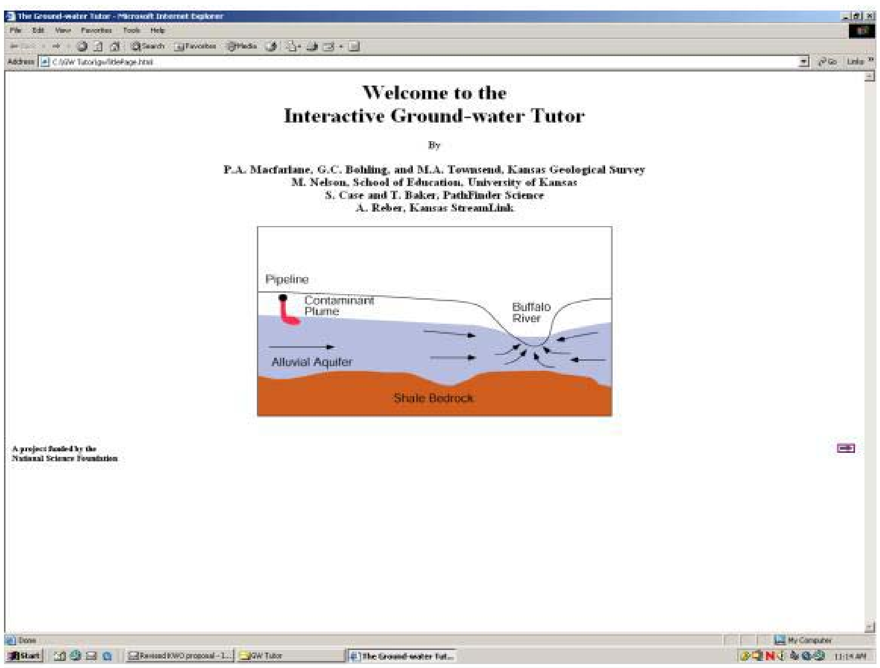
Kansas Geological Survey

A PRELIMINARY TEACHER'S GUIDE TO THE INTERACTIVE GROUND-WATER TUTOR

By

P. Allen Macfarlane, M.A. Townsend, G. Bohling, S. Case, and A. Reber



Kansas Geological Survey Open File Report 2003-65

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Preface
The Interim Teacher's Guide to the Ground-water Tutor is designed for use with the interactive ground-water tutor during the alpha and beta testing and development stages in the formulation of the prototype, eventually Web-based software. In its final form, the manual will contain more information on assessment rubrics that can be used by teachers to evaluate student science learning as well as well as the results of the evaluations conducted as part of this NSF-funded project.

Users are advised to read the Computer System Requirements section of the manual prior to loading the software. This section provides operating system requirements, suggested browsers for viewing the HTML pages, and screen resolution control settings. The software and installer are contained on the CD that accompanies this manual. Prior to downloading and installing from the CD, the installer checks your operating system to determine if the JAVA programming language is present. If not, the installer comes with JAVA and will install it as part of the process.

The ground-water tutor is in two parts: a set of HTML pages that have been grouped into sections, some of which have been linked in sequence to guide the student through introductory material; and a JAVA-based ground-water model that simulates the flow of water and the movement of contaminants through an aquifer. The software is also divided into Phase 1 and Phase 2. These are sequential and with the completion of Phase 1 the student moves on to Phase 2.

The software is designed in such a way that it is not necessary to read through the teacher's guide prior working through the ground-water tutor. Adequate directions are provided in the HTML pages that this step is not necessary. Starting the ground-water tutor involves opening the HTML file, gwTitlePage. The JAVA application (gwTutor) can be opened at this stage but it is not necessary. These files can be found by scrolling down through the GW Tutor directory.

For teachers, the manual (1) identifies the science, environmental science, mathematics, and geography standards addresses by the tutor, (2) describes the student role-play, (3) outlines the sequence of operations followed as the student progresses through the tutor, (4) provides useful information on how best to integrate the software in earth and environmental science classes and (5) gives teachers tips to help guide students through the tutor. Terms that might be unfamiliar to users are underlined and defined in the Glossary at the back of this guide.

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

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A PRELIMINARY TEACHER'S GUIDE TO THE INTERACTIVE GROUND-WATER TUTOR

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Overview

Using the interactive ground-water tutor, students take on the role of an environmental consultant and apply the principles of ground-water flow and well hydraulics to solve a simulated contamination problem. Introduction of the tutor should follow basic instruction covering the hydrologic (water) cycle, the principles of ground-water flow, and concepts related to the effect of wells withdrawing or adding water on an aquifer. Follow-up activities can range from discussion of environmental policy and ethics to the role of technology in solving societal and environmental problems. The tutor is appropriate for grade 11-12 and introductory, undergraduate Earth and Environmental Science classes.

Students use ground water and other science, mathematics, and geography concepts to simulate the cleanup of a chemical spill from a ruptured pipeline. The chemical spill has contaminated an aquifer and if unchecked, the contaminants will travel through the aquifer from the spill site, seep into a nearby river, and pollute a downstream public water supply. In this exercise, the student plays the role of an environmental consultant hired by the pipeline owner solve this environmental problem. The consultant's objective is to eliminate the contamination from the aquifer in the shortest amount of time for the least cost to the pipeline owner. Well installation, chemical analyses of water samples from wells, and operation of the wells used for remediation have associated with them time and money costs and in some cases, regulatory requirements also have an associated time cost. In the first phase of the tutor, the student uses the concepts of hydraulic gradient, the porosity and permeability properties of aquifer materials, Darcy's law, and average ground-water velocity to estimate the location of the contaminants in the aquifer at any given time. Locating the contamination requires the student to install monitoring wells in the aquifer. In the second part of tutor, the student uses the concepts of cone of impression, cone of depression, zone of influence, and capture zone to design a wellfield to remove the contaminants from the aquifer. The wellfield consists of production wells or a production well/injection well couplet and as it is operated, students observe the simulated removal of the contaminants from the aquifer. The ground-water tutor gives students the opportunity to apply their knowledge of ground-water systems in the context of a simulated real-world situation.

Science and Environmental Policy Context

Water is temporarily stored in a number of different reservoirs and moves from one reservoir to another in a hydrologic cycle that encompasses the atmosphere, biosphere, and lithosphere (Figure 1). Water cycles within the hydrosphere by solar-driven evaporation from the oceans and other water bodies, evaporates from near the atmosphere/lithosphere boundary, and through transpiration and respiration from the biosphere, replenishes the atmospheric reservoir. Precipitation transports water back to the earth's surface where it either infiltrates into the subsurface or runs off to streams, lakes, and eventually the oceans. That portion of water that infiltrates into the subsurface below the root zone of plants may eventually reach the water table and recharge the ground-water system.

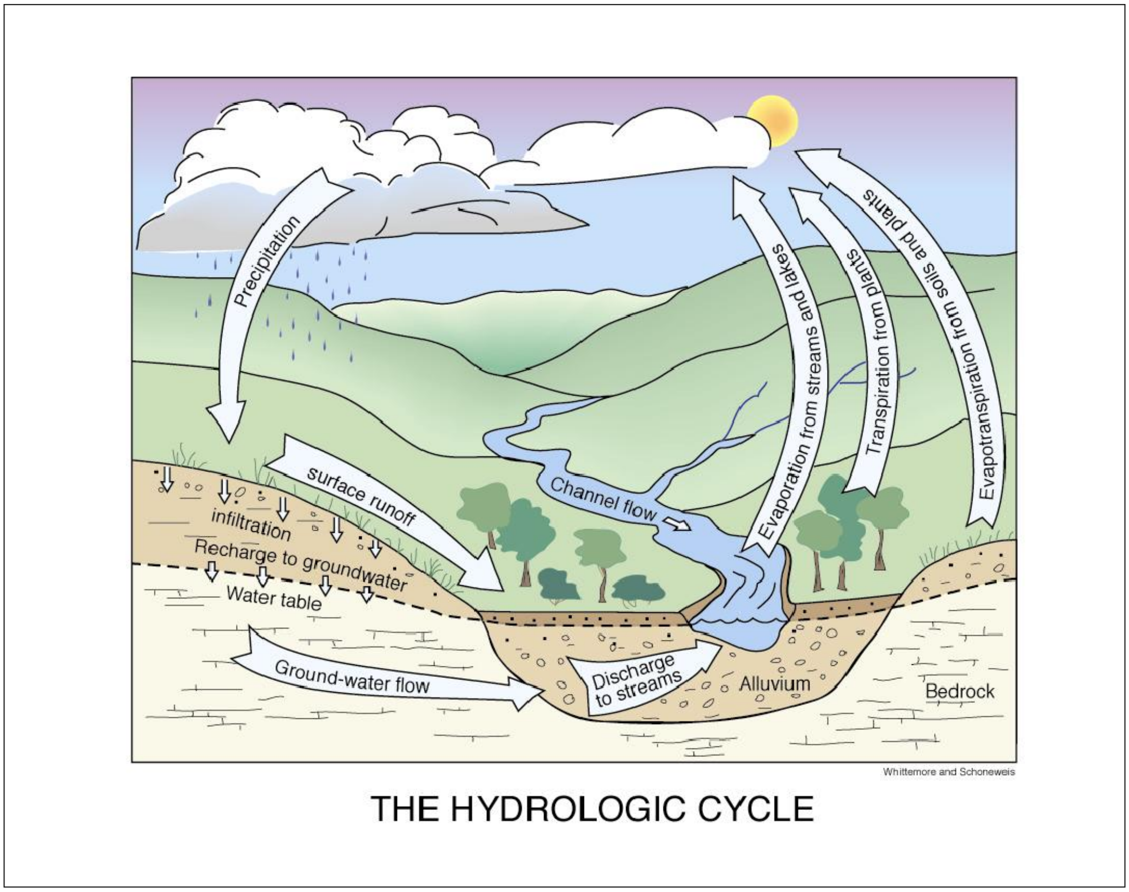


Figure 1. The drainage basin hydrologic cycle.

Water is the elixir 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. Water is needed for everything from daily consumption to food and energy production. Ground water plays a significant role since it accounts for approximately 25% of all the freshwater near the Earth's surface with much of the rest stored as ice in polar ice caps and glaciers. Of the available freshwater to the majority of human society, ground water represents 94% of the total. In the United States ground water accounts for 25% of all water resources utilized by industrial society. Aquifers also supply approximately 51% of the drinking water consumed in the United States (US EPA, 1998). These sources of water are under increasing pressure because of contamination as a result of human activity.

Public perception of the issues surrounding ground-water use and protection from contamination is lacking because, unlike water bodies at the Earth's surface, ground water cannot be observed directly in most cases. Contrary to the public perception of water flowing in underground rivers, ground-water typically moves at rates that are orders of magnitude lower than rates for water in streams and is generally not confined to discrete channels. This inability to visualize how water flows through aquifer systems from areas of recharge to areas of discharge 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. Figure 2 is a concept map of the Buffalo River drainage and the human impacts simulated in the ground-water tutor.

Secondary Education Standards

The interactive ground-water tutor addresses both federal and state science education standards and the Kansas mathematics, environmental science, and geography education standards. The National Science Education Standards (NAS, 1996) for grades 9-12 state that students should develop an understanding of the geochemical cycles and the role of water as a carrier of material (Earth and Space Science Content Standard D, p. 187). Under the Science in Personal and Social Perspectives Content Standard F (p. 193) students are to develop an understanding of the impact of human activity on natural resources and environmental quality through control of the hydrologic cycle and disposal of wastes. Under this standard, understanding of basic concepts and principles of science and technology should precede active debate of science- and technology-related issues.

Tables 1-4 identify the Kansas science, mathematics, environmental, and geography education standards, benchmarks, and indicators relevant to the ground-water tutor.

What Students Gain from Working through the Ground-water Tutor

The benefits to the student from working with the ground-water tutor are fivefold.

First, the tutor forces the student to draw on concepts from geology, geography, ground-water science, mathematics, and economics to remedy this environmental problem. By drawing on the concepts from these diverse sources, the student can begin to see how these disciplines fit together as an integrated body of knowledge and tools.

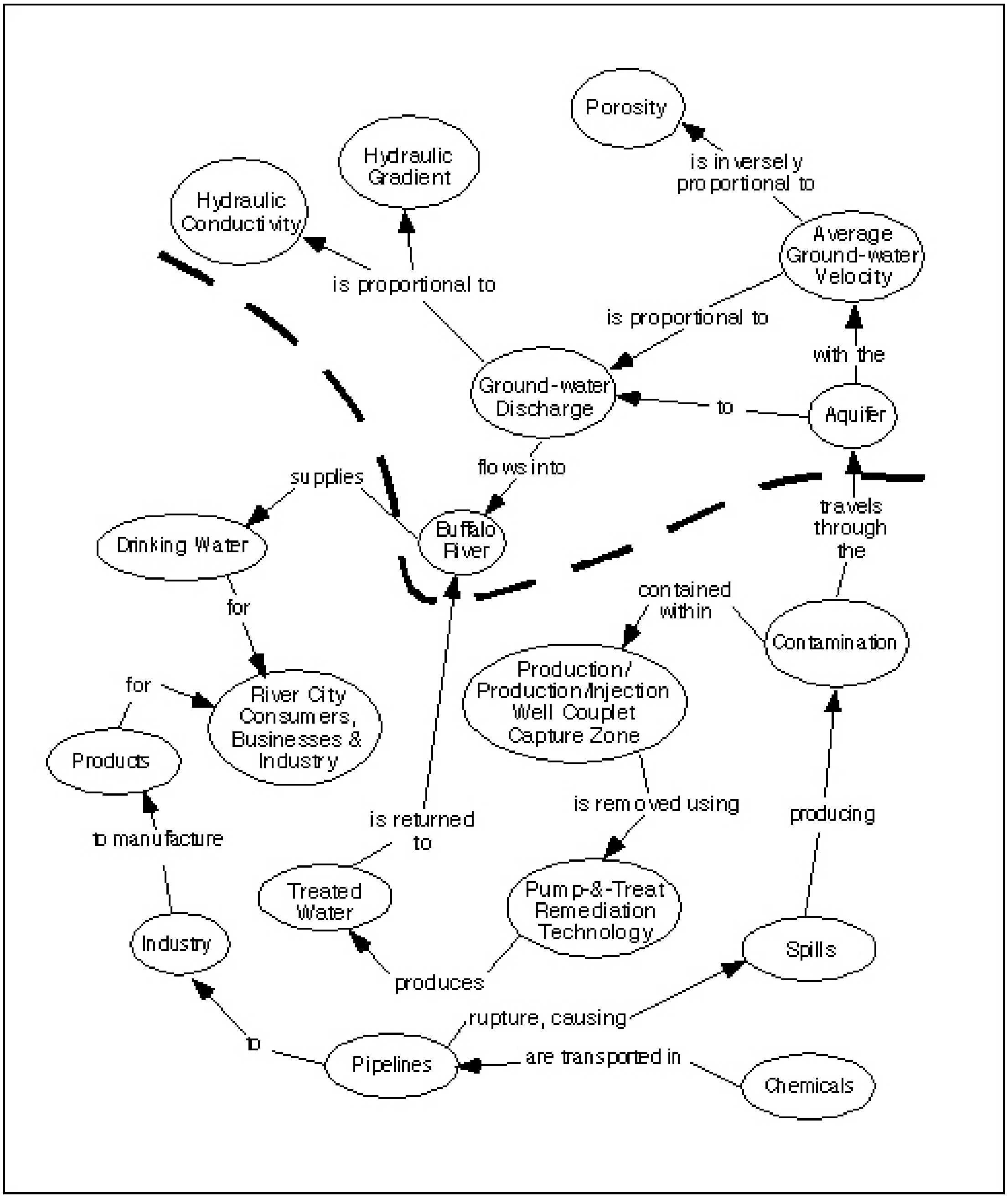


Figure 2. Concept map of the water cycle in the human-impacted Buffalo River drainage basin as it is portrayed in the ground-water tutor. The linked concepts above the dashed line represent the surface and ground-water parts of the basin hydrologic cycle that are pertinent to the tutor. The linked concepts below the dashed line represent human impacts portrayed in the ground-water tutor.

Table 1. Kansas science education standards, benchmarks, and indicators relevant to the ground-water tutor. (Excerpted and adapted from Kansas State Board of Education, 2001)

	Standard	Benchmark	Indicator
By the end of 8th grade	Science As Inquiry	Benchmark 1: Demonstrate abilities necessary to do the processes of scientific inquiry	Design and conduct a scientific investigation Use appropriate tools, mathematics, technology, and techniques to gather, analyze, and interpret data Apply mathematical reasoning to scientific inquiry Differentiate between a qualitative and a quantitative investigation
		Benchmark 2: Apply different kinds of investigations to different kinds of questions	Develop questions and adapt the inquiry process to guide an investigation
	Earth and Space Science	Benchmark 1: Develop an understanding that the structure of the earth system is constantly changing due to the earth's physical and chemical processes	Model earth's cycles
	Science in Personal and Environmental Perspectives	Benchmark 2: Develop an understanding of the impact of human activity on resources and environment	Investigate the effects of human activities on the environment
	History and Nature of Science	Benchmark 1: Develop scientific habits of mind	Base decisions on evidence
By the end of 12th grade	Science As Inquiry	Benchmark 1: Demonstrate the fundamental abilities necessary to do scientific inquiry	Use technology and mathematics to improve investigations and communications Formulate and revise scientific explanations and models using logic and evidence
	Earth and Space Science	Benchmark 2: Develop an understanding of the actions and interactions of the earth's subsystems: the geosphere, hydrosphere, atmosphere, and biosphere	The students will understand the processes of the carbon, rock, and water cycles.
	Science in Personal and Environmental Perspectives	Benchmark 1: Develop an understanding of the overall functioning of human systems and their interaction with the environment in relation to specific mechanisms and processes related to health issues	The students will understand that hazards and the potential for accidents exist for all human beings.
		Benchmark 3: Develop an understanding that human populations use natural resources and influence environmental quality	The students will understand that materials from human activities affect both physical and chemical cycles of the earth.
		Benchmark 4: Develop an understanding of the effect of natural and human-influenced hazards	The students will understand that there is a need to assess potential risk and danger from natural and human-induced hazards.
		Benchmark 5: Develop an understanding of the relationship between science technology, and society	The students will understand that understanding basic concepts and principles of science and technology should precede active debate about the economics, policies, and ethics of various challenges related to science and technology.

Table 2. Kansas environmental education standards, benchmarks, and indicators relevant to the ground-water tutor. (Excerpted and adapted from Kansas Association for Conservation and Environmental Education, 1999).

Standard	Benchmark	Indicator
Standard 1: Earth as a Physical System	Benchmark 2: Explain how the process of photosynthesis transforms the sun's energy in plants and releases oxygen into the air	Illustrate how different elements and compounds cycle through ecosystems at different rates
Standard 3: The Varied Roles and Interactions between Humans and the Environment	Benchmark 1: Analyze the relationship between individuals, groups, cultures, and the environment	Describe how the actions of businesses, community groups, and other societal organizations may bring about unintended impacts on the environment
	Benchmark 2: Analyze the relationships among laws, politics, economics, and environment	Explain human rights, economic development, public health, resource allocation, and environmental quality from the perspectives of the individual, the community, the nation, and the world
		Describe the short-term and long-term costs and benefits of addressing local, national, and worldwide environmental problems
		Describe the governmental and non-governmental roles in addressing local, national, and worldwide environmental problems
	Benchmark 3: Investigate and analyze the relationships among resources, technology, and environment	Describe how technology has influenced the quality of life
		Describe how technology has altered the natural environment
		Describe how agriculture, mining, manufacturing, energy production, highway construction, and other economic development activities have altered the natural environment in Kansas
	Benchmark 4: Identify and evaluate environmental issues from multiple points of view	Identify the various uses of soil and water in Kansas
		Identify the risks and benefits that agriculture, petroleum production, manufacturing, energy production, human communities, and other economic development activities can have on soil and water in Kansas
		Describe the problems Kansans face in regard to solid and hazardous waste disposal
Standard 4: Development of the Abilities Necessary to Conduct Scientific Inquiry	Benchmark 1: Develop the abilities necessary to conduct scientific inquiries	Identify an environmental topic to be studied using primary and secondary sources of information, and pose a research question pr hypothesis, identifying key variables
	Benchmark 2: Demonstrate scientific inquiry skills	Apply observation and measurement skills in field situations
		Gather information from a variety of sources
		Integrate and summarize information from a variety of media
Standard 5: Development of the Abilities Necessary to Participate and Make Informed Decisions Regarding Environmental Issues	Benchmark 1: Demonstrate the skills necessary to understand and communicate ideas about environmental issues	Identify and clearly articulate environmental issues and their connections to other issues
		Identify different perspectives on environmental issues and approaches to resolving them
		Discuss social, political, and economic implications of environmental issues
		Project the likely consequences of failure to resolve a specific environmental issue

Table 3. Kansas mathematics education standards, benchmarks, and indicators relevant to the ground-water tutor. (Excerpted and adapted from Kansas State Board of Education, 2003)

Standard	Benchmark	Indicator
Standard 1: Number and Computation – Use of Numerical and Computational Concepts and Procedures in a Variety of Situations		The student:
	Benchmark 3: Estimation – Computational estimation with real numbers in a variety of situations	Adjusts original rational number estimate of a real-world problem based on additional information (a frame of reference) Determines if a real-world problem calls for an exact or approximate answer and performs the appropriate computation using various computational strategies including mental math paper and pencil, concrete objects, and/or appropriate technology Explains the impact of estimation on the result of a real-world problem (underestimate, overestimate, range of estimates)
	Benchmark 4: Computation – Models, performs, and explains computation with real numbers and polynomials in a variety of situations	Generates and/or solves multi-step, real-world problems with real numbers and algebraic expressions using computational procedures (addition, subtraction, multiplication, division, roots, and powers excluding logarithms) and mathematical concepts
Standard 2: Algebra – Use of algebraic concepts and procedures in a variety of situations		The student:
	Benchmark 3: Functions – Analysis of functions in a variety of situations	Translates between the numerical, graphical, and symbolic representations of functions Interprets the meaning of the x- and y-intercepts, slope, and/or points on and off the line on a graph in the context of real-world situations
	Benchmark 4: Models – Development and use of mathematical models to represent and justify mathematical relationships found in a variety of situations involving tenth grade knowledge and skills	Uses the mathematical modeling process to analyze and make inferences about real-world situations
Standard 3: Geometry – Use of geometric concepts and procedures in a variety of situations		The student:
	Benchmark 2: Measurement and Estimation – Estimation, measurement, and use of geometric formulas in a variety of situations	Solves real-world problems by using rates of change Estimates to check whether or not measurements or calculations for length, weight, volume, temperature, time distance, perimeter, area, surface area, and angle measurement in real-world problems are reasonable and adjusts the original measurement or estimation based on additional information (a frame of reference) Uses indirect measurements to measure inaccessible objects
Standard 4: Data – Use of concepts and procedures of data analysis in a variety of situations		The student:
	Benchmark 2: Statistics – Collection, organization, display, explanation, and interpretation of numerical (rational) and non-numerical data sets in a variety of situations	Uses data analysis (mean, median, mode, range, quartile, interquartile range) in real-world problems with rational number data sets to compare and contrast two sets of data, to make accurate inferences and predictions, to analyze decisions, and to develop convincing arguments from data displays Determines and explains the advantages and disadvantages of using each measure of central tendency and the range to describe a data set

Table 4. Kansas geography education standards, benchmarks, and indicators relevant to the ground-water tutor. (Excerpted and adapted from Kansas State Board of Education, 1999)

	Geography Standard	Benchmark	Indicator
By the end of 8th grade	Spatial organization of Earth's surface	Benchmark 1: Maps and Locations: Use maps and graphic representations to locate, use, and present information about people, places, environments	Locate major physical features of Earth from memory and compares the relative locations of these features. Develop and use different kinds of maps, globes, graphs, charts, databases, and models. Evaluate relative merits of maps, graphic representations, tools and technologies in terms of value in solving geographic problems: satellite photos, Geographic information systems, aerial photographs, topographic maps. Use geographic tools and technologies to pose and answer questions about past and present spatial distributions.
		Benchmark 2: Regions: Analyze spatial organization of people, places and environments that form regions on Earth's surface	Identify and compare physical characteristics of world regions in terms of climate, topography, location and resources. Identify and explain changing criteria that can be used to define a region such as physical characteristics. Identify how technology has influenced a region (e.g. perceptions of resource availability, economic development).
		Benchmark 3: Physical Systems: Understanding of Earth's physical systems and how physical processes shape Earth's surface	Explains patterns in the physical environment in terms of physical processes (i.e. erosion and deposition, hydrologic cycle) Explains the challenges faced by ecosystems (contamination of alluvial aquifer systems; overuse of aquifers; natural disasters)
		Benchmark 5: Human-Environment Interactions: Understand the effects of interactions between humans and physical systems	Explain and analyze the role of technology in past, present, future of human modifications of environment (movement of water; water-quality alterations, contamination of aquifers) Describe local, national, international impacts of use or misuse of resources (over-consumption of water, contamination of aquifers) Evaluates viewpoints regarding use of water Identifies and develops plans for management and use of resources

Table 4. Continued

	Geography Standard	Benchmark	Indicator
By the end of 11th grade	Spatial organization of Earth's surface	Benchmark 1: Maps and Locations: Use maps and graphic representations to locate, use, and present information about people, places, environments	Locate major physical features of Earth from memory and compares the relative locations of these features. Interprets maps and other graphical representations to analyze and suggest solutions to problem (such as contamination of municipal water supply) Use geographic tools and technology to interpret and justify spatial organization.
		Benchmark 2: Regions: Analyze spatial organization of people, places and environments that form regions on Earth's surface	Student demonstrates how regional frameworks are used to interpret the complexity of the Earth (vegetation, climate, resources). Explains factors that contribute to physical changes in regions (overuse of water, contamination of water supplies)
		Benchmark 3: Physical Systems: Understanding of Earth's physical systems and how physical processes shape Earth's surface	Explain Earth's physical processes, patterns, and cycles using concepts of physical geography (hydrologic cycle, erosion, deposition) Describe ways in which Earth's physical processes are dynamic and interactive (wind and water deposition, stream and aquifer interactions) Analyze and ecosystem to understand and solve problems regarding environmental issues (groundwater-contamination, impacts of contaminants on plants and animals, water supply issues)
		Benchmark 5: Human-Environment Interactions: Understand the effects of interactions between humans and physical systems	Evaluate local-to-global impacts of technology on human modifications of the physical environment (toxic waste, farming practices, overuse of water) Evaluate alternative strategies to respond to constraints placed on human systems by physical environment (irrigation, sustainable agriculture, water diversion) Evaluates policies and programs for resource management (e.g., EPA, water-rights in western states, use of recycled water)

Secondly, to locate the contamination in the alluvial aquifer students use both qualitative and quantitative information. In this part of the tutor students also must deal with uncertainty because of the need for the student to make estimates based on qualitative information.

Thirdly, the student gains confidence from being able to solve a real-world problem. In working with the tutor, 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 the time it will take for the contamination to reach the river, but also by economic and regulatory realities.

Fourthly, the tutor also introduces the student to the application of technology to the solution of environmental problems. Using the available information, the student designs and operates a remediation wellfield to remove contamination from the aquifer. Well hydraulics is not typically included in secondary- and minimally introductory undergraduate-level earth science classes.

Thus, the tutor provides the student with an opportunity to develop a qualitative understanding of this topic.

Finally, the tutor also provides a lead-in to discussions focusing on environmental policy, including the means to achieving 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.

Science Concepts

The focus of the tutor is on the application of ground-water concepts to finding ground-water contaminants in an aquifer in Phase 1 and removing them from the aquifer in Phase 2.

To accomplish the Phase 1 task, the student uses Darcy's law and the data provided to determine the average ground-water flow velocity and the likely path taken by the contaminants from the spill site to the nearby river. To locate the contaminated ground water in the aquifer, the student must estimate how long the contamination has been moving with the ground-water flow from the spill site. This task is similar to the task faced by those who play the board game Battleship, except that the target is moving in a predictable manner. The main science concepts stressed in this part of the tutor include:

- An alluvial aquifer consists of porous and permeable materials deposited by physical processes in river channels and on floodplains that can store and transmit water at rates fast enough to supply reasonable amounts to wells (Figure 3).
- The water table is the upper boundary of an unconfined aquifer (Figure 4).
- The hydraulic head is the elevation of the water level in wells penetrating an aquifer (Figure 5). In unconfined aquifers, it is equivalent to the elevation of the water table and the elevation of the water surface in surface water bodies, such as lakes and streams (Figure 4).
- Ground water flows from regions of high hydraulic head (high potential energy) to areas of low hydraulic head (low potential energy) (Figure 5).
- The hydraulic gradient is the slope of the water table and is calculated as the change in hydraulic head per unit distance in the direction of ground-water flow (Figure 5).
- A monitoring well is a well designed for measuring water levels and testing ground-water quality.
- Hydraulic conductivity is a measure of the capacity of earth materials to transmit fresh water.
- Porosity is a measure of the relative amount of void space in earth materials (Figure 6).
- Darcy's law states that the flow rate of water through porous materials is proportional to the hydraulic gradient. The constant of proportionality is the hydraulic conductivity (Figure 7).
- The average ground-water velocity is the speed and direction of travel of ground water through an aquifer.
- Contaminants often move laterally through aquifers at the same speed and in the same direction as the ground-water flow.
- The distance traveled and the direction of movement of contaminants moving with the ground-water flow can be calculated from the average ground-water flow velocity.

The hydraulic gradient is calculated from measurements of water-table elevation in at least two wells (Figure 5). This parameter is important because ideally the direction of ground-water flow

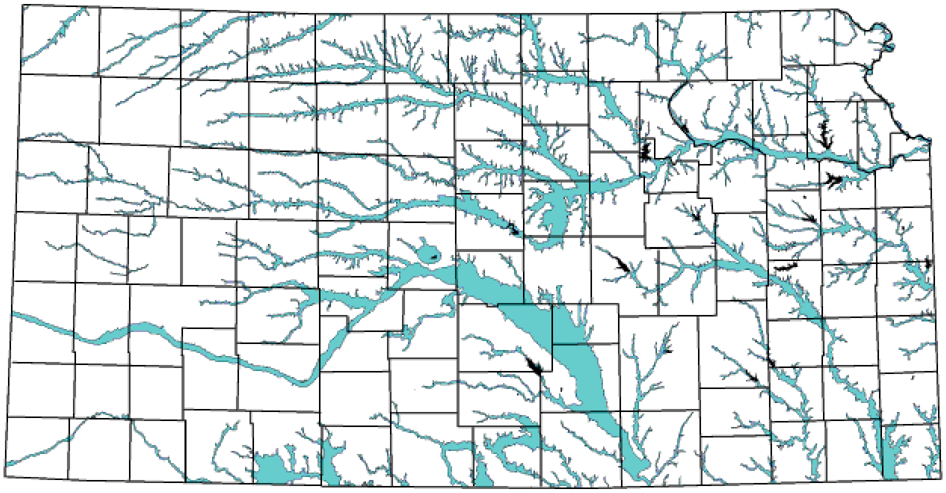


Figure 3. The alluvial aquifers of Kansas.

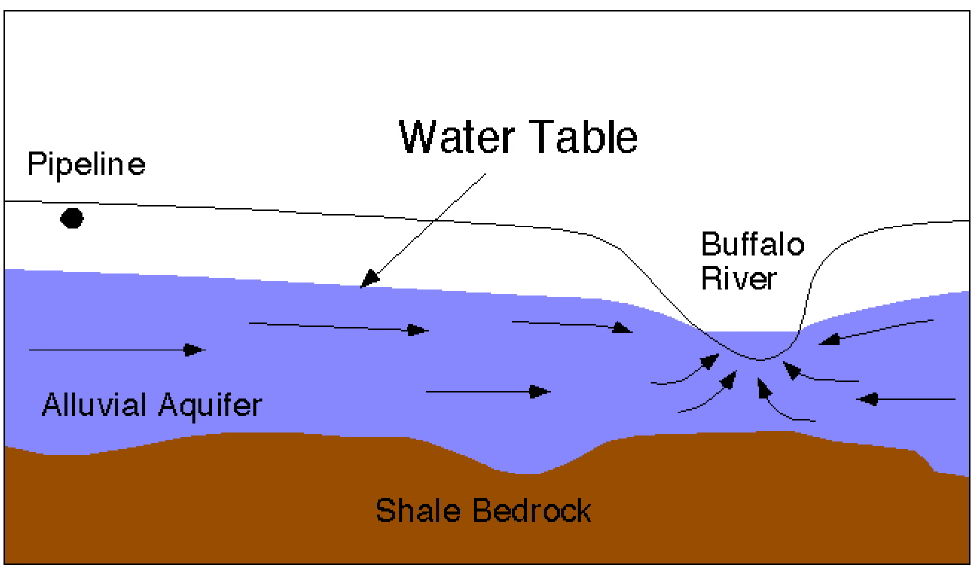


Figure 4. The water table defined the upper saturated part of an unconfined alluvial aquifer. Because the flow of water is from the alluvial aquifer to the stream, the stream is considered to be gaining.

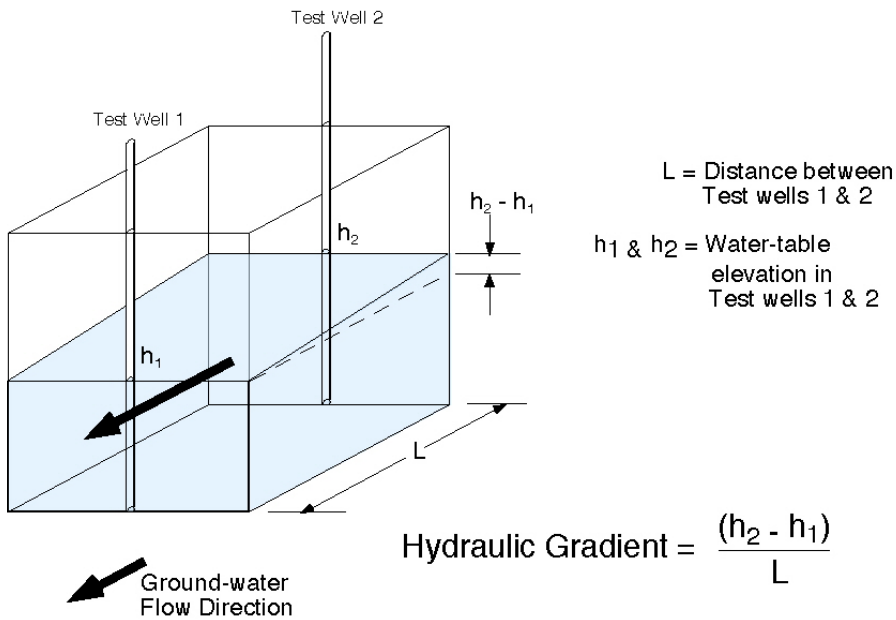
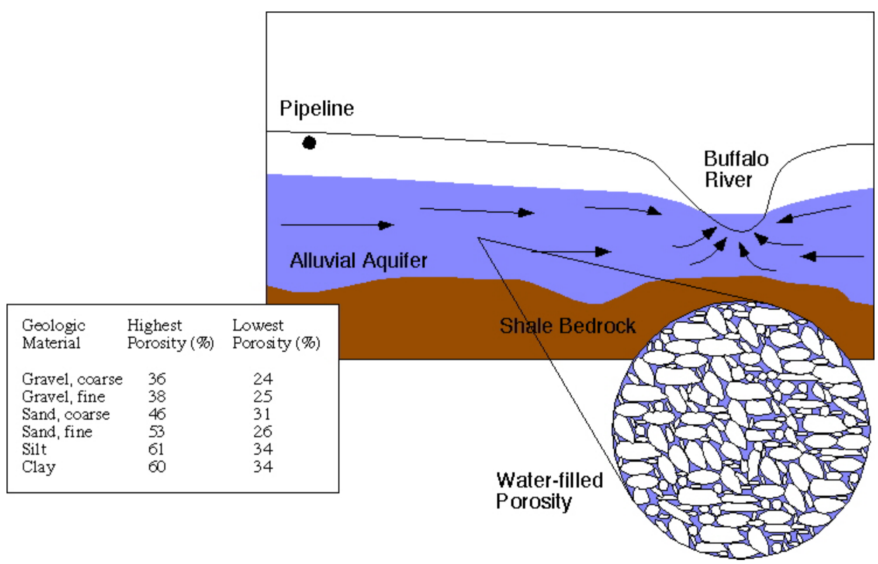
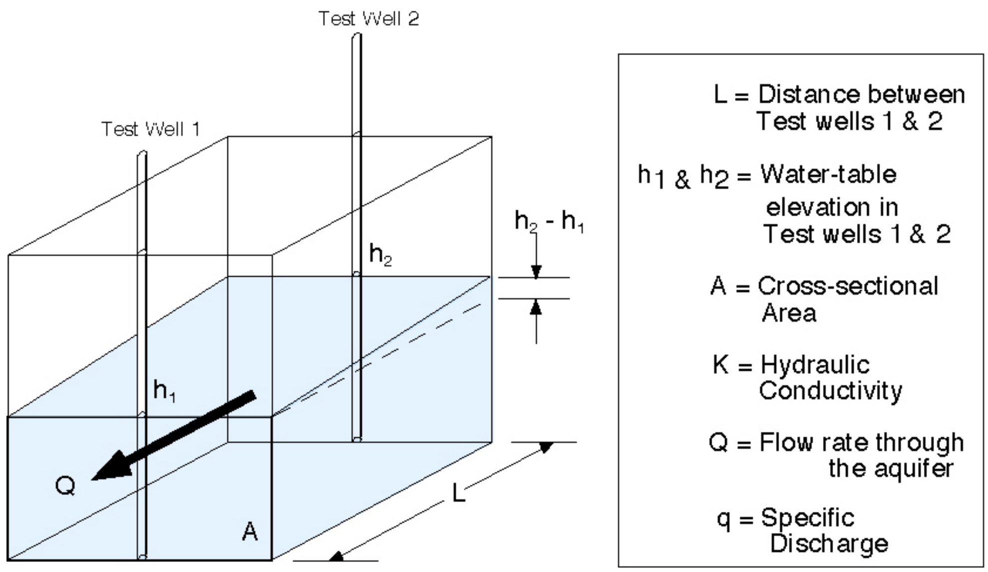


Figure 5. Hydraulic head is equivalent to the elevation of the water table above sea level. The hydraulic gradient is the change in hydraulic head ($h_1 - h_2$) over a horizontal distance L in the direction of ground-water flow.



Geologic Material	Highest Porosity (%)	Lowest Porosity (%)
Gravel, coarse	36	24
Gravel, fine	38	25
Sand, coarse	46	31
Sand, fine	53	26
Silt	61	34
Clay	60	34

Figure 6. Porosity is the relative amount of void space or the space between the sediment grains in the alluvial aquifer and is usually expressed as a percentage of the bulk volume (the space occupied by the grains and the voids).



Darcy's Law: $$\frac{Q}{A} = q = K\frac{(h_2 - h_1)}{L}$$

Figure 7. Darcy's law is a fundamental equation of ground-water flow. It states that the flow, Q, is proportional to the hydraulic gradient and the cross-sectional area through which it passes. The constant of proportionality is the hydraulic conductivity. In shallow aquifers containing fresh water the hydraulic conductivity depends on the earth materials that constitute the aquifer.

is along the true hydraulic gradient from regions of higher hydraulic head (higher potential energy) to regions of lower hydraulic head (lower potential energy) (Figure 5). In real-world situations the hydraulic gradient of the water table surface is estimated using water level elevations in 3 wells.

Darcy's Law is a fundamental ground-water flow equation, developed experimentally by Henri Darcy in 1856. Darcy's Law is not typically covered in most secondary earth science or geology texts and is covered in most introductory geology texts at the undergraduate level. Darcy's Law relates the hydraulic gradient (the slope of the water table), the cross sectional area of the aquifer, and the hydraulic conductivity (permeability) of the aquifer to the ground-water flow rate (Figure 7):

$$Q = K(\Delta h/\Delta L)A,$$

where Q is the ground-water flow rate (seepage), K is the hydraulic conductivity, h is hydraulic head, L is the distance between two hydraulic-head measurement points, and A is the cross-sectional area of the aquifer through which flow is occurring. The quantity $(\Delta h/\Delta L)$ is the hydraulic gradient. In many applications the Darcy's Law is used to calculate the specific discharge:

$$\text{Specific Discharge} = Q/A = K(\Delta h/\Delta L),$$

which is the rate of flow per unit cross-sectional area (in terms of units: $L^3/T/L^2$ or L/T). The average ground-water velocity is calculated taking into account the aquifer cross-sectional area that is occupied mostly by aquifer material and the flow of ground water is restricted only to the interconnected pore space (porosity). The average ground-water flow velocity is calculated using the porosity and Darcy's Law:

$$\text{Ave. Ground-water Velocity} = K(\Delta h/\Delta L)/n,$$

where n is the porosity of the aquifer materials.

Using the distance = rate x time relation, the distance traveled by the contamination in the aquifer can be estimated if the elapsed time since the contaminants entered the aquifer can be estimated. These concepts and their relationships are shown in the diagram below in Figure 8.

To accomplish the Phase 2 task, the student applies ideas from well hydraulics to design the remediation wellfield that will be used to remove the contaminants from the aquifer. The student is limited to one of two possible wellfield designs: one or more production wells or one production well and one injection well. The student is also allowed to select rates of withdrawal less than or equal to 40 gallons per minute from the production and injection wells. The primary science concepts stressed in this part of tutor include:

- Ground-water withdrawal using a production well causes a local lowering of the water table in the well vicinity to create a cone of depression. The lowering of the water table results

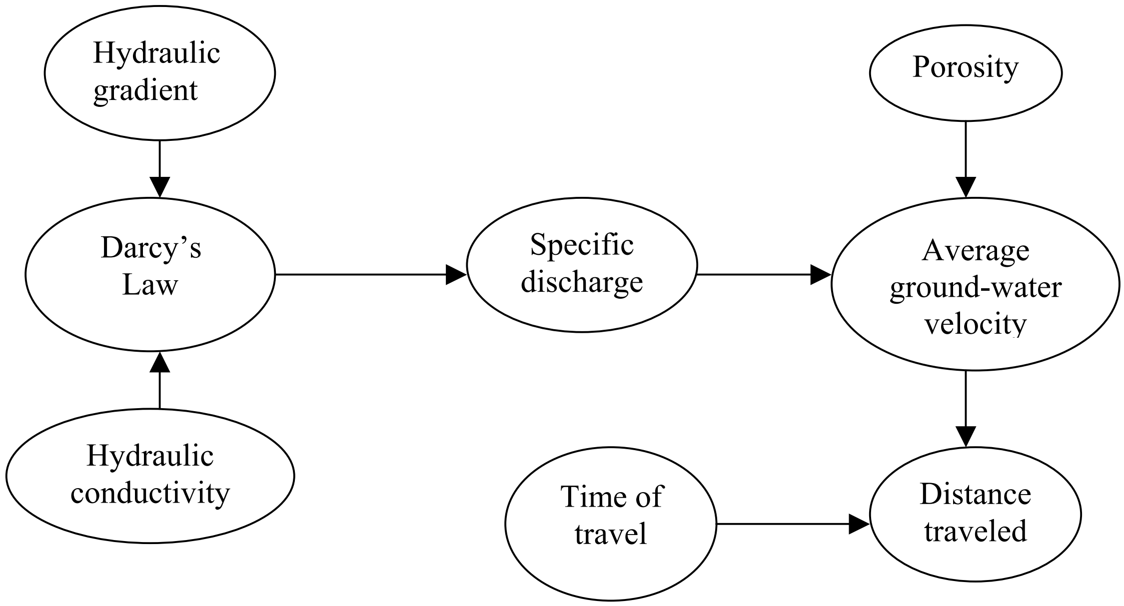


Figure 8. Science concepts and their relationship in the contaminant discovery phase of the interactive ground-water tutor.

because water is removed from the aquifer at a faster rate than it can be replenished by ground-water flow moving toward the well (Figure 9). For a given aquifer, the size of the cone of depression is determined by the rate at which ground water is being withdrawn from the aquifer.

- The addition of water to an aquifer through an injection well causes a local rise in the water table to create a cone of impression. The water table rise results when water is added to the aquifer at a faster rate than it can move away from the injection well into the surrounding aquifer by ground-water flow (Figure 10). For a given aquifer, the size of the cone of impression is determined by the rate at which water is added to the aquifer.
- The capture zone is the region of the aquifer contributing to ground-water flow to a well. The shape of the capture zone is parabolic and its size depends on the average linear ground-water velocity, the rate at which the well is being pumped, and the hydraulic conductivity of the aquifer (Figure 11). In the case of a production well-injection well couplet, the capture zone is elliptical in shape and its size depends on the average linear ground-water velocity, the rate at which the production and injection well are withdrawing from and adding water to the aquifer, and the aquifer hydraulic conductivity (Figure 12).
- The zone of influence is the region of the aquifer affected by the addition of water to the aquifer from an injection well (Figure 13). In plan view, its shape is parabolic and its size depends on the average linear ground-water velocity, the rate at which the well is added to the aquifer, and the aquifer hydraulic conductivity.
- Pump and treat is a common technology used to remove contaminants from aquifers using production wells to withdraw water from an aquifer or using a well couplet consisting of production well and an injection well (a well used put water into an aquifer) (Figures 14-15).

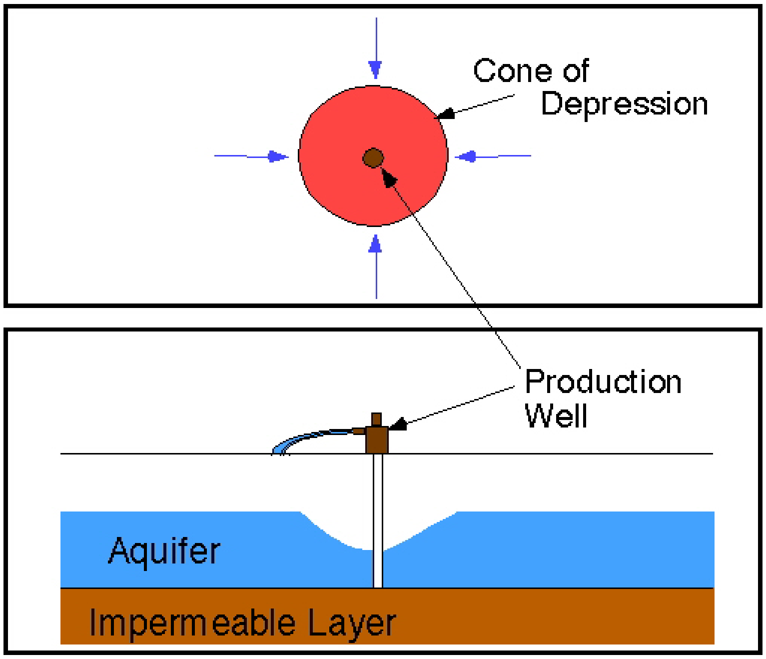


Figure 9. A <u>cone of depression</u> (shown in red in plan view) forms when a <u>production well</u> is pumped because water is being withdrawn from the <u>aquifer</u> than it is being replenished by ground-water flow (shown by the blue arrows). As a result the ground-water withdrawals cause a lowering of the <u>water table</u> (shown in the vertical cross section).

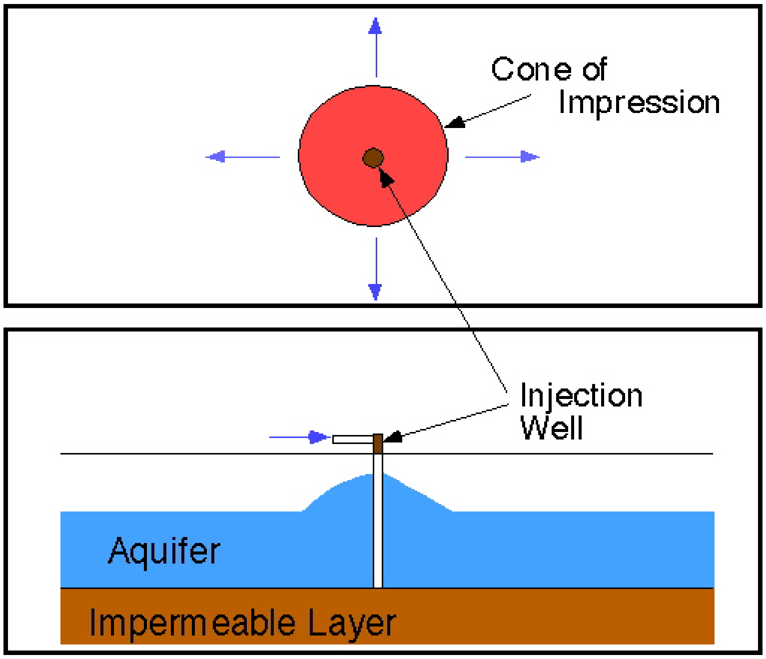


Figure 10. A <u>cone of impression</u> (shown in red in plan view) forms when an <u>injection well</u> is pumped because water is being added to the aquifer at a rate faster than it can move away from the well (shown by the blue arrows in plan view). As a result the addition of water causes a water-table rise near the well (shown in the vertical cross section).

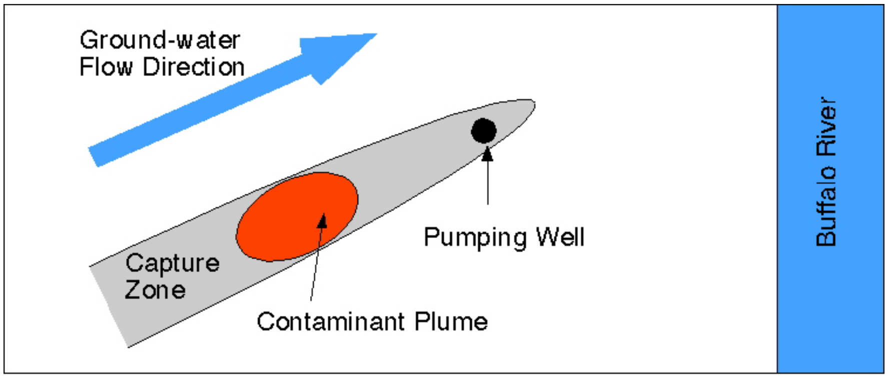


Figure 11. Capture zone created by pumping a production well. The capture zone outline is parabolic in shape and production well is located at the focus of the parabola. If the student elects to use a production well to remediate the aquifer, the limits of the contamination must be contained entirely by the capture zone created by the production well.

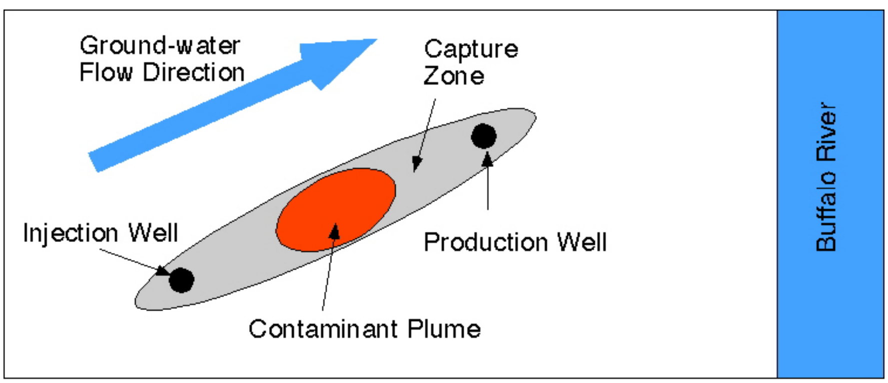


Figure 12. Capture zone created by pumping a production and injection well couplet. The capture zone outline is elliptical in shape. As in Figure 11, if the student elects to use production-injection well couplet to remediate the aquifer, the limits of the contamination must be contained entirely by the capture zone created by the couplet.

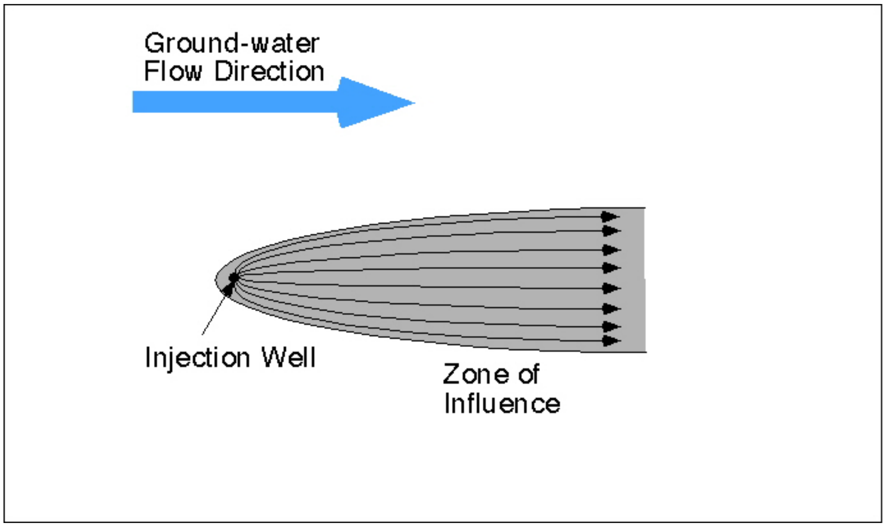


Figure 13. A zone of influence created by the addition of water to the aquifer from an injection well.

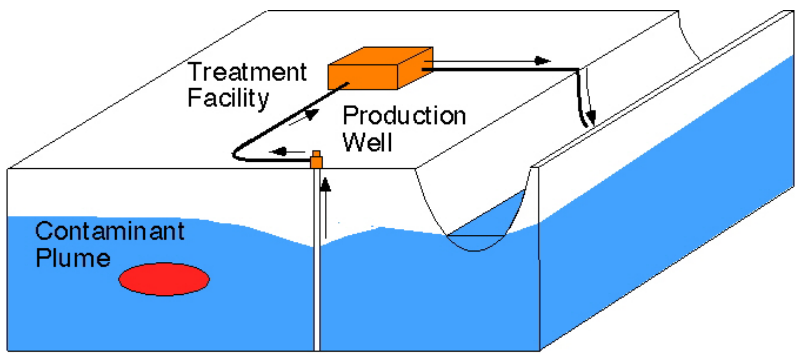


Figure 14. The pump-and-treat method of remediation using production wells only to remove contamination from an aquifer.

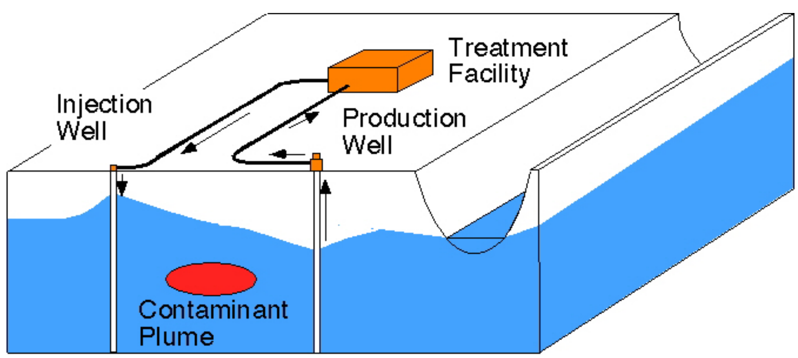


Figure 15. The pump-and-treat method of remediation using a production-injection well couplet to remove contamination from an aquifer.

From a vantage point above the aquifer, capture zones are parabolic in shape with the production well located at the focus of the parabola (Figure 11). For a production well, the capture zone is oriented parallel to the flow direction with the open end of the parabola pointing up gradient. The zone of influence created by water inflow to the aquifer through an injection is similarly shaped but is oriented with the open end of the parabola pointing down gradient from the well (Figure 13).

With a production well/injection well couplet, the injection well is placed upgradient and the production well is placed downgradient of the contaminated zone in the aquifer (Figure 12). As a result, the capture zone and the zone of influence overlap to create a new capture zone that is elliptical in shape. Within the capture zone, ground-water movement is directed to the production well from the injection at higher rates of flow than would be possible with only a production well withdrawing water at the same rate. This can significantly reduce the time required for remediation. The well couplet has the effect of hydraulically isolating the zone of contamination from the rest of the ground-water flow system.

Ideally, the maximum width of the capture zone or the zone of influence depends on the specific discharge (the product of the hydraulic conductivity and the hydraulic gradient, U), the aquifer thickness (B), and the rate of ground-water withdrawal by the production well or the rate of water inflow to the aquifer from the injection well (Q):

$$\text{Maximum Capture Zone or Zone of Influence Width} = Q/BU.$$

This relation assumes constant withdrawal or addition of water over long time periods approximating steady state conditions. In the ground-water flow model, the aquifer specific discharge and thickness are constant. The aquifer hydraulic conductivity varies slightly and is essentially a constant. Hence the relative maximum width of the capture zone or the zone of influence depends only on the rates of withdrawal or inflow from the production or the injection wells. The main concepts and their relationships stressed in the second task are shown in the diagrams below (Figure 16).

Structure of the Interactive Ground-water Tutor

The interactive ground-water tutor consists of a (1) JAVA-based model to simulate ground-water flow and the movement of contaminants through the aquifer and (2) a set of linked HTML pages. The user interacts with the numerical model through a screen called Map View that contains a gridded map of the spill site vicinity (Figure 17). Map View shows the location of the pipeline, the spill site, and the river. The dimensions of the map are 1,000 feet by 1,000 feet. At the top of the Map View screen, the current calendar date and the time in days since the contamination was found are posted. Map View also provides information on the money remaining in the consultant’s bank account that has been provided by the pipeline owner and the total amount of money spent on the project to date. Along the left side of Map View, there is a

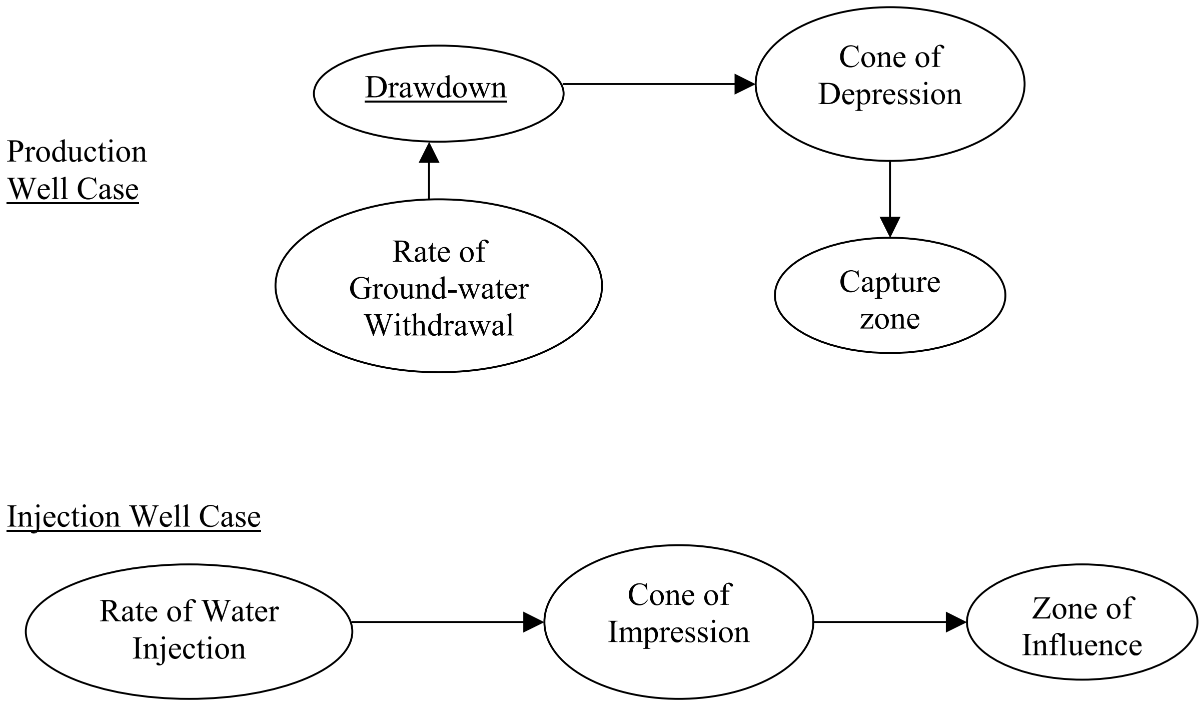


Figure 16. Science concepts and their relationship in the aquifer remediation phase of the interactive ground-water tutor.

series of radio buttons. Using these buttons, the student adds monitoring wells, adds and removes production and injection wells, modifies pumping rates, resamples monitoring wells, negotiates with the pipeline owner for more money, and advances the simulation in Phase 2.

The linked HTML pages are grouped into sections and structured to help guide the student through the tutor (Figures 18 and 19). The linked pages are shown on the left of each figure. In the Introduction sections to Phases 1 and 2, the stage is set for the task to be completed by the student. In the contaminant discovery phase (Phase 1), the student proceeds to the Rules for locating the plume (Figure 18). Once the rules have been described, the student is free to proceed to Locate the Plume and Map View or use the Resources and, if necessary, the Reference Library to provide guidance on locating the contamination in the aquifer. The Reference Library contains information on Darcy's Law, the calculation of ground-water velocity and distance traveled, and the Glossary of terms used in the tutor. In Phase 2 of the tutor, a section on Remediating the Plume is presented to make the student aware of the two alternative remediation wellfield designs that are available. A short summary section entitled Remediate the Plume provides information on how to place wells on the grid in Map View, selection of pumping rates, and how to preview the success of the proposed wellfield design. The Reference Library contains a section describing the concept of capture zones.

Student Interaction with the Tutor
From the student's point of view, the overall objective of the ground-water tutor is to remove the contamination from the aquifer with minimal cost in terms of time and money. To accomplish this objective, it is important for the student to:

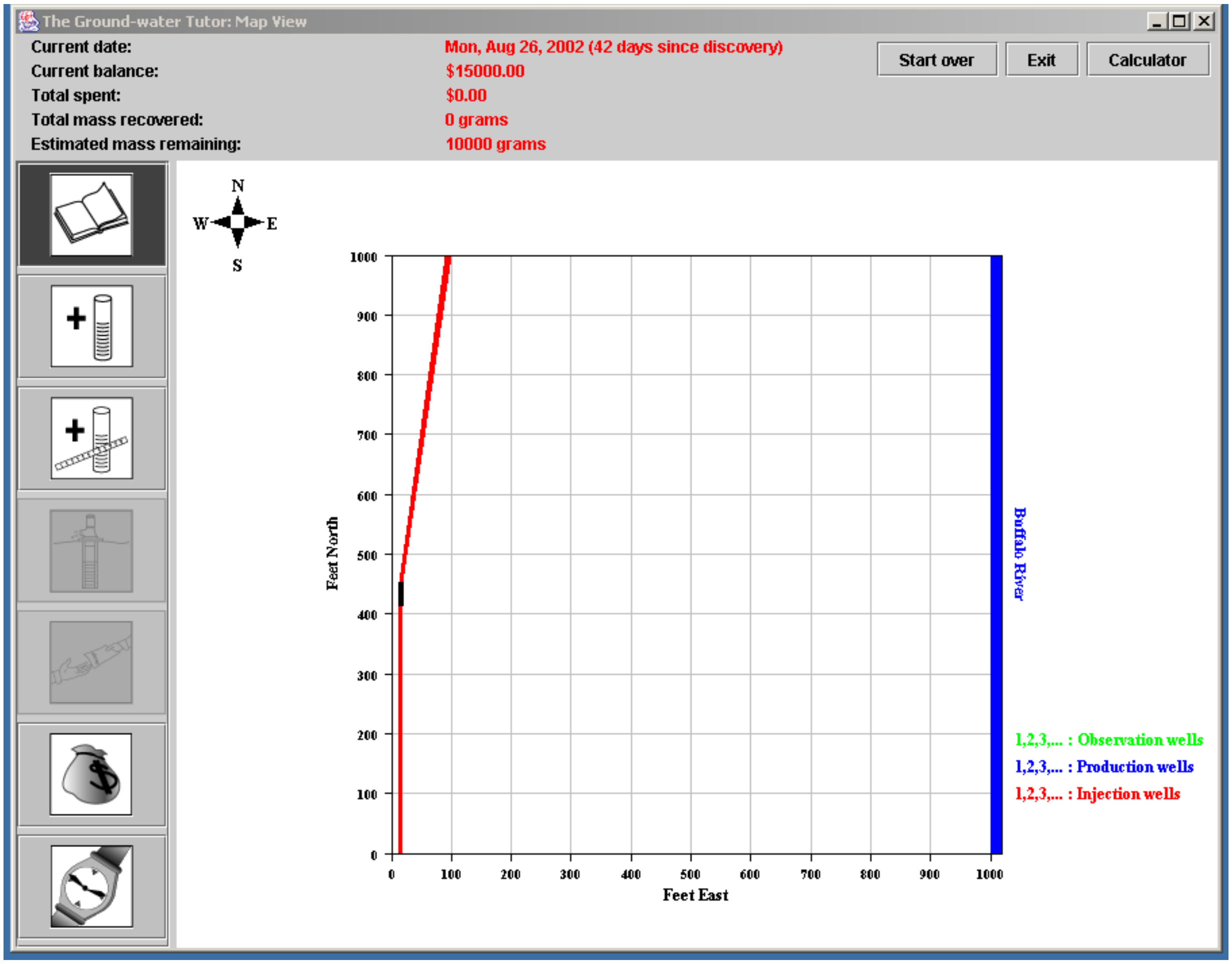


Figure 17. The Map View screen is the interface between the user and the ground-water model of the spill site vicinity.

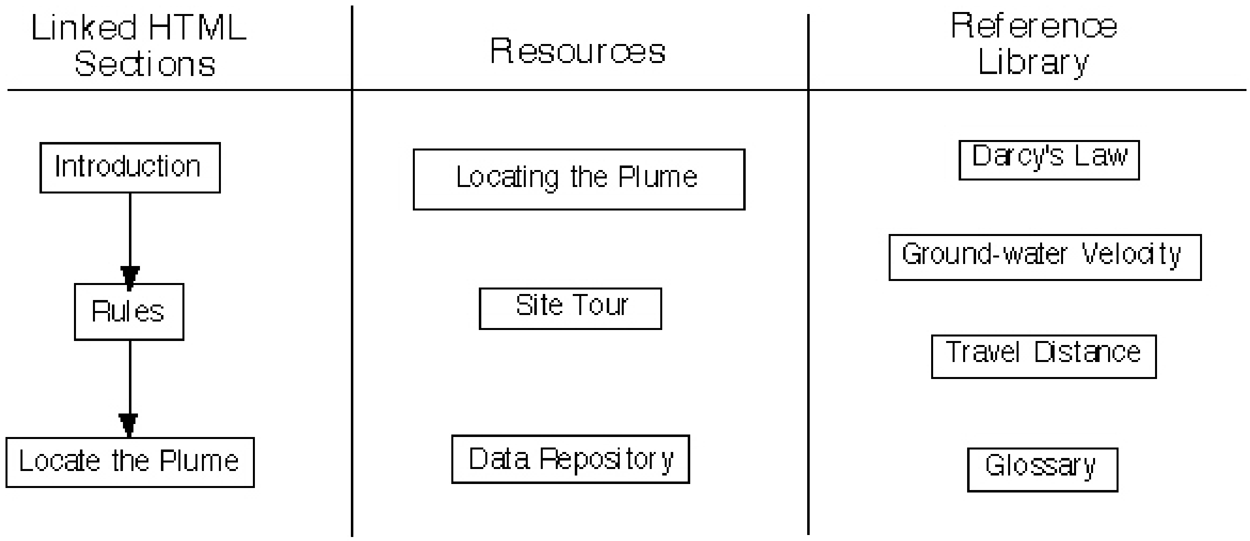


Figure 18. Outline of the sections in the HTML pages that pertain to Phase 1 of the ground-water tutor. Starting with the Introduction the student is directed in sequence to the Rules and Locate the <u>Plume</u> sections, but has access to the other sections in the Resources and Reference Library sections at all times using drop-down menus or by clicking on the section title.

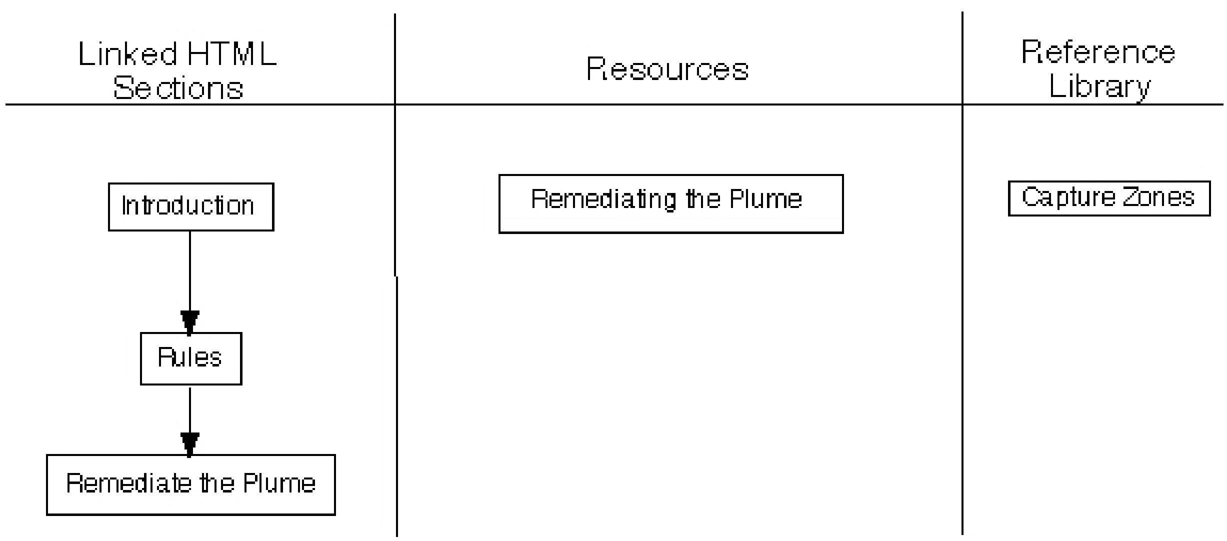


Figure 19. Outline of the sections in the HTML pages that pertain to Phase 2 of the ground-water tutor. Starting with the Introduction the student is directed in sequence to the Rules and Remediate the Plume sections, but has access to the other sections in the Resources and Reference Library sections at all times using drop-down menus or by clicking on the section title.

- Use the provided information to best estimate where the contamination is located in the aquifer at a specified time after the pipeline leak started and not to randomly install monitoring wells in the hope of finding the contamination, and
- Take advantage of the preview function in the Wellfield Remediation phase to determine if the proposed wellfield design will remove all of the contamination from the aquifer prior to operating the remediation design.

Following these guidelines will allow the student to move efficiently through the tutor.

Starting the Ground-water Tutor

Starting the ground-water tutor involves opening the HTML file, gwTitlePage. The JAVA application (gwTutor) can be opened at this stage but it is not necessary. These files can be found by scrolling down through the GW Tutor directory (Figure 20).

Phase 1

In the Introduction to this phase the student is informed that a pipeline transporting industrial chemicals, including trichloroethylene (TCE), has ruptured in a corn field in the Buffalo River valley and just upstream of River City (Figure 21). 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 (Figure 22). The emergency response team notes that the pipeline was leaking for some time prior to discovery of the break and that the contaminants from the pipeline have reached the water table of the alluvial aquifer. It is unclear if the contamination is moving toward the river but if it is moving in that direction, River City's water supply will be jeopardized.

At this point, the student takes on the role of an environmental consultant whose task is to find where the contamination from spill is in the aquifer and to remove it from the aquifer before it gets to the river and endangers the city water supply. It is assumed that prior instruction has been given on the principles of ground-water flow. The student is then provided with a menu of resources that are available to help solve this environmental problem (Figure 23). Sections are included in the Resources tab on the Locating the Plume, a Site Tour, and the Data Repository.

The main ideas presented in the Locating the Plume section are:

- The contaminants will move with the ground-water flow system in the alluvial aquifer.
- In Map View, the student locates the contamination using monitoring wells and from these wells is provided with data on water-table elevation and the chemical analysis of ground-water sample from the well.
- The location of the plume can be predicted and monitoring wells can be sited using average ground-water flow velocity and an estimate of the time since the spill reached the water table.
- The average ground-water flow velocity can be calculated from the information in the Data Repository
- The Calculator is used to calculate the average ground-water flow velocity and contaminant plume distance traveled.

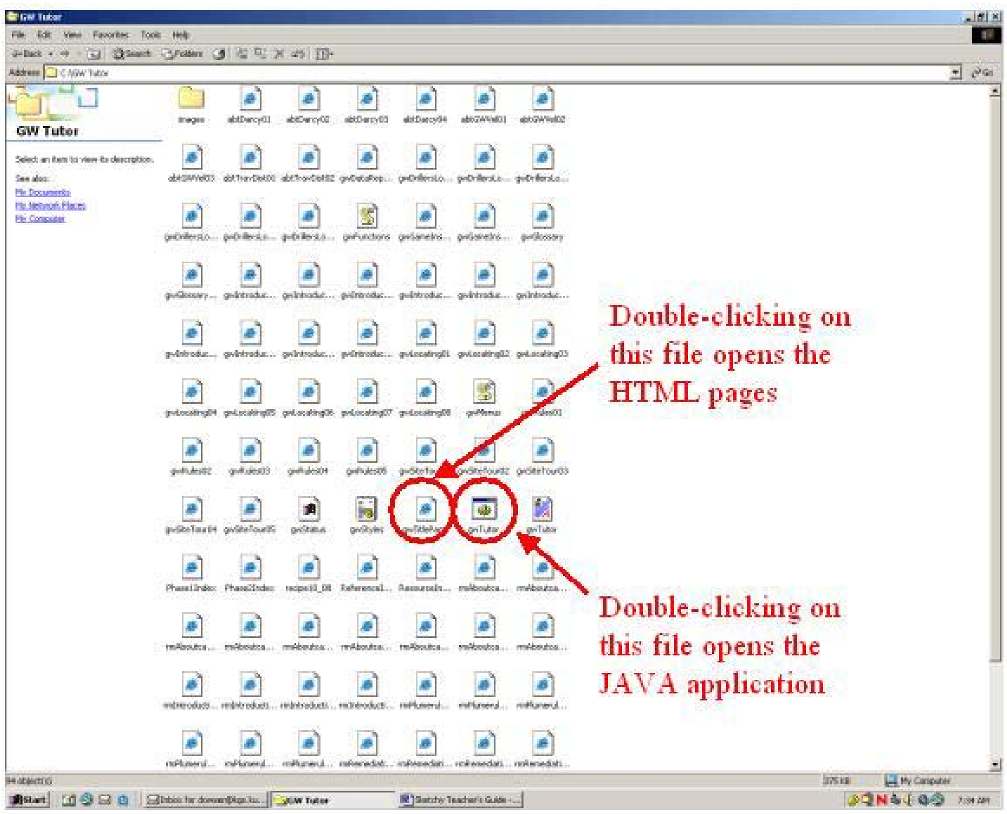


Figure 20. To start the ground-water tutor open the file gwTitlePage to access the HTML pages and gwTutor to open the JAVA application ground-water model.

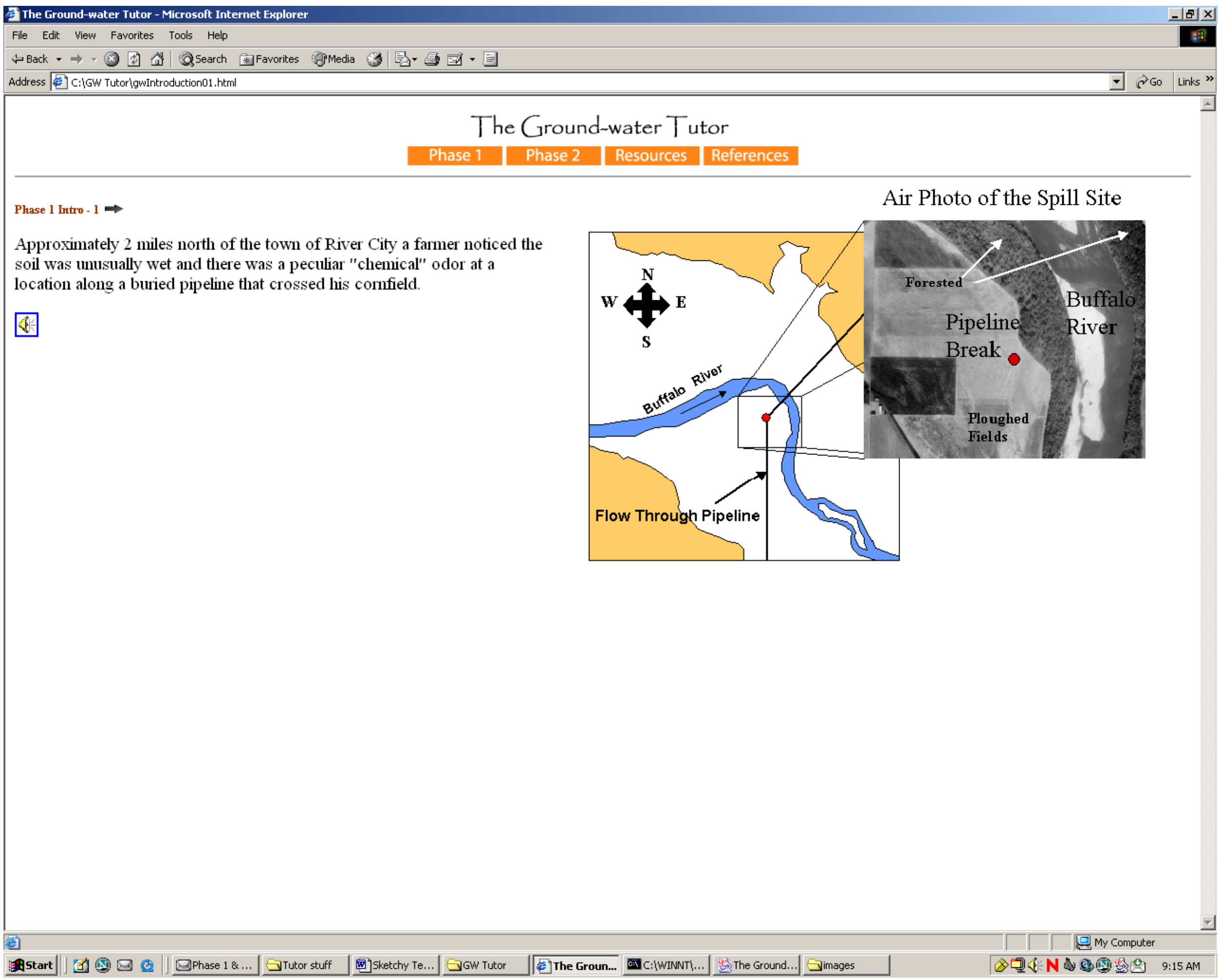


Figure 21. Introduction to the pipeline-spill problem to be solved by the student.

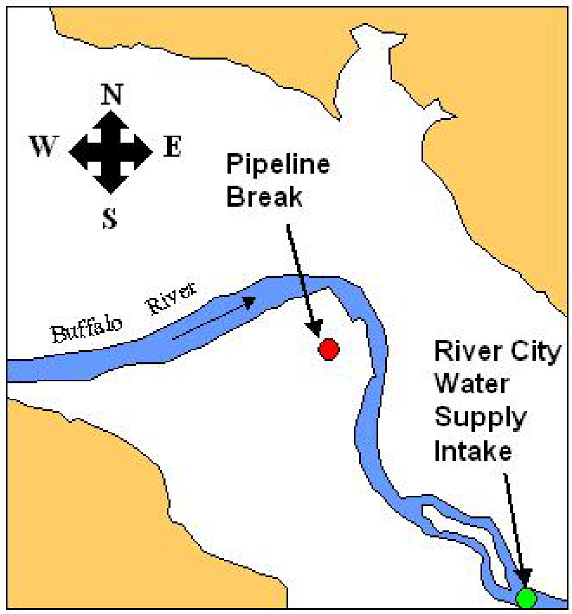


Figure 22. Location of the pipeline break in the Buffalo River valley with respect to the intake for the River City water supply.

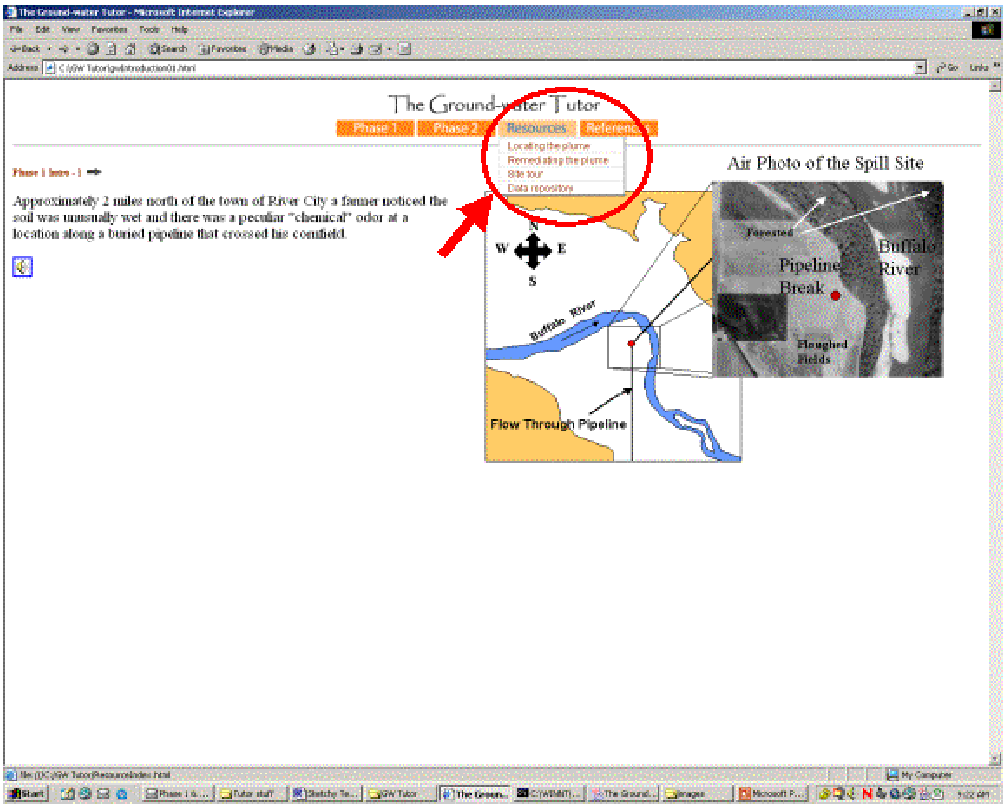


Figure 23. Drop-down menu of resources available to the student for Phases 1 and 2 of the ground-water tutor.

The Site Tour contains photos of the spill site, introduces to the student some of the protective clothing and other gear needed by those working at the site, and provides information on the soils at the site.

The Data Repository contains the drillers' logs of water wells drilled near the site (Figure 24). This information is presented graphically and in tabular form (Figure 24). The data contained in the repository also includes aquifer hydraulic conductivity and the estimated average hydraulic gradient range near the site (Figure 24). A table listing the porosity range of earth materials is provided and should be used in combination with the logs of the nearby water wells to estimate the minimum and maximum porosity of the aquifer materials near the spill site (Figure 25).

Under the Reference Library tab, summary information is also provided on Darcy's Law, Calculation of Ground-water Velocity, Calculation of Distance Traveled, and a Glossary of terms in the Reference Library.

The Rules are designed to provide some real-world constraints on the exploration for the contaminants in the aquifer. The consultant is provided with funds to conduct the exploration phase in small $15,000 allotments. Well installation and the chemical analysis of water samples cost money and time. The allotment provided by the pipeline owner is small enough that the consultant must negotiate for more money every time three wells are installed and water samples are analyzed for TCE. Each negotiation takes two weeks to complete, during which the contaminants are slowly migrating through the aquifer and toward the river. Thus, from the student's point of view, minimizing the number of negotiation sessions is the best strategy to follow in this phase of the tutor.

In Locate the Plume, summary instructions are provided to the student on how to use Map View, including a description of the radio buttons arranged along the left side of the screen (Figure 26). In Map View, the student places monitoring wells on the grid in Map View to find the contamination. The student has the option of siting a monitoring well by visually estimating the distance away from the pipeline spill or by using the ruler to place the well on the grid at distances away from the spill to the nearest foot (Figure 27). With the siting of each well, the student is provided with data on the water-table elevation and the contaminant concentration (Figure 28). After the third monitoring well has been sited, a map of the elevation of the water table in the alluvial aquifer appears (Figure 29) and the student can use the water-table elevation map to visually trace the path followed by the contaminants from the spill site to the river. If after the third well has been sited the student has not found any contamination, the Calculator should be used to update the estimate of distance traveled by the contaminants from the spill site using the true hydraulic gradient value at the top of the gridded map. This phase of the tutor ends when the student has found contamination in three wells.

The Calculator (Figure 30) is used to estimate average ground-water flow velocity, but the student does not explicitly interact with the Darcy's Law equation related to the calculation. However, to set up the calculation, the student uses the hydraulic conductivity and hydraulic gradient data provided in the Data Repository and the values of maximum and minimum aquifer porosity estimated from the drillers' logs of water wells in the Data Repository.

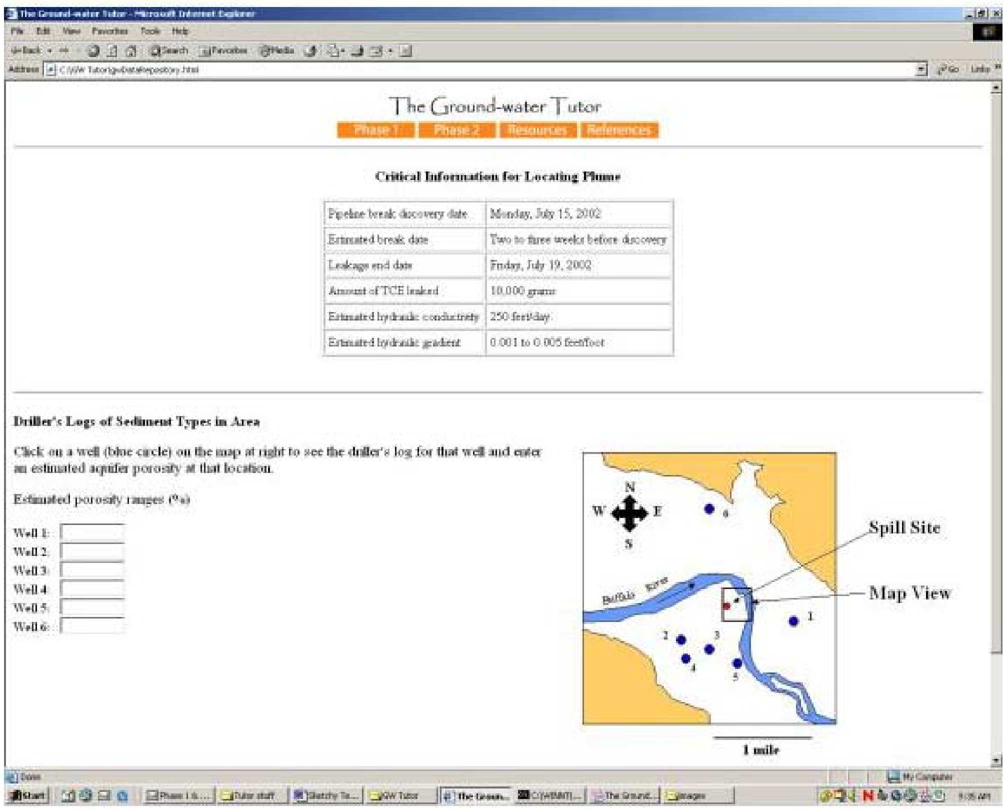


Figure 24. Initial Data Repository screen presented to the student.

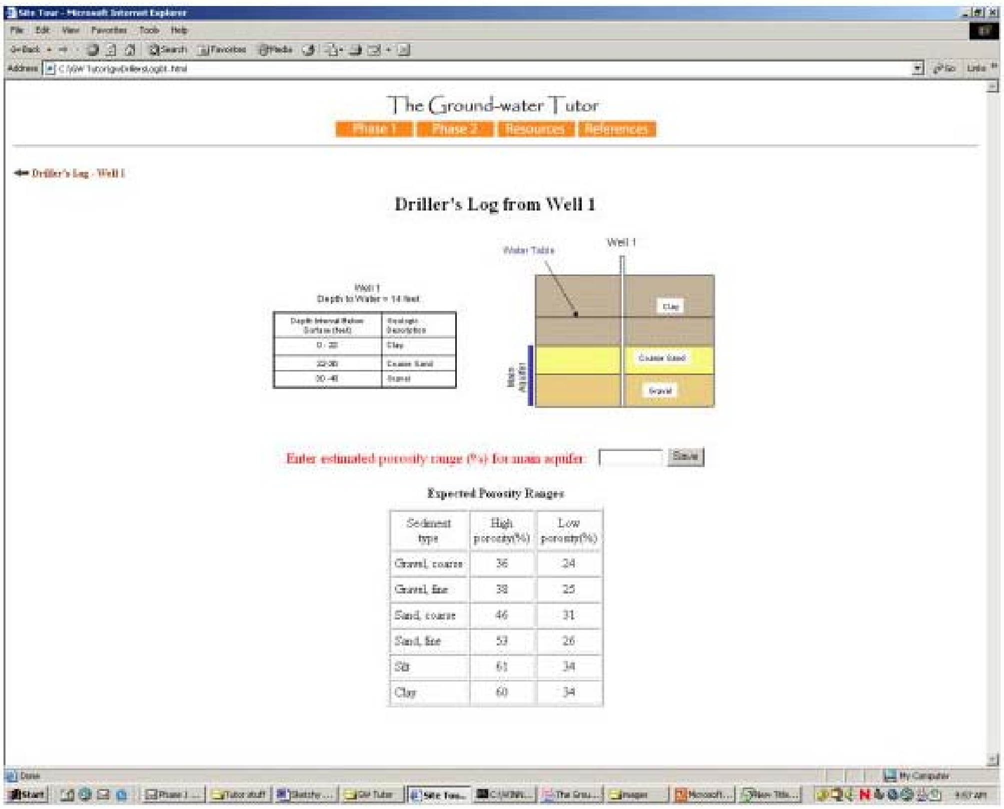


Figure 25. The driller's logs of water wells are presented in tabular and in graphical formats. A table showing the expected range of porosity values for typical sediment types is presented to assist the student in determining the likely range of porosity values for the main aquifer indicated on the left side of the graphic image by a blue vertical line. Once the minimum and maximum values of porosity for the main aquifer have been decided by the student, they are entered in box in the middle of the screen and student will click the save button to save the entered values.

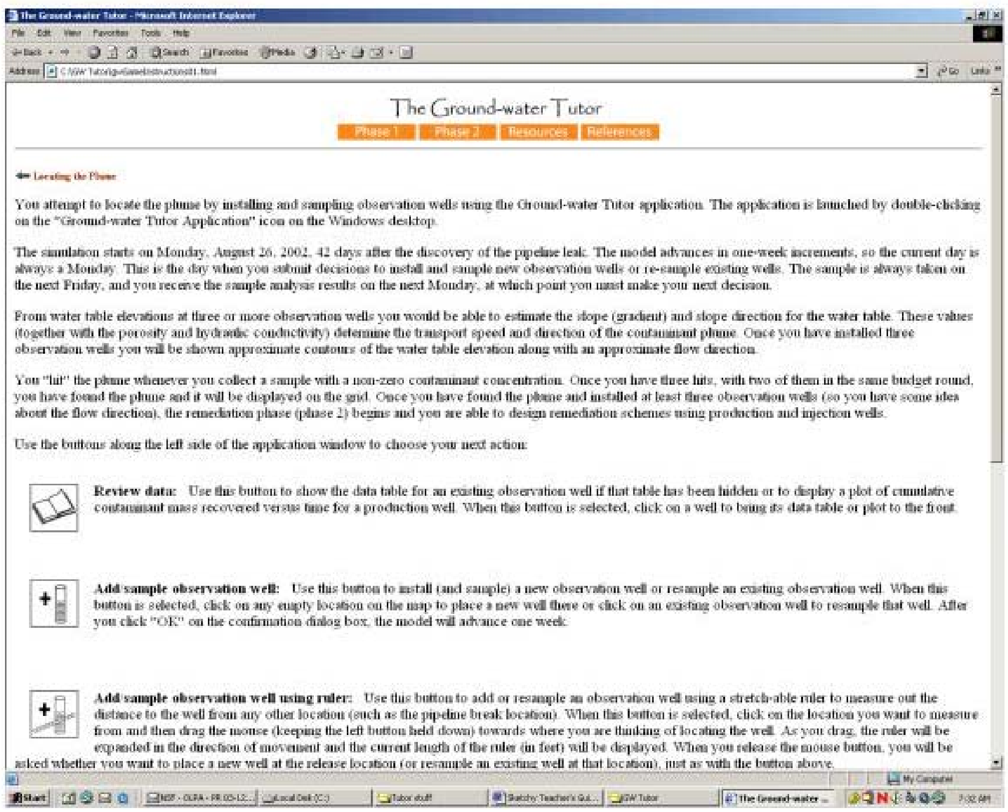


Figure 26. The Locate the Plume screen contains a summary of the rules, describes the functions that can be utilized by clicking on the buttons along the left side of Map View, and provides directions for installing monitoring wells to locate the plume.

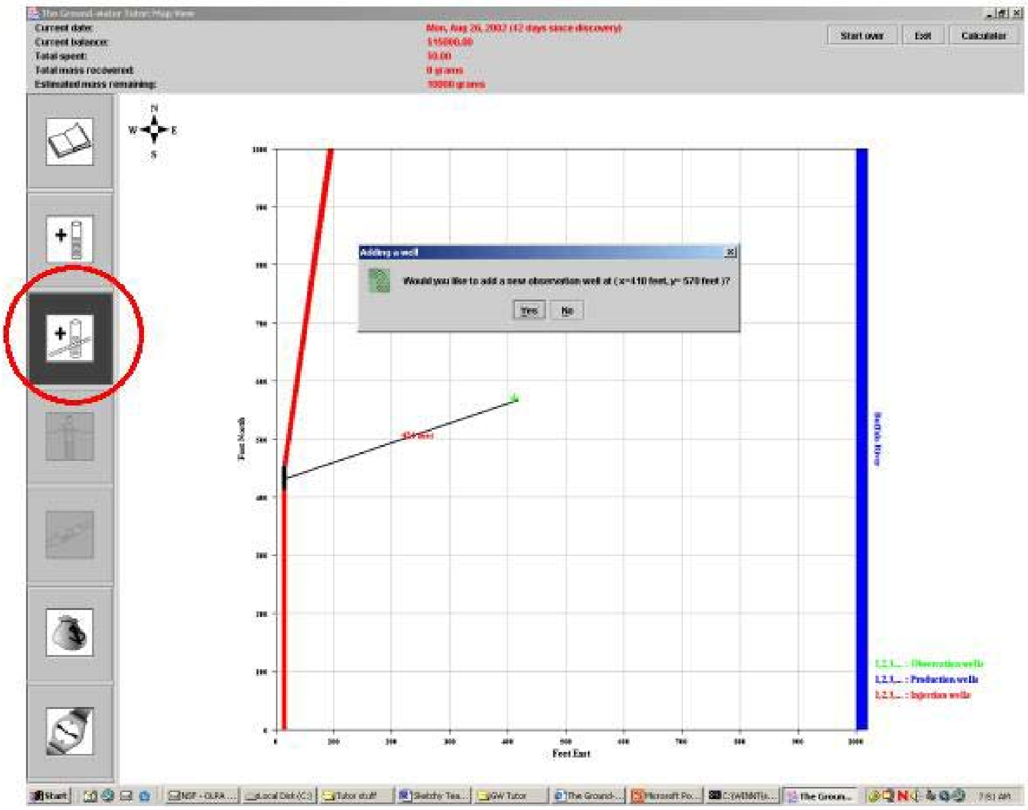


Figure 27. To site a <u>monitoring well</u>, the student has the choice of using visually estimating where it should be placed using the Add/Sample Monitoring Well button on the left side of Map View or by more precisely locating the well site using the Add/Sample Monitoring Well Well Using Ruler button, circled in red in the figure above. Directions on how to use these functions in Map View can be found on the Locate the Plume section of the HTML pages shown in Figure 26.

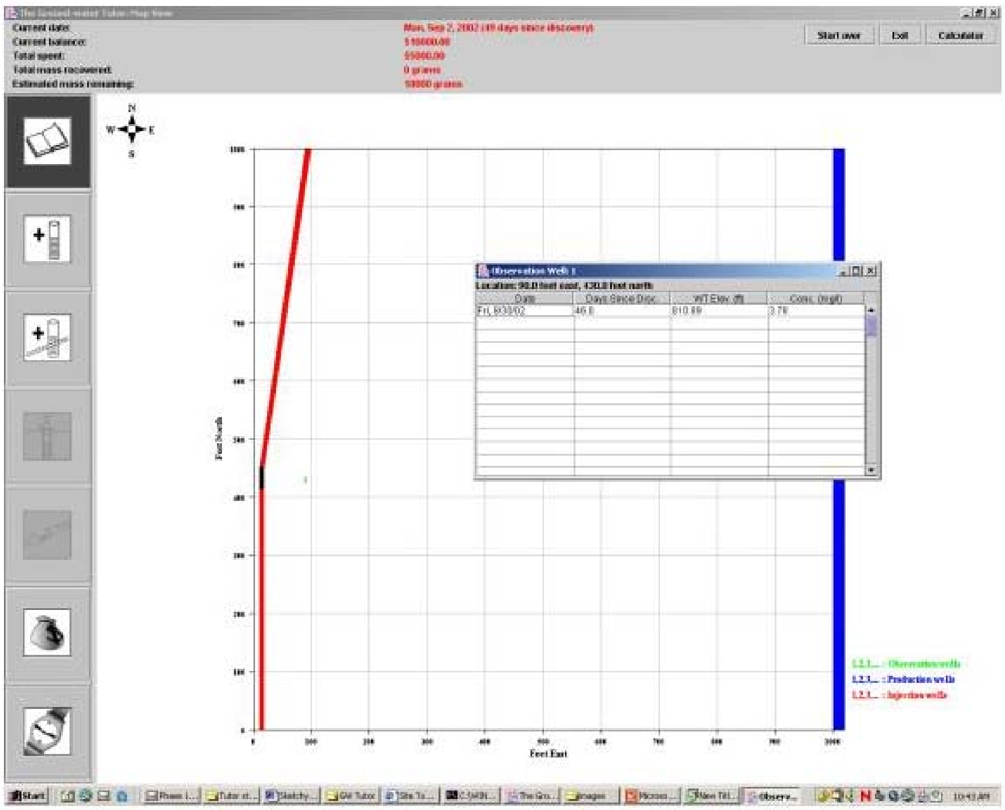


Figure 28. Water table-elevation and contaminant concentration data from the siting of monitoring wells in Phase 1. Also listed in the table is the date the well was sampled and the number of days since the pipeline spill was discovered.

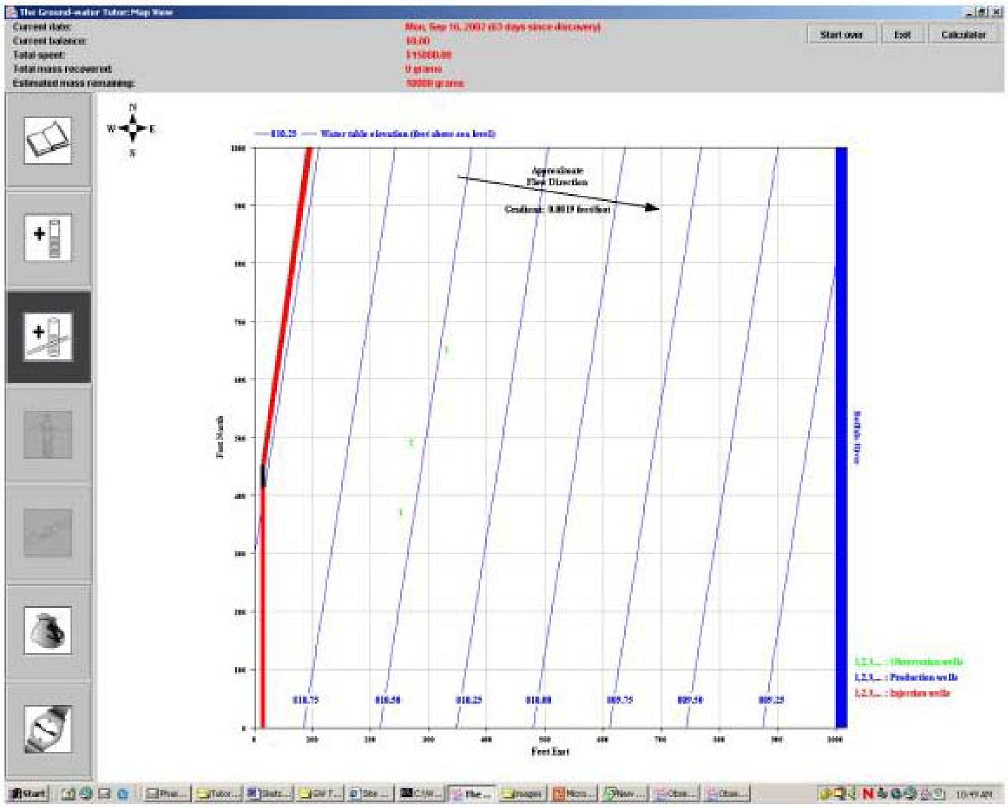


Figure 29. Map of the elevation of the water table in Map View. This map is displayed once three monitoring wells have been sited. At the top of the map grid the true hydraulic gradient is displayed and the arrow shows the true direction of ground-water flow between the pipeline and the Buffalo River.

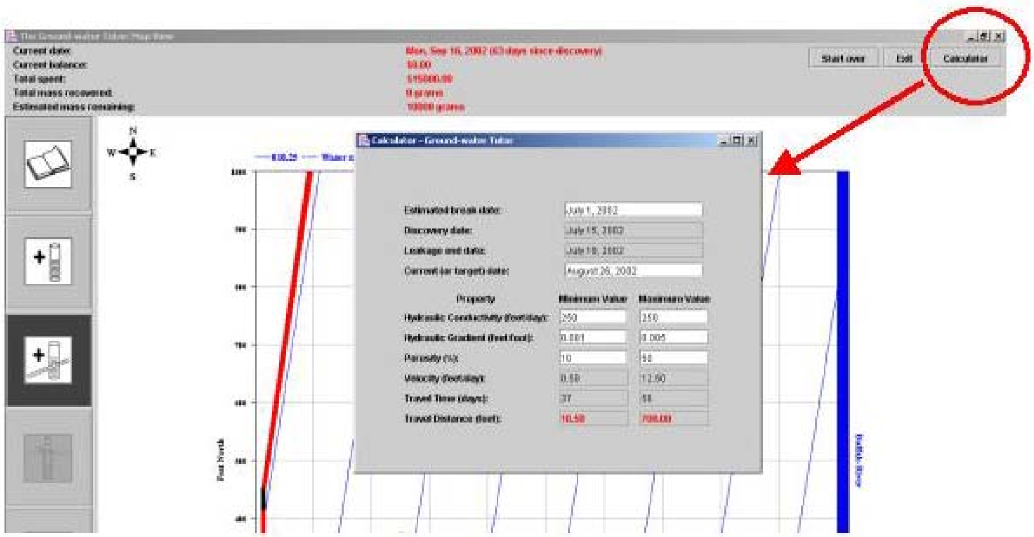


Figure 30. The student accesses the Calculator by clicking on the button in the upper right hand corner of Map View. The student can use the displayed Calculator to determine <u>average ground-water velocity</u> and the distance traveled by the <u>contamination</u> from the spill site.

The information needed to make the estimates of maximum and minimum porosity is contained in the Data Repository (Figure 24). This section contains a map showing the location of six wells for which drillers' logs are available (Figure 24). A driller's log is prepared by the driller as the well is being drilled and is a written description of the earth materials and the depths at which those materials were encountered. Students can click on a well location to view the log as a table and graphically as a vertical cross section of the geology below ground surface at the well site (Figure 25). Also provided is a chart of typical maximum and minimum porosity values of some granular earth materials and the well logs of water wells drilled near the contaminated site (Figure 25). To estimate maximum and minimum aquifer porosity, the student must examine the logs and make an overall judgment about the type of sediment that makes up the portion of the aquifer labeled Main Aquifer in the vicinity of each well log. The graphic images may help with this estimation. Once the student has decided the composition of the Main Aquifer, the porosity range of this part of the aquifer can be estimated at each well site using the porosity range chart (Figure 25). These estimates must then be extrapolated to the spill site vicinity to estimate the maximum and minimum aquifer porosities (Figure 24).

It is worth noting that there are no correct or incorrect methods for estimating the porosity ranges and extrapolating them to the aquifer between the spill site and the river. It is likely that students looking for a right or a wrong way to make these estimations will struggle with this part of the tutor. In real-world situations, ground-water scientists typically use these logs only to get a sense of the type of earth material that makes up most of an aquifer. Most of the logs presented show that the alluvial aquifer is composed of sand with a small amount of fine gravel. Thus the porosity range selected by the student should fall within the typical range of values for these types of earth materials.

Some students will wonder why the water table is higher than the top of the Main Aquifer noted on the graphic for each well site. Where the shallow part of the alluvium consists of a thick layer of clay, the main aquifer is confined or is partially confined. A partially confined aquifer is overlain by a layer that is somewhat less permeable than an aquifer.

The student completes phase 1 of the tutor by finding contamination in three monitoring wells, with 2 of them placed on the gridded map in the same budget round. When this occurs a banner is displayed across the screen indicating successful completion of this phase of the tutor. In Map View the extent of the contamination in the aquifer is then revealed to the student (Figure 31).

Phase 2

In the Introduction to this phase, the student is introduced to the pump-and-treat technology that is commonly used to remove and treat contaminated ground water, a process referred to as remediation (Figure 14). The student is also introduced to the concept of the maximum contaminant level (MCL) concentration as an environmental benchmark. The maximum contaminant level is the highest allowable concentration of a contaminant in water as set by either the US Environmental Protection Agency or the state environmental regulatory agency. The maximum level is set based on toxicology studies on laboratory animals. Most often, the results of these studies must be extrapolated to estimate the health risks to humans. Typically, aquifer remediation efforts cease once the level of contamination in ground water is below the MCL. As the environmental consultant on this remediation project, the student is reminded of the

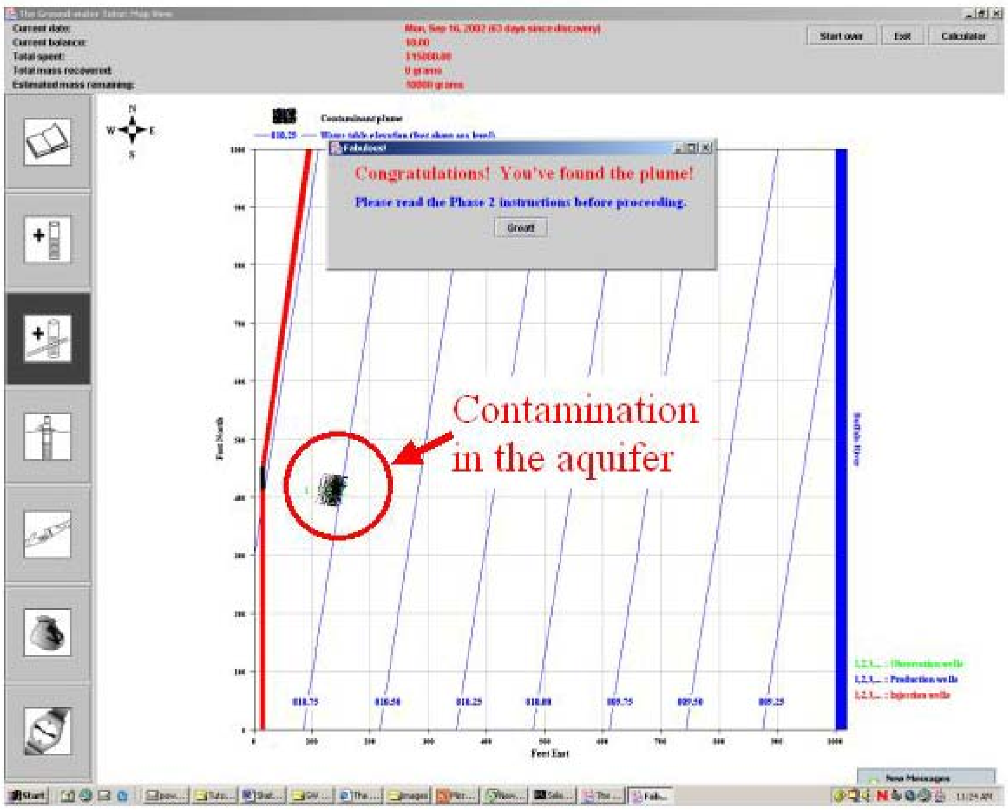


Figure 31. Map View at the end of Phase 1 showing the banner indicating success and the extent of the contamination in the aquifer.

necessity to sample the monitoring wells and the production well to assess the progress of the remediation effort. To monitor the progress of the remediation, the student is also encouraged to add more monitoring wells. As in Phase 1, installation and chemical analysis of the water samples cost in terms of time and money.

At the end of the Introduction, the student is made aware that there is a section of the Resources folder labeled Remediating the Plume (Figure 23). In this section, the student is provided with more information on the pump-and-treat method of remediation. Two alternative pump-and-treat designs are described. The simpler design involves only production wells used to pump water and contaminants from the aquifer (Figure 14). The production well is sited downgradient of the contaminants in such a way that the contaminated part of the aquifer is completely contained in the well's capture zone (Figure 11). An alternative design uses a production well to remove contaminants from the aquifer and an injection well to return the produced water back to the aquifer after it has passed through the treatment plant (Figure 15). As in the previous design, the production well is sited downgradient of the contamination. The injection well is sited close to the production well and upgradient of the plume. With both wells close together and operating, the injection well drives the contamination to the production well at a faster rate than would be possible if only a production well were used. Thus, it is possible to reduce the time needed to remediate the aquifer. However, the tradeoff is that it takes longer to acquire a permit from the state environmental protection agency to operate this than the other simpler design.

From the Introduction, the student is directed to the Rules section. As in the Phase 1 Rules section, the Phase 2 Rules pertain to the time or money costs associated with each action taken by the student. Of note, remediation wellfield operating costs are included in this section. The simulation keeps track of the time and the money spent by the consultant in both phases of the ground-water tutor.

At this point in the tutor, the student is directed to the Remediate the Plume Screen (Figure 32). In this screen, the student is made aware of the actions that are possible in the MapView interface for setting up and operating the remediation system. A key feature of Map View in this phase is the ability of the student to preview the likely success in remediating the aquifer once a wellfield design has been selected, the production or the production and injection well pumping rates have been selected. In Map View, the student submits these items to the tutor. The tutor displays the resulting capture zone on the grid and the effect of the wells on the elevation of the water table (Figure 33). If the contamination is completely contained within the capture zone, the proposed design will be successful and as the wellfield is operated over time the contamination will be completely removed from the aquifer. To approve the final design and begin remediation, the student must submit it to the model (Figure 34). If not, the student is given the opportunity to revise the design, well placement, and pumping rates.

Clicking on the time button in the Map View advances the model through time and operates the wellfield (Figure 35). With each click the simulation is advanced one week and the student can observe the movement of the contaminants toward the production well and their removal from the aquifer.

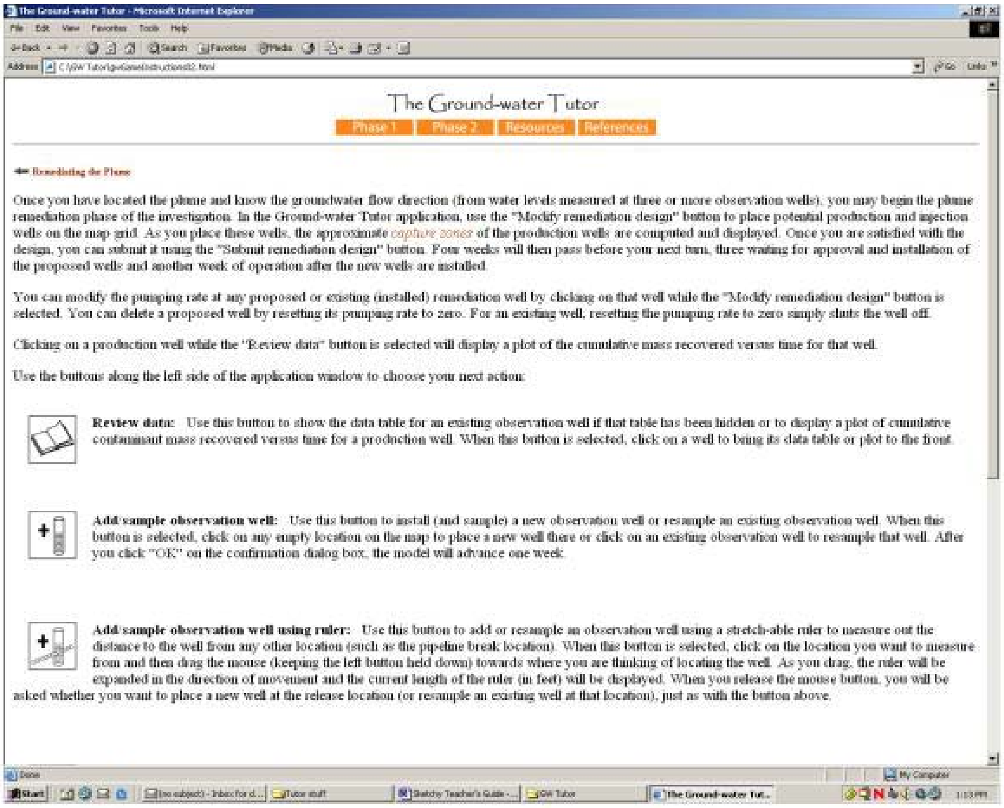


Figure 32. The Remediate the <u>Plume</u> screen contains a summary of the rules, describes the functions that can be utilized by clicking on the buttons along the left side of Map View, and provides directions for setting up the <u>remediation</u> wellfield.

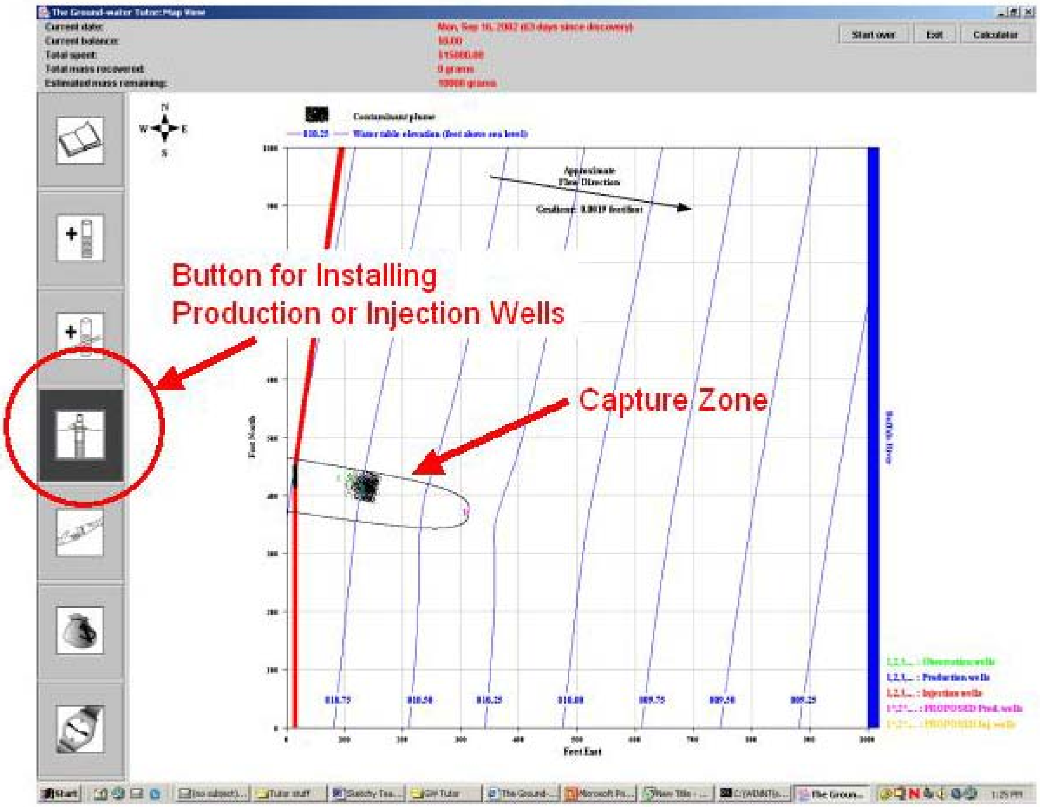


Figure 33. Button for submitting the design to the model for preview of the results.

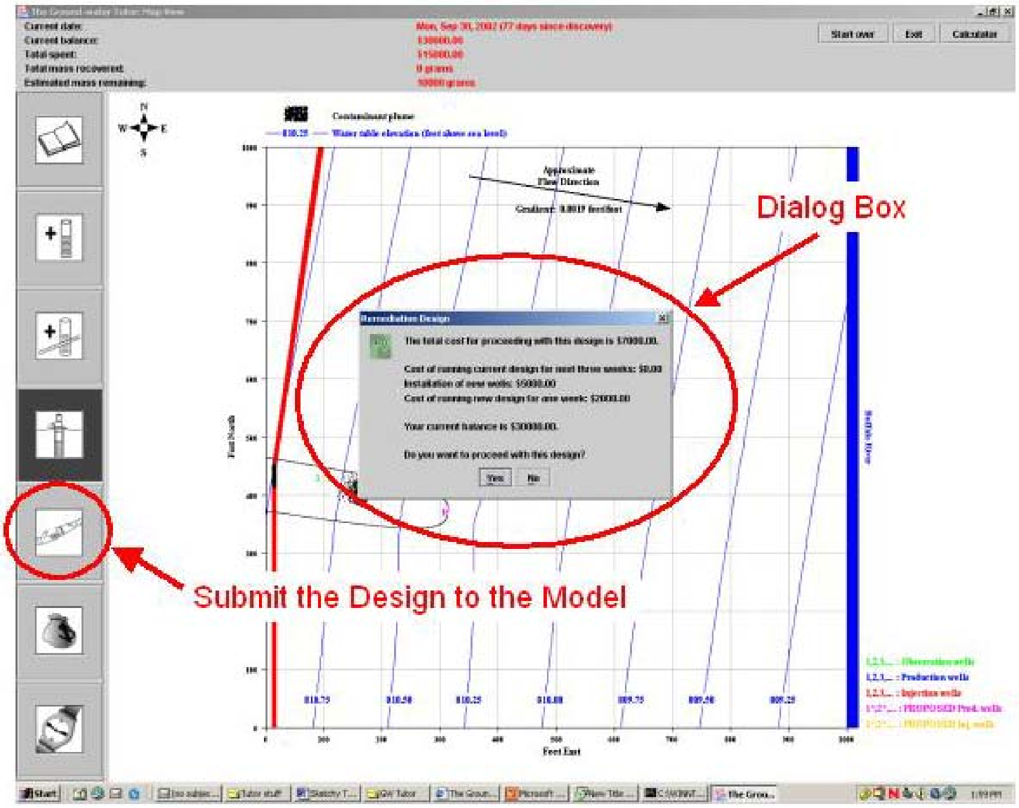


Figure 34. Submitting the Design to the model to initiate <u>remediation</u>. To do so, the student clicks on the mouse button on the left side of Map View. A dialog box will appear to inform the student of the cost of operating the remediation <u>wellfield</u>. If there is not enough money in the bank to operate, the model informs the student to negotiate for more money from the pipeline owner. If there is enough money, the student activates the design and model advances one week in time.

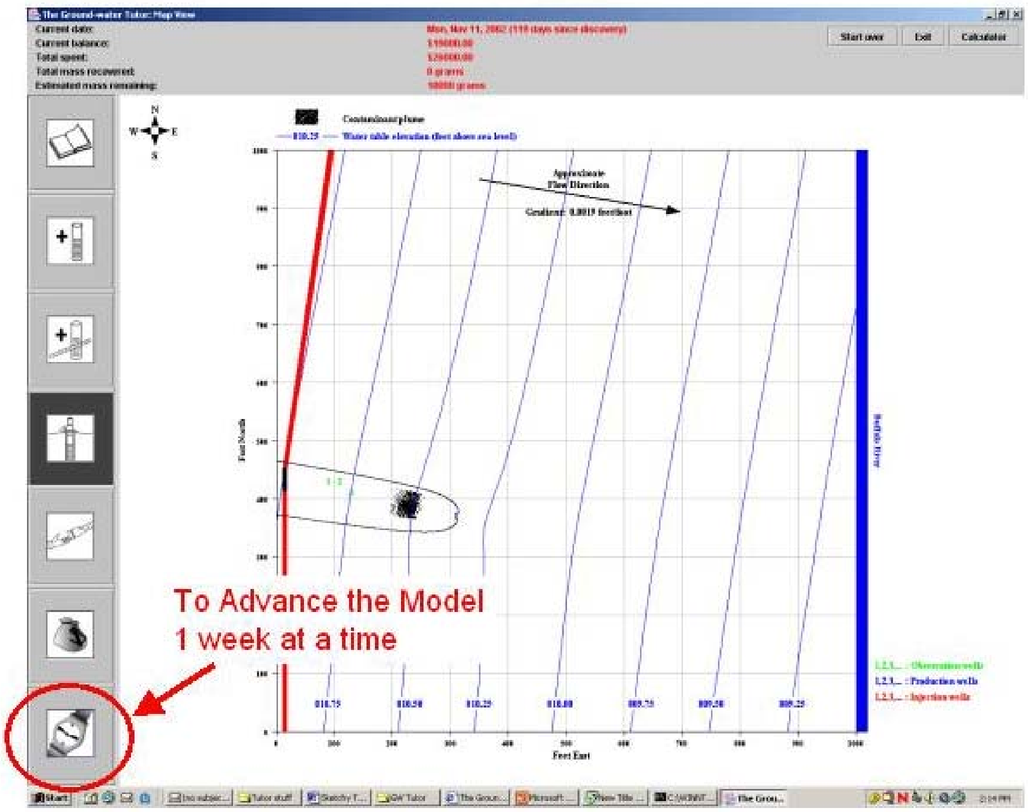


Figure 35. To advance the model through time by one week, the user clicks on this button in the lower left hand corner of Map View.

What Do Students Need to Know from Earth Science before Using the Tutor?
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
- Permeability of earth materials
- Hydraulic head
- Hydraulic gradient
- Confined and unconfined aquifers
- Darcy's Law
- Distance, time, and velocity relationships
- Interpretation of 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

Cone of depression, cone of impression, capture zone, and zone of influence are sufficiently well explained in the tutor to fulfill student needs if there is not enough time to cover these topics in the classroom.

What Basic Skills Do Students Need to Have before Using the Tutor?
The following is a list of the skills that should be helpful to students to working with the interactive ground-water tutor:

- 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

What to Pay Attention to in the Ground-water Tutor
The student's overall objective is to use his/her understanding of ground-water systems and the information provided by the tutor to find and remediate the plume in the shortest amount of time with the least cost to the pipeline owner.

To find the plume in Phase 1, the student must make some initial decisions of where to site monitoring wells based on the limited and somewhat sketchy information provided by the tutor. The Data Repository contains a range of hydraulic gradient values, an aquifer hydraulic conductivity value, and the well logs from which the student must estimate maximum and minimum aquifer porosity. The student is informed that the ground-water flow direction is toward the river in an easterly direction in the site vicinity. Estimation of the maximum and minimum aquifer porosity may be overwhelming for some students unless they realize that the logs are provided only to give them an overall impression of the aquifer makeup, which is the tack that most ground-water scientists would take. As mentioned earlier, there is no correct or incorrect method for making these estimates. Thus, the student is confronted with a fair amount of uncertainty in where to place the initial monitoring wells. Students need to remember that ground-water velocities are very low in comparison to the flow water in a stream or river. Ground-water flow velocities in sandy aquifers are typically on the order 1-2 foot per day. Use of the calculator to estimate ground-water flow velocities and travel distances should reinforce this generalization. Hence the initial monitoring wells should be located less than 150 ft from the spill site.

After the third monitoring well has been sited, the water-table map is presented to the student and the true hydraulic gradient is provided at the top of the gridded map. The hydraulic gradient information should be used to update ground-water-flow velocities. When estimating the distance traveled by the contamination, the student needs to remember that a week transpires between monitoring well sitings. When money is requested from the pipeline owner to site more wells or continue remediation, the simulation advances in time by two weeks. During that time the contamination continues to move with the ground-water flow to the river. Thus, it is important for the student to continually update his/her estimates of where the contamination is located in the aquifer before siting the next monitoring well. Using the current date information at the top of Map View will help the student make these estimates.

To remediate the contaminated aquifer in Phase 2 the most important consideration is that the production well must be able capture all of the contamination at the pumping rate selected by the student. Wellfield design consists of setting the locations of the production and injection wells and selecting pumping and injection rates. The production well should sited downgradient of the contamination (between the contamination and the river) and if an injection well is used, it should sited upgradient of the contamination. Wells should be sited near the contamination but not directly within it. Siting the production well within the contaminated portion of the aquifer will allow some of the contamination to move past the well to the river. Siting the remediation wells too far away from the contamination will only increase the time needed for remediation of the aquifer. The student will be prompted to enter a pumping rate once a well has been sited in Map View. Pumping rates for production wells are positive numbers and injection well rates are negative numbers. Thus the student would enter –10 gallons per minute for an injection well where water is being added to the aquifer or in the case of a production well where water is withdrawn from the aquifer, 10 gallons per minute. Once the design has been submitted, the boundaries of the capture zone will be displayed. To insure success the contamination must be completely contained within the capture zone boundaries.

Finally, it is also possible for the student to completely start over in Map View with the siting of the monitoring wells in Phase 1. This option was added to allow the student to learn from earlier trials of trying to locate the plume in this phase.

Keeping Score
Students will naturally want a measure of how well they performed with the ground-water tutor. Assuming the contamination is found after three monitoring wells have been installed and sampled and the remediation wellfield is sited appropriately, it is possible for the consultant to spend $40,000 to completely remove the contamination from the aquifer in 18 weeks (126 days). In this round, $15,000 was spent to locate the plume in 3 weeks (21 days) and $25,000 was spent to remediate the plume over a 15-week (105 day) period.

Linkages to Environmental Policy Issues
The ground-water tutor provides teachers with a means to initiate student exploration of a wide range of environmental issues. Listed below are some suggested topics:

- Source-water assessment, ground-water 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 the biosphere;
- The role of technology in the resolution of environmental issues;
- The social, political, and economic implications of environmental issues;
- 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 human health risks from pollutants.

More information can found by exploring the Internet links listed in the Resources section of this teacher's guide.

Assessment
The National Science Education Standards (NAS, 1996), the Benchmarks for Science Literacy (AAAS, 1994), and most local science education standards call for placing an emphasis on classroom environments that engage students in worthwhile scientific tasks and that facilitate discourse about science process. The interactive ground-water tutor is intended to increase student understanding of both environmental knowledge and problem solving process. The Tutor provides fertile ground where their students can transfer learning to multiple contexts by engaging them in complex, real-world issues and then asking them to acquire and apply skills and knowledge in a variety of contexts.

As the students work through the tutor they will be exposed work in all levels of Bloom's taxonomy of intellectual behaviors.

- Knowledge - seeking facts, testing recall and recognition
- Comprehension - translating, interpreting, and describing
- Application - demonstrating situations that are new or unfamiliar
- Analysis - creating categories or distinguishing events or behaviors
- Synthesis - combining or organizing components into a new pattern
- Evaluation - judging according to some criteria and providing a rationale

This sequence represents a general guide to assessment. Students should be asked to keep a "field log" of their work with the tutor. The field log should contain a record of their activity, decisions, and outcomes. They should also reflect on their outcomes and their decisions and explain their successes (or failures).

Suggested content for the field log:

- State the problem or issue
- Specify the assets and or needs that can be applied to this problem.
- Clearly articulate the approaches that have worked best in the past? (what do you know!)
- What is the student intending to do and what are the expected outcomes? Make sure to state any assumptions behind how and why your proposed program will work.
- Clearly lay out your planned work and your intended results.
- What was the outcome of your program?
- Is this the best possible outcome in terms of results, cost, and time?
- What will you do differently next time?

It might be worthwhile to have the students divide the log pages in half (top to bottom) and record information in the left column and their thoughts and reflections in the right column. This helps the students do both as they go along.

Resources

The ground-water part of the hydrologic cycle is difficult for students and adults to visualize and understand. Fortunately, 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

Lesson Plans and Resources for Teaching Environmental Sciences (TX Natural Resource Conservation Commission, TNRCC); good overview of surface and ground water issues K-8 lesson plans included http://www.tnrcc.state.tx.us/admin/topdoc/gi/268/chap02.pdf

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

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.

What is an Aquifer? Physical model to be built by students. Similar to Aquifer in a cup (see below) but has more questions suited to 9-12 students.
http://www.epa.gov/superfund/students/clas_act/haz-ed/aquifer.htm

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://wwwga.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/

USEPA groundwater model – groundwater model in a cup - more suited for 7-12 if students building model
http://www.epa.gov/region07/education_resources/teachers/activities/wateractivity1.htm

Aquifer in a Cup: Curricula for 4-6 grade but it is a useful exercise for getting students to think how an aquifer is put together and works in the hydrologic cycle. PDF download format
http://wildlifestewards.4h.oregonstate.edu/education%20tools/lesson.htm

USEPA Classroom experiments lesson plans all levels
http://www.epa.gov/OGWDW/kids/exper.html

USEPA Water Sourcebooks lesson plans for all ages including grades 9-12. Good selection of lesson plans on groundwater basics, hydraulic properties, flow nets for determining ground water flow direction, cleaning up groundwater etc. http://www.epa.gov/safewater/kids/wsb/

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

Porosity and Permeability experiments

Soil Permeability and Texture by Kimberly Flessner (intermediate – 8th grade lesson plan)
Also

POROSITY AND PERMEABILITY by Mark Skiles (High School level) – experiment to look at porosity and permeability of different materials
http://www.woodrow.org/teachers/esi/1999/princeton/projects/modeling/lab2app_c.html

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

Subsurface contamination of ground water by Jane Maczuzak: Example of how buried source can contaminate an aquifer. Could add a grid on surface of ground overlying buried source to work on location/mapping skills for identifying geographic location of contaminants
http://www.accessexcellence.org/AE/AEPC/WWC/1991/groundwater.html

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

National Park Service Environmental Contaminants Encyclopedia – look for TCE. It is a pdf downloadable file http://www.nature.nps.gov/toxic/list.html

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 – Predicitng 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 Wisonsin. 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

Computer System Requirements
Currently the ground-water tutor runs in a Windows operating system environment. The most recent version of the tutor runs on systems with Windows NT with Microsoft Office 2000 and Windows XP with Microsoft Office 2003. File sizes are generally small in kilobyte size range and the ground-water tutor occupies less than 4 Megabytes on the computer.

The HTML pages can be displayed with either Netscape or Explorer browsers, but seem to have the best appearance using Explorer. The main issue with part of the tutor is computer screen resolution, which needs to be set as high as possible. The graphics included on the HTML pages use a fixed number of pixels on the computer screen irrespective of screen 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 ground-water model uses the Java 2 SDK version of the JAVA programming language. This software is intended for use on Microsoft Windows 95, 98 (1^{st} or 2^{nd} 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.

Most of the newer Windows operating systems already have JAVA installed as part of the Windows operating system software. As part of the ground-water tutor installation package, the installer checks to determine if a Java run-time environment is present. If not, the installer will establish one as part of the software download for installation.

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Glossary

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.

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

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.

Biosphere – The realm of living things on Earth.

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).

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.

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.

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.

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.

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.

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.

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.

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

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 considerd 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.

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).

Plume -- See contaminant plume.

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.

Potential energy – The energy of position with respect to a reference elevation and is equal to the energy required to move a mass to a point above the reference elevation.

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

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.

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.

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

Specific discharge -- The volume of water transmitted through a permeable material per unit cross-sectional area calculated from Darcy's law.

Trichloroethylene (TCE) -- This organic compound is a chlorinated hydrocarbon, a colorless liquid, and a cancer-causing agent and is in the top 15 priority pollutant list compiled by the US Environmental Protection Agency.

Unconfined aquifer -- An aquifer in which the upper boundary is the water table.

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

Water sample -- A small volume of water collected from a surface- or ground-water 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.

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.

Zone of influence -- The area surrounding an injection well within which the water table has been changed due to recharge caused by the addition of fluids.