^{+3}) to ferrous (Fe^{+2}) iron for purpose of remediation using redox chemical reactions.

Injection well -- A well used to pump or drain fluids, such as treated water, into an aquifer.

Ion – An atom or molecule which has lost or gained one or more electrons, making it positively or negatively charged.

Liter (L) – A volume slightly larger than a quart and equal to approximately 0.26 gallons.

Lithosphere – The solid outer part of the planet Earth. Composed of rock usually considered considered to be the outer 50 mi (80 km) in thickness.

Maximum Contaminant Level (MCL) – (1) The greatest amount of a contaminant that can be present in drinking water without causing a risk to human health. (2) Maximum permissible level of a contaminant in water that is delivered to any user of a public water system. MCLs are enforceable standards established by the U.S. Environmental Protection Agency. EPA sets MCLs at levels that are economically and technologically feasible. Some states set MCLs which are more strict than EPA's.

Monitoring – (1) Repeated observation, measurement, or sampling at a site, on a scheduled or event basis, for a particular purpose. (2) Testing that water systems must perform to detect and measure contaminants. A water system that does not follow EPA's monitoring methodology or schedule is in violation, and may be subject to legal action.

Monitoring well – A well designed for measuring water levels and testing ground-water quality.

Native Groundwater Chemistry – The totality of the dissolved and suspended constituents in uncontaminated ground water.

Non-point Source – In reference to contamination, more than one source or a spatially distributed set of sources from which the contaminant emanates.

Oxidation – The loss of electrons from a molecule, atom, or ion.

Oxidation State – The oxidation state is an indicator of the degree of oxidation of an atom in a chemical compound. The formal oxidation state is the hypothetical charge that an atom would have if all bonds to atoms of different elements were 100% ionic. Oxidation states are represented by Arabic numerals and can be positive, negative, or zero.

P&T – Pump and treat.

PRB – Permeable reactive barrier.

Permeability – The ability of a material to allow the passage of a liquid, such as water through rocks. Permeable materials, such as gravel and sand, allow water to move quickly through them, whereas slightly permeable material, such as clay, does not allow water to pass through it freely.

Permeable – Capable of transmitting water (porous rock, sediment, or soil).

Permeable Reactive Barrier – A constructed wall with a permeable reactive zone containing elemental iron or other chemically active material and placed within an aquifer for the purpose of passively remediating contaminated ground water.

Plume – See contaminant plume.

Point-source – In reference to contamination, a specific single clearly identifiable source from which the contaminant emanates.

Pollutant – Any substance that, when present in a hydrologic system at sufficient concentration, degrades water quality in ways that are or could become harmful to human and/or ecological health or that impair the use of water for recreation, agriculture, industry, commerce, or domestic purposes.

Porosity – The ratio of the pore or void space to the total volume occupied by a material. With respect to water movement, it is not just the total magnitude of porosity that is important, but the size of the voids and the extent to which they are interconnected, as the pores in a formation may be open, or interconnected, or closed and isolated. For example, clay may have a very high porosity with respect to potential water content, but it constitutes a poor medium as an aquifer because the pores are usually so small.

Precipitate – An product of chemical reaction that has a low solubility in water.

Production well – A well used to withdraw water or fluids from an aquifer.

Production-injection well couplet – Used to withdraw contaminated water from the aquifer (production well) and installed down gradient of the plume and return treated water to the aquifer (injection well) up gradient of the plume.

Pump-and-treat method – This is the most common method of aquifer remediation.

Contaminants are removed from the aquifer by means of a production well. They produced water is treated to remove the contaminants and the treated water is returned to either a surface water body or the aquifer.

Pumping rate – The rate at which water is being withdrawn from an aquifer by a well.

Redox – An abbreviated form of a class of electrochemical reactions based on oxidation of one component and reduction of the other.

Reducing agent – An element or a compound in a redox (reduction-oxidation) reaction that donates electrons to another element or compound.

Reducible Iron Content – In the case of ISRM, the amount ferric (Fe^{+3}) iron in the aquifer materials.

Reduction – The gain of electrons by a molecule, atom, or ion.

Remediation system – the entirety of the physical plant including wells, piping, treatment plant, and other installations constructed and assembled for the purpose of cleaning up contamination.

Quartz – A mineral with the chemical composition of silicon dioxide (SiO_2).

Recharge – (1) Water added to an aquifer. (2) Process by which water is added to the zone of saturation to replenish an aquifer.

Remediation – Removal of the source of contamination and treatment of the ground water, the aquifer materials, or both to remove the contaminants in the water.

Retardation – A slowing of the movement of the plume through an aquifer due to adsorption of the contaminant onto aquifer material surfaces.

Single-well Hydraulic Tests – Tests conducted to estimate aquifer properties by monitoring the recovery of water levels back to the starting level caused by artificially raising or lowering the water level in a well.

Soil – The uppermost layer of the Earth's surface, containing unconsolidated rock and mineral particles mixed with organic material.

Source-water Assessment – A means by which the source of water for a public water supply and the potential sources of contamination that might threaten it are identified.

Summative Assessment – An evaluation of the end result of a process, such as learning.

Superposition – The net change in water table elevation caused by withdrawing water through a production well and adding water through a nearby injection well to the aquifer.

Treatment plant – Fabricated machinery designed to chemically or physically remove contamination from water.

Upgradient – Toward areas of higher hydraulic head or the recharge area or moving in the direction opposite to that of ground-water flow.

Water quality – The fitness of water for use being affected by physical, chemical, and biological factors.

Water sample – A small volume of water collected from a surface- or groundwater source that is chemically and physically representative of the larger water body.

Water supply – All of the processes that are involved in obtaining water for the user before use. Includes withdrawal, water treatment, and distribution.

Water table – (1) The level below the earth's surface at which the ground becomes saturated with water. (2) The top of an unconfined aquifer; indicates the level below which soil and rock are saturated with water.

Water-table Elevation – The height of the water table above sea level.

Water well – a cased or uncased boring from which water is withdrawn.

Weighted average – The mean of a set of values in which the relative importance of each value is taken into account using a weighting factor.

Well hydraulics – A body of knowledge that pertains to the flow of ground water toward a production well or away from an injection well.

Wellfield – The layout of production or production and injection wells.

Wellfield design – The act of planning the layout of production or production and injection wells based on the effects of pumping or injection on the aquifer and the contaminant plume. Pumping/injection rates are usually considered as part of the wellfield design. Placement of the wells is usually governed by the desired effect, such as controlling the movement of a contaminant plume.

Wellhead Protection Zones – An area where local regulations are in place prohibiting or restricting human activities that might lead to contamination of a public water supply's groundwater source, usually the recharge area.