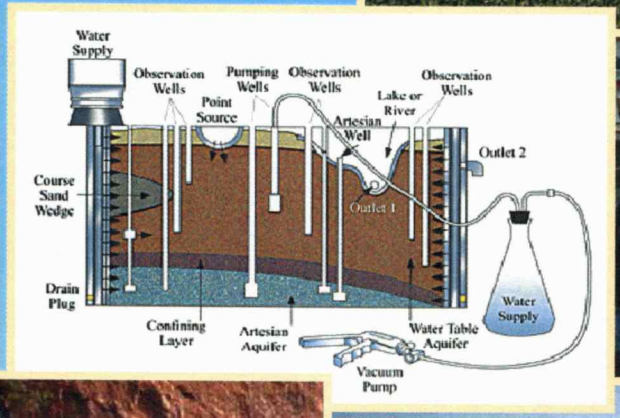
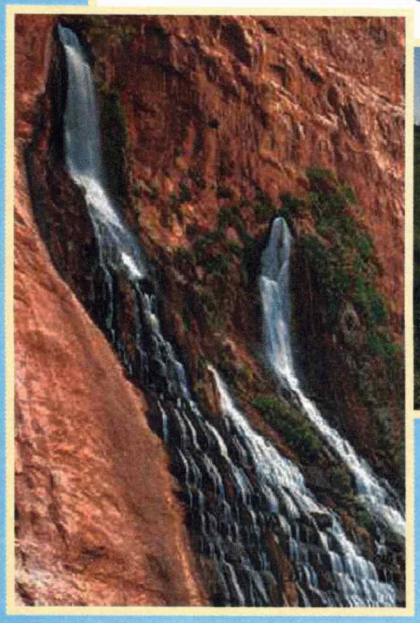
GROUNDWATER WORKSHOP
FOR
HIGH SCHOOL SCIENCE TEACHERS

JULY 25 - 29, 2004
KANSAS GEOLOGICAL SURVEY
UNIVERSITY OF KANSAS











Funded by the National Science Foundation

THE SUMMER 2004 GROUND-WATER WORKSHOP FOR SECONDARY TEACHERS OF EARTH AND ENVIRONMENTAL SCIENCE

By
P. Allen Macfarlane, Margaret A. Townsend, Geoffrey C. Bohling
Kansas Geological Survey;
And
Alison Reber, StreamLink;
And
Steve Case, School of Education, The University of Kansas

Project Purpose

The purpose of this project was to provide in-service instruction for teachers in the use of the ground-water tutor (Plume Busters) in high school earth and environmental science classes during the late summer 2004. Plume Busters is an innovative "hands-on" tool for the application of concepts related to ground-water flow and to the human impacts on surface- and ground-water systems (Macfarlane, et al., 2003; http://www.kgs.ku.edu/Hydro/Publications/OFR03_65/index.html). The project is funded through the NSF Geoscience Education program. Plume Busters is currently being tested in high school and introductory undergraduate-level classes to evaluate its educational potential.

Target Audience

The target audience for this project is high school teachers of earth and environmental science courses from urban and rural school districts. Of the 15 participants in the workshop 13 taught in Kansas schools.

In-Service Workshop

This project was a collaborative effort between the Kansas Geological Survey, Kansas StreamLink, and Steve Case, Center for Science Education, University of Kansas (KU), and could serve as a model for use in other locations with a similar audience. The Kansas Geological Survey (KGS) (http://www.kgs.ku.edu) is a nationally recognized research unit of KU and has long been involved in ground-water research. Kansas StreamLink (http://www.streamlink.org) is a network of stream study teams, watershed educators, and stream stewardship projects that focuses on water-resources literacy in Kansas. Steve Case conducts research to support the national efforts to reform science and technology education and is a recognized leader in this field.

The workshop goals were to (1) upgrade the science knowledge base of the participants such that the participants will be able to draw from common knowledge base as they work with the ground-water tutor, (2) introduce the Plume Busters software to the participants and describe strategies for integrating the tutor into earth and environmental science courses to improve science content, and (3) motivate teachers to engage their students in the exploration of environmental policy, technology, and socioeconomic issues using the ground-water tutor and other appropriate educational tools.

The workshop was team-taught and conducted over four days (July 26-29, 2004) on the University of Kansas campus at Lawrence, Kansas. At the beginning of the workshop, the participants were: (1) pre-tested to assess their understanding of ground-water and water-resources concepts and issues; and (2) provided with workshop notes, supplementary U.S. Geological Survey publications, and a guide to the Plume Busters software. The publications provided dealt with ground water, water use, and water resources issues. Most of the instruction was lecture-based using Powerpoint presentations. Instruction on the Plume Busters software took place in the KGS computer laboratory. Participants gained "hands-on" experience in working with and interpreting real-world, ground-water and water-quality data collected at the GEMS research site in the Kansas River valley, Darcy's law experiments conducted in the laboratory, and by completing a project to present to the class at the end of the workshop. Demonstrations were performed using commercially available sand-tank models to illustrate basic ground-water concepts, the movement of contaminants through aquifers, and the pump-and-treat method of aquifer remediation. A schedule of the sessions and activities is included at the end of this section (Appendix A).

Project Evaluation

Project evaluation is being conducted based on (1) a pre- and post-test to evaluate improvement in the participant's knowledge base on ground-water systems, (2) observation of the participants during the workshop, (3) the questions asked by the participants during the workshop, (4) comments solicited from the participants during and at the end of the workshop, (5) interest in using the ground-water tutor in participant's classrooms, (6) feedback from the participants as they explore the Plume Busters software in the workshop, and (7) evaluation of the writing projects submitted for additional graduate-level course credit. Dr. Kenneth Thompson, Earth Science Department, Emporia State University will conduct a quantitative evaluation of the pre- and post-test results as part of the NSF-funded project to develop the prototype ground-water tutor. The surveys used to evaluate the workshop and the pre- and post-test questions are included at the end of this section in Appendices B and C.

The Lecture Notes and Other Materials

The lecture notes are organized by presenter. Other materials included in the binder are classified as Miscellaneous Publications and Web Materials. The Miscellaneous Publications consist of copies of the Kansas Geological Survey Public Information Circulars that relate to ground water in Kansas.

References Cited

Macfarlane, P.A., Townsend, M.A., Bohling, G., Case, S., and Reber, A., 2003, A preliminary teacher's guide to the interactive ground-water tutor: Kansas Geological Survey Open-file Report 2003-65, 57 p. http://www.kgs.ku.edu/Hydro/Publications/OFR03_65/index.html

Appendix A
Summer 2004 Ground-water Workshop for High Science Teachers Schedule of Activities

Date	Time	Location	Topic	Presenter
Sun				
7/25	7:00 - 10:00PM	McCollum Hall	Welcome, Introductions, Orientation, Workshop Overview & Problem, Pre-test	Macfarlane, Townsend
Mon	8:00 - 10:00 AM	Hambleton Auditorium, KGS	Overview of Central Midwest Water Resources; Hydrologic Cycle, Ground-water Basics	Macfarlane
7/26	10:00 - 10:15AM	Hambleton Auditorium, KGS	Break	
	10:15 - Noon	Hambleton Auditorium, KGS	Ground-water Basics (continued)	Macfarlane
	Noon - 1:30PM	Dorm	Lunch	
	1:30 - 2:30PM	Hambleton Auditorium, KGS	Ground-water Basics (continued)	Macfarlane
	2:30 - 3:30PM	Hambleton Auditorium, KGS	Water quality basics	Townsend
	3:30 - 3:45PM	Hambleton Auditorium, KGS	Break	
	3:45 - 5:30PM	Hambleton Auditorium, KGS	Water quality basics, Drinking water standards, maximum contaminant levels in water	Townsend
	5:30 - 7:00PM	Dorms	Dinner	
	7:00 - 9:00PM	Computer Lab, KGS	Project work	
Tues	8:00 - Noon	GEMS site	Basic field measurements & techniques	Macfarlane, Townsend
7/27	1:30 - 2:45PM	Hambleton Auditorium, KGS	Ground-water manangement of the Ogallala Aquifer in western Kansas	Buchanan
	2:45 - 3:45PM	Hambleton Auditorium, KGS	Contaminant hydrogeology	Macfarlane, Townsend
	3:45 - 4:00PM	Hambleton Auditorium, KGS	Break	
	4:00 - 5:30PM	Hambleton Auditorium, KGS	Incorporation of educational software & technology in earth & environmental science classes	Case
	5:30 - 7:00PM	Dorms	Dinner	
	7:00 - 10:00PM	Rm 6040 Mallott Hall	The Darcy's Law experiment, Other ground-water flow and water quality experiments & demos	Macfarlane, Townsend
Wed	8:00 - 10:00AM	Hambleton Auditorium, KGS	Ground-water Remediation Technologies	Macfarlane
7/28	10:00 - 10:15AM	Hambleton Auditorium, KGS	Break	
	10:15 - Noon	Computer Lab, KGS	Introduction to Plume Busters	Macfarlane, Bohling
	Noon - 1:30PM	Dorms	Lunch	
	1:30 - 3:00PM	Computer Lab, KGS	Individual Plume Busters exploration	Macfarlane, Bohling
	3:00 - 5:00PM	Computer Lab, KGS	Project work	
	5:30 - 7:00PM	Dorms	Dinner	
	7:00 - 10:00PM	Computer Lab, KGS	Project work	
Thurs	8:00 - 9:30AM	Hambleton Auditorium, KGS	State & federal programs & legislation for ground- and surface-water protection	Reber
7/29	9:30 - 9:45AM	Hambleton Auditorium, KGS	Break	
	9:45 -11:45AM	Hambleton Auditorium, KGS	Project work	
	11:45 - 1:00PM	Dorms	Lunch	
	1:00 - 3:45PM	Hambleton Auditorium, KGS	Project presentations	
	3:45 - 4:00PM	Hambleton Auditorium, KGS	Break	
	4:00 - 5:00PM	Hambleton Auditorium, KGS	Wrap-up activities, participant evaluation	Macfarlane, Townsend
	5:00 - 5:30PM	Hambleton Auditorium, KGS	Participant post-test	Macfarlane, Townsend
	6:30 - 7:00PM	Paisano's	Social hour	
	7:00PM	Paisano's	Dinner	

Appendix B
Survey of Teachers Using Plume Busters
&
Survey of Teachers Taking the Summer 2004 Ground-water Workshop

Survey of Teachers Using the
Plume Busters in the Summer 2004 Ground-water Workshop

This information is intended to provide feedback to the developers of Plume Busters. The developers are seeking basic information on student users and student users' reactions to Plume Busters. Any information or feedback you can provide is greatly appreciated. Please respond to all items.

1. Last 4 digits of your Social Security Number (SSN): _____

2. Indicate which level(s) you teach:

   - ☐ High School
   - ☐ Junior High School

3. In Phase 1, how many times did you have to restart your search for the plume before you located it with 3 wells?

4. On your first successful attempt to locate and remediate the plume,

   How many days did it take you to complete Phase 1? _____

   How much money had you spent at the end of Phase 1? _____

   How many days did it take you to complete Phases 1 and 2? _____

   How much money had you spent at the end of Phase 2? _____

5. What features of Plume Busters were most useful to help you understand the subject matter and to improve your skills?

6. What features of Plume Busters were not helpful, were confusing, or need improvement? Please be specific and make recommendations.

Thank you for your participation in this research!
Remember to return this survey

Ground-Water and Plume Busters Workshop for High School, Junior High School, and Middle School Science Teachers
University of Kansas/Kansas Geological Survey
July 2004

Workshop Evaluation by Participants

This survey is intended to assist us in the assessment and evaluation of the workshop and the Plume Busters software. Your responses will be kept anonymous and confidential. Thank you for your cooperation.

Last four digits of your social security number_____

Name (0ptional)_____

1. # years teaching Earth Science, Environmental Science, or Geography _____

2. Total # of students you interact with per week _____

3. ***In the past school year***, approximately how many sections of each subject did you teach and how many students were enrolled (class size)?

Subject	Grade level	#Sections	Class size(s)
Earth Science			
Environmental Science			
Geography			
Other (please specify)			

4. What were the most challenging and most rewarding aspects of teaching Earth Science, Environmental Science, and or Geography this past year?

   a. Challenging:

   b. Rewarding:

6. How useful were each of the following elements of the workshop to improve your understanding of ground-water subject matter?

Use a 3-point scale (1=not useful; 2=useful; 3=very useful) or NA if the event did not occur.

a.	Overview of Midwest water resources	1	2	3	NA
b.	Overview of the hydrologic cycle	1	2	3	NA
c.	Overview of ground-water basics	1	2	3	NA
d.	Water quality basics	1	2	3	NA
e.	Basic field measurements and techniques	1	2	3	NA
f.	Ground-water management of the Ogallala aquifer	1	2	3	NA
g.	Contaminant hydrogeology	1	2	3	NA
h.	Educational software and technology	1	2	3	NA
i.	Darcy's Law and other experiments	1	2	3	NA
j.	Ground-water remediation technologies	1	2	3	NA
k.	Use of Plume Busters software	1	2	3	NA
l.	Information on ground- and surface-water protection	1	2	3	NA
m.	Individual and/or group project work and presentations	1	2	3	NA
n.	Pre- and post-tests	1	2	3	NA

Comments

(continue)

8. Regarding the Plume Busters (Ground-water Tutor) software, what features were confusing, not helpful, or need improvement? Please be specific and make recommendations.

9. The general workshop goals are to: 1) to enhance the science knowledge base of participants in order to work with the ground-water tutor (Plume Busters), 2) introduce the ground-water tutor and identify strategies for integrating it into courses, and 3) motivate teachers to engage their students to explore science-technology-society issues. Comment on the extent to which the goals were addressed and achieved. Identify some positive and some not so positive experiences.

THANK YOU FOR COMPLETING AND RETURNING YOUR SURVEY!

Appendix C
Pre- and Post-test Questions

Question 1:
The hydrologic cycle is driven by:

A. Water moving from higher to lower elevation
B. Radiant energy
C. Potential energy
D. Evaporation of water from the oceans

Question 2:
The difference between the total input and the total output of water from a region or a hydrologic entity is equal to:

A. The specific retention
B. The specific storage, if the input and output remain at constant levels.
C. The change in storage
D. The specific yield

Question 3:
Eastern Kansans rely on surface water but western Kansans rely primarily on ground water because:

A. Evapotransporation increases from east to west across the state.
B. Annual precipitation decreases from east to west across the state.
C. Surface-water sources are available in eastern but not in western Kansas
D. Ground-water sources are more available in western than in eastern Kansas
E. All of the above

Question 4:
Porosity is:

A. The void space fraction of the bulk volume
B. The sum of the specific yield and the specific retention
C. Classified as intergranular, fracture, and solution
D. All of the above
E. Only A and C

Question 5:
Which statement is true?

A. Sand has a lower porosity than clay
B. As a sediment is transformed by diagenesis into a sedimentary rock, its total porosity increases and its interconnected porosity decreases.
C. Shale has more interconnected porosity than most sandstones.

Question 6:
The hydraulic conductivity of an earth material depends on its permeability and the properties of the fluid passing through it.

A. True
B. False

Question 7:
Which statement is true?

A. Shale is more permeable than sandstone because it has more total porosity than sandstone
B. Shale has more interconnected porosity than most sandstones.
C. Permeability is a measure of the ease with which fluids pass through an earth material

Question 8:
Which statement is false?

A. Aquifer and confining units are defined based on relative differences in permeability, which can span several orders of magnitude or more in value.
B. Confining units make good sources of ground water for wells because they store a lot of water.

Question 9:
If an aquifer is bounded above by the water table:

A. It is a confined aquifer
B. It is an unconfined aquifer
C. It is a perched aquifer
D. It could be either B or C
E. It could be either A or C

Question 10:
Streams are always considered to be areas where ground water is discharged back to the surface.

A. True
B. False

Question 11:
The hydraulic head is:

A. The elevation of the potentiometric surface above sea level.
B. The elevation of the water table above sea level.
C. Equal to the sum of the elevation head and the pressure head
D. All of the above

Question 12:
Ground water always moves from areas of low hydraulic head to areas of high hydraulic head.

A. True
B. False

Question 13:
Darcy's law states that the rate of flow of water through an earth material is:

A. Inversely proportional to the hydraulic gradient and directly related to the cross-sectional area through which flow is occurring.
B. Inversely proportional to both the hydraulic gradient and the cross-sectional area through which flow is occurring.
C. Directly related to both the hydraulic gradient and the cross-sectional area through which flow is occurring.

Question 14:
The constant of proportionality in Darcy's law is:

A. The hydraulic conductivity
B. The specific retention
C. The specific yield
D. The porosity
E. None of the above

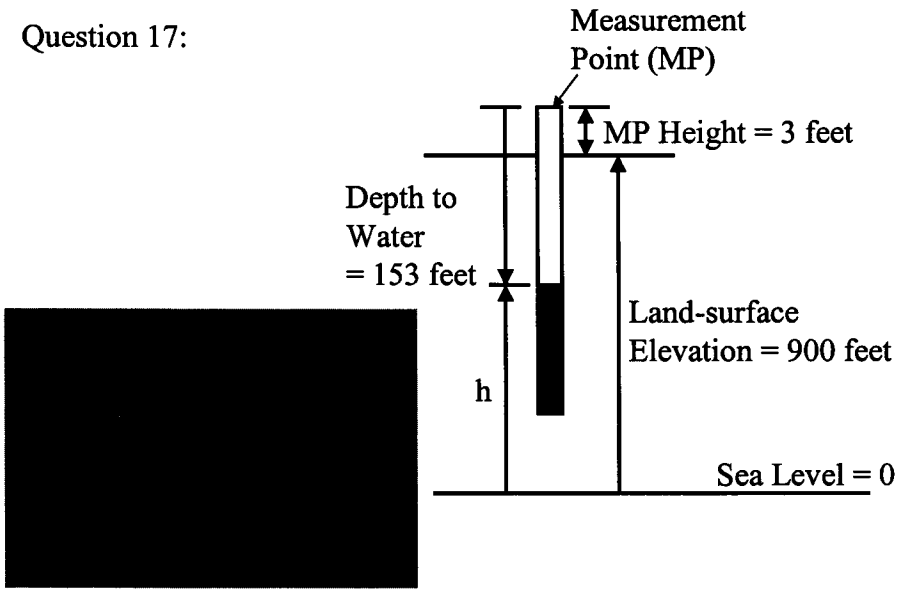
Question 15:
Why do hydrogeologists map ground-water flow systems?

A. To delineate ground-water flow paths and systems
B. To estimate ground-water flow rates
C. To determine ground-water residence time
D. All of the above

Question 16:
How many point measurements of hydraulic head taken at different map locations does it take to determine the lateral ground-water flow direction in an aquifer?

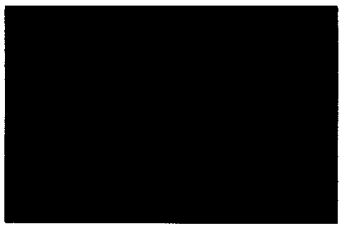
A. 2
B. 4
C. 5
D. 3

Question 17:



Question 18:
In these maps of the water-table elevation above sea level, which one shows a true direction of ground-water flow?

A



B

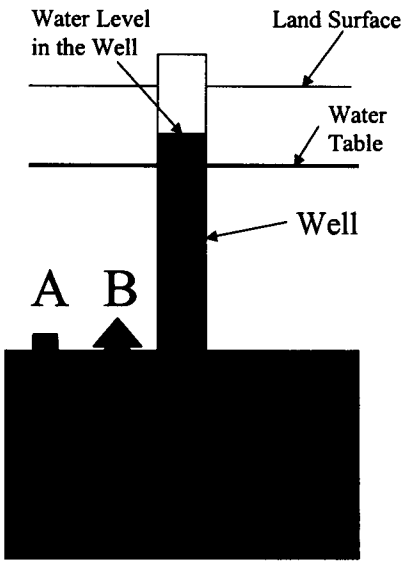


C



Question 19:
Which way is ground water moving across the confining layer?

A. A
B. B
C. It is not moving across the confining layer.



Question 20:
A ground-water flow system consists of a recharge area, a discharge area, and an integrated network of flow paths

A. True
B. False

Question 21:
Lakes, streams, and marshes may be sources of recharge or act as discharge areas depending on wet or dry season conditions or ground-water withdrawals.

A. True
B. False

Question 22:
Which statement best illustrates stream-aquifer interaction?

A. Stream is losing discharge at all times
B. Fluctuating water table
C. Stream is dry at all times because the water table is below the stream
D. An artesian well is in the area but the stream is dry

Question 23:
When a well pumps water from an unconfined aquifer a cone of impression is created in the water table surface.

A. True
B. False

Question 24:
If the water table is sloping, all of the water contained within the zone of influence moves towards the well.

A. True
B. False

Question 25:
What chemical parameter is represented by "TDS"?

A. Specific conductance
B. Temperature
C. The sum of the concentrations of the dissolved solutes
D. pH

Question 26:
What field chemical parameters would best distinguish surface from ground water?

A. pH, temperature, turbidity, atrazine
B. Nitrate, pH, specific conductance, temperature
C. Temperature, pH, specific conductance, turbidity
D. pH, specific conductance, atrazine, nitrate

Question 27:
Which field method is used to collect water sample from a well without a pump installed?

A. Drill rig
B. Bailer
C. Measuring cup
D. Hose

Question 28:
Which rock is most likely to be dissolved by rainwater?

A. Shale
B. Sandstone
C. Granite
D. Limestone

Question 29:
Which field chemical test gives you an estimate of how salty the water is?

A. pH
B. Temperature
C. Specific conductance
D. Turbidity

Question 30:
What does the term redox zone mean?

A. Zone where excess carbon dioxide causes dissolution
B. Zone where dissolved oxygen occurs in the water
C. Zone where reduction or oxidation of metals occurs
D. Zone where biodegradation is likely to occur

Question 31:
Contaminants are transported through ground-water systems primarily by means of diffusion.

A. True
B. False

Question 32:
If a source continuously supplies contaminants to a ground-water system, the zone of contamination in the aquifer is referred to as a:

A. A slug
B. A plume

Question 33:
To locate contamination in an aquifer using monitoring wells, you need to know:

A. The porosity
B. The hydraulic conductivity
C. The average ground-water velocity
D. The direction of ground-water flow
E. Only B and D
F. Only A and C
G. Only C and D

Question 34:
To remediate an aquifer using the pump-and-treat technology all of the ground-water contamination must be contained within the zone of influence.

A. True
B. False

Question 35:
The water table in the western part of the High Plains aquifer (the Ogallala aquifer) in western Kansas is declining in elevation and the saturated thickness is decreasing because:

A. Global warming is causing recharge to the aquifer to decrease.
B. Discharge from the Ogallala to streams such as the Arkansas River is increasing as streamflow declines.
C. Pumpage from the aquifer by public water supplies is increasing over time.
D. Irrigation pumpage, the primary use of the aquifer, is orders of magnitude greater than the annual recharge rate.

Question 36:
The federal Clean Water Act does not cover which of the following:

A. Ground-water quality
B. The National Point Discharge Elimination (NPDES) System
C. Surface-water quality
D. Source Water Assessments
E. Well-head Protection
F. None of the above

Question 37:
The purpose of Superfund is:

A. Provide funding for public water supply enhancements.
B. Provide funding for non-point source programs
C. Provide funding to clean up serious contamination threats in cases where a responsible party cannot be identified
D. Provide funding for the Brownfields program efforts

Question 38:
US EPA sets water quality standards at the federal and state level

A. True
B. False

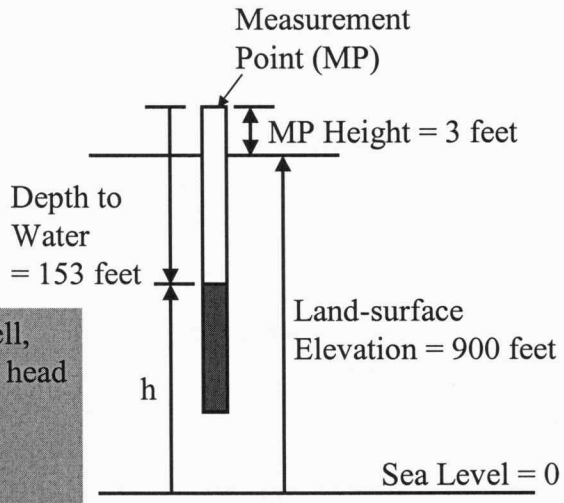
Question 39:
The TMDL approach is being used to manage ground-water quality.

A. True
B. False

Question 40:
Which piece of federal legislation authorizes Superfund?

A. The Clean Water Act
B. The Resource Conservation Recovery Act
C. The Comprehensive Environmental Response, Compensation, and Liability Act
D. Federal Insecticide, Fungicide and Rodenticide Act

Question 17:

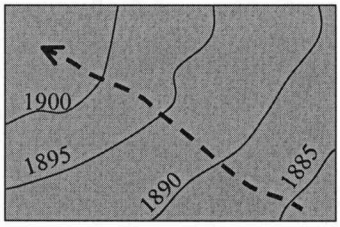


In the diagram of this well, what is the hydraulic head value (h)?

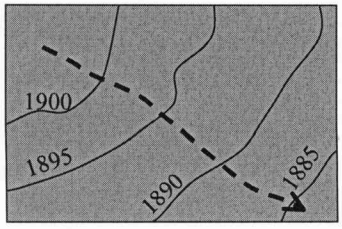
A. 153 feet
B. 750 feet
C. 150 feet

Question 18:
In these maps of the water-table elevation above sea level, which one shows a true direction of ground-water flow?

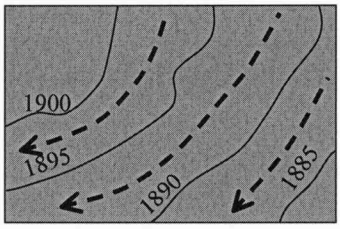
A



B

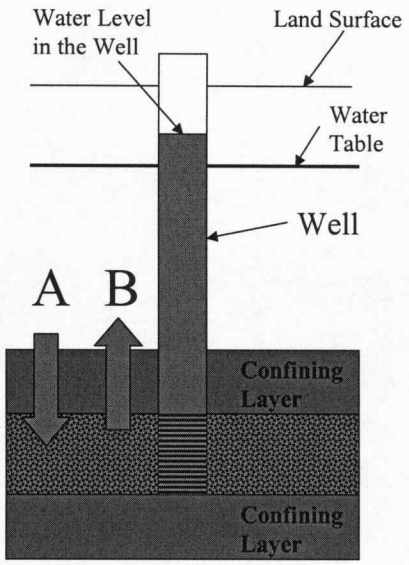


C



Question 19:
Which way is ground water moving across the confining layer?

A. A
B. B
C. It is not moving across the confining layer.



Question 20:
A ground-water flow system consists of a recharge area, a discharge area, and an integrated network of flow paths

A. True
B. False

Introduction to Plume Busters

Kansas Geological Survey

28 July 2004

Purpose of Plume Busters

- Provide virtual field exercise to *reinforce* understanding of groundwater flow and contaminant transport
- Student plays role of environmental consultant hired to locate and clean up a contaminant plume
- Goal is to clean up plume as quickly and economically as possible

Plume Busters Components

- HTML Pages (*PlumeBusters*)
  - Introduce simulated contamination scenario
  - Explain how to use Java application
  - Provide background/resource material
- Java application (*PlumeBusters Map View*)
  - Simulates contaminant plume movement
  - Student plays role of environmental consultant
  - Two phases: i) locate, ii) remediate plume

Installation CD (Windows)

- Plume Busters Installer (pbSetup.msi)
  - Copies files to hard drive
  - Sets up two desktop shortcuts
- Java runtime installer (j2re-1-3-*etc*.exe)
  - In case computer does not have (recent) Java
  - *Not* installed automatically
- Two Windows Installer installers
  - In case computer's installer software is too old
- Sub-folder with all the Plume Busters files
  - For *manual* copying in case all else fails







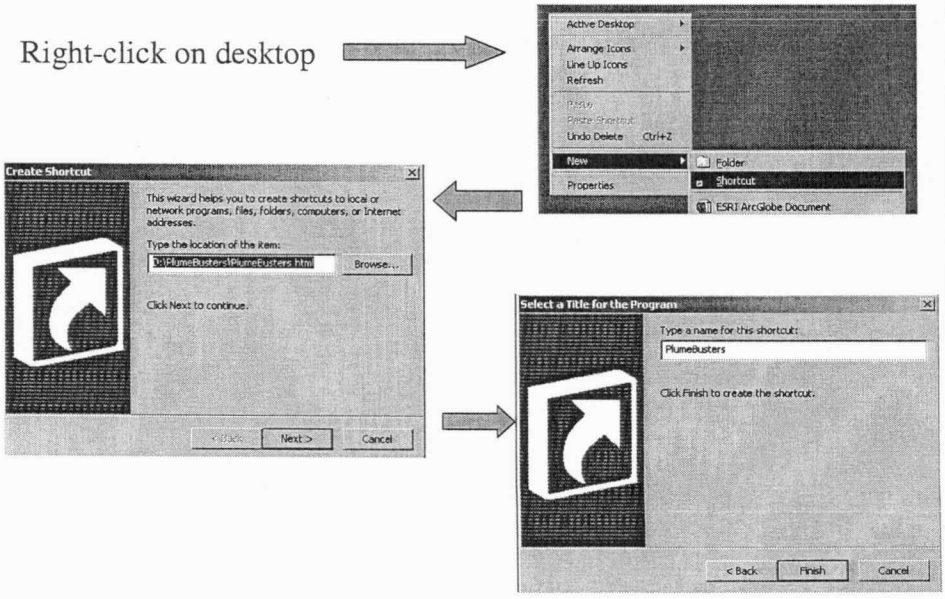


Manual Copying and Shortcuts (*in case installer doesn't work*)

- Copy PlumeBusters folder to hard drive
- Create desktop shortcut (*PlumeBusters*) pointing to **PlumeBusters.html** in PlumeBusters folder
- Create desktop shortcut (*PlumeBusters Map View*) pointing to **PlumeBusters.jar** in PlumeBusters folder

Creating Shortcuts

Right-click on desktop



Getting Started

- Double-click *PlumeBusters* shortcut
  - Points to PlumeBusters.html, the opening HTML page
  - Clicking right arrow on this page leads to beginning of narrative . . .

A PRELIMINARY TEACHER'S GUIDE TO PLUME BUSTERS

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

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.

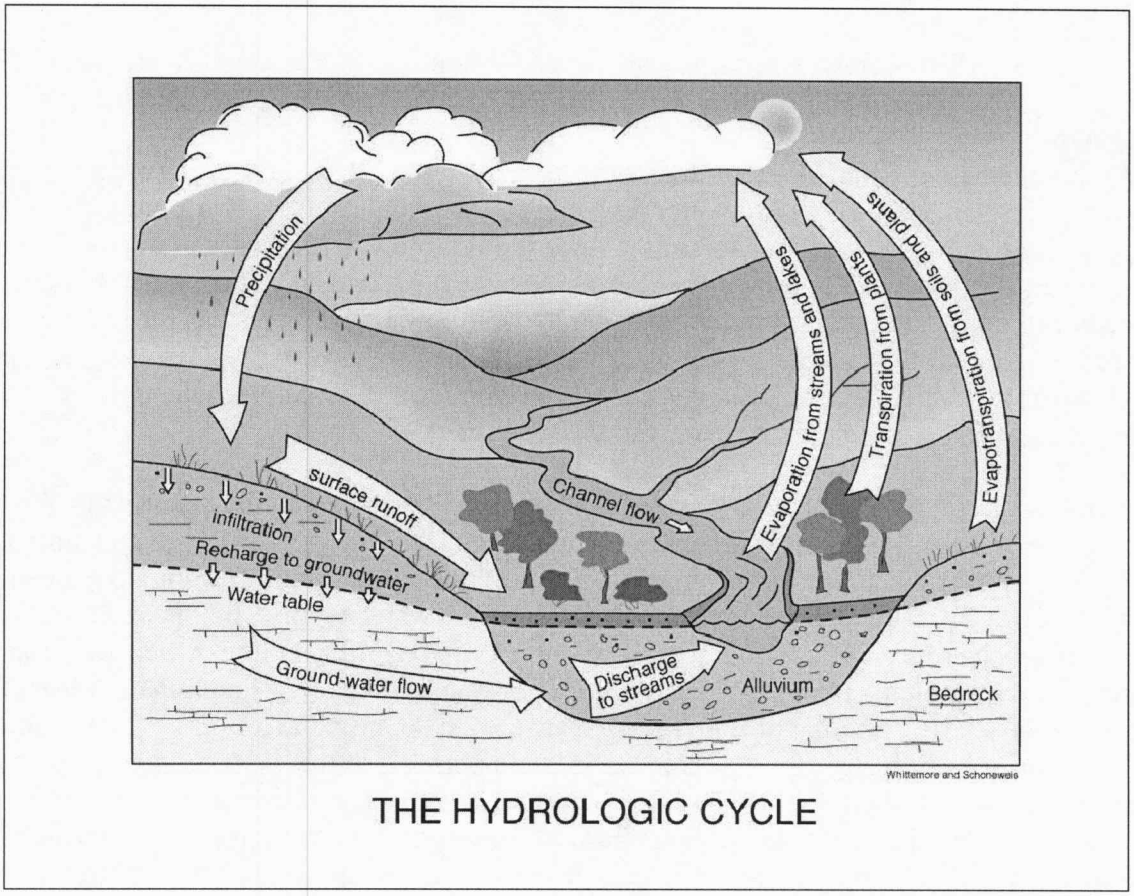


Figure 1. The drainage basin hydrologic cycle.

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.

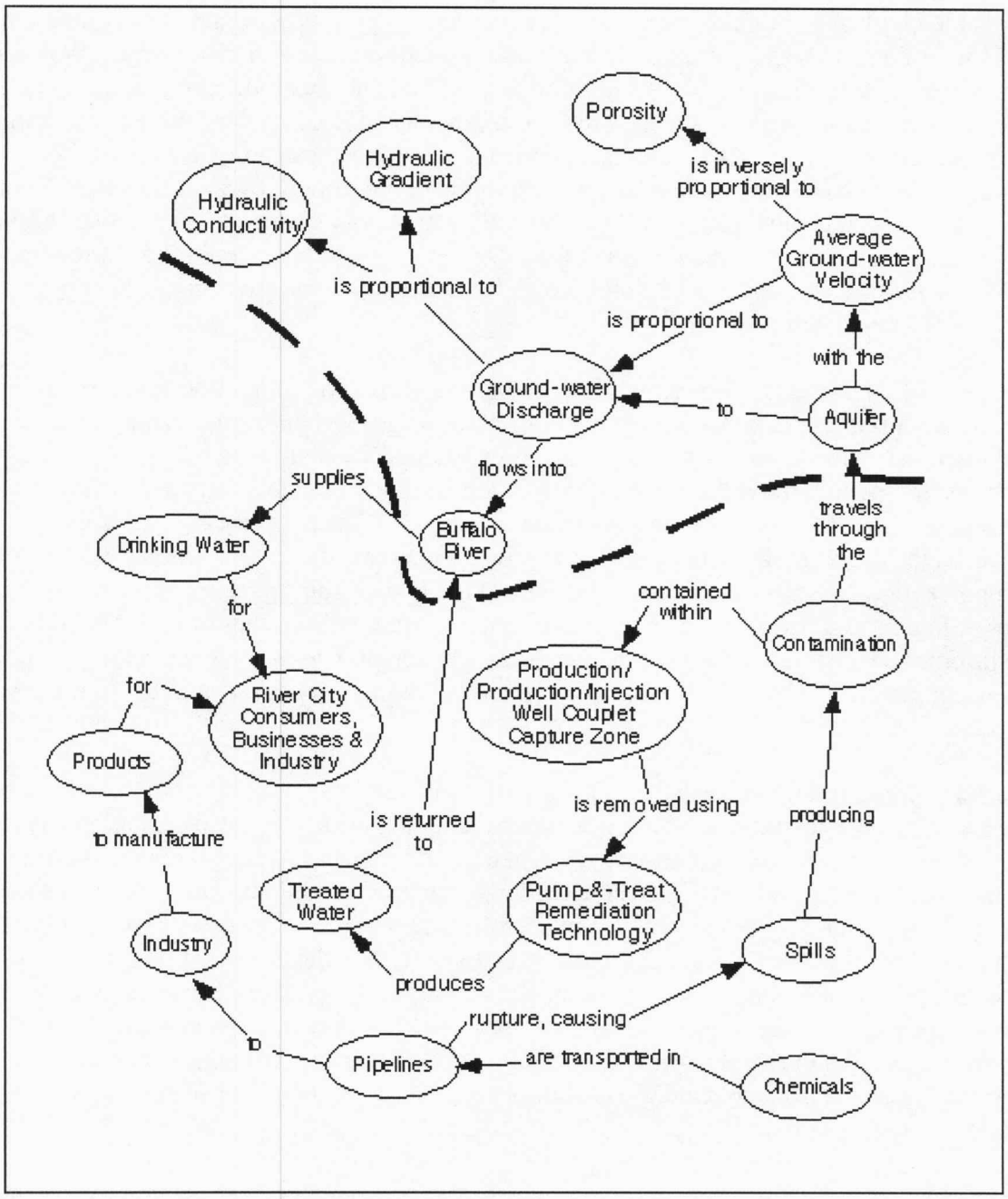


Figure 2. Concept map of the water cycle in the human-impacted Buffalo River drainage basin as it is portrayed in the ground-water tutor. The linked concepts above the dashed line represent the surface and ground-water parts of the basin hydrologic cycle that are pertinent to the tutor. The linked concepts 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	Benchmark 3: Estimation – Computational estimation with real numbers in a variety of situations	The student: 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	Benchmark 3: Functions – Analysis of functions in a variety of situations	The student: 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	Benchmark 2: Measurement and Estimation – Estimation, measurement, and use of geometric formulas in a variety of situations	The student: 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	Benchmark 2: Statistics – Collection, organization, display, explanation, and interpretation of numerical (rational) and non-numerical data sets in a variety of situations	The student: 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 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

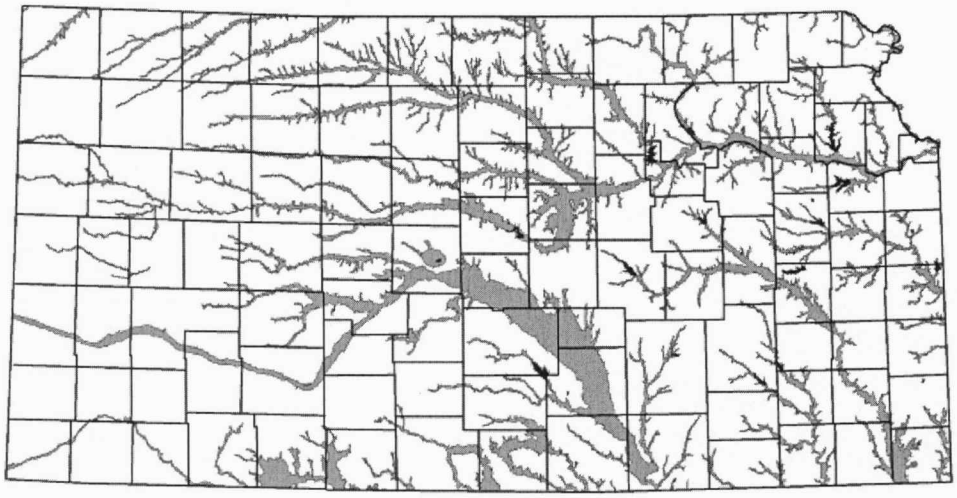


Figure 3. The alluvial aquifers of Kansas.

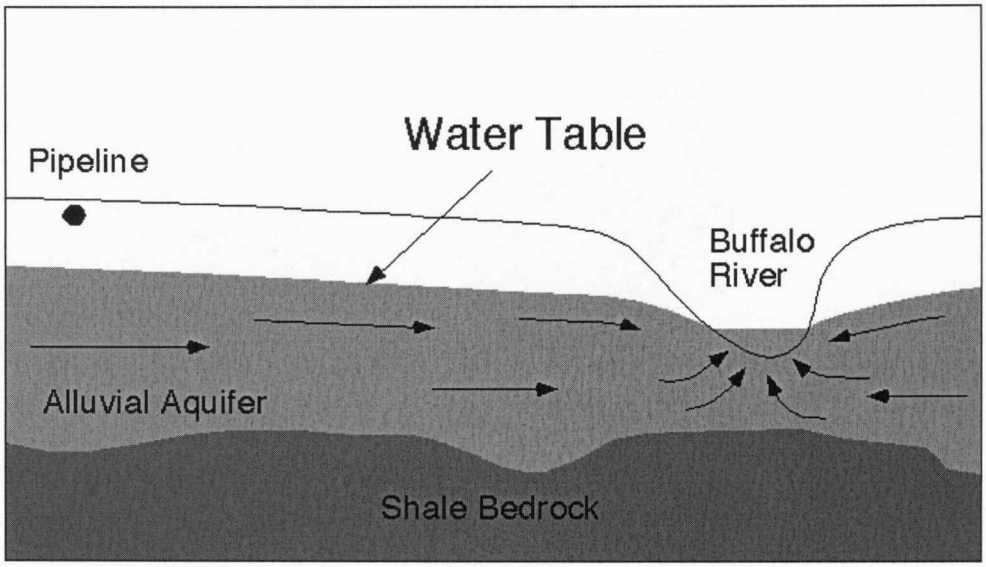


Figure 4. The water table defined the upper saturated part of an unconfined alluvial aquifer. Because the flow of water is from the alluvial aquifer to the stream, the stream is considered to be gaining.

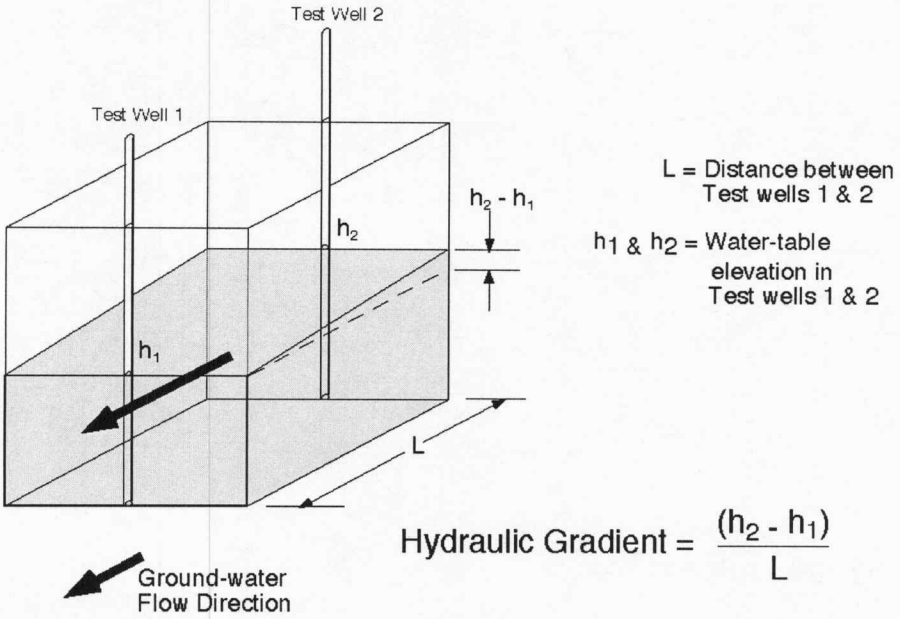
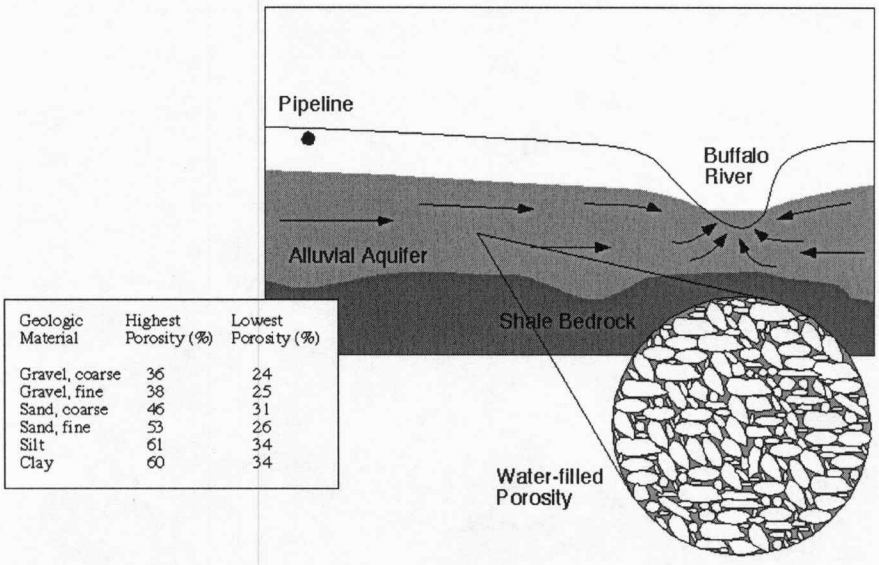
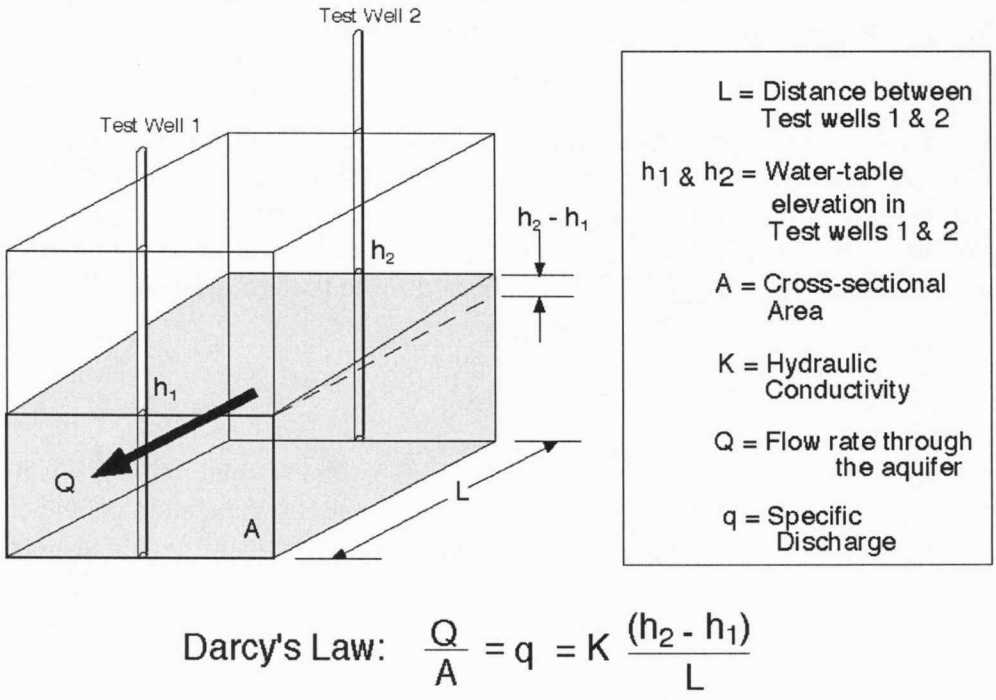


Figure 5. Hydraulic head is equivalent to the elevation of the water table above sea level. The hydraulic gradient is the change in hydraulic head ($h_1 - h_2$) over a horizontal distance L in the direction of ground-water flow.



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).



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

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

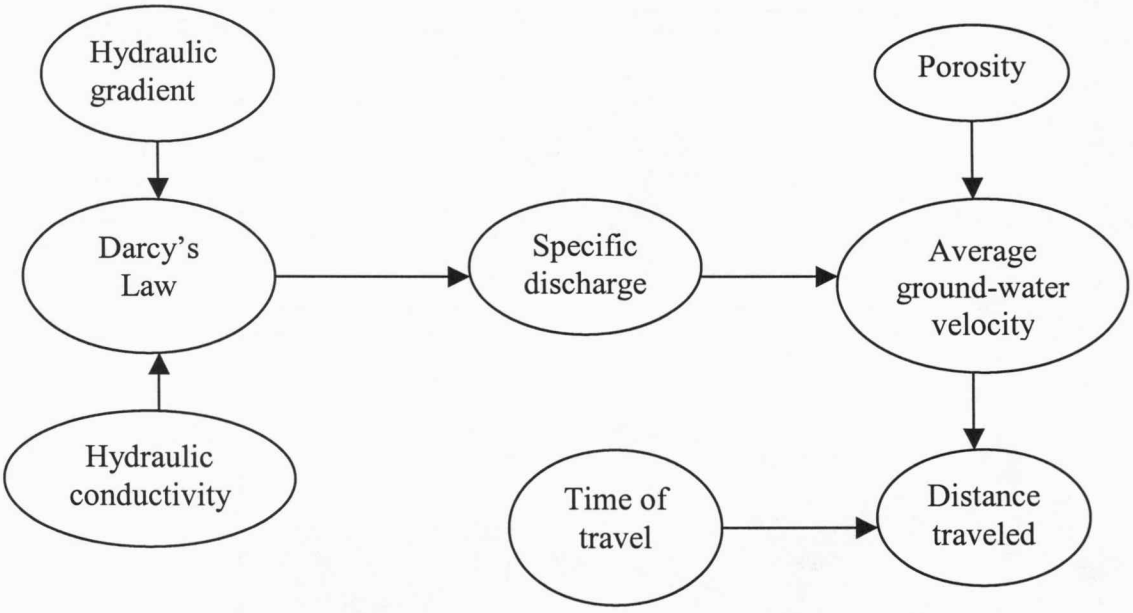


Figure 8. Science concepts and their relationship in the contaminant discovery phase of the interactive ground-water tutor.

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 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).

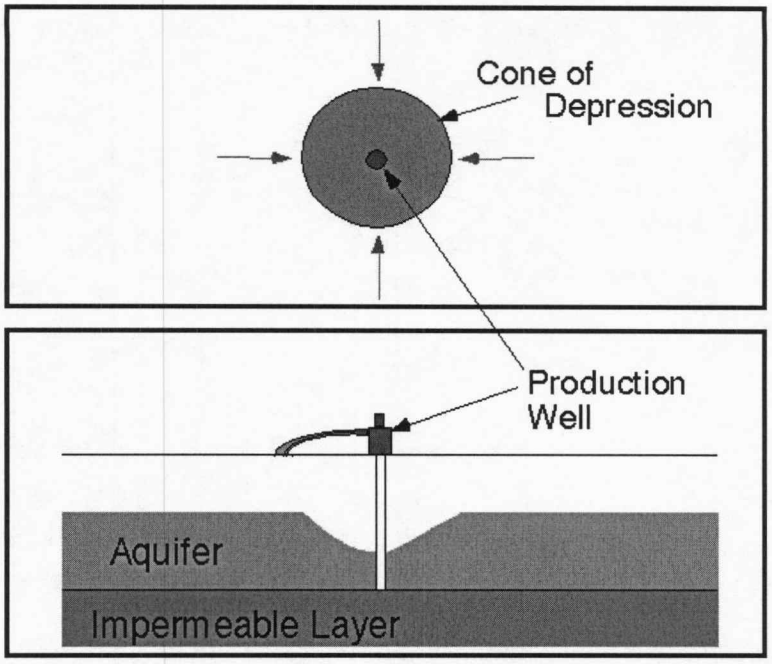


Figure 9. A cone of depression (shown in red in plan view) forms when a production well is pumped because water is being withdrawn from the aquifer than it is being replenished by ground-water flow (shown by the blue arrows). As a result the ground-water withdrawals cause a lowering of the water table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

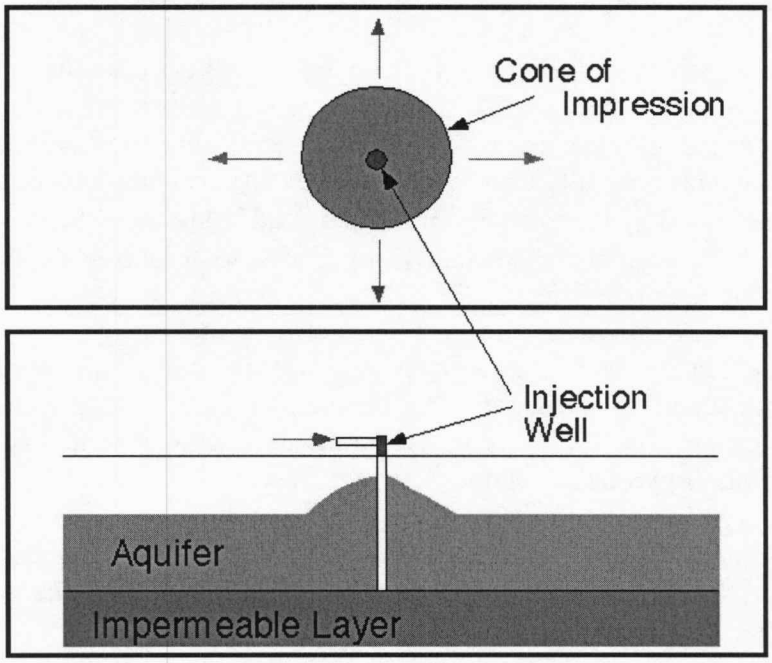


Figure 10. A cone of impression (shown in red in plan view) forms when an injection well is pumped because water is being added to the aquifer at a rate faster than it can move away from the well (shown by the blue arrows in plan view). As a result the addition of water causes a water-table rise near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

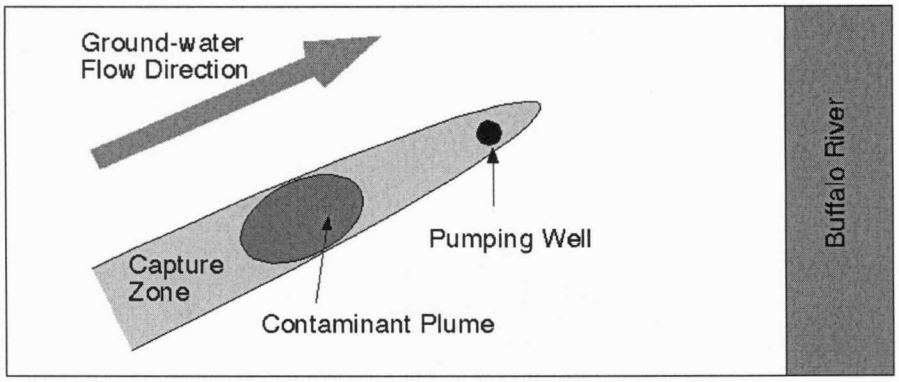


Figure 11. Capture zone created by pumping a production well. The capture zone outline is parabolic in shape and production well is located at the focus of the parabola. If the student elects to use a production well to remediate the aquifer, the limits of the contamination must be contained entirely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

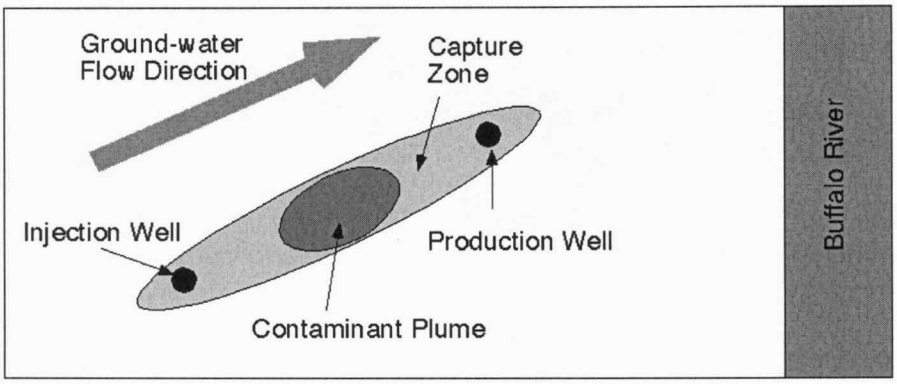


Figure 12. Capture zone created by pumping a production and injection well couplet. The capture zone outline is elliptical in shape. As in Figure 11, if the student elects to use production-injection well couplet to remediate the aquifer, the limits of the contamination must be contained entirely by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

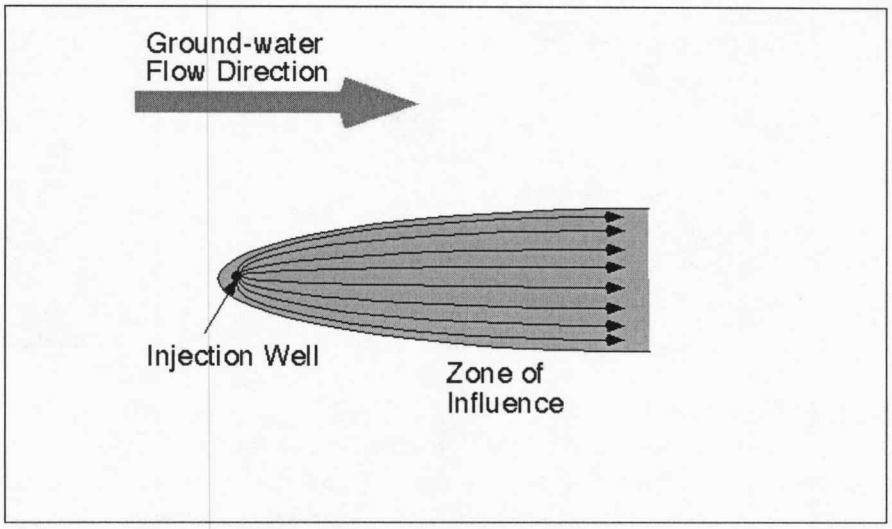


Figure 13. A zone of influence created by the addition of water to the aquifer from an injection well.

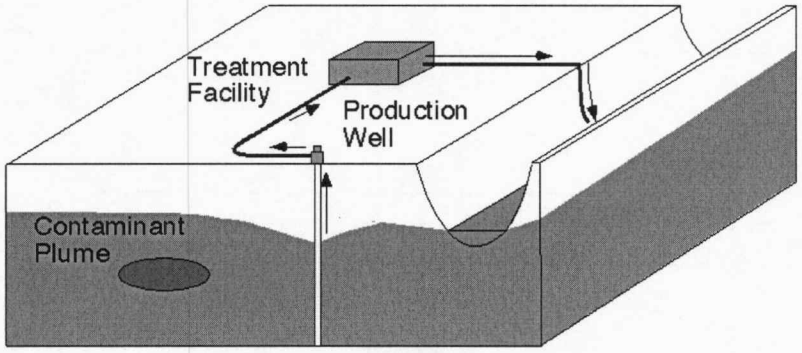


Figure 14. The pump-and-treat method of remediation using production wells only to remove contamination from an aquifer.

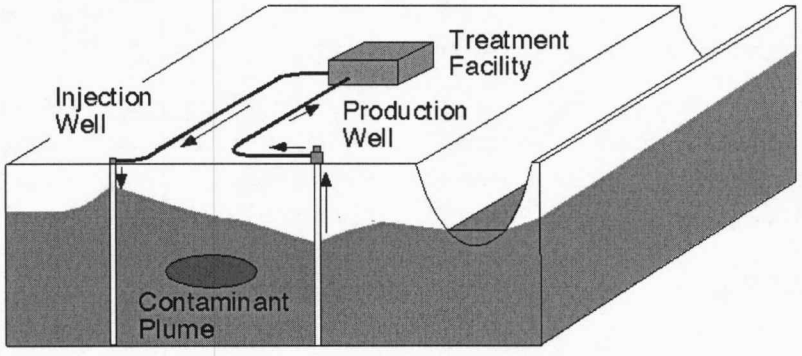


Figure 15. The pump-and-treat method of remediation using a production-injection well couplet to remove contamination from an aquifer.

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 but 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 if 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).

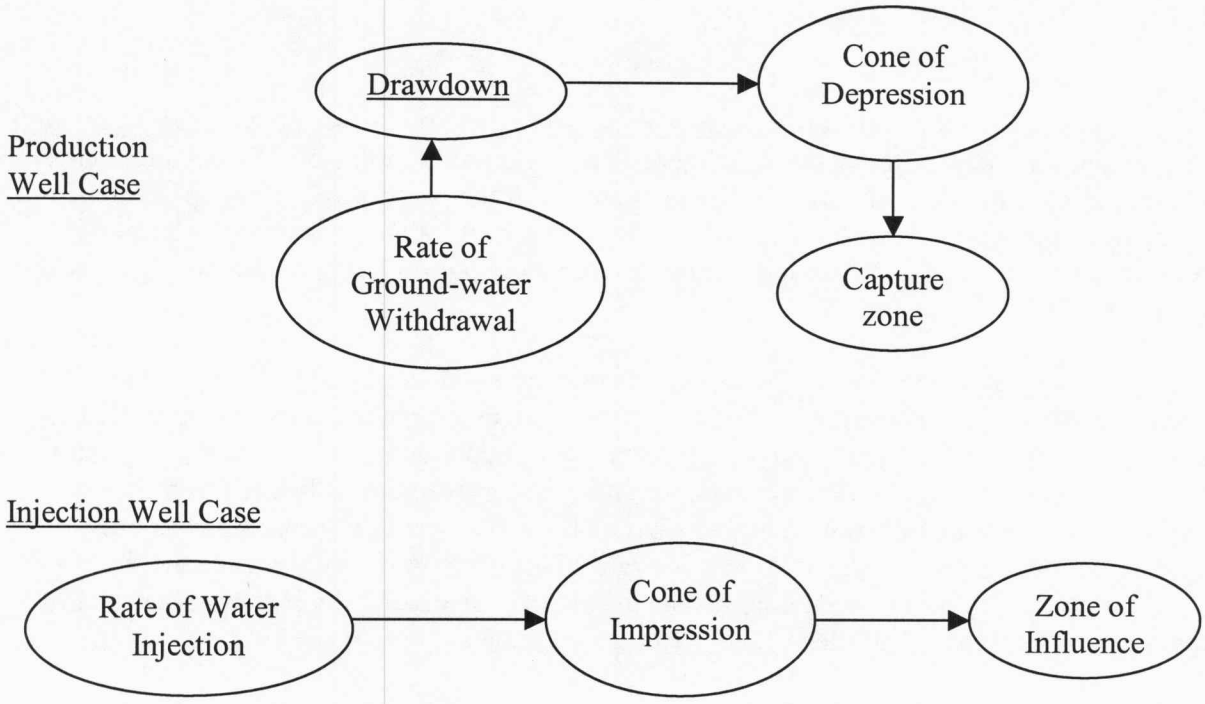
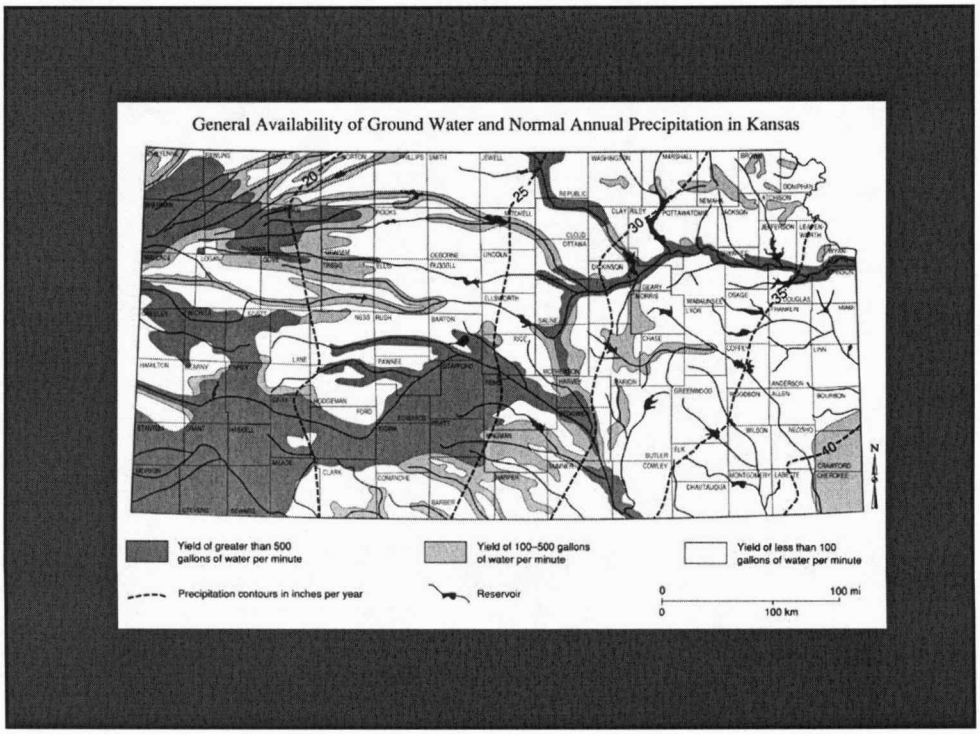
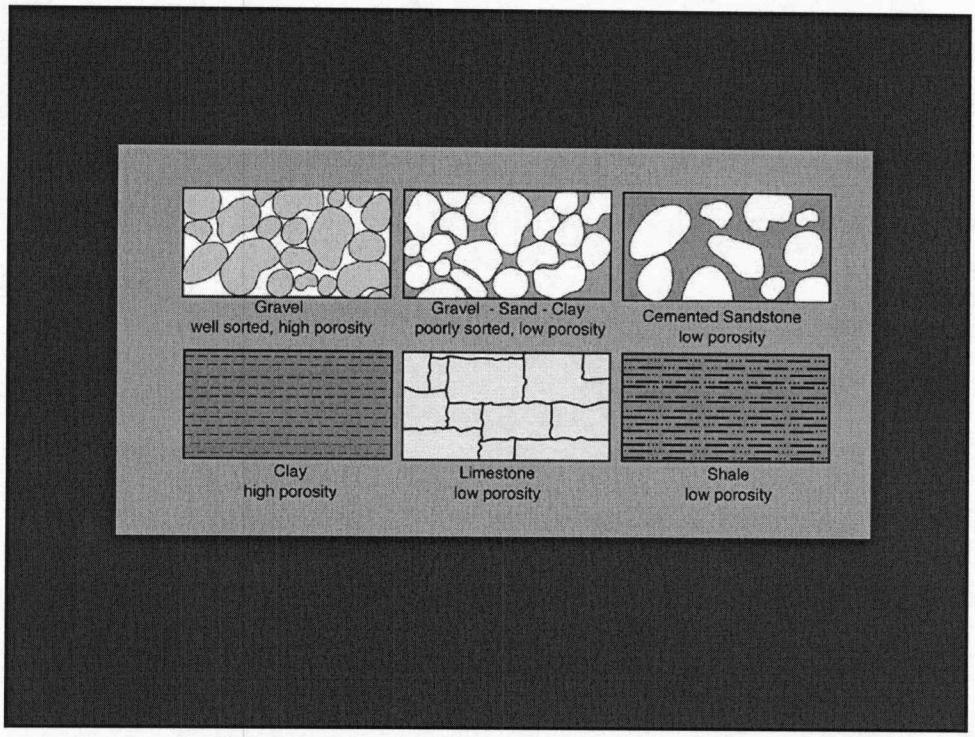
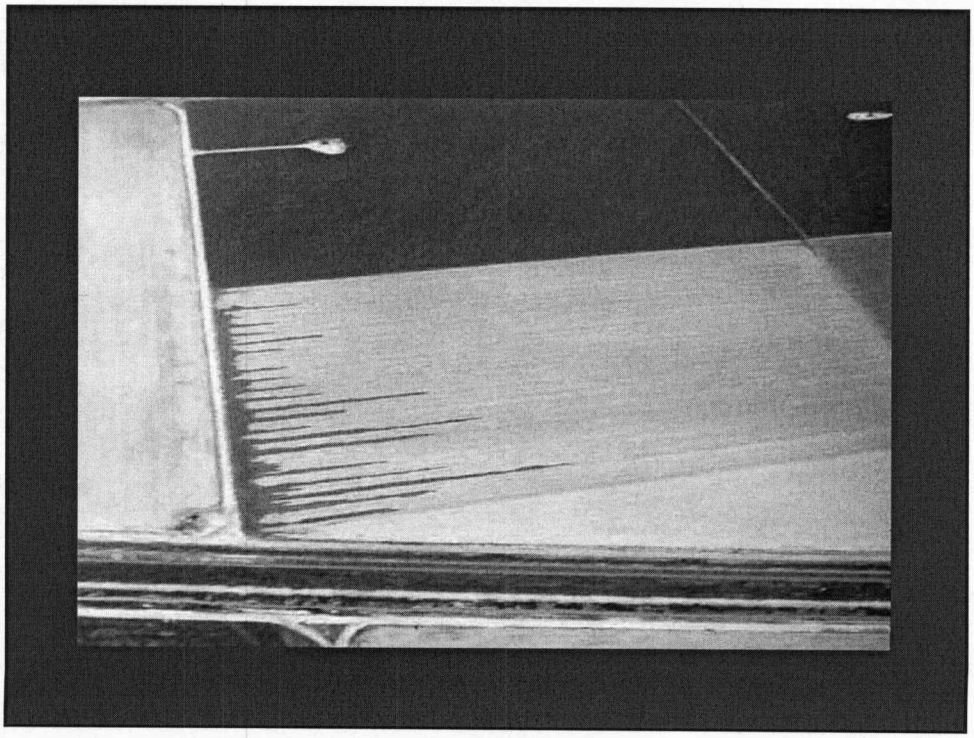


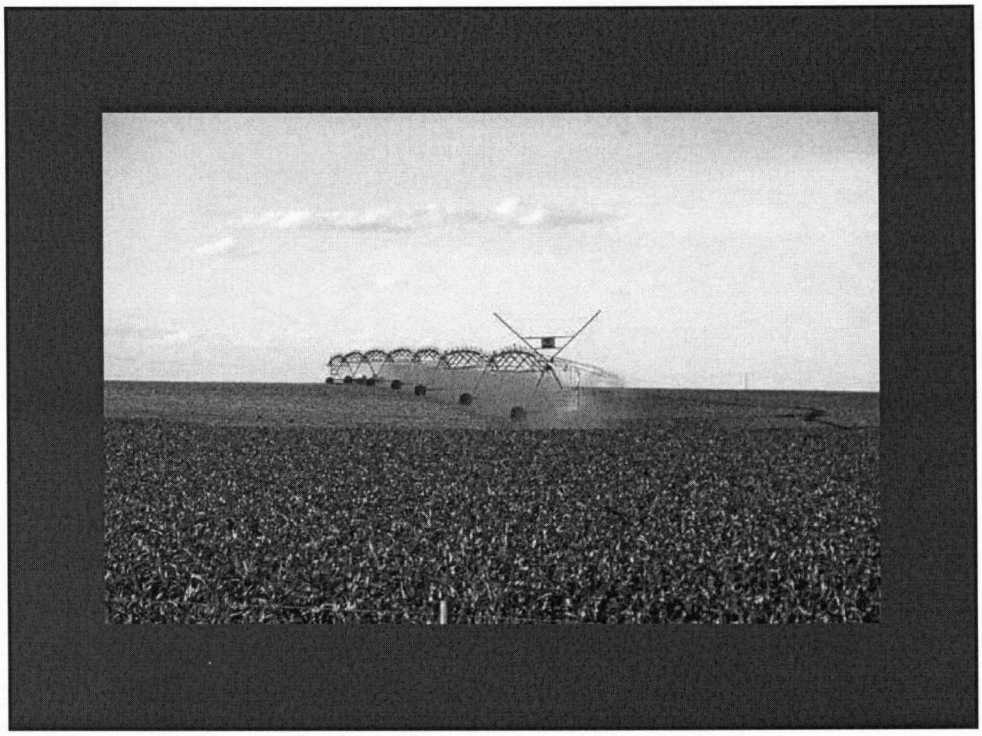
Figure 16. Science concepts and their relationship in the aquifer remediation phase of the interactive ground-water tutor.

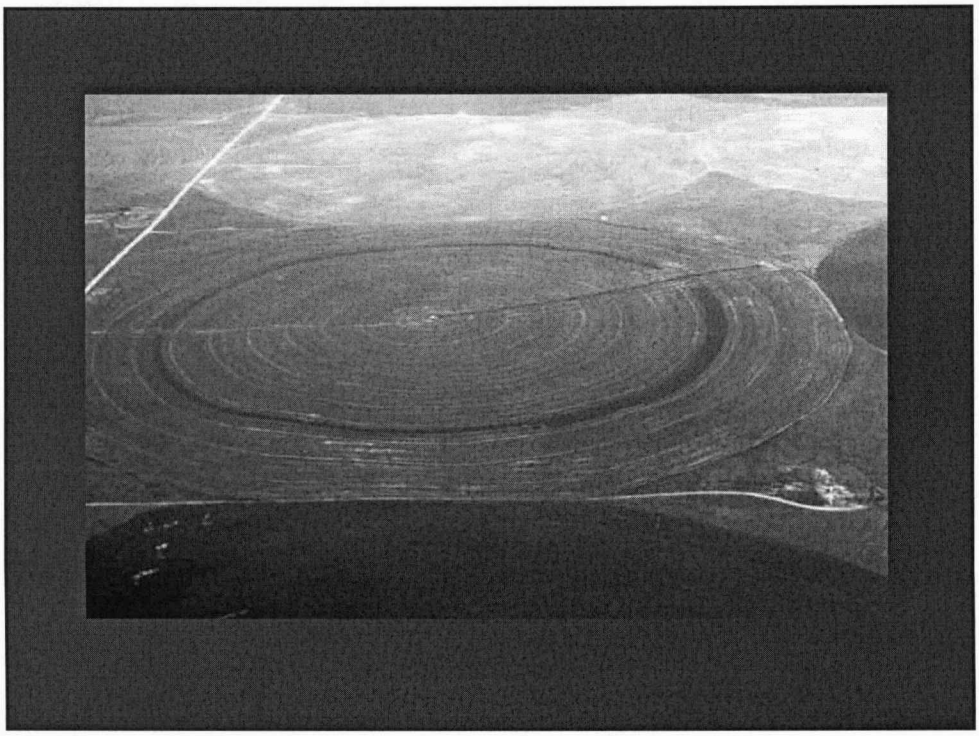

Springs, Streams, and Groundwater
Rex Buchanan, Kansas Geological Survey

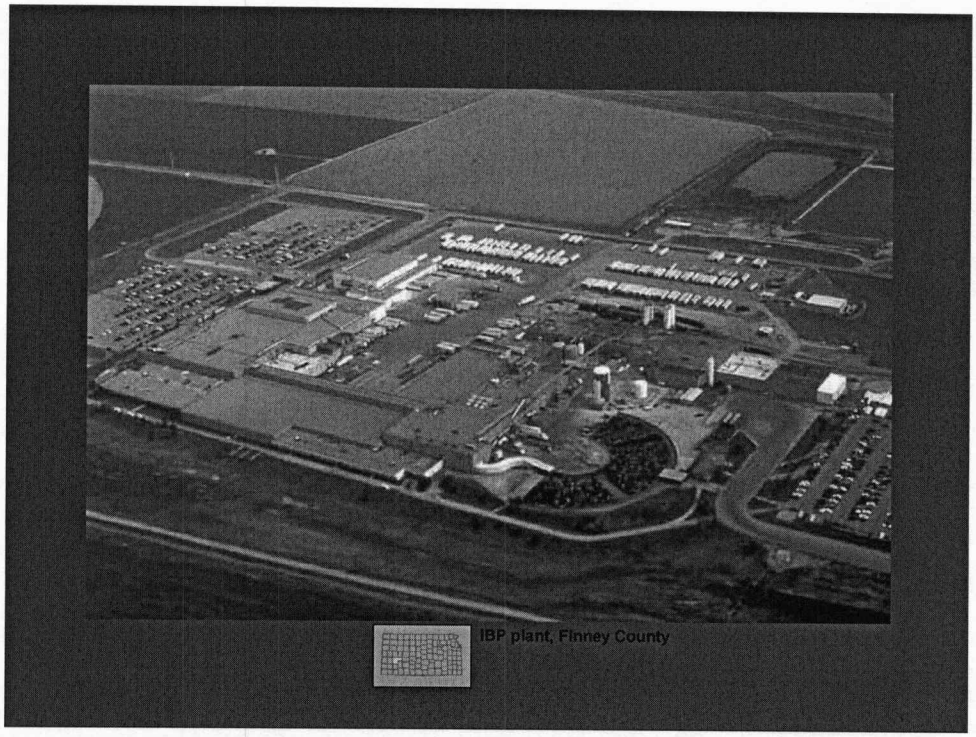

General Availability of Ground Water and Normal Annual Precipitation in Kansas
Yield of greater than 500 gallons of water per minute
Yield of 100–500 gallons of water per minute
Yield of less than 100 gallons of water per minute
Precipitation contours in inches per year
Reservoir
0 100 mi
0 100 km
N

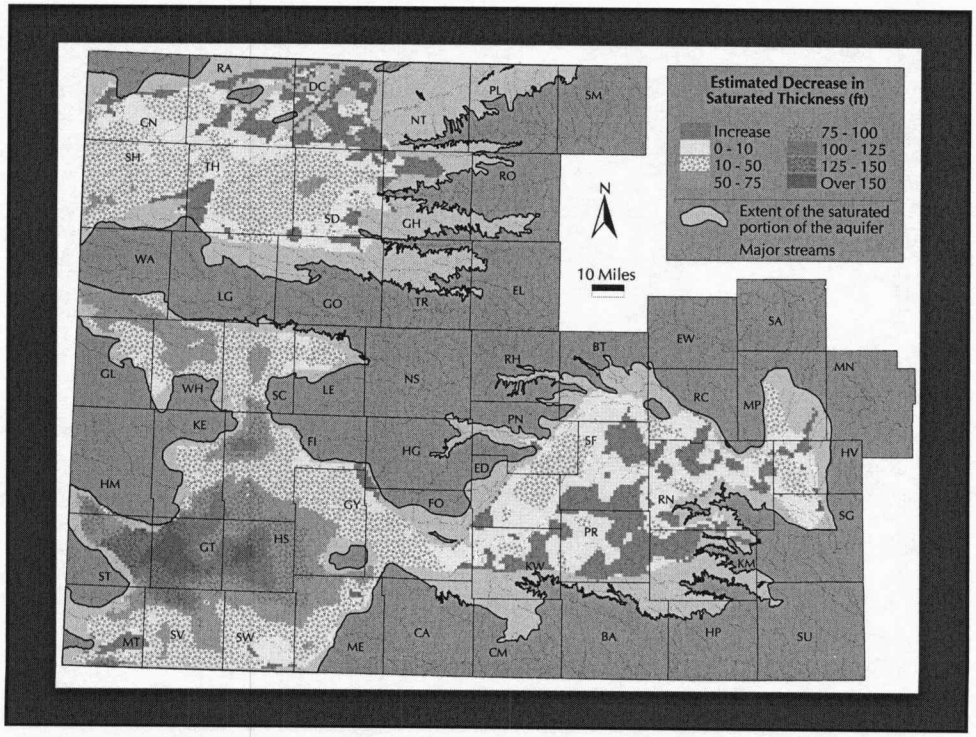

Gravel
well sorted, high porosity
Gravel - Sand - Clay
poorly sorted, low porosity
Cemented Sandstone
low porosity
Clay
high porosity
Limestone
low porosity
Shale
low porosity

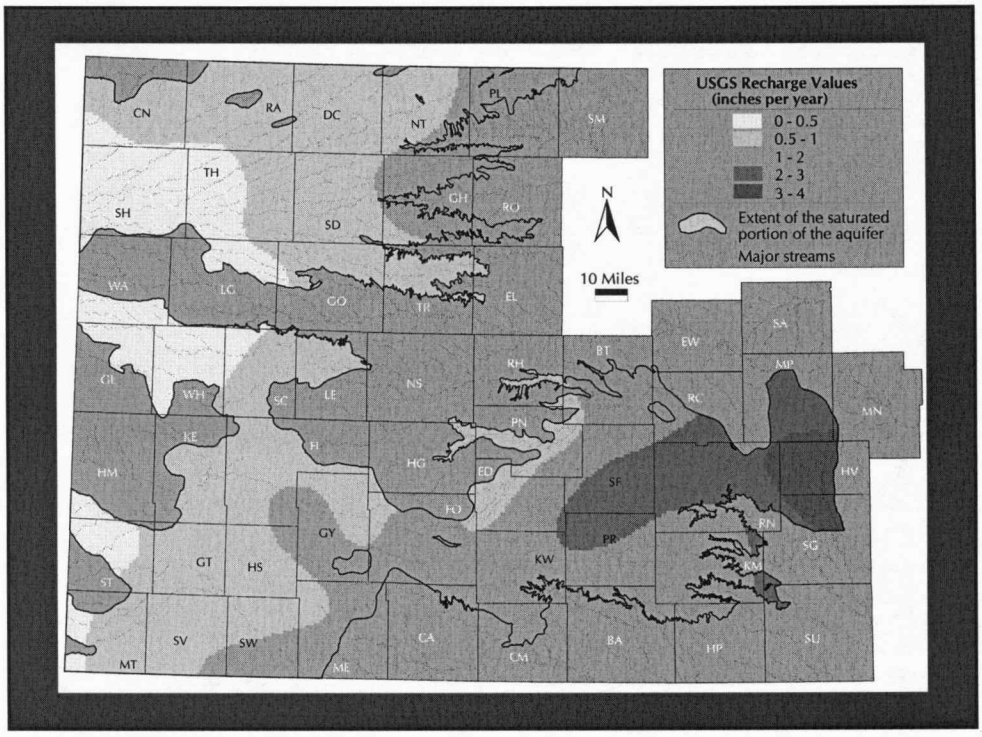


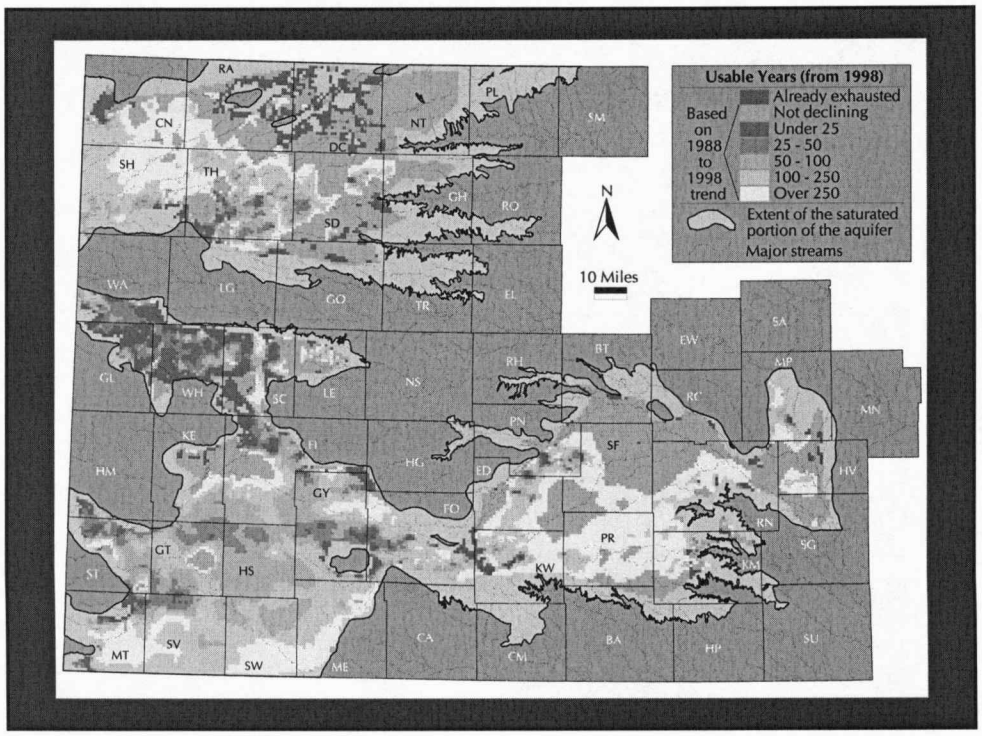


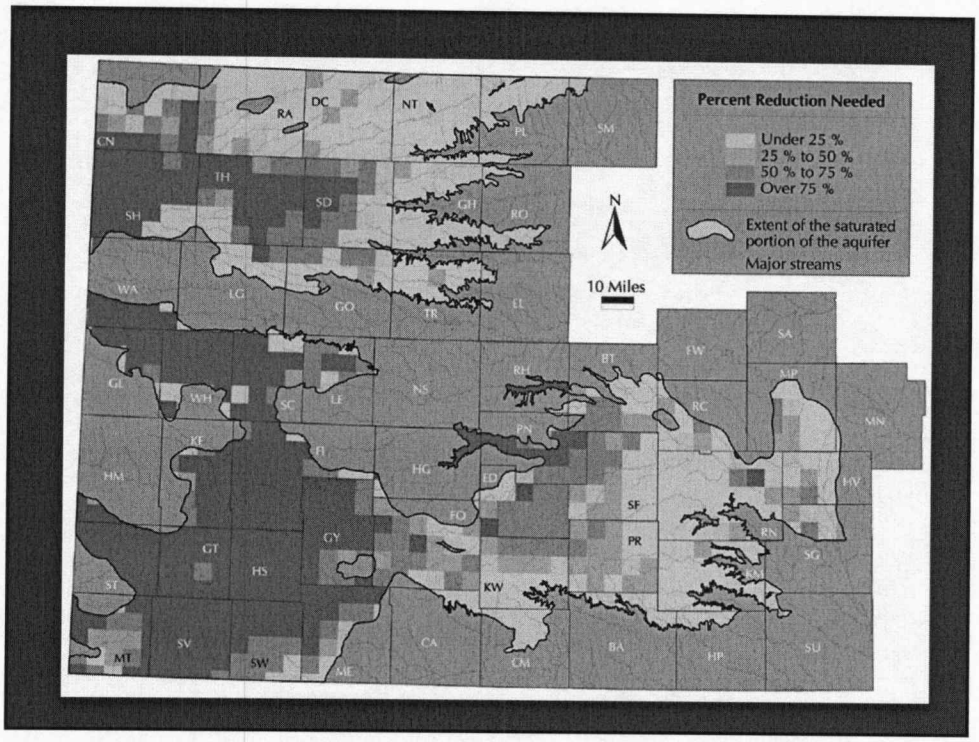


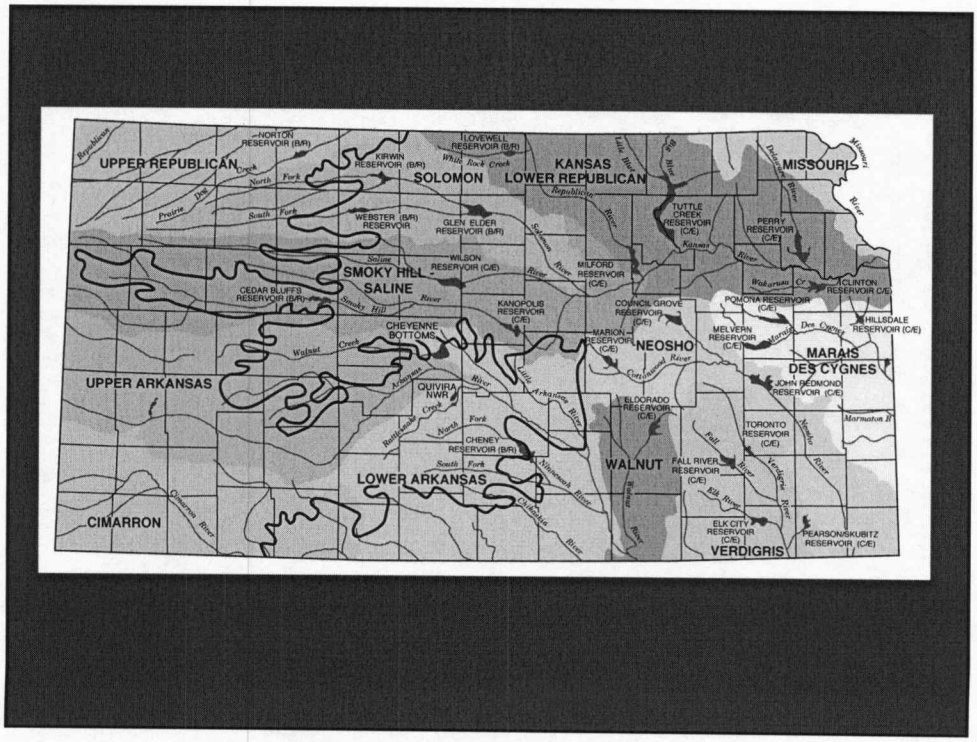

IBP plant, Finney County

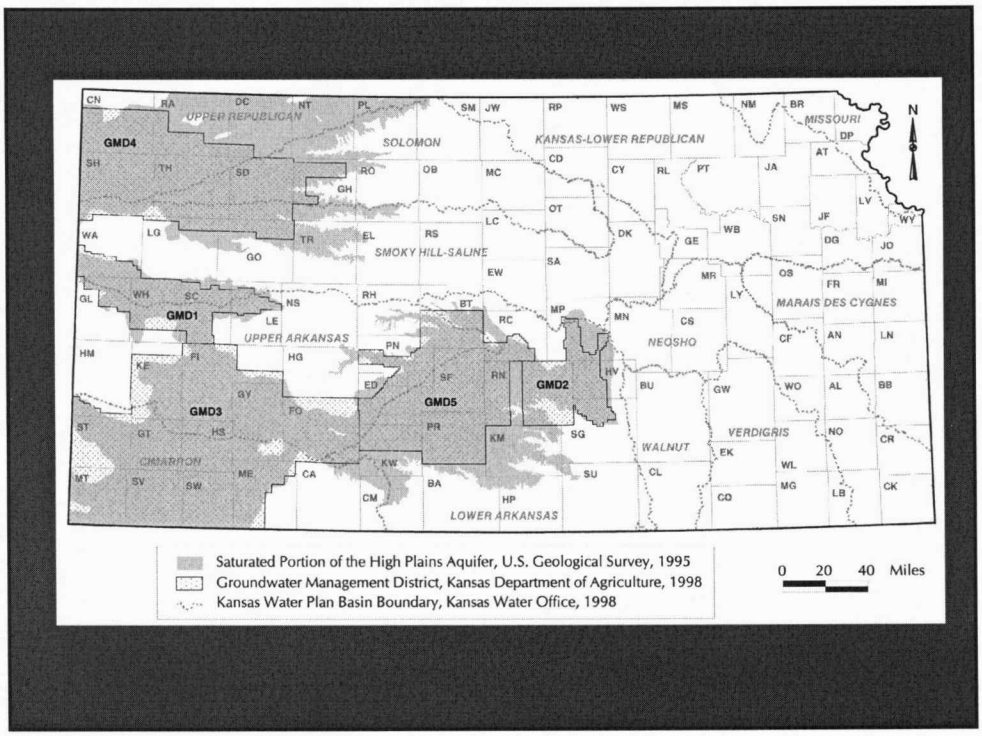

Estimated Decrease in Saturated Thickness (ft)
Increase
0 - 10
10 - 50
50 - 75
75 - 100
100 - 125
125 - 150
Over 150
Extent of the saturated portion of the aquifer
Major streams
N
10 Miles
RA
DC
PL
SM
CN
NT
SH
TH
RO
SD
GH
WA
LG
GO
TR
EL
SA
EW
BT
RH
MN
GL
WH
SC
LE
NS
RC
MP
KE
PN
FI
HG
SF
HV
ED
HM
GY
FO
RN
SG
PR
GT
HS
KW
KM
ST
MT
SV
SW
ME
CA
CM
BA
HP
SU


USGS Recharge Values
(inches per year)
0 - 0.5
0.5 - 1
1 - 2
2 - 3
3 - 4
Extent of the saturated portion of the aquifer
Major streams
N
10 Miles
CN
RA
DC
NT
PL
SM
TH
SH
SD
GH
RO
WA
LG
GO
TR
EL
BT
EW
SA
MP
GL
WH
SC
LE
NS
RH
RC
MN
PN
KE
HM
HG
ED
SF
HV
FO
GY
PR
RN
SG
GT
HS
KW
ST
SM
SV
SW
CA
BA
HP
SU
MT
ME
CM


Usable Years (from 1998)
Based on 1988 to 1998 trend
Already exhausted
Not declining
Under 25
25 - 50
50 - 100
100 - 250
Over 250
Extent of the saturated portion of the aquifer
Major streams
N
10 Miles
RA
CN
PL
NT
SM
DC
SH
TH
GH
RO
SD
WA
LG
GO
TR
EL
SA
EW
BT
MP
GL
WH
SC
LE
NS
RH
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SF
HV
GY
FO
RN
SG
PR
GT
HS
KW
ST
SM
MT
SV
SW
CA
BA
HP
SU
ME
CM


Percent Reduction Needed
Under 25 %
25 % to 50 %
50 % to 75 %
Over 75 %
Extent of the saturated portion of the aquifer
Major streams
N
10 Miles
RA
DC
NT
PL
SM
CN
TH
SD
GH
RO
SH
WA
LG
GO
TR
EL
FW
SA
BT
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HP
SU
MT
SW
ME
OM


UPPER REPUBLICAN
SOLOMON
KANSAS
LOWER REPUBLICAN
MISSOURI
SMOKY HILL
SALINE
NEOSHO
MARAIS
DES CYGNES
UPPER ARKANSAS
WALNUT
LOWER ARKANSAS
CIMARRON
VERDIGRIS
NORTON RESERVOIR (B/R)
KIRWIN RESERVOIR (B/R)
LOVEWELL RESERVOIR (B/R)
WEBSTER (B/R) RESERVOIR
GLEN ELDER RESERVOIR (B/R)
WILSON RESERVOIR (C/E)
CEDAR BLUFFS RESERVOIR (B/R)
KANOPOLIS RESERVOIR (C/E)
MILFORD RESERVOIR (C/E)
TUTTLE CREEK RESERVOIR (C/E)
PERRY RESERVOIR (C/E)
CLINTON RESERVOIR (C/E)
COUNCIL GROVE RESERVOIR (C/E)
POMONA RESERVOIR (C/E)
HILLSDALE RESERVOIR (C/E)
CHEYENNE BOTTOMS
MARION RESERVOIR (C/E)
MELVERN RESERVOIR (C/E)
JOHN REDMOND RESERVOIR (C/E)
QUIVIRA NWR
ELDORADO RESERVOIR (C/E)
TORONTO RESERVOIR (C/E)
CHENEY RESERVOIR (B/R)
FALL RIVER RESERVOIR (C/E)
ELK CITY RESERVOIR (C/E)
PEARSON-SKUBITZ RESERVOIR (C/E)


UPPER REPUBLICAN
SOLOMON
KANSAS-LOWER REPUBLICAN
MISSOURI
GMD4
SMOKY HILL-SALINE
GMD1
UPPER ARKANSAS
GMD3
GMD5
GMD2
NEOSHO
MARAIS DES CYGNES
VERDIGRIS
WALNUT
CIMARRON
LOWER ARKANSAS
N
Saturated Portion of the High Plains Aquifer, U.S. Geological Survey, 1995
Groundwater Management District, Kansas Department of Agriculture, 1998
Kansas Water Plan Basin Boundary, Kansas Water Office, 1998
0 20 40 Miles

KEY CONCEPTS FOR MACFARLANE'S PART OF THE GROUND-WATER WORKSHOP

Hydrologic Cycle

The hydrologic cycle links the atmosphere, hydrosphere, biosphere, and the lithosphere together and is driven by radiant energy and in turn acts to transport energy and water between the poles and the equator.

Of all the freshwater sources ground water is the most available and accounts for 29% of the total fresh water reservoir.

In the drainage basin, the main source of water is precipitation and the export is apportioned between stream flow, evapotranspiration, and deep ground-water flow.

The hydrologic equation states that the difference between the input and the output of water from a region or a hydrologic entity is equal to the change in storage.

Water Resources and Use

Since 1950, the dominant uses of water have been for electric power generation and crop irrigation.

In 2000 Nebraska and Kansas relied primarily on ground-water sources and used them primarily for crop irrigation whereas Missouri relied more on surface water than ground water but used most of its ground water for crop irrigation.

Because of the westward decrease in precipitation and increase in evapotranspiration and the availability of ground water, eastern Kansans rely on surface water and western Kansans rely primarily on ground water.

Earth Material Properties

Porosity is the total void space fraction of the bulk volume of an earth material and consists of connected and isolated void space.

The three types of porosity are intergranular, fracture, and solution.

In sediments and sedimentary rocks the intergranular porosity amount depends on its texture and diagenetic history.

Intrinsic permeability is a property of earth materials, is the ease with which fluids pass through earth materials, and is dependent on the interconnected porosity.

The hydraulic conductivity parameter is commonly used in hydrogeology and depends on the permeability the earth material and the properties of the fluid passing through it.

The specific yield is relative amount of water that will drain naturally from a saturated earth material and the specific retention is the relative amount of water that remains in the earth material after drainage. The sum of both is equal to the total porosity.

Aquifer and Confining Units

Aquifer and confining units are defined based on relative differences in permeability. An aquifer is usually defined as a permeable unit capable of storing and transmitting water wells at economically feasible rates, whereas a confining layer is a less permeable unit that can store but not transmit water to wells at economically feasible rates.

An unconfined aquifer is bounded above by a water table and below by a confining layer.

The water table marks the top of the zone of saturation with respect to water.

A confined aquifer is fully saturated with water and bounded above and below by confining units and its potentiometric surface is above the top of the aquifer.

A perched aquifer is of limited areal extent, is bounded below by a low permeability layer in the unsaturated zone above the water table and above by a water table.

A stream-aquifer system consists of an alluvial aquifer and its adjacent stream, to which it is hydraulically connected.

Hydraulic Head

The hydraulic head is a measure of the amount of energy contained in water and is the sum of the elevation head above a datum and the pressure head. Ground water flows from regions of high hydraulic head to regions of low hydraulic head.

The hydraulic head is the elevation of the water table in an unconfined aquifer, but is the elevation of the potentiometric surface in a confined aquifer.

Darcy's Law

Darcy's law states that the flow rate through an earth material is proportional to the cross-sectional area and the hydraulic gradient. In ground-water science, the constant of proportionality is the hydraulic conductivity.

Mapping Ground-water Flow Directions

The goals for mapping ground-water flow systems are to delineate ground-water flow paths and to determine rates of flow and residence time.

In map view, ground-water flow direction is parallel but opposite in direction to the hydraulic gradient, which is perpendicular to contours of equal hydraulic head (elevation of the water table or the potentiometric surface).

Ground-water direction can also be upward or downward depending on the hydraulic-head difference in the vertical direction.

Hydraulic head is calculated from depth-to-water measurements taken in wells. The hydraulic head is equal to the land-surface elevation plus or minus the measurement point above or below land surface minus the depth-to-water from the measurement point.

Ground-water Flow System Anatomy and Hierarchies

A ground-water flow system consists of a recharge area and a discharge area connected by an integrated network of ground-water flow paths.

Surface-water bodies may be sources of recharge or act as discharge areas depending on wet season or dry season conditions and ground-water withdrawals.

Large-scale flow systems consist of a hierarchy of local and intermediate systems superimposed on a regional system. Local systems involve usually one drainage basin; intermediate systems involve multiple drainage basins; regional systems may involve multiple intermediate systems.

Effects of Pumping and Injection Wells

When the pump in a well is turned ground water flows to the well in response to a decrease in hydraulic head within the casing that eventually propagates to the surrounding aquifer creating a cone of depression in the water table or potentiometric surface. The cone of depression will continue to grow in areal extent until the aquifer is able to supply of ground water into the area affected by the cone of depression at the same rate as the rate of withdrawal by the well.

Where the potentiometric surface or the water table is tilted, the outline of the cone of depression approaches a parabola in shape with the open end pointing in the direction opposite to that of the ground-water flow. The area inside the parabola is referred to as the capture zone.

Likewise, injection of water to an aquifer increases the hydraulic head in the well casing causing water to flow out into the aquifer. The flow creates a mounding in the water table or potentiometric surface referred to as a cone of impression.

Where the potentiometric surface or the water table is tilted, the outline of the cone of impression approaches a parabola in shape with the open end pointing in the direction of the ground-water flow. The area inside the parabola is referred to as the zone of influence.

A pumping well and a nearby injection well will create a couplet where inflow from the injection well is completely captured by the pumping well.

Well pumping near a stream will cause water to flow from the stream to the aquifer and toward the pumping well. This will result in a reduction of stream discharge.

Contaminant Hydrogeology

Contaminants in solution move through the ground-water system primarily by means of mechanical dispersion, and advection and secondarily by diffusion.

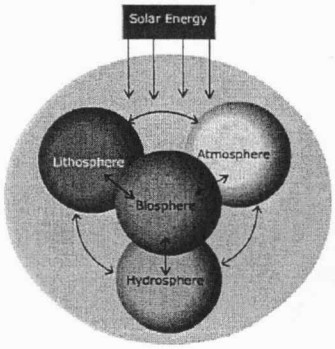
Ground-water contamination from a source over an extended period of time creates a plume that moves in the direction of ground-water flow that can be traced back to its source.

Ground-water contamination from a source over a short period of time creates a relatively well-defined zone of contamination spheroid in shape and referred to as a slug.

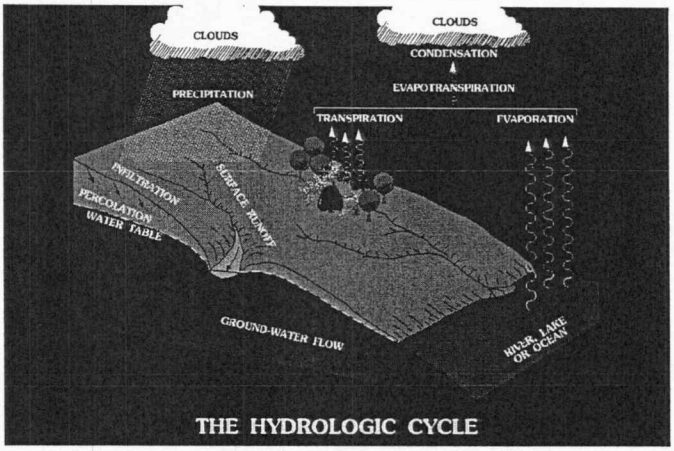
The Summer 2004 Ground-water Workshop For Secondary Science Teachers

Session 1
The Hydrologic Cycle

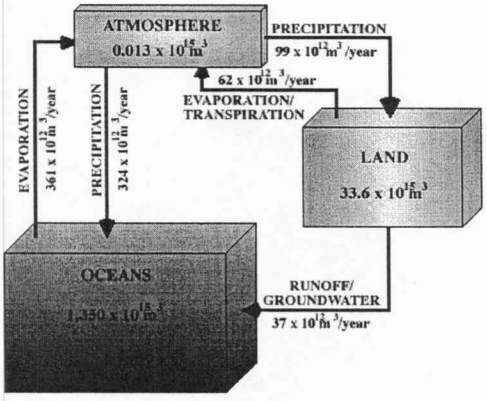
Global Energy & Mass Transfer



Global Hydrologic Cycle

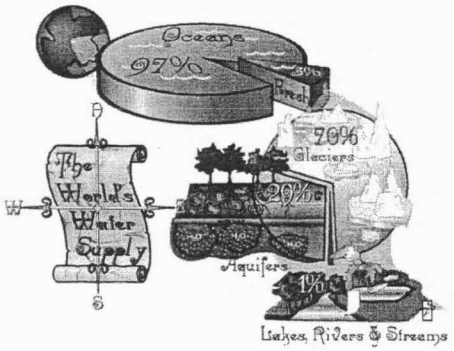


Water in Storage & in Transit: Global View



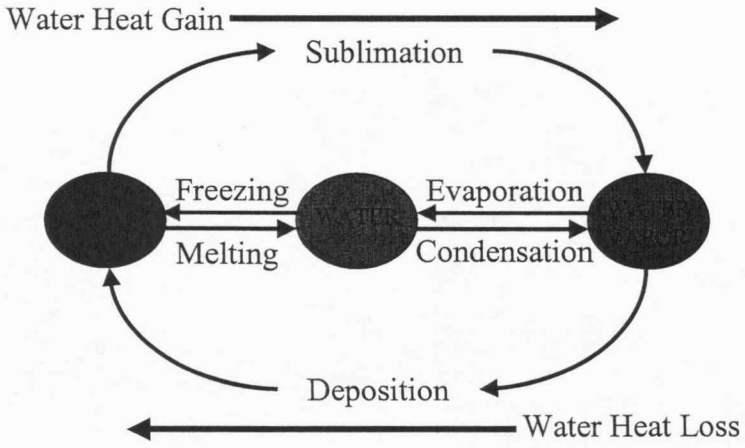
Conservation of Mass principle: Everything has to be someplace

Where's the Fresh Water?

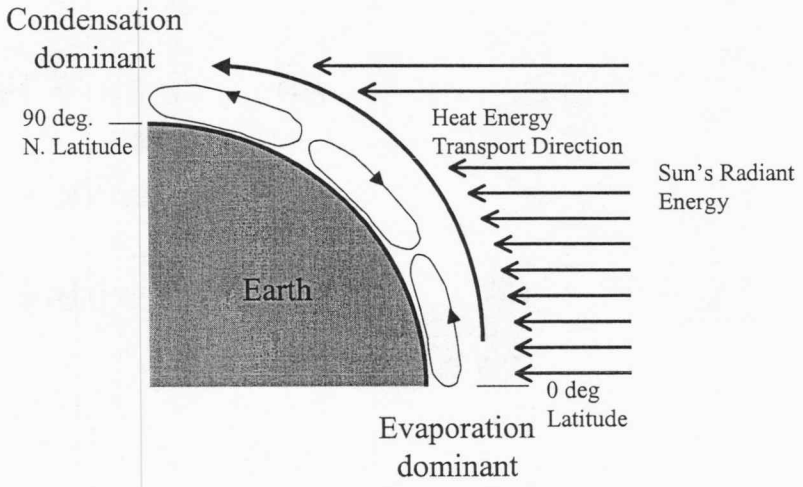


Approximately 29% of the readily available world's fresh water resource exists in aquifers

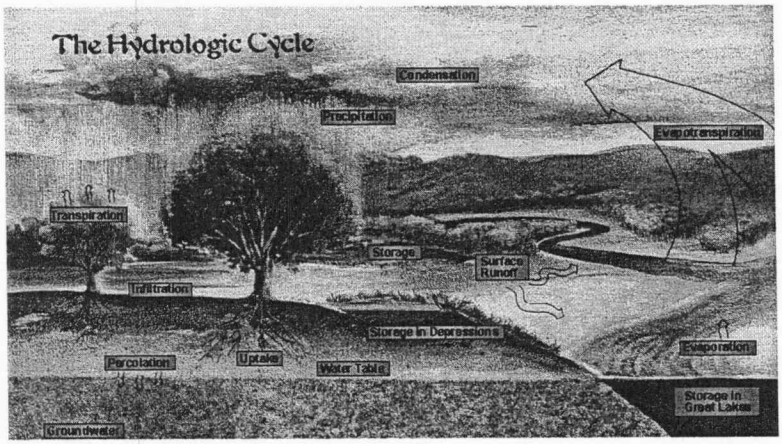
Phases & Phase Changes of Water



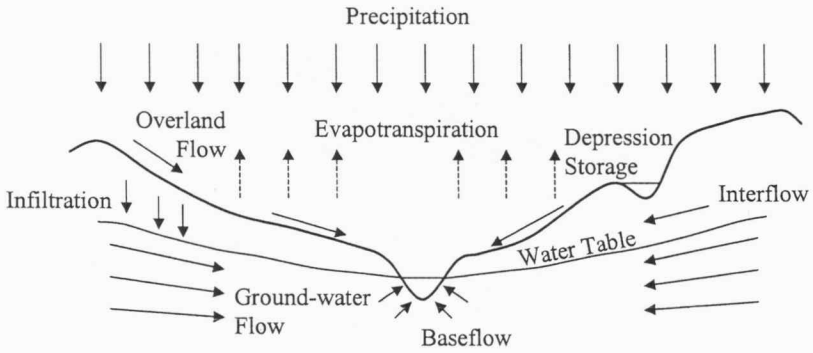
Heat Transfer, Northern Hemisphere



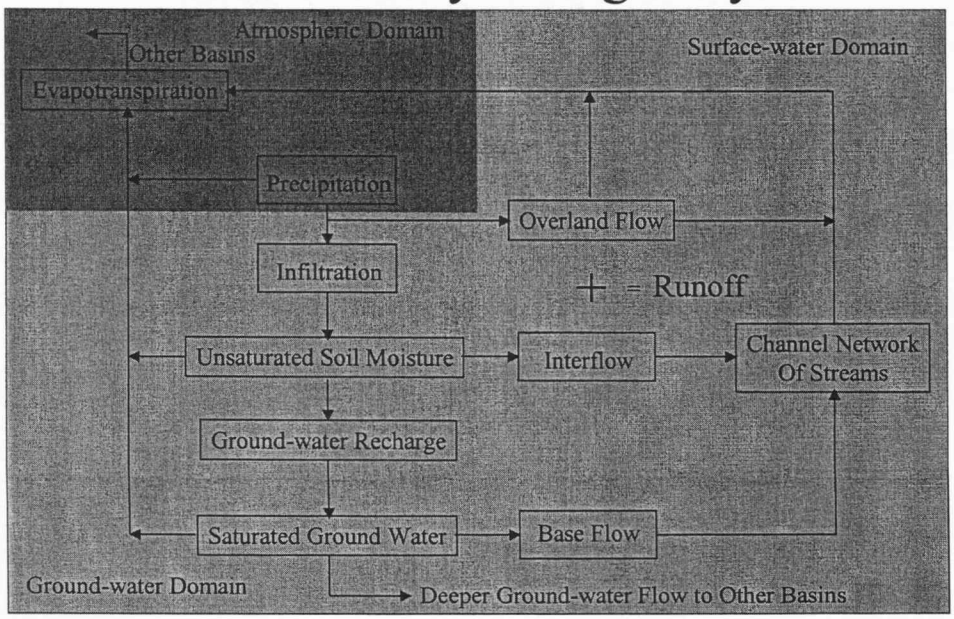
The River Basin Hydrologic Cycle



Parts & Processes Associated with the Basin Hydrologic Cycle

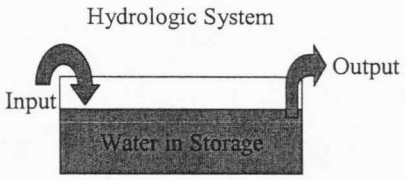


The Basin Hydrologic Cycle



The Hydrologic Equation:

Water Balance



Input – Output = Change in Storage (Quantities)

Time Rate of Change In Input — Time Rate of Change In Output = Time Rate of Change of Storage

(Rates of change)

The Basin Water Balance Equation

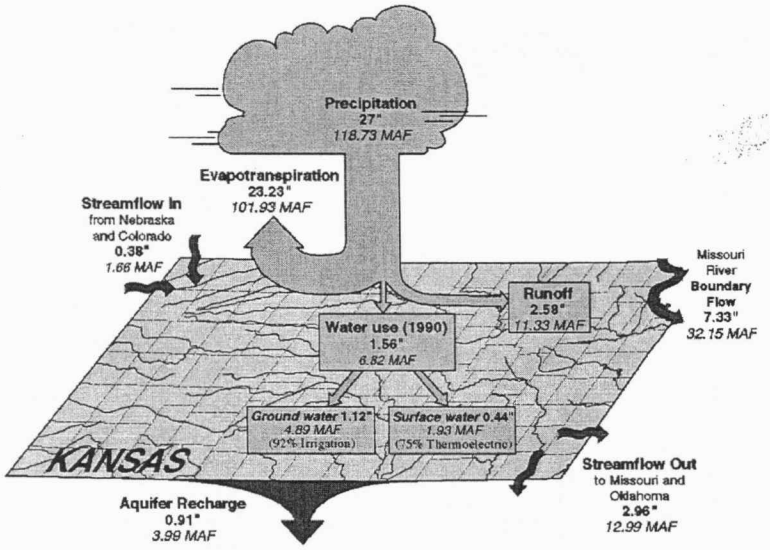
Surface- & Ground-water Portion (Land Domain Only)

Sum of all Inputs — Sum of all Outputs = Change in Storage

- Precipitation
- Ground-water inflow
- Inflow from recharge projects

- Evaporation
- Transpiration
- Stream outflow
- Ground-water outflow
- Surface water withdrawals
- Ground-water withdrawals

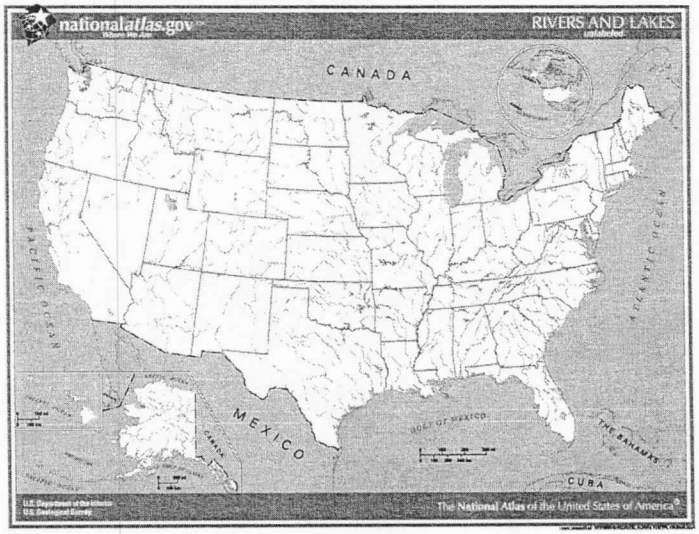
The Kansas Water Budget



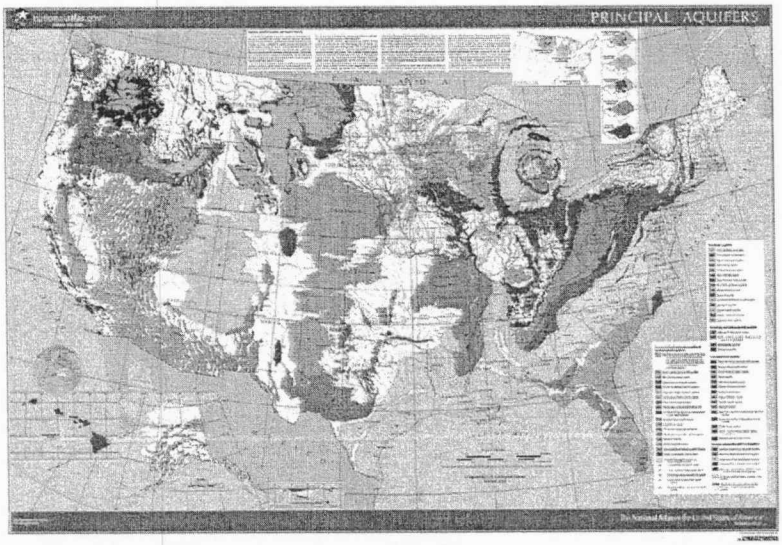
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Session 2
Water Resources & Use

Surface-water Sources



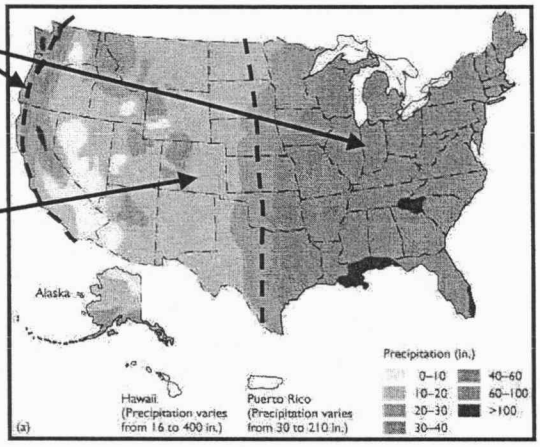
Ground-water Sources



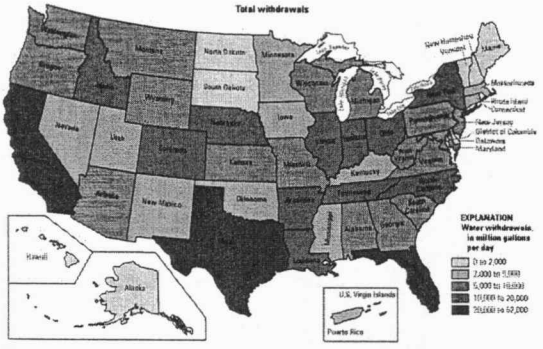
Surface Water, Ground Water or Both?

Surface- & Ground-water dependent

Ground-water dependent



US Total Fresh & Saline Water Use in 2000

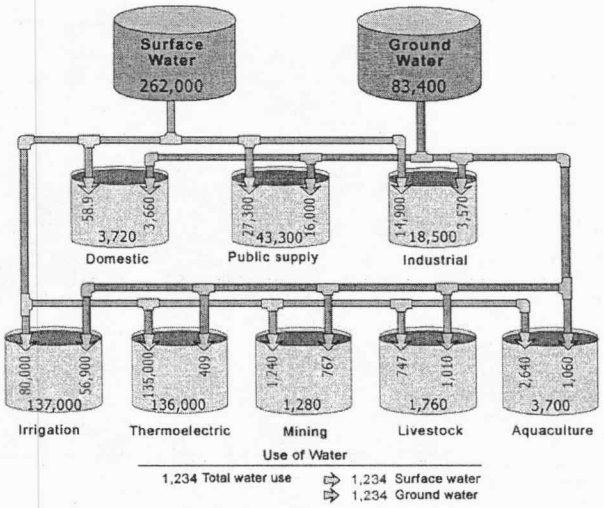


Fresh: 346 Billion gallons per day

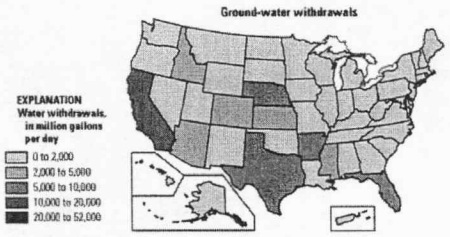
Saline: 62.3 Billion gallons per day

Total Water Use:
408 Billion gallons per day
Or about 1,430 gallons/per person per day

US Water Use by Source & Category in 2000

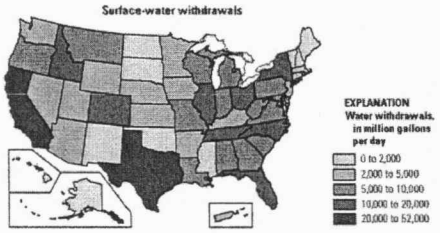


State by State Total Fresh & Saline Ground Water Use in 2000



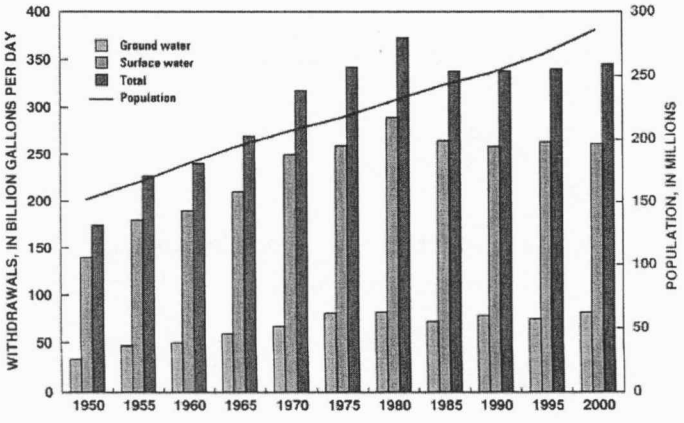
Relative Amounts of Fresh Ground-water by Intended Use:
68% Crop Irrigation
19% Public Supply
13% All Other Uses

State by State Total Fresh & Saline Surface Water Use in 2000

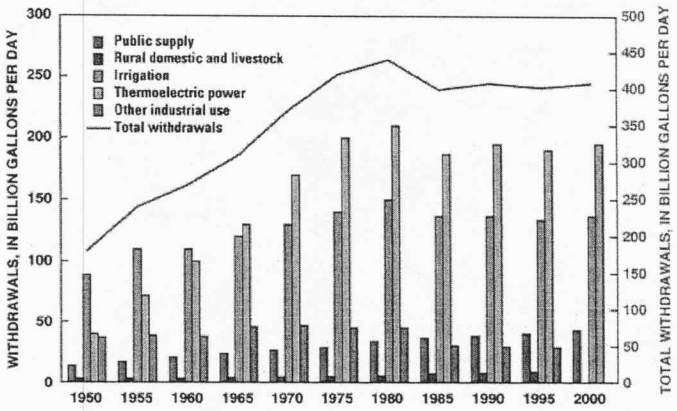


Relative Amounts of Fresh Surface-water by Intended Use:
52% Electric Power Production
31% Crop Irrigation
17% All Other Uses

Water-Use Trends in Relation to Population Growth



Water-Use Trends in Relation to Use



What Does It All Mean?

Changes in water use nationally seem to reflect:

- Technologic advances that advance water conservation
- Population shifts between regions of the country & from rural to urban areas

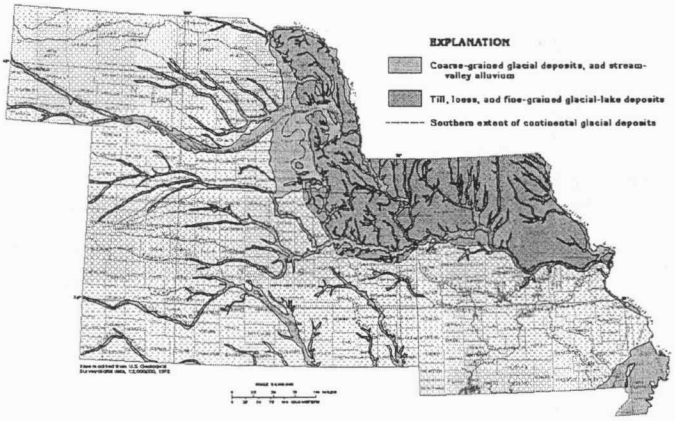
Surface Water Sources in the Central Midwest Region

(Missouri, Kansas, & Nebraska)



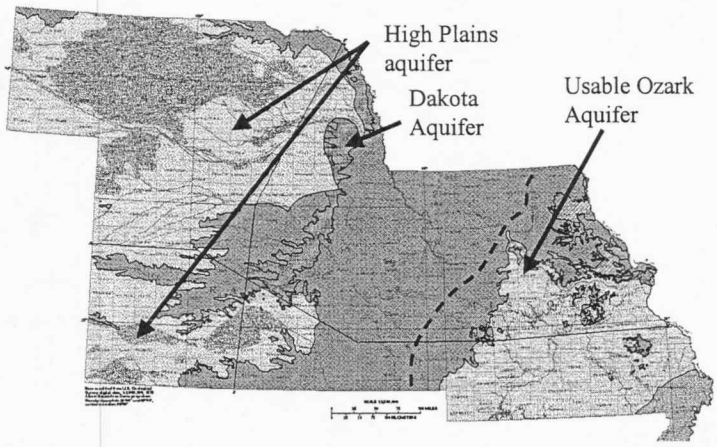
Shallow Ground Water Sources in the Central Midwest Region

(Missouri, Kansas, & Nebraska)



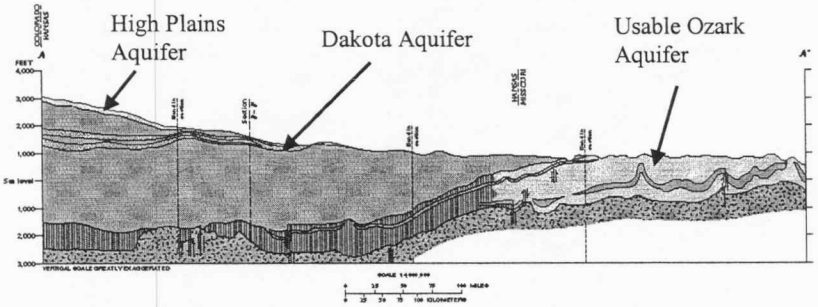
Deeper Ground Water Sources in the Central Midwest Region

(Missouri, Kansas, & Nebraska)



Shallow Ground Water Sources in the Central Midwest Region

(Missouri, Kansas, & Nebraska)



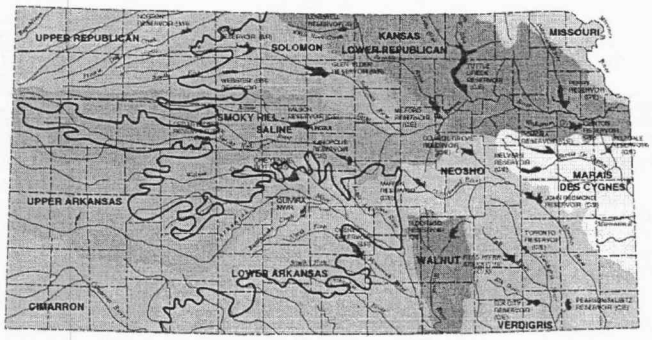
Regional Water Use in 2000
(Missouri, Kansas, & Nebraska)

State	Total Withdrawal (millions of gallons per day)	Percent Ground Water
Kansas	6,610	57
Missouri	8,230	22
Nebraska	12,300	64

Intended Water Use in 2000
(Missouri, Kansas, & Nebraska)

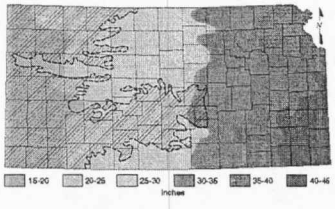
State	Total Ground-water Withdrawal (millions of gallons per day)	Percent For Crop Irrigation
Kansas	3,790	91
Missouri	1,780	78
Nebraska	7,860	94

Kansas River Basins & Reservoirs

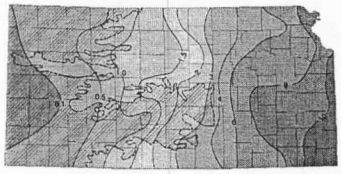


Ground- & Surface-water Use in Kansas

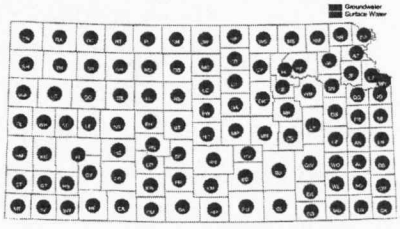
Mean Annual Precipitation



Mean Annual Runoff



Proportion of Ground- to Surface- water Rights by County



Factors influencing water-right type:

- Westward decline in precipitation & runoff
- Source type availability

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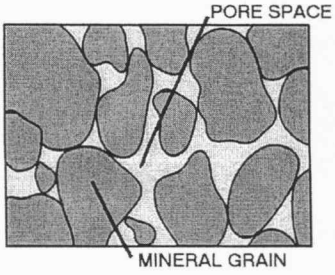
Session 3
Earth Material Hydraulic Properties

Porosity Definition

All earth materials contain void space or porosity

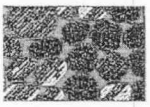
Earth Material Bulk Volume (V_T) =

Volume of the Matrix (V_M) + Volume of the Voids (V_V)

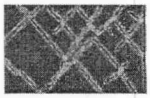


$$\text{Porosity} = \frac{V_V}{V_T} \times 100\%$$

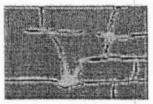
Porosity Types



Intergranular — Unconsolidated sediments & sedimentary rocks



Fracture — Igneous & metamorphic rocks



Solution — Carbonate sedimentary rocks & Marble

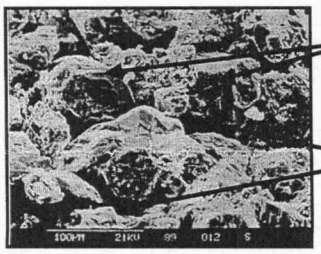
Intergranular Porosity

Factors controlling the amount:

- Grain size, shape, & roundness
- Packing of the grains
- Uniformity of the sediment grains (sorting)

] Texture

- Cementation



Intergranular Porosity
Grain Size

Sediment Type	Porosity Range (%)
Coarse Gravel	24 – 36
Fine Gravel	25 – 38
Coarse Sand	31 – 46
Fine Sand	26 – 53
Silt	34 – 61
Clay	34 – 60

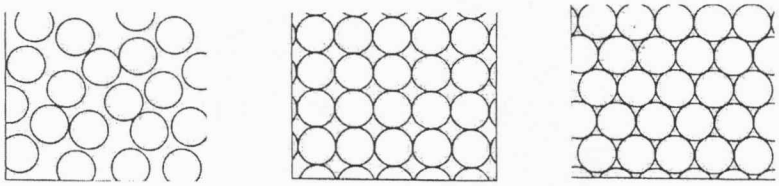
Decreasing Grain Size ↓

↑ Decreasing Porosity

From
Domenico and Schwartz (1990)

Intergranular Porosity
Grain Packing

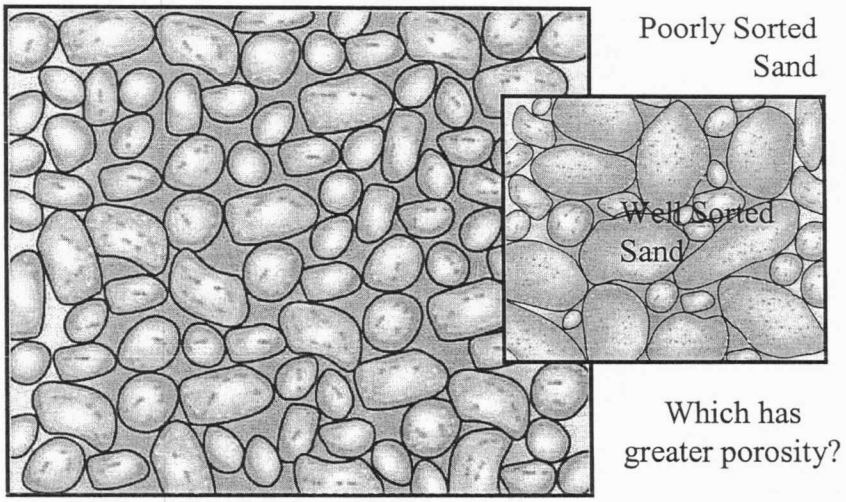
Increased Density of Packing →



← Increased Porosity

Intergranular Porosity

Grain Sorting



Which has greater porosity?

How Do Sediments Become Sedimentary Rocks?

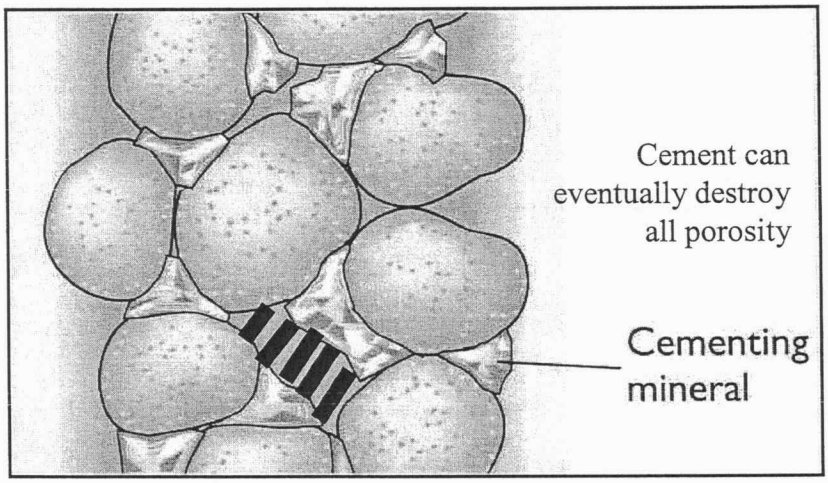
Sediment

Diagenesis
- Compaction
- Cementation
- Mineral solution
- Mineral precipitation
- Mineral transformation
- Other rock-water chemical interactions

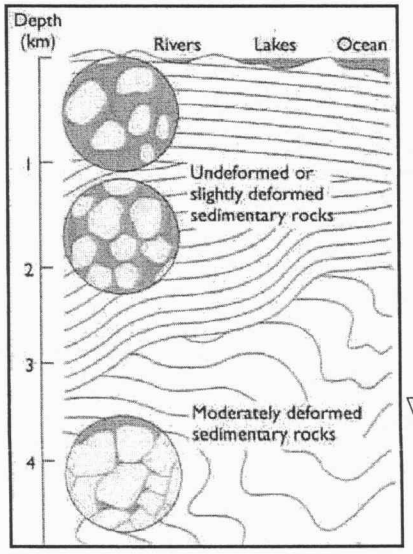
Sedimentary Rock

Intergranular Porosity

Cementation



Porosity & Burial



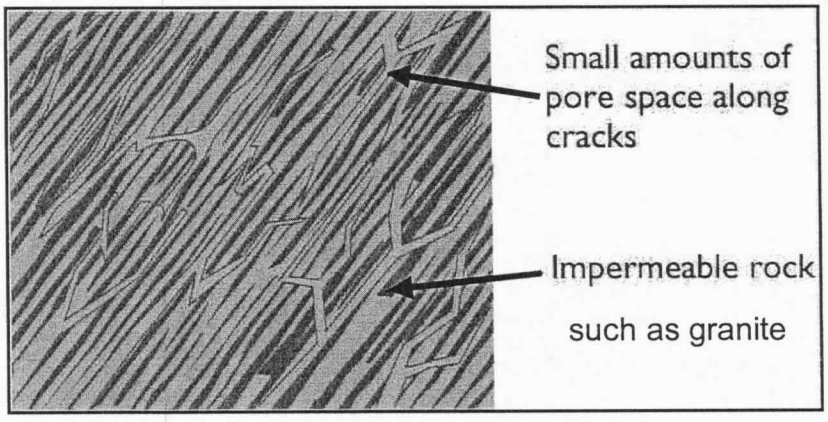


- Loose, unconsolidated sediment
- Consolidated sediment partly cemented
- Well compacted and cemented sediments

Granular Sedimentary Rock Porosity Values

Sedimentary Rock	Total Porosity Range (%)	Total Connected Porosity Range (%)
Sandstone	5 – 30	0.5 – 20
Siltstone	21 – 41	0.5 – 10
Shale	1 – 10	0.5 – 5

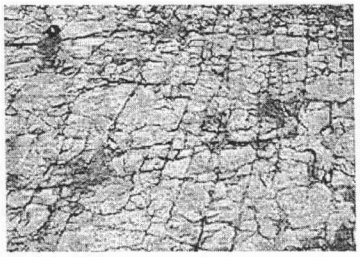
Fracture Porosity



Fracture Porosity

Factors Influencing the Amount:

- Fracture width
  - Porosity decreases with depth as fracture width decreases
- Fracture spacing or density
  - Porosity increases with decrease in spacing



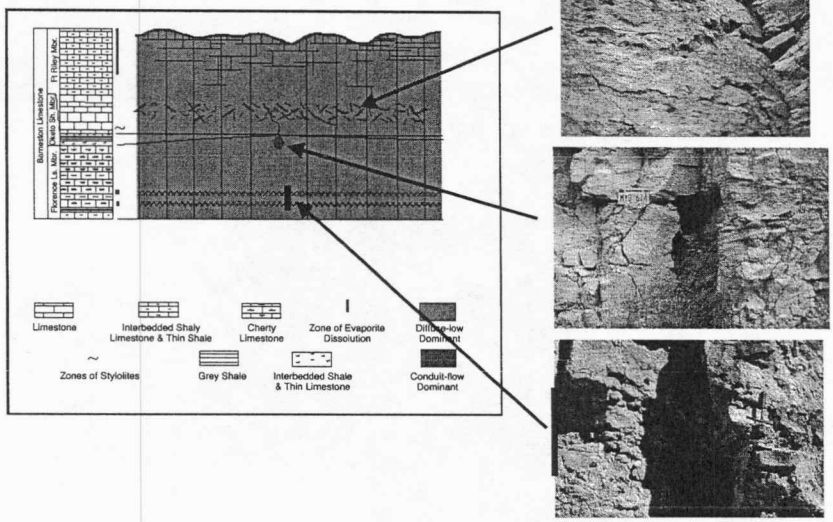
Solution Porosity (Karst)

Dominant Influences on the Amount:

- Solubility of the minerals that form the rock
  - Bedded halite and gypsum are the most soluble followed by limestone. Dolomites are the least prone to development of solution porosity.

- Dynamic ground-water flow system

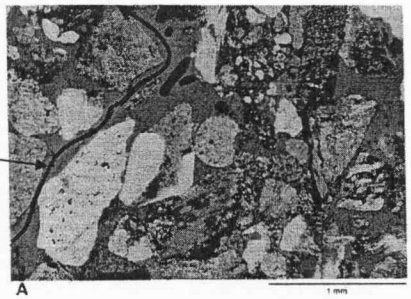
Solution Feature Size Range



Permeability Definition

The ease with which fluids pass through an earth material.

Permeability is a measure of the connectedness of the pores in the sediment or the rock



Permeability is sensitive to the:

- Tortuousity &
- Distribution of pathways through the earth material

Permeability & Hydraulic Conductivity

(Intrinsic) Permeability (k)
- An earth material property

Hydraulic Conductivity (K)
- Dependent on permeability & the properties of the moving fluid
- $K = \frac{k \rho g}{\mu}$ ρ = fluid density, μ = fluid viscosity

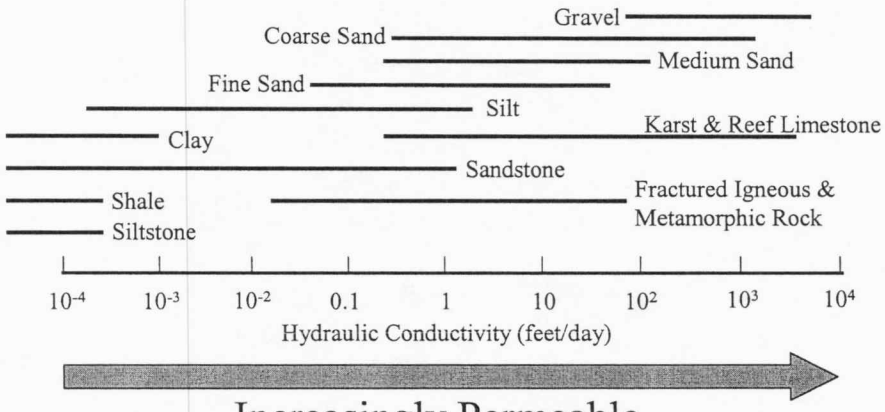
Permeability & Hydraulic Conductivity Units

Intrinsic permeability (k) units: darcies, millidarcies, or cm^2

Hydraulic conductivity (K) units: feet/day, meters/day, or centimeters/second

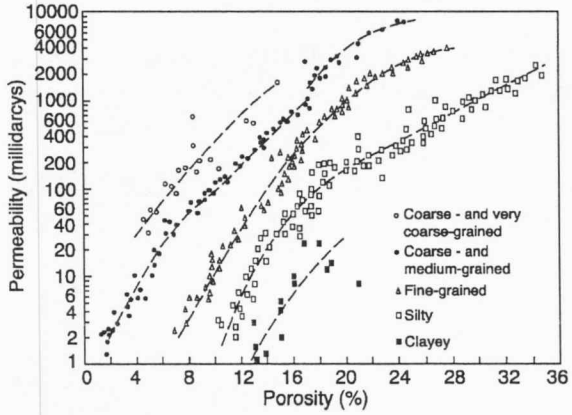
1 darcy (d) = 1,000 millidarcies (md) = 2.74 feet/day

Range of Hydraulic Conductivity Values for Earth Materials



Increasingly Permeable

Relationship of Porosity to Intrinsic Permeability in Granular Sediments



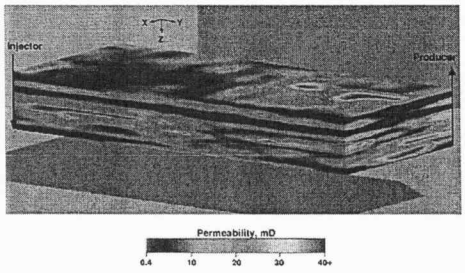
Hydraulic Properties Variability

In natural deposits of sediment or sedimentary rocks:

- The range of porosity values may exceed 10%,

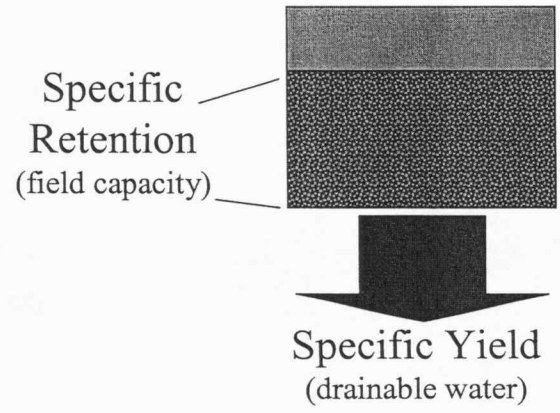
but

- The range of hydraulic conductivity (or intrinsic permeability) values may be greater than several orders of magnitude



Specific Yield & Specific Retention Definitions

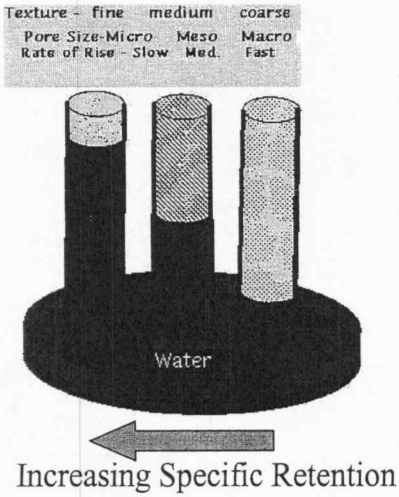
Porosity = Specific yield + Specific Retention



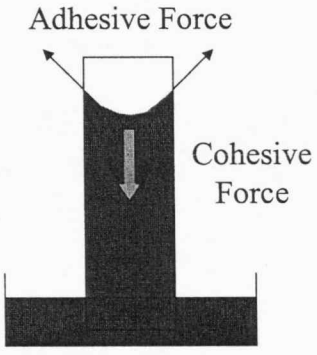
Porosity, Specific Yield, & Specific Retention Values

Earth Material	Porosity (%)	Specific Yield (%)	Specific Retention (%)
Coarse Gravel	24 – 36	23 – 36	1 – 0
Fine Gravel	25 – 38	24 – 35	1 – 3
Coarse Sand	31 – 46	28 – 45	1 – 3
Fine Sand	26 – 53	23 – 53	1 – 3
Silt	34 – 61	5 – 10	29 – 51
Clay	34 – 60	1 – 5	33 – 55

Specific Retention



Increasing Specific Retention



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Session 4
Short Review of
Basic Geology Principles & Concepts

Sedimentary Strata as Former Sediments & the Uniformatarianism Principle

- Sedimentary rocks form from the weathering and erosion of pre-existing sedimentary, metamorphic, & igneous rocks.

- The processes that form these rocks can be readily observed acting at the Earth's surface now as they did in the geologic past.

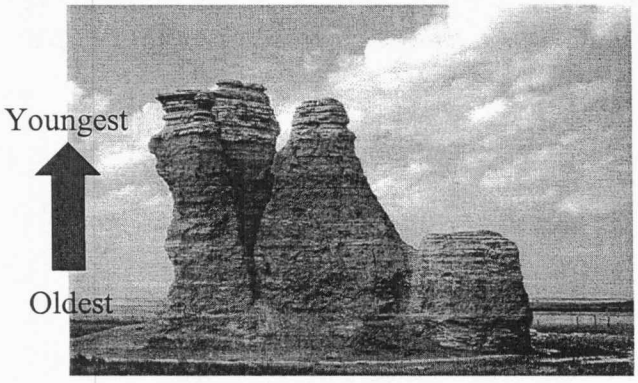
Principle of Original Horizontality

- Stratification is a layered arrangement of the particles that constitute sediment or sedimentary rock.
- The principal states that at the time of deposition, sediments are generally deposited in almost horizontal layers



The Superposition Principle

In a sequence of sedimentary rock layers, the oldest layers are at the bottom & the youngest layers are at the top.



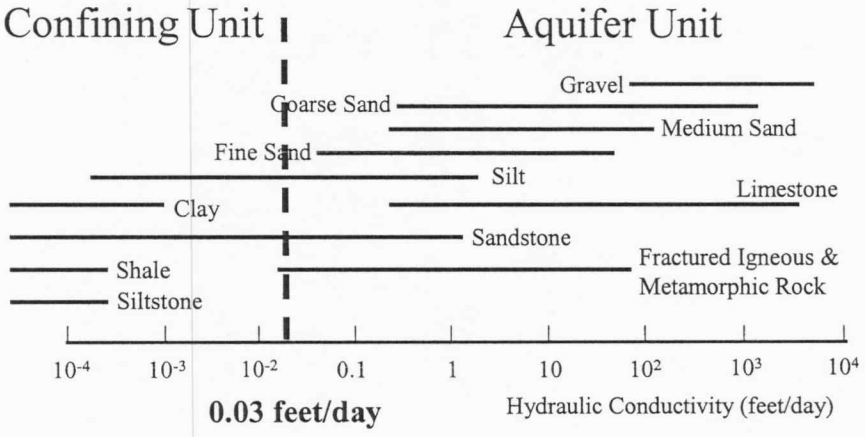
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Session 5
Aquifers & Confining Units

Aquifer & Confining Unit Definitions

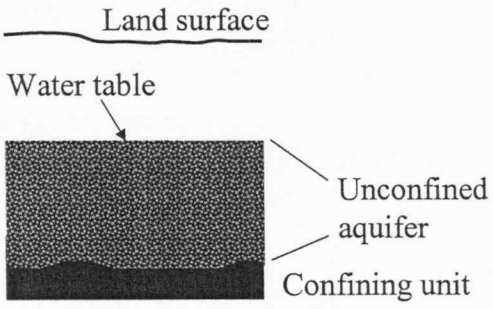
- Aquifer & confining units are defined based relative relative permeability differences.
- An aquifer unit is defined as a sequence of permeable sediment or rock units that can store and transmit water to wells at economically feasible rates.
- A confining unit is defined as a sequence of low permeability units not capable of storing or transmitting water to wells at economically feasible rates.

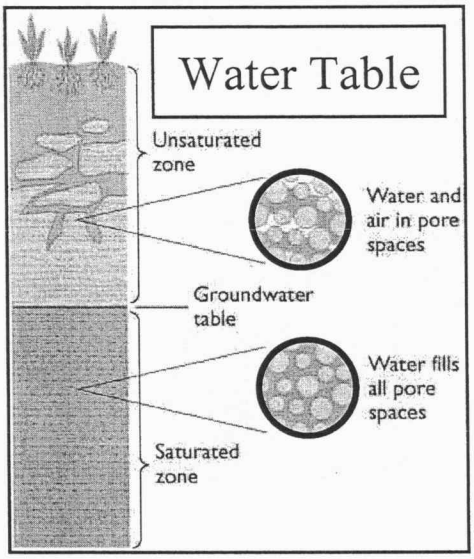
Aquifer & Confining Units



Aquifer Unit Types

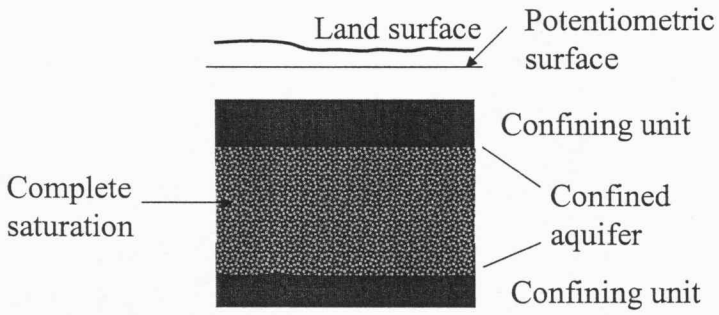
Unconfined Aquifer



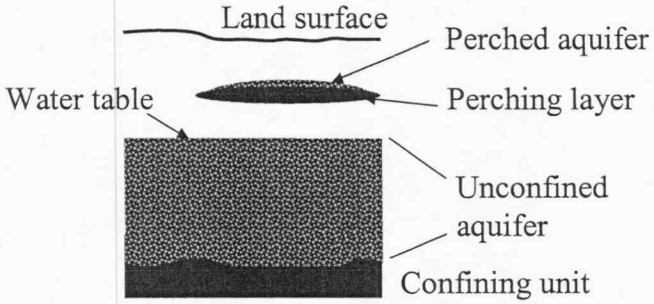


Aquifer Unit Types

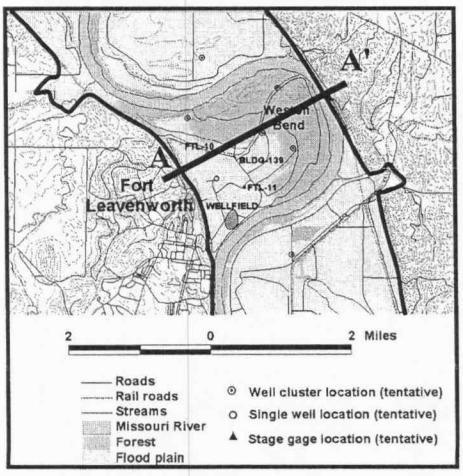
Confined Aquifer

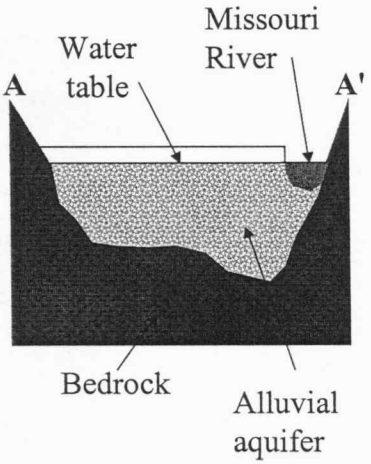


Aquifer Unit Types
Perched Aquifer



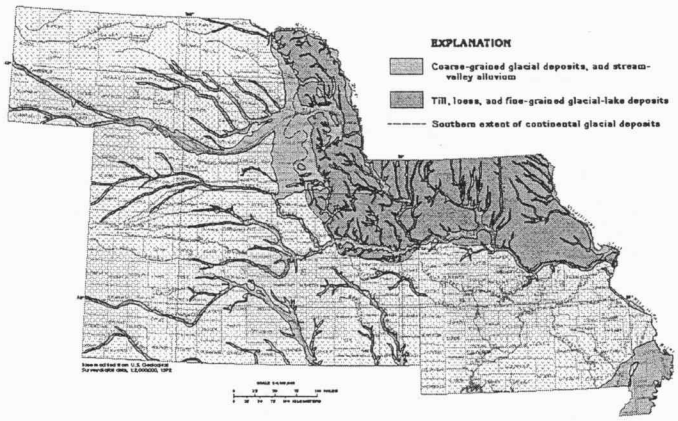
Aquifer Unit Types
Stream-Aquifer Systems





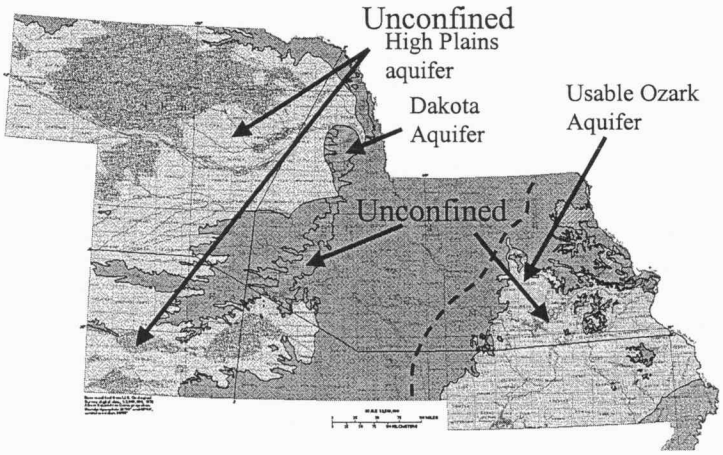
Stream-aquifer Systems in the Central Midwest Region

(Missouri, Kansas, & Nebraska)



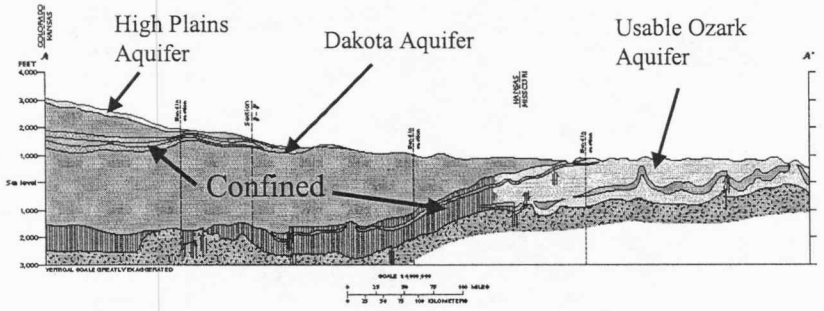
Deeper Ground Water Sources in the Central Midwest Region

(Missouri, Kansas, & Nebraska)



Shallow Ground Water Sources in the Central Midwest Region

(Missouri, Kansas, & Nebraska)

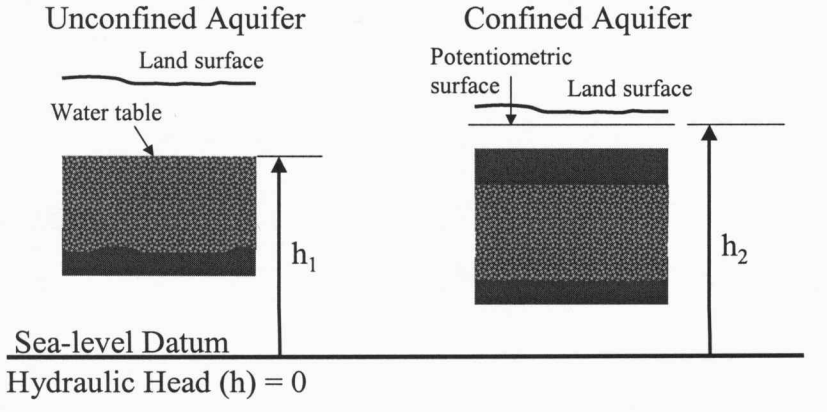


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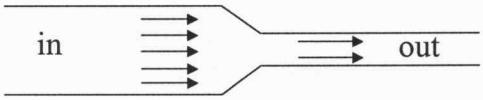
Session 6
Darcy's Law

Potential Energy & Hydraulic Head

Hydraulic head is a measure of the energy contained in the water
"Water flows downhill (and loses energy)."



Bernoulli's Law



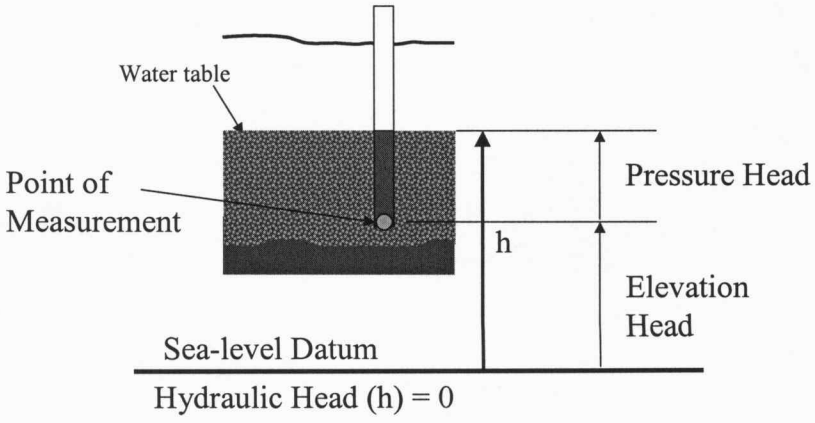
Conservation of Energy

$$E_{in} = E_{out}$$

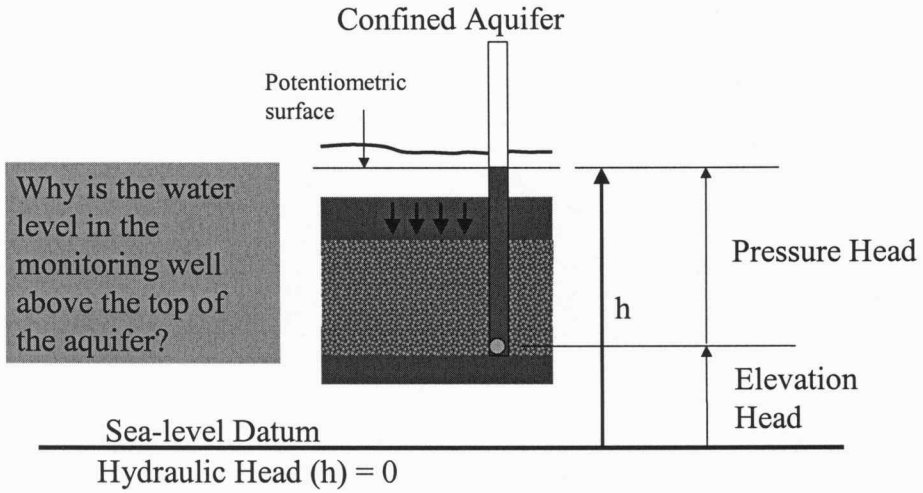
$$\text{Elevation Head}_{in} + \text{Pressure Head}_{in} + \text{Velocity Head}_{in} = \text{Elevation Head}_{out} + \text{Pressure Head}_{out} + \text{Velocity Head}_{out}$$

What is Hydraulic Head?

Unconfined Aquifer

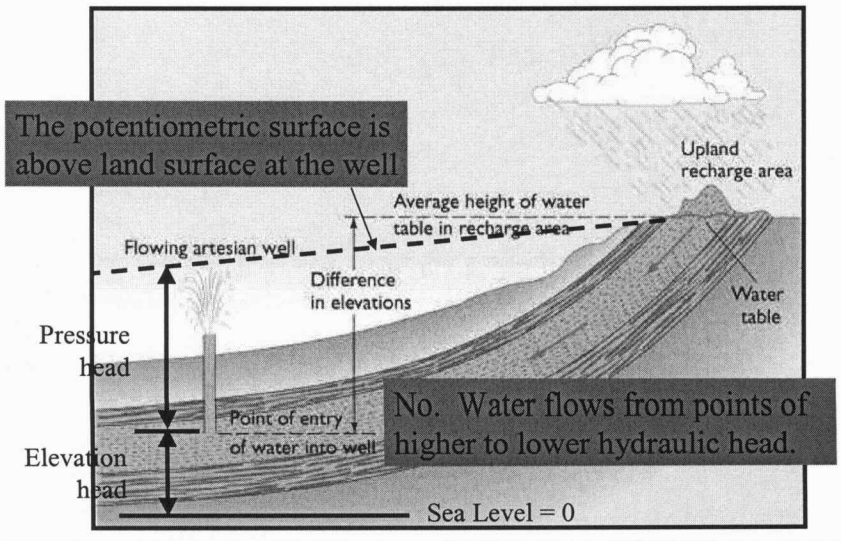


What is Hydraulic Head?



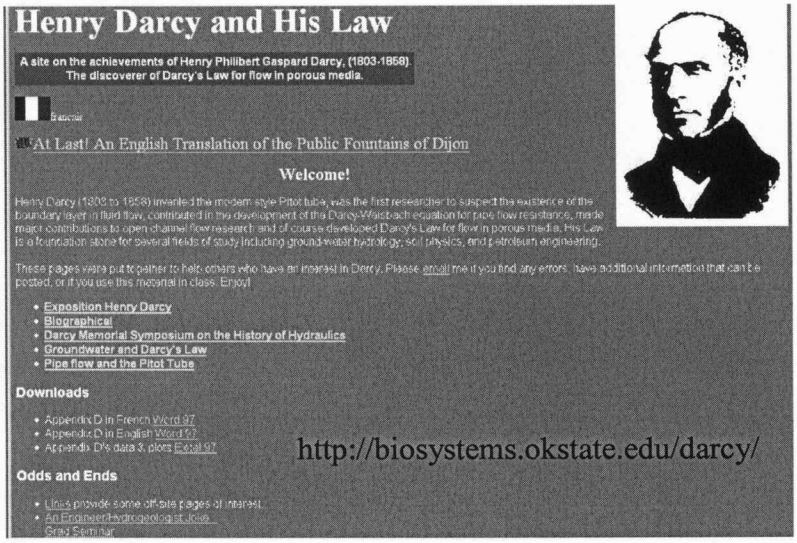
Confining Pressure

Does Water Always Flow Downhill?

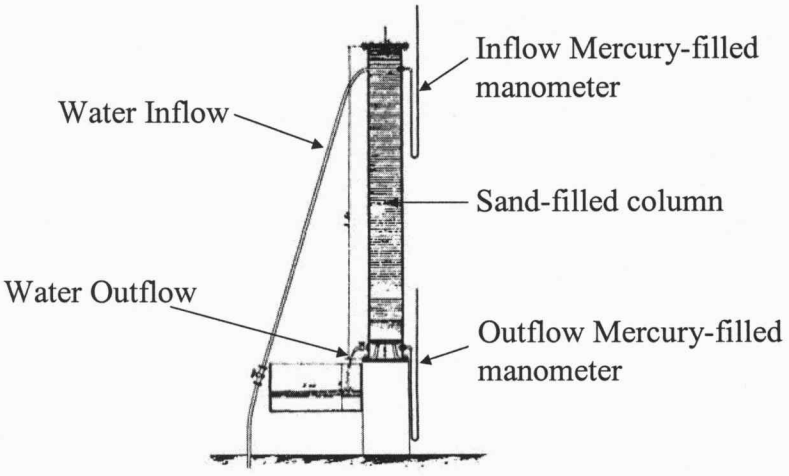


No. Water flows from points of higher to lower hydraulic head.

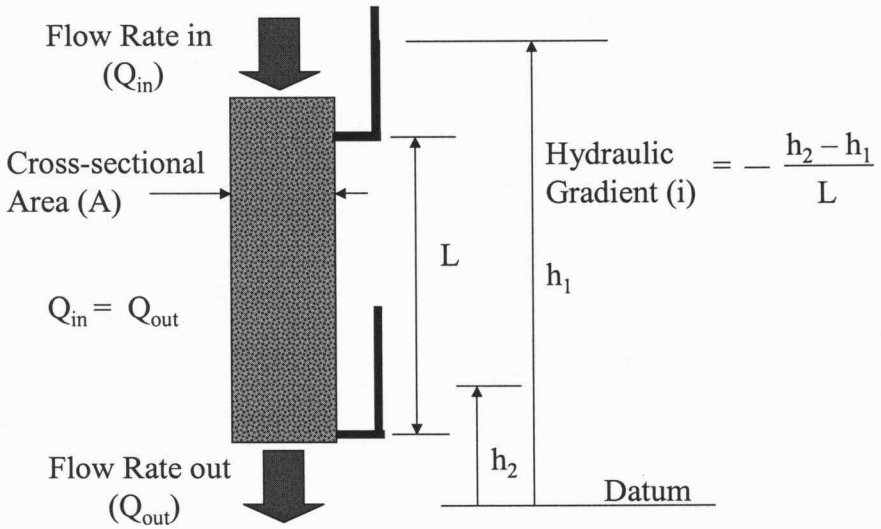
Henri Darcy's Experiment



Darcy's Experimental Apparatus



Schematic of the Apparatus & Measured Parameters



The Experiments

His objective:
To determine the relation between the volumetric flow rate of water through sand beds and the hydraulic head loss

First Experiment: The inlet pressure was varied for each experiment while holding the outlet at atmospheric pressure.
Second experiment: Both inlet and outlet pressure was varied.

A total of 35 experiments were reported and used in the final analysis.

Darcy's Experiments

Darcy concluded that:

The flow rate (Q) is proportional to the
- Hydraulic head difference ($h_2 - h_1$)
- Cross-sectional area (A) &

Inversely proportional to the
- Length (L)

$$Q \propto -A(h_2 - h_1)/L$$

$$Q = (-)Kai$$

where K is hydraulic conductivity

Darcy's Law

$$Q = (-)KAi$$

Specific Discharge (q) = Q/A

Then: $q = (-)Ki$

The minus sign tells us that the flow is in the direction opposite to that of the hydraulic gradient.

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Session 7
Mapping Ground-water Flow Direction

What is the Goal in Mapping?

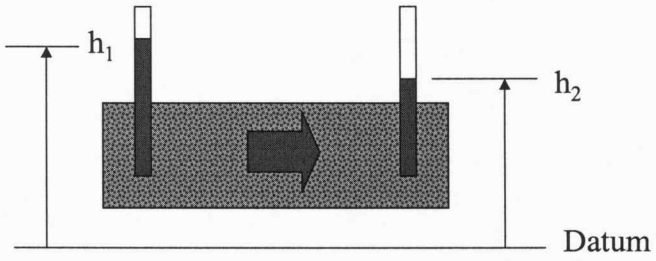
Ground water is always in motion

To determine the variation in ground-water flow direction and rate of movement.

- Define flow paths & flow systems
- Estimate rates of movement & residence time

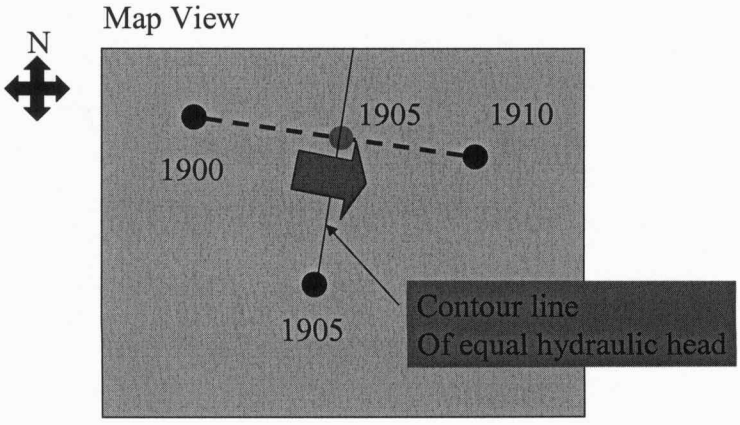
Determining Ground-water Flow Direction

One Dimension



Determining Ground-water Flow Direction

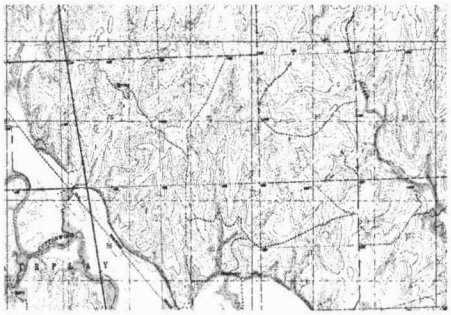
Two Dimensions



Contour Maps

Used to show the variation in a property, parameter, or characteristic in previously defined two dimensional region

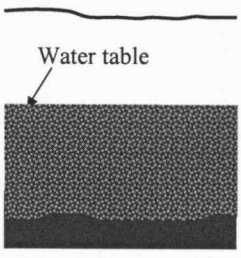
• Topogaphic maps – used to show variation in elevation above sea level

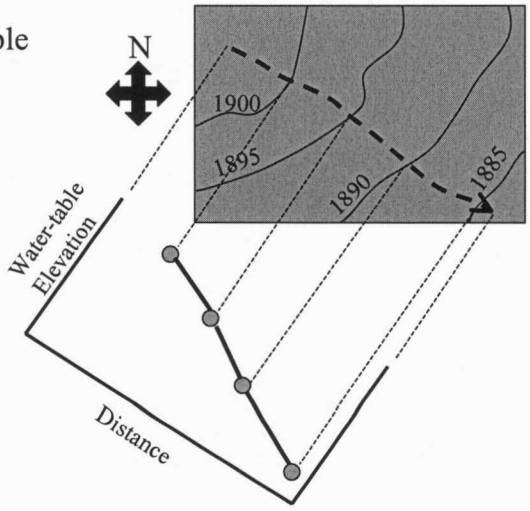


Maps of Hydraulic Head

Unconfined Aquifer

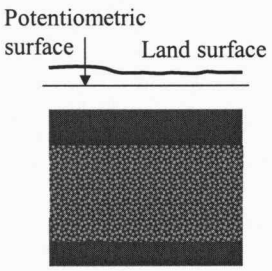
Elevation of the water table above sea level



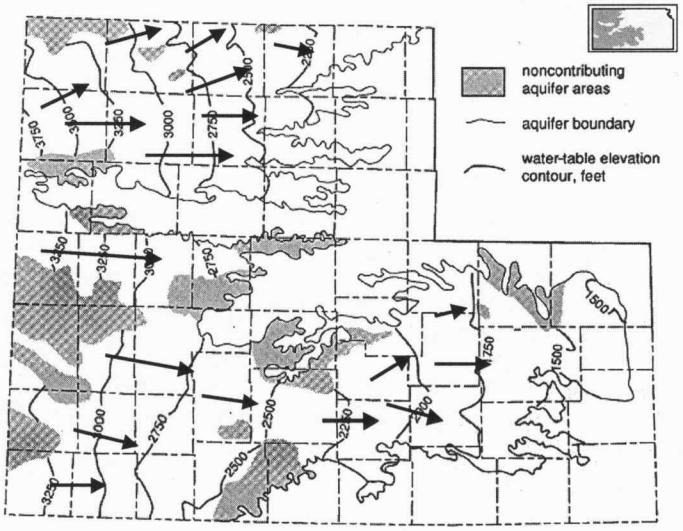


Maps of Hydraulic Head
Confined Aquifer

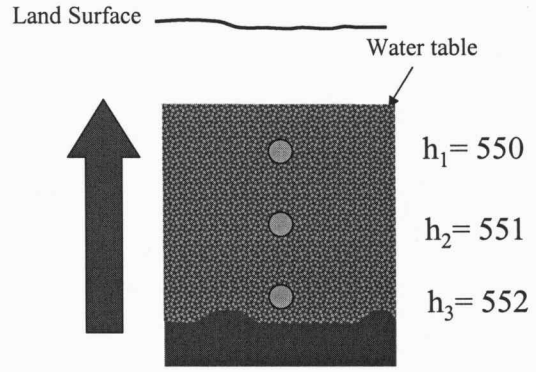
Elevation of the potentiometric surface above sea level



Example: High Plains Aquifer

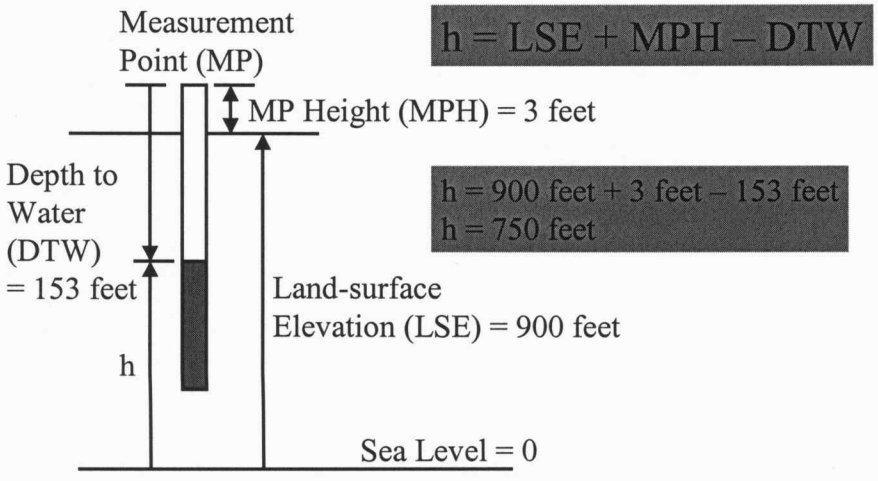


Mapping Vertical Ground-water Flow



Is the ground-water flow direction upward or downward?

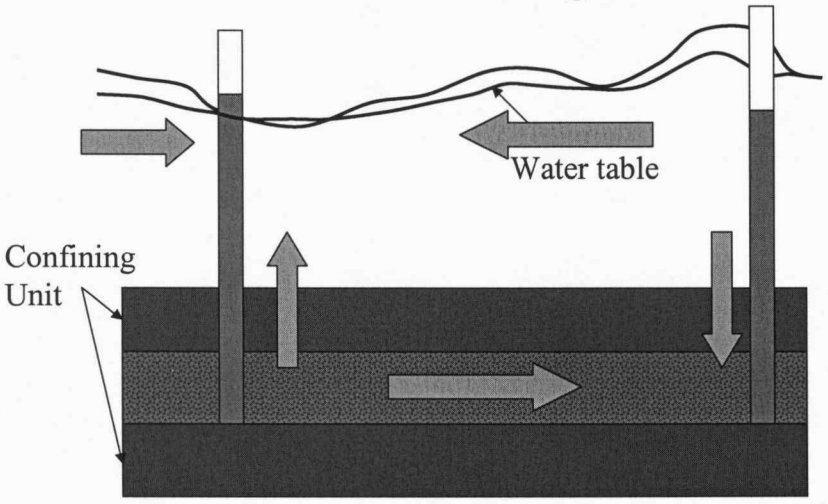
How do We Measure Hydraulic Head?



h = LSE + MPH – DTW

h = 900 feet + 3 feet – 153 feet
h = 750 feet

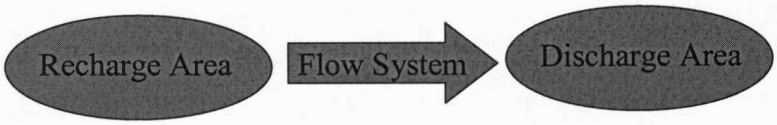
In Which Direction(s) Is Ground-water Flowing?



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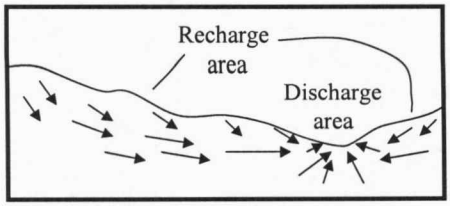
Session 8
The Ground-water Flow System
& Flow System Hierarchy

Anatomy of a Ground-water Flow System

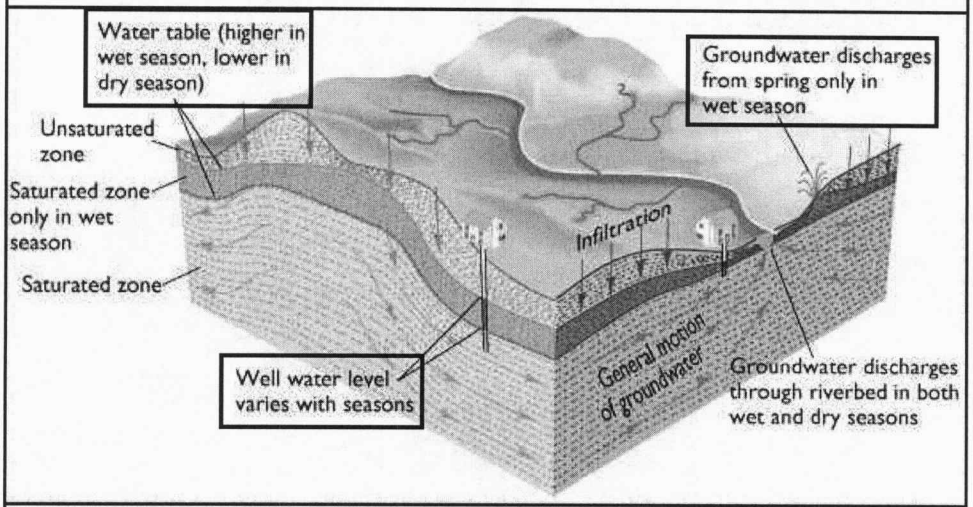


- Upland areas
- Deeper water table
- Higher hydraulic head

- Lowland areas
- Very shallow water table
- Lower hydraulic head



Water Table Characteristics



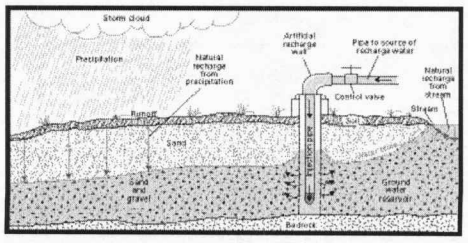
Recharge

Natural

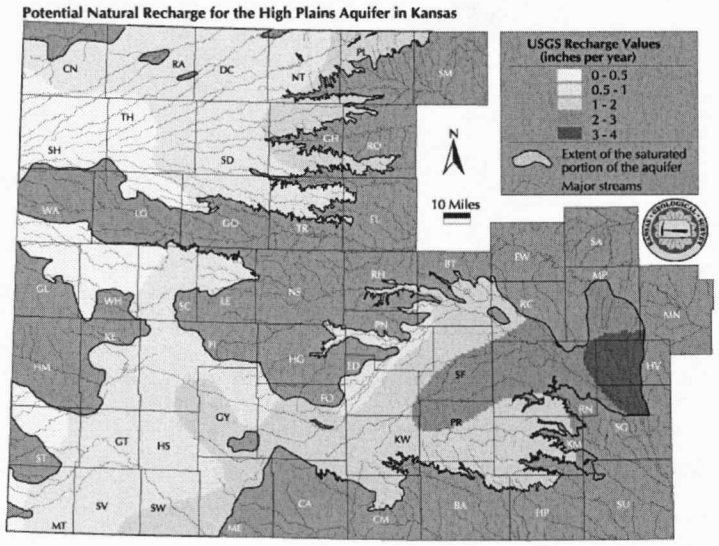
- Precipitation
- Melting snow
- Infiltration by streams and lakes

Artificial

- Recharge wells
- Spread water over land in pits, furrows, ditches, or erect small dams in stream channels to detain and deflect water



Potential Natural Recharge in the Kansas High Plains



Ground-surface Water Interactions

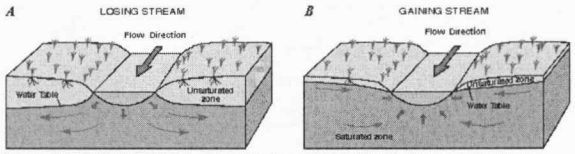
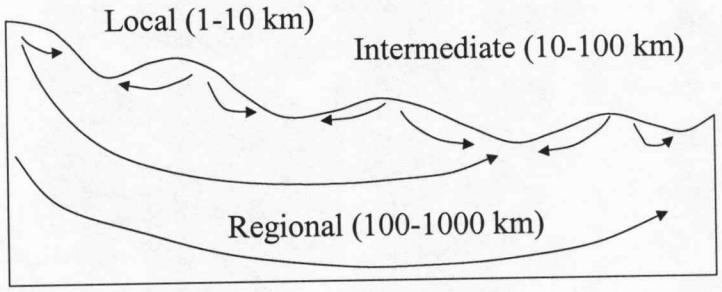
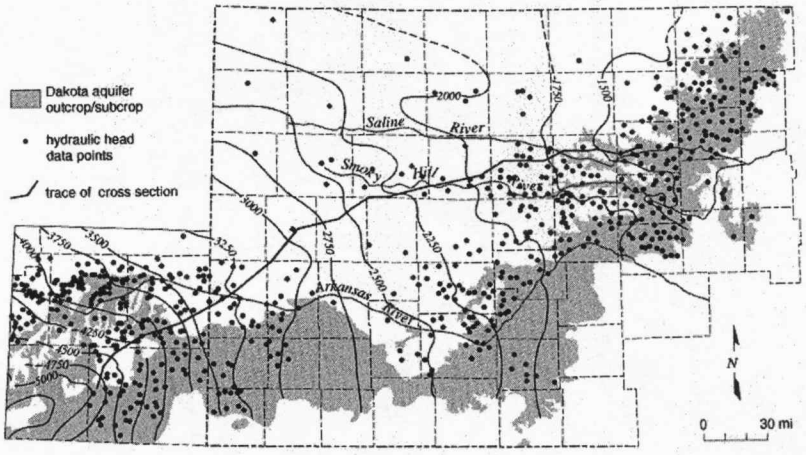


Figure 6. Interaction of streams and groundwater. Losing streams (A) lose water to the groundwater system, whereas gaining streams (B) receive water from the groundwater system (adapted from Winter et. al., USGS Circular 1139, 1998)

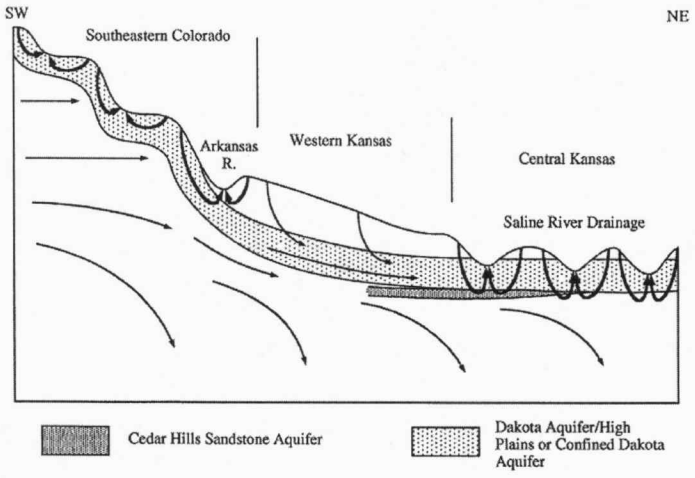
Ground-water Flow System Hierarchies



Dakota Aquifer Example

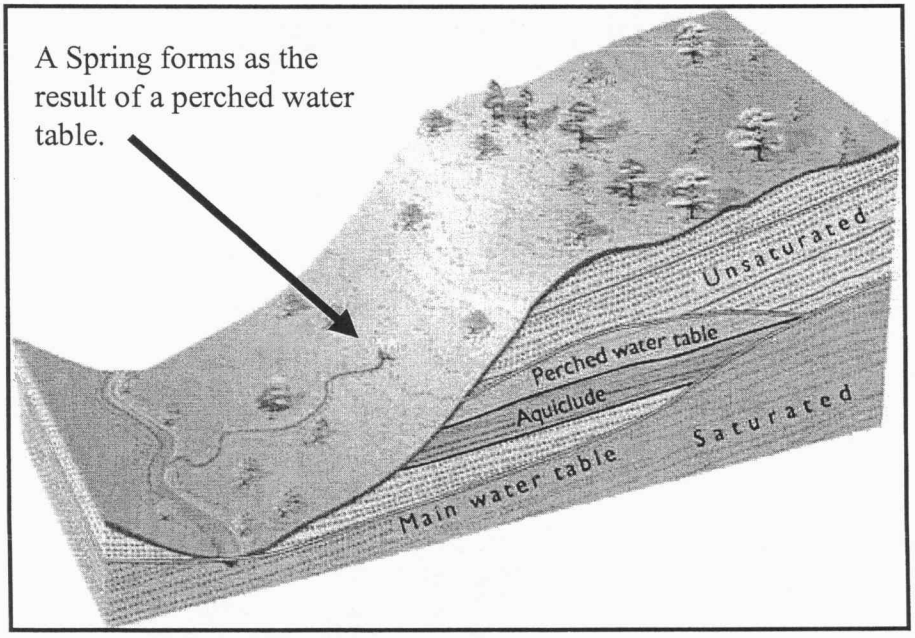


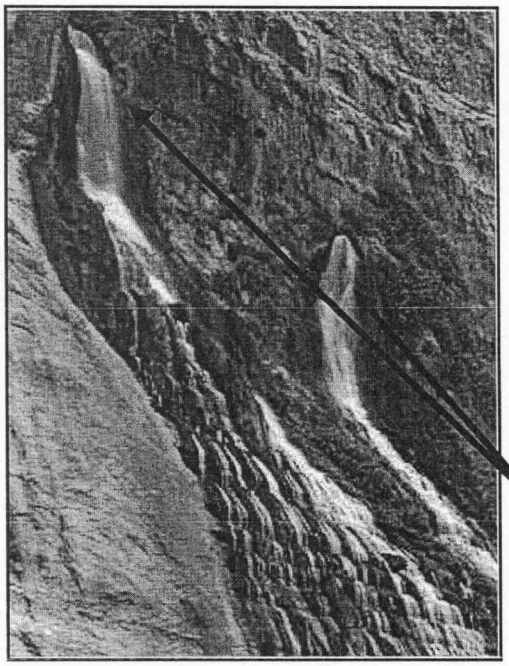
Dakota Aquifer Example



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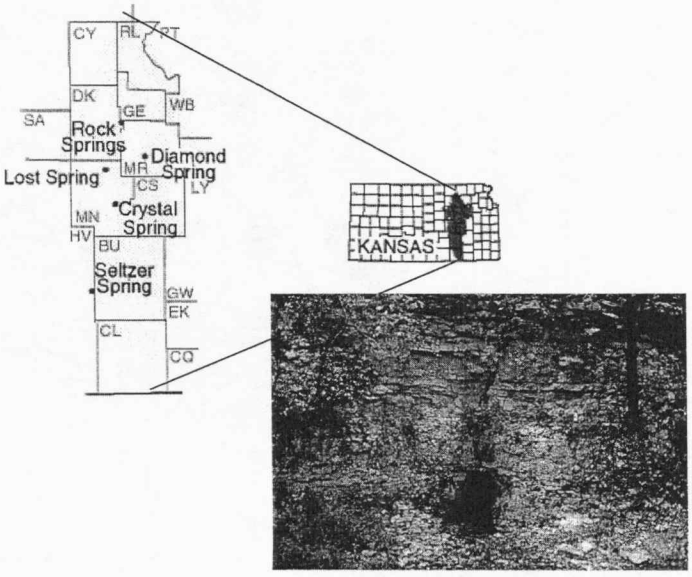
Session 10
Surface Manifestations of Ground-water Flow



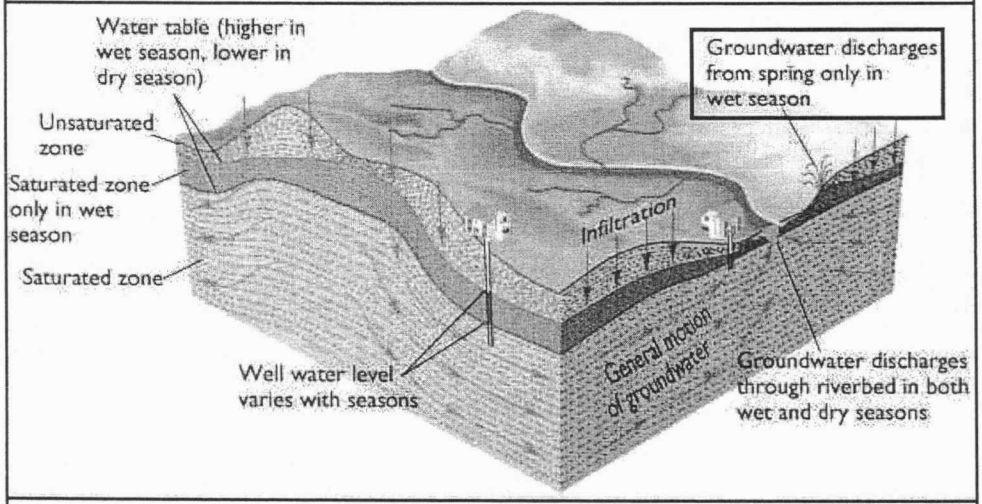


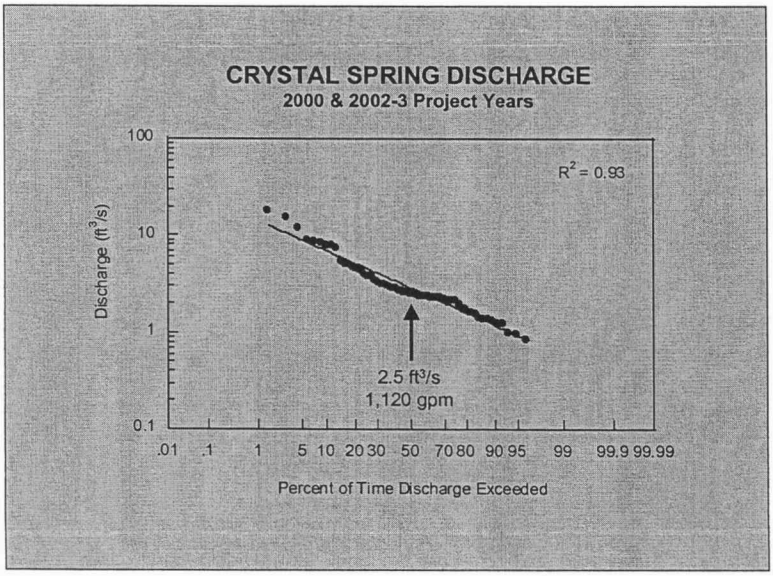
Springs often occur when groundwater is forced to the surface by a confining layer.

Flint Hills Springs



Water Table Characteristics





The Summer 2004 Ground-water Workshop For Secondary Science Teachers

Session 11
The Ground- and Surface-water Interactions

Ground-surface Water Interactions

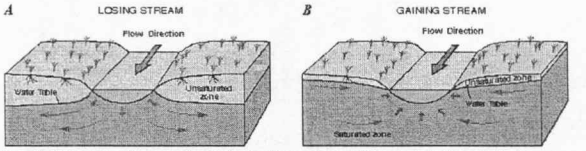
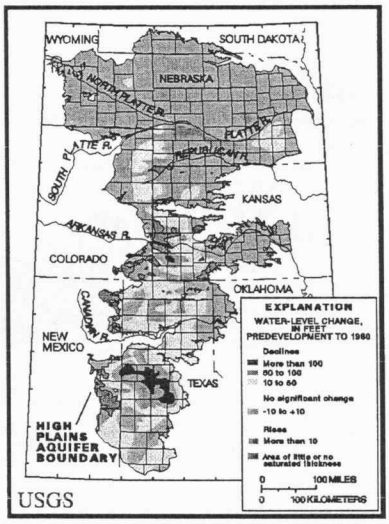
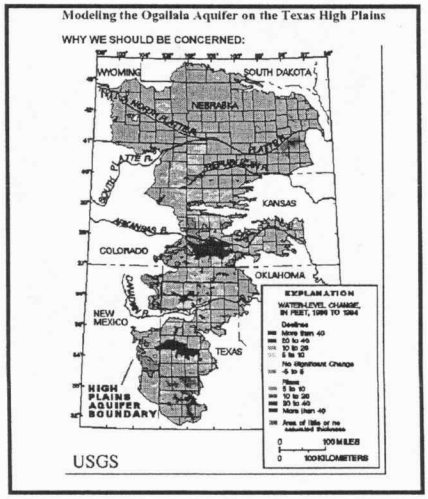


Figure 6. Interaction of streams and groundwater. Losing streams (A) lose water to the groundwater system, whereas gaining streams (B) receive water from the groundwater system (adapted from Winter et. al., USGS Circular 1139, 1998)

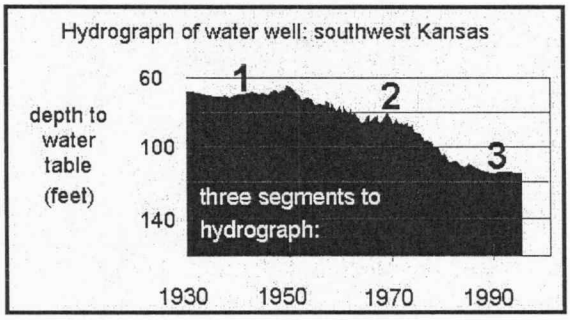
Water Level Change from Predevelopment to 1980



Water Level Change from 1980 to 1994



Sample Hydrograph



Major Perennial Streams in Kansas in 1961 & 1994

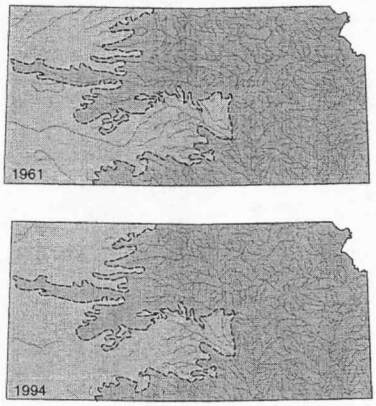


Figure 7. Major perennial streams in Kansas in 1961 and 1994. The area west of the dashed line shows the extent of the High Plains aquifer in Kansas (adapted from Angelo, 1994).

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Session 12
Well Construction

Water Well Purpose

- Water supply
- Monitoring
- Contaminant removal
- Heating/cooling
- Dewatering
- Underground injection

Steps in Well Construction

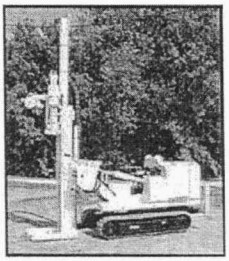
- Determine ground-water availability
- Conduct test drilling to locate local sources of ground water
- Drill the borehole for the well
- Construct & install the well casing/screen
- Develop the well
- Test pump the well to determine yield/ collect water samples for analysis
- Install the pump, electrical lines, & above-ground plumbing

Drilling

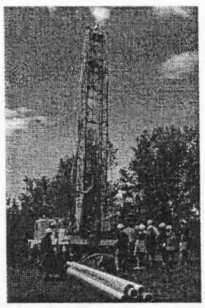
Auger



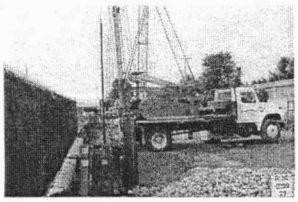
Geoprobe



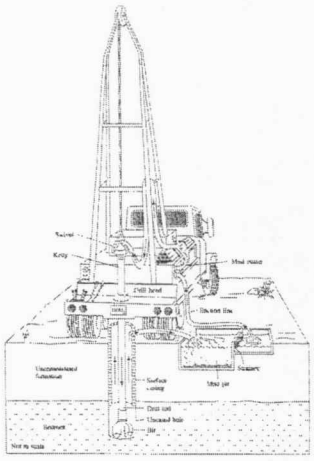
Mud/Air Rotary



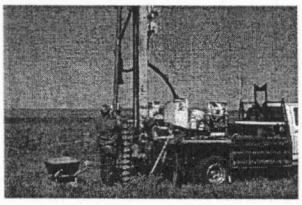
Cable-tool

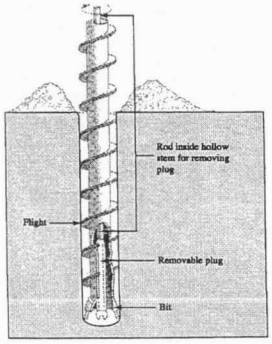


Rotary Drilling

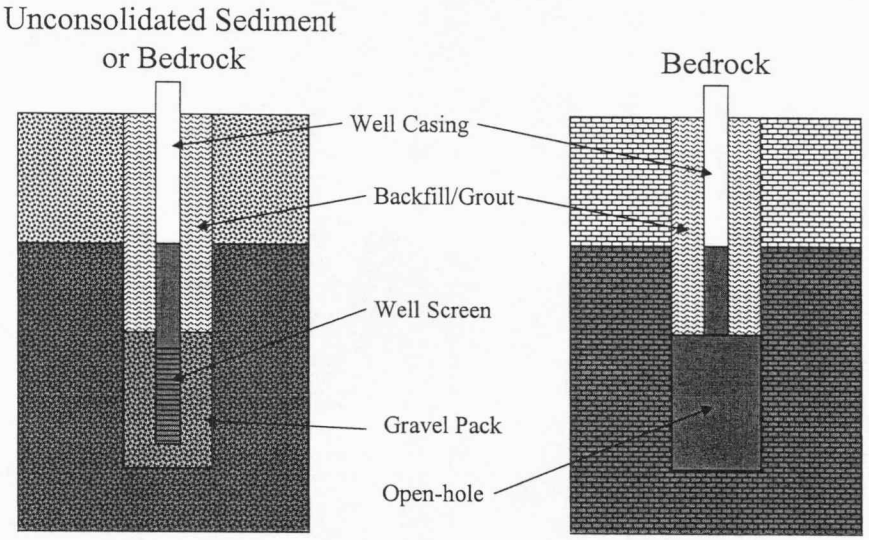


Drilling With a Hollow-stem Auger





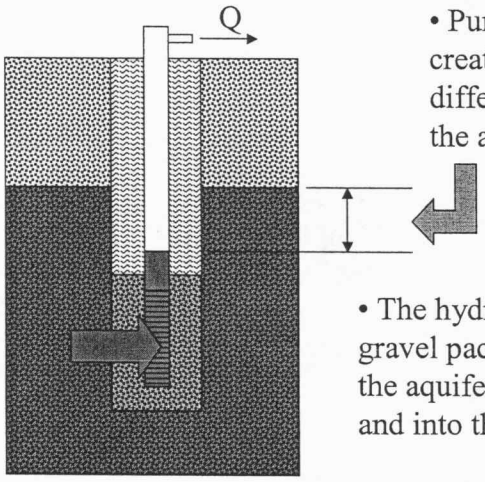
Well Construction



The Summer 2004 Ground-water Workshop For Secondary Science Teachers

Session 13
Effects of Well Pumping & Fluid Injection

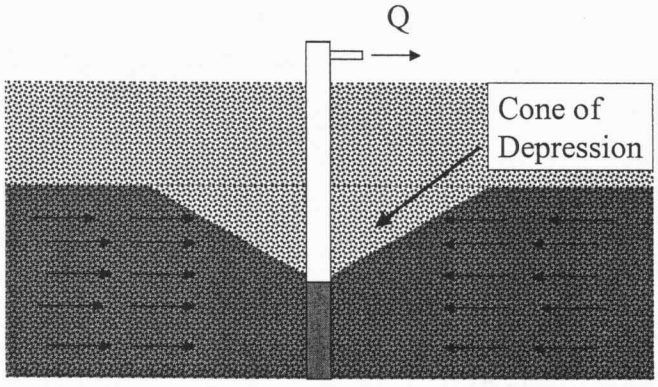
How Does a Well Continue to Produce Water?



- Pumping water from the casing creates a hydraulic-head difference between the well and the aquifer.
- The hydraulic gradient across the gravel pack causes water to flow from the aquifer, through the well screen, and into the casing.

What Happens When the Pump is Turned on?

Flat Water table



Why does the cone of depression continue to grow in size?

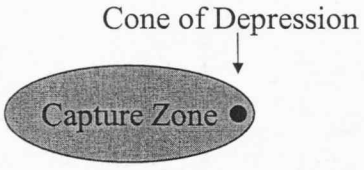
What Happens When the Pump is Turned on?

Sloping Water table

Map View

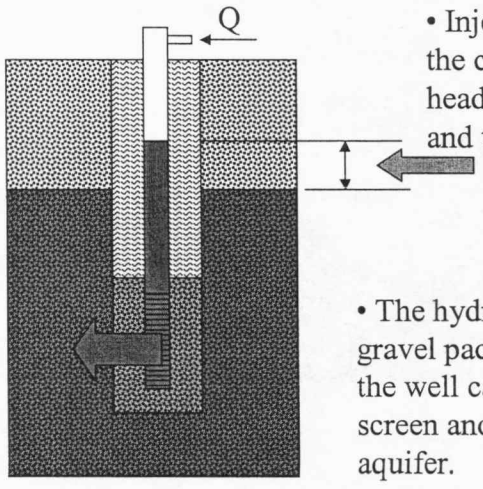


Ground-water Flow



Pumping well

What Happens When Water is Injected into an Aquifer?

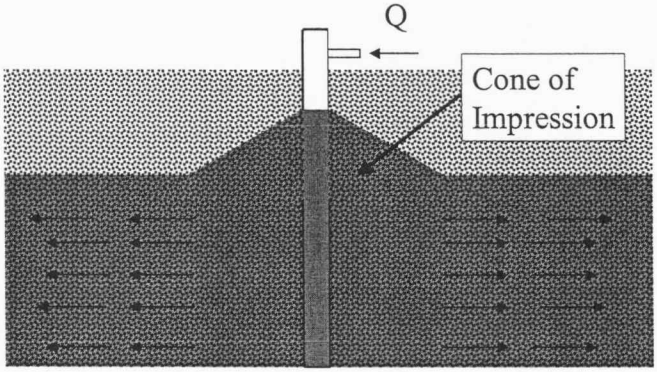


- Injecting (adding) water into the casing creates a hydraulic-head difference between the well and the aquifer.

- The hydraulic gradient across the gravel pack causes water to flow from the well casing, through the well screen and gravel pack and into the aquifer.

What Happens When Fluid is Added Using an Injection Well?

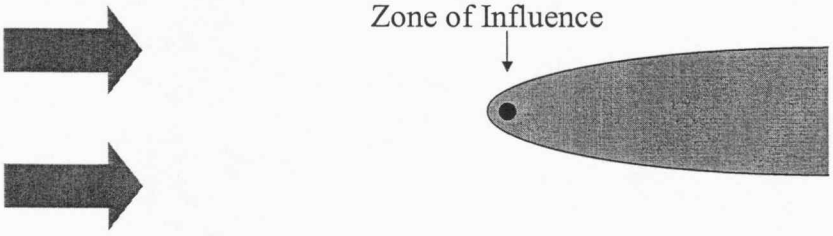
Flat Water Table



What Happens When Fluid is Added Using an Injection Well?

Sloping Water table

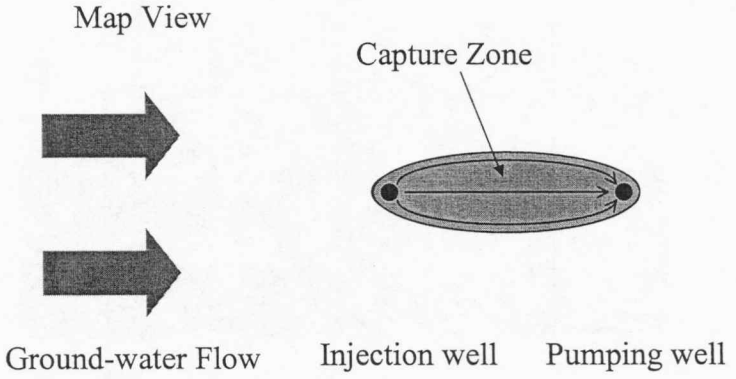
Map View



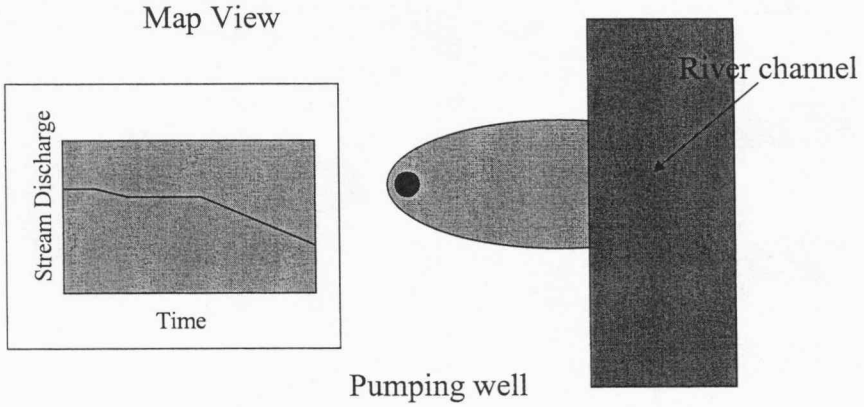
Ground-water Flow

Injection well

What Happens with a Pumping & Injection Well Couplet?



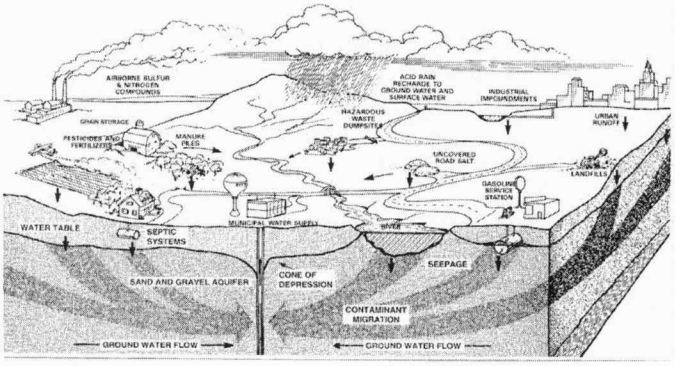
Well Pumping In a Stream-Aquifer System



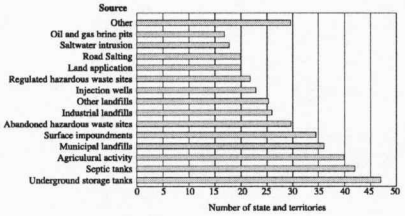
The Summer 2004 Ground-water Workshop For Secondary Science Teachers

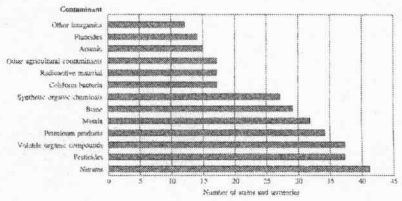
Session 14
Ground-water Contamination

Sources of Contamination



Sources & Types of Contamination



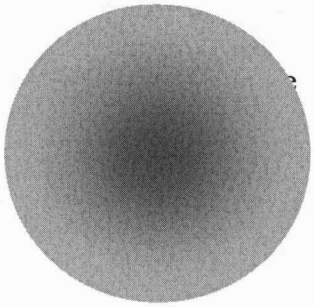


Transport of Contaminants Through Ground-water Systems

- Diffusion
- Advection
- Dispersion

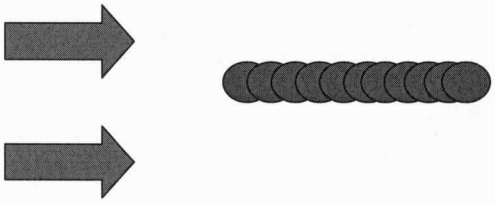
Diffusion

Transport by molecular motion causing a spreading of the solute in a solution with no fluid motion.



Advection

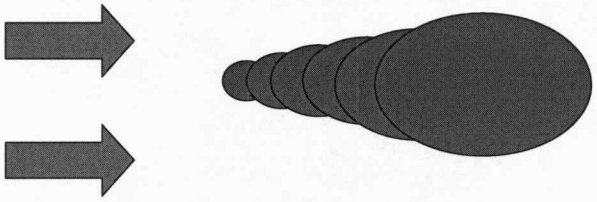
Solutes move with the ground-water flow



Ground-water
Flow Direction

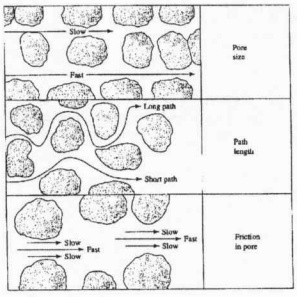
Dispersion

A spreading out of the contaminant in a moving ground-water system.



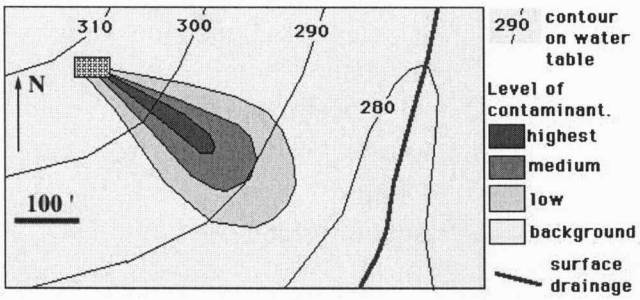
Ground-water
Flow Direction

Causes of Mechanical Dispersion



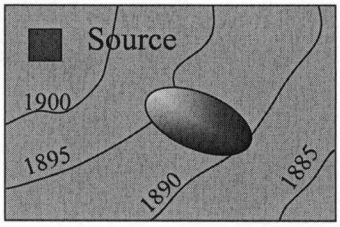
A Contaminant Plume

Results from a continuous release of the contaminant into the ground-water system.



A Contaminant Slug

Results from a contaminant release over a finite period of time.



Waste Disposal Practices

Regulated

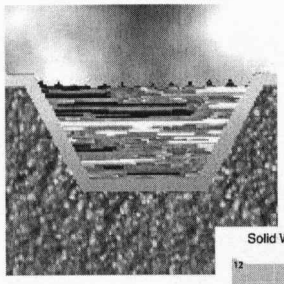
- Municipal landfills
- Hazardous waste disposal facilities
- Underground injection wells
- Irrigation
- Composting

Land Application

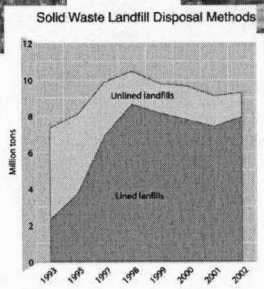
Unregulated

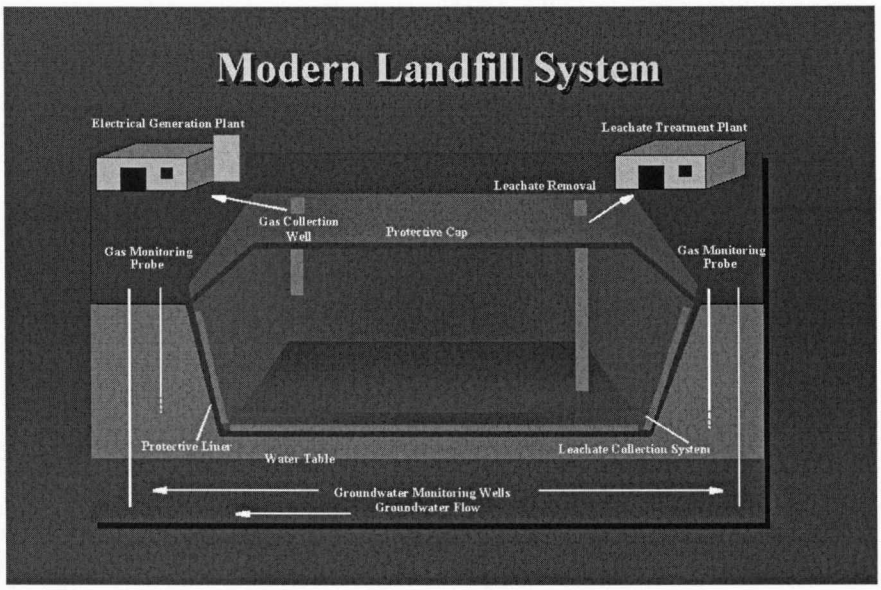
- Dumps
- Septic systems

Liner Systems

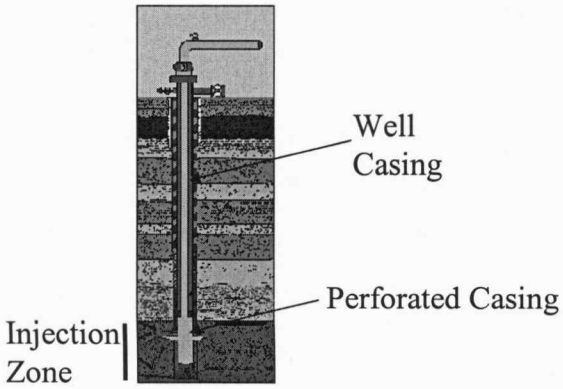








Construction of a Typical Underground Injection Well



KEY CONCEPTS FOR MACFARLANE'S PART OF THE GROUND-WATER WORKSHOP

Hydrologic Cycle

The hydrologic cycle links the atmosphere, hydrosphere, biosphere, and the lithosphere together and is driven by radiant energy and in turn acts to transport energy and water between the poles and the equator.

Of all the freshwater sources ground water is the most available and accounts for 29% of the total fresh water reservoir.

In the drainage basin, the main source of water is precipitation and the export is apportioned between stream flow, evapotranspiration, and deep ground-water flow.

The hydrologic equation states that the difference between the input and the output of water from a region or a hydrologic entity is equal to the change in storage.

Water Resources and Use

Since 1950, the dominant uses of water have been for electric power generation and crop irrigation.

In 2000 Nebraska and Kansas relied primarily on ground-water sources and used them primarily for crop irrigation whereas Missouri relied more on surface water than ground water but used most of its ground water for crop irrigation.

Because of the westward decrease in precipitation and increase in evapotranspiration and the availability of ground water, eastern Kansans rely on surface water and western Kansans rely primarily on ground water.

Earth Material Properties

Porosity is the total void space fraction of the bulk volume of an earth material and consists of connected and isolated void space.

The three types of porosity are intergranular, fracture, and solution.

In sediments and sedimentary rocks the intergranular porosity amount depends on its texture and diagenetic history.

Intrinsic permeability is a property of earth materials, is the ease with which fluids pass through earth materials, and is dependent on the interconnected porosity.

The hydraulic conductivity parameter is commonly used in hydrogeology and depends on the permeability the earth material and the properties of the fluid passing through it.

The specific yield is relative amount of water that will drain naturally from a saturated earth material and the specific retention is the relative amount of water that remains in the earth material after drainage. The sum of both is equal to the total porosity.

Aquifer and Confining Units

Aquifer and confining units are defined based on relative differences in permeability. An aquifer is usually defined as a permeable unit capable of storing and transmitting water wells at economically feasible rates, whereas a confining layer is a less permeable unit that can store but not transmit water to wells at economically feasible rates.

An unconfined aquifer is bounded above by a water table and below by a confining layer.

The water table marks the top of the zone of saturation with respect to water.

A confined aquifer is fully saturated with water and bounded above and below by confining units and its potentiometric surface is above the top of the aquifer.

A perched aquifer is of limited areal extent, is bounded below by a low permeability layer in the unsaturated zone above the water table and above by a water table.

A stream-aquifer system consists of an alluvial aquifer and its adjacent stream, to which it is hydraulically connected.

Hydraulic Head

The hydraulic head is a measure of the amount of energy contained in water and is the sum of the elevation head above a datum and the pressure head. Ground water flows from regions of high hydraulic head to regions of low hydraulic head.

The hydraulic head is the elevation of the water table in an unconfined aquifer, but is the elevation of the potentiometric surface in a confined aquifer.

Darcy's Law

Darcy's law states that the flow rate through an earth material is proportional to the cross-sectional area and the hydraulic gradient. In ground-water science, the constant of proportionality is the hydraulic conductivity.

Mapping Ground-water Flow Directions

The goals for mapping ground-water flow systems are to delineate ground-water flow paths and to determine rates of flow and residence time.

In map view, ground-water flow direction is parallel but opposite in direction to the hydraulic gradient, which is perpendicular to contours of equal hydraulic head (elevation of the water table or the potentiometric surface).

Ground-water direction can also be upward or downward depending on the hydraulic-head difference in the vertical direction.

Hydraulic head is calculated from depth-to-water measurements taken in wells. The hydraulic head is equal to the land-surface elevation plus or minus the measurement point above or below land surface minus the depth-to-water from the measurement point.

Ground-water Flow System Anatomy and Hierarchies

A ground-water flow system consists of a recharge area and a discharge area connected by an integrated network of ground-water flow paths.

Surface-water bodies may be sources of recharge or act as discharge areas depending on wet season or dry season conditions and ground-water withdrawals.

Large-scale flow systems consist of a hierarchy of local and intermediate systems superimposed on a regional system. Local systems involve usually one drainage basin; intermediate systems involve multiple drainage basins; regional systems may involve multiple intermediate systems.

Effects of Pumping and Injection Wells

When the pump in a well is turned ground water flows to the well in response to a decrease in hydraulic head within the casing that eventually propagates to the surrounding aquifer creating a cone of depression in the water table or potentiometric surface. The cone of depression will continue to grow in areal extent until the aquifer is able to supply of ground water into the area affected by the cone of depression at the same rate as the rate of withdrawal by the well.

Where the potentiometric surface or the water table is tilted, the outline of the cone of depression approaches a parabola in shape with the open end pointing in the direction opposite to that of the ground-water flow. The area inside the parabola is referred to as the capture zone.

Likewise, injection of water to an aquifer increases the hydraulic head in the well casing causing water to flow out into the aquifer. The flow creates a mounding in the water table or potentiometric surface referred to as a cone of impression.

Where the potentiometric surface or the water table is tilted, the outline of the cone of impression approaches a parabola in shape with the open end pointing in the direction of the ground-water flow. The area inside the parabola is referred to as the zone of influence.

A pumping well and a nearby injection well will create a couplet where inflow from the injection well is completely captured by the pumping well.

Well pumping near a stream will cause water to flow from the stream to the aquifer and toward the pumping well. This will result in a reduction of stream discharge.

Contaminant Hydrogeology

Contaminants in solution move through the ground-water system primarily by means of mechanical dispersion, and advection and secondarily by diffusion.

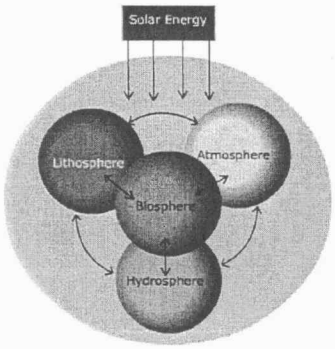
Ground-water contamination from a source over an extended period of time creates a plume that moves in the direction of ground-water flow that can be traced back to its source.

Ground-water contamination from a source over a short period of time creates a relatively well-defined zone of contamination spheroid in shape and referred to as a slug.

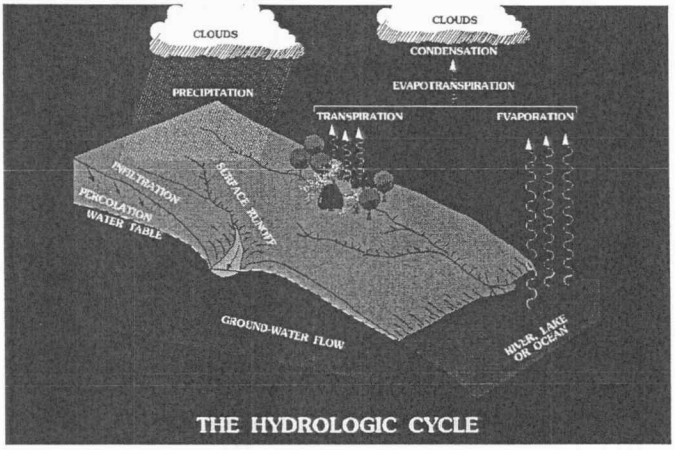
The Summer 2004 Ground-water Workshop For Secondary Science Teachers

Session 1
The Hydrologic Cycle

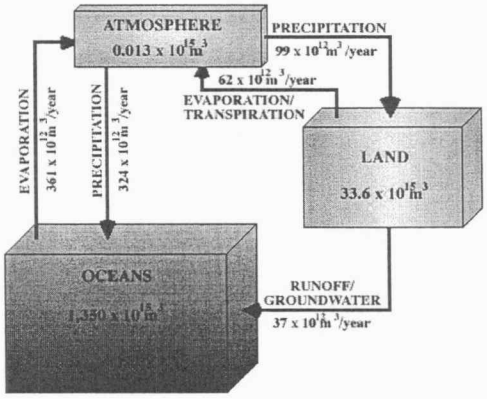
Global Energy & Mass Transfer



Global Hydrologic Cycle

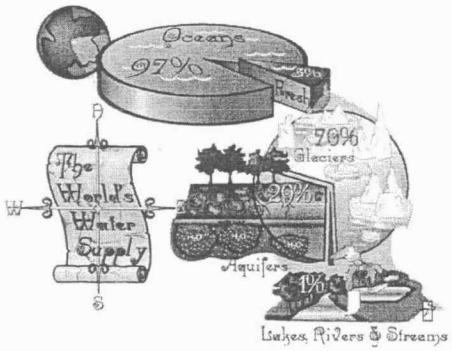


Water in Storage & in Transit: Global View



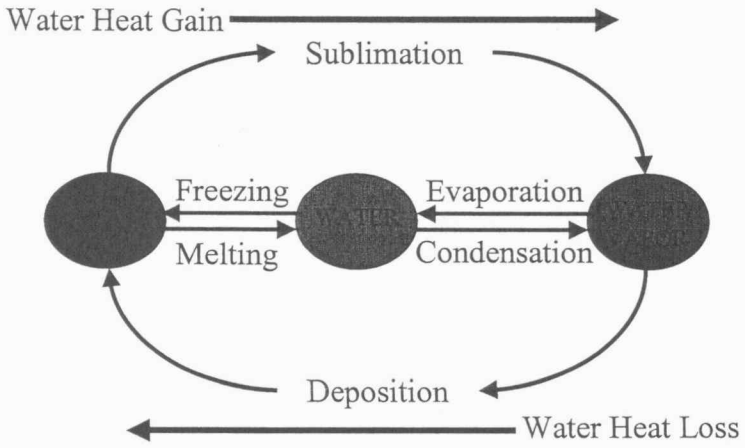
Conservation of Mass principle: Everything has to be someplace

Where's the Fresh Water?

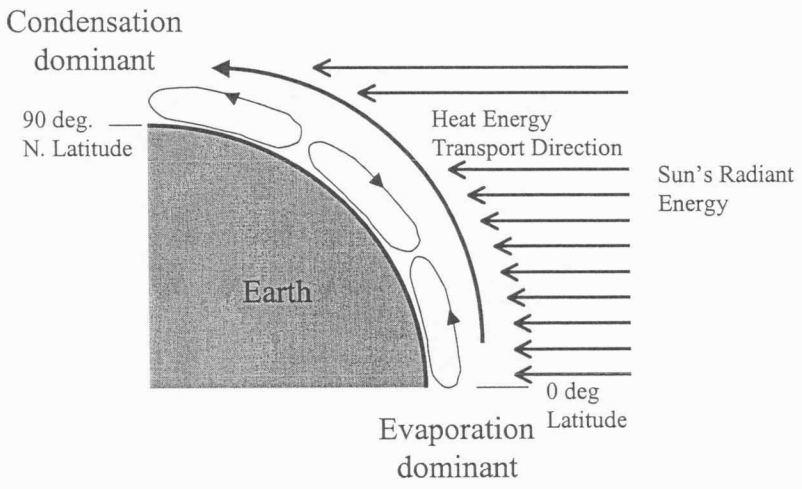


Approximately 29% of the readily available world's fresh water resource exists in aquifers

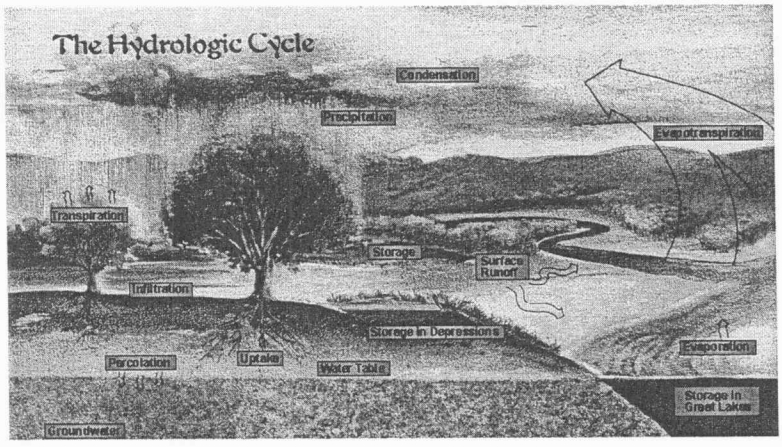
Phases & Phase Changes of Water



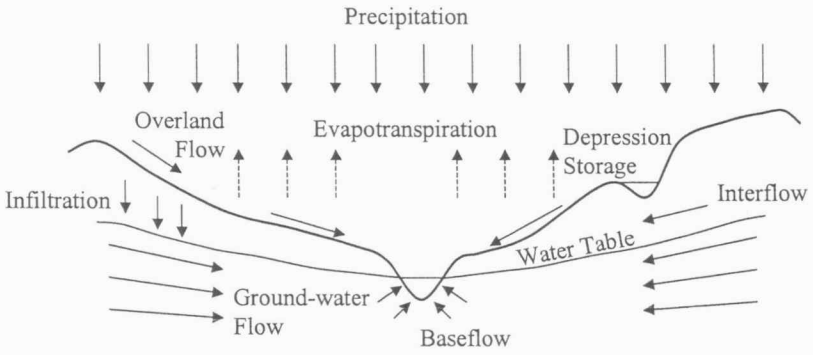
Heat Transfer, Northern Hemisphere



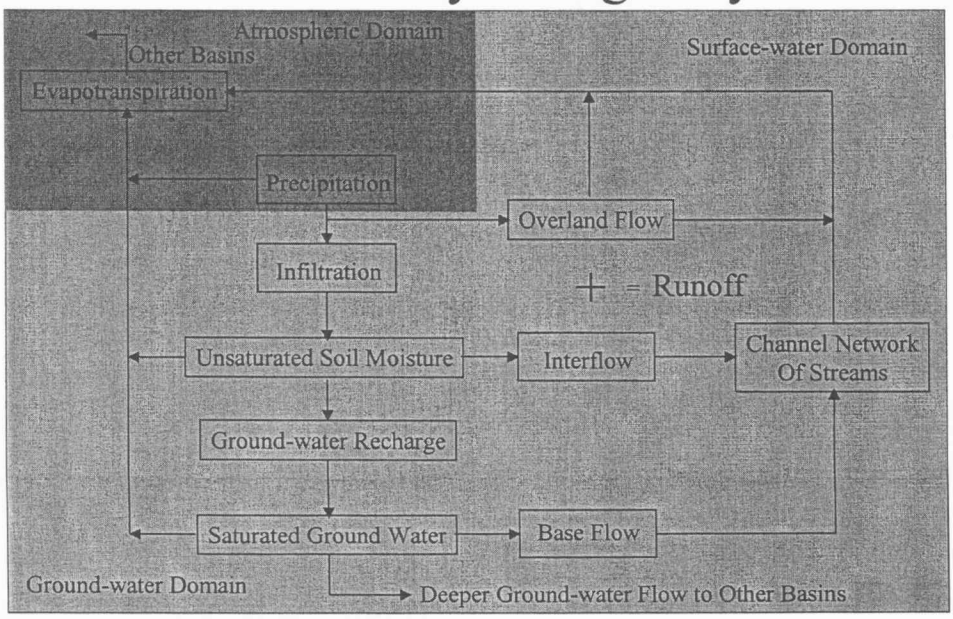
The River Basin Hydrologic Cycle



Parts & Processes Associated with the Basin Hydrologic Cycle

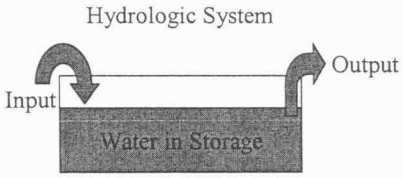


The Basin Hydrologic Cycle



The Hydrologic Equation:

Water Balance



Input – Output = Change in Storage (Quantities)

Time Rate of Change In Input — Time Rate of Change In Output = Time Rate of Change of Storage

(Rates of change)

The Basin Water Balance Equation

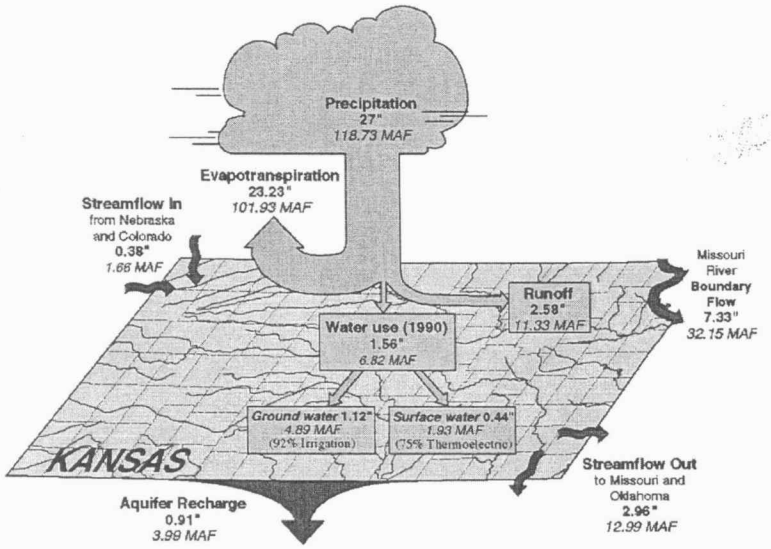
Surface- & Ground-water Portion (Land Domain Only)

Sum of all Inputs — Sum of all Outputs = Change in Storage

- Precipitation
- Ground-water inflow
- Inflow from recharge projects

- Evaporation
- Transpiration
- Stream outflow
- Ground-water outflow
- Surface water withdrawals
- Ground-water withdrawals

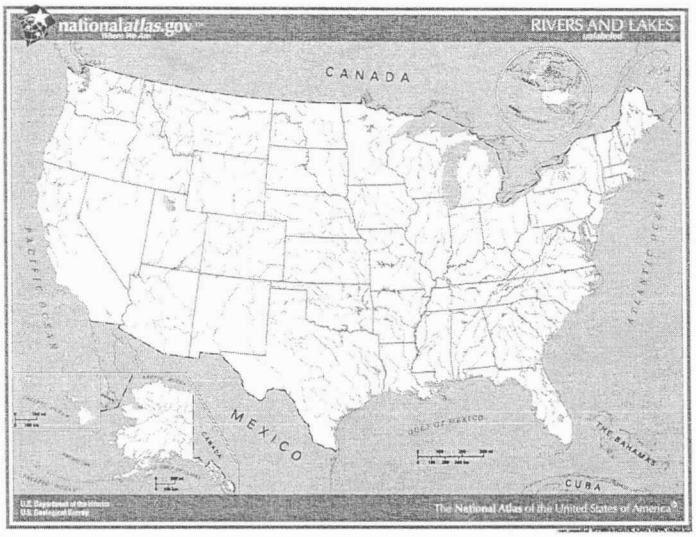
The Kansas Water Budget



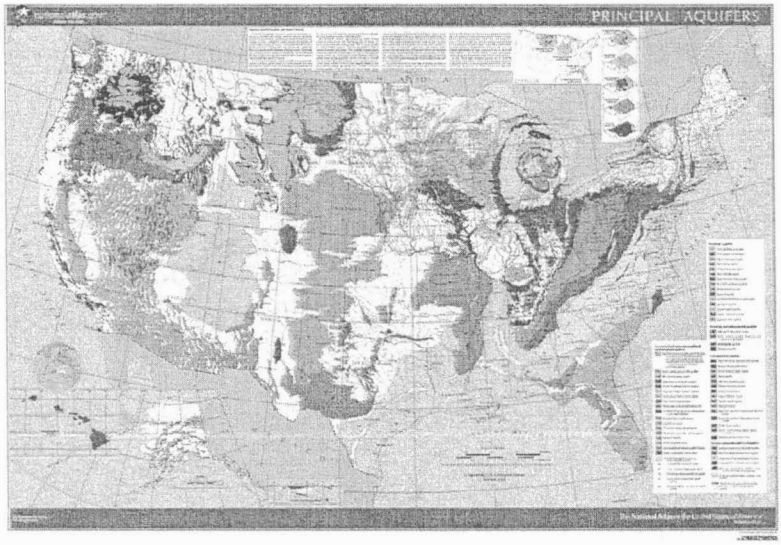
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Session 2
Water Resources & Use

Surface-water Sources



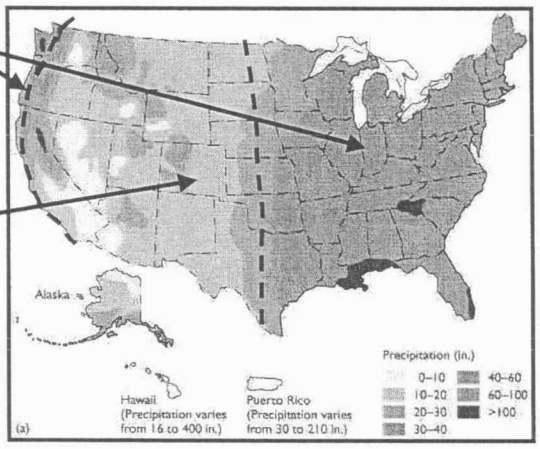
Ground-water Sources



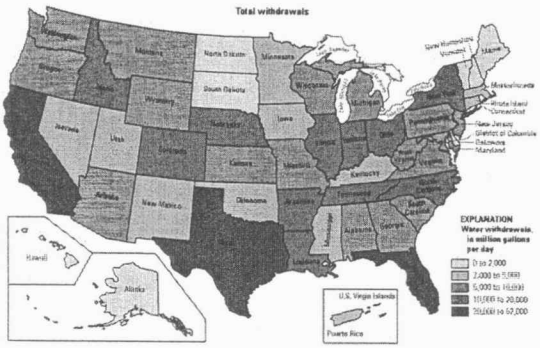
Surface Water, Ground Water or Both?

Surface- & Ground-water dependent

Ground-water dependent



US Total Fresh & Saline Water Use in 2000

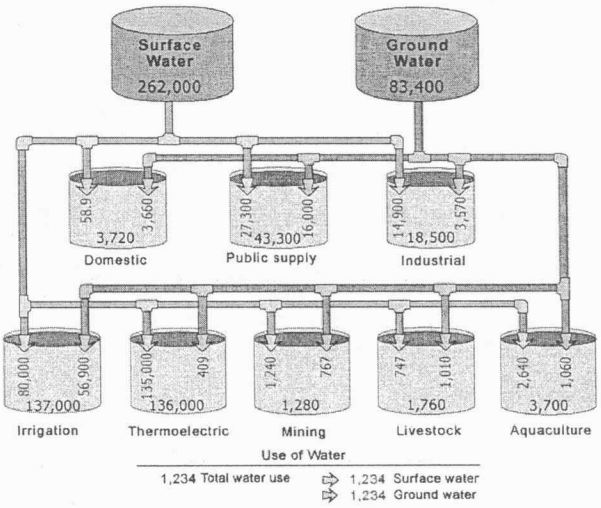


Fresh: 346 Billion gallons per day

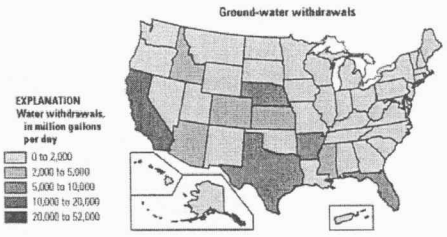
Saline: 62.3 Billion gallons per day

Total Water Use:
408 Billion gallons per day
Or about 1,430 gallons/per person per day

US Water Use by Source & Category in 2000



State by State Total Fresh & Saline Ground Water Use in 2000



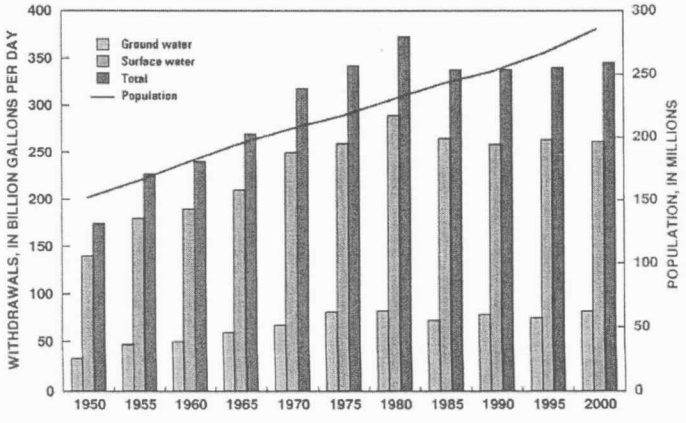
Relative Amounts of Fresh Ground-water by Intended Use:
68% Crop Irrigation
19% Public Supply
13% All Other Uses

State by State Total Fresh & Saline Surface Water Use in 2000

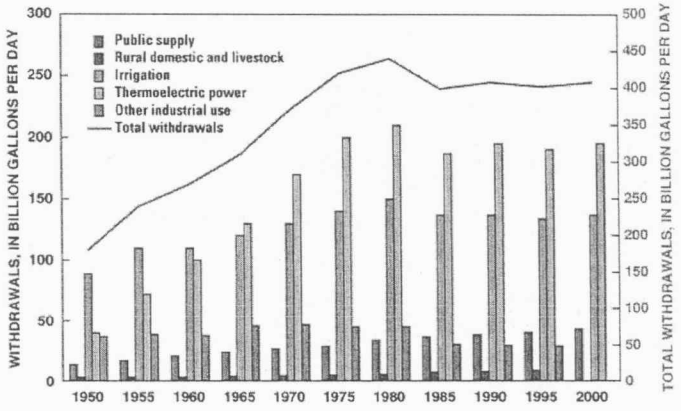


Relative Amounts of Fresh Surface-water by Intended Use:
52% Electric Power Production
31% Crop Irrigation
17% All Other Uses

Water-Use Trends in Relation to Population Growth



Water-Use Trends in Relation to Use



What Does It All Mean?

Changes in water use nationally seem to reflect:

- Technologic advances that advance water conservation
- Population shifts between regions of the country & from rural to urban areas

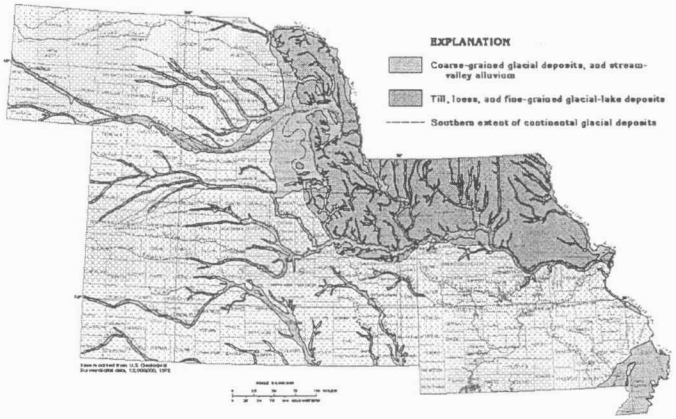
Surface Water Sources in the Central Midwest Region

(Missouri, Kansas, & Nebraska)



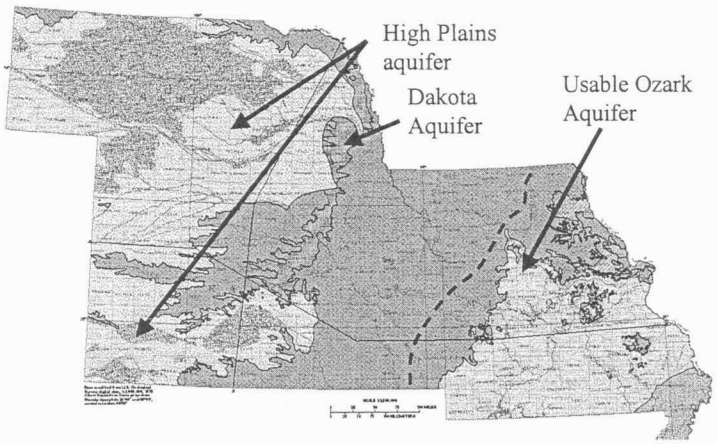
Shallow Ground Water Sources in the Central Midwest Region

(Missouri, Kansas, & Nebraska)



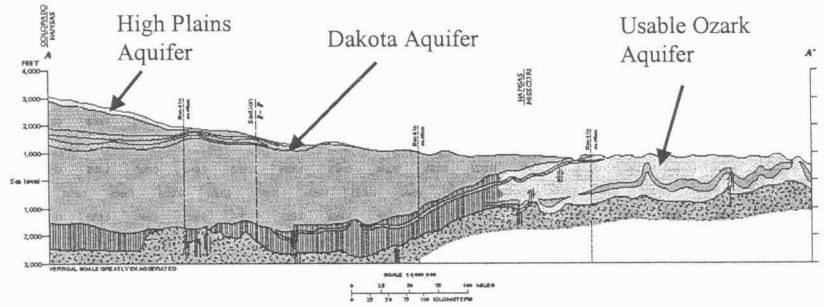
Deeper Ground Water Sources in the Central Midwest Region

(Missouri, Kansas, & Nebraska)



Shallow Ground Water Sources in the Central Midwest Region

(Missouri, Kansas, & Nebraska)



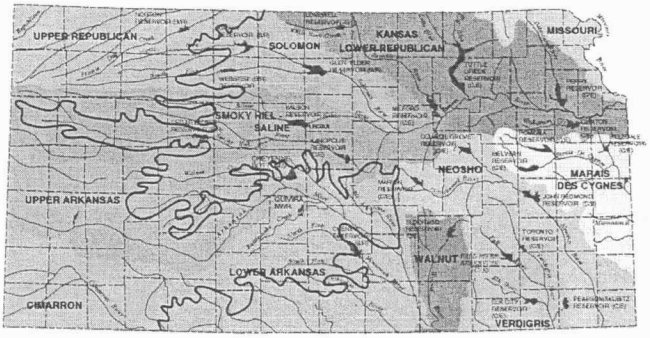
Regional Water Use in 2000
(Missouri, Kansas, & Nebraska)

State	Total Withdrawal (millions of gallons per day)	Percent Ground Water
Kansas	6,610	57
Missouri	8,230	22
Nebraska	12,300	64

Intended Water Use in 2000
(Missouri, Kansas, & Nebraska)

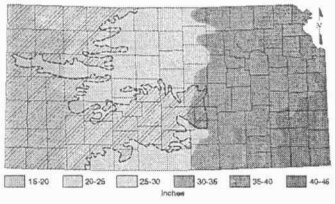
State	Total Ground-water Withdrawal (millions of gallons per day)	Percent For Crop Irrigation
Kansas	3,790	91
Missouri	1,780	78
Nebraska	7,860	94

Kansas River Basins & Reservoirs

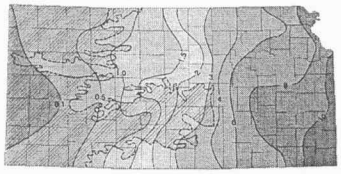


Ground- & Surface-water Use in Kansas

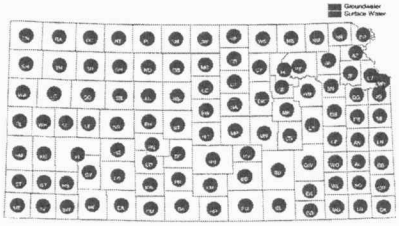
Mean Annual Precipitation



Mean Annual Runoff



Proportion of Ground- to Surface- water Rights by County



Factors influencing water-right type:

- Westward decline in precipitation & runoff
- Source type availability

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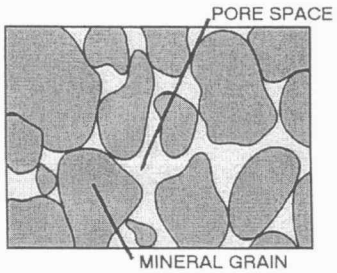
Session 3
Earth Material Hydraulic Properties

Porosity Definition

All earth materials contain void space or porosity

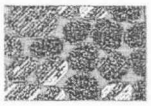
Earth Material Bulk Volume (V_T) =

Volume of the Matrix (V_M) + Volume of the Voids (V_V)



$$\text{Porosity} = \frac{V_V}{V_T} \times 100\%$$

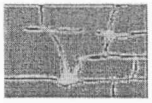
Porosity Types



Intergranular — Unconsolidated sediments & sedimentary rocks



Fracture — Igneous & metamorphic rocks



Solution — Carbonate sedimentary rocks & Marble

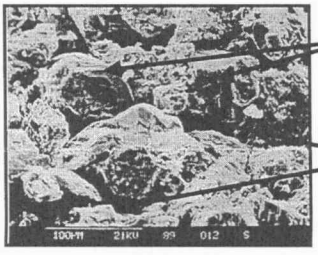
Intergranular Porosity

Factors controlling the amount:

- Grain size, shape, & roundness
- Packing of the grains
- Uniformity of the sediment grains (sorting)

] Texture

- Cementation



Intergranular Porosity
Grain Size

Sediment Type	Porosity Range (%)
Coarse Gravel	24 – 36
Fine Gravel	25 – 38
Coarse Sand	31 – 46
Fine Sand	26 – 53
Silt	34 – 61
Clay	34 – 60

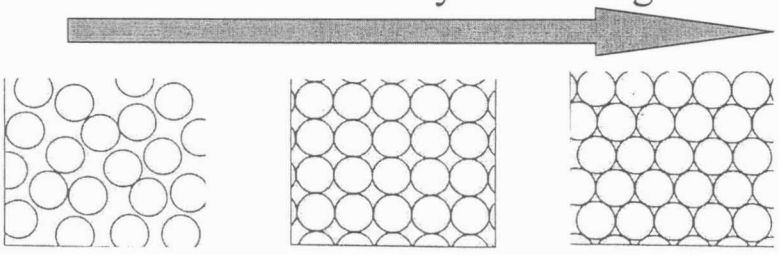
Decreasing Grain Size ↓

↑ Decreasing Porosity

From
Domenico and Schwartz (1990)

Intergranular Porosity
Grain Packing

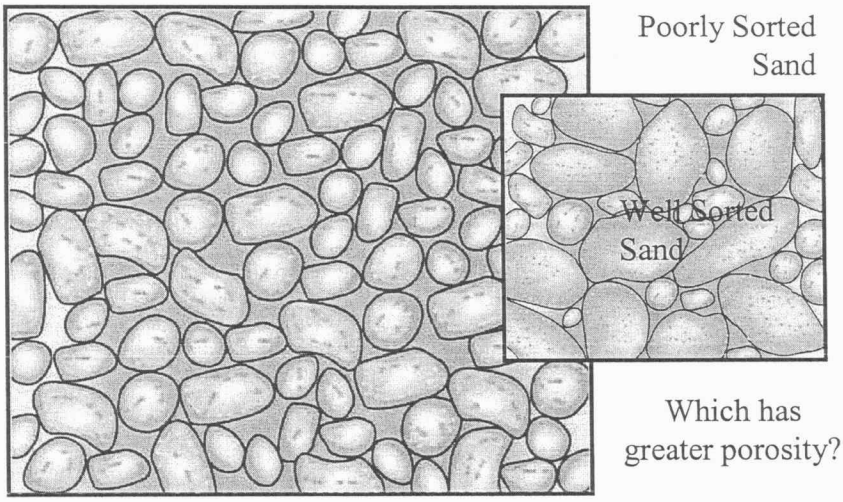
Increased Density of Packing



Increased Porosity

Intergranular Porosity

Grain Sorting



Which has greater porosity?

How Do Sediments Become Sedimentary Rocks?

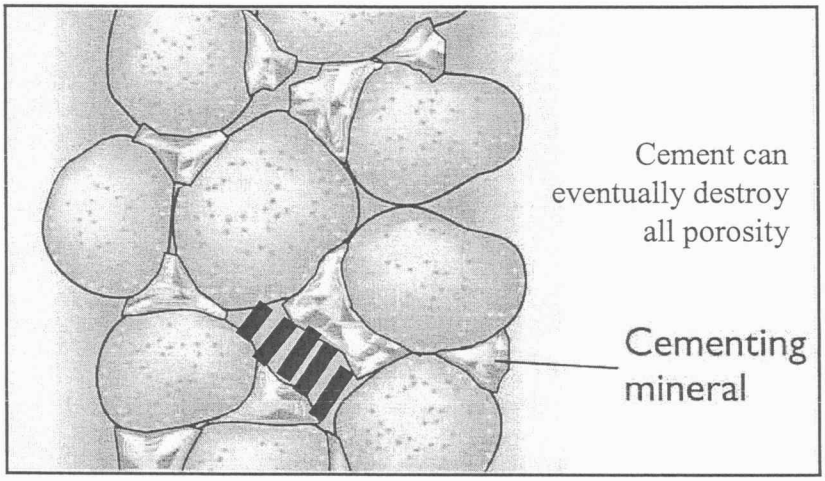
Sediment

Diagenesis
- Compaction
- Cementation
- Mineral solution
- Mineral precipitation
- Mineral transformation
- Other rock-water chemical interactions

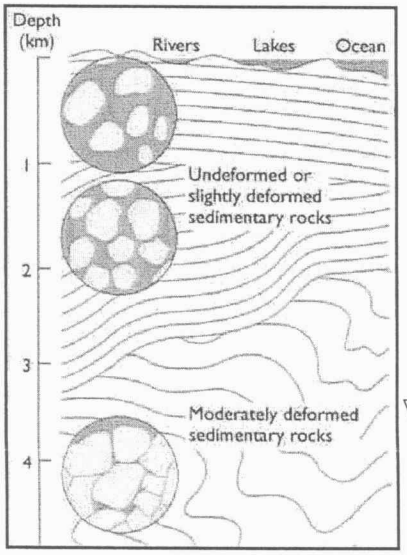
Sedimentary Rock

Intergranular Porosity

Cementation



Porosity & Burial



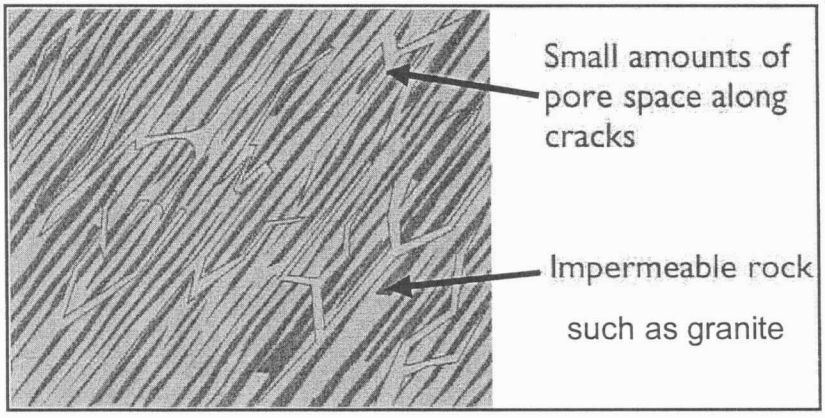


- Loose, unconsolidated sediment
- Consolidated sediment partly cemented
- Well compacted and cemented sediments

Granular Sedimentary Rock Porosity Values

Sedimentary Rock	Total Porosity Range (%)	Total Connected Porosity Range (%)
Sandstone	5 – 30	0.5 – 20
Siltstone	21 – 41	0.5 – 10
Shale	1 – 10	0.5 – 5

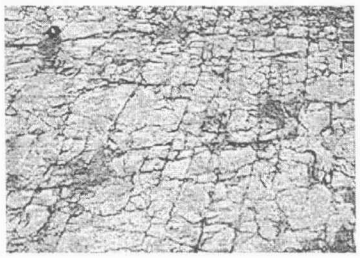
Fracture Porosity



Fracture Porosity

Factors Influencing the Amount:

- Fracture width
  - Porosity decreases with depth as fracture width decreases
- Fracture spacing or density
  - Porosity increases with decrease in spacing

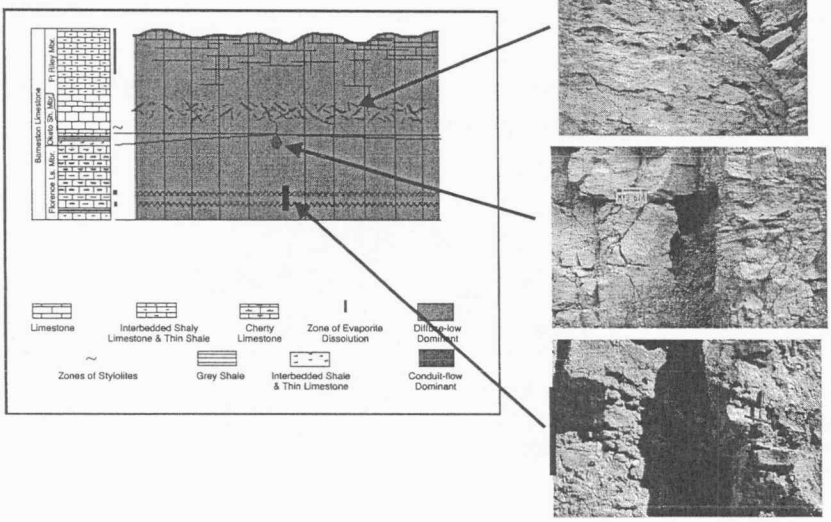


Solution Porosity (Karst)

Dominant Influences on the Amount:

- Solubility of the minerals that form the rock
  - Bedded halite and gypsum are the most soluble followed by limestone. Dolomites are the least prone to development of solution porosity.
- Dynamic ground-water flow system

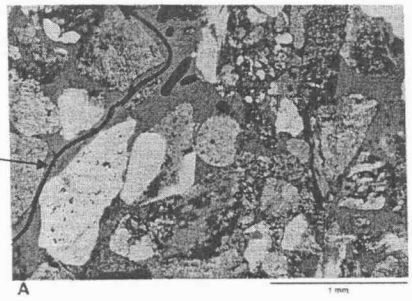
Solution Feature Size Range



Permeability Definition

The ease with which fluids pass through an earth material.

Permeability is a measure of the connectedness of the pores in the sediment or the rock



Permeability is sensitive to the:

- Tortuousity &
- Distribution of pathways through the earth material

Permeability & Hydraulic Conductivity

(Intrinsic) Permeability (k)
- An earth material property

Hydraulic Conductivity (K)
- Dependent on permeability & the properties of the moving fluid
- $K = \frac{k \rho g}{\mu}$ ρ = fluid density, μ = fluid viscosity

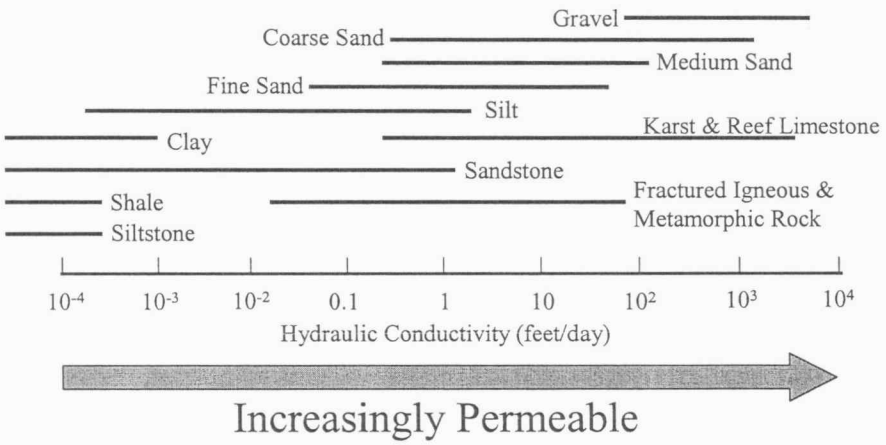
Permeability & Hydraulic Conductivity Units

Intrinsic permeability (k) units: darcies, millidarcies, or cm^2

Hydraulic conductivity (K) units: feet/day, meters/day, or centimeters/second

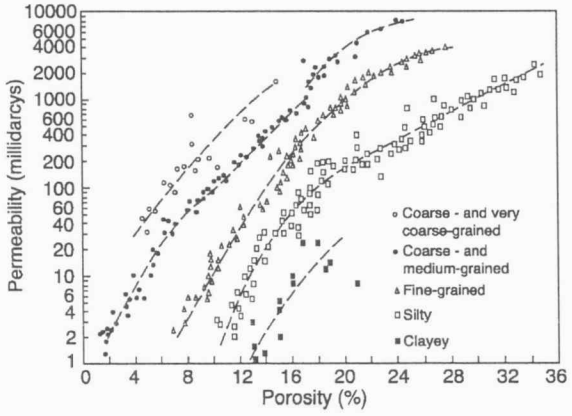
1 darcy (d) = 1,000 millidarcies (md) = 2.74 feet/day

Range of Hydraulic Conductivity Values for Earth Materials



Increasingly Permeable

Relationship of Porosity to Intrinsic Permeability in Granular Sediments



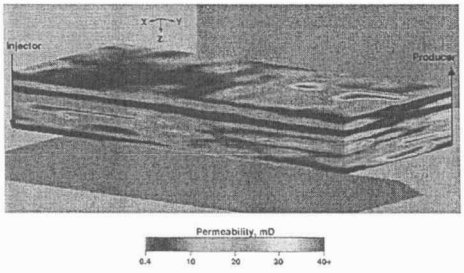
Hydraulic Properties Variability

In natural deposits of sediment or sedimentary rocks:

- The range of porosity values may exceed 10%,

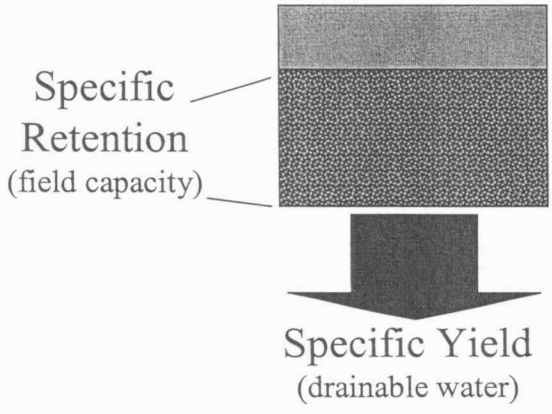
but

- The range of hydraulic conductivity (or intrinsic permeability) values may be greater than several orders of magnitude



Specific Yield & Specific Retention Definitions

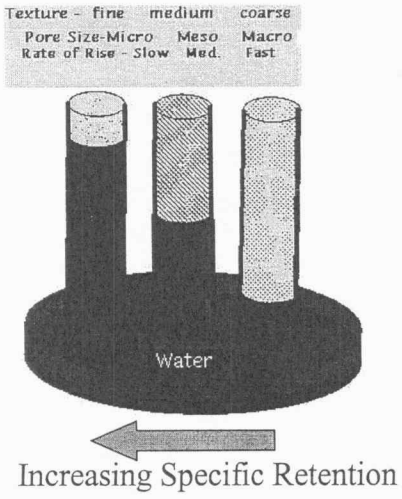
Porosity = Specific yield + Specific Retention



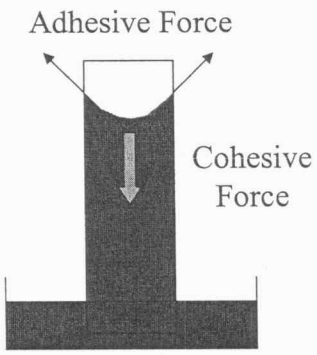
Porosity, Specific Yield, & Specific Retention Values

Earth Material	Porosity (%)	Specific Yield (%)	Specific Retention (%)
Coarse Gravel	24 – 36	23 – 36	1 – 0
Fine Gravel	25 – 38	24 – 35	1 – 3
Coarse Sand	31 – 46	28 – 45	1 – 3
Fine Sand	26 – 53	23 – 53	1 – 3
Silt	34 – 61	5 – 10	29 – 51
Clay	34 – 60	1 – 5	33 – 55

Specific Retention



Increasing Specific Retention



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Session 4
Short Review of
Basic Geology Principles & Concepts

Sedimentary Strata as Former Sediments & the Uniformatarianism Principle

- Sedimentary rocks form from the weathering and erosion of pre-existing sedimentary, metamorphic, & igneous rocks.

- The processes that form these rocks can be readily observed acting at the Earth's surface now as they did in the geologic past.

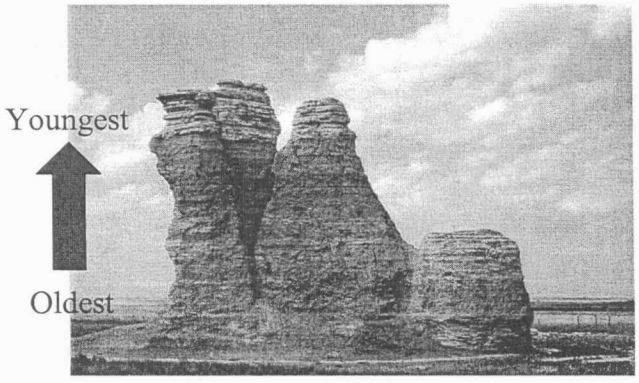
Principle of Original Horizontality

- Stratification is a layered arrangement of the particles that constitute sediment or sedimentary rock.
- The principal states that at the time of deposition, sediments are generally deposited in almost horizontal layers



The Superposition Principle

In a sequence of sedimentary rock layers, the oldest layers are at the bottom & the youngest layers are at the top.



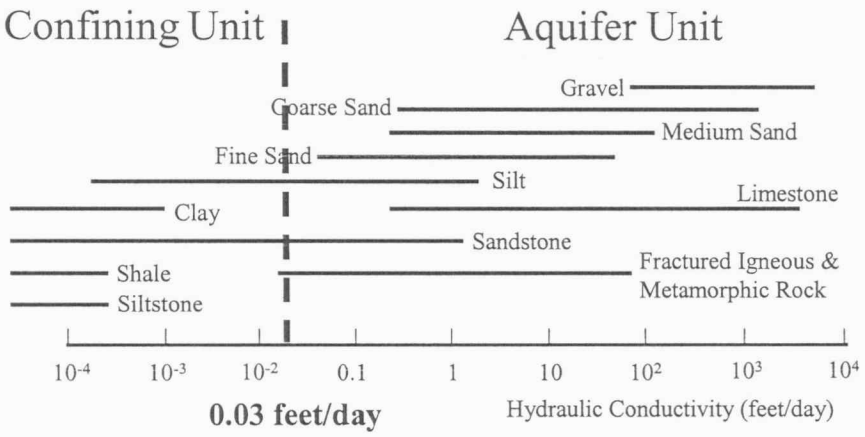
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Session 5
Aquifers & Confining Units

Aquifer & Confining Unit Definitions

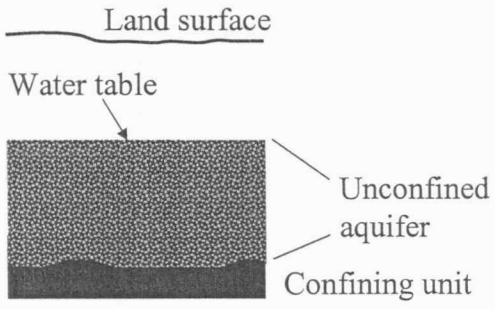
- Aquifer & confining units are defined based relative relative permeability differences.
- An aquifer unit is defined as a sequence of permeable sediment or rock units that can store and transmit water to wells at economically feasible rates.
- A confining unit is defined as a sequence of low permeability units not capable of storing or transmitting water to wells at economically feasible rates.

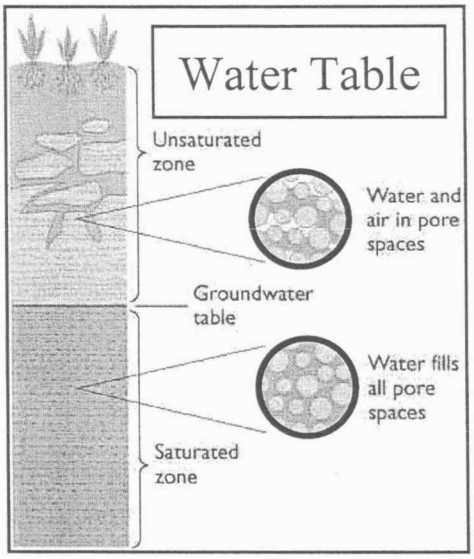
Aquifer & Confining Units



Aquifer Unit Types

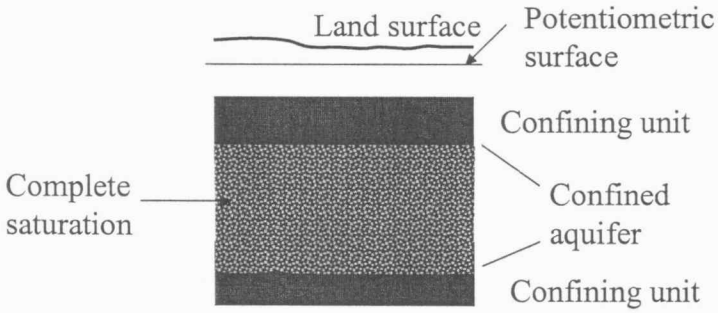
Unconfined Aquifer



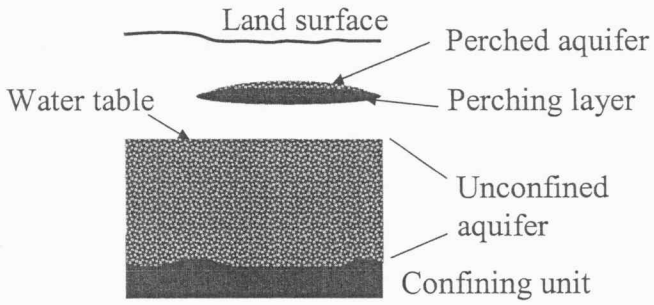


Aquifer Unit Types

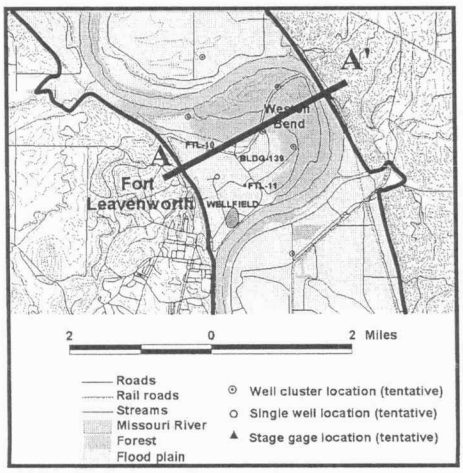
Confined Aquifer

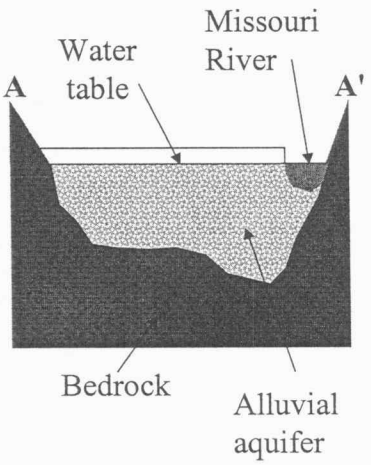


Aquifer Unit Types
Perched Aquifer



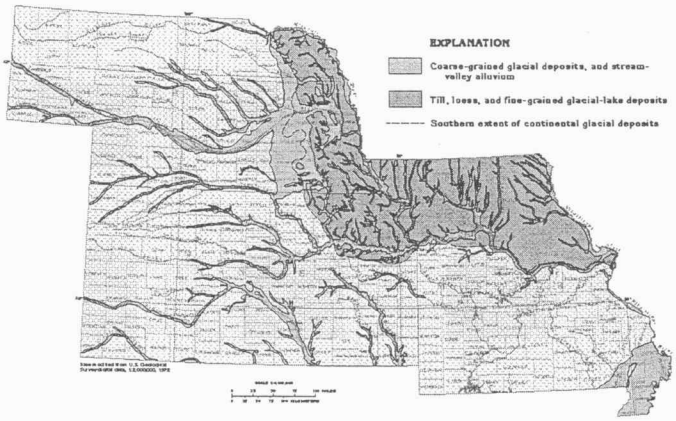
Aquifer Unit Types
Stream-Aquifer Systems





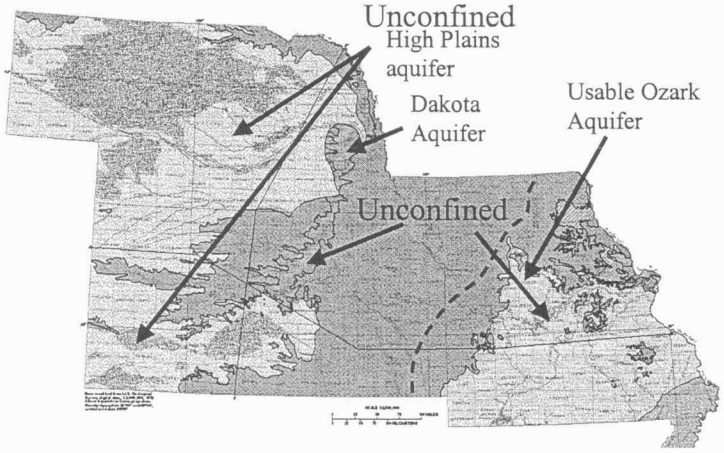
Stream-aquifer Systems in the Central Midwest Region

(Missouri, Kansas, & Nebraska)



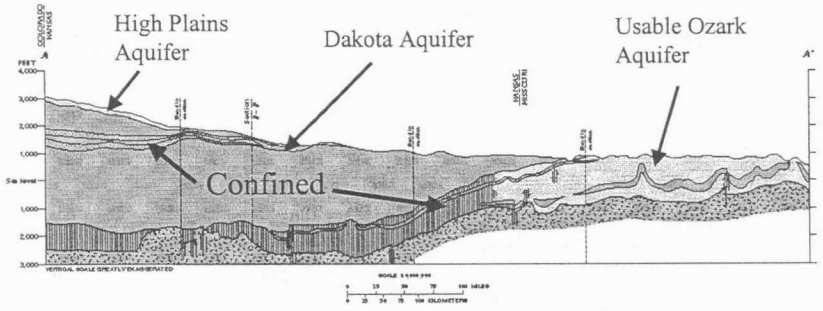
Deeper Ground Water Sources in the Central Midwest Region

(Missouri, Kansas, & Nebraska)



Shallow Ground Water Sources in the Central Midwest Region

(Missouri, Kansas, & Nebraska)

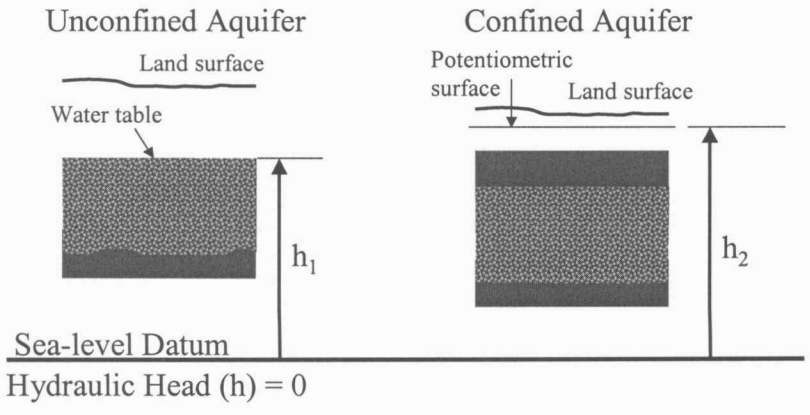


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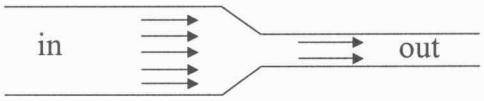
Session 6
Darcy's Law

Potential Energy & Hydraulic Head

Hydraulic head is a measure of the energy contained in the water
"Water flows downhill (and loses energy)."



Bernoulli's Law



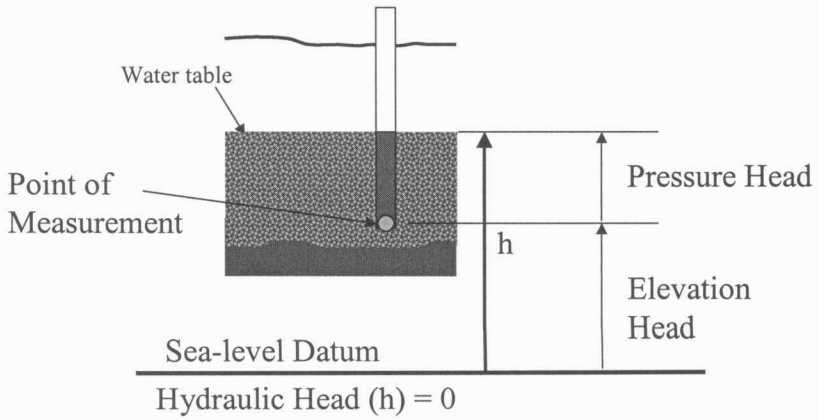
Conservation of Energy

$$E_{in} = E_{out}$$

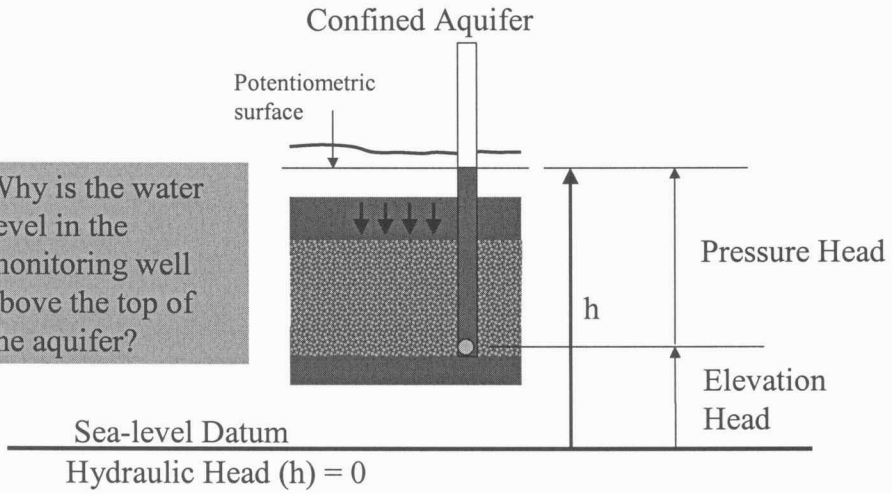
$$\text{Elevation Head}_{in} + \text{Pressure Head}_{in} + \text{Velocity Head}_{in} = \text{Elevation Head}_{out} + \text{Pressure Head}_{out} + \text{Velocity Head}_{out}$$

What is Hydraulic Head?

Unconfined Aquifer



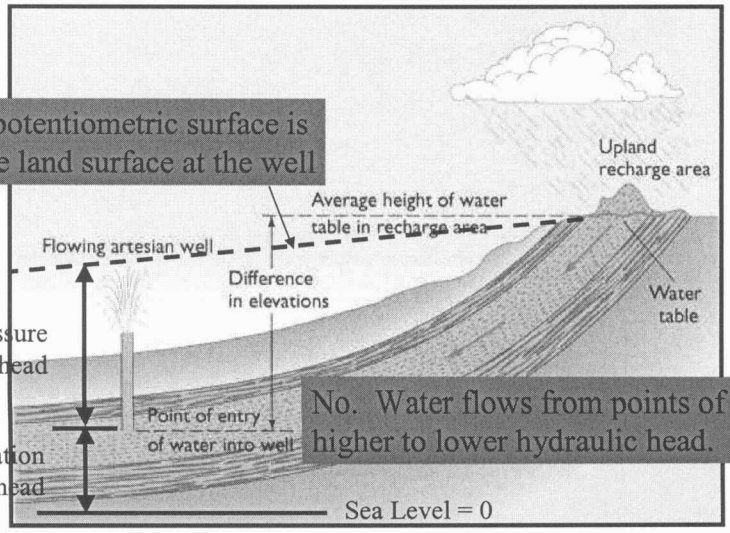
What is Hydraulic Head?



Why is the water level in the monitoring well above the top of the aquifer?

Confining Pressure

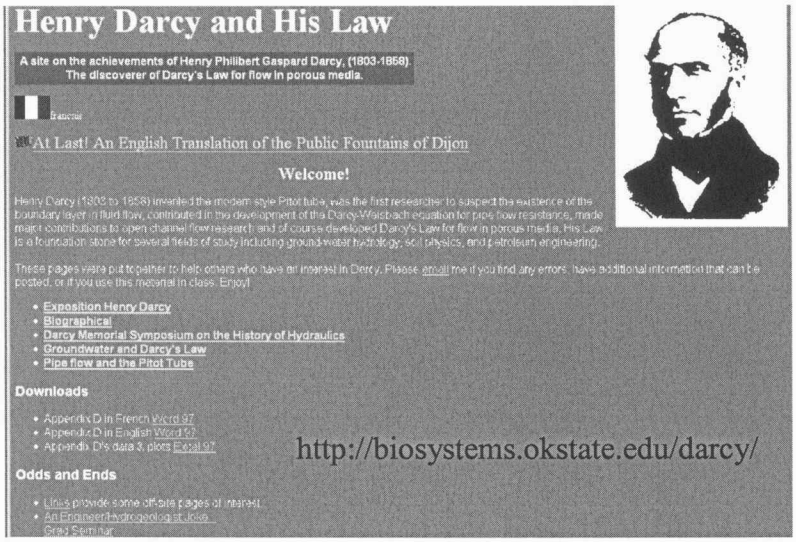
Does Water Always Flow Downhill?



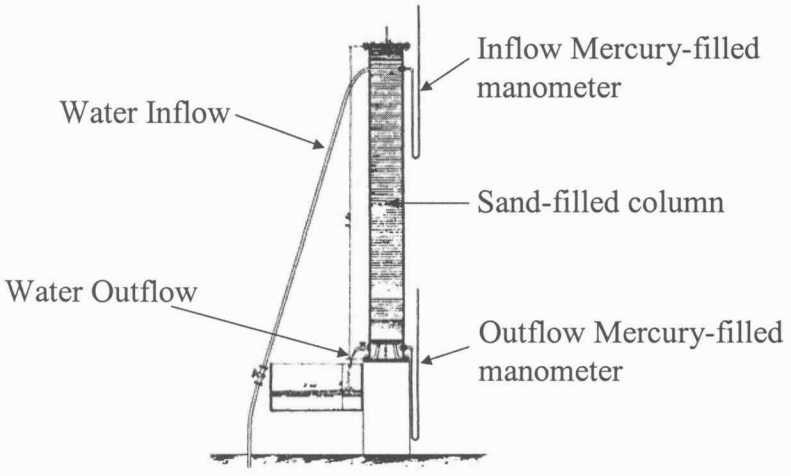
The potentiometric surface is above land surface at the well

No. Water flows from points of higher to lower hydraulic head.

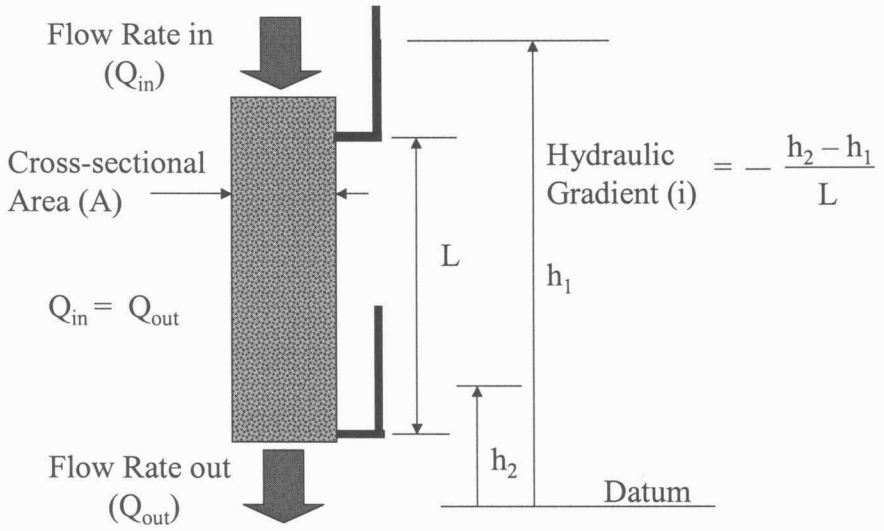
Henri Darcy's Experiment



Darcy's Experimental Apparatus



Schematic of the Apparatus & Measured Parameters



The Experiments

His objective:
To determine the relation between the volumetric flow rate of water through sand beds and the hydraulic head loss

First Experiment: The inlet pressure was varied for each experiment while holding the outlet at atmospheric pressure.
Second experiment: Both inlet and outlet pressure was varied.

A total of 35 experiments were reported and used in the final analysis.

Darcy's Experiments

Darcy concluded that:

The flow rate (Q) is proportional to the
- Hydraulic head difference ($h_2 - h_1$)
- Cross-sectional area (A) &

Inversely proportional to the
- Length (L)

$$Q \propto -A(h_2 - h_1)/L$$

$$Q = (-)Kai$$

where K is hydraulic conductivity

Darcy's Law

$$Q = (-)KAi$$

Specific Discharge (q) = Q/A

Then: $q = (-)Ki$

The minus sign tells us that the flow is in the direction opposite to that of the hydraulic gradient.

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Session 7
Mapping Ground-water Flow Direction

What is the Goal in Mapping?

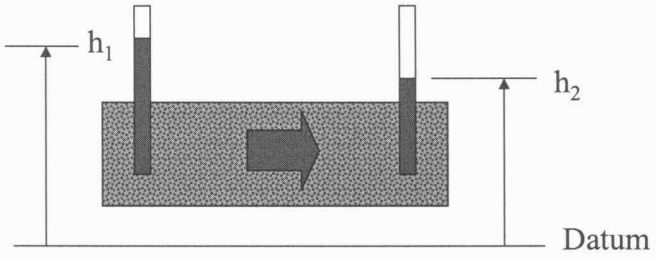
Ground water is always in motion

To determine the variation in ground-water flow direction and rate of movement.

- Define flow paths & flow systems
- Estimate rates of movement & residence time

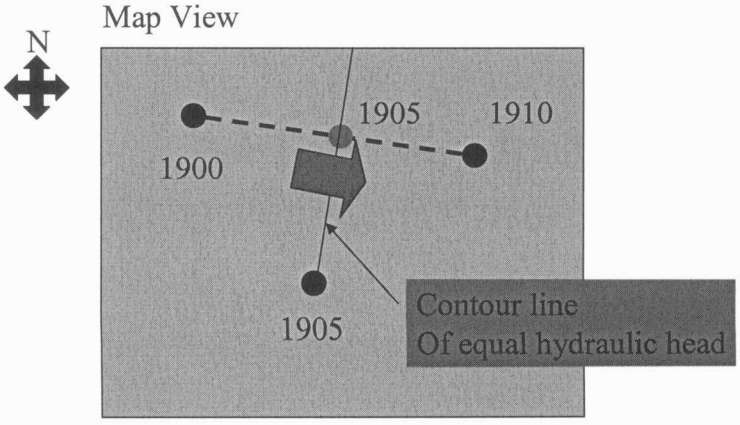
Determining Ground-water Flow Direction

One Dimension



Determining Ground-water Flow Direction

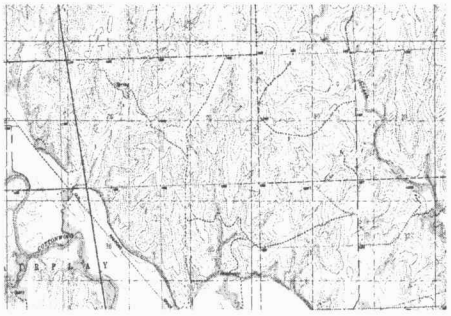
Two Dimensions



Contour Maps

Used to show the variation in a property, parameter, or characteristic in previously defined two dimensional region

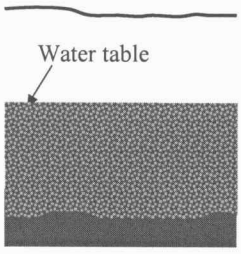
• Topogaphic maps – used to show variation in elevation above sea level

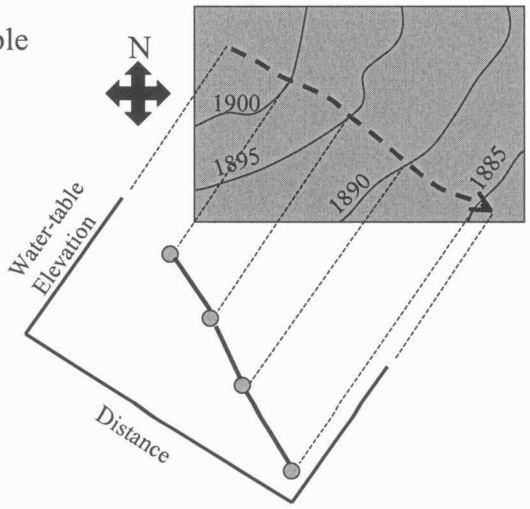


Maps of Hydraulic Head

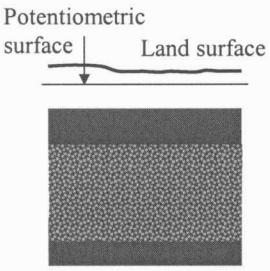
Unconfined Aquifer

Elevation of the water table above sea level



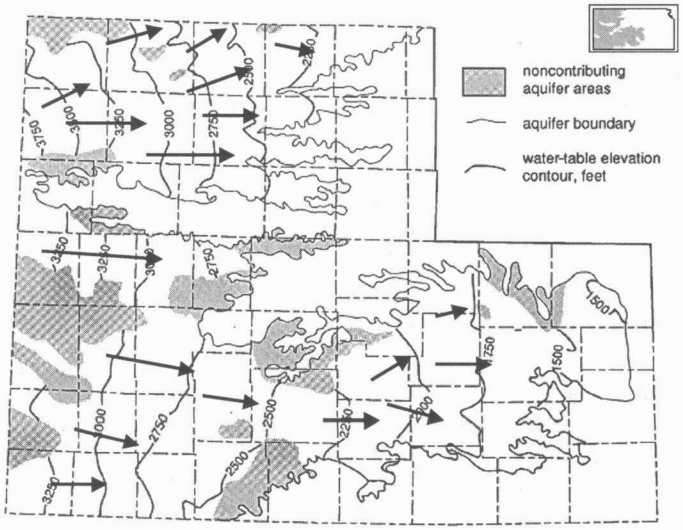


Maps of Hydraulic Head
Confined Aquifer

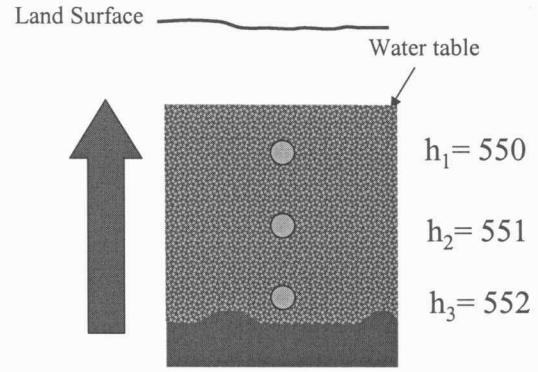


Elevation of the potentiometric surface above sea level

Example: High Plains Aquifer

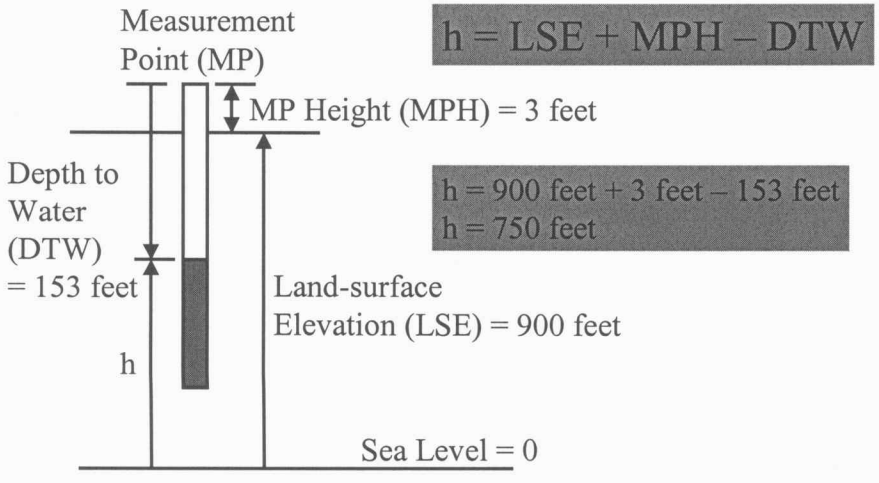


Mapping Vertical Ground-water Flow

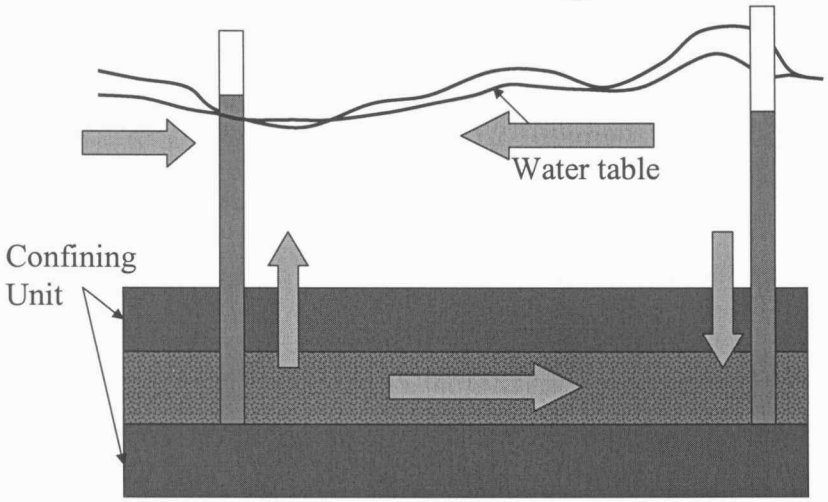


Is the ground-water flow direction upward or downward?

How do We Measure Hydraulic Head?



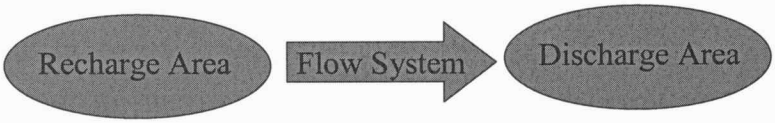
In Which Direction(s) Is Ground-water Flowing?



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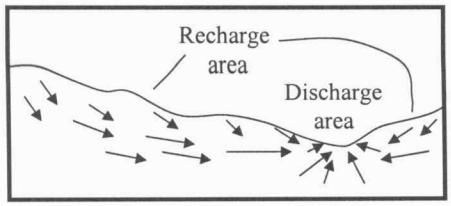
Session 8
The Ground-water Flow System
& Flow System Hierarchy

Anatomy of a Ground-water Flow System

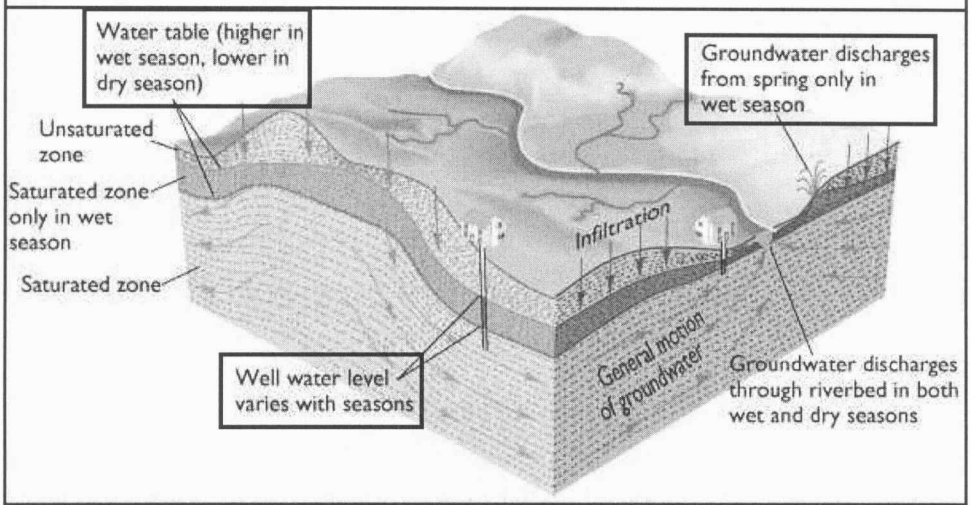


- Upland areas
- Deeper water table
- Higher hydraulic head

- Lowland areas
- Very shallow water table
- Lower hydraulic head



Water Table Characteristics



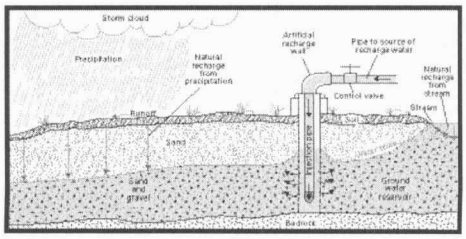
Recharge

Natural

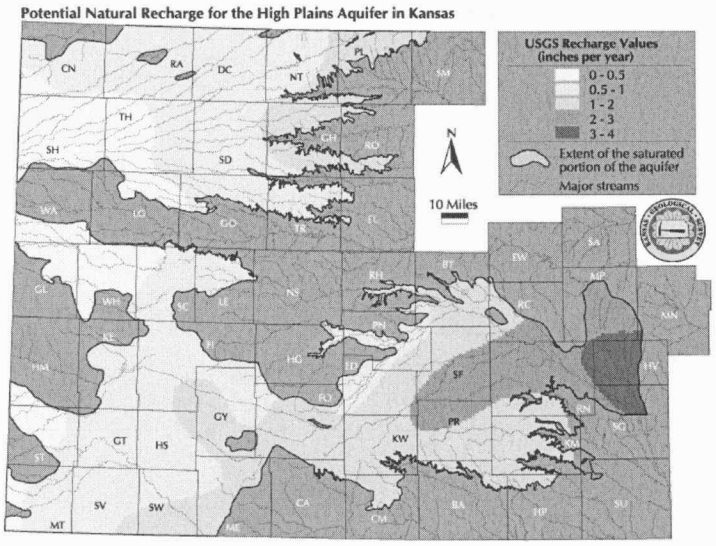
- Precipitation
- Melting snow
- Infiltration by streams and lakes

Artificial

- Recharge wells
- Spread water over land in pits, furrows, ditches, or erect small dams in stream channels to detain and deflect water



Potential Natural Recharge in the Kansas High Plains



Ground-surface Water Interactions

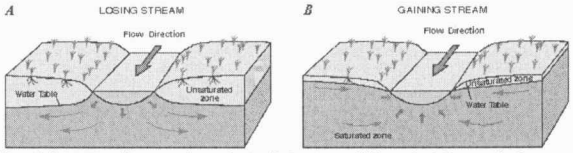
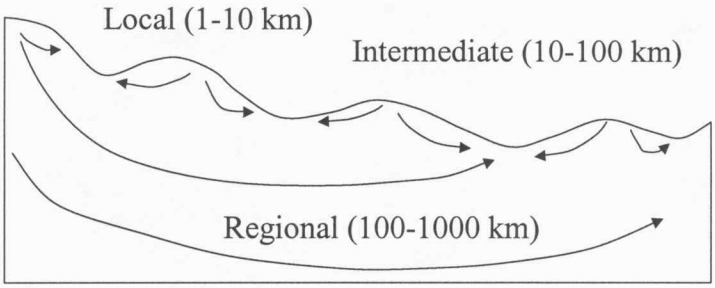
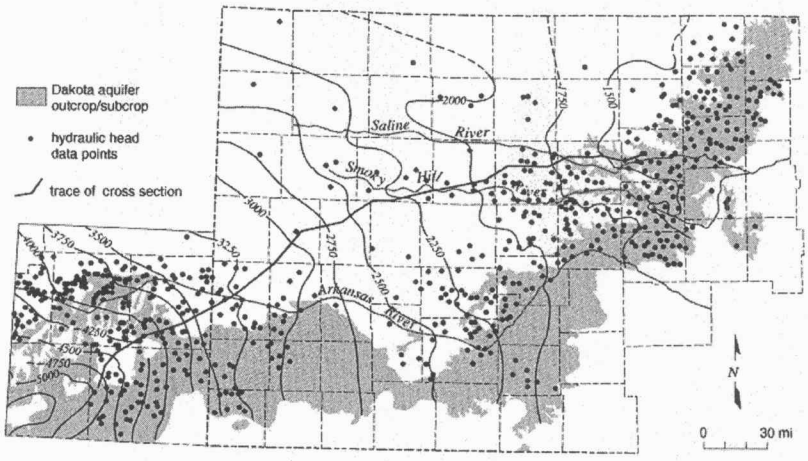


Figure 6. Interaction of streams and groundwater. Losing streams (A) lose water to the groundwater system, whereas gaining streams (B) receive water from the groundwater system (adapted from Winter et. al., USGS Circular 1139, 1998)

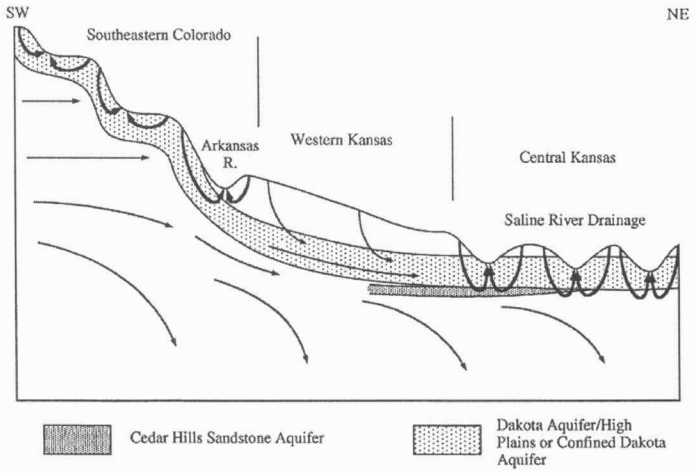
Ground-water Flow System Hierarchies



Dakota Aquifer Example

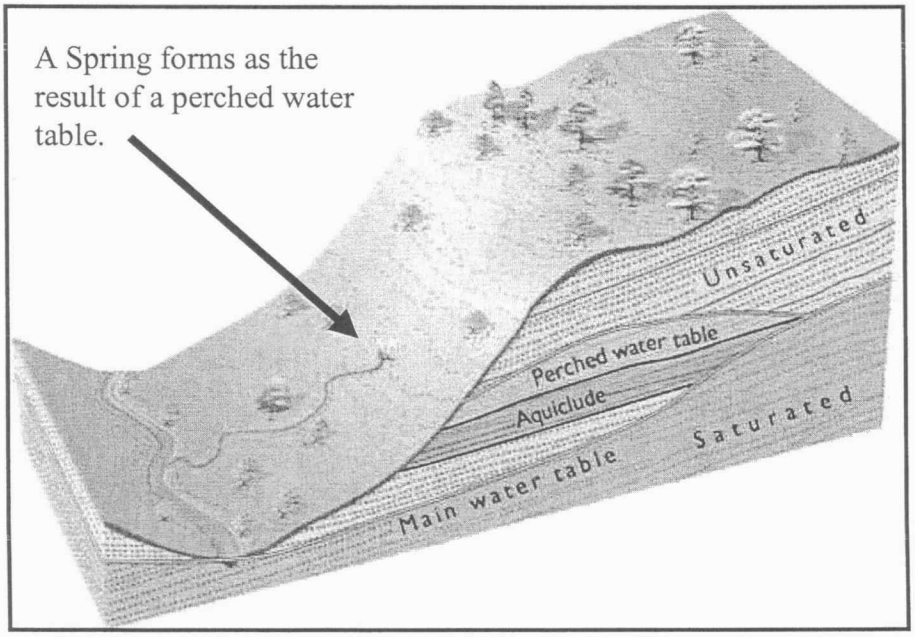


Dakota Aquifer Example



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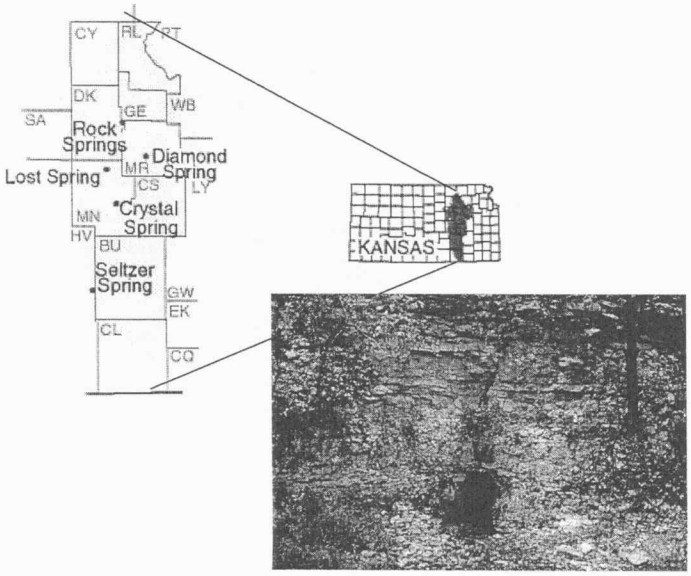
Session 10
Surface Manifestations of Ground-water Flow



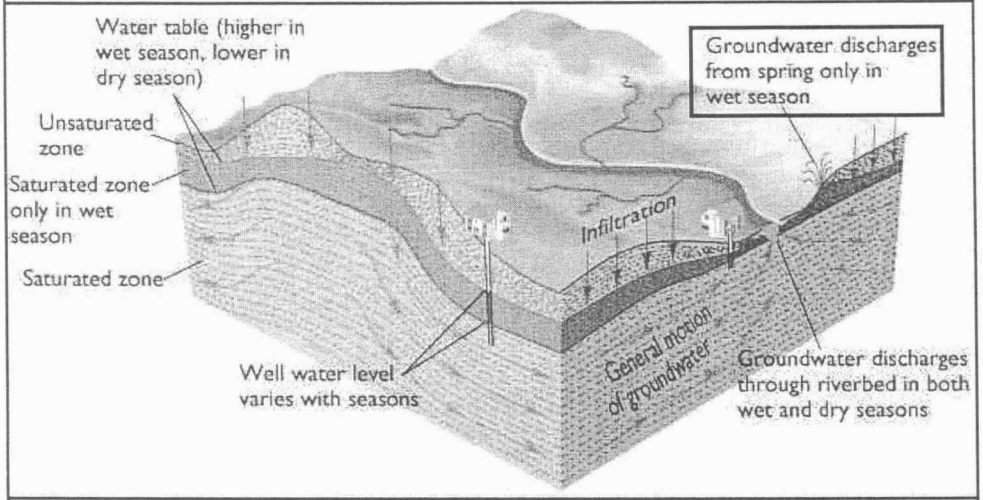


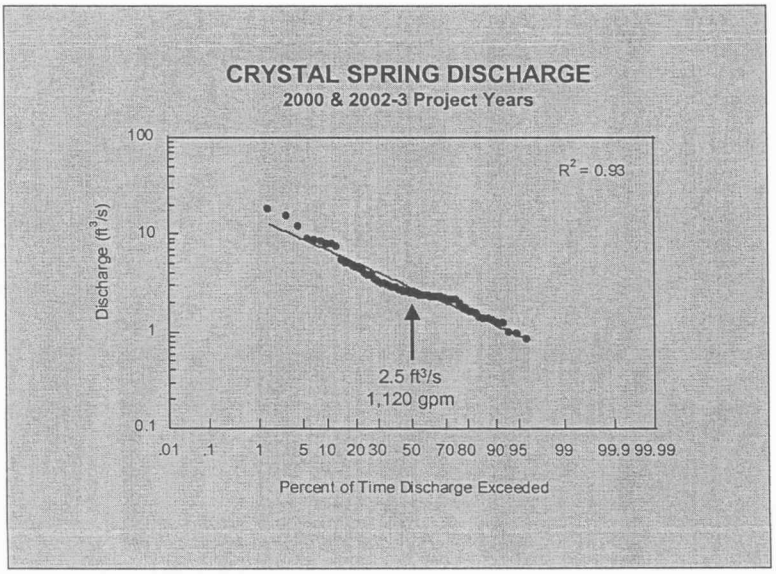
Springs often occur when groundwater is forced to the surface by a confining layer.

Flint Hills Springs



Water Table Characteristics





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Session 11
The Ground- and Surface-water Interactions

Ground-surface Water Interactions

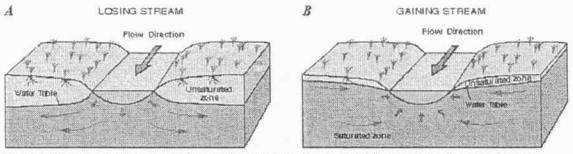
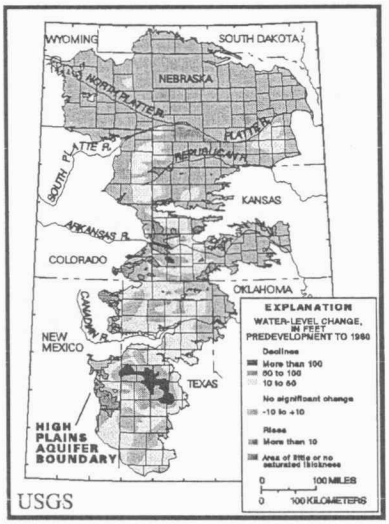
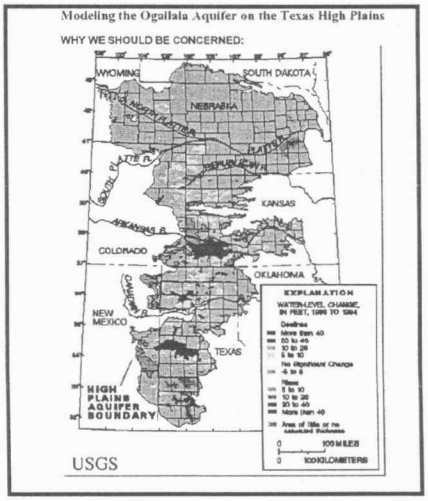


Figure 6. Interaction of streams and groundwater. Losing streams (A) lose water to the groundwater system, whereas gaining streams (B) receive water from the groundwater system (adapted from Winter et. al., USGS Circular 1139, 1998)

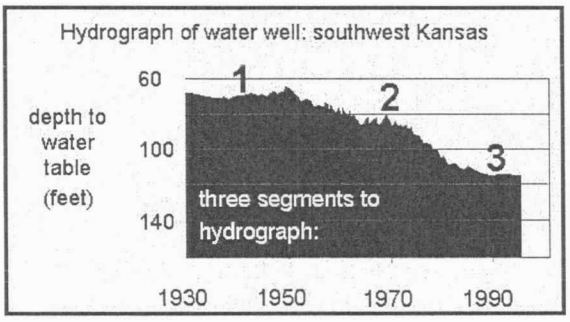
Water Level Change from Predevelopment to 1980



Water Level Change from 1980 to 1994



Sample Hydrograph



Major Perennial Streams in Kansas in 1961 & 1994

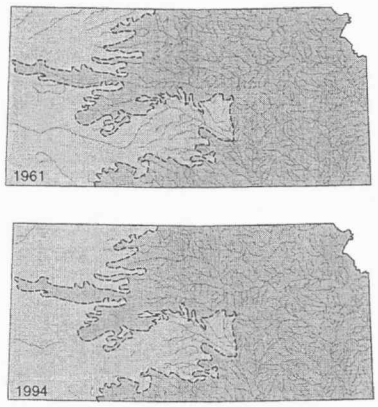


Figure 7. Major perennial streams in Kansas in 1961 and 1994. The area west of the dashed line shows the extent of the High Plains aquifer in Kansas (adapted from Angelo, 1994).

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Session 12
Well Construction

Water Well Purpose

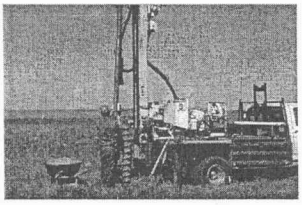
- Water supply
- Monitoring
- Contaminant removal
- Heating/cooling
- Dewatering
- Underground injection

Steps in Well Construction

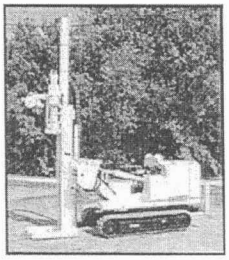
- Determine ground-water availability
- Conduct test drilling to locate local sources of ground water
- Drill the borehole for the well
- Construct & install the well casing/screen
- Develop the well
- Test pump the well to determine yield/ collect water samples for analysis
- Install the pump, electrical lines, & above-ground plumbing

Drilling

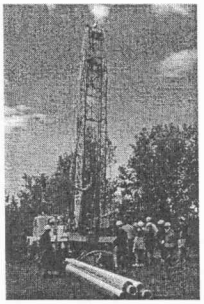
Auger



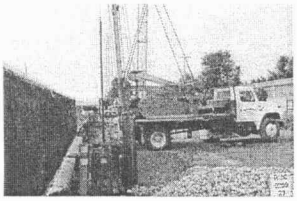
Geoprobe



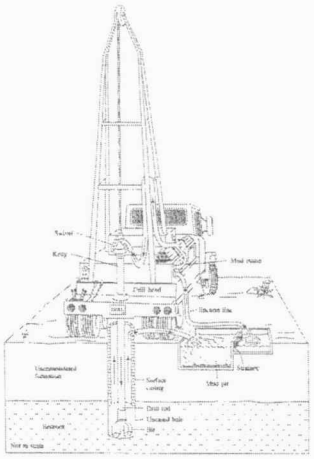
Mud/Air Rotary



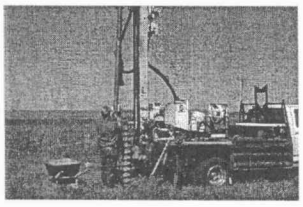
Cable-tool

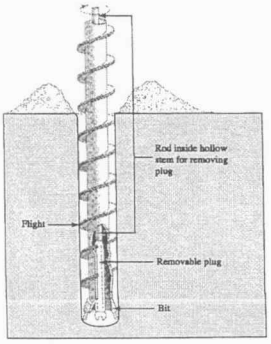


Rotary Drilling

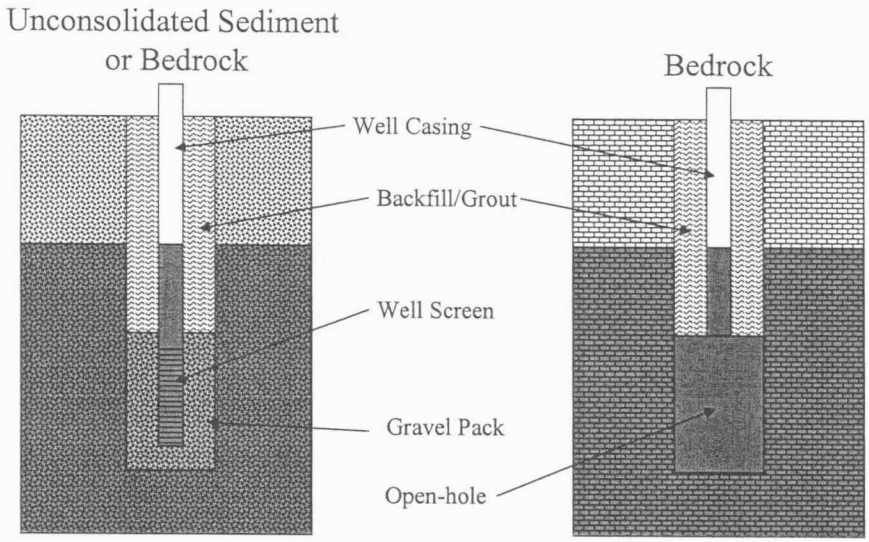


Drilling With a Hollow-stem Auger





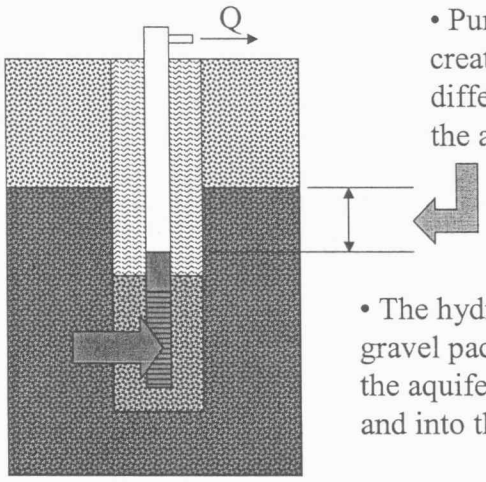
Well Construction



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Session 13
Effects of Well Pumping & Fluid Injection

How Does a Well Continue to Produce Water?

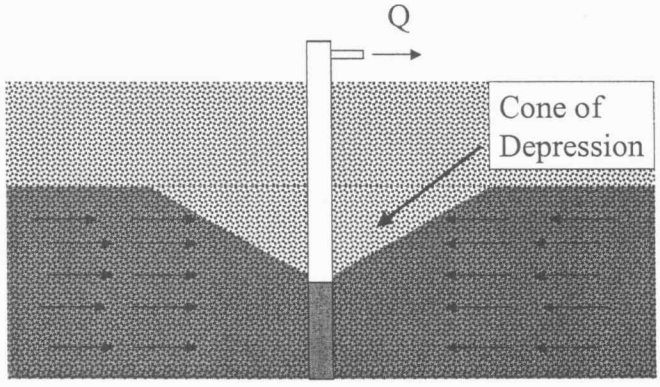


- Pumping water from the casing creates a hydraulic-head difference between the well and the aquifer.

- The hydraulic gradient across the gravel pack causes water to flow from the aquifer, through the well screen, and into the casing.

What Happens When the Pump is Turned on?

Flat Water table

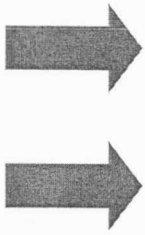


Why does the cone of depression continue to grow in size?

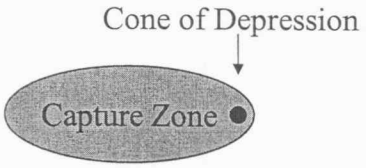
What Happens When the Pump is Turned on?

Sloping Water table

Map View

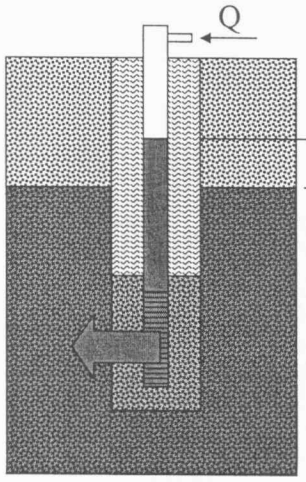


Ground-water Flow



Pumping well

What Happens When Water is Injected into an Aquifer?

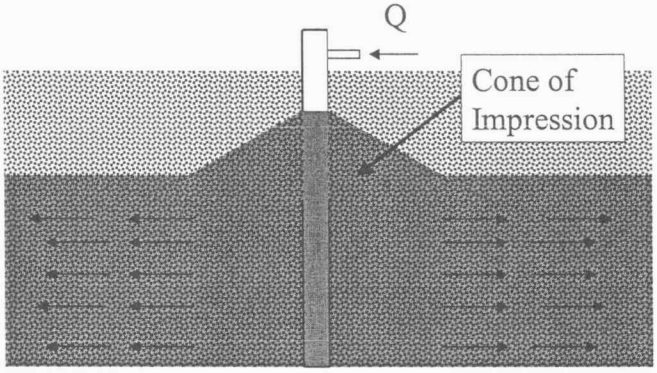


- Injecting (adding) water into the casing creates a hydraulic-head difference between the well and the aquifer.

- The hydraulic gradient across the gravel pack causes water to flow from the well casing, through the well screen and gravel pack and into the aquifer.

What Happens When Fluid is Added Using an Injection Well?

Flat Water Table



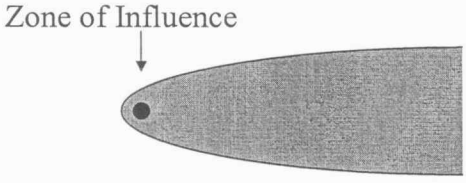
What Happens When Fluid is Added Using an Injection Well?

Sloping Water table

Map View

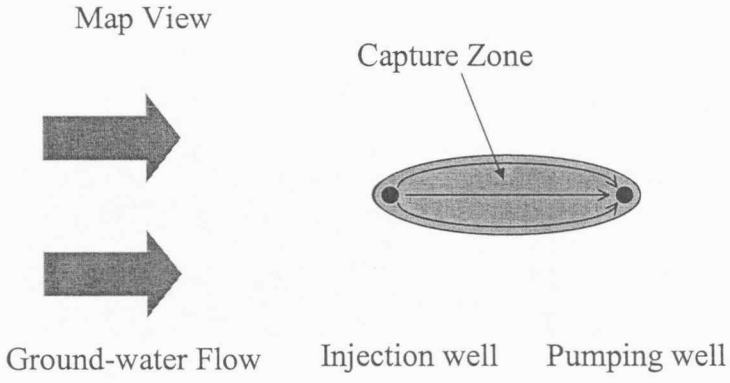


Ground-water Flow

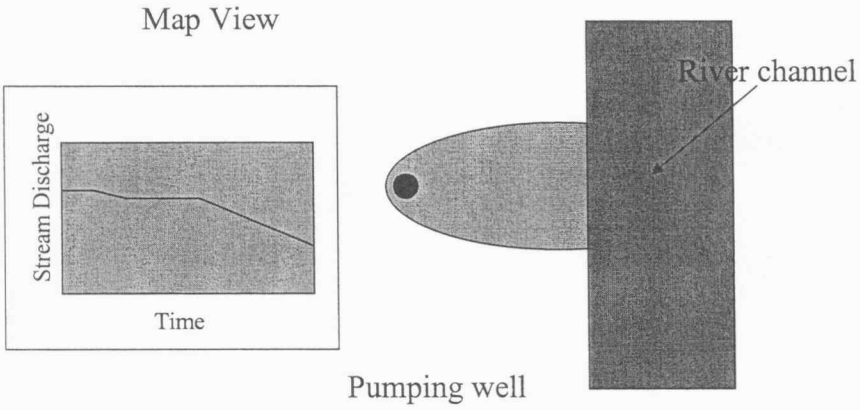


Injection well

What Happens with a Pumping & Injection Well Couplet?



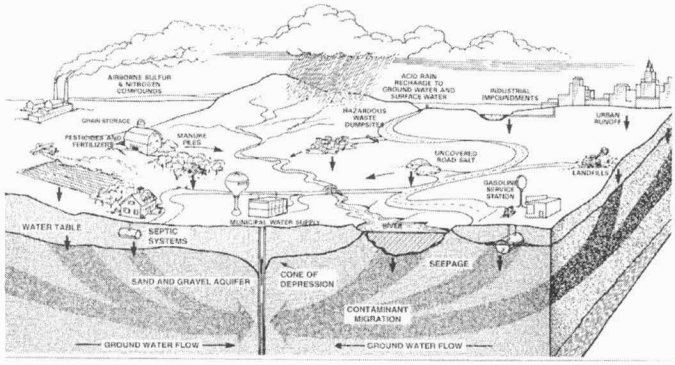
Well Pumping In a Stream-Aquifer System



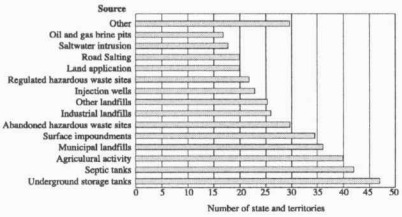
The Summer 2004 Ground-water Workshop For Secondary Science Teachers

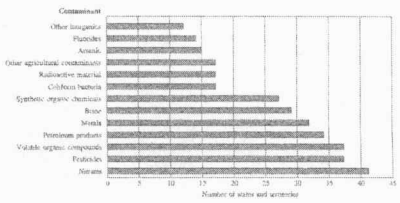
Session 14
Ground-water Contamination

Sources of Contamination



Sources & Types of Contamination



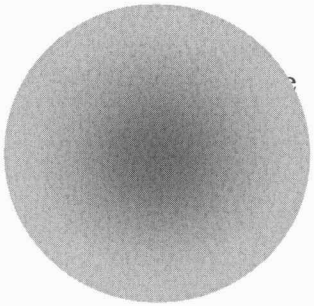


Transport of Contaminants Through Ground-water Systems

- Diffusion
- Advection
- Dispersion

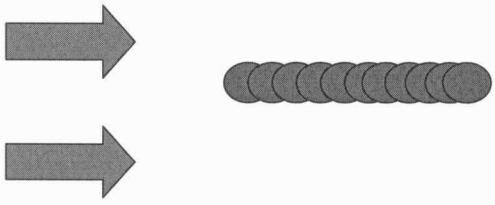
Diffusion

Transport by molecular motion causing a spreading of the solute in a solution with no fluid motion.



Advection

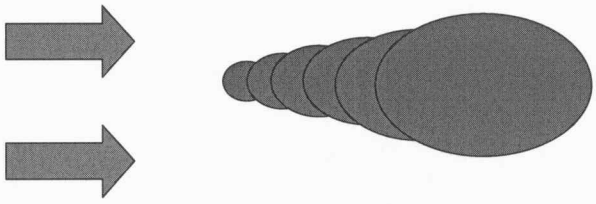
Solutes move with the ground-water flow



Ground-water
Flow Direction

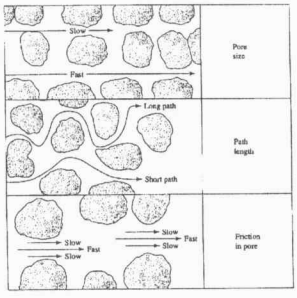
Dispersion

A spreading out of the contaminant in a moving ground-water system.



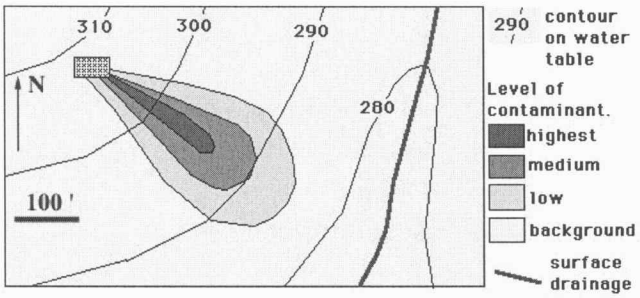
Ground-water
Flow Direction

Causes of Mechanical Dispersion



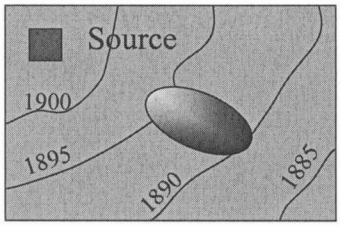
A Contaminant Plume

Results from a continuous release of the contaminant into the ground-water system.



A Contaminant Slug

Results from a contaminant release over a finite period of time.



Waste Disposal Practices

Regulated

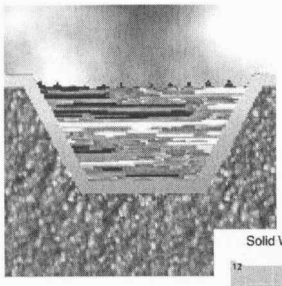
- Municipal landfills
- Hazardous waste disposal facilities
- Underground injection wells
- Irrigation
- Composting

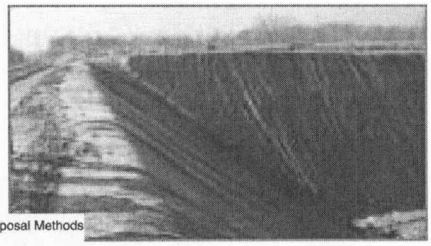
Land Application

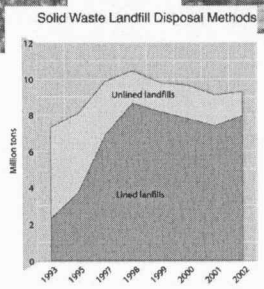
Unregulated

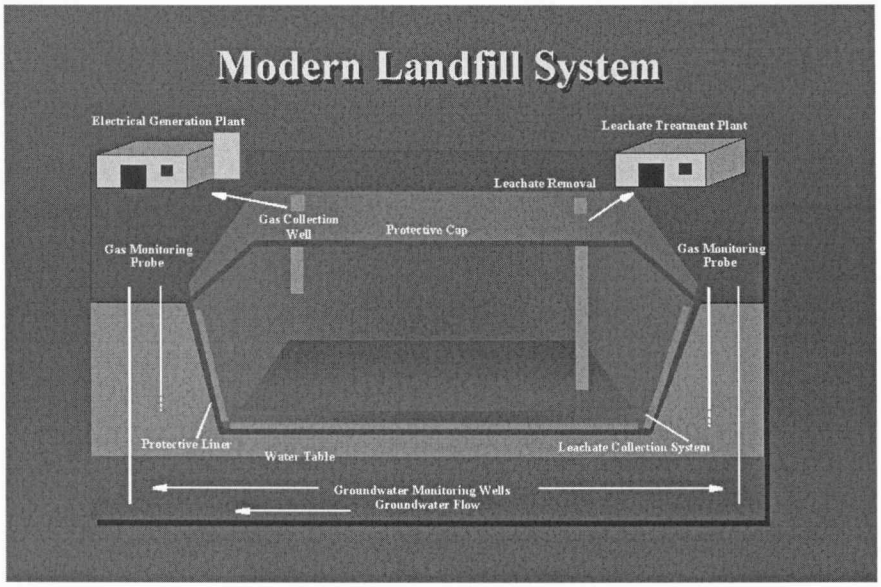
- Dumps
- Septic systems

Liner Systems

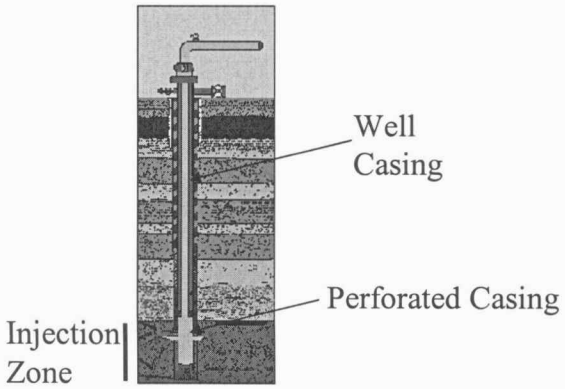




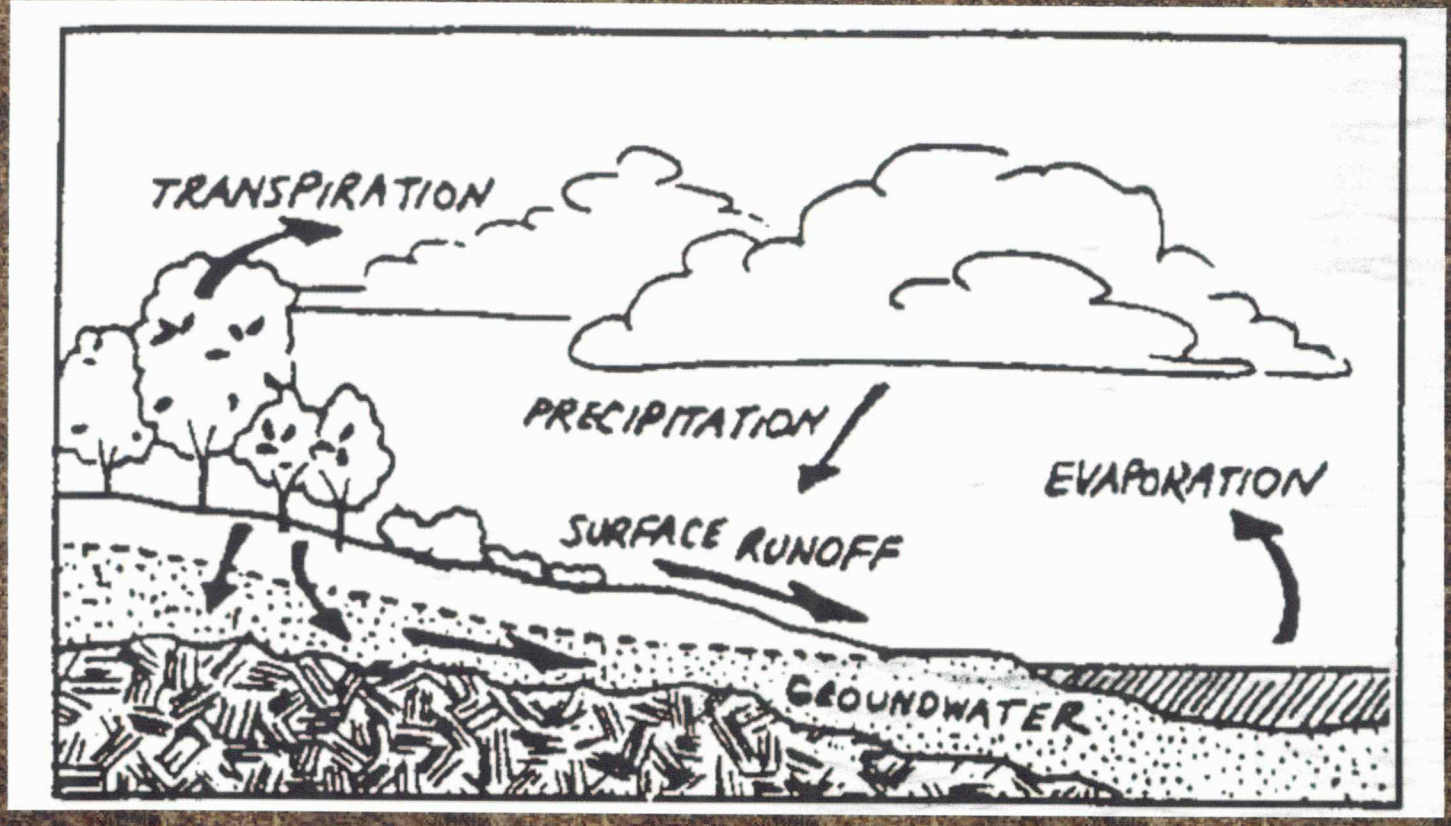




Construction of a Typical Underground Injection Well



Clear as Mud: Whose Water is it Anyway?



Alison L. Reber, Kaw Valley Heritage Alliance

July 2004





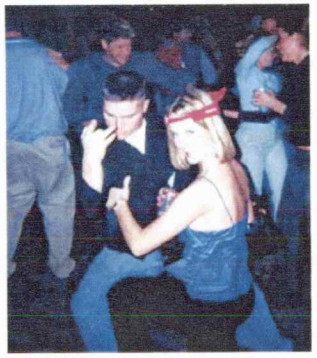














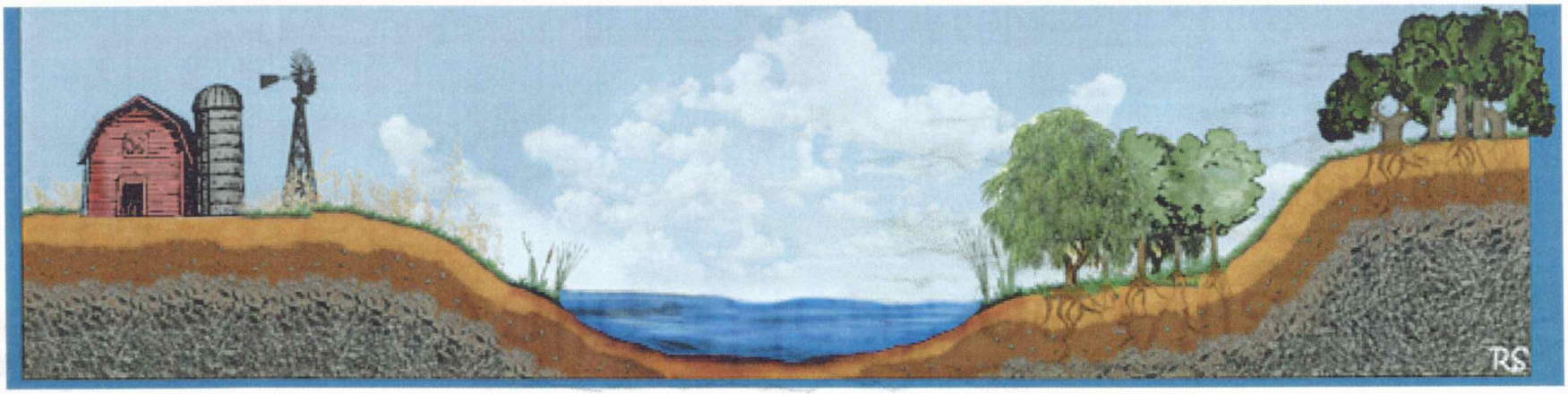

Varsity





Kansas StreamLink is a program of the Kaw Valley Heritage Alliance, a 501(c)3 nonprofit organization.

Kansas StreamLink is funded in part by grants from the Environmental Protection Agency Region 7, Kansas Department of Health and Environment, and Kansas Department of Wildlife and Parks. Additional funding is provided through donations from individual team sponsors.



Kaw Valley Heritage Alliance

- The people of the Kaw Valley will maintain a strong sense of place and community.
- The Valley will be a land of farms and families, of neighborhoods, towns and cities.
- It will be a place where industry and business thrive; where natural and historical places are preserved; and where clean, healthy rivers and streams support aquatic life and offer recreational opportunities.
- People will build consensus for resource conservation and will promote responsible use of air, water, and land, while supporting a healthy economy.



Quantity Vs. Quality



Photo by Lawrence Journal-World July 13, 1951

Systems of Governance

Riparian Doctrine Landowner Owns Land & Water

****

Prior Appropriations

Landowner Owns Land; State Owns Most of the Water



Kansas is a
"Prior Appropriations" state.

Water Rights are held by the
Kansas Water Office
and enforced by the
Kansas Dept. of Agriculture.

Water Users, Usage, and Use Classification

The Kansas Water Authority manages the state's water resources to ensure that water right holders are able to procure their full allocations.

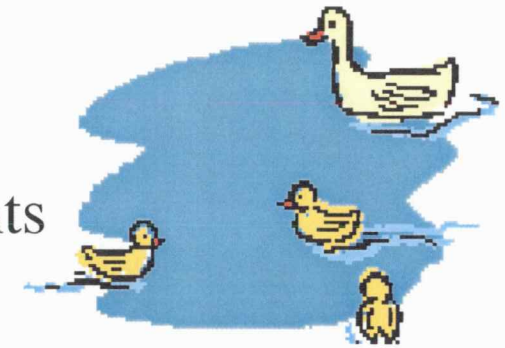
Water Right = the legal right to use a certain number of acre/feet of water for a specific use category

- First in Time, First in Line….

  Vested Rights, Water Right #s

- Consumptive vs Non-Consumptive Rights

- Fully Allocated



The National Environmental Policy Act 1969

Created a National Policy for the Environment and established the Council on Environmental Quality.

 Each Generation is trustee of the environment for succeeding generations.

 All Americans should have safe, healthful, productive, and aesthetically & culturally pleasing surroundings.

 We will attain the widest range of beneficial uses of the environment without degradation, risk to health or safety, or other undesirable and unintended consequences.

 We will preserve important historic, cultural, and natural aspects of our national heritage, and maintain, wherever possible, an environment which supports diversity, and variety of individual choice.

 We will achieve a balance between population and resource use which will permit high standards of living and a wide sharing of life's amenities.

 We will enhance the quality of renewable resources and approach the maximum attainable recycling of depletable resources.

The congress recognizes that each person should enjoy a healthful environment and that each person has a responsibility to contribute to the preservation and enhancement of the environment.

Federal water legislation dates back to the nineteenth century when Congress enacted the River and Harbor Act of 1886, recodified in the Rivers and Harbors Act of 1899.

Federal Water Pollution Control Act 1972
Clean Water Act 1977


Established the basic structure for regulating discharges of pollutants into the waters of the United States.


Gave EPA the authority to implement pollution control programs such as setting wastewater standards for industry.


Continued requirements to set water quality standards for all contaminants in surface waters.


Made it unlawful for any person to discharge any pollutant from a point source into navigable waters, unless a permit was obtained under its provisions.


Funded the construction of sewage treatment plants under the construction grants program.

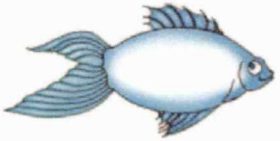

And recognized the need for planning to addres the critical problems posed by nonpoint source pollution.







CWA 303(d) & the Designated Uses

Aquatic Life 

 Contact Recreation

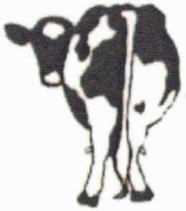
Domestic Water Supply 

 Food Procurement

Ground Water Recharge 

 Industrial Water Supply

Irrigation Use 

 Livestock Watering

Water Quality Standards

(aka Who's on First, Watt's on Second)

1) EPA establishes national criteria for water quality parameters. (Criteria are for guidance and are not compulsory)

2) States and Tribes adopt standards based on designated uses.

3.) EPA approves state and tribe standards.

4) States determine the designated use of a water body.





Waters that do not meet standards for their designated uses are listed on the state's 303(d) list.



Weighing our Water on the 303(d) Scale



YIKES: Kansas' 303(d) list is 10x longer than our midwest neighbors.

OHHH: Kansas has different water quality standards than neighboring states.

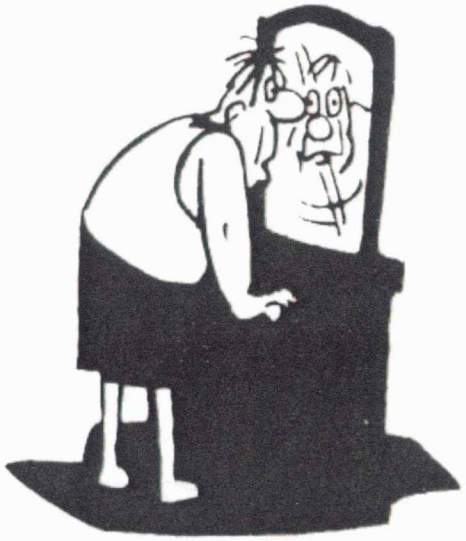
AHHH: Kansas has more water condition information available to help make the 303(d) than most states.

Lakes and streams on the 303(d) list receive special attention.

Total Maximum Daily Loads (TMDLs)

A 303(d) Listee Looks in the Mirror

What's causing the problem?
How bad is the problem?
What can be done to fix the problem?
How can we be sure we fixed it?
When should we look again?



p.s. There was a rather large debate over who should get to ask these questions! It was finally settled in court. The STATE will determine the corrective actions necessary to bring a 303(d) listee into compliance. This is based on the fact that it is the STATE that makes the determination to make a 303(d) listing to begin with....

30 years of the Clean Water Act

(Lets get to the point - or NOT!)



Point Source Pollution has been largely brought under control through the TMDL and permitting processes.

In 1995, the Kansas Natural Resource Council and the Sierra Club filed a complaint against the EPA, compelling it to enforce Section 303(d) of theClean Water Act by establishing TMDLs addressing nonpoint source pollution.

Nonpoint Source Pollution remains our nation's and Kansas' unmet water quality challenge.



Kansas StreamLink

Local Stream Teams work in tributaries feeding into the lake.

Citizen's have expressed interest in becoming more involved.





Tree Planting at the St. George Kaw River Access 4/2003

Concept Review Tied Back to Groups Pre-Event Attitudes



Creating Community Dialogue Strands
(through community interaction)

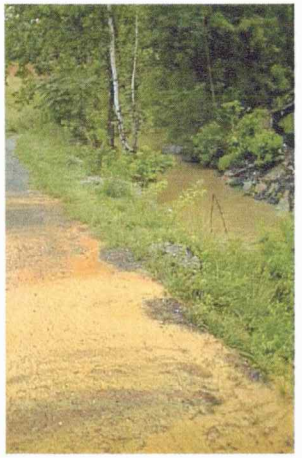


Streambank Protection & Restoration

- setback ordinances; targeted stabilizing

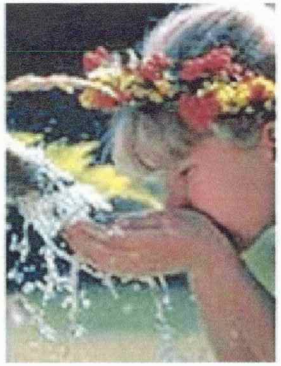
Land Use Considerations

- aligning usage with erosion factors



Water Consumer Education

- public perception doesn't match reality



Confusion

Confrontation

Courtrooms

What makes you feel safe?



Watershed Restoration and Protection Strategy Program

--WRAPS--

for

Clinton Lake & Upper Wakarusa Watershed

Kaw Valley Heritage Alliance

Water and Natural Resources Subcommittee

-2004-

The development of this plan was funded in part by EPA Section 319 grant provided by KDHE Clean Water Neighbor (CWN) Grant, and a Community Based Environmental Protection Program and Water Quality Cooperative Agreement grant from the EPA.



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❖People will build consensus for resource conservation and will promote responsible use of air, water, and land, while supporting a healthy economy.



WRAPS Core Working Group

*City of Lawrence Department of Utilities

*Douglas County Conservation District

*Kansas Biological Survey

*KS Dept. Health & Environment

*KSU Extension Watershed Specialist

*KSU Extension Office of Local Government

*Kaw Valley Heritage Alliance

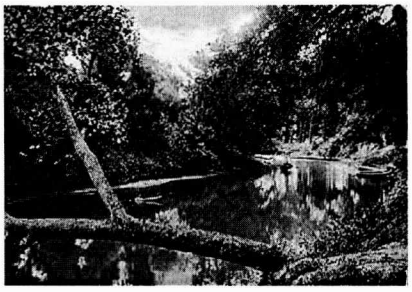
*Shawnee County NRCS

Rationale for Development of Single, Comprehensive WRAPS

- Stakeholders share common goals but have different mechanisms to contribute to the achievement of these goals.
- By recognizing and working together under a single, comprehensive plan the stakeholders formalize and sustain their working relationship.
- Documenting and recognizing the contributions of each stakeholder will help each obtain technical and financial assistance in the future—synergy results in greater probability that the overall goals of the watershed plan will be met.
- Followed KSU Research & Extension 15-Step Process.

Finding a Common Language

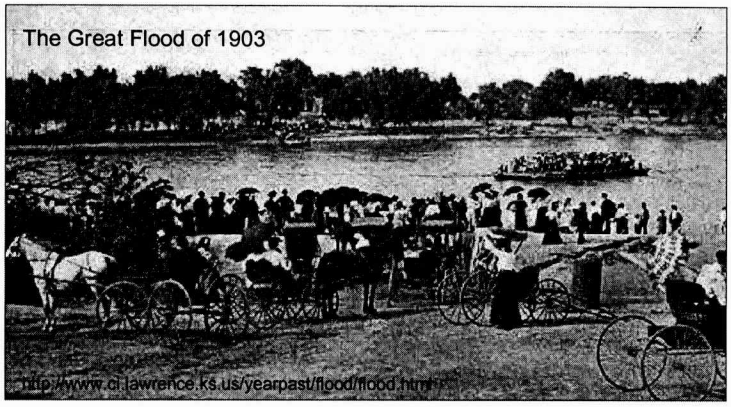
Quality of Water / Quality of Life



The Gentle Wakarusa River

Early postcards captured the calm serenity of the Wakarusa, with its tranquil pools, gently flowing current, rocky banks, and wooded shores.... By the early 1900s the Wakarusa was a favorite recreation area for Lawrence residents, with walking paths, picnic areas, boat moorings and favorite fishing spots.

The Great Flood of 1903



http://www.ci.lawrence.ks.us/yearpast/flood/flood.html

About six weeks after the water subsided, U. S. Engineers established a cable ferry.... North and South Lawrence were joined again, and the community was on its way to recovery....

Views of the Great Kansas River Flood by F.M. Knight, photographer and publisher, Lawrence, Kansas.

Same Song Second Verse....

July 13, 1951



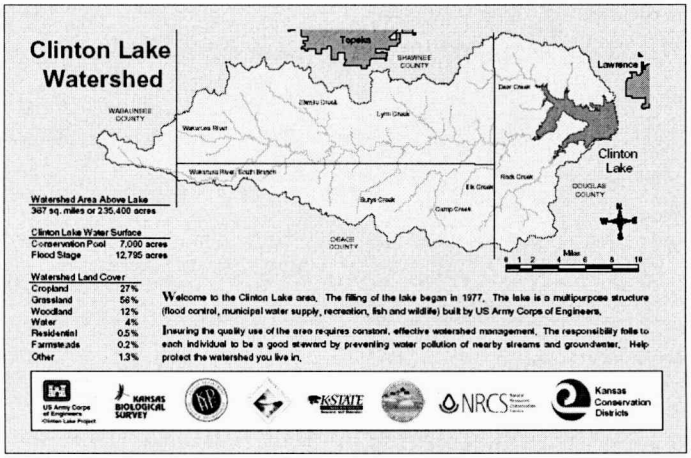
Photo by Lawrence Journal-World

- Flood Control Authorized in 1954
- Clinton Lake Authorized in 1962
- Appropriations Authorized in 1971

$55 Million; 9 Million Cubic Yards of Earth Later….



- Flood protection for 156 square miles
- Drinking water supply for +100,000 people
- 800,000 people use park facilities annually



Annual field crop production is estimated to be $19,993,499.



Annual livestock/poultry production is estimated to be $9,750,317.





Visitors to Clinton Lake spent an estimated **$17,134,000** in 2001.

What the WRAPS does

- Acknowledge and bring together the efforts of all agencies doing work in the watershed.
- Summarize historic information into one document.
- State the current condition of the watershed.
- Establish general water quality objectives based on TMDL goals.
- Recommend water pollution control practices and policies and review financial resources available.

Land Use

Several small towns,
more livestock than people.

<u>Overall</u>
27% Cropland
56% Rangeland

<u>Within 1/8 mile of most streams</u>
37% Cropland
38% Grassland

Physical Setting

- **Floodplain width varies from less than a mile to several miles**
- **Hydrologic system is still adjusting including stream bank erosion**
- **Soil erosion has reduced fertility resulting in increased use of fertilizers.**
- **This leads to more runoff of phosphorus and nitrogen into the watershed and lake.**

Total Maximum Daily Load (TMDL) Development

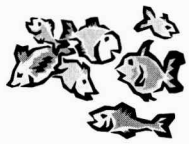
<u>Wakarusa River</u>
Fecal Coliform Bacteria

<u>Clinton Lake</u>
Eutrophication
Nitrogen and Phosphorus

Challenge is to reduce input of nutrients and sediment into the lake.

Working Together for Future Thirsts

- Protecting the reservoir space
- Protecting the water





WRAPS Tools

- Priority subwatersheds
- Specific actions needed
- Tracking objectives

- Single most effective action is

riparian restoration

to reduce stream bank erosion, sediment, nitrogen and phosphorus.

- Next most effective action is

riparian protection.

Priority Areas

- Subwatersheds grouped into four priority rankings
- Highest priority are watersheds nearest the lake and areas within one mile of tributaries
- Target incentives and financial assistance to these areas first.

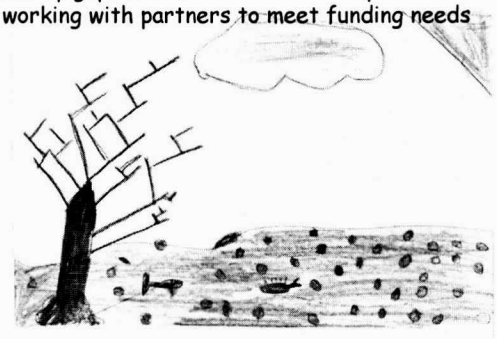


KVHA works as a base for a functionally integrated plan....

*focus / create a system to track goals and objectives of WRAPS and the progress being made by agencies & entities

*working with the partnerships to prioritize actions as related to meeting the goals & objectives

*identify gaps and holes in WRAPS implementation working with partners to meet funding needs



Community Cooperation

Meeting the public on common ground.....

- Attitudes Towards Water, Water Quality, and Water Stewardship
- Attitudes Towards Land Use Changes
- Attitudes Towards the Lake and its Purpose
- Attitudes Towards Government, Private vs. Public Need, etc...

Creating a Watershed Community

Creating Community Dialogue Strands
(through community interaction)



Streambank Protection & Restoration

•setback ordinances; targeted stabilizing

Land Use Considerations

•aligning usage with erosion factors



Water Consumer Education

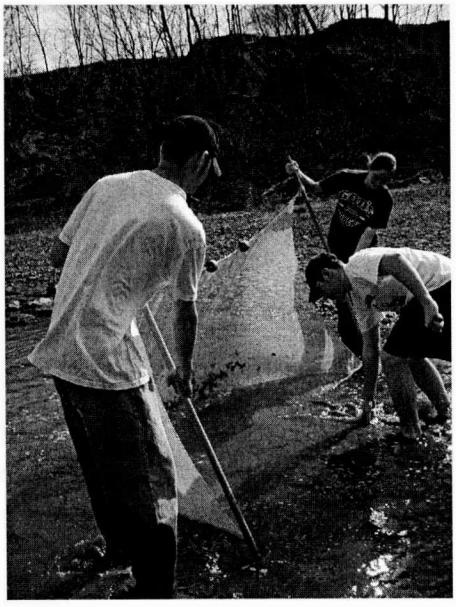
•public perception doesn't match reality



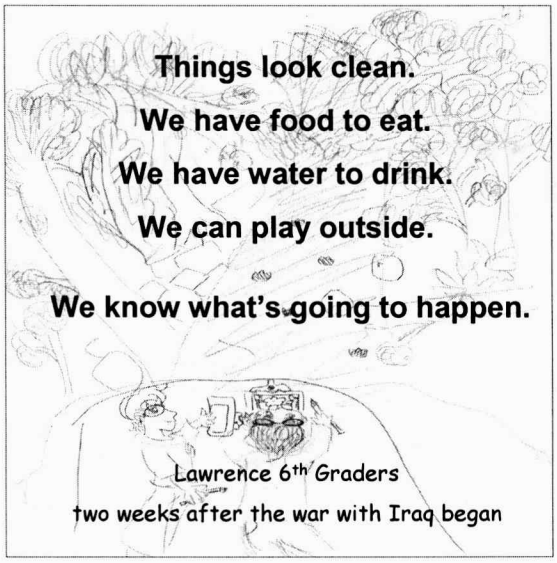
Kansas StreamLink

Local Stream Teams work in tributaries feeding into the lake.

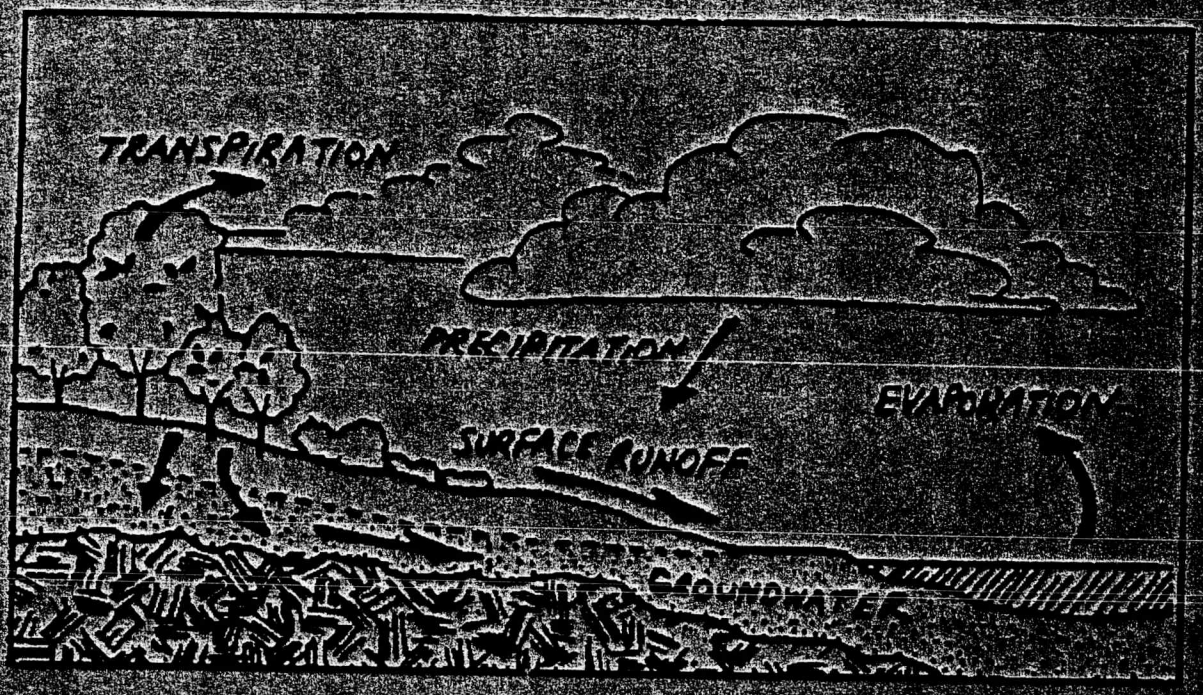
Citizen's have expressed interest in becoming more involved.



What makes you feel safe?



"Clear as Mud"
Who's Water is it Anyway?



Alison L. Reber
Kansas StreamLink
Kaw Valley Heritage Alliance
www.streamlink.org www.kvha.org

The National Environmental Policy Act 1969

Created a National Policy for the Environment & Established a Council on Environmental Quality


Each generation is trustee of the environment for succeeding generations.


All Americans should have safe, healthful, productive, and aesthetically and culturally pleasing surroundings.


We will attain the widest range of beneficial uses of the environment without degradation, risk to health or safety, or other undesirable and unintended consequences.


We will preserve important historic, cultural, and natural aspects of our national heritage, and maintain, wherever possible, an environment which supports diversity, and variety of individual choice.


We will achieve a balance between population and resource use which will permit high standards of living and a wide sharing of life's amenities.


We will enhance the quality of renewable resources and approach the maximum attainable recycling of depletable resources.

The Congress recognizes that each person should enjoy a healthful environment and that each person has a responsibility to contribute to the preservation and enhancement of the environment.

Federal water legislation dates back to the nineteenth century, when Congress enacted the River and Harbor Act of 1886, recodified in the Rivers and Harbors Act of 1899.

Federal Water Pollution Control Act 1972 Clean Water Act 1977


established the basic structure for regulating discharges of pollutants into the waters of the United States.


gave EPA the authority to implement pollution control programs such as setting wastewater standards for industry.


continued requirements to set water quality standards for all contaminants in surface waters.


made it unlawful for any person to discharge any pollutant from a point source into navigable waters, unless a permit was obtained under its provisions.


funded the construction of sewage treatment plants under the construction grants program

and recognized the need for planning to address the critical problems posed by nonpoint source pollution.

CWA 303(d) & the Designated Uses



- Aquatic Life
- Contact Recreation
- Domestic Water Supply
- Food Procurement
- Ground Water Recharge
- Industrial Water Supply
- Irrigation Use
- Livestock Watering

Water Quality Standards

(aka Who's on First, Watt's on Second)

1) EPA establishes national criteria for water quality parameters. (Criteria are for guidance and are not compulsory.)

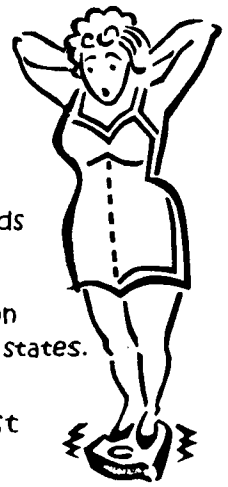
2) States & Tribes adopt standards based on designated uses.

3) EPA approves state & tribe standards.

4) States determine the designated use of a water body.

Waters that do not meet standards for their designated uses are listed on the state's 303(d) list.

Weighing our Water on the 303(d) Scale



YIKES: Kansas' 303(d) list is 10x longer than our midwest neighbors.

OHHH: Kansas is has different water quality standards than neighboring states.

AHHH: Kansas has more water condition information available to help make the 303(d) than most states.



Lakes & streams on the 303(d) list receive special attention.

Total Maximum Daily Loads (TMDLs)

A 303(d) Listee Looks in the Mirror

What's causing the problem?
How bad is the problem?
What can be done to fix the problem?
How can we be sure we fixed it?
When should we look again?



PS There was a rather large debate over who should get to ask these questions! It was finally settled in court. The **state** will determine the corrective actions necessary to bring a 303(d) listee into compliance. This is based on the fact that it is the **state** that makes the determination to make a 303(d) listing to begin with.....





30 years of the Clean Water Act

(Let's get to the point - or NOT!)



Point Source Pollution has been largely brought under control through the TMDL and permitting processes.

In 1995, the Kansas Natural Resource Council and the Sierra Club filed a complaint against the EPA, compelling it to enforce Section 303(d) of the Clean Water Act by establishing TMDLs addressing nonpoint source pollution.

Nonpoint Source Pollution remains our nation's and Kansas' unmet water quality challenge.



a big bowl of alphabet soup



S.B. 204 ("the Nations waters")

SWAP (Source Water Protection Plan)

BMP (Best Management Practices)

NPDES (National Pollution Discharge Elimination System)

SCC (State Conservation Commission)
NRCS (Natural Resource Conservation Service)
RC&D (Resource Conservation & Development)

KWO (Kansas Water Office)
KDHE (KS Dept. Health & Environment)
KDWP (KS Dept. Wildlife & Parks)
KDA (KS Dept. Agriculture)

2002 KANSAS WATER QUALITY ASSESSMENT (305(b) REPORT) April 1, 2002

Kansas Department of Health and Environment
Division of Environment
Bureau of Environmental Field Services
Suite #430 1000 SW Jackson
Topeka, Kansas 66612-1367

PART I: EXECUTIVE SUMMARY/OVERVIEW This report, the *2002 Kansas Water Quality Assessment*, also known as the 305(b) Report, is the biennial assessment of the state's surface water quality as required by 33 USC 466 *et seq.* , the Federal Water Pollution Control Act, commonly referred to as the Clean Water Act. The guidance by U. S. Environmental Protection Agency (EPA) for the preparation of this report provided options for reporting. The Kansas Department of Health and Environment (KDHE) elected to provide the an electronic report accompanied by an abbreviated narrative report. The abbreviated narrative report contains only the information required by law that has **changed** from the last report (2000 Kansas Water Quality Assessment 305(b) Report), March 31, 2000) and a simple reference to that report.

The Kansas Department of Health and Environment assessed the water quality for the period of 1998 through 2001, of 19,827 miles of streams, all of which were considered monitored. This report represents an increased assessment of 1,591 miles from the 2000 305(b) Report. This increase in milage is due (1) to assessment of four years of monitoring data and (2) to the increase in both in the number of stream chemistry and biological monitoring sites. A total of 188,487 lake acres were assessed. Of these, 175,894 acres were monitored and the conditions of an additional 12,593 lake acres were evaluated using professional judgement. An assessment of cumulative designated use stream mileage revealed that 67 % of the designated uses were fully or partially supported. Of the assessed streams, 24 % (in stream miles) supported all designated uses. Of the assessed lakes, 19 % of the total acres were fully supporting but threatened for at least one designated use and 77 % were impaired for one or more uses.

The *2002 Kansas Water Quality Assessment Report* includes four years of ambient stream chemistry data (1998 - 2001) and only acute aquatic life use support application. Fish consumption advisories and swimming beach closures were applied in lieu of published criteria for food procurement and primary contact recreation. These approaches are consistent with the 1997 US EPA guidance and reflect the manner in which most states have prepared past 305(b) reports. The assessments contained in this report are otherwise consistent with the application of the numeric and narrative 2001 Kansas surface water quality standards.

The major causes of nonsupport for streams, in order of prevalence, are sulfate, pathogen indicators (fecal coliform), organic enrichment, and chlorides. The major causes for lake impairments were sediments, turbidity, taste and odor, and nutrients/eutrophication. Sources responsible for widespread pollutant loadings and beneficial use impairments of streams include agriculture (nonirrigated and irrigated crop production, and intensive animal feeding operations), natural sources, habitat modification, municipal point sources, and groundwater withdrawal. Major sources for lake impairment included agriculture and municipal point sources. Of the assessed lake acreage in Kansas, 69% was stable over time, while slightly more than 12% appeared to be undergoing measurable eutrophication. Thirteen percent of total lake acres showed appreciable improvement in trophic state condition during this reporting cycle. Municipal point sources, natural sources, and agriculture were the primary contributing factors to lake eutrophication.

High nitrate concentrations accounted for about 85% of the documented exceedences of the federal drinking water maximum contaminant levels (MCLs) during 2000 through 2001 for the groundwater monitoring network. Other isolated concerns of groundwater contamination included the presence of volatile organic compounds, heavy metals, petroleum products and/or bacteria. The major sources of these contaminants included active industrial facilities, spills, leaking storage tanks, mineral extraction activities, and agricultural activities.

The imposition of more stringent permit limits and the resulting upgrades of municipal and industrial wastewater treatment facilities continue to result in notable improvements in surface water quality. As the number of point sources causing or contributing to significant water quality impairments continues to decline, future attention will necessarily shift to the remaining sources, primarily nonpoint sources. It is anticipated that watershed pollution control efforts, predicated on the development of Total Maximum Daily Loads (TMDLs) and on the allocation of allowable pollutant loadings among point, nonpoint, and natural sources, will play an increasingly important role in the abatement of surface water pollution and improvement in water quality in Kansas. By June 30, 2002 Kansas will have established TMDLs for waterbodies listed in the 1998 Kansas 303(d) List in nine of the twelve river basins.

Federally Promulgated Standards

Water Quality Standards for Kansas Fact Sheet (EPA-823-F-03-008)

July 2003

Summary U.S. EPA is promulgating a primary contact recreation use designation for 1,062 waters, an aquatic life use designation for one of these primary contact recreation use waters, and a secondary contact recreation use designation for 225 waters in the State of Kansas to replace the use designations for those waters adopted by Kansas but disapproved by EPA in 1998. EPA is promulgating final water quality standards for the State of Kansas at this time pursuant to a court order to take such action by June 30, 2003.

Background EPA's water quality standards regulations require states to designate uses for all water bodies within their jurisdiction.

- Designated uses determine what water quality criteria apply to specific water bodies. EPA's regulations interpret the Clean Water Act's goal of "...water quality which provides for the protection and propagation of fish, shellfish, and wildlife and recreation in and on the water ..." by requiring that water quality standards provide for "fishable/swimmable" uses unless they have been shown to be unattainable through a use attainability analysis (UAA).
- When the Agency disapproves a state or tribal water quality standard, and the state or tribe does not make appropriate changes, EPA's Administrator must propose and promulgate revised standards.

In February 1998, EPA disapproved portions of Kansas' water quality standards submission. Kansas corrected, and EPA approved, some of the disapproved water quality standards provisions in 1999.

The Kansas Natural Resource Council and Sierra Club sued EPA in August 1999, claiming that EPA failed to promptly propose replacement water quality standards in Kansas for the remaining disapproved issues. EPA entered into a consent decree with the plaintiffs and published a proposed rule on July 3, 2000, addressing the six remaining issues that had not been resolved. Since then, Kansas has resolved all the remaining issues except EPA's outstanding disapproval of 1,456 waters without UAAs demonstrating that primary contact recreation is not attainable.

On December 13, 2000, the plaintiffs again sued EPA requesting that the court order EPA to publish a final rule promulgating water quality standards for Kansas that would address this final issue.

About this Action On March 31, 2003, the court ordered EPA to promulgate a final rule for Kansas within 90 days (June 30, 2003) addressing EPA's outstanding disapproval of the 1,456 waters without recreation uses. In its decision, the court held that EPA must use the "rebuttable presumption" approach contained in the regulations (i.e., in the absence of data, EPA presumes that water bodies are able to attain "fishable/swimmable" uses). EPA's Federal designation of a primary contact recreation use for 1,062 waters, an aquatic life use for one of these primary contact recreation waters, and a secondary contact recreation use for 225 waters, will ensure that the water quality will be appropriately protected for recreation and aquatic life unless an analysis is done and provided to EPA that shows the water cannot achieve the water quality necessary to protect the designated use.

In its decision, the court recognized that the order "may result in bodies of water being given a primary contact recreation designation when a use attainability analysis might rebut such a designation." Under state statute, Kansas is required to conduct use attainability analyses for all state waters by October 2005. Kansas has completed 523 UAAs for waters that were subject to EPA's July 2000 proposal. EPA evaluated these UAAs when determining which waters should be included in the final regulation.

Kansas is continuing to perform UAAs for recreation uses to comply with the state's statute. Once the State of Kansas has completed the necessary UAAs and any corresponding changes to its water quality standards, EPA will initiate a rulemaking to withdraw the Federally promulgated designated uses applicable to those waters.

This rule imposes no direct cost on any entity. Some facilities discharging to waters for which EPA has promulgated a use may need to alter their pollution control measures to ensure their discharge will maintain the designated use.

Kansas, however, has considerable discretion in how it implements its standards when it develops effluent limits for any affected facility. EPA does not anticipate significant impacts to dischargers or the agricultural industry.

Additional Information

For information concerning today's final rule, contact Mr. Martin Kessler, Public Affairs Specialist at r7actionline@epa.gov or at U.S. EPA Region VII, Office of External Programs, 901 North 5th Street, Kansas City, Kansas, 66101 (Telephone: 913-551-7003).

The public record for this rulemaking has been established and is located at EPA Region 7, Information Resource Center, 901 North 5th Street, Kansas City, Kansas 66101, between 8 a.m. and 4:30 p.m. Central Time, Monday through Friday, excluding legal holidays. For further information regarding access to the docket materials, call (913) 551-7241. You may have to pay a reasonable fee for copying.

Lawrence Journal World

EPA upgrades Kansas water-quality standards

By Scott Rothschild, Journal-World
TUESDAY, JULY 1, 2003

TOPEKA — **Under court order, federal environmental** officials Monday upgraded the designated use of more than 1,000 bodies of water in Kansas to be clean enough for humans to swim and fish in them.

"Slowly but surely, we are making progress," said Charles Benjamin, a Lawrence attorney representing the Kansas chapter of the Sierra Club, who sued the Environmental Protection Agency to force it to take the action.

He described the new EPA rules as a victory for "all the people of Kansas because the vast majority of the people of Kansas want to see the waters of Kansas cleaned up."

The court order and announcement of the rules came after years of political and legal wrangling on complex water quality issues.

The result was that the EPA designated 1,062 bodies of water across the state as "primary contact recreational," which means the waters should be clean enough to fish and swim in. Therefore, industries and municipalities that discharge into these waters may have to improve their treatment processes to remove more bacteria from their waste, officials said.

The Kansas River is designated "primary contact recreational," which means it should be clean enough to fish or swim in, but it often has amounts of bacteria that would make it unsafe for swimmers.

EPA officials were quick to point out that any changes would not be required until permits for dischargers were being renewed.

Before the court order, EPA had not placed designations on the waters; instead it awaited results of state-conducted scientific reviews to determine whether a stream should be held to the fishable-swimmable standard or some lower level.



Thad Allender/Journal-World Photo

The Kansas River meanders east toward Lawrence northwest of the Westar Lawrence Energy Center. Federal environmental officials Monday upgraded the designated use of more than 1,000 bodies of water in Kansas to be clean enough for humans to fish and swim in them. The Kansas River is designated "primary contact recreational," which means it should be clean enough to fish or swim in, but it often has amounts of bacteria that would make it unsafe for swimmers.

Benjamin had argued EPA had turned the federal Clean Water Act "on its head."

Waters should be designated first as swimmable and fishable, and if the state wanted to challenge that designation it had to conduct the scientific study to show that that higher standard could not be reached, Benjamin maintained.

On March 31, U.S. District Judge G. Thomas Van Bebber of Kansas City, Kan., agreed.

"The plain language of the Clean Water Act limits the options of the court," he said.

He ordered EPA to take final action by Monday in setting the highest levels of protection for the disputed bodies of water.

But federal and state officials downplayed the significance of the new rules that were signed by outgoing EPA Administrator Christine Todd Whitman on her last day in office before leaving the Bush administration.

"In the short term, the impact will be negligible," said Pat Miller, an attorney with the regional EPA office.

That is because, Miller said, the state and EPA are conducting scientific reviews of the streams and stream segments that could downgrade many of the bodies of water to a lower water quality designation.

Kansas has completed 523 of these studies. Of those, EPA so far has approved 164 state water-use designations. About 60 were for the fishable-swimmable designation; 60 were for a lower standard; the rest of the stream segments were determined to be nonexistent, officials said.

The list of EPA standards and water designations will be published in the Federal Register later this month on a date that has yet to be determined.

When published, the Federal Register notice will be available online at www.epa.gov/waterscience/standards/actions.htm.

Ideas for Wrapping Up Environmental Issues Forums

Sometimes ending an EIF forum can seem like the most difficult part. How can a moderator help the group wrap up its discussion so that participants go away knowing that they've accomplished something? Here are several ideas for bringing closure to the discussion.

Focus on what has happened to individuals' thinking:

- How has your thinking about this issue changed?
- How has your thinking about other people's views changed?

Focus on the group's understanding of the issue:

- Is there any difference between the way we as citizens see the issue and the way experts and political leaders see it? What is the difference?
- Now that we've considered these choices, how would we define the problem?
- What makes this issue so difficult? What pulls us in different directions and creates tension?
- Given that each of us is motivated by things to which we attach great importance, can we redescribe the issue in a way that highlights what each of us values?

Focus on directions for action:

- What trade-offs are we willing to make to resolve the issue?
- What consequences are unacceptable? What are we not willing to give up?
- What are we willing and unwilling to do to resolve the issue?
- Do we see any possibilities for action that we didn't see before?
- Is there a range of actions we might all be able to live with, even if it isn't ideal from our personal points of view?
- How far have we moved toward a shared sense of purpose and direction?
- If our political representatives were here, what would we tell them? If they were making a decision about this issue, what would we want them to care about?

Focus on the future:

- How can we use what we learned in this forum?
- What have we talked about that we can take back to others?
- What haven't we been able to work through? Which conflicts weren't resolved? What requires more deliberation?
- What needs to happen in order to make progress in resolving this issue?
- What do we need more information about?

Through its Windows on the Wild program and other community outreach and education efforts, World Wildlife Fund (WWF) supports local forum programs, provides facilitator training, and develops issue materials. The forthcoming EIF book about marine fisheries entitled, *Fisheries for the Future*, will be published by WWF in 2002. WWF also supports forum programs using the EIF book, *The Biodiversity Debate.*

National Issues Forums
100 Commons Road
Dayton, OH 45459-2777
800.433.7834
www.nifi.org

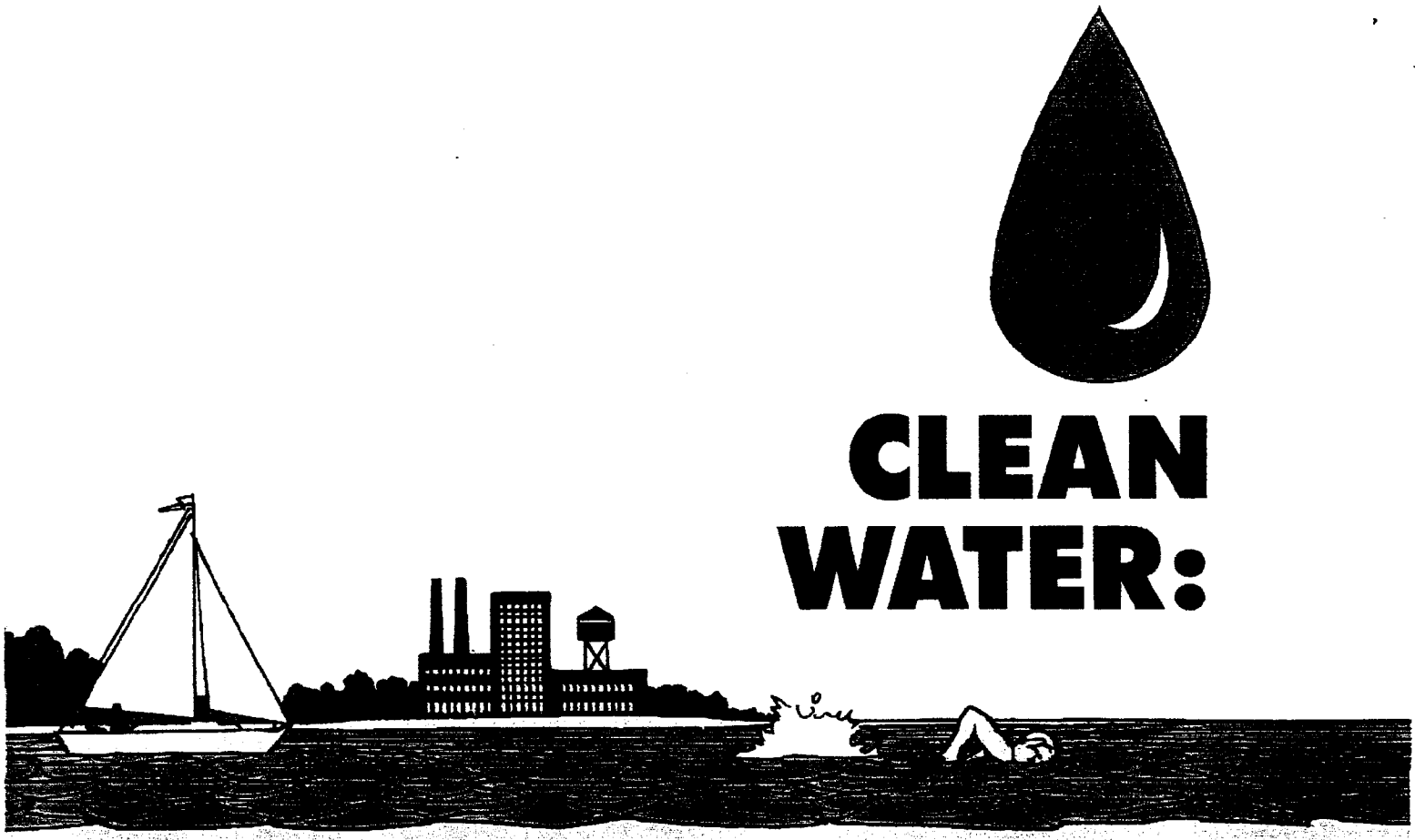
The National Issues Forums (NIF) is a nationwide network of thousands of civic and educational organizations that convene local discussion of national issues. Each year, NIF develops three new issue books. NIF sometimes collaborates with regional or national partners to develop new issue materials, and it publishes a variety of materials about running forums. In addition, members of the NIF network around the country hold training programs known as Public Policy Institutes.

Study Circles Resource Center
P.O. Box 203
Pomfret, CT 06258
860.928.2616
www.studycircles.org

The Study Circles Resource Center (SCRC) is a project of the Topsfield Foundation. It promotes the use of small-group, democratic, highly participatory discussions known as study circles. In contrast to issue forums, study circles generally encompass more than one meeting. SCRC provides consultation by phone or mail, networking services, and topical discussion programs on issues such as race relations, police-community relationships, community growth and development, education, and immigration. SCRC offers publications on creating discussion materials, organizing study circles, and training study circle leaders.

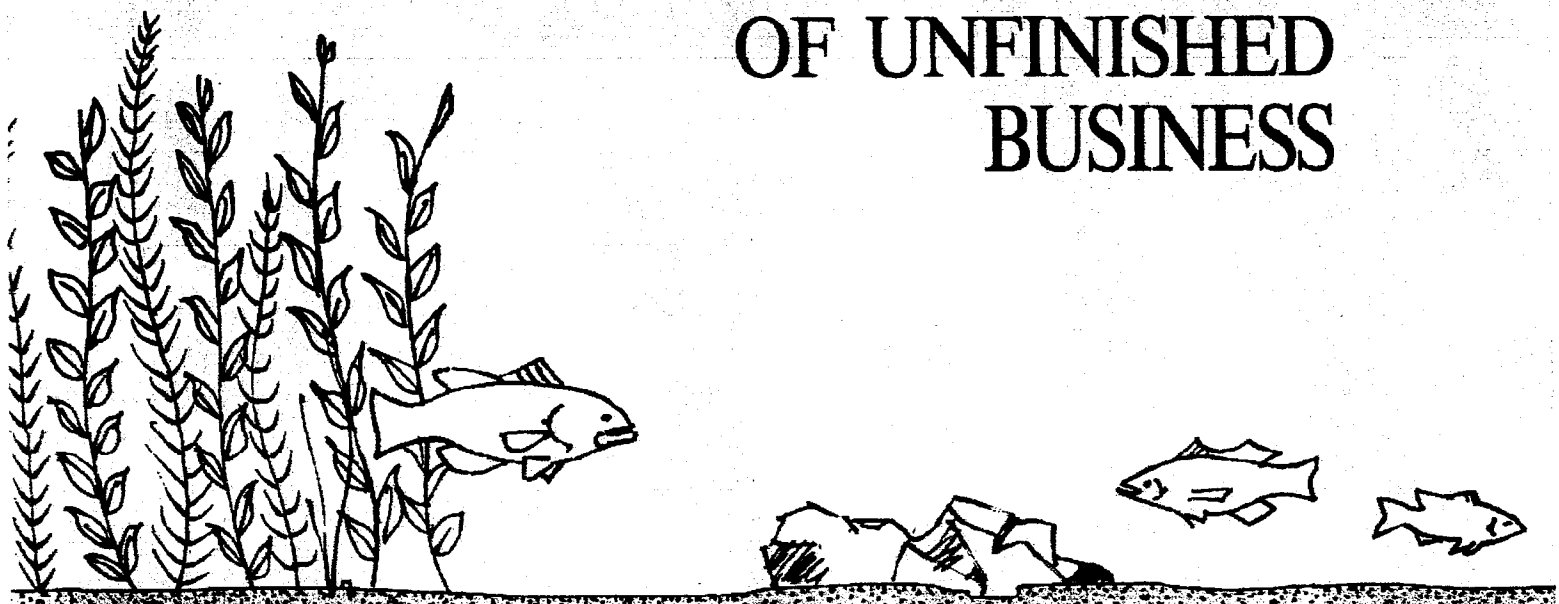
Kendall/Hunt Publishers
4060 Westmark Drive
P.O. Box 1840
Dubuque, IA 52004-1840
800.338.8290 or 800.542.6657
www.kendallhunt.com

Limited quantities of EIF issue books and issue-in-brief booklets are available from Kendall/Hunt Publishers. (Please contact the Harbinger Institute if the materials you desire are not available.)



CLEAN WATER:

TAKING CARE OF UNFINISHED BUSINESS



ENVIRONMENTAL ISSUES FORUMS

NORTH AMERICAN ASSOCIATION FOR ENVIRONMENTAL EDUCATION

Elements of an issue book
Clean Water: Taking Care of Unfinished Business

	Choice 1: Completing the Regulatory Net	Choice 2: Taking Responsibility for Water Pollution	Choice 3: Getting Our Priorities Straight	Choice 4: Working with Nature
What is the real problem?	We aren't fully using existing regulations and haven't regulated all the problems we know about.	We're asking "How much pollution is OK?" rather than "How can we prevent pollution?"	The need for balance in pollution control policies is no longer clear.	Our efforts do not match the geography of our watersheds, nor how our communities work.
In general terms, how can we solve the problem?	Extend the regulatory net and make sure laws and regulations are enforced.	Prevent pollution, based on a change in personal attitudes and social norms.	Use market-based and quantifiable means to set priorities and protect clean water.	Reorganize government water quality management by watersheds.
What specific actions will help?	• Standards, permits, monitoring, enforcement, subsidies • Set timetables and enforcement mechanisms • BMPs for nonpoint source pollution • Avoid voluntary approaches, which tend to get stuck in the planning phase • Research on water resources, pollution sources, effects of controls	• Non-polluting lifestyles: composting toilets, gray-water systems, conservation • Change transportation, farm, and development policies/practices • Industry reduce use of toxics; ban most dangerous; inform public • Treat water as natural capital • Include ecological costs in prices • Clarify our values	• Use environ. risk to set priorities • Science helps us decide how much pollution to accept • Take cost of regulatory compliance into account • Market-based incentives, e.g., pollution charges, tradable permits, removing market barriers • Use and enhance expertise of farmers, corporations, etc.	• Build on watershed planning efforts (national program and integrated efforts) • Make other resource decisions in watershed framework • Address cross-media pollution • Involve people where they live; offer education in that context • Build government/NGO cooperation
What's important to supporters of this choice? What do they value?	Fairness, technology, thoroughness, knowledge	Personal responsibility, respect for water, prevention, precaution, admit mistakes	Balance, flexibility, economic strength, informed risk-taking/investing societal resources, cooperation	Community, "place," citizenship, natural systems, integrated decision-making
What are the cons to this choice?	• Regulations inflexible and restrictive • Isn't fair; costs go to communities that can't pay • Comm. & control won't stop NPS	• Will lead to economic disaster • Unrealistic and unnecessary expectation for lifestyle change • Unrealistic idea of zero risk	• Private industry too autonomous • Market doesn't handle environmental values well • Risk warps values • Pollutant-by-pollutant approach	• Changes, tax increases will meet resistance • Will create another level of bureaucracy • Unrealistic view of community life

Environmental Issues Forums

Using the Environmental Issues Forums (EIF) approach, you can bring citizens together in locally initiated, nonpartisan discussions about environmental problems that concern them.

EIF was developed by the North American Association for Environmental Education. It is based on the successful National Issues Forums model, an update and re-creation of the traditional town meeting, pioneered by the Kettering Foundation. This model for public discussion has been used in thousands of communities across the country by civic and education organizations including high schools and colleges, libraries, service organizations, religious groups, government agencies, and many others. Each organization adapts the approach and materials to the needs of the local community.

In the back of each issue book, you'll find answers to some frequently asked questions about EIF:

- What happens in forums?
- Can I participate if I'm not well informed about the issues?
- Do forums lead to political action?

Resources for Public Dialogue

The North American Association for Environmental Education no longer supports the EIF program. It may be useful to think of EIF as an approach to community dialogue, rather than a program. Several sources of support for your EIF efforts do exist:

The Harbinger Institute
Howard Terry and Michele Archie
575 Cooke Street, Suite A-2100
Honolulu, HI 96813
866.223.2300
harbinger@aloha.net

The Harbinger Institute offers training and consulting services related to EIF and other approaches to public dialogue and group decision-making. Services include adapting the EIF process to local and regional issues, developing and writing discussion materials, and designing and implementing public dialogue programs.

World Wildlife Federation
Education Department
1250 24th Street N.W.
Washington, DC 20037
www.wwf.org

BUSINESS AND INDUSTRY ACTIONS

- Meet–and surpass–requirements for pollution control.
- Provide monitoring data that contribute to nationwide research on water quality issues.

STATE/PROVINCIAL AND LOCAL POLICIES

- Implement and enforce groundwater protection plans.
- Implement and enforce nonpoint source pollution management programs.

NATIONAL GOVERNMENT POLICIES

- Require states, provinces, and localities to protect groundwater, and provide technical assistance.
- Make full use of existing legislative authority, for example to designate water quality management areas and set drinking water standards.
- Set–and hold states and provinces to–mandatory minimum requirements for water quality.
- Extend regulatory control to nonpoint source pollution.
- Fund research that will add to our knowledge about the effects of certain regulatory tools.

- Audit operations to discover ways of eliminating nonpoint source pollution.
- Reformulate products to eliminate toxics used.
- Participate in educational programs about the effects of toxic chemicals.
- Industry groups, for example in agriculture, should come up with and voluntarily adopt practices that reduce water pollution.

- Create regulations that provide incentives for people to treat their wastewater at home.
- Offer technical assistance for individuals and businesses seeking to reduce nonpoint source pollution.
- Implement strict land-use regulations aimed at reducing nonpoint source pollution.
- Join forces with the national government to eliminate toxics use.

- Require labeling of toxic materials in products.
- Ban production and use of the most dangerous of toxic chemicals.
- Mandate dramatic reductions in the use of toxic chemicals by industry.
- Instate pollution taxes or fees to reflect the cost of water pollution in the price of a product.

- Fund efforts to improve the science of risk assessment and comparison.
- Collaborate with government policymakers in developing market-based strategies for reducing pollution.
- Spread the word about the economic benefits of pollution prevention to other businesses.
- Share strategies for preventing pollution with other businesses.

- Rely on tools that work with the market to reduce water pollution.
- Consider socioeconomic impacts when setting water quality standards and applying regulations.
- Create clearinghouses for exchanging information about pollution prevention among businesses.

- Fund additional development of tools for weighing the risks posed by various environmental threats.
- Allocate environmental protection resources where they will alleviate the most risk.
- Consider socioeconomic impacts when setting water quality standards.

- Become partners in watershed planning and management.
- Voluntarily reduce point- and nonpoint source water pollution.

- Participate in and financially support watershed planning and management efforts.
- Give authority for a broad range of natural resource management decisions to the watershed institutions.
- Organize volunteer monitoring networks.

- Create a national program of watershed planning and management, providing authority and support to the watershed level efforts.
- Provide for the protection of resources–such as groundwater–that cross watershed boundaries. Address problems, such as PCB use and acid rain, that affect watersheds from outside.
- Encourage states and provinces to take a more integrated approach to natural resource management.

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March 1-2, 2002

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ACTION AND POLICY CHART

The chart on these two pages suggests ways in which individuals, communities, businesses, industries, and government bodies can address the unfinished business of assuring clean water. Each of the choices outlined in this book presents a different slate of actions.

CHOICES	INDIVIDUAL ACTIONS	COMMUNITY ACTIONS
#1 **We should make a new commitment to regulatory control of water pollution problems, fully using the tools we have in place already and imposing new restrictions where needed. Using this approach, we can build on the successes of our current framework of regulations.**	• Comply with water quality laws and regulations. • Join and support environmental watchdog groups. • Support directing tax money to water quality regulation, monitoring, and enforcement.	• Conduct "community audits" of local industries to learn about potential sources of water pollution and regulatory tools. • Educate for community awareness of laws and regulations that are important in protecting clean water.
#2 **Pollution prevention must be the hallmark of our efforts to assure clean water. Individually and in our business, we should conserve water and avoid using or making products that add to pollution. This approach would replace our "flush and forget" attitude with a fundamental respect for water.**	• Carefully conserve water at home. • Where possible, use composting toilets and on-site wastewater treatment devices. • Reduce use of products made with toxic substances, and dispose of those you use properly. • Control runoff from your yard, keep your septic system running properly, and clean up after your pets. • Question the necessity of everyday activities that add to water pollution.	• Educate people about the effects of their everyday actions on water quality, and help them explore the values of clean water. • Collect household hazardous waste for safe disposal, and publicize non-toxic alternatives. • Provide assistance to landowners in reducing nonpoint source pollution from their property. • Create a community-wide effort to change polluting practices in such basic areas as transportation and land use.
#3 **We must look at water pollution in the context of all of our environmental problems, spending our resources to address those that pose the most risk. When we do decide to act on a water pollution problem, government should rely on cooperative approaches rather than more regulation.**	• Resist the temptation to respond to each claim of a new environmental crisis. • Learn about the risks posed by different environmental problems. • Support government efforts to target environmental protection resources efficiently.	• Educate consumers and businesses about the environmental and economic benefits of pollution prevention.
#4 **We need to take a more integrated approach to assuring clean water, concentrating effort and authority in individual watersheds. This approach will reduce interagency conflict, engage people in protecting water resources close to home, and integrate water quality with other resource management issues.**	• Volunteer to monitor water quality locally. • Participate in public meetings, committees, and other efforts to make sure the public is involved in managing water resources. • Reduce your personal contribution to water pollution problems. • Learn about the watershed you live in. Where does your drinking water come from? What plants and animals depend on clean water to survive? What industries affect your water? What government officials are in charge?	• Create collaborative efforts to engage citizens in watershed and management across political boundaries. • Educate people about the effects of their everyday activities on local water resources. • Educate people about their watershed and about the broad range of factors that affect water quality within it.

CHOICE #1

. . . rests on a faith in the regulatory process for assuring clean water. Advocates of this view maintain that we have not made full use of the regulatory framework we already have in place, and that we have been slow in regulating all the water quality problems we already know about. Efforts should be focused on monitoring and enforcement to fulfill legislated mandates, say proponents of this view, and new regulations should be put in place for outstanding problem areas such as nonpoint source pollution. Proponents also argue for better research to provide a base of information for regulatory efforts.

CHOICE #2

. . . says that there must be fundamental changes in our cultural view of water as a vehicle for flushing away wastes if we are to effectively address our water pollution problems. In this view, the "flush and forget" attitude we learn when using the toilet at home must be replaced by a fundamental respect for water. Advocates of this view argue for a policy approach that aims to prevent pollution rather than control it. At the heart of that approach are water conservation and on-site treatment of household waste water, changing elements of our lifestyles that cause pollution, and programs aimed at stopping the use of toxics.

CHOICE #3

. . . expresses the view that water pollution problems have been blown out of proportion, and that the progress we have made in assuring clean water has been hidden by overly negative assessments. Proponents of this view suggest that we step back, look at the risks associated with various environmental problems, and target our efforts where they will make the most difference. They also argue that government efforts will be more efficient if they work in cooperation with private industry rather than throwing more regulations in the way of economic growth.

CHOICE #4

. . . asserts that at the heart of our continuing water quality problems is the fragmented approach we use to address them. Our efforts to assure clean water, say supporters of this view, should focus on individual watersheds, the natural basins in which most natural and human activities affect water quality. Working within these natural boundaries will help us reduce interagency conflict, engage people in protecting water close to home, and integrate water quality with other resource management issues.

Each of these approaches offers a different assessment of the root of our water pollution problems. Taken together, they provide a framework in which to discuss the water quality issues that we face locally, regionally, and nationally. It is not possible to cover all the complexities of these issues, and their local variations, in this discussion guide. Undoubtedly, the basic information offered here will prompt new questions that you will be able to answer only with others in your community. The viewpoints that shape these choices–and the policy proposals that grow out of them–are not necessarily incompatible. The best approach may involve parts of different choices. Give each choice a fair hearing. By considering these choices and the arguments for and against them, you may find that your knowledge of water pollution problems deepens, that you learn more about how other people think about the issue, and that your own perspective is challenged. This may be the starting point for a new societal agreement on how best to tackle the unfinished business of assuring clean water in Canada and the United States.

"In an age when man has forgotten his origins and to blind even to his most essential needs for survival, water along with other resources becomes the victim of his indifference."

From *Silent Spring* by Rachel Carson. Copyright 1962, Houghton Miffiin. Used by permission.

U.S. Geological Survey studies suggest that the U.S. has large amounts of clean groundwater, but these studies also highlight two areas of special concern. One concern is with localized contamination from point sources. The other is with widespread contamination from nonpoint sources. The problem with point sources is that pollutants can be highly concentrated near the source, causing local problems with groundwater. Sources include leaking underground storage tanks, waste disposal sites, and chemical- or waste-handling areas. This kind of groundwater pollution is common in urban or industrial areas, and often involves toxic metals, organic chemicals, or petroleum products. Nonpoint sources, such as urban areas, farms and feedlots, and septic systems, can cause more widespread harm. In many regions, large numbers of shallow wells are polluted with substances such as nitrate and microorganisms.

Groundwater

Groundwater is water below the land's surface. It fills the spaces between grains of sand, particles of soil. or chunks of gravel, or fills up cracks, crevices, and other spaces in underground rock. Groundwater is replenished–or *recharged*–by rain or snowmelt filtering down through the soil.

Groundwater is almost always flowing downhill, moving from upland recharge areas to lower-lying areas where it can be *discharged* to a spring, a stream, or another body of surface water. Depending on the slope it follows and the resistance offered by the materials it flows through, groundwater may move at a rate that ranges from inches per year to feet per minute.

The word *aquifer* often is used when talking about groundwater. An aquifer is an area of rock or granular materials–like gravel or sand–that transmit water easily. Groundwater moves through aquifers as it moves from recharge areas to discharge points. In addition to providing routes for transporting water, aquifers also store large volumes of water, which can be accessed through wells.

Some groundwater contamination problems are unique to certain areas. Examples include acid mine drainage in the Appalachian coal fields, the intrusion of sea water into aquifers in coastal areas, and the return of water that has been used for irrigation–and may contain pesticides or fertilizers–to aquifers. Other sources of contamination, such as septic tanks, landfills, and underground petroleum storage tanks, are more widespread.

Key sources of groundwater contamination are:

- industrial wastes
- municipal landfills
- agricultural chemicals
- septic system and cesspool effluents
- leaks from petroleum pipelines and storage tanks
- animal wastes
- acid mine drainage
- oil field brines
- saltwater intrusion
- irrigation return flow

While spills of industrial wastes and leakage from landfills may receive the most attention, it is the more common contamination sources–such as septic tanks, agricultural chemicals, and animal wastes–that account for the most frequent and widespread contamination.

Source: C. Abdalla, D. Allee, and L. Danielson, eds.,"What is Groundwater?". This is the first in a series of seventeen leaflets produced by the Groundwater Policy Education Project.

Besides groundwater pollution, another example of water pollution problems that are difficult to see is *cross-media pollution.* This term refers to pollutants that do not stay where we put them in the first place. This happens in a number of ways. After sulfur dioxide and nitrous oxides are released into the air by cars and coal-burning plants, for instance, they can combine with water in the clouds, and fall back to the earth and into bodies of water as acid rain. "Cross-media pollution" can also occur if water runs through waste materials that we dump in a landfill and picks up contaminants. Also, pesticides that are put on the soil may be washed away by rain water and end up in a nearby river or in groundwater.

Toxic contamination, which can come from many sources–including industry, waste disposal, and agricultural and urban runoff–is also difficult to see and is a growing concern. Scientists have long suspected that toxic substances in water cause human and environmental problems. Rachel Carson's well-known book, *Silent Spring*, sounded warnings about harmful pesticides in 1962. In the last decade or so, the long-term health and environmental effects of persistent toxics have begun to be documented. Scientific research is confirming a range of impacts, and concern is growing.

Advances in technology now allow us to detect toxic substances at trace levels that could not be detected before. Some toxics appear to be harmful in minute quantities that we cannot detect by taste, sight, or smell. In laboratory tests, for example, one form of dioxin (an organic compound) was lethal to rainbow trout at concentrations as low as 40 parts per quadrillion. This low concentration would be equal to a thimble-full of dioxin in the water contained in 50,000 Olympic-sized swimming pools.

ENVIRONMENTAL ISSUES FORUMS

The Environmental Issues Forums (EIF) program brings citizens together in locally initiated, nonpartisan discussions about environmental problems that concern them. EIF is based on the enormously successful National Issues Forums model, an update and re-creation of the traditional town meeting, pioneered by the Kettering Foundation.

Civic and education organizations–high schools and colleges, libraries, service organizations, religious groups, government agencies, and many other types of groups–convene forums and study circles in their communities as part of the EIF program. Each participating organization assumes ownership of the program, adapting the approach and materials to its own mission and to the needs of the local community.

Here are answers to some of the most frequently asked questions about EIF:

WHAT HAPPENS IN FORUMS AND STUDY CIRCLES?

EIF forums and study circles aim to stimulate and sustain a certain kind of conversation–a genuinely useful conversation that moves beyond the bounds of partisan politics and the airing of grievances to mutually acceptable responses to common problems. Unlike most public discussions or debates about environmental issues, forums and study circles invite discussions about each of several approaches to an issue, and encourage in-depth consideration of the costs, benefits and consequences of those approaches in the light of individual and community values. The discussions do not aim to develop a specific group consensus; rather, they aim at developing a common sense of community problems and priorities.

CAN I PARTICIPATE IF I'M NOT WELL INFORMED ABOUT THE ISSUES?

People don't need to be experts to discuss environmental issues. The central task of EIF is not to help participants acquire a detailed knowledge of environmental issues, but to focus on which public actions should be taken. That's a matter of judgment that requires collective deliberation. Forums and study circles help people grasp the dilemma at the heart of each issue, and to understand basic facts and trends. And, most important, they help participants ponder and discuss the kernel of conviction on which each alternative approach is based, to sort out conflicting principles and preferences, to uncover areas of disagreement and to work toward areas of agreement.

DO FORUMS AND STUDY CIRCLES LEAD TO POLITICAL ACTION?

Neither the organizations that run forums and study circles locally nor the North American Association for Environmental Education (NAAEE) advocates partisan positions or specific solutions to environmental problems. The purpose of forums and study circles is to influence the process of addressing environmental issues in a more fundamental way. Before elected officials decide upon specific proposals, they need to know what kind of initiatives the public favors. Forums and study circles provide an occasion for people to consider alternative viewpoints, and move toward a decision on the broad direction that public action should take.

WHAT DO I DO IF I WANT TO CONDUCT AN EIF FORUM OR STUDY CIRCLE?

NAAEE trains individuals interested in learning more about EIF how to run forums and study circles, and holds occasional training of trainers workshops to certify individuals as EIF moderator trainers. There is also a growing network of NAAEE professionals who have conducted forums and may be able to help in your community. In addition, the Kettering Foundation has a great deal of information available on how to plan and conduct forums and study circles through the National Issues Forums program; most of these materials can be easily adapted to the EIF program.

For information on the EIF program or training opportunities, please contact the EIF Coordinator at NAAEE, Suite 400, 1255 23rd St. NW, Washington, DC 20037. Phone (202) 884-8914, fax (202) 884-8701. E-mail: ashotkin@aed.org.

For information on how to order additional books in the EIF series, or EIF's *Guide to Planning and Conducting Environmental Issues Forums and Study Circles*, contact the NAAEE Publications and Membership Office at P.O. Box 400, Troy, OH 45373. Phone and fax (513) 676-2514. E-mail: jthoreen @igc.apc.org.

A New Generation of Pollution Problems

In *Currents of Change*, the final report of the Canadian Inquiry on Federal Water Policy, the authors note that "protecting the quality of our natural environment has emerged as a major issue of our time." It is clear that, when it comes to water quality, we have not fully satisfied that concern. We have a long way to go to restore the health of our nations' waters. But in order to make progress, we need to understand the challenges we face today.

The image of a factory or sewage plant dumping foul-smelling waste into a river does not fully describe our water pollution problems. Keith Melville of the Public Agenda Foundation notes that the environment problems of the 1990s are more difficult to address than those that came before for two basic reasons. First, he says, "many of today's pressing environmental hazards are less visible, and thus more difficult to call to the public's attention. . . Second, responsibility for environmental hazards is widely shared." Exploring these characteristics can help us understand our problems in a new way.

Many of today's water pollution problems are less visible–or less obvious–than those that we addressed before.

It is easier to respond to a problem that we can see, taste, or feel. The water pollution problems of the 1950s and '60s offered plenty of vivid images that grabbed our attention. By contrast, we cannot always see or taste the effects of today's most pressing threats to water quality.

Groundwater contamination, for example, is a growing concern in Canada and the United States. Groundwater is held in cracks, crevices, and other spaces in underground rock, gravel, or soil. It is recharged by rain and snowmelt percolating down through the soil. One out of every four Canadians and half of the residents of the U.S. rely on groundwater for drinking water. Nearly all of the people living in rural areas of the United States get their drinking water from these underground sources.

The extent of underground pollution is difficult to gauge. Groundwater is more difficult to obtain for testing than is surface water. When groundwater is polluted, the contaminants usually travel undetected until they show up in tests of well water or spring water. We are also unsure of how much groundwater pollution there is because research methods are not always consistent and there is a lack of data about many pollutants. Although we do not know the full story, research results suggest that there are many areas with widespread pollution. Groundwater near the surface seems especially prone to problems. Once groundwater is polluted, it is costly–and sometimes impossible–to clean up. The problems may last for decades.

Pollutants and Their Sources

Common Pollutant Categories

	Biological Oxygen Demand	Bacteria	Nutrients	Ammonia	Turbidity	Total Dissolved Solids	Acids
Point Sources							
Municipal Sewage Treatment Plants	■	■	■	■			
Industrial Facilities	■						
Combined Sewer Overflows	■	■	■	■	■	■	
Nonpoint Sources							
Agricultural Runoff	■	■	■		■	■	
Urban Runoff	■	■	■		■	■	
Construction Runoff			■		■		
Mining Runoff					■	■	■
Septic Systems	■	■	■				
Landfills/Spills	■						
Silviculture Runoff	■		■		■		

U.S. Environmental Protection Agency

Elements of an Issue Book
Issue Matrix

	Choice 1	Choice 2	Choice 3
What's the real problem?			
In general terms, how can we solve the problem?			
What specific actions will help?			
What is important to supporters of this choice? What do they value?			
What are the cons (or downsides) of this choice?			

Common Types of Water Pollution

Water pollution is a very broad term. It includes any activity that changes aquatic systems to the point where plant or animal life may be harmed, human health may be threatened, or water may become so dirty that we can no longer enjoy it or use it for recreation. Listed below are some of the major causes of water pollution. Look at these carefully. You may be surprised at some of the forms pollution can take.

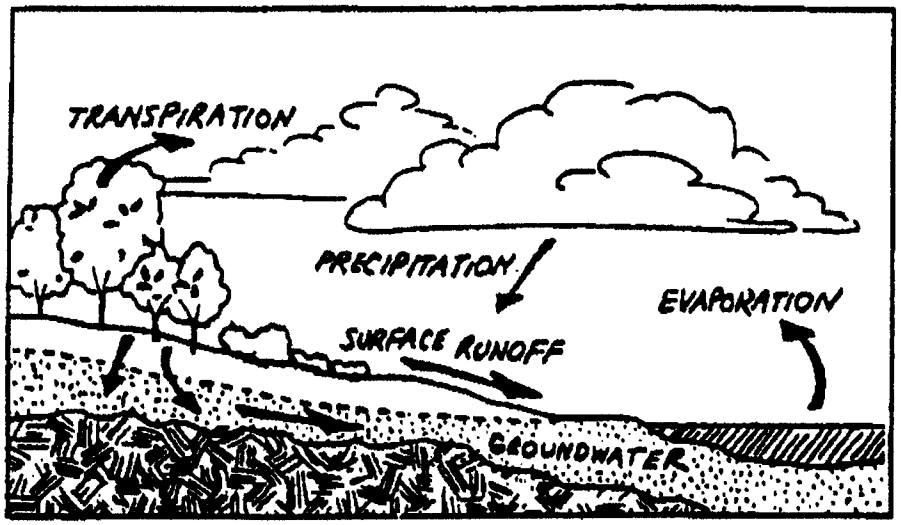
Type of pollution	Effects	Some Sources
Sediment	• Interferes with plant photosynthesis, which reduces the amount of oxygen in the water • Suffocates fish and bottom dwellers, and destroys fish feeding and spawning grounds • Clogs reservoirs, irrigation canals, rivers, lakes, and harbors • Makes it necessary to filter drinking water	• Runoff from farmland, city streets and parking lots, construction and logging sites, and active and abandoned mines • Changing natural streambanks, constructing dams, and dredging
Nutrients (such as nitrates found in fertilizers and phosphates found in detergents)	• Prompt excessive growth of aquatic plants and algae. As they die and decay, bacteria feed on them, using up the dissolved oxygen in the water and cutting off light in deeper waters. This causes: * Fish and other aquatic life forms to suffocate * Foul odors to develop * Recreational and aesthetic enjoyment to decrease	• Soil erosion • Food-processing industries • Runoff from barnyards, feedlots, and farmlands • Untreated or poorly treated sewage • Industrial wastes • Household detergents • Automobile exhaust
Oxygen-demanding wastes	• These organic wastes feed large colonies of bacteria and protozoa, which can use up the oxygen dissolved in the water. This causes: * Some species of fish to be replaced by species that are less sensitive to low oxygen conditions, and many fish killed outright * Organisms such as mayflies–that provide food for fish and other animals–to die * Foul odors to develop	• Soil erosion • Sewage • Leaves and grass clippings • Garbage • Runoff from urban areas during storms • Runoff from livestock feedlots and pastures • Industrial wastes (e.g. from slaughterhouses, canneries, cheese factories, and oil refineries)
Disease-causing organisms (such as bacteria, viruses, and protozoans)	• Water-borne diseases such as cholera, typhoid fever, dysentery, polio, and infectious hepatitis • Symptoms such as fever, nausea, and diarrhea	• Human and animal wastes from sewers, storm water drains, septic systems, runoff from livestock pens, and boats that dump sewage
Heavy metals (such as mercury, lead and cadmium, and selenium) and **toxic chemicals** (such as PCBs and dioxin)	• Cause death or reproductive failure in fish, shellfish, and wildlife • Pose health risks to humans	• Industrial discharges (either direct, or indirect via releases to sewage treatment plants) • Runoff from city streets • Mining activities • Water that drains through landfills
Pesticides and herbicides	• Often persist in the environment for long periods of time • May accumulate in fish, shellfish, and wildlife • Pose health risks to humans	• Runoff from farmland and lawns • Runoff from urban areas (where, for example, pesticides may be used for termite control)
Heat	• Disrupts aquatic systems, changing the kinds of fish and plants that can survive in lakes and streams • Interferes with fish reproduction • Increases susceptibility of fish to diseases and toxics	• Discharge of warm water from electrical power, steel, and chemical plants • Streamside activities such as grazing that remove vegetation that shades the water

Source: U.S. Environmental Protection Agency, *The Quality of Our Nation's Water.*

Ground Rules for Our Forum

- Everyone is encouraged to participate.
- No one dominates.
- Listening is as important as speaking.
- We speak to each other, not just to the facilitator.
- We all help to keep the discussion on track and focused on the choices.
- We consider each option fairly and examine its tradeoffs as fully as we can.

"Clear As Mud"
Whose Water is it Anyway?



Alison L. Reber
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Kansas StreamLink is a program of the Kaw Valley Heritage Alliance, a 501(c)3 nonprofit organization.

Kansas StreamLink is funded in part by grants from the Environmental Protection Agency Region 7, Kansas Department of Health and Environment, and Kansas Department of Wildlife and Parks. Additional funding is provided through donations from individual team sponsors.

The National Environmental Policy Act 1969

Created a National Policy for the Environment & established a Council on Environmental Quality.

- Each Generation is trustee of the environment for succeeding generations.
- All Americans should have safe, healthful, productive, and aesthetically & culturally pleasing surroundings.
- We will attain the widest range of beneficial uses of the environment without degradation, risk to health or safety, or other undesirable and unintended consequences.
- We will preserve important historic, cultural, and natural aspects of our national heritage, and maintain, wherever possible, an environment which supports diversity, and variety of individual choice.
- We will achieve a balance between population and resource use which will permit high standards of living and a wide sharing of life's amenities.
- We will enhance the quality of renewable resources and approach the maximum attainable recycling of depletable resources.

The congress recognizes that each person should enjoy a healthful environment and that each person has a responsibility to contribute to the preservation and enhancement of the environment.

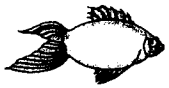
Federal water legislation dates back to the nineteenth century, when Congress enacted the River and HarborAct of 1886, recodified in the Rivers and Harbors Act of 1899.

Federal Water Pollution Control Act 1972
Clean Water Act 1977

- Established the basic structure for regulating discharges of pollutants into the waters of the United States.
- Gave EPA the authority to implement pollution control programs such as setting wastewater standards for industry.
- Continued requirements to set water quality standards for all contaminants in surface waters.
- Made it unlawful for any person to discharge any pollutant from a point source into navigable waters, unless a permit was obtained under its provisions.
- Funded the construction of sewage treatment plants under the construction grants program.
- And recognized the need for planning to addres the critical problems posed by nonpoint source pollution.



CWA 303(d) & the Designated Uses

Aquatic Life 


Contact Recreation

Domestic Water Supply 


Food Procurement

Ground Water Recharge 


Industrial Water Supply

Irrigation Use 


Livestock Watering

Water Quality Standards

(aka Who's on First, Watt's on Second)

1) EPA establishes national criteria for water quality parameters. (Criteria are for guidance and are not compulsory)

2) States and Tribes adopt standards based on designated uses.

3.) EPA approves state and tribe standards.

4) States determine the designated use of a water body.




Waters that do not meet standards for their designated uses are listed on the state's 303(d) list.

Weighing our Water on the 303(d) Scale





YIKES: Kansas' 303(d) list is 10x longer than our midwest neighbors.

OHHH: Kansas has different water quality standards than neighboring states.

AHHH: Kansas has more water condition information available to help make the 303(d) than most states.

Lakes and streams on the 303(d) list receive special attention.

Total Maximum Daily Loads (TMDLs)

A 303(d) Listee Looks in the Mirror

What's causing the problem?
How bad is the problem?
What can be done to fix the problem?
How can we be sure we fixed it?
When should we look again?



p.s. There was a rather large debate over who should get to ask these questions! It was finally settled in court. The STATE will determine the corrective actions necessary to bring a 303(d) listee into compliance. This is based on the fact that it is the STATE that makes the determination to make a 303(d) listing to begin with....

2002 KANSAS WATER QUALITY ASSESSMENT (305(b) REPORT) April 1, 2002

Kansas Department of Health and Environment
Division of Environment
Bureau of Environmental Field Services
Suite #430 1000 SW Jackson
Topeka, Kansas 66612-1367

PART I: EXECUTIVE SUMMARY/OVERVIEW This report, the *2002 Kansas Water Quality Assessment*, also known as the 305(b) Report, is the biennial assessment of the state's surface water quality as required by 33 USC 466 *et seq.*, the Federal Water Pollution Control Act, commonly referred to as the Clean Water Act. The guidance by U. S. Environmental Protection Agency (EPA) for the preparation of this report provided options for reporting. The Kansas Department of Health and Environment (KDHE) elected to provide the an electronic report accompanied by an abbreviated narrative report. The abbreviated narrative report contains only the information required by law that has **changed** from the last report (2000 Kansas Water Quality Assessment 305(b) Report), March 31, 2000) and a simple reference to that report.

The Kansas Department of Health and Environment assessed the water quality for the period of 1998 through 2001, of 19,827 miles of streams, all of which were considered monitored. This report represents an increased assessment of 1,591 miles from the 2000 305(b) Report. This increase in milage is due (1) to assessment of four years of monitoring data and (2) to the increase in both in the number of stream chemistry and biological monitoring sites. A total of 188,487 lake acres were assessed. Of these, 175,894 acres were monitored and the conditions of an additional 12,593 lake acres were evaluated using professional judgement. An assessment of cumulative designated use stream mileage revealed that 67 % of the designated uses were fully or partially supported. Of the assessed streams, 24 % (in stream miles) supported all designated uses. Of the assessed lakes, 19 % of the total acres were fully supporting but threatened for at least one designated use and 77 % were impaired for one or more uses.

The *2002 Kansas Water Quality Assessment Report* includes four years of ambient stream chemistry data (1998 - 2001) and only acute aquatic life use support application. Fish consumption advisories and swimming beach closures were applied in lieu of published criteria for food procurement and primary contact recreation. These approaches are consistent with the 1997 US EPA guidance and reflect the manner in which most states have prepared past 305(b) reports. The assessments contained in this report are otherwise consistent with the application of the numeric and narrative 2001 Kansas surface water quality standards.

The major causes of nonsupport for streams, in order of prevalence, are sulfate, pathogen indicators (fecal coliform), organic enrichment, and chlorides. The major causes for lake impairments were sediments, turbidity, taste and odor, and nutrients/eutrophication. Sources responsible for widespread pollutant loadings and beneficial use impairments of streams include agriculture (nonirrigated and irrigated crop production, and intensive animal feeding operations), natural sources, habitat modification, municipal point sources, and groundwater withdrawal. Major sources for lake impairment included agriculture and municipal point sources. Of the assessed lake acreage in Kansas, 69% was stable over time, while slightly more than 12% appeared to be undergoing measurable eutrophication. Thirteen percent of total lake acres showed appreciable improvement in trophic state condition during this reporting cycle. Municipal point sources, natural sources, and agriculture were the primary contributing factors to lake eutrophication.

High nitrate concentrations accounted for about 85% of the documented exceedences of the federal drinking water maximum contaminant levels (MCLs) during 2000 through 2001 for the groundwater monitoring network. Other isolated concerns of groundwater contamination included the presence of volatile organic compounds, heavy metals, petroleum products and/or bacteria. The major sources of these contaminants included active industrial facilities, spills, leaking storage tanks, mineral extraction activities, and agricultural activities.

The imposition of more stringent permit limits and the resulting upgrades of municipal and industrial wastewater treatment facilities continue to result in notable improvements in surface water quality. As the number of point sources causing or contributing to significant water quality impairments continues to decline, future attention will necessarily shift to the remaining sources, primarily nonpoint sources. It is anticipated that watershed pollution control efforts, predicated on the development of Total Maximum Daily Loads (TMDLs) and on the allocation of allowable pollutant loadings among point, nonpoint, and natural sources, will play an increasingly important role in the abatement of surface water pollution and improvement in water quality in Kansas. By June 30, 2002 Kansas will have established TMDLs for waterbodies listed in the 1998 Kansas 303(d) List in nine of the twelve river basins.

1996 KANSAS WATER QUALITY ASSESSMENT (305(b) REPORT)

December 1996

Kansas Department of Health and Environment, Division of Environment
Bureau of Environmental Field Services
Forbes Field, Building 283, Topeka, Kansas 66620-0001

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PART IV: GROUNDWATER ASSESSMENT

Much of Kansas is underlain by porous geological formations containing appreciable quantities of groundwater. The largest such formations consist of unconsolidated materials (gravel, sand, and silt) deposited by streams. Some unconsolidated glacial deposits and consolidated bedrock formations also contain appreciable quantities of groundwater. The total freshwater storage in all major Kansas aquifers is estimated at 590 million acre-feet.

Groundwater resources are relatively abundant in the western two-thirds of the state where surface water is scarce. Groundwater resources are limited in the eastern one-third of Kansas where surface water is more plentiful. Ninety percent of all water use within the state is supplied from groundwater. Irrigation continues to account for the greatest consumptive use of this resource.

A total of 637 community public water supplies are dependent on groundwater, either solely or in combination with surface water sources. These supplies serve a total population of 1,717,464. In most rural areas, groundwater provides the primary source of drinking water.

Groundwater quality in most of the state is generally sufficient to maintain existing uses. The mineral content of the soil and rock formations in which groundwater is found causes the water to be quite hard (greater than 200 mg/L as calcium carbonate). Groundwater quality problems are generally site-specific. A few of these site specific problems are the result of natural source contamination, but usually the contamination is due to human activities. The Kansas Department of Health and Environment is cognizant of over 500 isolated groundwater pollution problems not including Leaking Underground Storage Tanks (LUST) sites.

Groundwater Monitoring Program

The department's groundwater quality monitoring network is the primary ambient groundwater program in Kansas. Public water supply wells are monitored by KDHE's Bureau of Water (BOW) for compliance with state and federal drinking water standards. Additional monitoring is done in intensive groundwater usage areas by five groundwater management districts (GMDs).

A statewide Wellhead Protection Program (WHPP) was recently approved by EPA. At least three Kansas counties are in the process of developing or establishing local WHPP plans and several other communities in the state have expressed interest and/or have started collecting information about forming local WHPPs. The City of Hays already has adopted a local WHPP.

Numerous other state programs have been established or are in the developmental stages to assist in groundwater protection and pollution prevention (Table 34).

Table 34. Summary of State Groundwater Protection Programs

Programs or Activities	Check (X)	Implementation Status	Responsible State Agency
Active SARA Title III program	X	fully established	KDHE*
Ambient groundwater monitoring	X	fully established	KDHE
Aquifer vulnerability assessment	X	on going	KDHE*
Aquifer mapping	X	fully established	KGS
Aquifer characterization	X	on going	KGS
Comprehensive data management	X		
EPA-endorsed Core Comprehensive State Groundwater Protection Program	X	under review	KDHE
Groundwater discharge permits	X	fully established	KDHE
Groundwater Best Management Practices	X	fully established	KDHE
Groundwater legislation	X		
Groundwater classification	X		
Groundwater quality standards	X	not established	KDHE
Interagency coordination for groundwater protection initiatives	X		
NPS controls	X	fully established	KDHE*
Pesticide State Management Plan	X	under revision	KDA
Pollution Prevention Program	X	fully established	KDHE
RCRA Primacy	X	fully established	KDHE
State Superfund	X	fully established	KDHE
State RCRA with more stringent requirements than RCRA Primacy	X	fully established	KDHE
State septic system regulations	X	fully established	KDHE
Underground Storage Tank (UST) installation requirements	X	fully established	KDHE

UST Remediation Fund	X	fully established	KDHE
UST Permit Program	X	fully established	KDHE
Underground Injection Control Program	X	fully established	KCC & KDHE
Vulnerability assessment for drinking water/wellhead protection	X	in process	KDHE
Well abandonment regulations	X	fully established	KDHE
Wellhead Protection Program (EPA-approved)	X	approved by EPA	KDHE
Well installation regulations	X	fully established	KDHE

*principal administrative agency

Groundwater Quality Monitoring Network

The Kansas groundwater quality monitoring network (Figure 9), established in 1976 as a cooperative program between USGS and KDHE, is the principal statewide groundwater quality monitoring effort. In 1990, KDHE assumed sole responsibility for the monitoring network.

The primary goal of the network is to procure long-term, statewide groundwater quality data for use in the identification of temporal and spatial trends in groundwater quality associated with the following: (1) alterations in land use, (2) application of land treatment methods and other NPS best management practices, (3) changes in groundwater availability or withdrawal rates, and (4) variations in climatological conditions within the state. In addition, the network is intended to assist in the identification of groundwater contamination problems in Kansas.

The current (1995) Kansas groundwater quality monitoring network is composed of 242 wells including public water supply (PWS)(71%), irrigation (14%), rural-domestic (10%), multiple use (3%), livestock watering (1%), and industrial wells (1%). During the period 1991-1995, 628 well samples were analyzed for common inorganic chemicals and heavy metals; 490 well samples were analyzed for pesticides; 113 well samples were analyzed for volatile organic compounds (VOCs); and 124 well samples were analyzed for radionuclides (Appendix Part I.E.). Additionally, some of the network wells were also sampled by other programs.

Most wells were sampled more than once during this reporting period. Each network well is sampled for inorganics every other year. The wells chosen to be sampled each year for pesticides, VOCs, and radionuclides are rotated systematically throughout the network; five of the wells repeatedly sampled for radiation are located in southeastern Kansas because of known problems in that region. Beginning in 1993, an allotment of 10 radiation samples per year was also analyzed for radon.

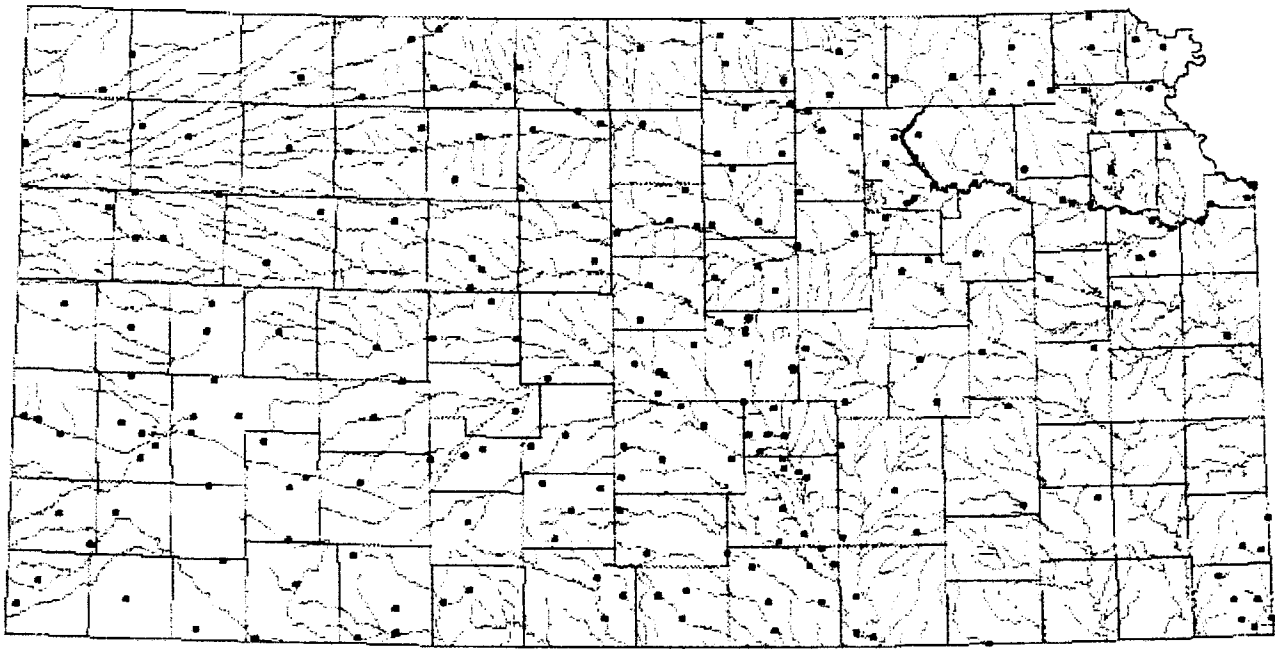
In evaluating the data from 1991-1995, 126 instances were found in which the chemical quality of the raw groundwater samples exceeded federal drinking water Maximum Contaminant Levels (MCLs). Of these, 81 were due to nitrate exceedences. The occurrence of nitrate in groundwater is generally attributed to human activities (such as agricultural fertilizer applications, malfunctioning septic systems, etc.), natural conditions, or both.

Special Studies

In response to the "flood of 1993", CDC funded a systematic study of private water wells in Kansas and eight other midwest states to determine the extent of microbiological and/or chemical contamination of groundwater resulting from flood waters or subsequent high watertables. The department's Division of Health implemented the Kansas portion of this multi-state study.

The surveyed wells were analyzed for total coliform bacteria, *Escherichia coli*, nitrate, atrazine, and lead. In addition to the collection of water samples, a questionnaire for each well was completed that covered the following topics: well construction, depth, age, location in relation to possible sources of contamination, demographic data, and health of the well users.

FIGURE 9. GROUNDWATER MONITORING NETWORK



KANSAS DEPARTMENT OF HEALTH AND ENVIRONMENT

1996 305(b) Report

The results of this study indicated that certain types of wells, especially dug wells, are more susceptible to contamination. However, since the survey tested wells randomly derived from intersecting points on a map grid, samples were collected regardless of whether the well was properly constructed or sealed.

For this reason and because the samples were collected from a faucet inside the homes with minimal purging (lead samples were taken from the first flow), this study does not give a true representation of actual groundwater quality. Nevertheless, the study does provide useful insight concerning drinking water quality "at the tap" of typical rural-domestic well users in Kansas.

Major Causes and Sources of Groundwater Contamination

Based on the most recent available compilation by KDHE's Bureau of Environmental Remediation (BER), there are 645 documented contamination sites on the Identified Sites List (ISL) within the state, excluding sites under the jurisdiction of the Kansas Corporation Commission (KCC). Of these ISL sites, 120 were resolved leaving 525 active sites. The most common sources of contamination are operational problems at active facilities, spills, and leaking and/or overflowing lagoons (KDHE 1996).

Within recent years, BER has expanded the petroleum storage tank program which has uncovered several occurrences of groundwater contamination and has implicated leaking storage tanks as a significant source of groundwater contamination.

The Underground Petroleum Storage Tank Release Trust Fund was established to provide reimbursements to tank owners for corrective action costs. A total of 197 new site applications were received by the Fund in 1995.

Nonpoint sources of pollution comprise another major concern in Kansas; however, it is an extremely difficult issue to address due to the widespread nature of the problem. Nonpoint sources of groundwater contamination potentially include such things as agricultural activities, urban runoff, mining, application of residential lawn chemicals, highway deicing materials, feedlots, salvage yards, airports, golf courses, and many other factors.

Additionally, certain regions of the state have groundwater quality problems due, in part, to naturally occurring conditions. One example would be brine intrusion from underlying salt deposits in some areas. Table 35 lists a few of the most significant sources of groundwater contamination in the state based on the best professional judgement of KDHE staff.

Table 35. Major Sources of Groundwater Contamination

Twelve Highest Priority Contaminant Sources	Factors Considered in Selecting a Contaminant Source	Types of Contaminants
AGRICULTURAL ACTIVITIES: Agricultural chemical facilities	D,A,C	C,E
Agricultural chemical applications	A,C,D	E,B
Animal feedlots	D,A,C	J,E
STORAGE AND TREATMENT: Storage tanks (AST/LUST)	D,B,A,C	D
Surface impoundments	E,A	J,E
DISPOSAL ACTIVITIES: Landfills/illegal dumping	E,C,A	H
OTHER: Abandoned facilities	A,B,C	C,H
Industrial facilities	A,B,C	C,H
Oil and gas activities	D,A,B,C	D,G
Pipelines and sewer lines	E,A	D,E
Salt water intrusion	E,C,B	G
Spills	D,A	D,C

Factors Considered in Selecting a Contaminant Source:

(A) Human health and/or environmental risk (toxicity)
(B) Size of population at risk
(C) Location of sources relative to drinking water sources
(D) Number and/or size of contaminant sources
(E) Hydrogeologic sensitivity

Types of Contaminants:

(A) Inorganic pesticides
(B) Organic pesticides
(C) Halogenated solvents
(D) Petroleum compounds
(E) Nitrate
(F) Fluoride
(G) Salinity/brine
(H) Metals
(I) Radionuclides
(J) Bacteria
(K) Protozoa
(L) Viruses

Nationally, the EPA has identified 1,245 contaminated sites that are included on the 1995 National Priorities List (NPL) and are targeted for cleanup under Superfund (EPA 1995b). Presently, there are twelve NPL sites located in Kansas. All but one of these 12 NPL sites are located in the eastern half of the state.

With the possible exception of the nitrate problem, most of the groundwater contamination occurs mainly as isolated situations due to human activity involving VOCs, heavy metals, and/or petroleum products. In a few areas, naturally occurring constituents, such as fluoride, selenium, and radionuclides, may locally exceed MCLs. A summary of all known groundwater contamination sites is presented in Table 36.

Summary of Groundwater Quality

Kansas groundwater is generally very hard (usually greater than 200 mg/L) and often contains relatively high concentrations of TDS, manganese, and iron. In some areas, elevated levels of ammonia, sulfate, sodium, and chloride also exist. These constituents normally do not cause health-related problems; however, they may create aesthetic problems such as scale deposits, stains, odor, and undesirable taste.

Nitrate contamination in groundwater is a major concern due to the many, widespread sources. Nitrate accounted for most instances in which federal drinking water MCLs were exceeded. During the period 1991-1995, excessive concentrations of nitrate (greater than 10 mg/L as N) were observed in approximately 12% of 681 well samples collected from the Kansas groundwater quality monitoring network (most wells were sampled more than once), compared to 14% during the period 1976-1981.

A majority of the well samples with excessive concentrations of nitrate during this reporting period were obtained from relatively shallow wells that were 100 feet or less in total depth. Wells located in areas of the state where the soils are extremely sandy and where the water table is relatively close to the surface have a greater chance of yielding higher nitrate levels. Water quality in most Kansas aquifers may be highly variable which makes definitive source assessment of nitrates difficult.

Groundwater contamination in Kansas is typically site-specific. Isolated groundwater pollution problems are occasionally due to natural sources, but more often are due to human activity or a combination of both. Despite these various documented problems, groundwater quality in the state is generally adequate to maintain present uses, if pollution prevention and groundwater protection practices continue to be implemented.

Table 36. Groundwater Contamination Summary. Statewide Summary for the Period of 1991-1995

Source Type	Present in Kansas	# of Kansas Sites	# of Sites with Confirmed Releases	# with Confirmed Groundwater Contamination	Primary Contaminants	# of Site Investi-gations	# of Sites with Source Removed	# of Sites with CAPs	# of Sites with Active Remediation	# of Sites with Cleanup Completed
NPL	yes	15	15	13	VOCs, metals	15			8	3
CERCLIS (non-NPL)	yes	557	424	360	VOCs, metals & pesticides	557	323			
DOD/DOE	yes	47	31	26	VOCs, metals	23	1	4	4	0
LUST	yes	4,498	2,257	unavailable	petroleum	4,498	1,305		1,620	953
RCRA Corrective Action	yes	under EPA control								
Underground Injection *	yes	33	0	0		0	0	0	0	0
State Sites **	yes	481	481	299	VOCs, metals	265			138	78
NPS	yes	unknown								
Totals		5,631	3,208	698		5,358	1,629	4	1,770	1,034

CAPs - Corrective Action Plans
CERCLIS - Comprehensive Environmental Response, Compensation, and Liability Information System
DOD/DOE - Department of Defense/Department of Energy
LUST - Leaking Underground Storage Tanks
NPL - National Priority List
NPS - Non Point Source
RCRA - Resource Conservation and Recovery Act

* Represents Class I, III, and V injection wells, but does not include Class II brine injection wells.
** Numbers are for 1993 only and do not include sites under KCC jurisdiction

2004
KANSAS WATER QUALITY ASSESSMENT
(305(b) REPORT)



April 1, 2004

Kansas Department of Health and Environment
Division of Environment
Bureau of Environmental Field Services
Suite #430
1000 SW Jackson
Topeka, Kansas 66612-1367

PART IV: GROUNDWATER

The Kansas Groundwater Monitoring Network was discontinued in 2001. Any groundwater monitoring done in the State was through Remediation, Waste Management, or PWS Programs.

Summary tables have been provided as follows:

Table 14. Summary of State Groundwater Protection Programs
Table 15. Major Sources of Groundwater Contamination
Table 16. Groundwater Contamination Summary
Table 17. Aquifer Monitoring Data

Table 14. Summary of State Groundwater Protection Programs

Programs or Activities	Check (X)	Implementation Status	Responsible State Agency
Active SARA Title III program	X	fully established	KDHE*
Ambient groundwater monitoring			
Aquifer vulnerability assessment	X	on going	KDHE*
Aquifer mapping	X	fully established	KGS
Aquifer characterization	X	on going	KGS
Comprehensive data management	X	on going	KDHE
EPA-endorsed Core Comprehensive State Groundwater Protection Program	X	under review	KDHE
Groundwater discharge permits	X	fully established	KDHE
Groundwater Best Management Practices	X	fully established	KDHE
Groundwater quality standards			
Interagency coordination for groundwater protection initiatives	X	on going	KWO
NPS controls	X	fully established	KDHE*
Pesticide State Management Plan	X	EPA approved plan implementation proceeding	KDA
Pollution Prevention Program	X	fully established	KDHE
RCRA Primacy	X	fully established	KDHE
Source Water Assessment Program (SWAP	X	fully established	KDHE
State Superfund	X	fully established	KDHE
State RCRA with more stringent requirements than RCRA Primacy	X	fully established	KDHE
State septic system regulations	X	fully established	KDHE
Underground Storage Tank (UST) installation requirements	X	fully established	KDHE
UST Remediation Fund	X	fully established	KDHE
UST Permit Program	X	fully established	KDHE
Underground Hydrocarbon Storage Well Program	X	fully established	KDHE
Underground Injection Control Program	X	fully established	KCC & KDHE
Vulnerability assessment for drinking water/wellhead protection	X	EPA approved plan implementation proceeding	KDHE
Well abandonment regulations	X	fully established	KDHE
Wellhead Protection Program (EPA-approved)	X	EPA approved plan implementation proceeding	KDHE
Well installation regulations	X	fully established	KDHE

*principal administrative agency

Table 15. Major Sources of Groundwater Contamination

Ten Highest Priority Contaminant Sources	Factors Considered in Selecting a Contaminant Source	Types of Contaminants
AGRICULTURAL ACTIVITIES: Ag. chemical facilities/applications	D,A,C	E,B,C
Animal feedlots	D,A,C	J,E
STORAGE AND TREATMENT: Storage tanks (AST/LUST)	D,B,A,C	D
Surface impoundments	E,A	J,E
DISPOSAL ACTIVITIES: Landfills/illegal dumping	E,C,A	H
OTHER: Active/abandoned industrial facilities	A,B,C	C,H
Oil and gas activities	D,A,B,C	D,G
Pipelines and sewer lines	E,A	D,E
Salt water intrusion	E,C,B	G
Spills	D,A	D,C

Factors Considered in Selecting a Contaminant Source:
(A) Human health and/or environmental risk (toxicity)
(B) Size of population at risk
(C) Location of sources relative to drinking water sources
(D) Number and/or size of contaminant sources
(E) Hydrogeologic sensitivity

Types of Contaminants:
(A) Inorganic pesticides
(B) Organic pesticides
(C) Halogenated solvents
(D) Petroleum compounds
(E) Nitrate
(F) Fluoride
(G) Salinity/brine
(H) Metals
(I) Radionuclides
(J) Bacteria
(K) Protozoa
(L) Viruses

Table16. Groundwater Contamination Summary. Statewide Cumulative Summary Through December 31, 2003

Source Type	# of Kansas Sites	# of Sites with Confirmed Releases	# with Confirmed Groundwater Contamination	Primary Contaminants	# of Site Assess-ments	# of Sites with Source Removed	# of Sites with CAPs	# of Sites with Active Remediation	# of Sites with Cleanup Resolved
NPL	13	13	13	VOCs, metals	13	unavailable	1	7	5
CERCLIS (non-NPL)	690	690	690	VOCs, metals & pesticides	690	unavailable	unavailable	127	89
DOD/DOE	43	43	43	VOCs, metals	43	unavailable	unavailable	6	1
LUST	9,884	5,207	2,620	gasoline and diesel fuels	9,884	4,090	unavailable	2,328	2,818
RCRA Corrective Action	under EPA control								
Underground Injection *	32	0	0	0	0	0	0	0	0
Underground Hydrocarbon Storage Wells	10	1	0	methane	1	1	1	1	0
State Sites **	647	647	647	VOCs, metals	647	unavailable	unavailable	121	88
NPS	unknown								

CAPs - Corrective Action Plans
CERCLIS - Comprehensive Environmental Response, Compensation, and Liability Information System
DOD/DOE - Department of Defense/Department of Energy
LUST - Leaking Underground Storage Tanks
NPL - National Priority List
NPS - Non Point Source
RCRA - Resource Conservation and Recovery Act
* Represents Class I and III injection wells and hydrocarbon storage sites, but does not include Class II brine injection wells.
** Numbers do not include sites under KCC jurisdiction or LUST sites.

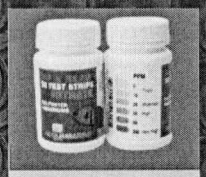
Table17. Aquifer Monitoring Data
Statewide summary for the period of 2000-2003

Monitoring Data Type	Total # of Well Samples in the Assessment	Parameter Groups	Parameters Not Detected or Nitrate • 5 mg/L	Parameters Detected or Nitrate >5 to • 10 mg/L	Parameters Exceeding the MCLs	Removed From Service	Background Parameters Exceeding MCLs
Public Water Supply Network: groundwater sources*	1,831	VOC	1,636	175*	20	30	0
	2,159	SOC	1,934	221	4	35	0
	1,831	EDB	1,765	61	5	30	0
	2,007	FLUORID	113	1,891	3	28	0
	1,659	MERCUR	1,643	15	1	28	0
	5,593	NITRATE	3,595	1,527	471	131	280
	1,659	SELENIU	203	1,450	6	28	57

NOTES: (1) Some wells may of been sampled more than once during the reporting period (2000-2003).
(2) All data obtained from the Kansas Public Water Supply Monitoring Network.
(3) Only inorganic parameters with federal drinking water MCLs were included in this summary.
(4) Groundwater monitoring network samples were collected after well purging and prior to any treatment.
(5) Some wells have more than one VOC parameter detected.
(6) VOC= volatile organic compound; SOC=synthetic organic compound; EDB= ethylene dibromide.
(*) Finished water after treatment; may have occasional surface water influence.

Water Chemistry Basics and Field Testing Methods



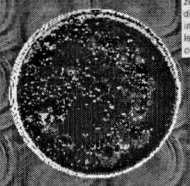


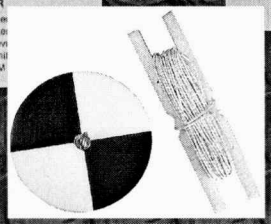
NITRATE FOR SALT & FRESH WATER

Nitrate test is scale
zero. Nitrate saltwate
dip and 2 minute dev
indicates nitrate ni
levels over 23 PPM
corals.









CHEMICAL BONDING

- **Ionic bonds - formed by the electrostatic attraction between oppositely charged ions.**

$$Na + Cl \longrightarrow Na^{+} + Cl^{-}$$

Na contributes electron, leaving it with a closed shell
Cl gains electron, leaving it with a closed shell

- **Covalent bonds - bonds formed by sharing of electrons.**

$$H + H \longrightarrow H\ H$$

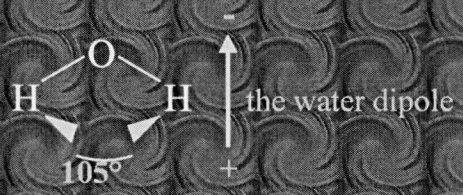
- **Polar Covalent bonds - the sharing of the electron pair is unequal. There is a charge separation with one atom being slightly more positive and the other more negative.**

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WHY DO WE CARE IF A BOND IS IONIC OR COVALENT?

- All physical and chemical properties of a compound depend on the character of the bonds.
- Solubility in water (general rule - like dissolves like)

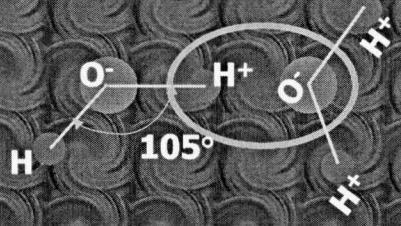
Water is a polar covalent solvent - 39% ionic & 61% covalent - meaning there is a positive and a negative pole to the molecule.



Water dissolves ionic solids (e.g., NaCl, K_2SO_4) very well. On the other hand, polar water is a very poor solvent for many organic compounds, e.g., toxic benzene (C_6H_6).

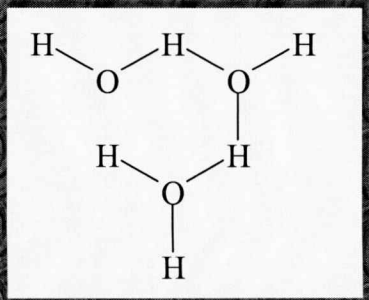
http://www.mines.edu/students/h/hseo/research.htm

PROPERTIES OF WATER



Because each water molecule has a positive and a negative end, these can attract one another to form a *hydrogen bond.*

- The hydrogen bonding of water is responsible for many anomalous properties of water.

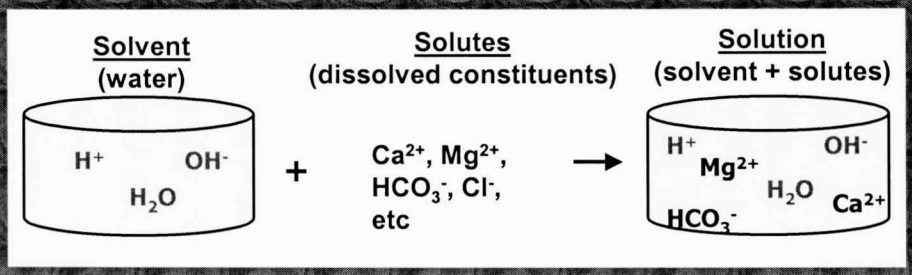


- high boiling point & melting point
- The maximum density is at 4C.
- Ice is less dense than the liquid water.

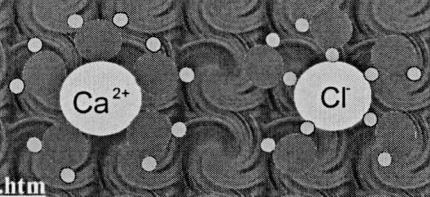
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PROPERTIES OF WATER

- **Solvent : Water dissolves some amount of virtually every solid or gas.**



- **Also because of the polar nature of water, ions will be surrounded by water dipoles (hydrated) in solution.**
- **Hydration isolates the ions from their neighbors and neutralizes the attractive forces that hold minerals together.**



http://www.mines.edu/students/h/hseo/research.htm

pH

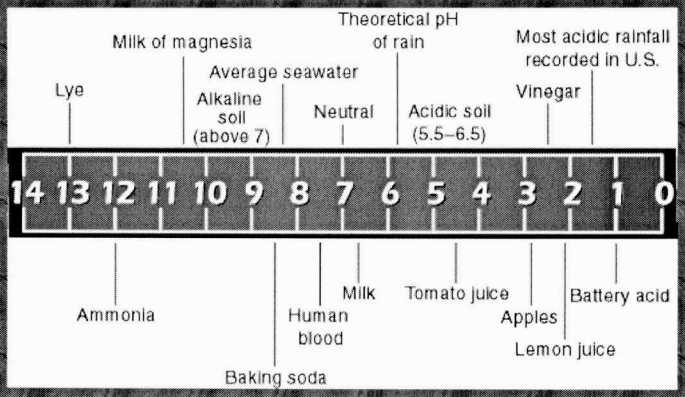
Pure water has the same number (or concentration) of H^+ as OH^- ions.

Acidic solutions have more H^+ ions than OH^- ions.

Basic solutions have the opposite.

An acid causes an increase in the numbers of H^+ ions.

A base causes an increase in the numbers of OH^- ions.



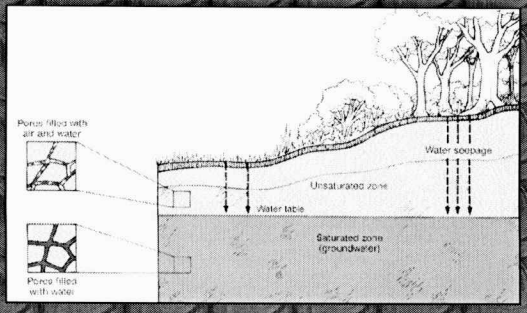
sjr.state.fl.us/.../ landscape/principle2.html

pH is the negative $\log_{10}$ ($-\log [H^+]$)of the hydrogen ion concentration.

Changes in pH can result in dissolution or precipitation of minerals or degradation by microbes.

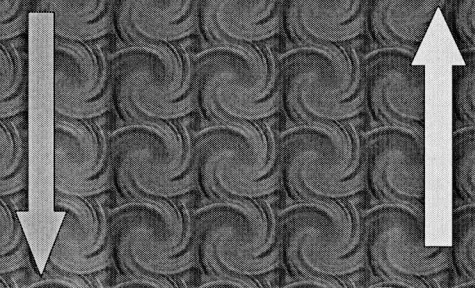
What controls recharge water chemistry at the water table?

- **Composition of recharge:**
  - Leaching of salts accumulated in vadose zone by evapotranspiration
  - Soil weathering and biological processes
  - **These Produce CO_2 !**



http://www.mines.edu/students/h/hseo/research.htm

- **Composition of subsurface rock:**
  - Calcite is common and ubiquitous
  - Silicates not very soluble – low contribution to water
  - **Both Are Affected by Increase in Acidity (decrease in pH)**



pH

Dissolution

Carbonate in Water

An important set of reactions are:

$CO_2(g) + H_20 = CO_2(aq)$

$CO_2(aq) + H_20 \Leftrightarrow H_2CO_3$

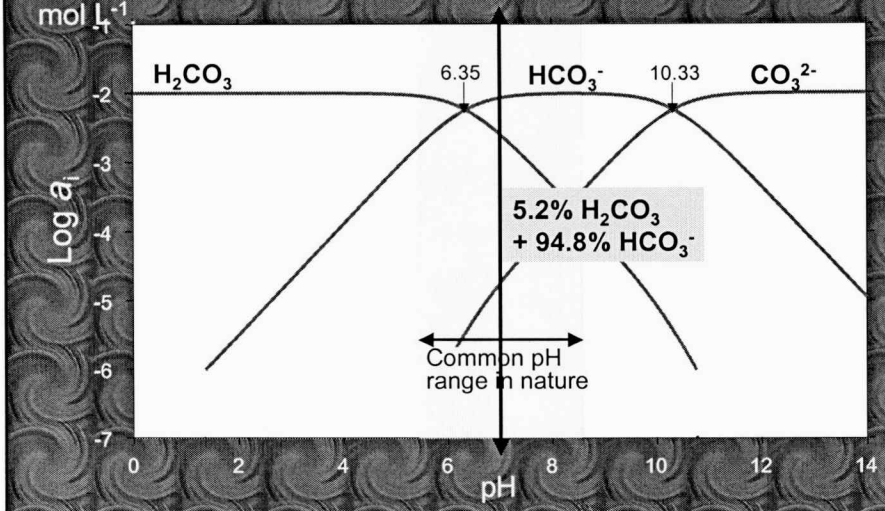
$H_2CO_3 \Leftrightarrow H^+ + HCO_3^-$

….as CO_2 is added to water, the acidity increases –
the pH goes down

→ Groundwater TDS increases

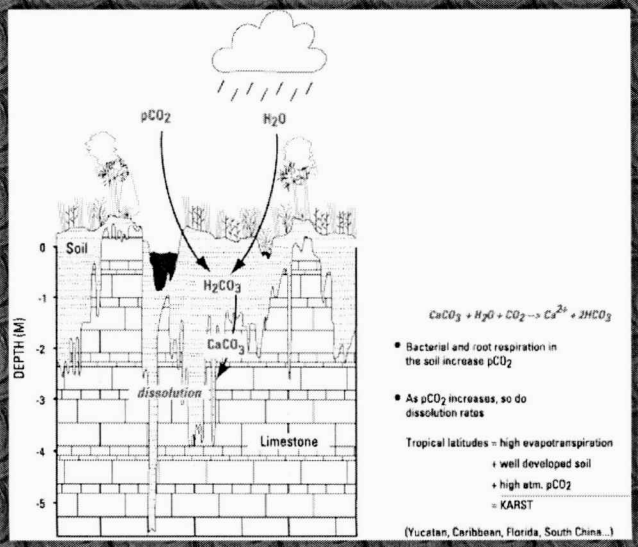
http://www.mines.edu/students/h/hseo/research.htm

Bjerrum plot showing the activities of inorganic carbon species as a function of pH for a value of total inorganic carbon of 10^{-3} mol L^{-1}.



In most natural waters, **bicarbonate** is the dominant carbonate species!

http://www.mines.edu/students/h/hseo/research.htm



http://coastal.er.usgs.gov/publications/ofr/00-180/intro/karst.html

Total Alkalinity is defined as the amount of acid required to lower the pH of the sample to the point where all of the bicarbonate [HCO3-] and carbonate [CO3--] could be converted to carbonic acid [H2CO3].

This is called the carbonic acid equivalence point or the carbonic acid endpoint.

(1) $H^+ + CO3 \Longrightarrow HCO_3^-$

(2) $H^+ + HCO3^- \Longrightarrow H_2CO_3$

Alkalinity conversion: $CaCO_3/0.8202 = HCO_3^-$ concentration

http://www.mines.edu/students/h/hseo/research.htm

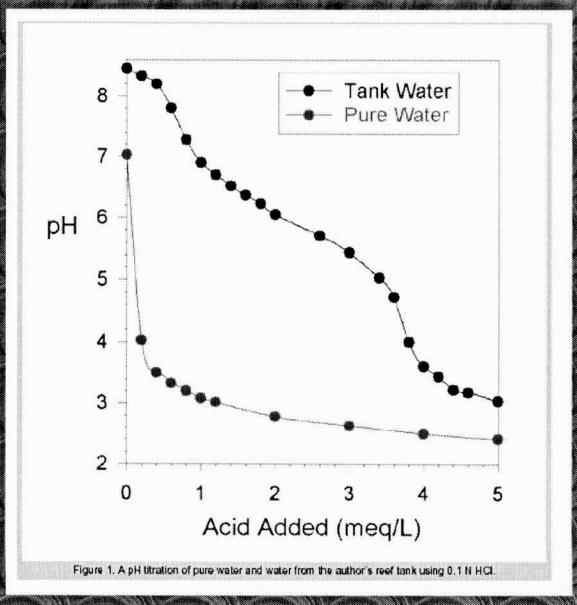


Figure 1. A pH titration of pure water and water from the author's reef tank using 0.1 N HCl.

Alkalinity conversion: $CaCO_3/0.8202 = HCO_3^-$ concentration

Chemical Species	Relative Contribution To Alkalinity
HCO_3^- (bicarbonate)	89.8
CO_3^{--} (carbonate)	6.7
$B(OH)_4^-$ (borate)	2.9
$SiO(OH)_3^-$ (silicate)	0.2
$MgOH^+$ (magnesium monohydroxylate)	0.1
OH^- (hydroxide)	0.1
HPO_4^{--} and PO_4^{---} (phosphate)	0.1

Electrolytic Conductivity (EC) is defined as the ability of a substance to conduct electric current.

Amount of conductivity varies widely:

Extremely low (insulators - benzene, glass) to

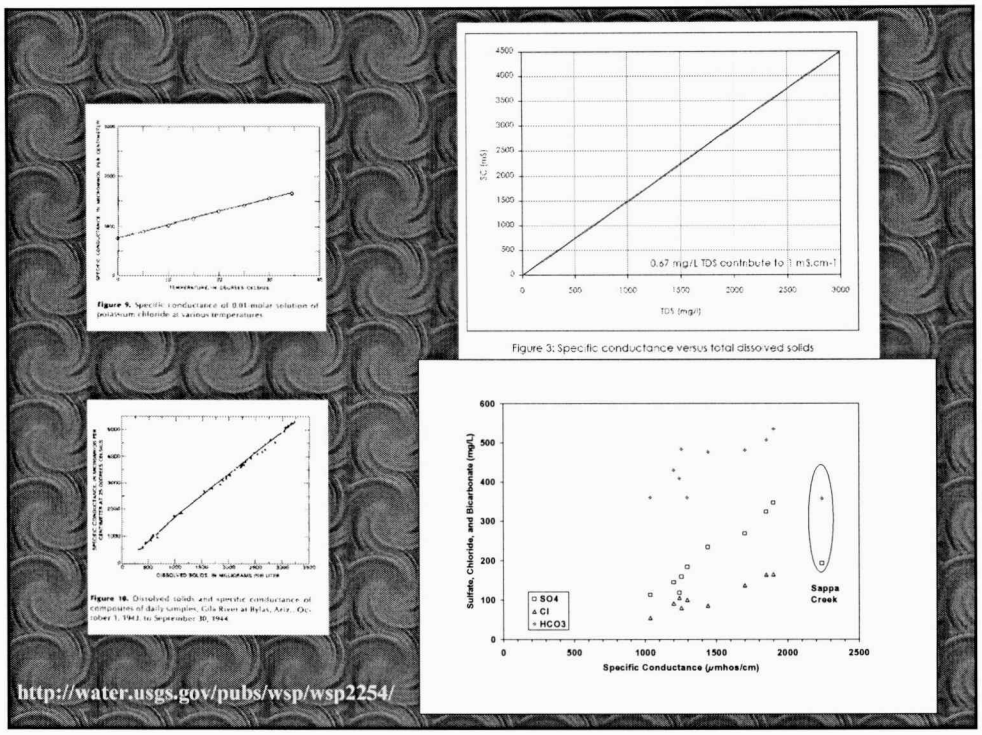
Very high (silver, copper, and metals in general).

The conductivity measurement of liquids, which generally consists of ionic compounds dissolved in water.

Conductivity can be measured quite easily by electronic means, and this offers a simple test that can tell much about the quality of the water

ranging from pure water (low conductivity) to concentrated chemical streams (high).

http://www.mines.edu/students/h/hseo/research.htm



Total Dissolved Solids Calculation

LAB	SiO2	Ca	Mg	Na	K	Sr	CO3	HCO3	SO4	Cl	F	NO3-UV	B	SUM OF	SUM OF
SP C	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppb	CATIONS	ANIONS
680	16.2	75.2	32.2	16.2	1.1	18.6		387	55.5	6.0	1.05	1.7	92	7.56	7.75

Sum of cations and anions + bicarbonate *0.4917.

Bicarbonate correction assumes ½ concentration volatilized as CO_2 and water. Reporting as carbonate

Ca + Mg + Na + K + Sr +SO4 + Cl + F + NO3 + B + (HCO3 * 0.4917)

TDS = 396

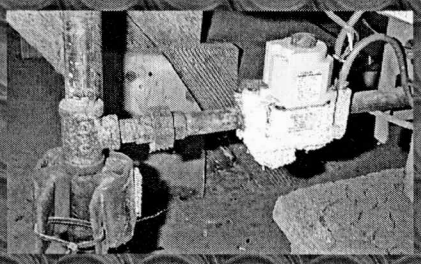
Specific conductance * 0.6 = TDS (approximately)

680 * 0.6 = 408

Hard Water

Water described as "hard" is high in dissolved minerals, specifically calcium and magnesium.

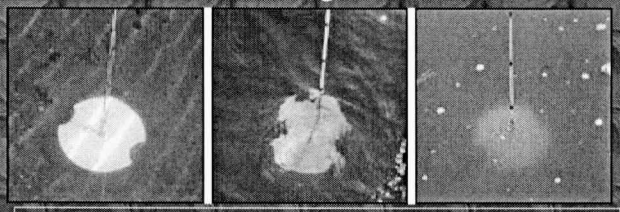
Hard water is not a health risk, but a nuisance because of mineral buildup on fixtures and poor soap and/or detergent performance.



Classification	mg/l or ppm
Soft	0 - 17.1
Slightly hard	17.1 - 60
Moderately hard	60 - 120
Hard	120 - 180
Very Hard	180 & over

A Secchi Disk is Used to Measure Water Clarity in Surface Water (TURBIDITY)

Standardized measurement of water clarity helps monitor changes and communicate these changes to others.

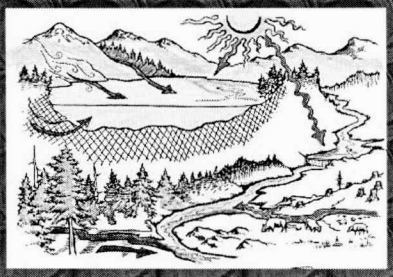


19 – 21 m 10 m 1 – 1.4 m

Sources of turbidity are usually sediment (brownish muddy color), phytoplankton (greenish color), humic stain (tea color from decaying leaves or plants) or some combination of these.

http://earthobservatory.nasa.gov/Study/WaterQuality/water_quality2.html

Temperature



Cooling Influences

- Cool air from high altitudes flows downhill, cooling lakes and streams.
- Riparian trees shade the water and runoff from dense forests is cold.
- Water percolates down into underground aquifers which release cold water throughout the year into lakes and streams.

Warming Influences

- Solar radiation directly warms lakes and streams.
- If there are no riparian trees, water receives more solar radiation.
- Reservoirs behind dams have large surface areas exposed to the sun's rays. If water is released from the surface, it warms streams below.
- Water diverted for flood irrigation returns to streams and lakes at much warmer temperatures.
- Organic and inorganic matter delivered to streams by runoff from the land causes water temperatures to rise more per unit of heat that is absorbed.

http://www.krisweb.com/krisweb_kt/shasta/wqtemp.htm

REDOX Reactions

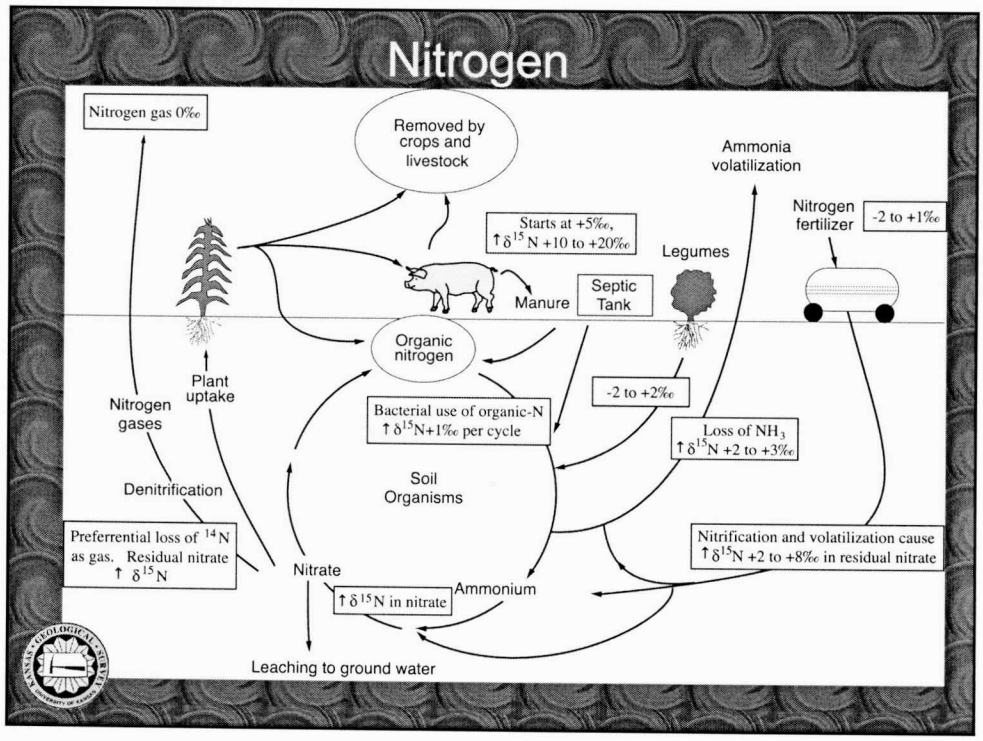
- Oxidation refers to the removal of electrons from an atom, changing its oxidation number (the net charge of a compound)
- Reduction is the addition of an electron
- In nature such redox reactions are invariably mediated by bacteria, which use the reactions as an energy source

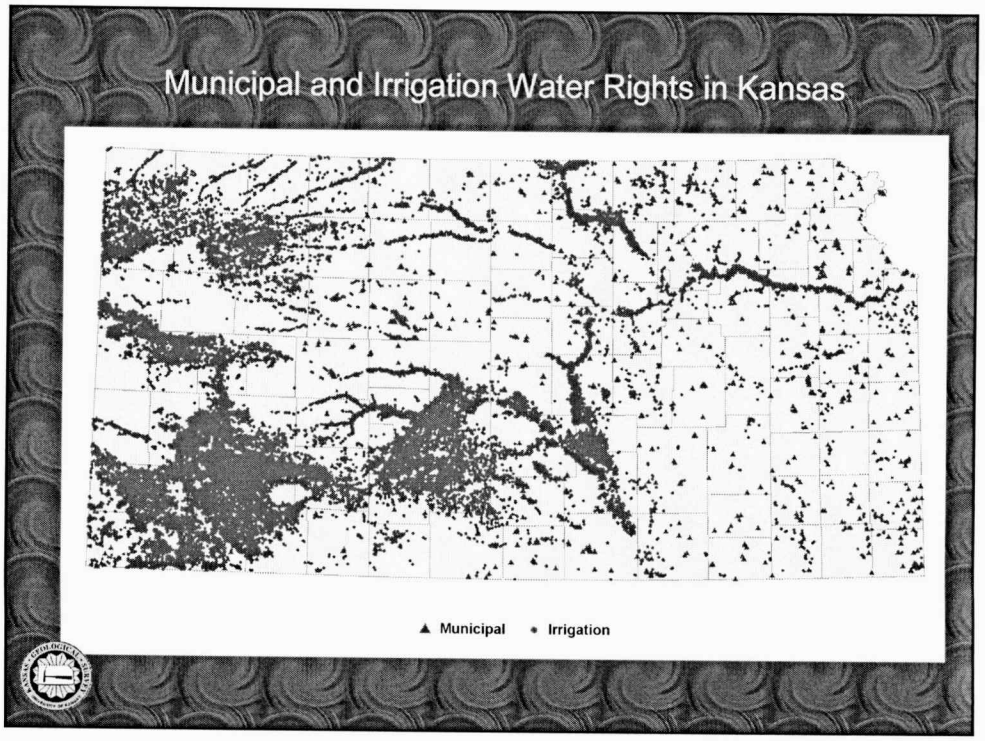
Reduced compound A (reducing agent) — Oxidized compound B (oxidizing agent)

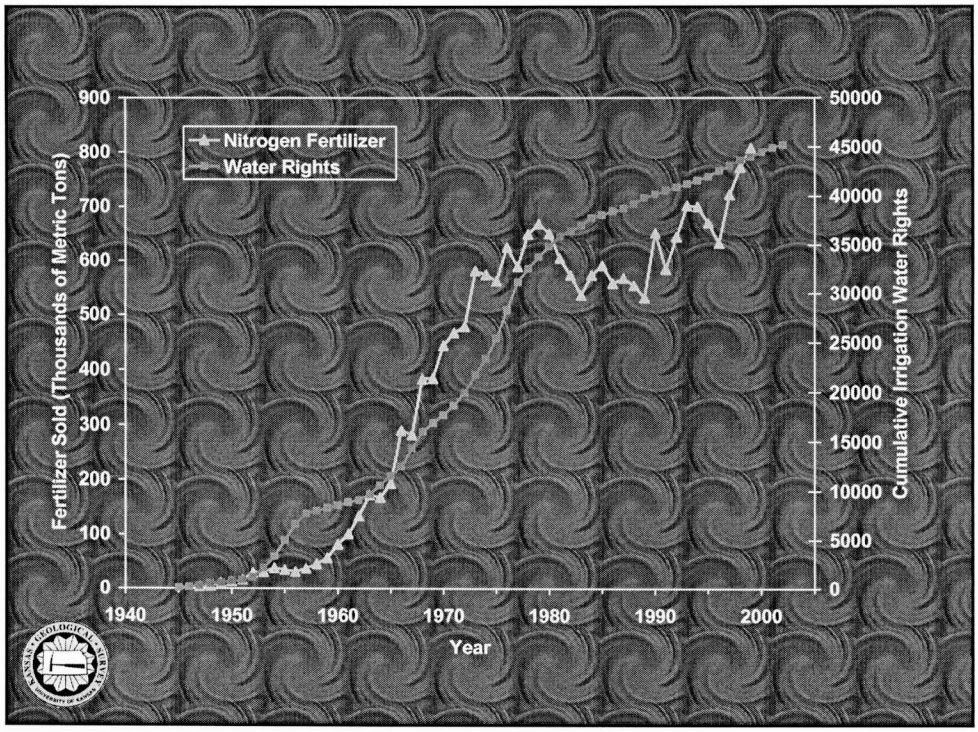
- Oxidation—loss of electrons
- Reduction—gain of electrons
- Oxidized—lost electrons
- Reduced—gained electrons
- Agents—oxidizing agent, reducing agent

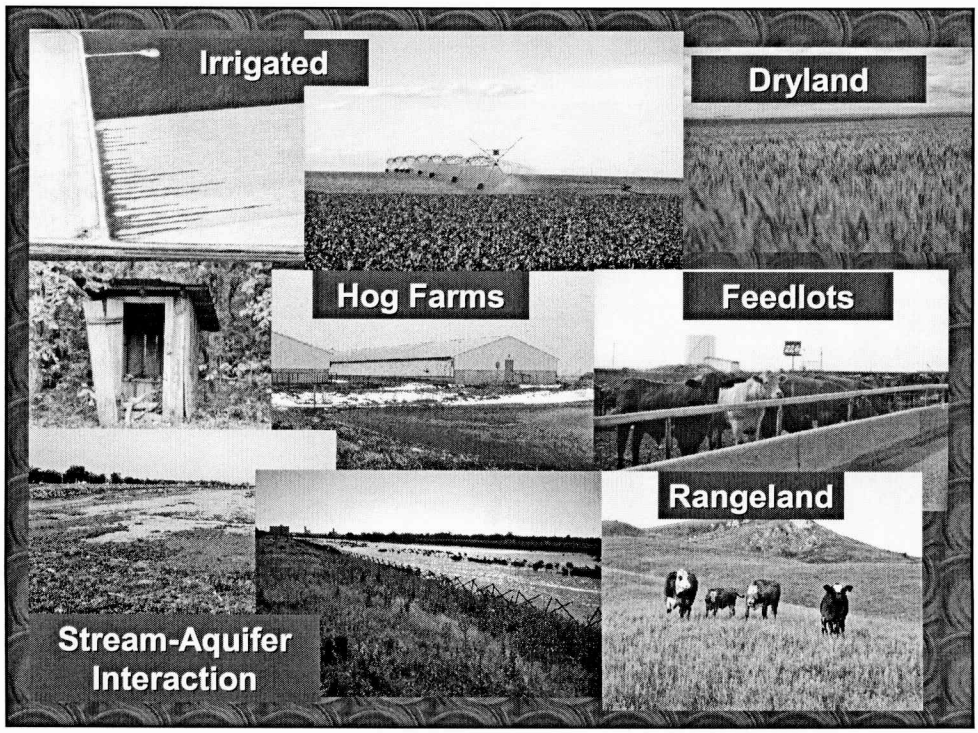
Cannot have one without the other; paired reactions (redox)

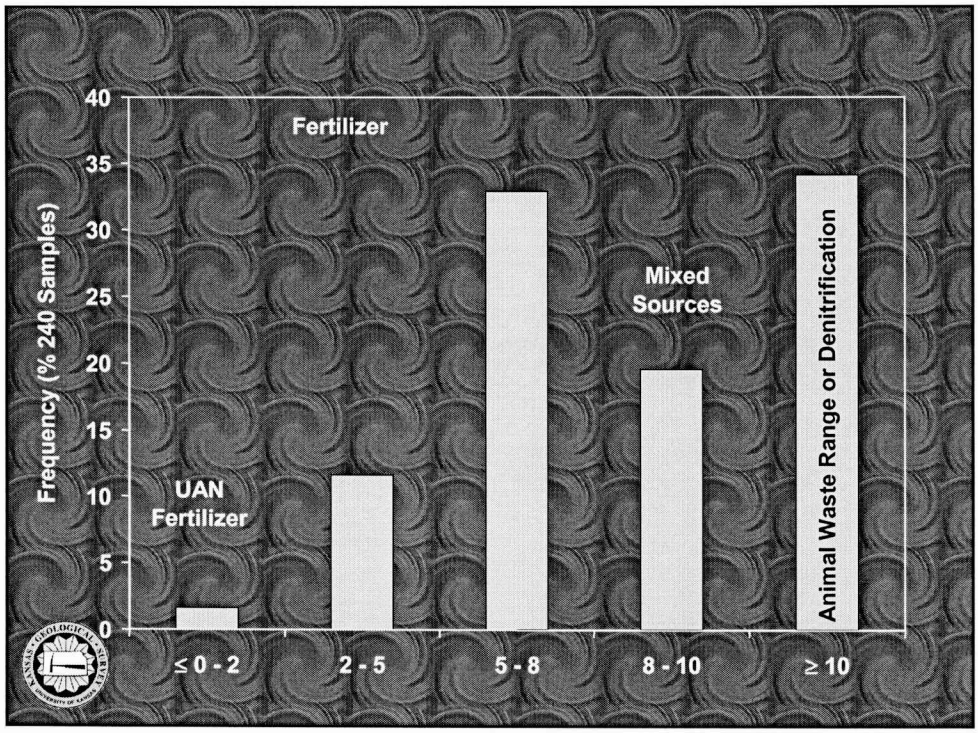
Oxidized compound A — Reduced compound B

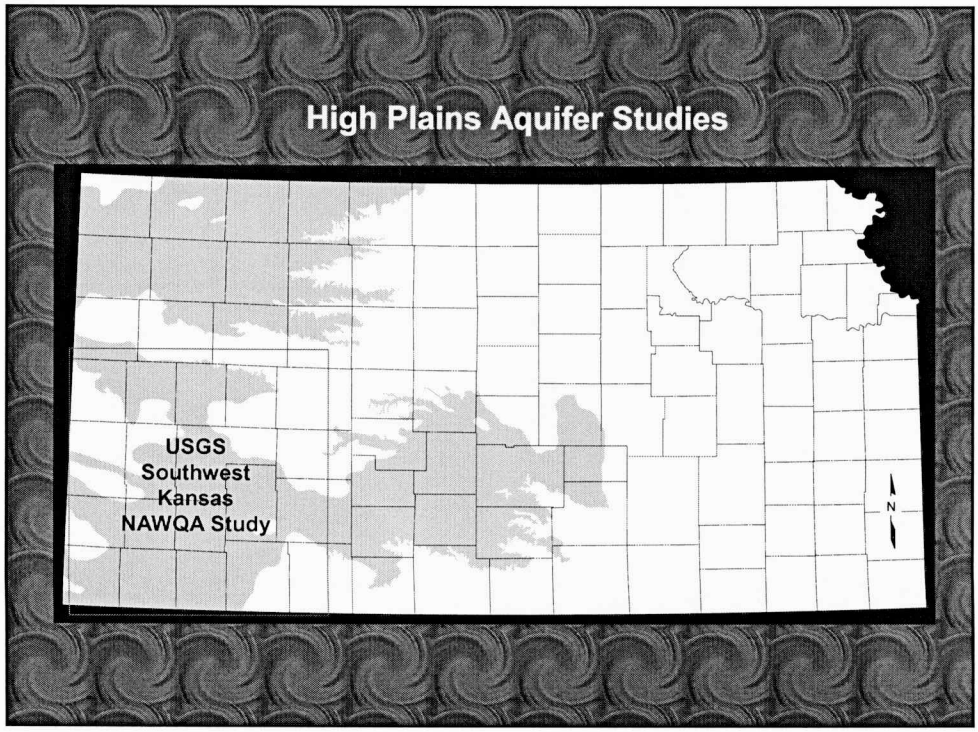

Nitrogen
Nitrogen gas 0‰
Removed by crops and livestock
Ammonia volatilization
Nitrogen fertilizer
-2 to +1‰
Starts at +5‰, ↑δ15N +10 to +20‰
Legumes
Manure
Septic Tank
Organic nitrogen
Plant uptake
Nitrogen gases
-2 to +2‰
Bacterial use of organic-N ↑δ15N+1‰ per cycle
Loss of NH3 ↑δ15N +2 to +3‰
Soil Organisms
Denitrification
Preferrential loss of 14N as gas. Residual nitrate ↑ δ15N
Nitrification and volatilization cause ↑δ15N +2 to +8‰ in residual nitrate
Nitrate
Ammonium
↑δ15N in nitrate
Leaching to ground water

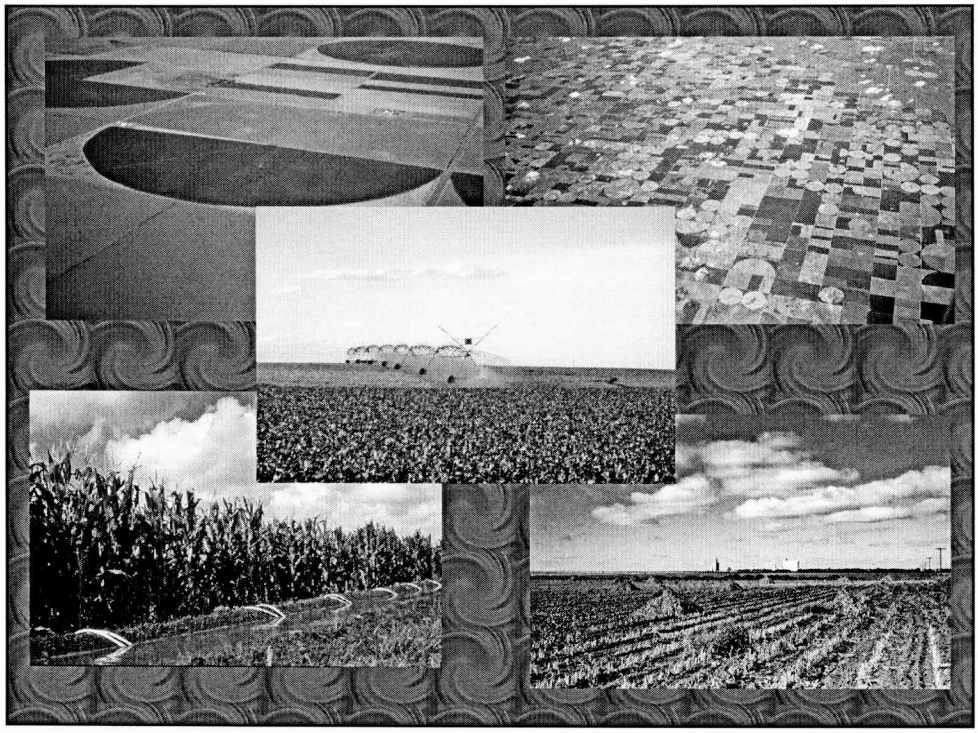

Municipal and Irrigation Water Rights in Kansas
▲ Municipal
• Irrigation

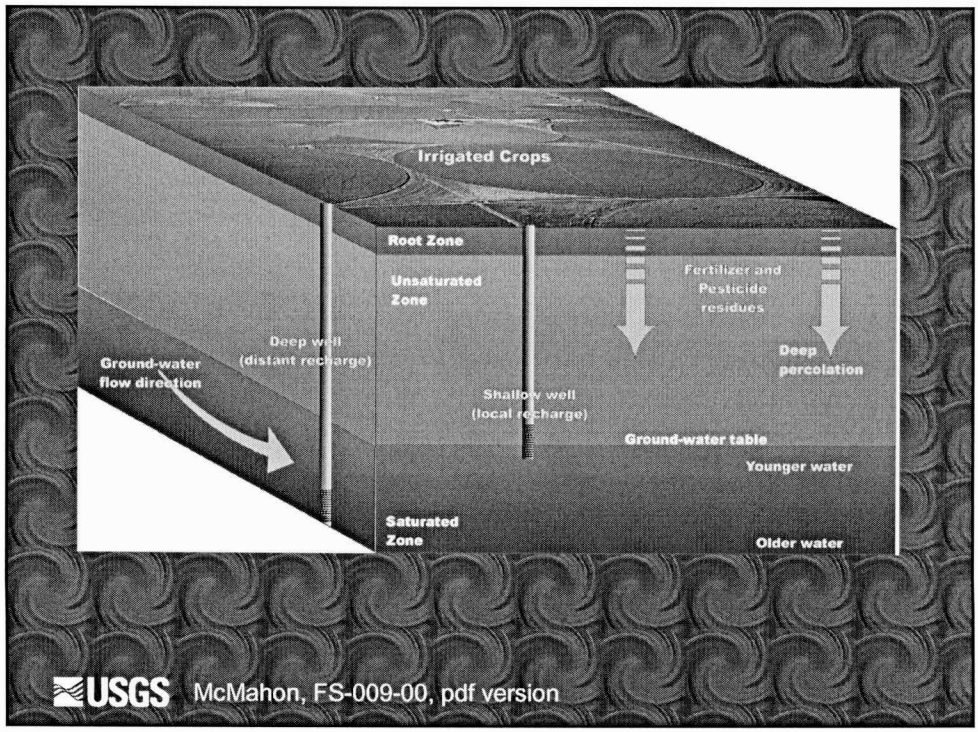

Nitrogen Fertilizer
Water Rights
Fertilizer Sold (Thousands of Metric Tons)
Cumulative Irrigation Water Rights
Year
900
800
700
600
500
400
300
200
100
0
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
1940
1950
1960
1970
1980
1990
2000

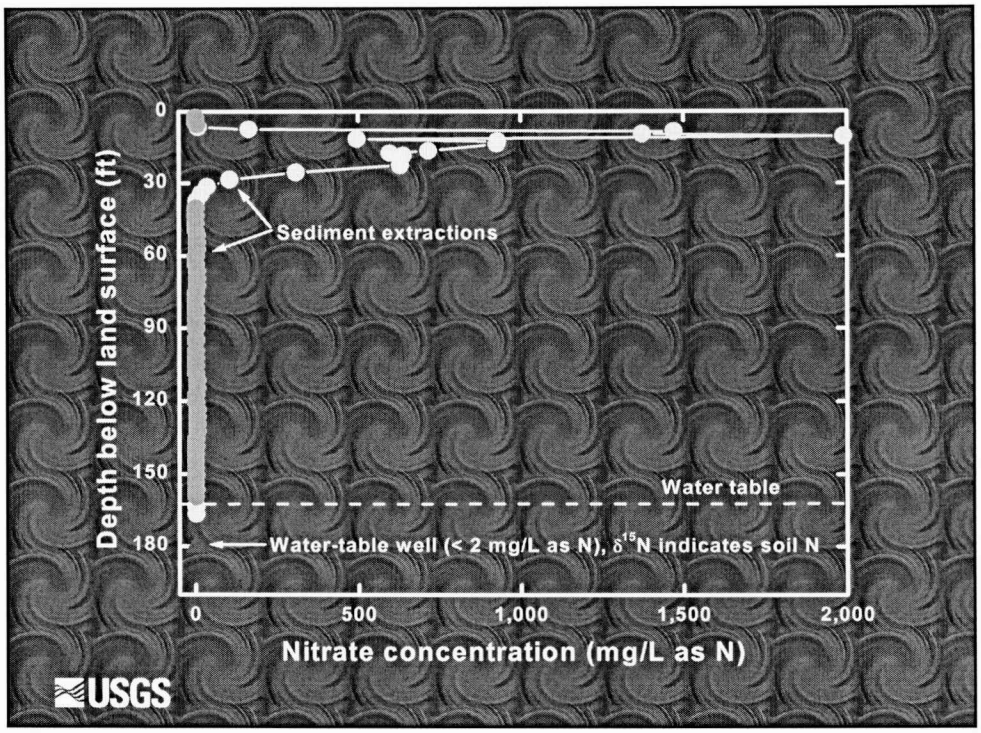

Irrigated
Dryland
Hog Farms
Feedlots
Rangeland
Stream-Aquifer Interaction

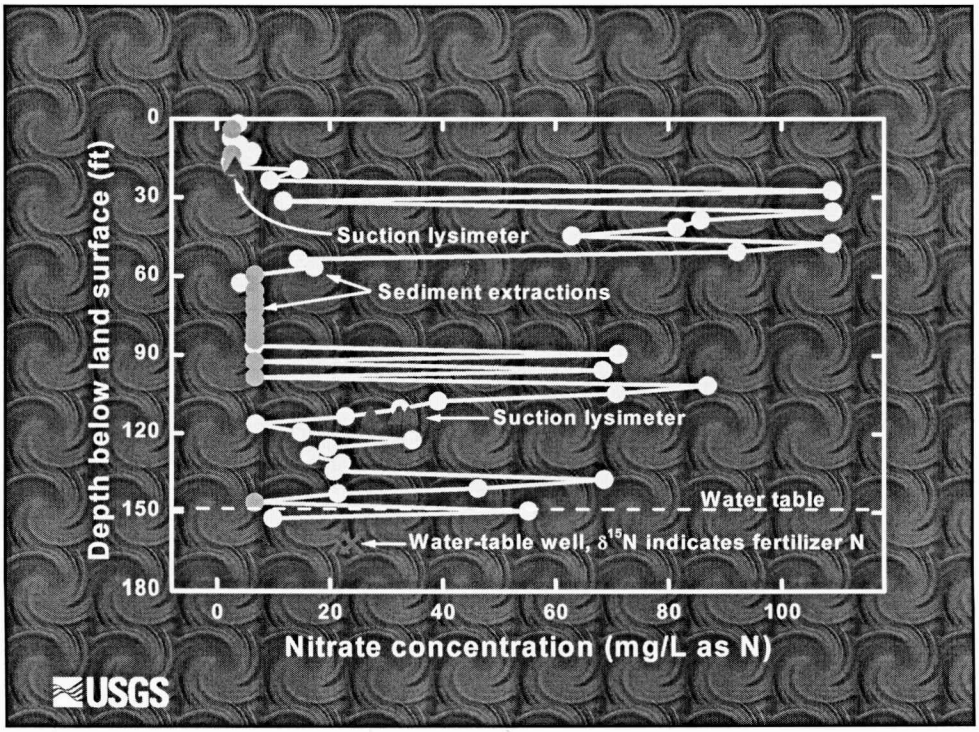

Frequency (% 240 Samples)
40
35
30
25
20
15
10
5
0
Fertilizer
UAN Fertilizer
Mixed Sources
Animal Waste Range or Denitrification
≤ 0 - 2
2 - 5
5 - 8
8 - 10
≥ 10

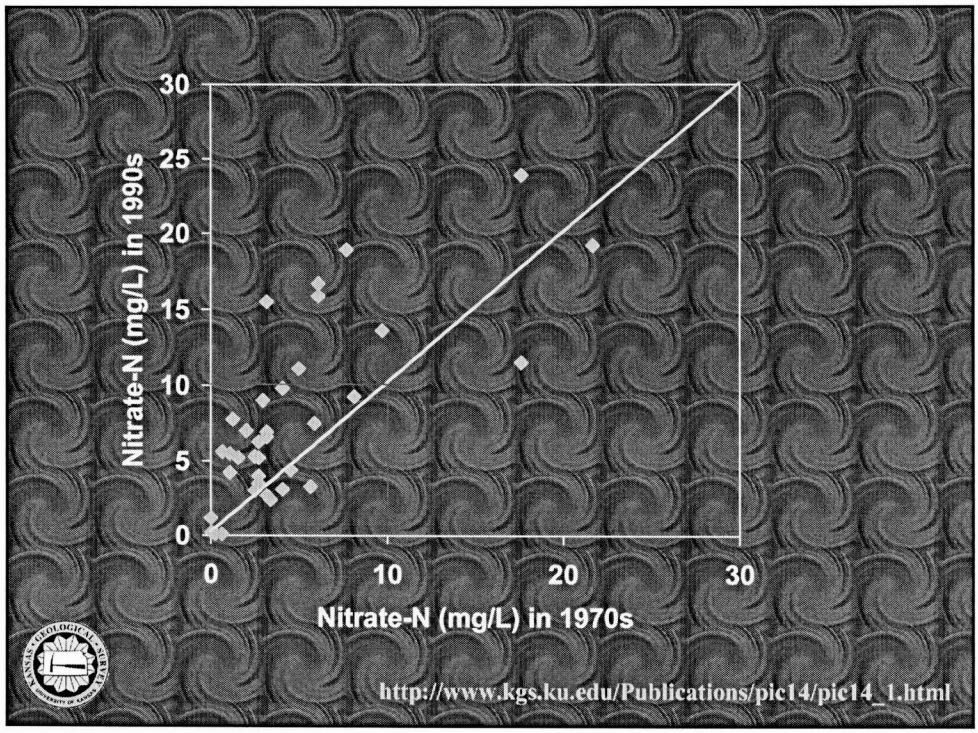

High Plains Aquifer Studies
USGS
Southwest
Kansas
NAWQA Study
N

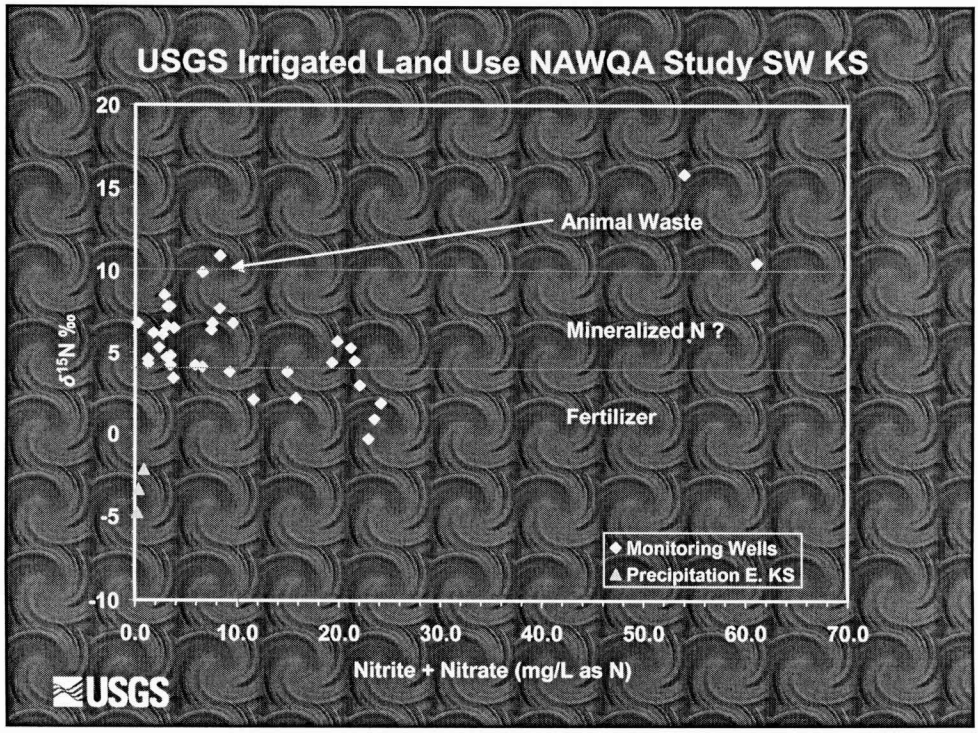


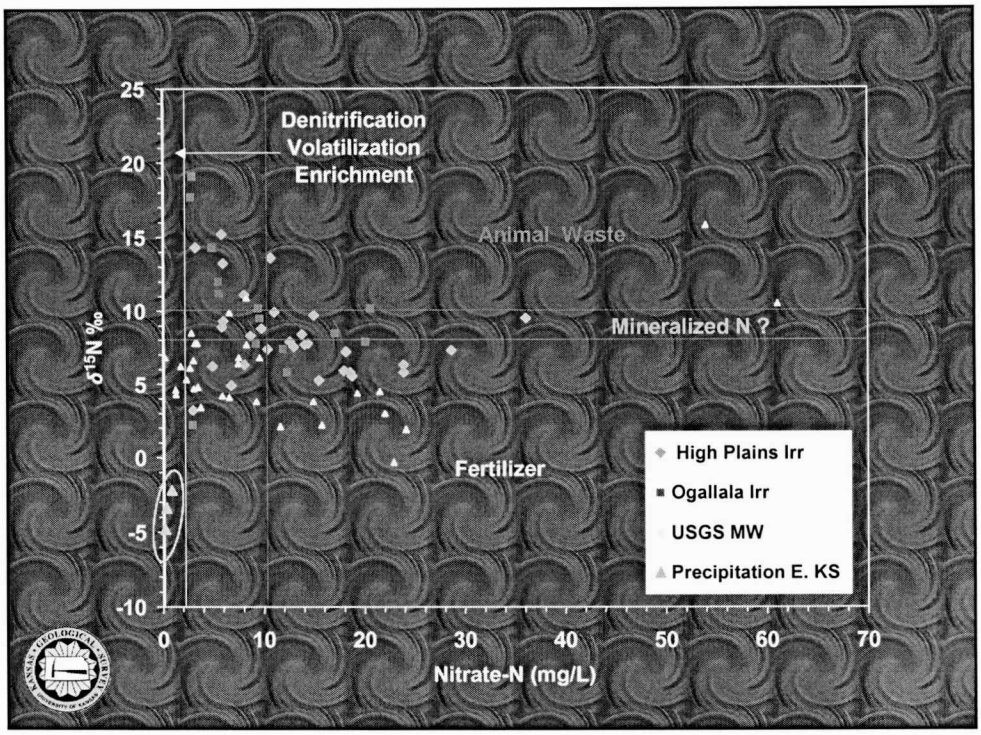

Irrigated Crops
Root Zone
Unsaturated Zone
Fertilizer and Pesticide residues
Deep percolation
Deep well (distant recharge)
Ground-water flow direction
Shallow well (local recharge)
Ground-water table
Younger water
Saturated Zone
Older water
USGS
McMahon, FS-009-00, pdf version


Depth below land surface (ft)
0
30
60
90
120
150
180
Sediment extractions
Water table
Water-table well (< 2 mg/L as N), δ15N indicates soil N
0
500
1,000
1,500
2,000
Nitrate concentration (mg/L as N)
USGS


Depth below land surface (ft)
0
30
60
90
120
150
180
Suction lysimeter
Sediment extractions
Suction lysimeter
Water table
Water-table well, δ15N indicates fertilizer N
0
20
40
60
80
100
Nitrate concentration (mg/L as N)
USGS


Nitrate-N (mg/L) in 1990s
30
25
20
15
10
5
0
0
10
20
30
Nitrate-N (mg/L) in 1970s
http://www.kgs.ku.edu/Publications/pic14/pic14_1.html


USGS Irrigated Land Use NAWQA Study SW KS
20
15
10
5
0
-5
-10
δ15N ‰
Animal Waste
Mineralized N ?
Fertilizer
◆ Monitoring Wells
▲ Precipitation E. KS
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
Nitrite + Nitrate (mg/L as N)
USGS

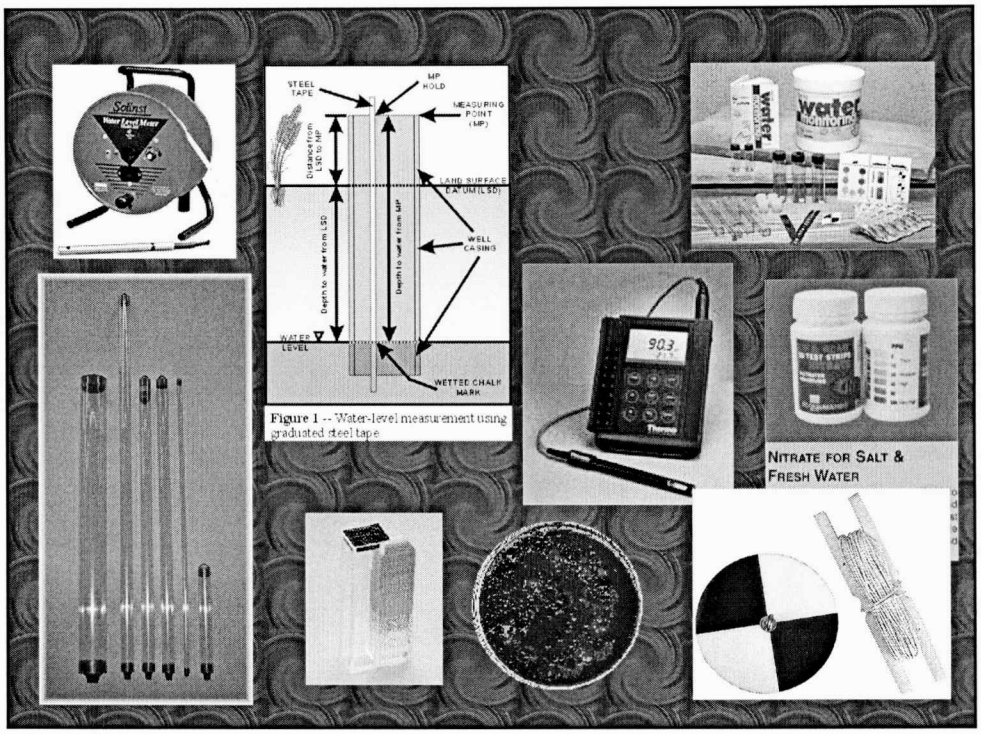


USGS High Plains Aquifer SWKS Irrigated Agriculture Land-Use Study:

Atrazine at water table (DTW ~ 20m – 50m)

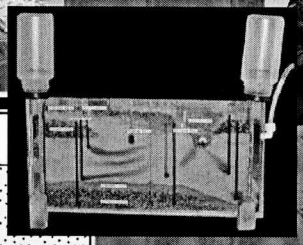
- Nitrate: 10 of 30 samples > 10 mg/L
- Median nitrate-N: 7.05 mg/L
- Nitrogen-15 ratios indicate Fertilizer source
- Tritium (Recent Recharge since 1960s)

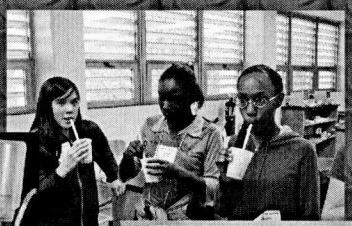
USGS NAWQA (2001)

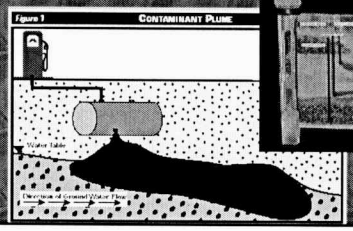

Salinst
Water Level Meter
STEEL TAPE
MP HOLD
MEASURING POINT (MP)
Distance from LSD to MP
LAND SURFACE DATUM (LSD)
Depth to water from LSD
Depth to water from MP
WELL CASING
WATER LEVEL
WETTED CHALK MARK
Figure 1 -- Water-level measurement using graduated steel tape
903
Thermo
NITRATE FOR SALT & FRESH WATER

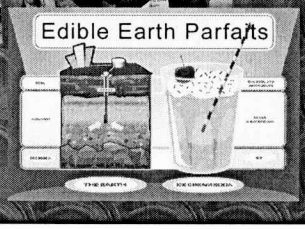
Ground Water Chemistry





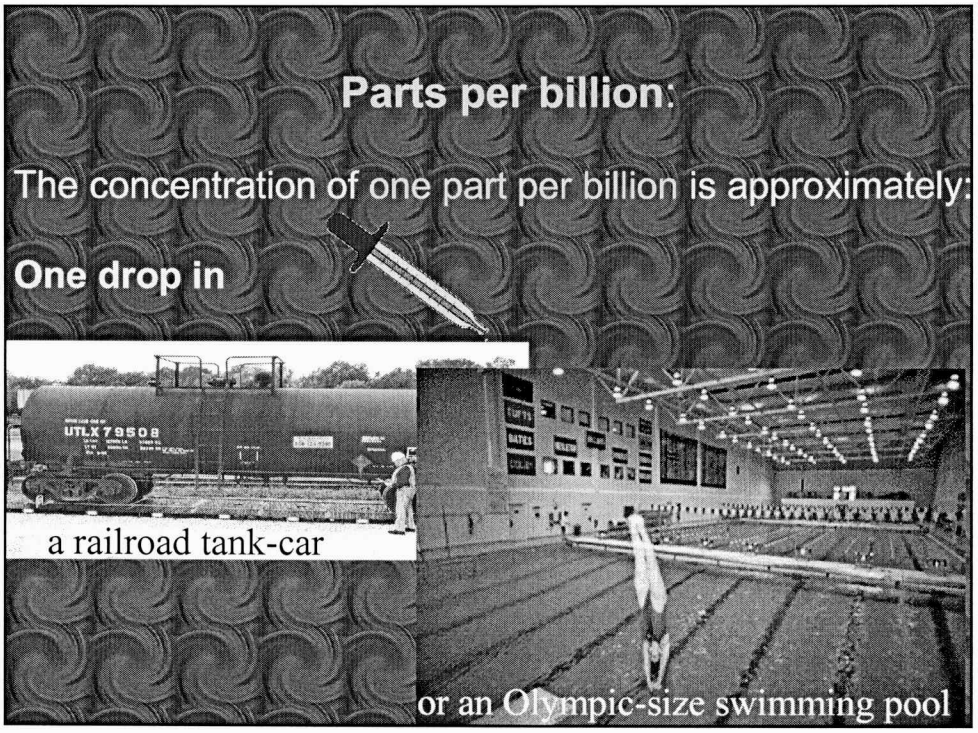


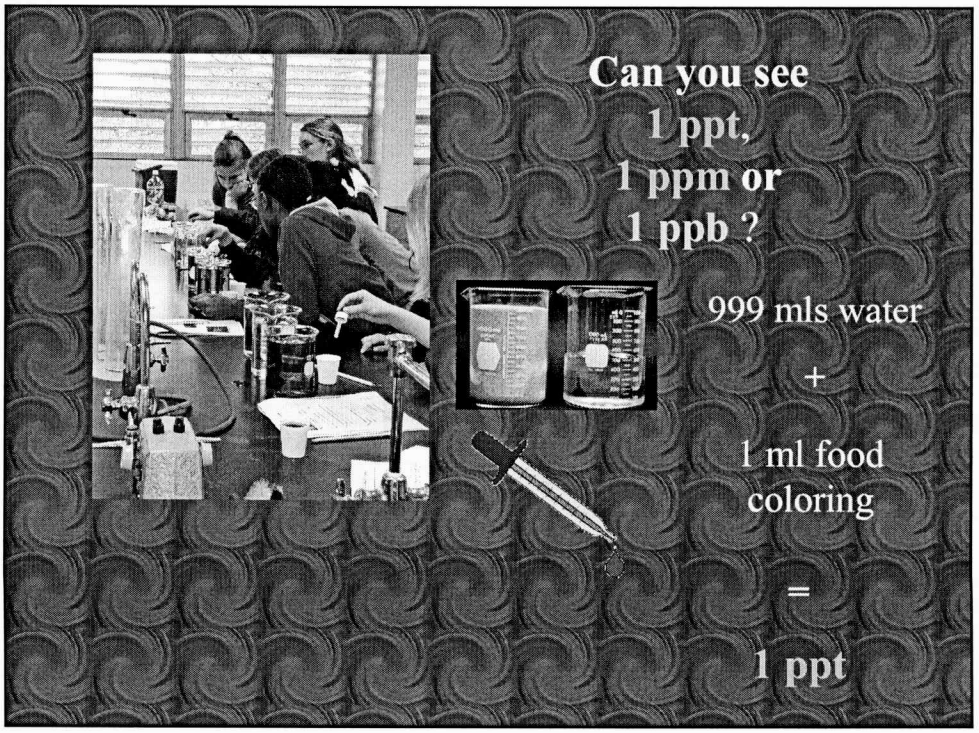


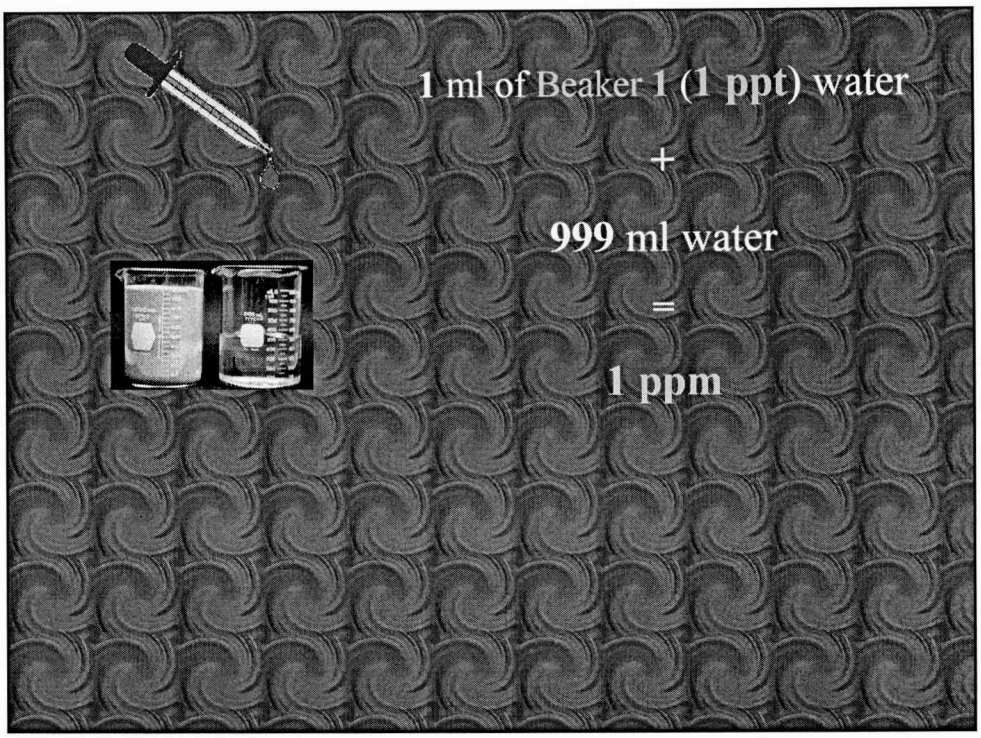


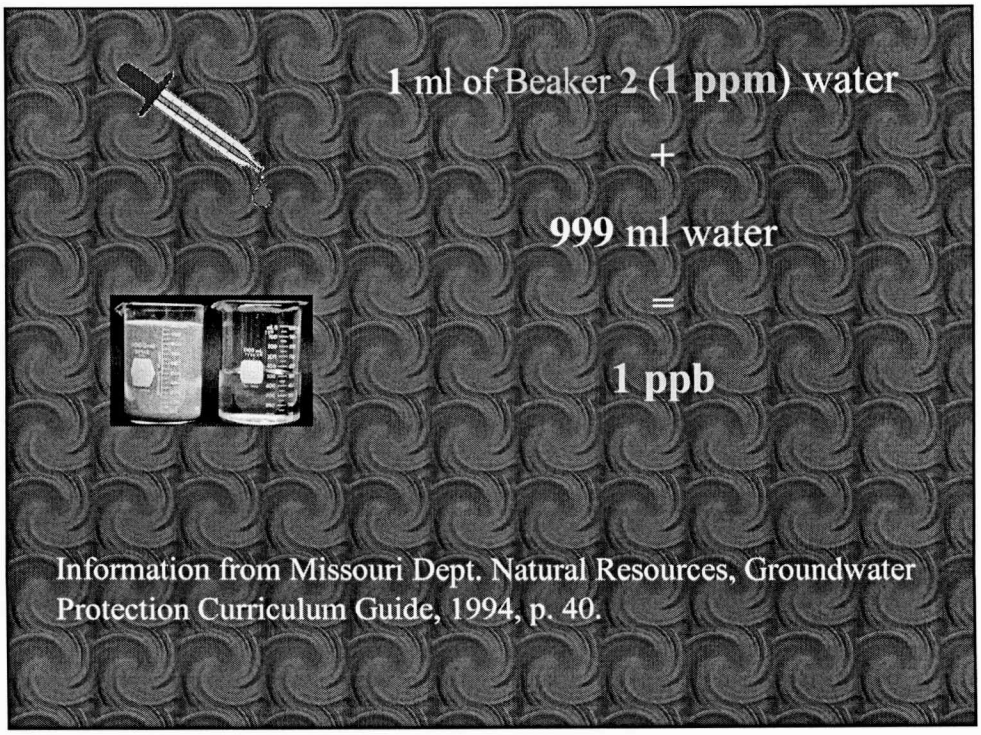
The **units** for reporting chemicals in water are usually in
ppt (parts per thousand)
ppm (parts per million) or
ppb (parts per billion)

What do these units represent?


Parts per billion:
The concentration of one part per billion is approximately:
One drop in
a railroad tank-car
or an Olympic-size swimming pool


Can you see
1 ppt,
1 ppm or
1 ppb ?
999 mls water
+
1 ml food
coloring
=
1 ppt


1 ml of Beaker 1 (1 ppt) water
+
999 ml water
=
1 ppm


1 ml of Beaker 2 (1 ppm) water
+
999 ml water
=
1 ppb
Information from Missouri Dept. Natural Resources, Groundwater Protection Curriculum Guide, 1994, p. 40.

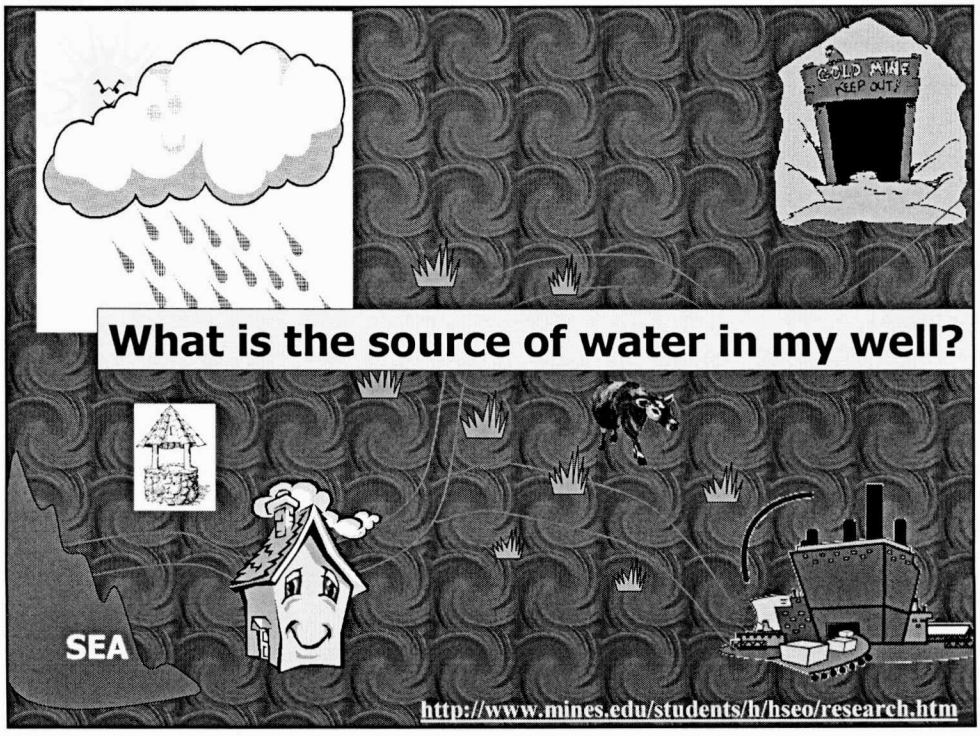
Question:

Can the pollutant still be toxic at the minute concentration of 1 ppb? Possibly.

Many pollutants including hazardous substances and metals remain hazardous to human health even at 1 ppb.

Information from Missouri Dept. Natural Resources, Groundwater Protection Curriculum Guide, 1994, p. 40.

(reference on web sites listed on CD).



Water quality is
A measure of the suitability of water for a particular use

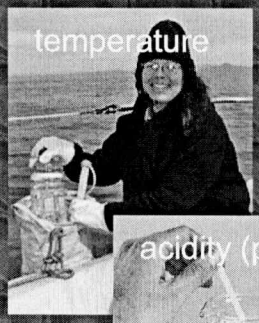
based on selected physical, chemical, and biological characteristics.



To determine water quality,
Scientists measure characteristics of the water such as:
temperature
dissolved mineral content,
and number of bacteria.

Selected characteristics are compared to numeric standards and guidelines to decide if the water is suitable for a particular use.

How is water quality measured?
Some aspects of water quality can be determined right in the stream or at the well. These include:

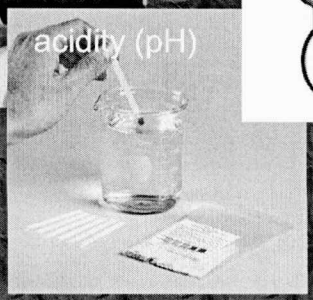


dissolved oxygen





electrical conductance (an indirect indicator of dissolved minerals in the water).



Analyses of individual chemicals generally are done at a laboratory.

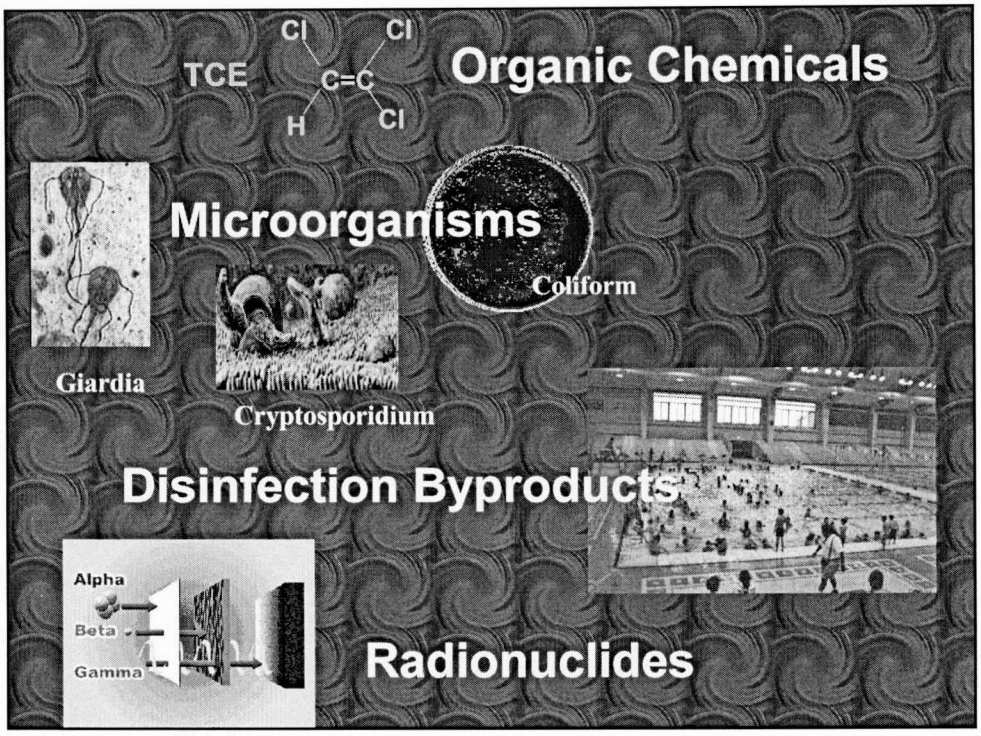
IMPURITIES IN NATUAL WATER

Origin	Positive Ions	Negative Ions
Contact of water with minerals, soils, and rocks	Ca^{+2}, Fe^{+2} Mg^{+2}, Mn^{+2} K^{+}, Na^{+}, Zn^{+2}	HCO_3^-, CO_3^{-2} Cl^-, F^-, NO_3^- PO_4^{-3}, OH^-, SO_4^{-2} $H_2BO_3^-$, H_3SiO_4
The atmosphere, in rain	H^+	HCO_3^-, Cl^-, SO_4^{-2}
Decomposition of organic matter in the environment	NH_4^+, H^+, Na^+	Cl^-, HCO_3^-, OH^-, NO_2^-, NO_3^-, HS^- Organic radicals
Municipal, industrial, and agricultural sources and other human activity	Inorganic ions, including a variety of heavy metals	Inorganic ions, organic molecules, color

Common constituents are not considered harmful to human health

Some constituents can affect the taste, smell, or clarity of water.

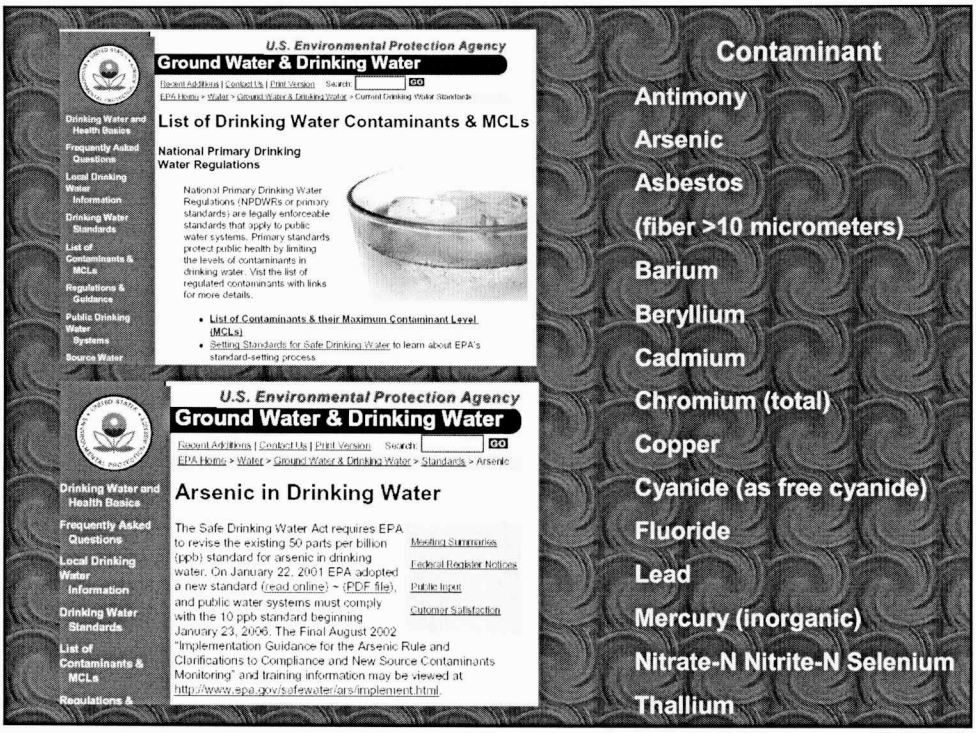
Plant nutrients and trace elements in water can be harmful to human health and aquatic life if they exceed standards or guidelines.



Dissolved gases such as oxygen and radon are common in natural waters.

Adequate oxygen levels in water are a necessity for fish and other aquatic life.

Radon gas can be a threat to human health when it exceeds drinking-water standards.



	Variable	Descriptor	Reason for Monitoring
1	Alkalinity, Total as CaCO3 (mg/L)	General	Drinking water standard. Indicator of Carbonate species concentrations; Acid neutralizing capacity (ANC) of water (buffering effect on pH)
2	Bromide (mg/L)	Ion	Total anion component.
3	Cadmium, Dissolved (mg/L)	Metal	Water Quality standard; Indicator of pollution from mining activity (at elevated levels).
4	Cadmium, Total (mg/L)	Metal	Drinking water standard: Indicator of pollution form mining activity (at elevated levels).
5	Calcium (mg/L)	Major Ion	Drinking Water Standard; Hardness indicator (imparts hardness to water); Typically in form of carbonate species.
6	Chloride (mg/L)	Major Ion	Drinking water standard; Water quality standard Indicator (at high concentrations) of industrial and sewage effluent; High levels render water unpalatable.
7	Coliform Total (/100mL)	Microorganism	Drinking water standard; Indicator of potentially harmful bacteria.
8	Escherichia coli (/100L)	Microorganism	Indicates presence of wastewater or fecal contamination.
9	Fluoride (mg/L)	Ion	Drinking Water Standard; Water quality standard; Found in wastewater due to use in industrial applications; Also occurs naturally.
10	Hardness, Total as CaCO3 (mg/L)	General	Treatment implications; Hard water causes scaling in water heaters/boilers, and soft water is considered corrosive.
11	Iron, Dissolved (mg/L)	Metal	Water quality standard; Affects treatment (can cause taste and discoloration).
12	Iron, Total (mg/L)	Metal	Drinking water standard; Water quality standard; Affects treatment (can cause taste and discoloration).
13	Lead, Dissolved (mg/L)	Metal	Drink water standard; Water quality standard; Indicator of pollution from mining activity (at elevated levels).
14	Magnesium (mg/L)	Major Ion	Hardness indicator (imparts hardness to water).
15	Manganese, Dissolved (mg/L)	Metal	Water quality standard; Undesirable impurity (aesthetic – taste and odor) in water supplies resulting from oxidation.
16	Manganese, Total (mg/L)	Metal	Drinking water standard; Water quality standard; Undesirable impurity (aesthetic – taste and odor) in water supplies resulting from oxidation.
17	Molybdenum, Dissolved (mg/L)	Metal	Indicator of pollution from mining activity (at elevated levels).
18	Molybdenum, Total (mg/L)	Metal	Indicator of pollution from mining activity (at elevated levels).
19	Nitrogen, Ammonia (mg/L)	Nutrients	Water quality standard; Aquatic life protection; Indicator of organic pollution by sewage or industrial effluent, agricultural wastes and fertilizers.
20	Nitrogen, Nitrate (mg/L)	Nutrients	Drinking water standard; Water quality standard; Potential health risk (especially infants); helps the assessment of the character and degree of oxidation in surface waters.
21	Nitrogen, Nitrite (mg/L)	Nutrients	Drinking water standard; Water quality standard; Indicator of microbiological quality of water (increased levels associated with unsatisfactory quality).
22	Nitrogen, Total Kjeldahl (mg/L)	Nutrients	Determination of total organic nitrogen; Increased levels of organic nitrogen indicate pollution of water bodies.
23	Oxygen, Dissolved (mg/L)	General	Water quality standard; Essential for aquatic life; Indicator of organic pollution, destruction of organic substances, and the level of self-purification in natural water (oxygen is involved in, or influences, all chemical/biological processes within water bodies).

Important Drinking Water Definitions:

MCLG: Maximum Contaminant Level Goal:
The level of a contaminant in drinking water below which there is no known or expected risk to health.
MCLGs allow for a margin of safety.

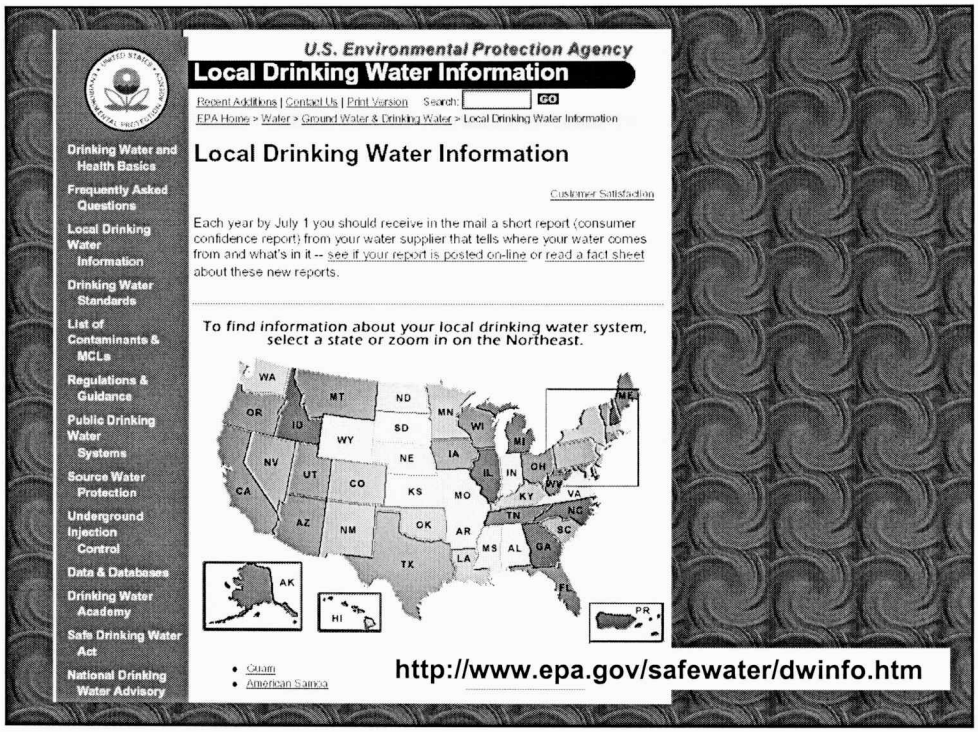
MCL: Maximum Contaminant Level: The highest level of a contaminant that is allowed in drinking water.

MCLs are set as close to the MCLGs as feasible using the best available treatment technology.

TT: Treatment Technique: A required process intended to reduce the level of a contaminant in drinking water.

AL: Action Level: The concentration of a contaminant which, if exceeded, triggers treatment or other requirements which a water system must follow.





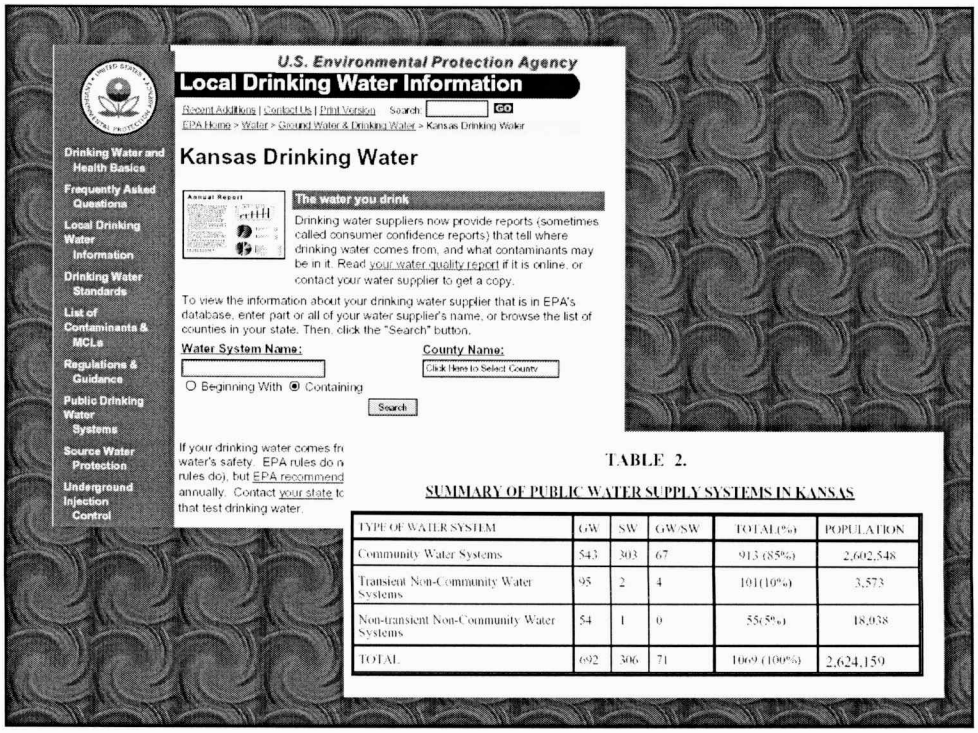
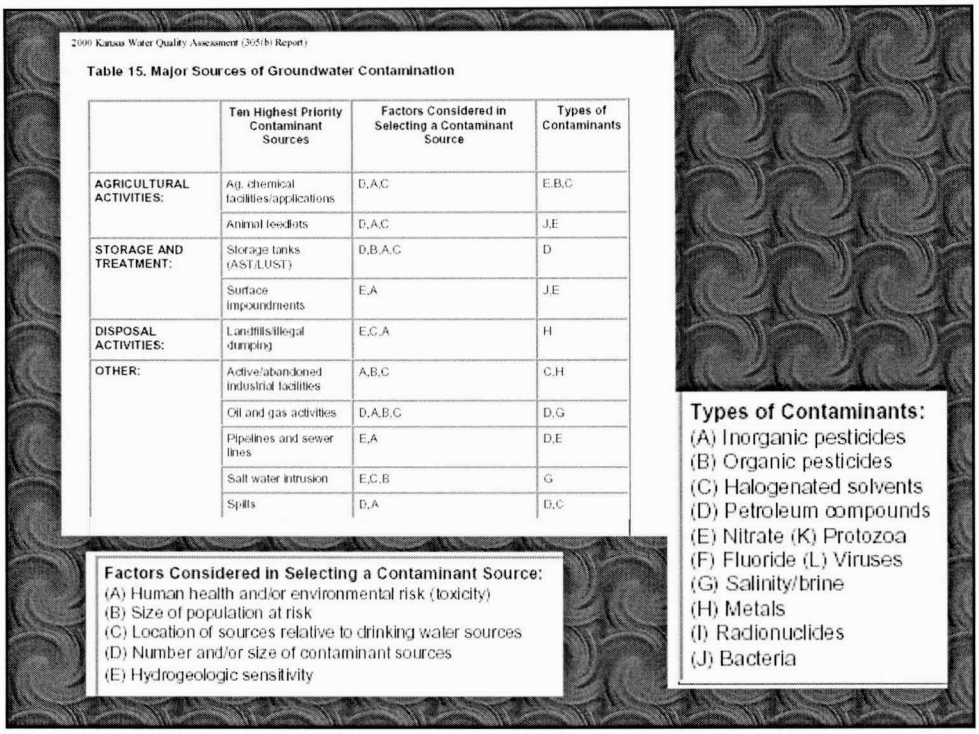


TABLE 2.

SUMMARY OF PUBLIC WATER SUPPLY SYSTEMS IN KANSAS

TYPE OF WATER SYSTEM	GW	SW	GW/SW	TOTAL(%)	POPULATION
Community Water Systems	543	303	67	913 (85%)	2,602,548
Transient Non-Community Water Systems	95	2	4	101(10%)	3,573
Non-transient Non-Community Water Systems	54	1	0	55(5%)	18,038
TOTAL	692	306	71	1069 (100%)	2,624,159



2000 Kansas Water Quality Assessment (305(b) Report)

Table 15. Major Sources of Groundwater Contamination

	Ten Highest Priority Contaminant Sources	Factors Considered in Selecting a Contaminant Source	Types of Contaminants
AGRICULTURAL ACTIVITIES:	Ag. chemical facilities/applications	D,A,C	E,B,C
	Animal feedlots	D,A,C	J,E
STORAGE AND TREATMENT:	Storage tanks (AST/LUST)	D,B,A,C	D
	Surface impoundments	E,A	J,E
DISPOSAL ACTIVITIES:	Landfills/illegal dumping	E,C,A	H
OTHER:	Active/abandoned industrial facilities	A,B,C	C,H
	Oil and gas activities	D,A,B,C	D,G
	Pipelines and sewer lines	E,A	D,E
	Salt water intrusion	E,C,B	G
	Spills	D,A	D,C

Factors Considered in Selecting a Contaminant Source:
(A) Human health and/or environmental risk (toxicity)
(B) Size of population at risk
(C) Location of sources relative to drinking water sources
(D) Number and/or size of contaminant sources
(E) Hydrogeologic sensitivity

Types of Contaminants:
(A) Inorganic pesticides
(B) Organic pesticides
(C) Halogenated solvents
(D) Petroleum compounds
(E) Nitrate (K) Protozoa
(F) Fluoride (L) Viruses
(G) Salinity/brine
(H) Metals
(I) Radionuclides
(J) Bacteria

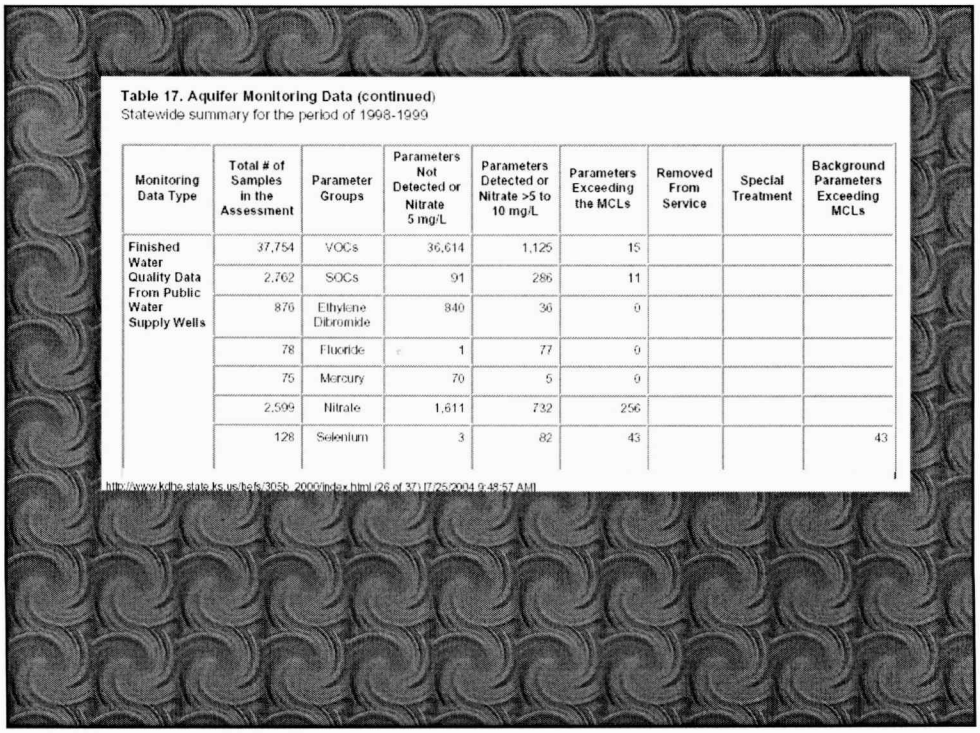
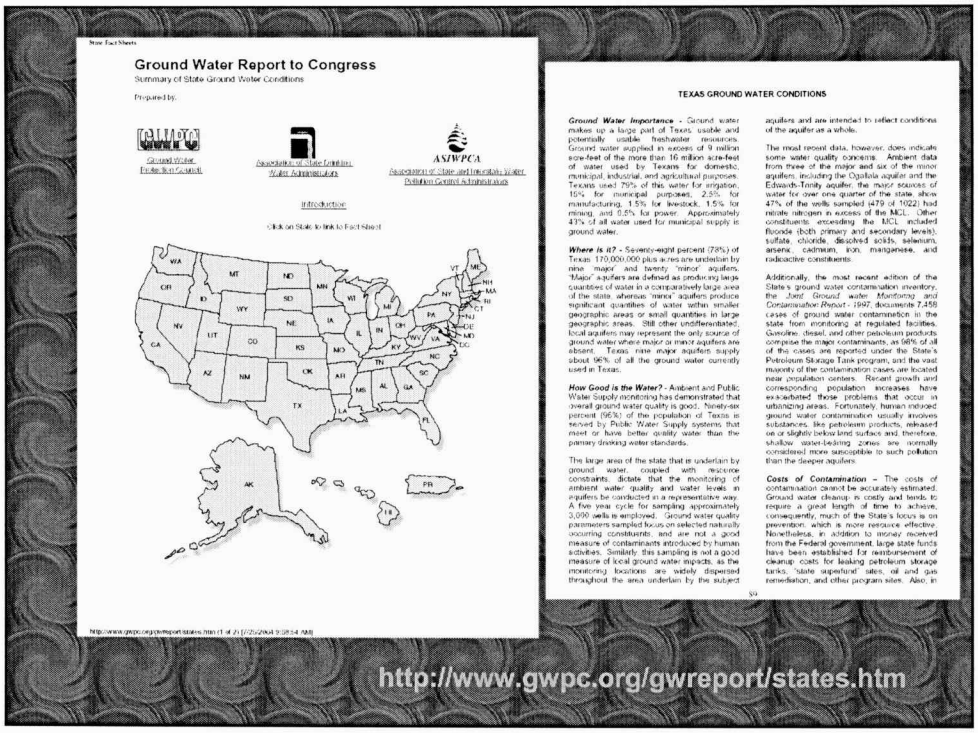


Table 17. Aquifer Monitoring Data (continued)
Statewide summary for the period of 1998-1999

Monitoring Data Type	Total # of Samples in the Assessment	Parameter Groups	Parameters Not Detected or Nitrate 5 mg/L	Parameters Detected or Nitrate >5 to 10 mg/L	Parameters Exceeding the MCLs	Removed From Service	Special Treatment	Background Parameters Exceeding MCLs
Finished Water Quality Data From Public Water Supply Wells	37,754	VOCs	36,614	1,125	15			
	2,762	SOCs	91	286	11			
	876	Ethylene Dibromide	840	36	0			
	78	Fluoride	1	77	0			
	75	Mercury	70	5	0			
	2,599	Nitrate	1,611	732	256			
	128	Selenium	3	82	43			43

http://www.kdhe.state.ks.us/befs/305b_2000/index.html (26 of 37) [7/25/2004 9:48:57 AM]



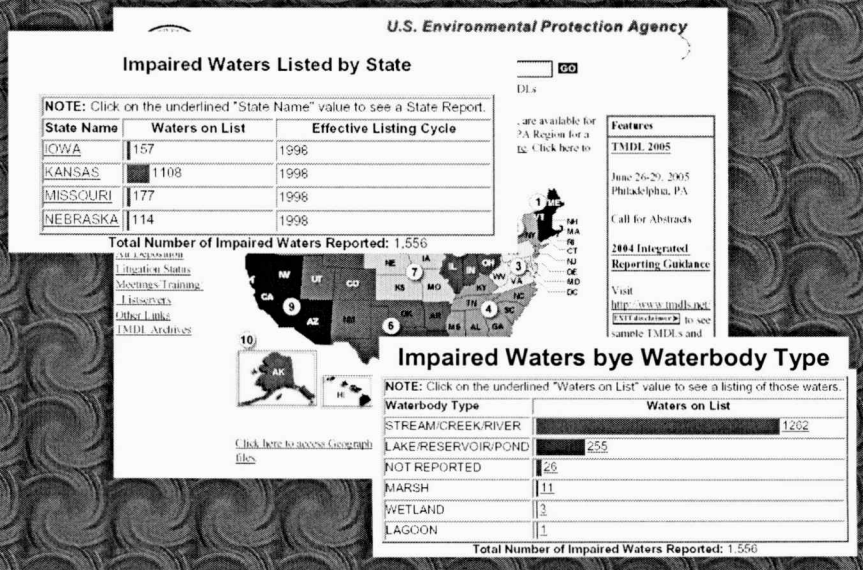
A TMDL or Total Maximum Daily Load is:

1. Calculation of the maximum amount of a pollutant that a waterbody can receive
2. Meet water quality standards, and an allocation of that amount to the pollutant's sources.
3. Water quality standards are set by States, Territories, and Tribes.
4. Standards identify the uses for each waterbody:
   a. drinking water supply,
   b. contact recreation (swimming),
   c. aquatic life support (fishing),
   d. and the scientific criteria to support that use.

A TMDL is

5. The sum of the allowable loads of a single pollutant from all contributing point and nonpoint sources.
6. The sum of the allowable loads of a single pollutant from all contributing point and nonpoint sources.
7. Includes a margin of safety to ensure that the waterbody can be used for the purposes the State has designated.
8. Must also account for seasonal variation in water quality.
9. The Clean Water Act, section 303, establishes the water quality standards and TMDL programs.

TMDLs



U.S. Environmental Protection Agency

Impaired Waters Listed by State

NOTE: Click on the underlined "State Name" value to see a State Report.

State Name	Waters on List	Effective Listing Cycle
IOWA	157	1998
KANSAS	1108	1998
MISSOURI	177	1998
NEBRASKA	114	1998

Total Number of Impaired Waters Reported: 1,556

Impaired Waters bye Waterbody Type

NOTE: Click on the underlined "Waters on List" value to see a listing of those waters.

Waterbody Type	Waters on List
STREAM/CREEK/RIVER	1202
LAKE/RESERVOIR/POND	255
NOT REPORTED	26
MARSH	11
WETLAND	3
LAGOON	1

Total Number of Impaired Waters Reported: 1,556

http://www.epa.gov/owow/tmdl/

City Of Wichita Web Document

2000 Average Chemical Analysis of Treated Water

Constituent	Wichita	Units	MDL	MCL
Aluminum	0.01	mg/L	0.01	
Ammonia-N	0.38	mg/L	0.007	
Antimony	<MDL	µg/L	2.5	6
Arsenic	2	µg/L	1	50
Barium	0.036	mg/L	0.005	2
Beryllium	<MDL	µg/L	1	4
Bromide	0.04	mg/L	0.02	
Cadmium	<MDL	µg/L	1	5
Calcium	20.9	mg/L	0.01	
Calcium Hardness	52	mg/L	0.02	
Chloride	113	mg/L	5	
Chlorine Residual, Combined	2.06	mg/L	0.05	
Chromium	<MDL	µg/L	1	100
Copper	<MDL	mg/L	0.005	TT
Cyanide	<MDL	µg/L	5	200
Dissolved Oxygen	10	mg/L	0.1	
Fluoride	0.28	mg/L	0.01	4
Iron	<MDL	mg/L	0.005	
Langlier Corrosivity Index	0.07	LCI		
Lead	1	µg/L	1	TT
Magnesium	14	mg/L	0.05	
Manganese	0.002	mg/L	0.001	
Mercury	<MDL	µg/L	0.1	2
Nickel	<MDL	mg/L	0.005	

Constituent	Wichita	Units	MDL	MCL
Nitrate-N	0.67	mg/L	0.01	10
Nitrite-N	<MDL	mg/L	0.01	1
Nitrite + Nitrate-N	0.67	mg/L	0.02	10
Ortho Phosphate-P	0.01	mg/L	0.01	
Partial Alkalinity (as CaCO3)	<MDL	mg/L	1	
pH	8.5	pH UNITS		
Potassium	4.6	mg/L	0.05	
Selenium	<MDL	µg/L	2	50
Silica	7.8	mg/L	0.05	
Silver	<MDL	mg/L	0.01	
Sodium	88	mg/L	0.1	
Specific Conductance	630	µmhos/cm²	2	
Sulfate	75	mg/L	5	
Temperature	15.5	°C	0.1	
Thallium	<MDL	µg/L	1.7	2
Total Alkalinity (as CaCO3)	82	mg/L	2	
Total Dissolved Solids	374	mg/L	10	
Total Hardness (as CaCO3)	130	mg/L	1	
Total Organic Carbon	2.6	mg/L	0.1	
Total Phosphorus-P	0.05	mg/L	0.03	
Total Solids	392	mg/L	10	
Total Trihalomethanes	28.1	µg/L	2	100
Turbidity	0.28	mg/L	0.1	TT
Vanadium	<MDL	mg/L	0.002	
Zinc	<MDL	mg/L	0.005	

Once you have the data....



What do you do with it?

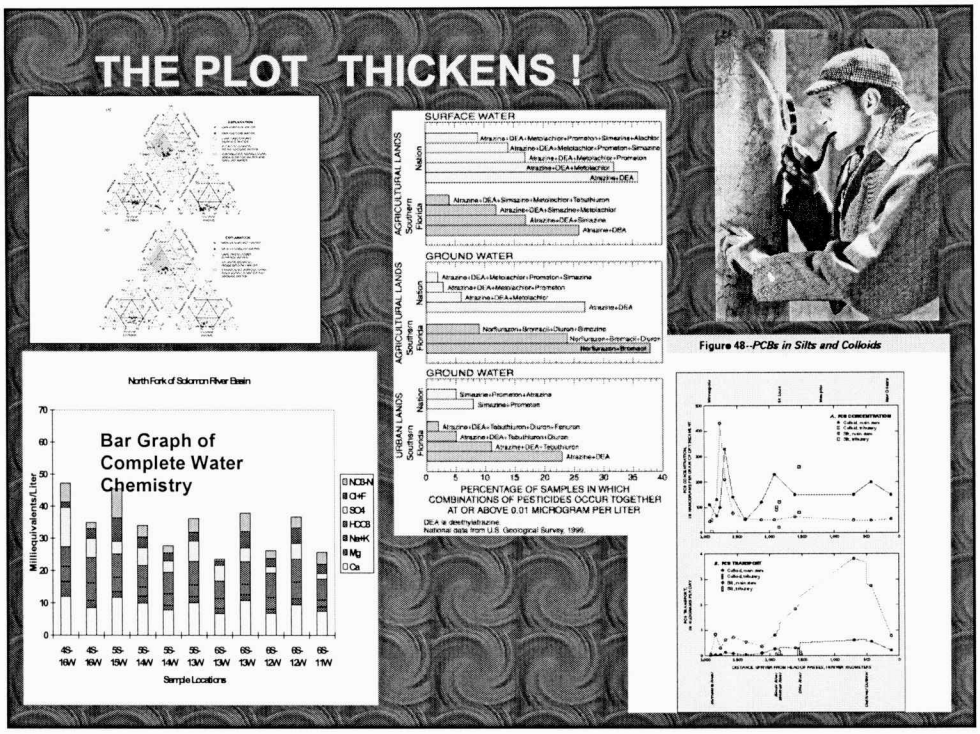


Figure 48--*PCBs in Silts and Colloids*

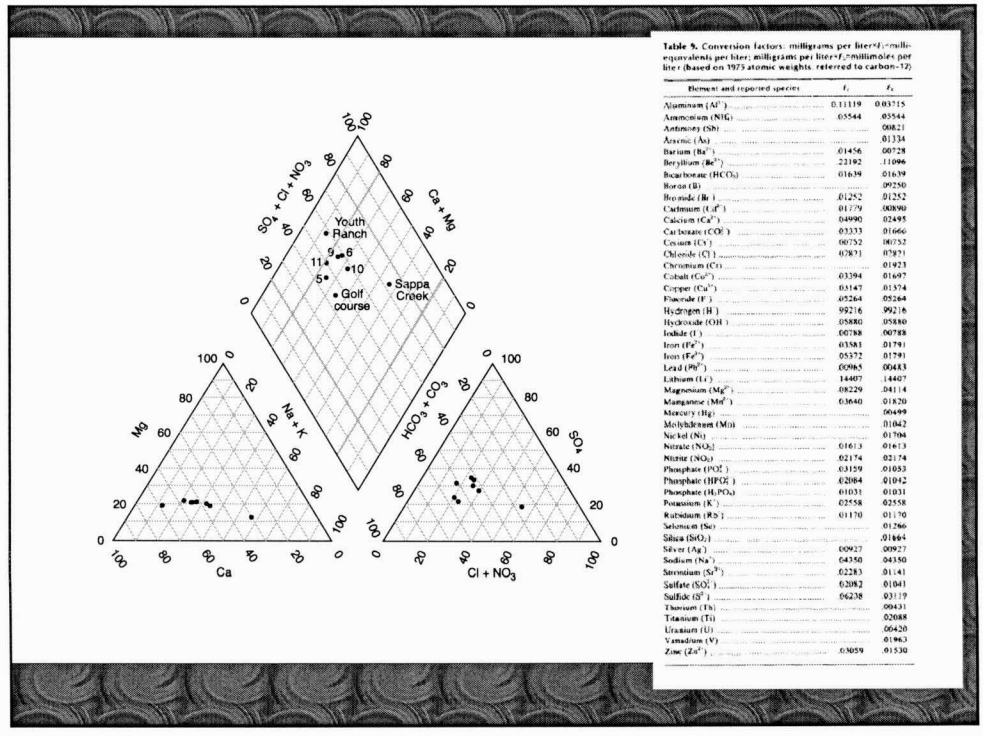
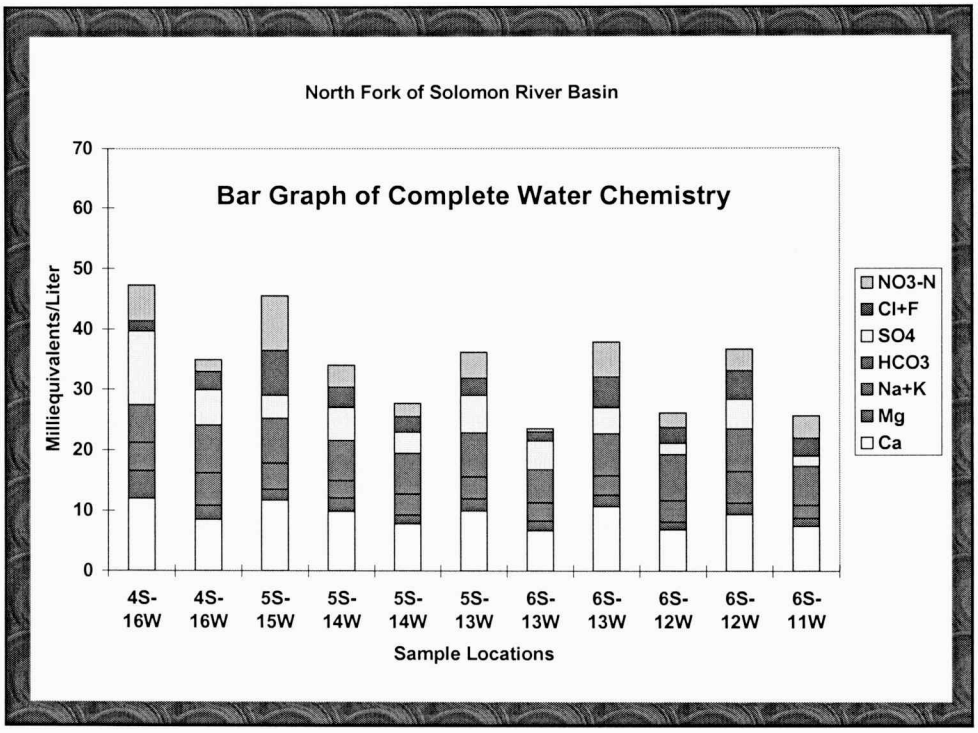
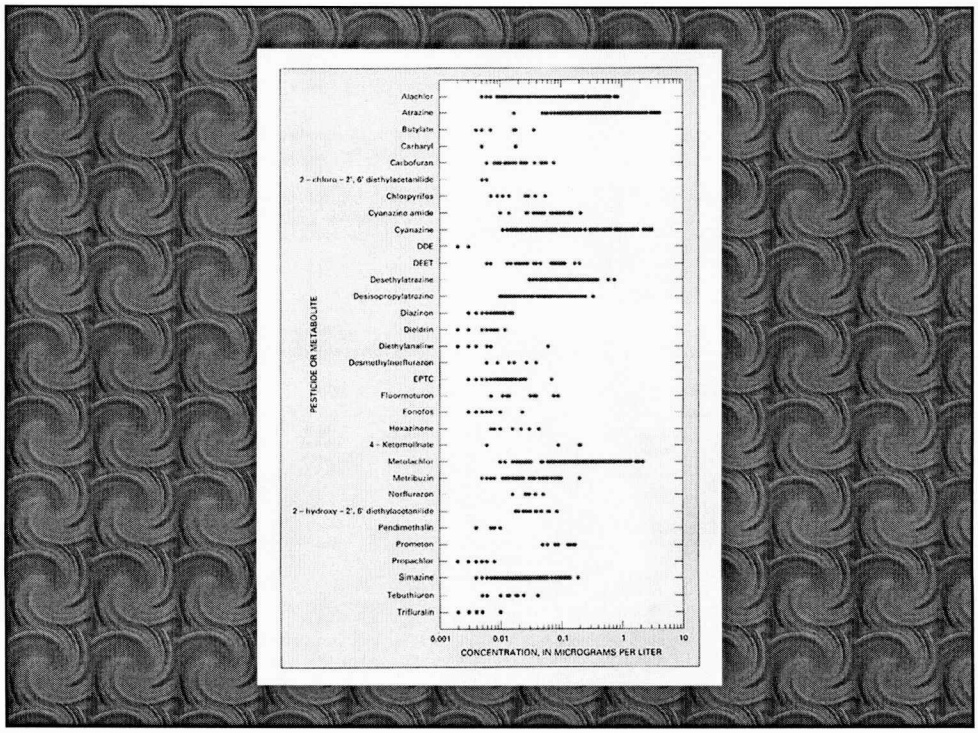


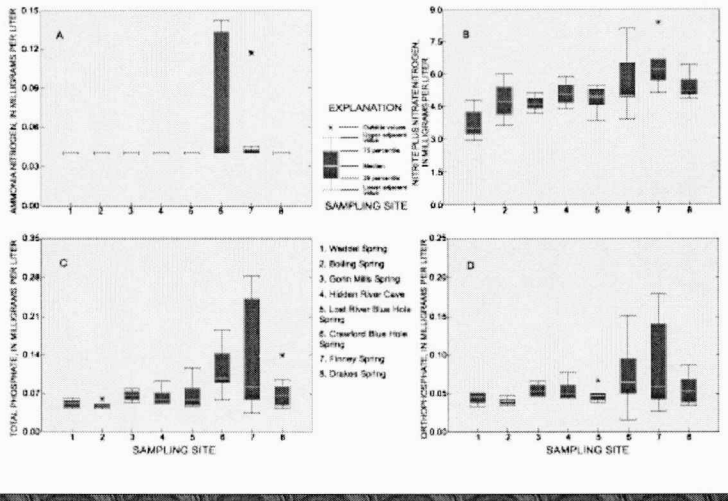
Table 9. Conversion factors: milligrams per liter×f_1=milliequivalents per liter; milligrams per liter×f_2=millimoles per liter (based on 1973 atomic weights, referred to carbon-12)

Element and reported species	f_1	f_2
Aluminum (Al^{3+})	0.11119	0.03715
Ammonium (NH_4^+)	.05544	.05544
Antimony (Sb)		.00821
Arsenic (As)		.01334
Barium (Ba^{2+})	.01456	.00728
Beryllium (Be^{2+})	.22192	.11096
Bicarbonate (HCO_3^-)	.01639	.01639
Boron (B)		.09250
Bromide (Br^-)	.01252	.01252
Cadmium (Cd^{2+})	.01779	.00890
Calcium (Ca^{2+})	.04990	.02495
Carbonate (CO_3^{2-})	.03333	.01666
Cesium (Cs^+)	.00752	.00752
Chloride (Cl^-)	.02821	.02821
Chromium (Cr)		.01923
Cobalt (Co^{2+})	.03394	.01697
Copper (Cu^{2+})	.03147	.01574
Fluoride (F^-)	.05264	.05264
Hydrogen (H^+)	.99216	.99216
Hydroxide (OH^-)	.05880	.05880
Iodide (I^-)	.00788	.00788
Iron (Fe^{3+})	.03581	.01791
Iron (Fe^{2+})	.05372	.01791
Lead (Pb^{2+})	.00965	.00483
Lithium (Li^+)	.14407	.14407
Magnesium (Mg^{2+})	.08229	.04114
Manganese (Mn^{2+})	.03640	.01820
Mercury (Hg)		.00499
Molybdenum (Mo)		.01042
Nickel (Ni)		.01704
Nitrate (NO_3^-)	.01613	.01613
Nitrite (NO_2^-)	.02174	.02174
Phosphate (PO_4^{3-})	.03159	.01053
Phosphate (HPO_4^{2-})	.02084	.01042
Phosphate ($H_2PO_4^-$)	.01031	.01031
Potassium (K^+)	.02558	.02558
Rubidium (Rb^+)	.01170	.01170
Selenium (Se)		.01266
Silica (SiO_2)		.01664
Silver (Ag^+)	.00927	.00927
Sodium (Na^+)	.04350	.04350
Strontium (Sr^{2+})	.02283	.01141
Sulfate (SO_4^{2-})	.02082	.01041
Sulfide (S^{2-})	.06238	.03119
Thorium (Th)		.00431
Titanium (Ti)		.02088
Uranium (U)		.00420
Vanadium (V)		.01963
Zinc (Zn^{2+})	.03059	.01530

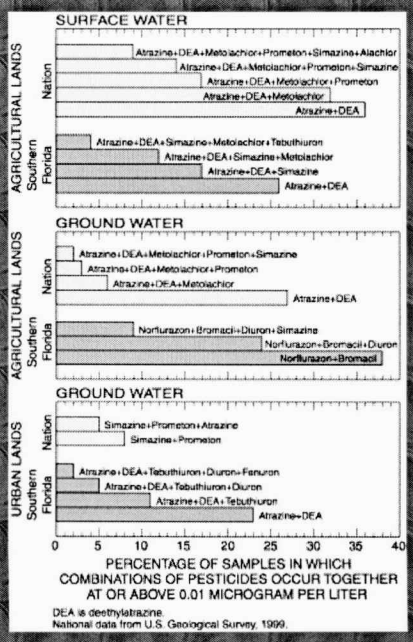

North Fork of Solomon River Basin
Bar Graph of Complete Water Chemistry
Milliequivalents/Liter
70
60
50
40
30
20
10
0
4S-16W
4S-16W
5S-15W
5S-14W
5S-14W
5S-13W
6S-13W
6S-13W
6S-12W
6S-12W
6S-11W
Sample Locations
NO3-N
Cl+F
SO4
HCO3
Na+K
Mg
Ca


Alachlor
Atrazine
Butylate
Carbaryl
Carbofuran
2-chloro-2',6'-diethylacetanilide
Chlorpyrifos
Cyanazine amide
Cyanazine
DDE
DEET
Desethylatrazine
Desisopropylatrazine
Diazinon
Dieldrin
Diethylaniline
Desmethylnorflurazon
EPTC
Fluormeturon
Fonofos
Hexazinone
4-Ketomolinate
Metolachlor
Metribuzin
Norflurazon
2-hydroxy-2',6'-diethylacetanilide
Pendimethalin
Prometon
Propachlor
Simazine
Tebuthiuron
Trifluralin
PESTICIDE OR METABOLITE
0.001
0.01
0.1
1
10
CONCENTRATION, IN MICROGRAMS PER LITER

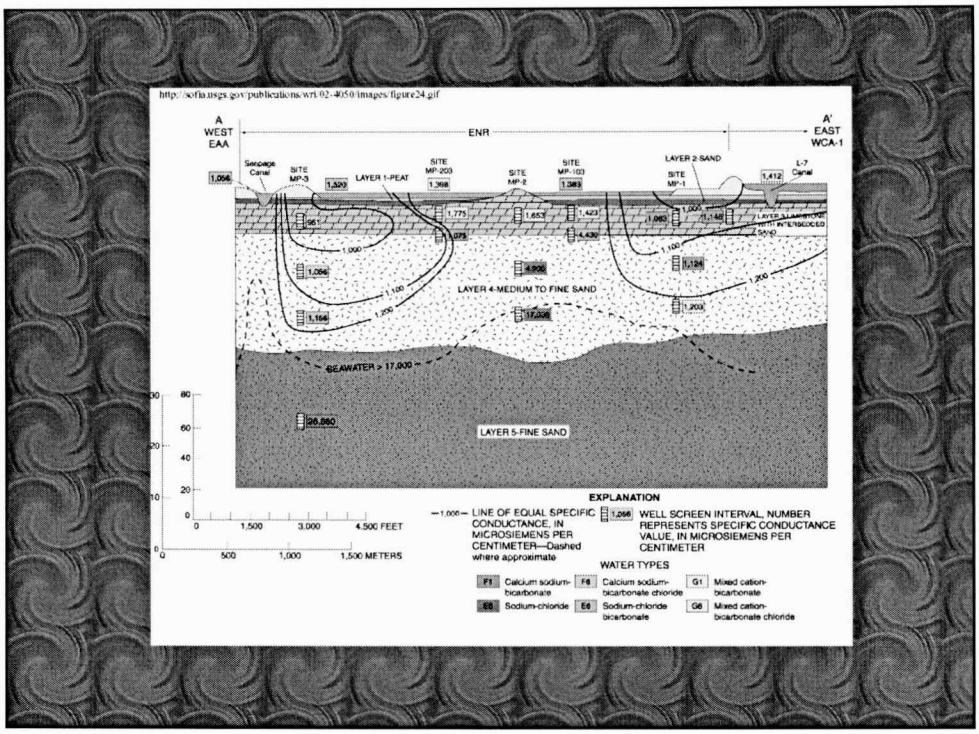
Statistical Range Bar Graphs



http://ky.water.usgs.gov/pubs/FAC_13301/html/figure4.htm



http://sofia.usgs.gov/publications/circular/1207/index.html


http://sofia.usgs.gov/publications/wri/02-4050/images/figure24.gif
A
WEST
EAA
ENR
A'
EAST
WCA-1
Seepage Canal
SITE MP-3
LAYER 1-PEAT
SITE MP-203
SITE MP-2
SITE MP-103
LAYER 2-SAND
SITE MP-1
L-7 Canal
LAYER 4-MEDIUM TO FINE SAND
SEAWATER > 17,000
LAYER 5-FINE SAND
EXPLANATION
LINE OF EQUAL SPECIFIC CONDUCTANCE, IN MICROSIEMENS PER CENTIMETER—Dashed where approximate
WELL SCREEN INTERVAL, NUMBER REPRESENTS SPECIFIC CONDUCTANCE VALUE, IN MICROSIEMENS PER CENTIMETER
WATER TYPES
F1 Calcium sodium-bicarbonate
F6 Calcium sodium-bicarbonate chloride
G1 Mixed cation-bicarbonate
E6 Sodium-chloride bicarbonate
G6 Mixed cation-bicarbonate chloride
0 1,500 3,000 4,500 FEET
0 500 1,000 1,500 METERS

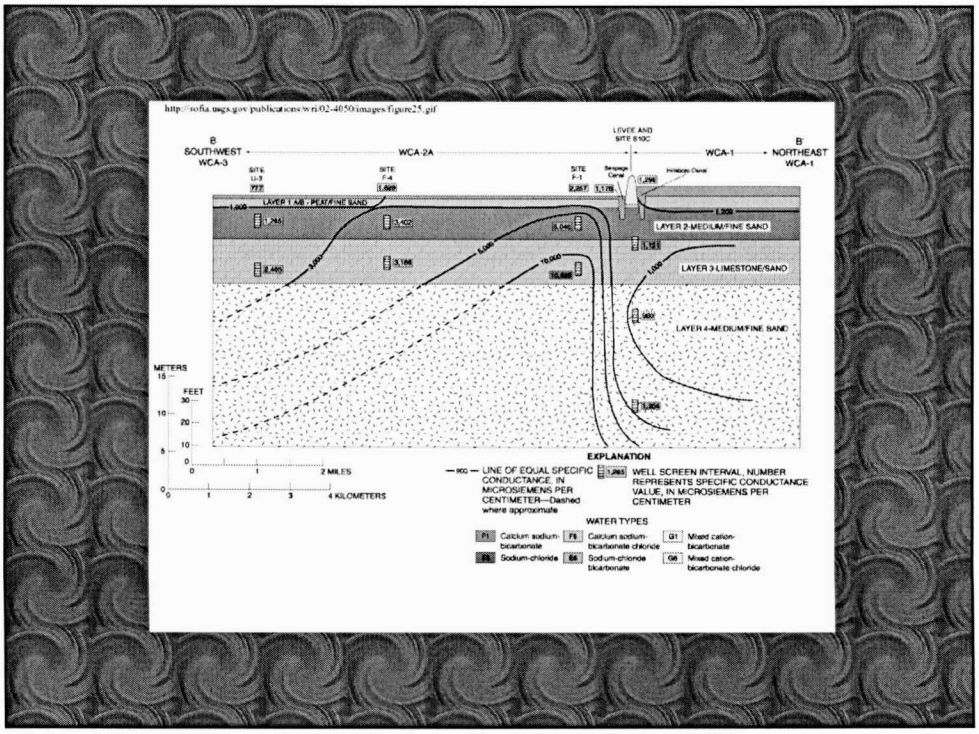
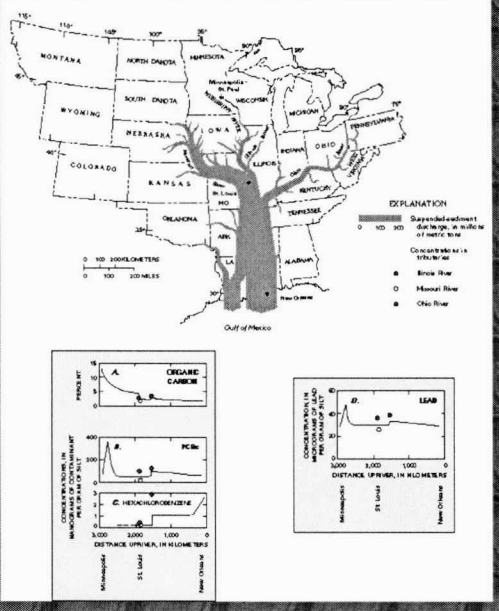
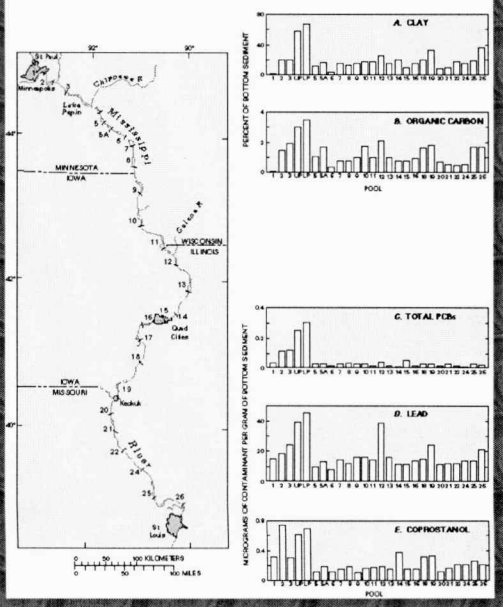

http://sofia.usgs.gov/publications/wri/02-4050/images/figure25.gif
B
SOUTHWEST
WCA-3
WCA-2A
LEVEE AND SITE 63OC
WCA-1
B'
NORTHEAST
WCA-1
SITE U-3
SITE F-4
SITE F-1
Seepage Canal
Intrabay Canal
LAYER 1 MUD / PEAT/FINE SAND
LAYER 2-MEDIUM/FINE SAND
LAYER 3-LIMESTONE/SAND
LAYER 4-MEDIUM/FINE SAND
METERS
FEET
EXPLANATION
LINE OF EQUAL SPECIFIC CONDUCTANCE IN MICROSIEMENS PER CENTIMETER—Dashed where approximate
WELL SCREEN INTERVAL, NUMBER REPRESENTS SPECIFIC CONDUCTANCE VALUE, IN MICROSIEMENS PER CENTIMETER
WATER TYPES
F1 Calcium sodium-bicarbonate
F6 Calcium sodium-bicarbonate chloride
G1 Mixed cation-bicarbonate
E6 Sodium-chloride bicarbonate
G6 Mixed cation-bicarbonate chloride
0 1 2 MILES
0 1 2 3 4 KILOMETERS

Figure 2--*Contaminants in Suspended Sediment*

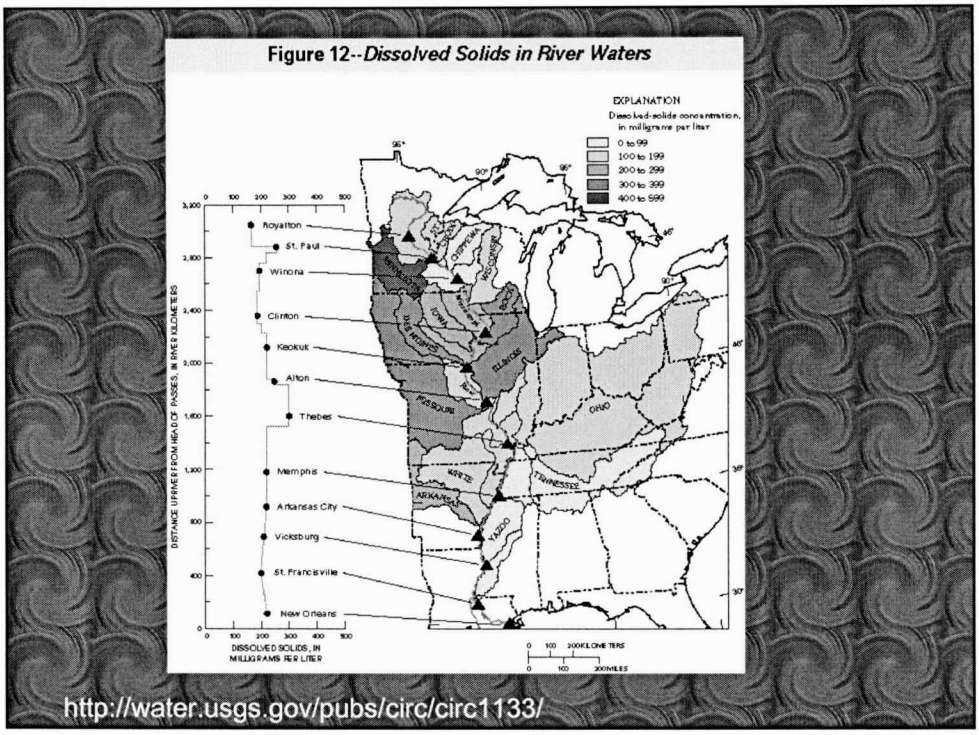


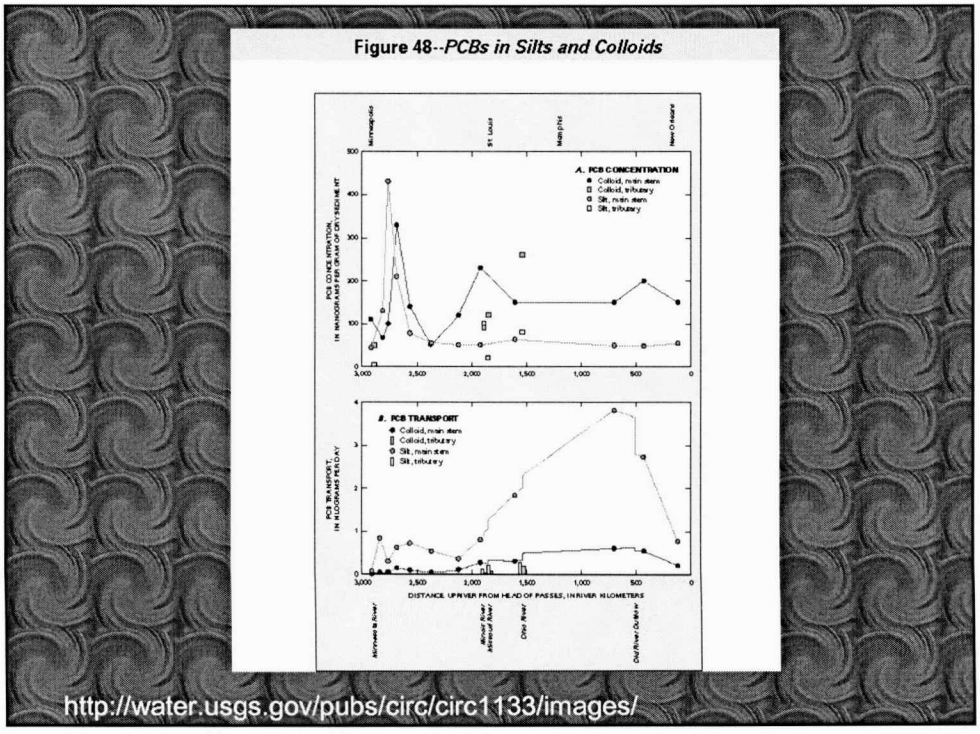
http://water.usgs.gov/pubs/circ/circ1133/

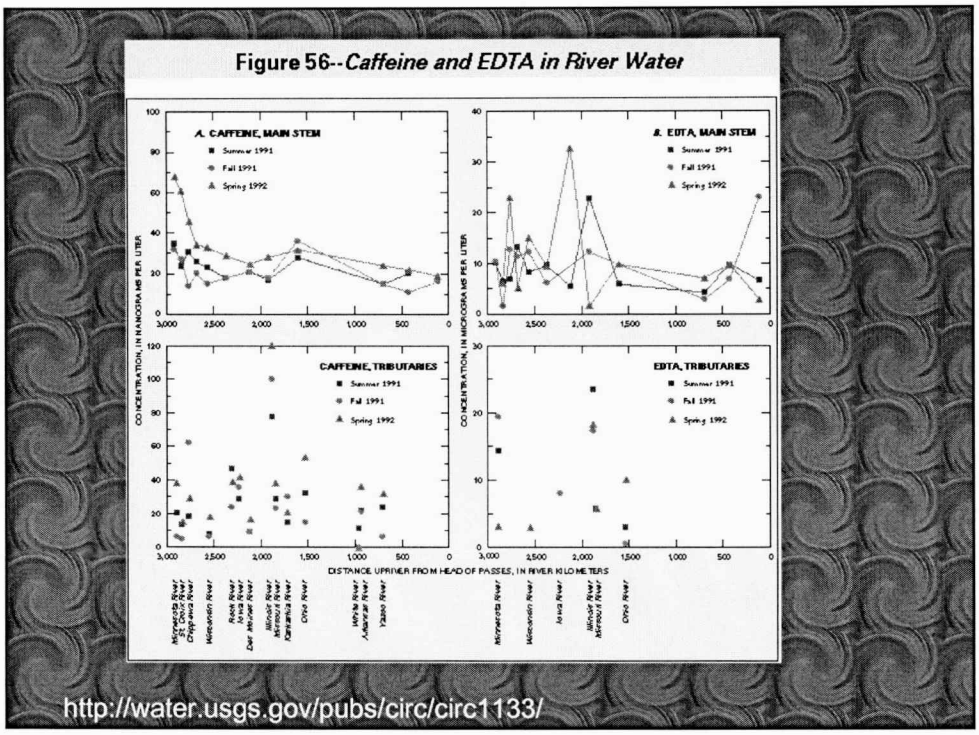
Figure 3--*Contaminants in Bed Sediments*

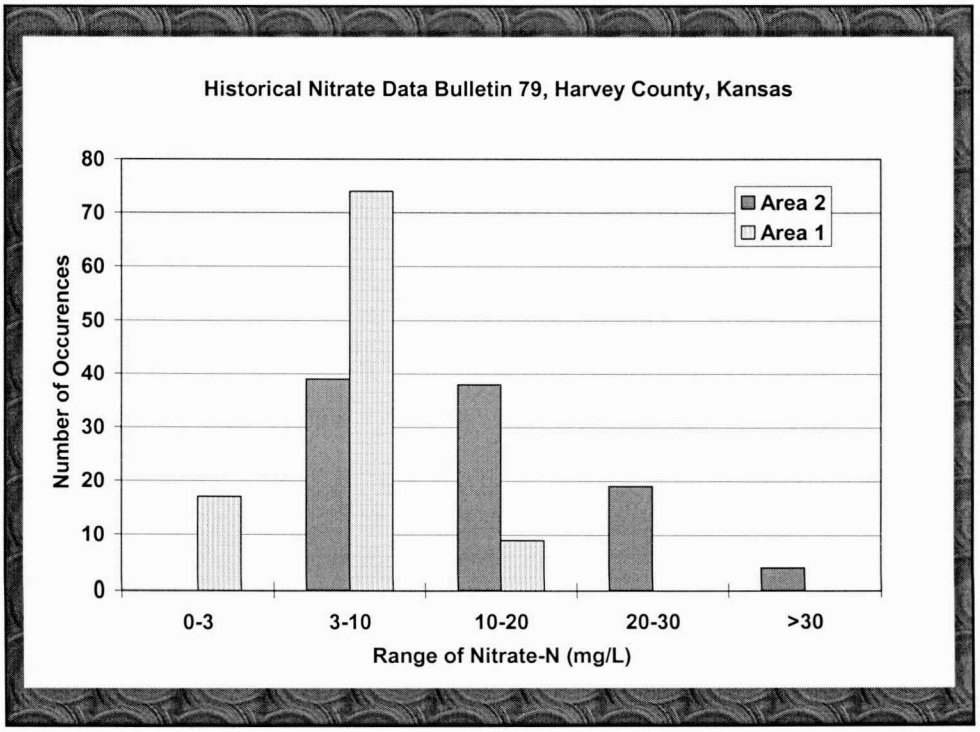


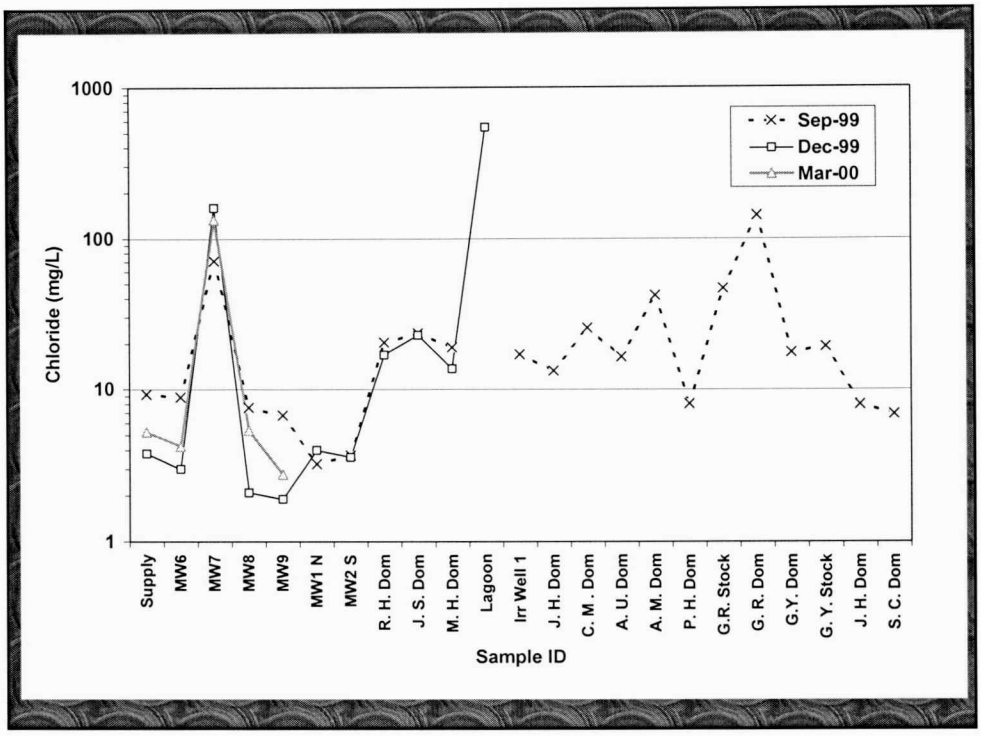
http://water.usgs.gov/pubs/circ/circ1133/

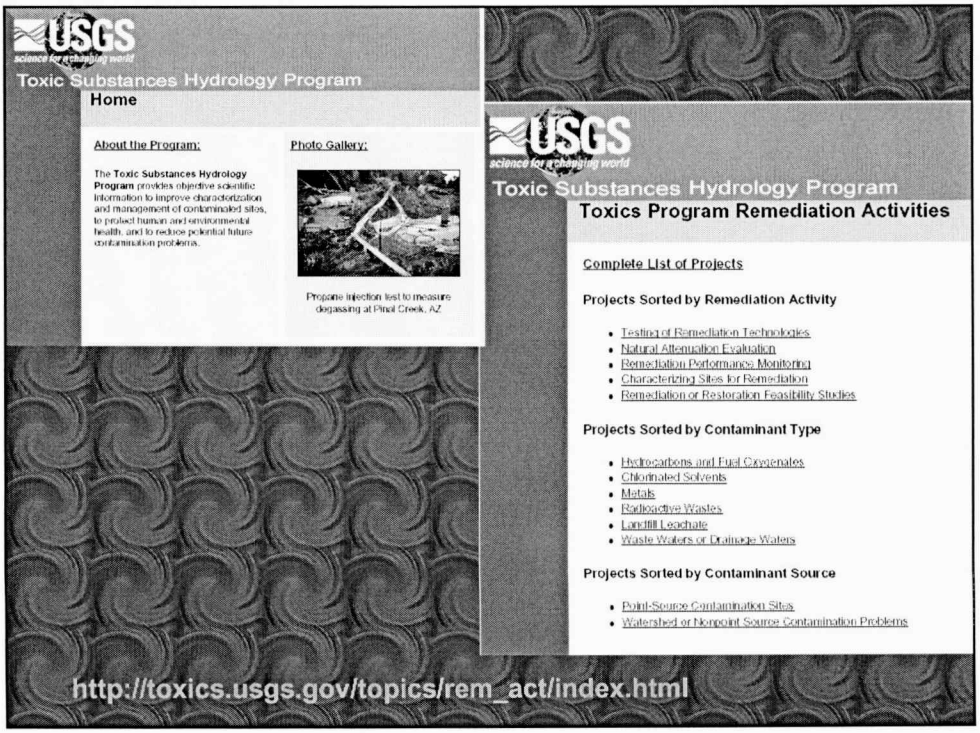

Figure 12--Dissolved Solids in River Waters
EXPLANATION
Dissolved-solids concentration, in milligrams per liter
0 to 99
100 to 199
200 to 299
300 to 399
400 to 599
Royalton
St. Paul
Winona
Clinton
Keokuk
Alton
Thebes
Memphis
Arkansas City
Vicksburg
St. Francisville
New Orleans
DISTANCE UPRIVER FROM HEAD OF PASSES, IN RIVER KILOMETERS
DISSOLVED SOLIDS, IN MILLIGRAMS PER LITER
0 100 200 KILOMETERS
0 100 200 MILES
http://water.usgs.gov/pubs/circ/circ1133/


Figure 48--PCBs in Silts and Colloids
A. PCB CONCENTRATION
Colloid, main stem
Colloid, tributary
Silt, main stem
Silt, tributary
PCB CONCENTRATION, IN NANOGRAMS PER GRAM OF DRY SEDIMENT
B. PCB TRANSPORT
PCB TRANSPORT, IN KILOGRAMS PER DAY
DISTANCE UPRIVER FROM HEAD OF PASSES, IN RIVER KILOMETERS
http://water.usgs.gov/pubs/circ/circ1133/images/


Figure 56--Caffeine and EDTA in River Water
A. CAFFEINE, MAIN STEM
B. EDTA, MAIN STEM
CAFFEINE, TRIBUTARIES
EDTA, TRIBUTARIES
Summer 1991
Fall 1991
Spring 1992
CONCENTRATION, IN NANOGRAMS PER LITER
CONCENTRATION, IN MICROGRAMS PER LITER
DISTANCE UPRIVER FROM MOUTH OF PASSES, IN RIVER KILOMETERS
http://water.usgs.gov/pubs/circ/circ1133/


Historical Nitrate Data Bulletin 79, Harvey County, Kansas
Area 2
Area 1
Number of Occurences
0
10
20
30
40
50
60
70
80
0-3
3-10
10-20
20-30
>30
Range of Nitrate-N (mg/L)


1000
100
10
1
Chloride (mg/L)
Sep-99
Dec-99
Mar-00
Supply
MW6
MW7
MW8
MW9
MW1 N
MW2 S
R. H. Dom
J. S. Dom
M. H. Dom
Lagoon
Irr Well 1
J. H. Dom
C. M. Dom
A. U. Dom
A. M. Dom
P. H. Dom
G.R. Stock
G. R. Dom
G.Y. Dom
G. Y. Stock
J. H. Dom
S. C. Dom
Sample ID

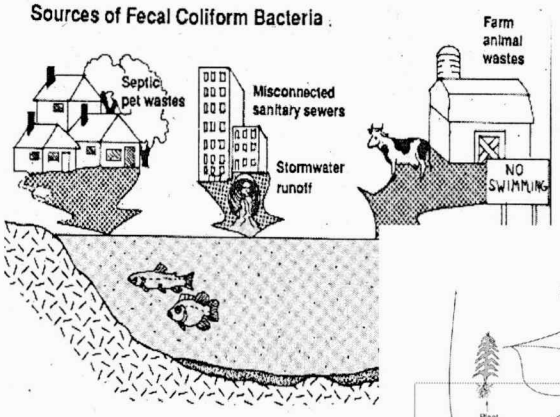

USGS
science for a changing world
Toxic Substances Hydrology Program
Home
About the Program:
The Toxic Substances Hydrology Program provides objective scientific information to improve characterization and management of contaminated sites, to protect human and environmental health, and to reduce potential future contamination problems.
Photo Gallery:
Propane injection test to measure degassing at Pinal Creek, AZ
USGS
science for a changing world
Toxic Substances Hydrology Program
Toxics Program Remediation Activities
Complete List of Projects
Projects Sorted by Remediation Activity
Testing of Remediation Technologies
Natural Attenuation Evaluation
Remediation Performance Monitoring
Characterizing Sites for Remediation
Remediation or Restoration Feasibility Studies
Projects Sorted by Contaminant Type
Hydrocarbons and Fuel Oxygenates
Chlorinated Solvents
Metals
Radioactive Wastes
Landfill Leachate
Waste Waters or Drainage Waters
Projects Sorted by Contaminant Source
Point-Source Contamination Sites
Watershed or Nonpoint Source Contamination Problems
http://toxics.usgs.gov/topics/rem_act/index.html

Nonpoint Sources of Contamination

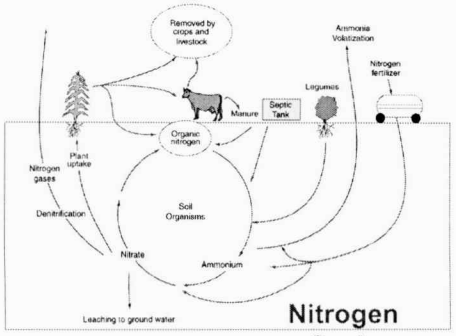
Table 1.

Pollutant	Primary Causes	Potential Health or Environmental Hazards	Water Supplies Most At Risk:
Sediment	Soil erosion from cropland, construction sites, streambeds, etc.	Causes cloudy water and fills lakes Reduces aquatic plant and animal life May also carry phosphates or other pollutants	Lakes Ponds Streams
Nitrate	Fertilizer use on farm and home sites Livestock waste Wastewater treatment systems Decomposition of organic matter	Health hazard to infants Health hazard to young livestock Excessive aquatic plant growth	Domestic wells Underground aquifers Lakes Streams
Phosphorus	Fertilizer use on farm and home sites Wastewater treatment systems Livestock waste systems Soil erosion	Excessive aquatic plant growth resulting in oxygen depletion, fish kills, undesirable odor and taste	Lakes Ponds Wetlands
Pesticides	Crop applications Lawn and garden applications Spills and handling accidents Manufacturing discharges	Cancer Birth defects Direct toxicity to animals or plants Harmful to desirable plants	Lakes Rivers Streams Domestic wells Underground aquifers
Bacteria (*E. coli*)	Septic systems Sewage system discharge Livestock wastes	Sickness and/or possibly death May be harmful to aquatic animals	Domestic wells Lakes Streams Underground aquifers
Hazardous Materials (Solvents) (Gasoline) (Oil) (Industrial wastes) (Metals)	Spills and leaks Dumping	Sickness or death Harmful to aquatic life Harmful to plants	Lakes Rivers Domestic wells

http://www.oznet.ksu.edu/library/h20ql2/mf2204.pdf

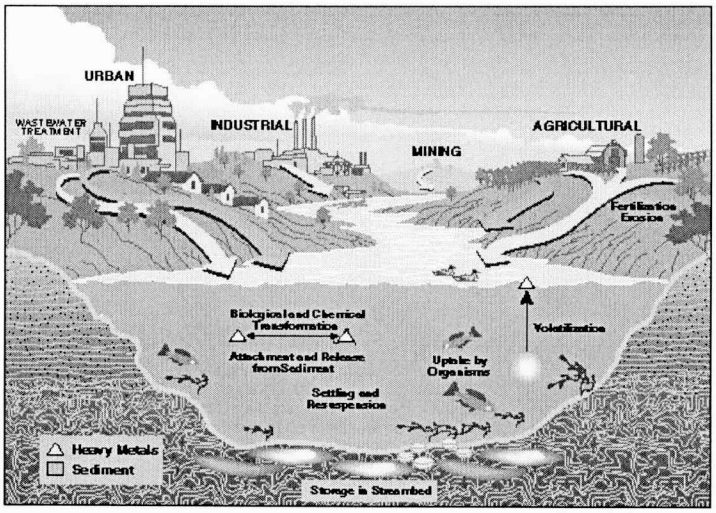


http://www.ecy.wa.gov/programs/wq/plants/management/joysmanual/fecalcoliform.html



Nitrogen Cycle

Figure 21--*Sources and Sinks of Heavy Metals*



http://water.usgs.gov/pubs/circ/circ1133/

Overview:

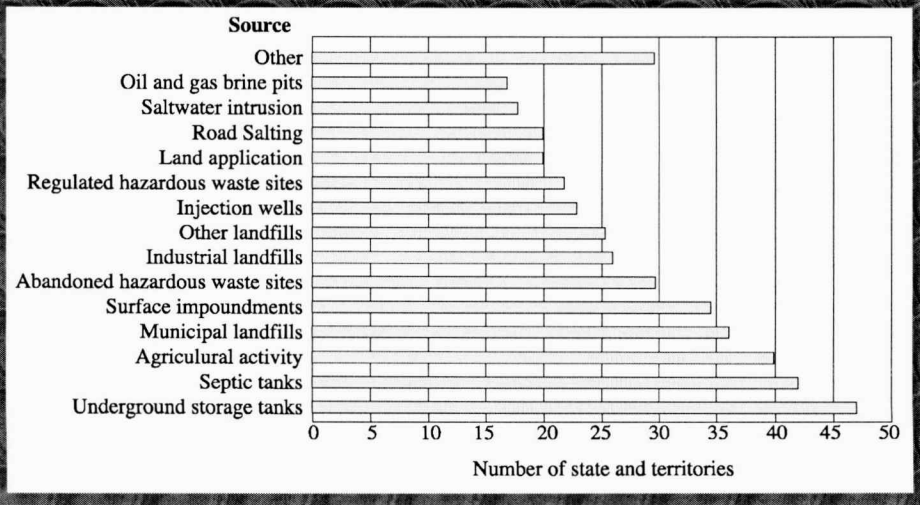
Biogeochemical Processes and Contaminant Fate in the Groundwater – Surface Water Interface

RTDF Sediments Remediation Action Team Meeting
October 29, 2002

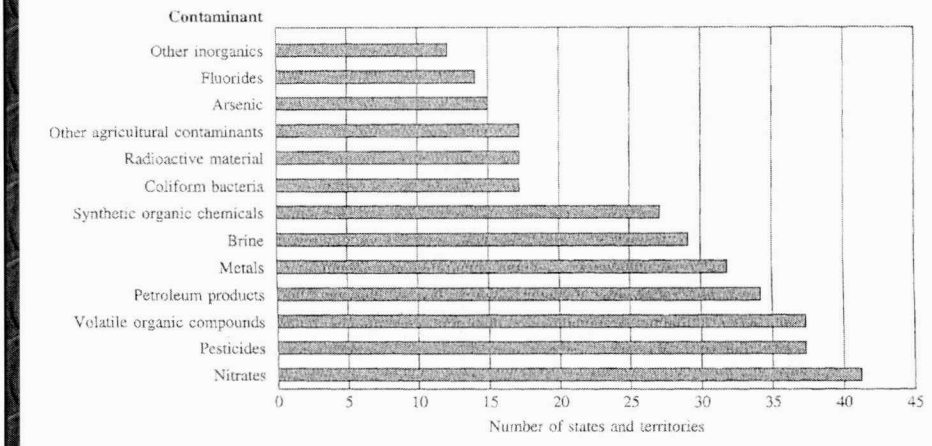
E. Erin Mack Ph.D.
DuPont Corporate Remediation Group

http://www.rtdf.org/public/sediment/minutes/103002/mack.pdf

Sources of Contamination



Contaminants

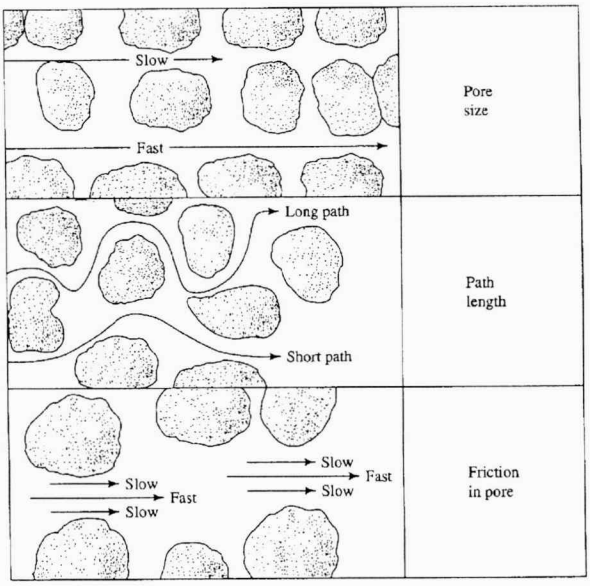


Nonpoint Sources of Contamination

Table 1.

Pollutant	Primary Causes	Potential Health or Environmental Hazards	Water Supplies Most At Risk:
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Nitrate	Fertilizer use on farm and home sites Livestock waste Wastewater treatment systems Decomposition of organic matter	Health hazard to infants Health hazard to young livestock Excessive aquatic plant growth	Domestic wells Underground aquifers Lakes Streams
Phosphorus	Fertilizer use on farm and home sites Wastewater treatment systems Livestock waste systems Soil erosion	Excessive aquatic plant growth resulting in oxygen depletion, fish kills, undesirable odor and taste	Lakes Ponds Wetlands
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http://www.oznet.ksu.edu/library/h20ql2/mf2204.pdf

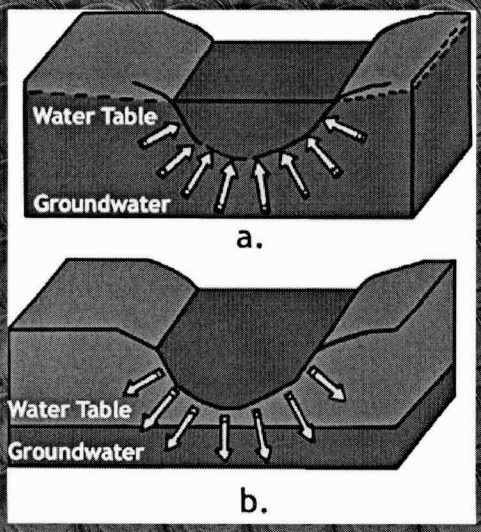


Outline

- Definition of the groundwater-surface water interface (GWSWI)
- Physicochemical characteristics of the GWSWI environment
- Biogeochemical processes in the GWSWI
- Effects of biogeochemical processes on contaminant fate
- Conclusions

What is the GWSWI?

- Subsurface zone in which the water shares characteristics of both the groundwater and the surface water.
- These characteristics might be :
  - Redox
  - Water Chemistry
  - Biological Populations (microbes, benthic organisms)
  - Contaminant Profile



http://www.ces.uga.edu/pubcd/B1217-4.jpg

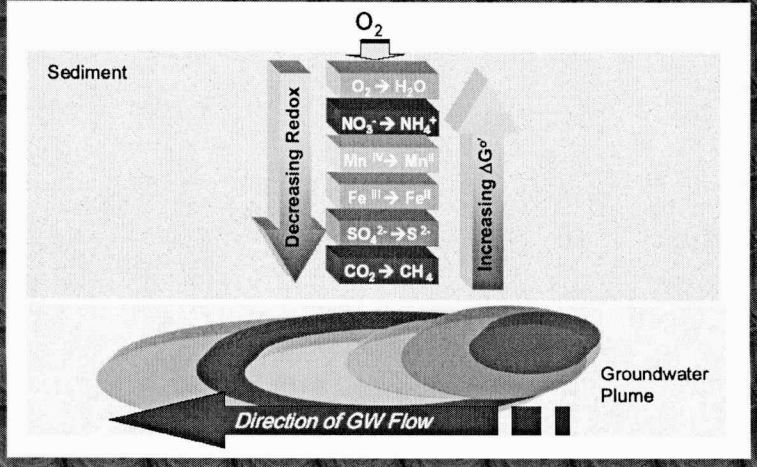
Characteristics of the GWSWI

-Zone of Gradients and Transitions

- Gradients
  - Oxygen / redox
  - Organic content
  - Contaminant concentration / form

- Transitions
  - Hydraulic conductivity
  - Substrate (adsorption qualities)
  - Microbial community
    - Aqueous and surface chemistry
    - Environmental fate of contaminants

Redox Gradients in GW and Sediments



Contaminant Fate and Transport

Dependent upon:

- **Physical-chemical characteristics of the contaminant**
- **Relative kinetics of the process vs. the discharge rate**
- **Depth and differences in surface water and groundwater chemistry**
- **Physiologies and competencies of the microbial population**

Environmental Fates of Contaminants

Transformation:

Chemical changes in contaminant can result in new mobility or toxicity characteristics. Not always desirable.

Ex: PCE → TCE → cDCE → VC → Ethene

$Hg_{inorganic}$ → MethylHg

Degradation:

Mineralization or transformation of contaminant to an innocuous compound.

Ex: Oxidation of BTEX compounds to CO_2

$$TCE + CH_4 + O_2 \rightarrow CO_2$$

By chemical or biological means

Retardation:

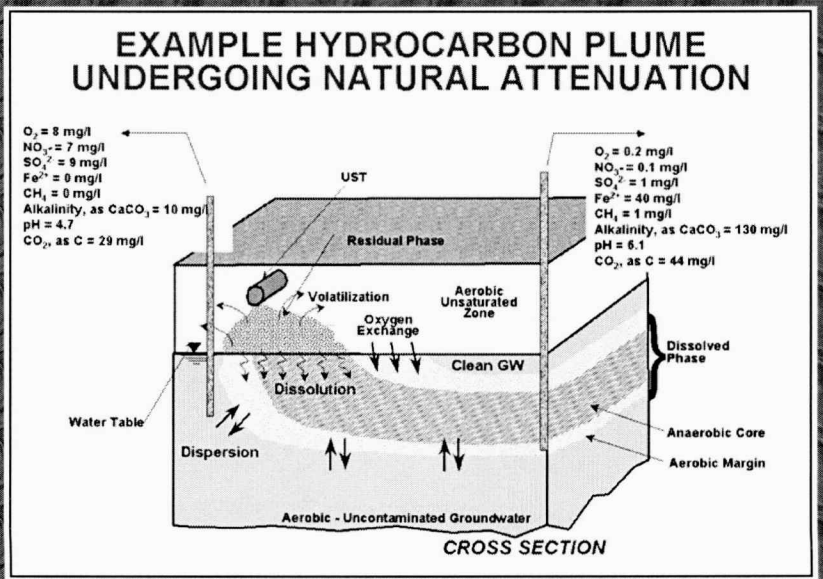
Contaminant transport is retarded through precipitation or sorption

reactions within the GWSWI.

Ex: $Metal^{2+} + Sulfide^{2-} \rightarrow$ Metal-sulfide Precipitate

Abiotic Processes Affecting Contaminant Fate

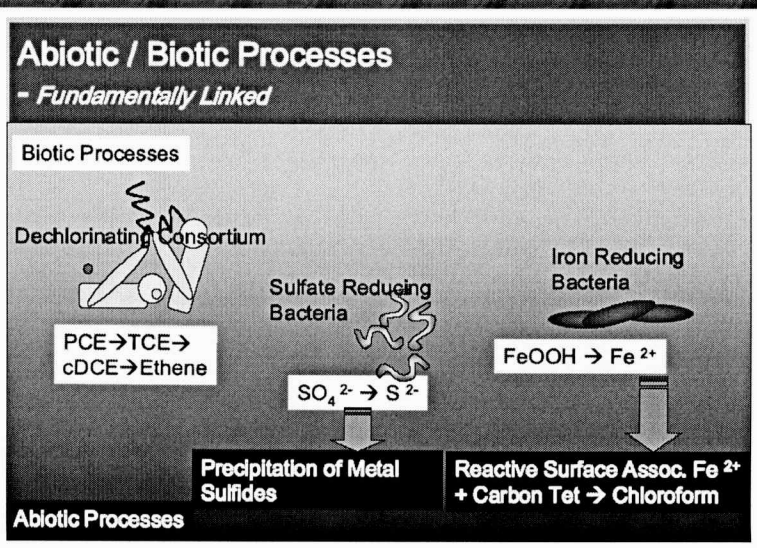
- Hydrology – affects residence time in the different transition zones
- Precipitation – immobilization of metals through sulfide precipitation
- Sorption – retardation of contaminant mobility through association with organic phases
- Surface Chemistry – chemical transformation of contaminants mediated by surface associated reactive minerals



Source: Gregory Rorech, Princeton Groundwater Inc. Remediation Course

Biotic Processes Affecting Contaminant Fate

- Direct: Contaminant transformation is directly linked to physiological processes
  - Reductive Dechlorination of Halogenated solvents
  - Oxidation of BTEX Compounds
- Indirect: Organism produces an end-product that in turn transforms the contaminant
  - Reduction of nitroaromatics by surface associated reduced iron minerals
  - Precipitation of metallic contaminants by sulfide

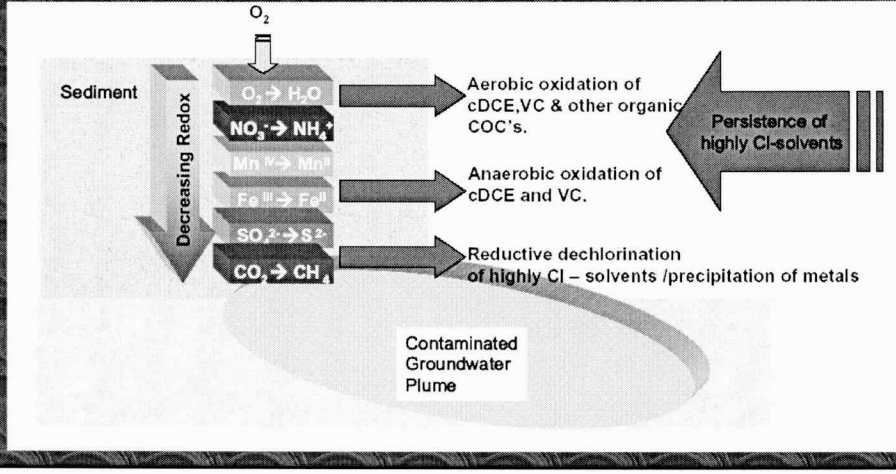


& Effects of hydrology, sorption and residence time…

Types of GWSWI's - 1

– *High Redox Plume Low Redox Interface*

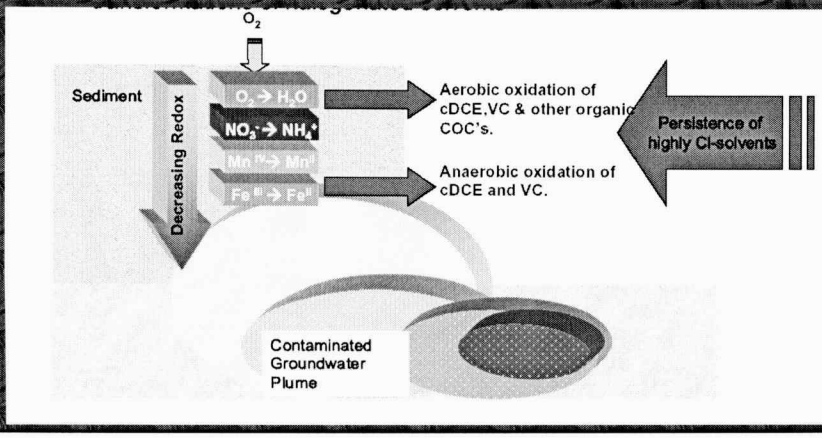
- High redox plume enters low redox GWSWI – zone of accelerated biodegradation for poly-halogenated solvents



Types of GWSWI's - 2

– *Low Redox Plume High Redox Interface*

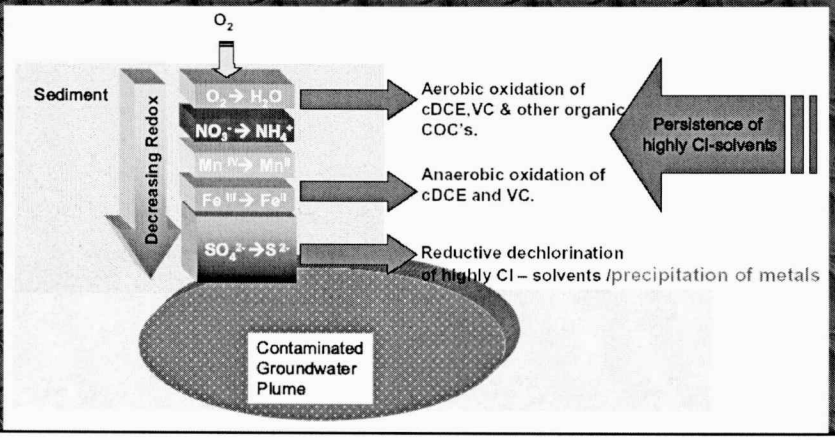
- Low redox plume enters high redox GWSWI – Respiration processes complete degradation of products of anaerobic transformations of halogenated solvents



Types of GWSWI's - 3

-Low Redox Plume
-Low Redox (Sulfate Reducing) Interface

– Low redox plume enters zone of sulfate reduction in GWSWI (low redox) allowing precipitation of metal contaminants



Biogeochemical Processes in the GWSWI

Conclusion - 1

- Abiotic and biotic processes in the GWSWI environment may lead to significant changes in the chemistry, toxicity, and/or mobility of a contaminant.

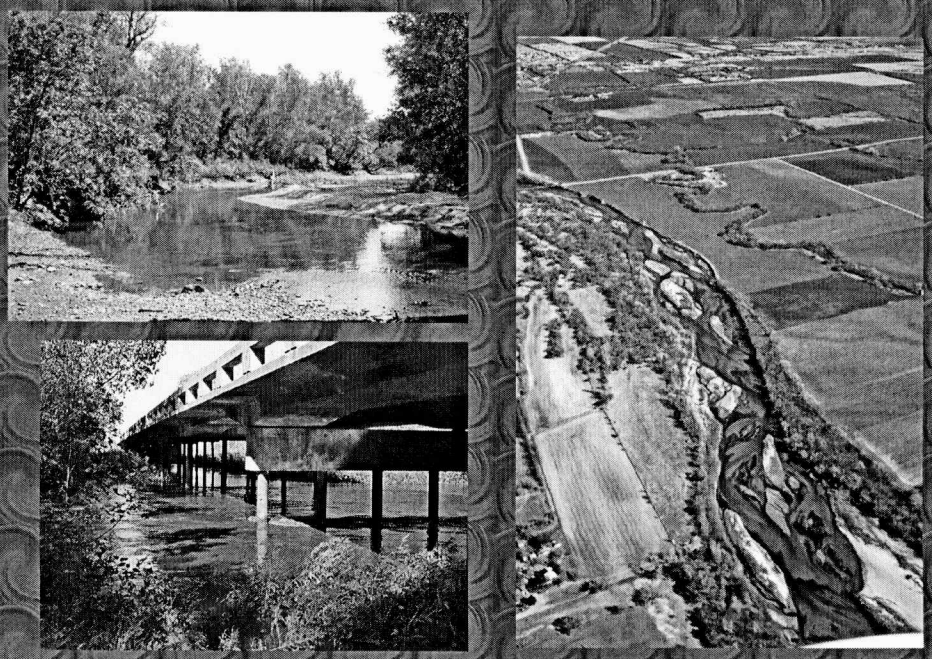


- Discharge of groundwater from a contaminated plume into surface water does not necessarily mean discharge of plume contaminants.

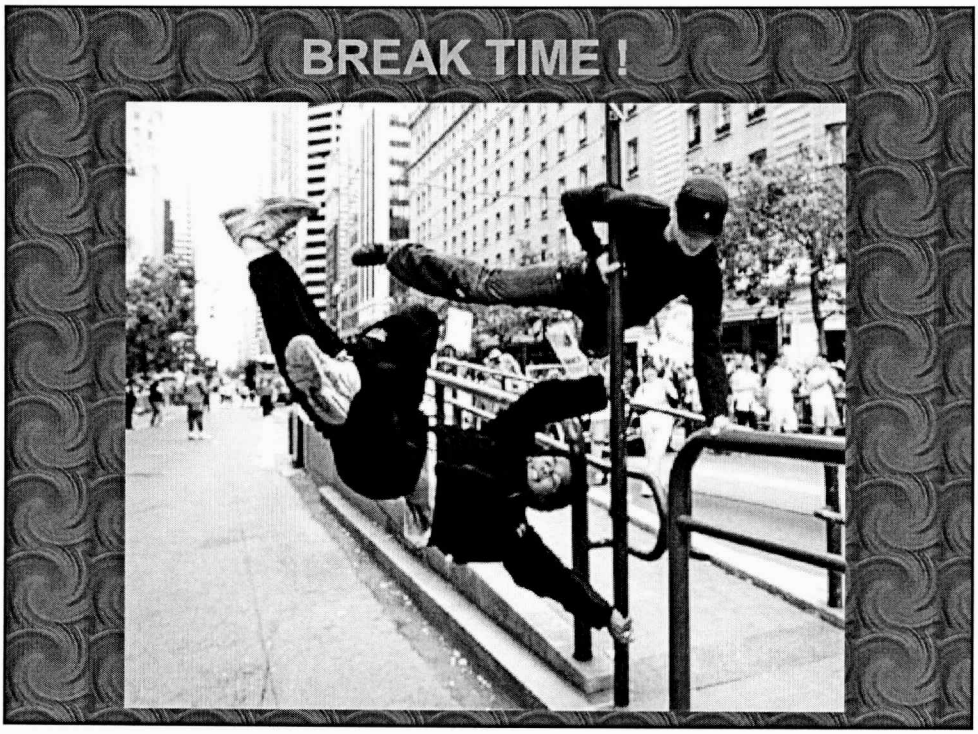
Biogeochemical Processes in the GWSWI

Conclusion - 2

- Characterization of the GWSWI environment is necessary for accurate determination of risk to human and environmental health and selection of best strategies for management of GW contaminants.



Photos by John Charlton, KGS; www.kgs.ku.edu

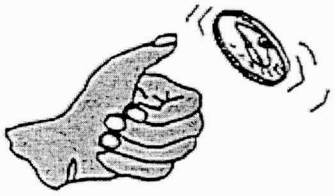

BREAK TIME !

Risk Concepts

Duration	1 class period
Grade Level	7-10
Key Terms/ Concepts	Environmental Risk Risk Probability
Suggested Subjects	Biology Chemistry Creative Writing English Life Science Physical Science Mathematics

Purpose

In this exercise, students explore the meaning of risk in terms of a simple exercise in probability. They explore the idea that not all risks have the same consequences and are not likely to occur at the same rate. The exercise helps students to evaluate the impact of risk on the basis of probabilities, benefits, and their perceptions.



Background

Nothing in life is a "sure thing." While it is unlikely that it will snow in Texas in April, it is possible. In the same way, it is unlikely that it will be 80 degrees in Massachusetts in December, but it is possible. Saying something is "unlikely" or that it "probably will happen" is an indication of the **probability** that this particular thing will occur. Every day you weigh probabilities even without realizing it.

For example, when you take a test, you think about the chances of getting an "A." How likely you think it is that you'll get an "A" depends on how well you studied and how hard you think the test will be. Or, if you want to be picked for a team, the chances that you'll make it depends on how many other people want to play and how good you are in comparison to everyone else.

When it comes to the environment, the chance of something dangerous happening is called **risk.** Each type of hazardous substance, hazardous waste, or dangerous situation involves a different amount of risk. The risk is made up of two parts:

(1) the chance that people will be exposed to the substance, and (2) the chance that exposure will injure or harm them. **Environmental risk** measures the probability that the environment will be damaged by a particular hazardous situation. Decisions on cleaning up a Superfund site are based on the risks the site poses to people and the environment.

There are generally many factors involved in determining the risks surrounding a particular hazardous situation. These factors include the potential for damage each particular substance can cause, the chances that the substance is going to spread from the original site through water, wind, or some other means, and the chance that people will come in contact with the substance.

In this Warm-up, students perform a simple exercise in probability to gain a beginning understanding of how chance operates. For additional information on probability, and risk, and environmental risk assessment, see the Suggested Reading list found at the end of the Haz-Ed materials. Other Haz-Ed materials that are related to this topic include *Activity 7: Identifying Risks at a Superfund Site* and *Activity 9: Making Decisions about Hazardous Waste Cleanup.*

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ACTIVITIES EXCHANGE

Subsurface Contamination of Groundwater

Jane Maczuzak
1991 Woodrow Wilson Biology Institute

OBJECTIVES:

The major objective of this demonstration is to show students how difficult it is to study subsurface contaminants contained in underground storage tanks.

BACKGROUND INFORMATION:

Ground water is the water that lies beneath the earth's surface. It is currently estimated that 25% of the available ground water in the United States is contaminated. Common pollutants include gasoline, heating oil, wastes from septic tanks and various toxic chemicals stored in underground storage tanks (UST's). The EPA regulates 30% of the known UST's. The remaining 70% are found on private property, usually hold less than 1,100 gallons of material and are a major source of ground water pollution.

MATERIALS:

Materials needed are inexpensive household items:

- plastic milk containers or paper cartons
- toothpicks
- paper clips

RESOURCES:

United States Environmental Protection Agency. **Environmental Resource Curricula: Approaching Environmental Science Education Using Case Studies.** "Activity 3.1-Subsurface Investigations." Washington , D.C.: 1990.

Woodrow Wilson Index

Activities Exchange Index

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A Plume of Contamination

Goals: To have students understand how contaminants can enter and move with groundwater and what is meant by "plume of contamination." To help students realize why it is often difficult to determine the source of groundwater contamination.

Subjects: Science, Health, Home Economics, Environmental Science

DPI Objectives: SC: A1-A3, B3

EH: B4, C4

Grades: 6-9

Materials:

- A Plume of Contamination activity sheet
- clear plastic shoe boxes* or large plastic deli boxes—one for demonstration and one for each group of 3-4 students
- sand
- powdered grape drink mix (do not add water)
- powdered lemonade mix (do not add water)
- for each group of 3-4 students:
  - watering cans or spray bottles
  - plastic straw, cut in half
  - pH paper
  - tape
- plastic shoe box lids or pencil erasers for props

* available at discount stores

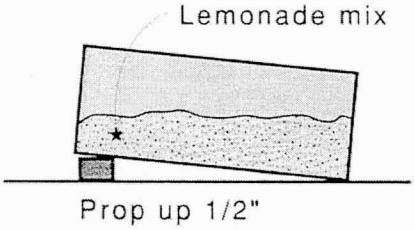
Background: Contaminants on the surface of the ground can move slowly through soils and reach groundwater. Contaminants spread outward from the point of origin, forming a plume which "points" to the source of contamination. A small amount of some contaminants can ruin a large quantity of groundwater.

Some chemical contaminants are easily detected by changes in color, odor, or taste of groundwater. However, most contaminants are "invisible" and require chemical testing for detection. Testing of many wells in an area may be required to determine the source of contamination.

Procedure:

A) Preparation.

1. Before class, fill one clear plastic shoe box for each group of 3-4 students with 1 inch of sand. Wet the sand with water and smooth off the surface. Station boxes around classroom.



2. Prop up one end of each box about 1/2 inch.

3. Make a small depression in the sand and add 1/2 teaspoon of dry lemonade mix at the elevated end. Cover the lemonade with sand. Vary the location of the lemonade contaminant in each box and keep a record of the contaminant location. After the demonstration, students will use pH paper to find the source of contamination.

B) Demonstration.

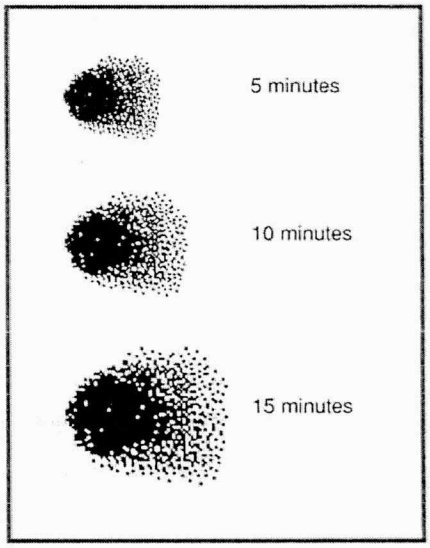
1. Prepare a plastic box as above, but don't add lemonade.

2. Make a small depression on the elevated side of the box. Place about 1/4 teaspoon of powdered grape drink mix in the depression. This represents a chemical contaminant.

3. "Rain" water on the contaminant, using the spray bottle or watering can. The "rain" should be light so the food coloring is diluted and seeps into the sand rather than running off the surface. If sand erodes badly, try again, using lighter "rain" or spread a layer of pea gravel on top to hold the sand in place.

4. Every 2-3 minutes check the bottom of the box for evidence of color. After about five minutes, a plume of color should begin to appear. Draw the shape of this plume, to scale, on the chalkboard.

5. Check the size and shape of the plume after 1/2 hour and draw the new plume, to scale, on the chalkboard. Discuss the results. The plume should be broad and fanlike, pointing to the source of contamination. Notice that the red and blue dye components of the grape drink mix separate. Why do you think this happens?



C) Investigation.

1. Tell students they will now have to use a chemical test to find the source of an invisible contaminant. Point out the boxes in which you've placed the lemonade mix. Explain that a lemonade "contaminant" has been put in a different location in each box and they will be using pH paper to find the plume of contamination. Lemonade is acidic and will lower the pH of water it encounters. It may be helpful to review the meaning of pH and the use of pH paper. Remind students that as acidity increases, pH decreases.

2. Work in small groups at the lemonade contaminant stations.

3. Lay a 6 inch strip of pH paper on a dry desk or counter. You may need to secure the paper to the desk or counter by placing a piece of tape at each end. Put a small drop of water on one end of the pH paper, note the color and record the

pH of the water on your activity sheet.

4. With a watering can, "rain" lightly on the upper end of each box so there's no runoff. Keep watering lightly for about 5 minutes. Wait 15 to 20 minutes.

5. Using a piece of plastic straw, remove a plug of sand (and water) from one of the locations indicated on the activity sheet diagram. Drop the wet sand on the pH paper. Note the color of the pH paper and determine the pH of the sample. If the sample is more acidic (has a lower pH) than tap water, place a "+" on that location on your activity sheet. If the acidity is the same or lower (pH same or higher), place a "-" at that location on your activity sheet. Rinse the straw.

7. Take a total of 12 "test well" samples from the locations shown on the diagram, rinsing the straw after each sample. Determine the pH of each sample and record a "+" or "-" on your activity sheet at each location.

8. Complete the activity sheet and discuss your results.

- ❖ What makes a contaminant move from where it is buried?
- ❖ What is a "plume of contamination?"
- ❖ What are some real contaminants that could be seen, smelled or tasted if they got into groundwater?
- ❖ What are some real contaminants that could not be seen if they got into groundwater?
- ❖ In the real world, what factors underground might influence the movement of contaminants?

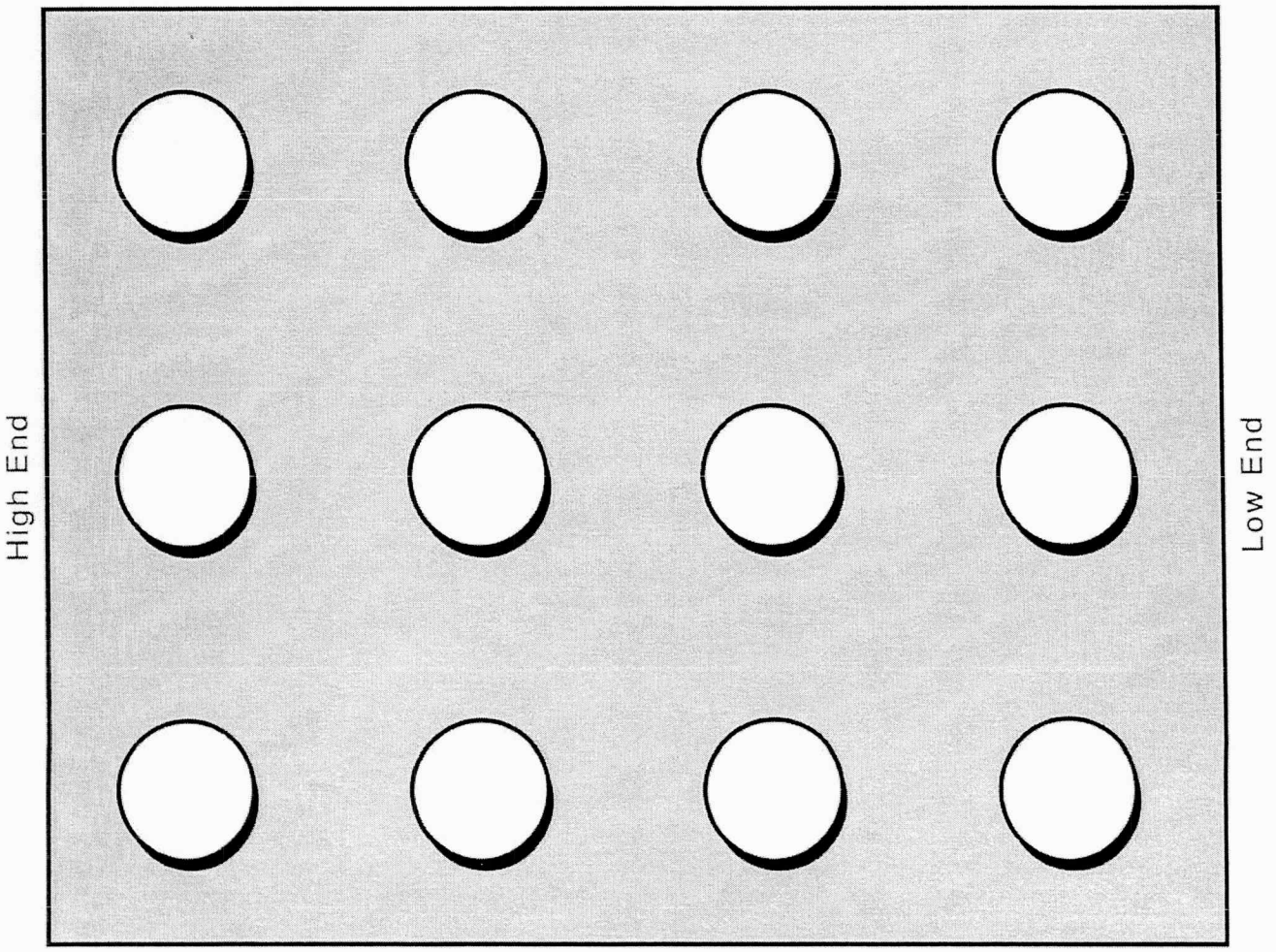
Going beyond:

1. Research and report on the types and effects of groundwater contamination from various sources in your area (e.g. private homes, schools, farms, landfills, gasoline stations, mine sites, septic tanks, industries, businesses, salt stockpiles, etc.).

2. Research and report on the effects contaminated groundwater may have on human health. Have a physician or public health official visit and discuss the topic.

3. Investigate bottled drinking water. Where does it come from? How much does it cost? What does the company do to insure that it is safe for human consumption? What regulations govern the quality of bottled water?

Adapted from: ***Groundwater Quality Protection in Oakland County. 1984.*** *The East Michigan Environmental Action Council.*



A Plume of Contamination activity sheet

Instructions:

1. Using pH paper, determine the pH of tap water.

pH of tap water _____

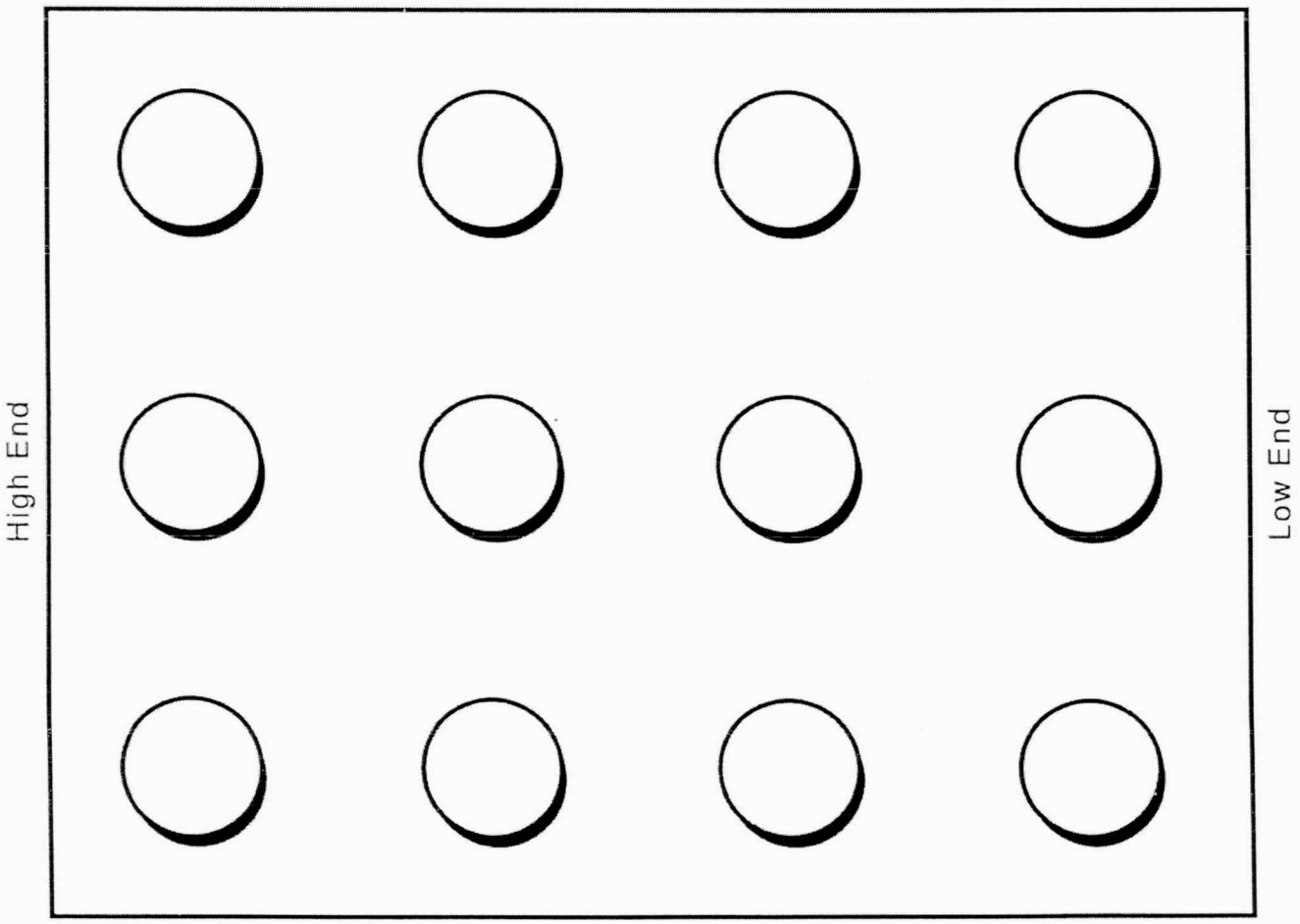
2. Take a sample of sand and "groundwater" from each test well location indicated. Test the groundwater at each location for contamination by placing the sand sample on a strip of pH paper. Rinse the straw after each sample.

3. Record your results for each location on the table below:

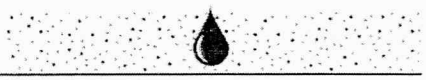
+ = contamination found (pH of sample < water)

- = no contamination (pH of sample = water)

Record the results directly on each test well location.



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4. Based on the results of your tests, sketch the shape of the plume of contamination.

5. Are there enough "test wells" to determine the source of contamination? _____

6. If you were to select three additional "test well" locations, where would they be? Indicate your proposed locations with the letter "T" on the activity sheet.

7. Rinse the straws with tap water and test the groundwater at each new test well location. Record your results. If the results show contamination, mark the well with a T+. If the results show no contamination, label the well T-.

8. Are more test wells needed to show the extent of the plume of contamination? _____

Nonpoint Source Pollution in Kansas

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Water is one of our most precious natural resources. All of us depend on water for drinking and household use. In addition, we use water for agriculture, industry, and recreation. Concerns exist in Kansas about the quality of our surface and groundwater.

A report in 1994 by the Kansas Department of Health and Environment indicated 97 percent of streams and 82 percent of lakes in Kansas would not fully support all uses as designated by state statute.

A high percentage of streams are contaminated by bacteria (an indicator of possible pathogens) and sediment. A high percentage of lakes are contaminated by nutrients and pesticides (Figure 1). Sources of water quality problems include both natural and man-made pollution. Pollution reaches water from many sources and pathways, which can generally be divided into point source and nonpoint source pollution.

Point Source Pollution

Point source pollution comes from specific, single locations, such as municipal sewage treatment plants, manufacturing plants, or large confined livestock feeding operations. These sources are often easy to identify and control. Controlling point source discharges came under federal regulation in 1972. It is estimated that only about 20 percent of today's water quality problems result from point sources.

Nonpoint Source Pollution

Nonpoint source pollution generally occurs:

- Over a large area,
- Over an intermittent period of time,
- From diverse sources, such as farms, ranches, transportation corridors, and urban areas.

Stormwater runoff and the pollutants it carries are the most common causes of nonpoint source pollution of lakes, rivers, and streams. Another example is the leaching of nitrate or other chemicals down through the soil into domestic wells or groundwater aquifers.

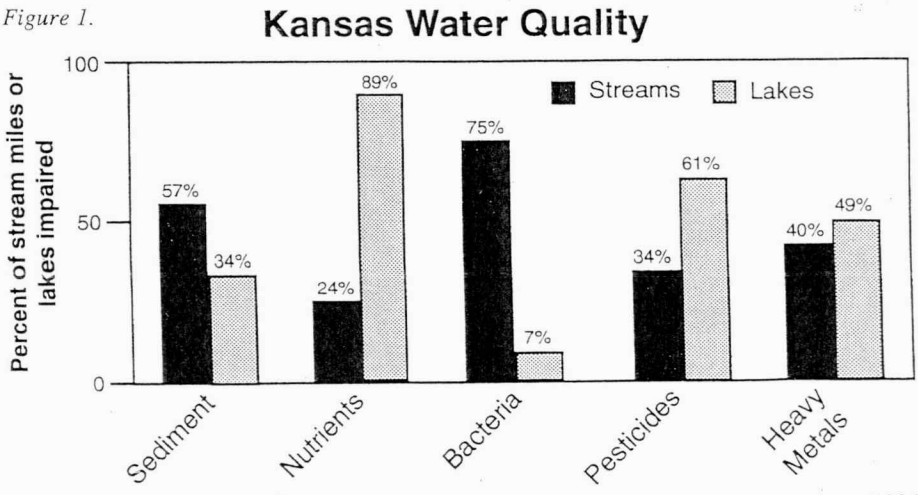
Nonpoint source pollution is not easily monitored at the point of origin. Contaminants are not generally traceable to an exact source. It usually occurs sporadically, and is often correlated with climatic events. Atrazine herbicide contamination of surface water is an example of nonpoint source pollution in Kansas. Atrazine in surface water is the result of runoff from hundreds, possibly thousands of farm fields in a watershed. Sometimes, after years of data collection, the problem can be pinpointed to specific fields. Often, many farms over an entire region must be targeted for use of a system of Best Management Practices (BMP's) to reduce this nonpoint pollution source.

Many water quality specialists believe most future improvements in water quality in the United States will be made by reducing nonpoint source pollution.

Major Contaminants of Water in Kansas

Many types of contaminants may enter surface and groundwater from urban and agricultural sites. Pollutants may come from crop fields, livestock

Figure 1.



Source: Kansas Department of Health and Environment, 1994

waste, septic systems, lawns and gardens, construction sites, underground fuel tanks, and urban storm water runoff. Some contaminants, such as bacteria from livestock wastes or septic systems, may pose a public health hazard. Others, including sediment from erosion of cropland, are a nuisance and may result in increased costs for water treatment plants.

Major water pollutants in Kansas are sediment, nutrients, bacteria, pesticides, and hazardous materials (Table 1).

Sediment. Sediment is the largest water pollutant in Kansas as measured by weight or volume, but it's not a health hazard. Sedimentation occurs when water carrying eroded soil particles slows long enough to allow soil particles to settle out. Eventually, sedimentation fills streams, rivers, and lakes. Turbidity from soil erosion clouds the water and reduces light penetration. This, in turn, reduces photosynthesis and has an adverse effect on fish and other aquatic life. Sediment may carry other contaminants, such as nutrients, organic matter, pesticides, and hazardous materials.

Nutrients. Nutrients, especially nitrogen and phosphorus, impair Kansas water quality. Nitrogen contamination is a concern to both ground and surface water, while phosphorus is mainly a problem for surface water. Both nutrients are essential for the growth of aquatic life. However, excess nitrogen and phosphorus levels in lakes and streams can lead to excessive aquatic plant growth referred to as algae blooms. This unwanted burden of aquatic plant growth is termed "eutrophication."

Water clogged with overabundant aquatic plant growth can lead to a number of undesirable consequences. The water can become undesirable for recreational activities. In addition, when these plants die and decompose, they consume oxygen in the water and severe fish kills may occur. Decaying algae and plants may cause undesir-

Table 1.

Pollutant	Primary Causes	Potential Health or Environmental Hazards	Water Supplies Most At Risk:
Sediment	Soil erosion from cropland, construction sites, streambeds, etc.	Causes cloudy water and fills lakes Reduces aquatic plant and animal life May also carry phosphates or other pollutants	Lakes Ponds Streams
Nitrate	Fertilizer use on farm and home sites Livestock waste Wastewater treatment systems Decomposition of organic matter	Health hazard to infants Health hazard to young livestock Excessive aquatic plant growth	Domestic wells Underground aquifers Lakes Streams
Phosphorus	Fertilizer use on farm and home sites Wastewater treatment systems Livestock waste systems Soil erosion	Excessive aquatic plant growth resulting in oxygen depletion, fish kills, undesirable odor and taste	Lakes Ponds Wetlands
Pesticides	Crop applications Lawn and garden applications Spills and handling accidents Manufacturing discharges	Cancer Birth defects Direct toxicity to animals or plants Harmful to desirable plants	Lakes Rivers Streams Domestic wells Underground aquifers
Bacteria (E. coli)	Septic systems Sewage system discharge Livestock wastes	Sickness and/or possibly death May be harmful to aquatic animals	Domestic wells Lakes Streams Underground aquifers
Hazardous Materials (Solvents) (Gasoline) (Oil) (Industrial wastes) (Metals)	Spills and leaks Dumping	Sickness or death Harmful to aquatic life Harmful to plants	Lakes Rivers Domestic wells

ible odor and taste in drinking water.

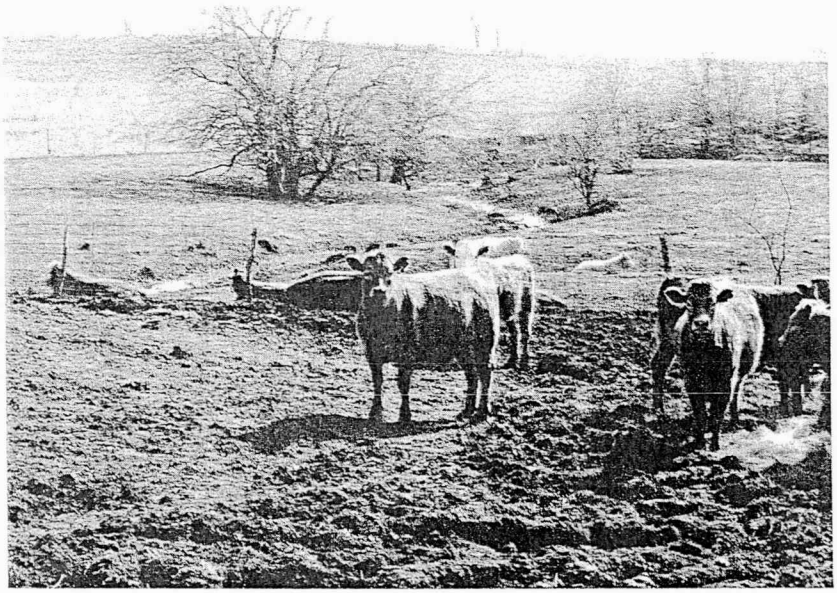
Lack of phosphorus is usually the limiting factor to aquatic growth. As a result, most efforts to keep aquatic plant growth in proper balance concentrate on controlling the amount of phosphorus entering the water body. Phosphorus comes from both point and nonpoint sources. Many of the nonpoint source pollution control programs in Kansas are designed to reduce phosphorus movement into surface waters.

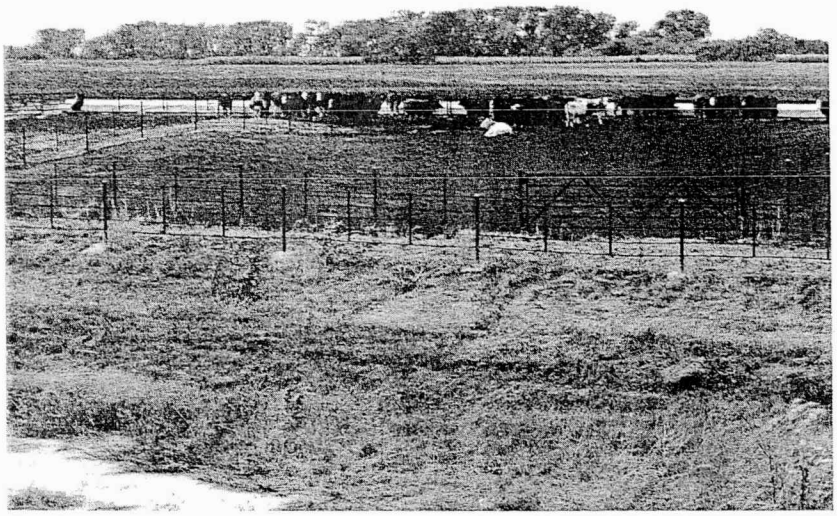
Nitrogen, in the form of nitrate, is a public health concern in drinking water supplies. Nitrate contamination is a greater problem in groundwater than surface water. Nitrate may come from nitrogen-containing fertilizer, livestock waste, septic systems, and decomposing animal and plant materials. Contamination of water wells generally results from an abundance of sources near the well. It is also influenced by poor well location, faulty construction, or inadequate maintenance. Contamination of underground aquifers, although less common than contamination of water wells, may occur when nitrogen levels exceed plant or microbial needs and water containing the excess nitrogen leaches down through the soil.

Bacterial indicators. The presence of E. coli or fecal coliform bacteria indicates that water is unsuitable for drinking and other domestic uses. Recreational uses and aquatic life also may be impaired. Potential sources of bacterial contamination include livestock wastes, septic system wastes, and sewer overflows. Wildlife is thought to be a less important source. These organisms live in the intestines of humans and warmblooded animals. Some will enter and contaminate lakes, streams, and water wells. They normally do not occur naturally in groundwater but may enter wells because of poor well location, faulty construction, or inadequate maintenance.

Pesticides. Pesticides are used to control weeds, insects, diseases, and rodents in agriculture and urban areas. Pesticides applied by farmers, homeowners, or industrial users may be moved by wind and surface runoff into streams and lakes. Pesticides may also leach into groundwater. In Kansas, pesticide contamination is a greater problem for surface water than for groundwater. Pesticide runoff into surface water is generally the most concern from mid-May to July, during and immediately following pesticide application. After entering streams and lakes, pesticides generally decompose to either more toxic or less toxic compounds, or may stay in their original form. Normally, the rate of decomposition is slower in water than in soil.

Hazardous Materials. Solvents, gasoline, oil, industrial wastes, and heavy metals are examples of hazardous materials that may be washed into streams and lakes. These substances can have detrimental effects on drinking water, aquatic life, plant growth, and associated equipment (pipes, pumps,

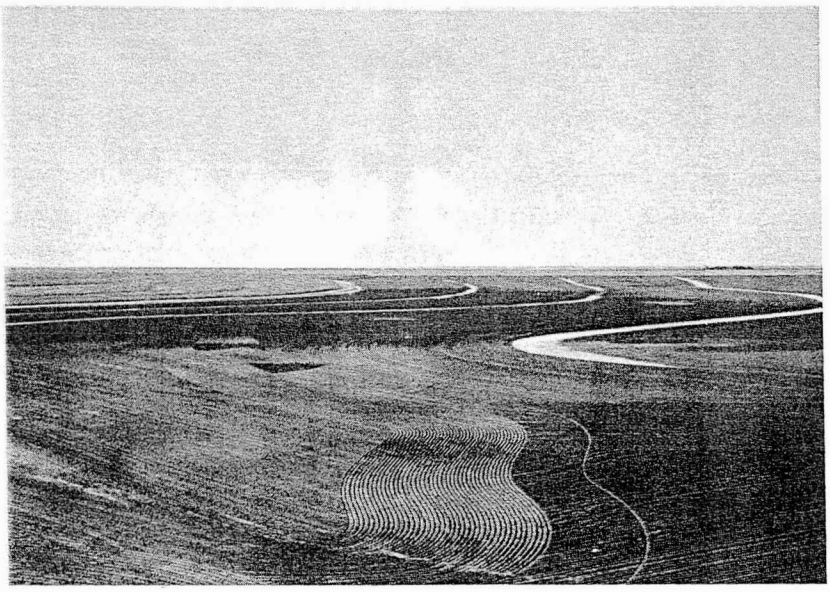




Before improvements (above), cattle on this farm were being kept near a stream. This was a pollution concern. The cattle were later moved into a new feeding area well away from the stream. A holding pond now collects waste runoff and passes it over a grass filter area to help keep pollutants from reaching surface water (below).



Soil erosion leads to a number of nonpoint source pollution problems, including sediment, phosphorous and certain pesticides. A system of storage terraces (below) is one of many Best Management Practices that can be used to reduce erosion.



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etc.). The effects of low levels of these substances is not known in most cases. Generally, the chance of contamination by hazardous materials is greatest near urban areas, business and industry, transportation routes, and farmsteads These substances can cause severe water contamination that can be difficult and expensive to clean up. Lead, zinc, copper, chromium, cadmium, nickel, and mercury are the metals that are most frequently present in urban runoff.

Managing Nonpoint Source Pollution

Because of the diverse nature of nonpoint source pollution and the large number of people contributing to the problem, it is difficult to manage and control. Nonpoint source control plans call for education and voluntary actions to reduce chances of contaminants reaching surface or groundwater.

Laws and regulations are being used only to address point source pollution and the effects of nonpoint source pollution. For example, water treatment plants are required by law to clean water to a certain standard. Additionally, higher water treatment costs are generally passed on to consumers.

Most nonpoint source pollution control programs in Kansas are aimed at voluntary acceptance of appropriate management practices. In agriculture, voluntary adoption by farmers of BMP's that reduce runoff and leaching losses of nutrients, pesticides, sediment, and animal wastes is key to reducing nonpoint source pollution. In urban areas, education through Kansas State University Cooperative Extension Service programs, state and local agencies, media, and lawn care services is the focus of nonpoint source pollution control efforts.

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Cooperative Extension Service, Manhattan, Kansas

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Direct-push geochemical profiling for assessment of inorganic chemical heterogeneity in aquifers

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Abstract

Discrete-depth sampling of inorganic groundwater chemistry is essential for a variety of site characterization activities. Although the mobility and rapid sampling capabilities of direct-push techniques have led to their widespread use for evaluating the distribution of organic contaminants, complementary methods for the characterization of spatial variations in geochemical conditions have not been developed. In this study, a direct-push-based approach for high-resolution inorganic chemical profiling was developed at a site where sharp chemical contrasts and iron-reducing conditions had previously been observed. Existing multilevel samplers (MLSs) that span a fining-upward alluvial sequence were used for comparison with the direct-push profiling. Chemical profiles obtained with a conventional direct-push exposed-screen sampler differed from those obtained with an adjacent MLS because of sampler reactivity and mixing with water from previous sampling levels. The sampler was modified by replacing steel sampling components with stainless-steel and heat-treated parts, and adding an adapter that prevents mixing. Profiles obtained with the modified approach were in excellent agreement with those obtained from an adjacent MLS for all constituents and parameters monitored (Cl, NO_3, Fe, Mn, DO, ORP, specific conductance and pH). Interpretations of site redox conditions based on field-measured parameters were supported by laboratory analysis of dissolved Fe. The discrete-depth capability of this approach allows inorganic chemical variations to be described at a level of detail that has rarely been possible. When combined with the mobility afforded by direct-push

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rigs and on-site methods of chemical analysis, the new approach is well suited for a variety of interactive site-characterization endeavors.
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Keywords: Direct-push geochemical profiling; Discrete depth; Chemical heterogeneity; Hydrochemical; Redox gradient

1. Introduction

Spatial variations in inorganic chemistry have been observed to occur in aquifers both naturally and as a result of contamination (Ronen et al., 1987a; Barcelona et al., 1989; Bjerg and Christensen, 1992; Baedecker et al., 1993; Vroblesky and Chapelle, 1994; Chapelle et al., 1995; Borden et al., 1995). In the last few decades, the importance of detailed characterizations of aquifer geochemistry has been demonstrated in applications ranging from the delineation of recharge sources to the design of remediation strategies. The high-resolution characterization of geochemical contrasts has also been found to be essential for understanding stream–aquifer interactions (Cirmo and McDonell, 1997), evaluating the intrusion of saline waters into aquifers (Whittemore, 1995) and identifying contamination caused by mining leachate (Nimick and von Guerard, 1998). More recently, the widespread use of monitored natural attenuation (Wiedemeier et al., 1998; Azadpour-Keeley et al., 2001; Brun and Engesaard, 2002), in situ remediation enhancement compounds (Norris, 1999) and permeable reactive barriers (United States Environmental Protection Agency (U.S. EPA), 1999) has placed renewed emphasis on detailed assessments of the inorganic chemistry of aquifers. Unfortunately, the inorganic chemical data essential for such efforts are often obtained as an afterthought or as accessory information during investigations designed for other purposes.

The assessment of geochemical heterogeneity in aquifers is usually accomplished with dense monitoring-well or MLS networks (Ronen et al., 1987b; Smith et al., 1991; Puls and Paul, 1997; Harper et al., 1997; Hurt et al., 2001). Because installation of such networks can be expensive and time consuming, sampling points are often limited to a spacing that is inadequate for characterization of relevant geochemical or biogeochemical processes. Moreover, modification of sampling spacing in response to new insights about a site or temporal changes in groundwater chemistry is difficult to implement using these techniques. Over the last decade, direct-push methods have been developed that overcome the limitations of traditional well-based approaches (Cordry, 1986; Tillman and Leonard, 1993; Farrar, 1996; Jacobs et al., 2000). These approaches, which allow detailed profiles of subsurface chemistry to be obtained in a single probehole, have been used extensively with field analytical tools to identify zones of groundwater contamination and guide the placement of permanent monitoring wells. Although numerous evaluations of direct-push samplers have yielded an array of methods for sampling organic contaminants, the parallel development of approaches for inorganic parameters has not occurred. The description, evaluation, and refinement of a direct-push-based approach for high-resolution sampling of inorganic parameters is the major focus of this paper.

Direct-push tools for groundwater sampling can generally be divided into two groups: those with exposed screens and those with shielded screens. Exposed-screen tools typically

consist of a short, screened segment of pipe at the leading end of a string of steel drive rods. Multilevel sampling is achieved in a single probehole by alternating driving and sampling. Although several authors have demonstrated that exposed-screen tools can yield representative samples of organic compounds (e.g., Church and Gvanato, 1996), the method is susceptible to screen blockage by fine materials and sample contamination by mixing with water from previous sample intervals (American Society for Testing and Materials (ASTM), 1999; U.S. EPA, 1997). These problems are partially overcome in a design by Pitkin et al. (1999) in which water is injected through a small sampling port as the probe is advanced. Shielded-screen samplers, which incorporate a screen that is not exposed to the formation until sampling, have also been used successfully to sample contaminants (Smolley and Kappmeyer, 1991; Zemo et al., 1994, 1995). Although the problem of screen blockage is eliminated by shielding the screen, most of the shielded-screen methods are limited to single-depth use and/or are designed primarily for the collection of small-volume samples for laboratory analysis. Because of its relative simplicity, flexibility for integration with other applications and capability to access multiple depths in a single probehole, an exposed-screen tool was initially used in this study. The results of the initial work revealed some fundamental limitations of the conventional exposed-screen sampler and led to the development of a modified sampler configuration. The development and evaluation of the new approach follows.

2. Methods

2.1. Experimental design

The evaluation and development of direct-push geochemical profiling methods were conducted in three phases. The initial phase examined a commercially available sampling tool designed primarily for use at sites of groundwater contamination (Geoprobe Systems, 2001). Despite their potential for releasing metals during sampling (Barcelona et al., 1983), steel rods and sampling components are widely used in conventional direct-push equipment. Given the possibility of sample contamination by metal leaching, the effect of tool composition on sample quality was the major focus of the first phase of the work. In the second phase of the work, the potential for sample contamination by water remaining in the rods after previous sampling was assessed. The results of the first two phases of the work were used to design a modified sampling approach, which was evaluated in the third phase. In all cases, samples obtained during direct-push profiling were compared to those collected from multilevel samplers (MLSs) located less than 1 m from the direct-push probeholes. Because they are composed of nonreactive polyethylene and have been sampled extensively in previous work (Hall, 1998; Kidwell, 1999; McVay, 2000; Schulmeister et al., 2001, in press-b), the MLS provided an excellent standard against which to test the direct-push method.

Chemical parameters and constituents chosen for analysis included those necessary for assessing sampler reactivity, those commonly used as conservative tracers and those used to indicate geochemical and biochemical processes. Dissolved oxygen (DO), oxidation–reduction potential (ORP), specific conductance, pH and temperature were measured in

the field prior to the collection of samples for laboratory determination of dissolved Cl, NO_3, Fe and Mn. In the final phase of the work, the laboratory data were used to assess the accuracy of interpretations of site redox conditions made on the basis of the field-measured parameters.

2.2. Monitoring site and instrumentation

Direct-push profiling was conducted at a research site at which significant vertical contrasts in chemistry and hydraulic conductivity had been previously identified (Hall, 1998; Schulmeister, 2000; Schulmeister et al., 2001; Butler et al., 2002). This site, the Geohydrologic Experimental and Monitoring Site (GEMS), is located on the alluvial sediments of the Kansas River floodplain, 3.4 km northeast of Lawrence, KS. The alluvium consists of 11 m of sand and gravel that is overlain by an 11-m confining unit composed primarily of silt and clay (Fig. 1a). The sand-and-gravel interval, which was the focus of this study, contains thin lenses of relatively less permeable material (Jiang, 1991; Butler et al., 1999; Schulmeister et al., in press-a). The hydraulic conductivity (K) of the sand-and-gravel interval increases with depth, from <1 m/day near the top of the unit to over 240 m/day near its bottom (Fig. 1b).

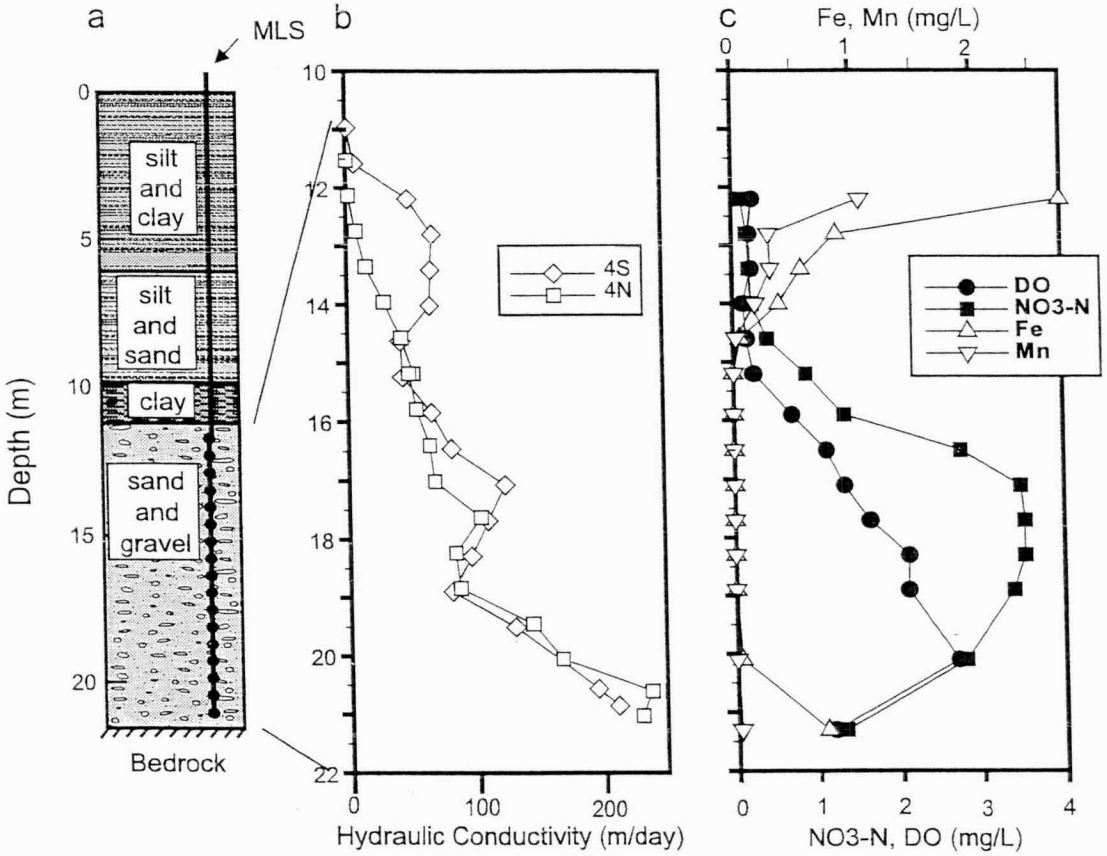


Fig. 1. Geologic, hydrologic and chemical conditions at GEMS. (a) Lithologic log with example MLS. The three MLS used in this study are located within 6 m of each other. (b) Hydraulic conductivity profiles at two wells obtained using multilevel slug tests (Butler et al., 2002). (c) Vertical trends in groundwater chemistry (Schulmeister et al., 2001). Aside from the presence of NO_3 and PO_4, groundwater at GEMS is uncontaminated.

GEMS is instrumented with a series of MLSs that extend across the entire thickness of the sand-and-gravel unit (Fig. 1a). Each MLS consists of 17 open-ended polyethylene tubes (0.5 cm diameter), the lower ends of which are spaced 0.6 m apart (McElwee and Butler, 1995). Data collected previously from the MLS have demonstrated the presence of a persistent redox sequence that ranges from Fe-/Mn-/NO_3- to O_2-reducing conditions over a short vertical distance (Hall, 1998; Kidwell, 1999; McVay, 2000; Schulmeister et al., 2001, in press-b). Measurable amounts of Fe and Mn are present in groundwater above a depth of about 15 m but are largely absent below that depth (Fig. 1c). DO and NO_3 concentrations are low or below detection above 15 m, but are present in higher concentrations below. Near the bottom of the sand and gravel, DO and NO_3 decrease while Fe and Mn increase. The persistent contrasts in the concentrations of redox-sensitive species and other constituents make GEMS an excellent site for the assessment of the discrete-depth sampling capabilities of direct-push methods.

2.3. Sampling equipment, methods and analyses

A Geoprobe™ DT66 direct-push rig with a hydraulic slide and a high-frequency percussion hammer was used to advance the sampler in this work. The exposed-screen sampler evaluated in this study initially consisted of a steel center stem, drive point, drive head and a stainless-steel slotted screen (Geoprobe Systems, 2001; Fig. 2). The steel drive

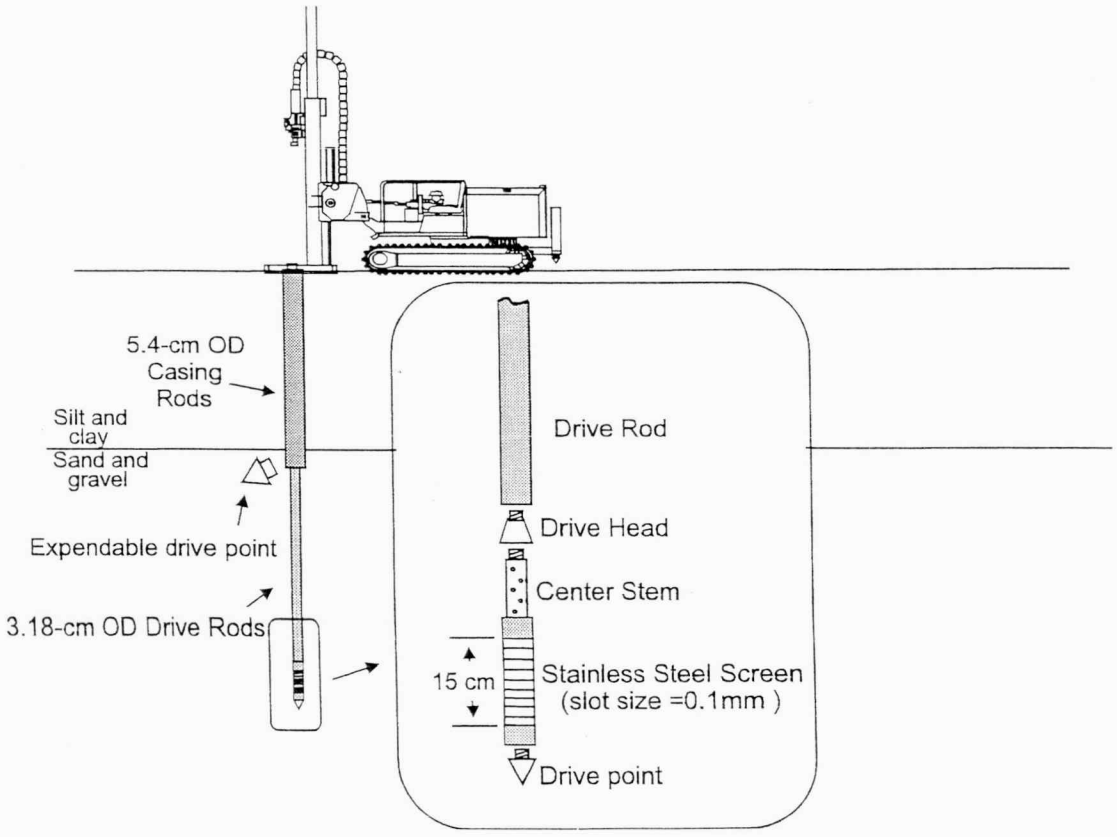


Fig. 2. Schematic of direct-push rig and sampler used in this study (not to scale).

rods and sampler components were later replaced with stainless-steel and/or heat-treated parts, as discussed below. In all phases of the work, the upper 11 m of fine-grained material was cased off with 5.4-cm OD rods, allowing the unshielded sampler to bypass silt and clay materials that would likely have blocked the screen. The leading 5.4-cm rod was configured with an expendable PVC drive point that was pushed aside as the smaller-diameter sampler and rods were advanced into the aquifer (Fig. 2).

At each sampling depth, the sampler was purged with a check-valve-fitted polyethylene tube to remove fine materials (ASTM, 1999). After at least three rod volumes were removed, the check-valve tubing was replaced with an open-ended polyethylene tube, and sampling was conducted with a peristaltic pump. At each depth, field measurements and samples were taken from the direct-push installation immediately before they were taken from the same depth at a nearby MLS. Each direct-push/MLS comparison was conducted over the course of 2 days. Throughout the sampling period, all 17 MLS ports were continuously pumped using two 10-channel peristaltic pumps to prevent cross flow between sampling depths. Pumping rates ranged from 150 to 200 ml/min during direct-push and MLS sampling.

An inline flow-through cell was used to determine when field parameters had stabilized, and field data and samples for laboratory analysis could be collected. Field measurements of DO, ORP, pH, temperature, and specific conductance were made using a YSI™ 600XL multiparameter sonde with a Rapid Pulse™ DO sensor (YSI Incorporated, 1998). The flow cell and sonde were attached to the polyethylene sampling tube upstream of the peristaltic pump using a short section of silicon tubing. Water was pumped through the flow cell until parameters stabilized. Measurements were taken every 5 s, and stabilization was considered obtained when values varied by less than 3% over a period of 3 min. Upon stabilization, the flow cell was disconnected, and samples were filtered with a 0.45-μm filter and collected in LDPE bottles. Samples for measurement of NO_3 and metals were acidified to a pH of less than 2 with 6 N hydrochloric acid. All samples were kept cold in the field and transported on ice to the Kansas Geological Survey Analytical Laboratory for analysis.

Instrument precision for DO, ORP, pH, temperature and specific conductance is reported by the manufacturer as 0.2 mg/l, 20 mV, 0.2 units, 0.15 °C and 0.5% of reading, respectively (YSI Incorporated, 1998), although our in-house tests routinely indicated that greater precision is possible for most parameters (Schulmeister, unpublished data). All probes were calibrated daily and monitored for drift at the end of, and periodically during, each day. During calibration monitoring, DO concentrations below 0.05 mg/l were observed in an oxygen-free $NaSO_3$ solution (American Public Health Association, 1971), indicating that reliable DO values could be obtained at levels as low as 0.05 mg/l. Instrument drift commonly associated with decreasing performance of platinum ORP electrodes was evaluated periodically over the 12-month period of this study by analyzing standard solutions made from quinhydrone and pH standard solutions (Dean, 1979). A difference of less than 20 mV was observed in the pre- and post-study calibration monitoring, indicating little drift during the study period.

Analyses made at the Kansas Geological Survey Analytical Laboratory were conducted with a Technicon™ Autoanalyzer II System for NO_3, Alpkem™ Flow IV system for Cl and a Jarrell-Ash™ Model 975 Plasma AtomComp Spectrophotometer with Mark II/Mark

III update for Mn and Fe. Analytical errors associated with these analyses were less than 3% of the measured concentrations.

3. Results and discussion

3.1. Sampler reactivity

To assess the impact of dissolution of metals from the steel sampler, DO and ORP were measured under the contrasting redox conditions that occur at GEMS. MLS and direct-push sample pairs were collected from five depths in the anaerobic region, three depths in the aerobic region and two depths in the transition zone between regions (Fig. 3). Vertical trends in DO and ORP in the MLS were consistent with those observed in previous studies (Hall, 1998; Kidwell, 1999; McVay, 2000; Schulmeister et al., 2001, in press-b), with low ORP and DO above the 15-m redox boundary and higher values below. Samples from the direct-push profile, however, were not in agreement with those obtained from the MLS below 15 m (Table 1). While MLS samples from below 15 m contained DO as high as 1.25 mg/l, none of the direct-push samples from this interval exceeded 0.4 mg/l. ORP values from the MLS were above zero below 15 m, while all direct-push ORP values were below zero. Because iron oxidation was visible on the sampler's center stem and drive head after sampling, the differences between the MLS and direct-push profiles were thought to be an indication of sampler reactivity at depths where higher concentrations of DO were present. The reactions

$$Fe^0 + O_2 + 2H_2O \rightleftarrows Fe^{2+} + 4OH^-,\ 4Fe^{2+} + O_2 + 10H_2O \rightleftarrows 4Fe(OH)_3 + 8H^+,$$
$$\text{and } 2Fe^{2+} + O_2 + 2H_2O \rightleftarrows 2FeOOH + 2H^+,$$

are known to proceed rapidly under oxidizing conditions when Fe is present in high concentrations (Hem, 1985; Langmuir, 1997) and may be responsible for the differences in

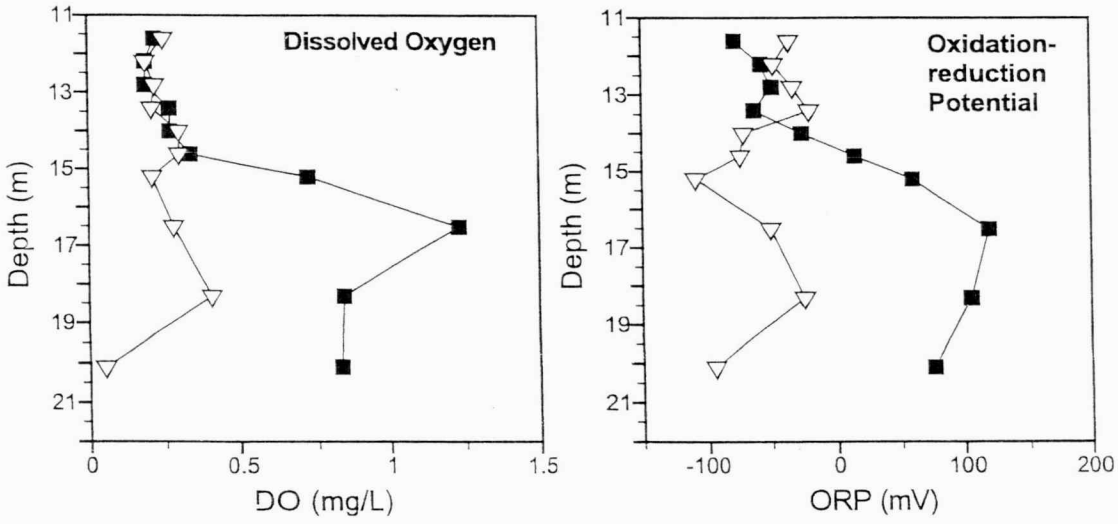


Fig. 3. DO and ORP in depth-paired MLS (squares) and direct-push (inverted triangles) water samples. Analytical accuracy is within the size of each data point.

Table 1
Spearman rank correlation coefficients (rho) for samples collected during each phase of this study (Siegel, 1956)

Phase	ORP	DO	Specific conductance	pH	Fe	Mn	Cl	NO_3-N	SO_4
1	−0.28/0.54	0.25/0.5							
2	0.64/0.23	0.83/0.01	0.94/<0.001	0.96/<0.001	0.77/0.02	0.47/0.23	0.34/0.4	0.86/0.007	0.29/0.48
3	0.98/<0.001	0.92/0.001	0.9/0.002	0.87/0.05	0.87/0.02	0.63/0.09	0.74/0.04	0.97/<0.001	0.92/0.001

Eight MLS–direct-push pairs used in each phase were selected from three depths in the anaerobic region, three depths in the aerobic region and two depths in the transition zone between regions. Correlation coefficients and probability values precede and follow the slash symbol, respectively, for each test. The largest correlation coefficients indicate the highest degree of correlation between data pairs. The smaller the p value, the greater the certainty of the reported correlation.

DO and ORP observed between direct-push and MLS samples. Upon its introduction to the solution, the dissolved iron could react with O_2 to form Fe-hydroxide or Fe-oxyhydroxide, causing this to become the dominant redox process. Because ORP represents a mixture of redox reactions occurring in a solution, and reported ORP values for the Fe-reduction reaction are usually much lower than those for NO_3- or O_2-reducing reactions (Drever, 1997), these results suggest that dissolved iron had an important influence on ORP measurements in the direct-push samples. In addition, stabilization times for ORP readings for direct-push samples were generally twice as long as those for MLS samples. The slow stabilization of the ORP probe is consistent with the presence of multiple redox couples and a solution that is in redox disequilibrium. The results of this comparison indicate that the

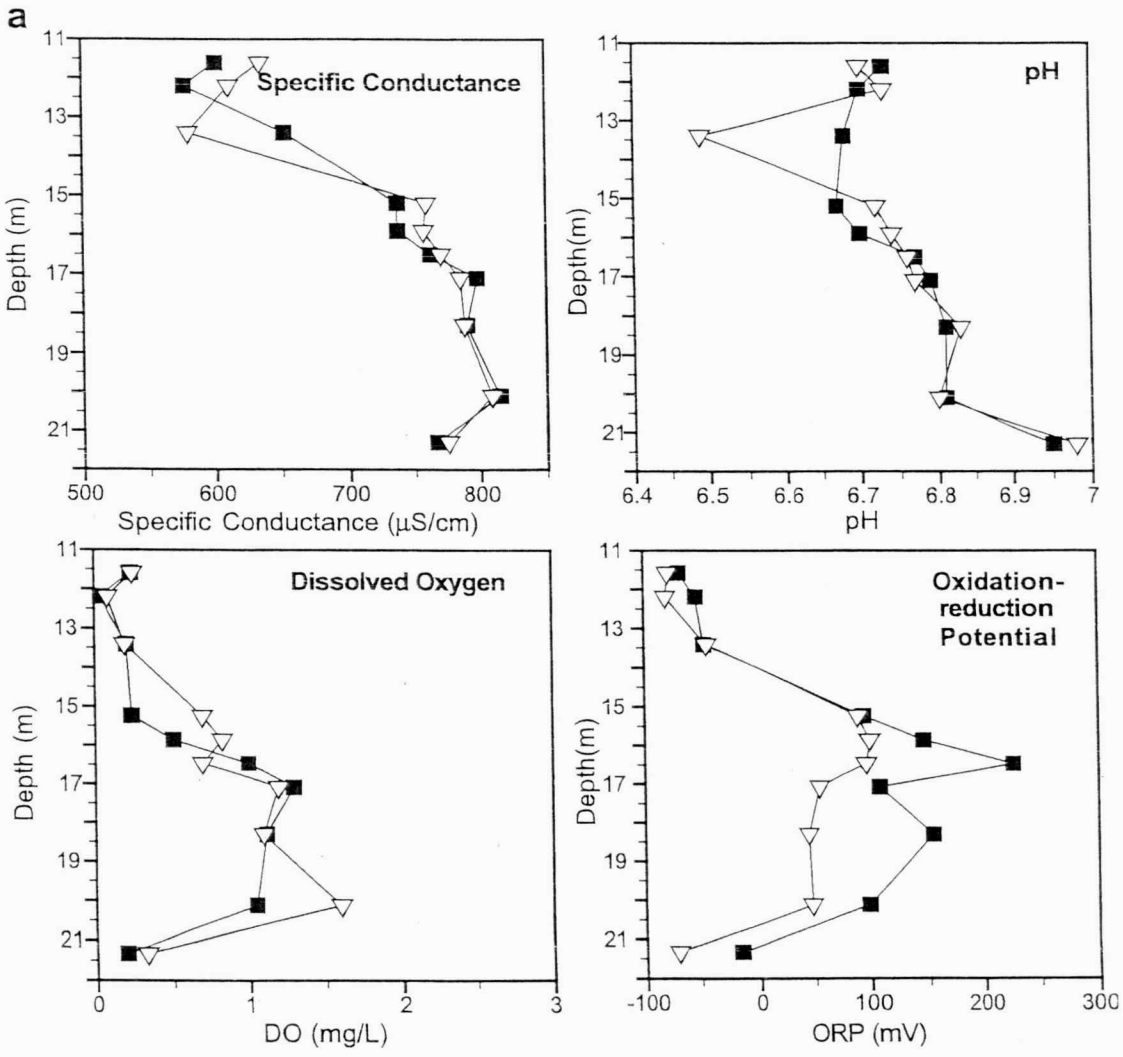


Fig. 4. (a) Field measurements in MLS (squares) and direct-push equipment using a stainless-steel sampler (inverted triangles). (b) Laboratory measurements of dissolved constituents in samples from MLS (squares) and direct-push sampling equipment using a stainless-steel sampler (inverted triangles). Analytical accuracy is within the size of each data point.

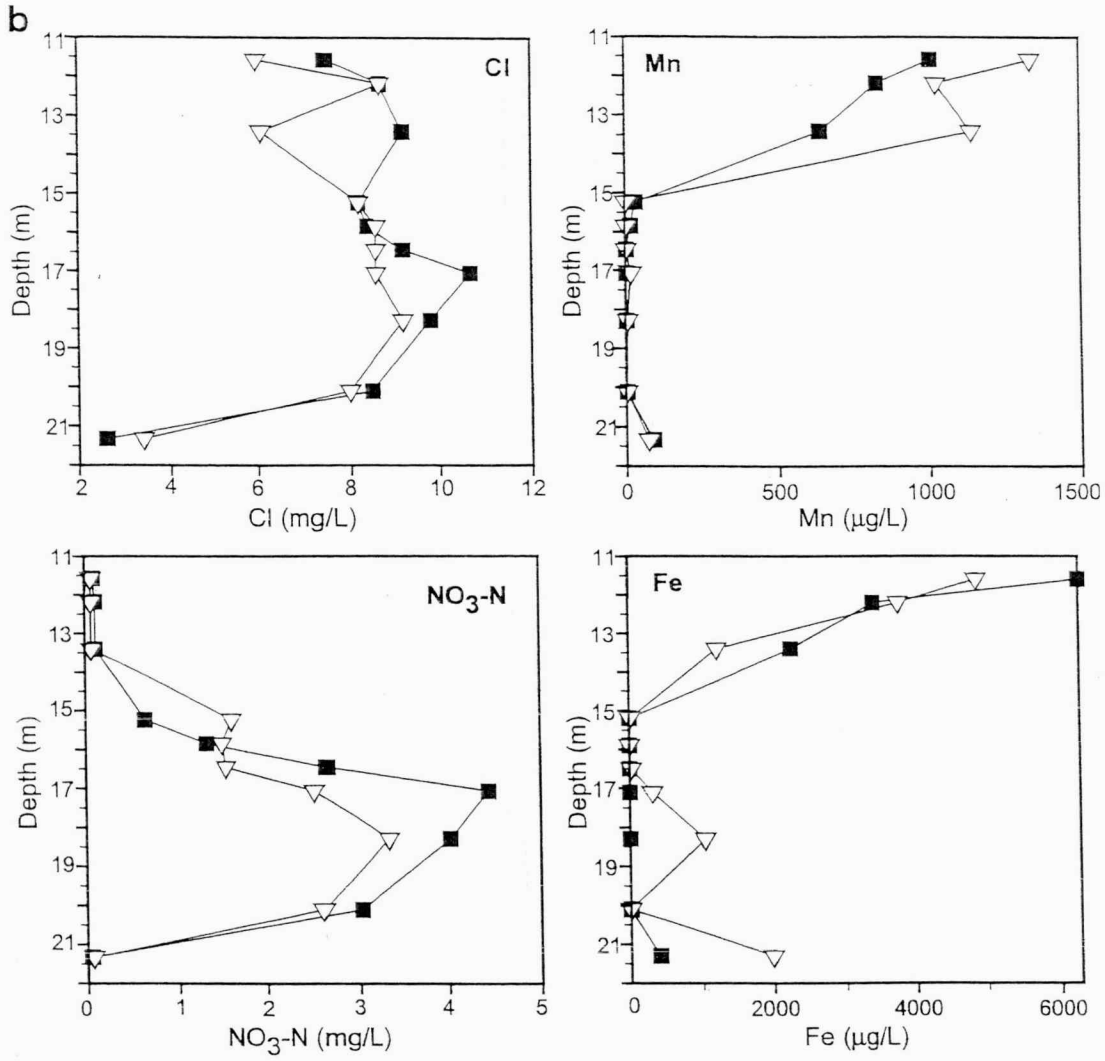


Fig. 4 (*continued*).

steel sampler components reacted with groundwater on the short time frame (less than 1 h) of a discrete-depth sampling event.

3.2. Discrete-depth geochemical profiling with a stainless-steel profiling tool

Based on the results of the above comparison, the steel drive head, center stem and drive-point sampler components were remanufactured from stainless steel prior to the next step of the investigation. In the second phase of the work, samples were collected for laboratory analysis of dissolved NO_3, Cl, Fe and Mn after field measurements of DO, ORP, pH and specific conductance were made. Four samples were collected from the anaerobic region, four from the aerobic region and two samples were taken from the transition zone at a second location (Fig. 4a–b). Although, in general, there was good agreement between the MLS and direct-push sample pairs, substantial differences were observed at some depths for virtually all constituents (Table 1). For example, the ORP value and Cl concentrations in direct-push

samples were lower than, or similar to, those in MLS samples. Purging and sampling procedures may partly explain these results. Water that entered the rods during previous sampling events may have been carried downward during profiling, not completely removed during purging and then mixed with water from the sample interval. The possibility of sample contamination by mixing with water stored in the rods has a significant impact on the discrete-depth sampling capability of the approach, as this mixing could partially or completely mask important vertical contrasts in water chemistry.

The use of a stainless-steel sampler did not completely eliminate the differences in ORP discussed in the previous section (Fig. 3). Although a reasonable agreement between direct-push and MLS results was again observed above 15 m, lower ORP values were measured in

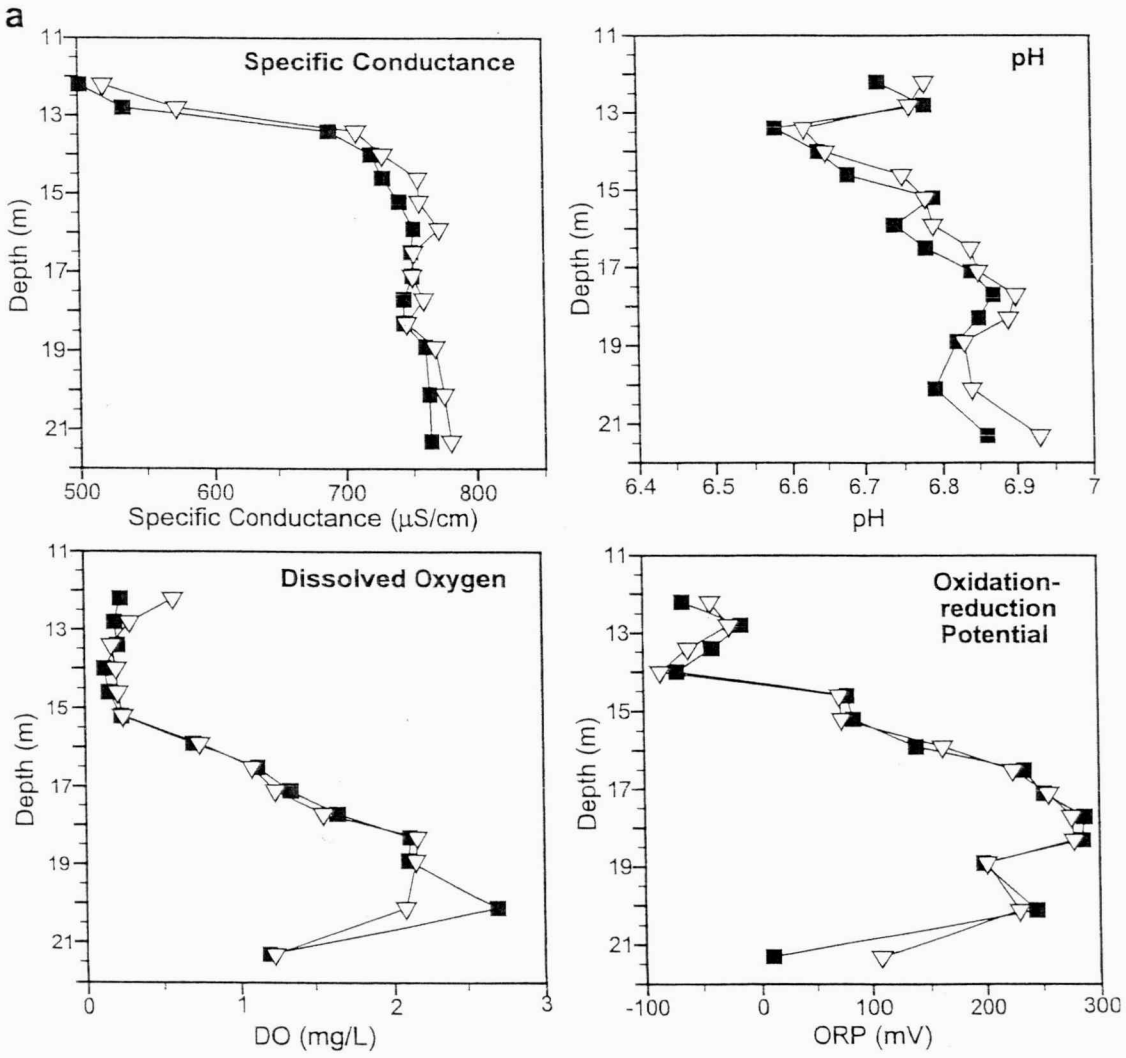


Fig. 5. (a) Field measurements in MLS (squares) and the modified direct-push sampler (inverted triangles). (b) Laboratory measurements of dissolved constituents in samples from MLS (squares) and the modified direct-push sampler (inverted triangles). Differences between direct-push and MLS samples from the deepest zone are believed to be due to a varying bedrock surface elevation and MLS sampling of the uppermost portion of the bedrock. Analytical accuracy is within the size of each data point.

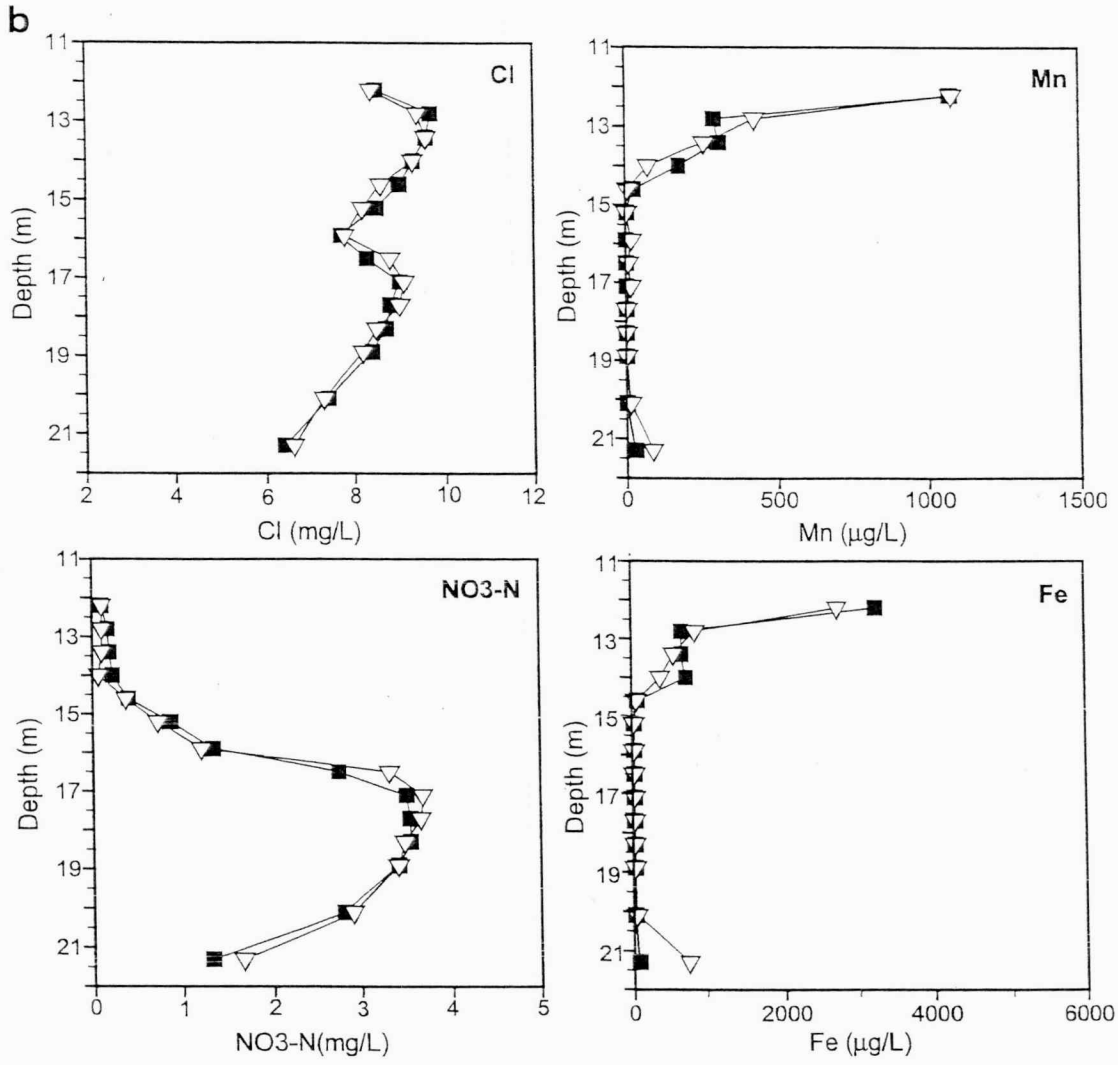


Fig. 5 (*continued*).

the direct-push samples below this depth (Fig. 4a). The presence of dissolved Fe may explain the lower ORP observed at some depths. Dissolved Fe was present above 15 m but, as in the previous comparison, did not appear in the deeper MLS samples other than at the lowermost sampling depth. Dissolved Fe in the aerobic zone at 17 and 18 m in the direct-push samples, however, indicated that the direct-push sampler components were still contributing Fe to the samples (Fig. 4b). Although stainless-steel sampler components were used in this phase of the work, the original steel drive rods were not replaced. A possible explanation for the presence of Fe in these samples therefore is that Fe was leached from the steel rods and then introduced to the sample as water stored in the rods mixed with that from the sample interval. Visible Fe oxidation observed on some of the rods after sampling supported this explanation. The differences in DO between the direct-push and MLS profiles suggest that the removal and introduction of purging and sampling tubes in the direct-push sampler, and the surging action during purging, may have introduced oxygen into the sampler that was difficult to remove using the low flow rates of the peristaltic pump.

3.3. A modified approach for discrete-depth geochemical profiling

In response to the differences observed in Fig. 4a–b, the sampler was further modified. A drive-head adapter was incorporated that produced a sealed connection between the sample tubing and the sampler, thereby isolating the water in the sampler from that in the drive rods. The new adapter was designed to prevent water that entered the rods during previous sampling events from mixing with water from the sample interval. This modification also shortens the sampling process by reducing the purge volume. To eliminate any possibility of Fe contamination, the reactive steel rods were replaced with relatively non-reactive, nitride-hardened steel rods. Nitride-hardened surfaces were obtained on conventional steel rods by heat-treating the rods in a nitrogen-gas atmosphere.

Chemical profiles obtained with the modified direct-push approach were in excellent agreement with those obtained from the MLS for all the parameters and constituents

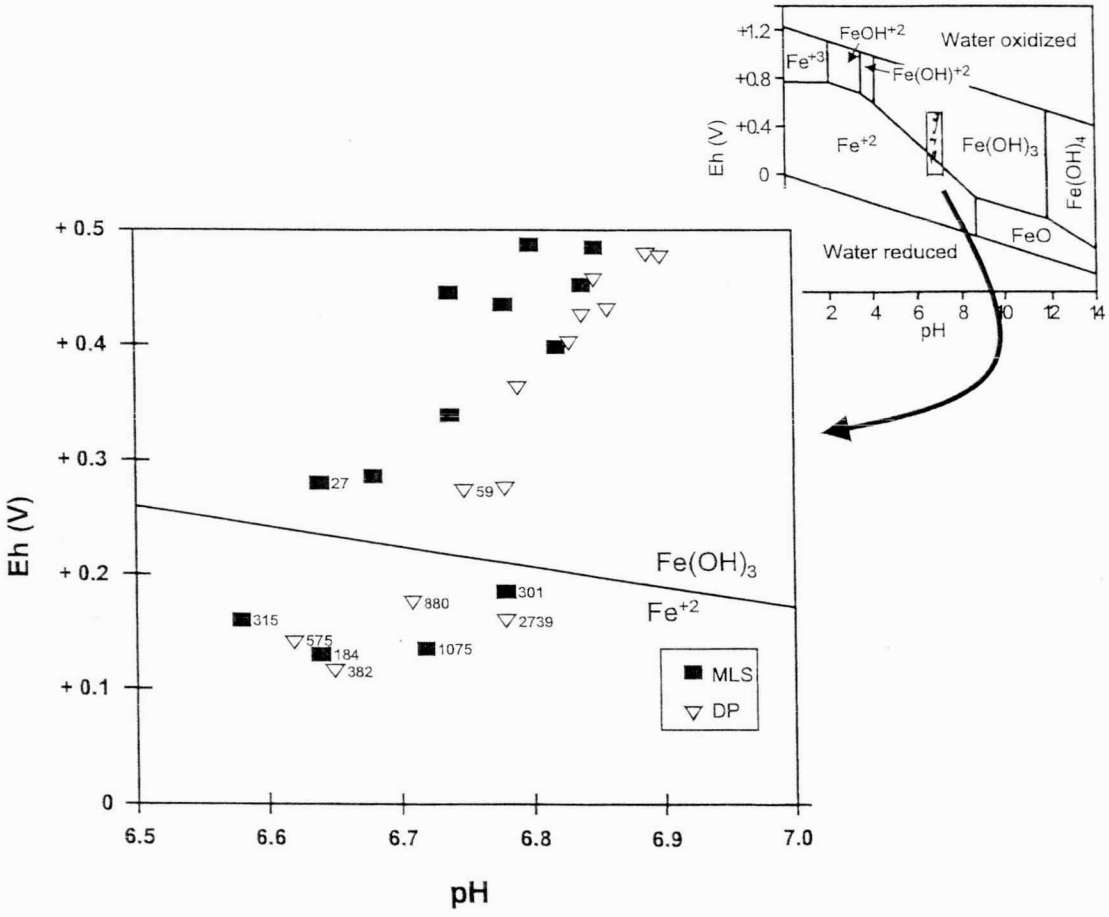


Fig. 6. pH–Eh diagrams for the Fe–O–H_2O system at 25 °C and 1 atm ($a_{Fe^{2+}} = 10^{-6}$ mol; Drever, 1997) and pH and Eh (ORP) data collected from the MLS and the modified direct-push sampler. Dissolved Fe concentrations (μg/l) are noted to the right of samples in which Fe was detected. ORP values were converted to Eh by adjusting for difference in response of the standard hydrogen electrode and the platinum electrode used as a reference in this study (+200 mV in Zobell's solution using 4 M KCl (YSI, 1999)). Samples that plot slightly above the stability boundary were collected at 14.6 m, just above the redox transition depth, and may reflect the presence of multiple redox reactions at this depth.

examined (Fig. 5a–b; Table 1). A more gradual transition from aerobic to anaerobic conditions was observed in this profile. The modified sampler accurately resolved all concentration gradients and correctly determined site redox conditions. Agreement between ORP, DO and Fe values in direct-push and MLS profiles suggests that previously observed Fe contamination problems were overcome using the modified approach. The ability of the modified approach to accurately characterize the shift from Fe- to O_2-reducing conditions is further demonstrated in Fig. 6. When converted to Eh, field-measured ORP values for samples collected from above the 15-m boundary fall in the pH–Eh stability field for ferrous Fe (Fe^{2+}), while those below this boundary fall in the field for ferric Fe ($Fe(OH)_3$). As shown in Fig. 6, this field-based interpretation of Fe-reducing conditions was supported by laboratory analyses of dissolved Fe. Only those samples containing detectable Fe plotted within the stability field for Fe^{2+}, demonstrating the ability of the approach to accurately assess redox conditions in aquifers where a transition from O_2- to Fe-reducing conditions occurs. These results show that reasonable field-based interpretations of redox conditions may be possible with the modified approach.

The modified sampler was designed to be driven without removing the drive-head adapter and sampling tube. However, screen blockage occurred in six of the fourteen depths sampled during profiling, requiring removal of the adapter assemblage, surging with the check-valve fitted tubing and reconnecting the adapter prior to sampling. The occurrence of screen blockage at various depths in the sand and gravel is in agreement with slug test results and geophysical data that indicate the presence of intermittent clay lenses throughout the sand-and-gravel interval (Butler et al., 2002; Schulmeister et al., in press-a).

4. Conclusions

This study demonstrates that direct-push sampling methods can be used for high-resolution characterization of inorganic chemical variations in unconsolidated aquifers. Potentially significant misinterpretations of geochemical conditions can result, however, if sampler composition and sampling protocols are not chosen to match to site-specific conditions. An incorrect assessment of redox conditions or dissolved metal concentrations is possible if steel sampling components are used in an aerobic environment. If water from previous sampling depths is allowed to mix with water from the sampled interval, vertical contrasts in groundwater chemistry may be subdued and important chemical transition zones may be overlooked. In this study, conventional direct-push sampling methods were modified to overcome these problems. These modifications included (1) use of stainless-steel sampling components, (2) incorporation of a tubing adapter that isolates the sampler from water stored in the rods and (3) use of relatively non-reactive rods. Although the results of this work indicate that the use of stainless-steel sampler components and the tubing adapter is essential during geochemical profiling, we did not evaluate whether the non-reactive drive rods are necessary when the sampler is isolated from water stored in the rods. Additional work is needed to address this issue.

The high resolution and flexibility of direct-push geochemical profiling are well suited for interactive investigations of spatial and temporal variations in groundwater geochemistry. Recent initiatives by the United States Environmental Protection Agency (Burton et al., 1995; ASTM, 1998; Robbat, 1998; U.S. EPA, 2001, 2002) call for the development of conceptual models during initial site investigations and rely on the rapid collection and interpretation of inorganic chemical data in the field. Direct-push geochemical profiling can be an important component of such an interactive investigation. A demonstration of the approach was conducted in a reconnaissance assessment of near-stream conditions along a river in Kansas (Schulmeister et al., 2001). Short-lived hydrochemical conditions that occur in the near-stream portions of an aquifer during a high-flow event were investigated using an integrative approach in which field measurements made during geochemical profiling were used to guide the selection of subsequent sampling points. Important insights regarding the transient near-stream conditions were obtained that would not have been possible using conventional monitoring approaches.

The field parameters chosen for this study are the appropriate parameters for use at sites characterized by O_2- and Fe-reducing conditions. At other sites, the measurement of additional redox indicators, such as H_2, H_2S and CH_4, may be necessary for the complete assessment of redox conditions. Additional work is therefore needed to evaluate the sampler's performance over a wider range of redox conditions. In the final phase of this study, field measurements of ORP, DO and pH were used to make interpretations about the redox conditions that were subsequently verified using laboratory data. Additional work is needed to identify the appropriate combination of field and laboratory techniques that would be necessary for efficient characterization of conditions at other sites.

Many investigations have underscored the need for understanding geochemical variations that can occur over very short distances in aquifers (e.g., Sudicky and Huyakorn, 1991; Ryan et al., 2000). The results of this work further emphasize the importance of high-resolution descriptions of these variations. For example, recognition of the sharp contrast in redox-sensitive species in the sand-and-gravel interval at GEMS is critical to understanding the transport and fate of solutes at the site. This trend could have easily been overlooked if traditional long-screened wells and well spacings had been used. When geochemical profiling is combined with other recently developed direct-push methods for high-resolution hydrostratigraphic characterization (e.g., Butler et al., 1999, 2002; McCall et al., in press; Schulmeister et al., in press-b), hydrogeologic data of unprecedented resolution can be obtained. Such high-resolution information should enhance the quality of site characterization and remediation efforts, and provide new insights into fundamental hydrogeologic processes.

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Ground-Water Model

The following photographs are from a web site that uses image processing as part of the format of the class (http://www.isat.jmu.edu/users/klevicca/Image/#Laboratories). The photos show the ground water model setup and plume migration after injection of a contaminant into the model. Contact information concerning use of the photos should be addressed to the faculty advisor of the project: Cindy Klevickis (klevicca@jmu.edu).

The first photograph shows the physical set up of the model including the aquifer layers, the monitoring and injection wells, and the discharge point from the lake.

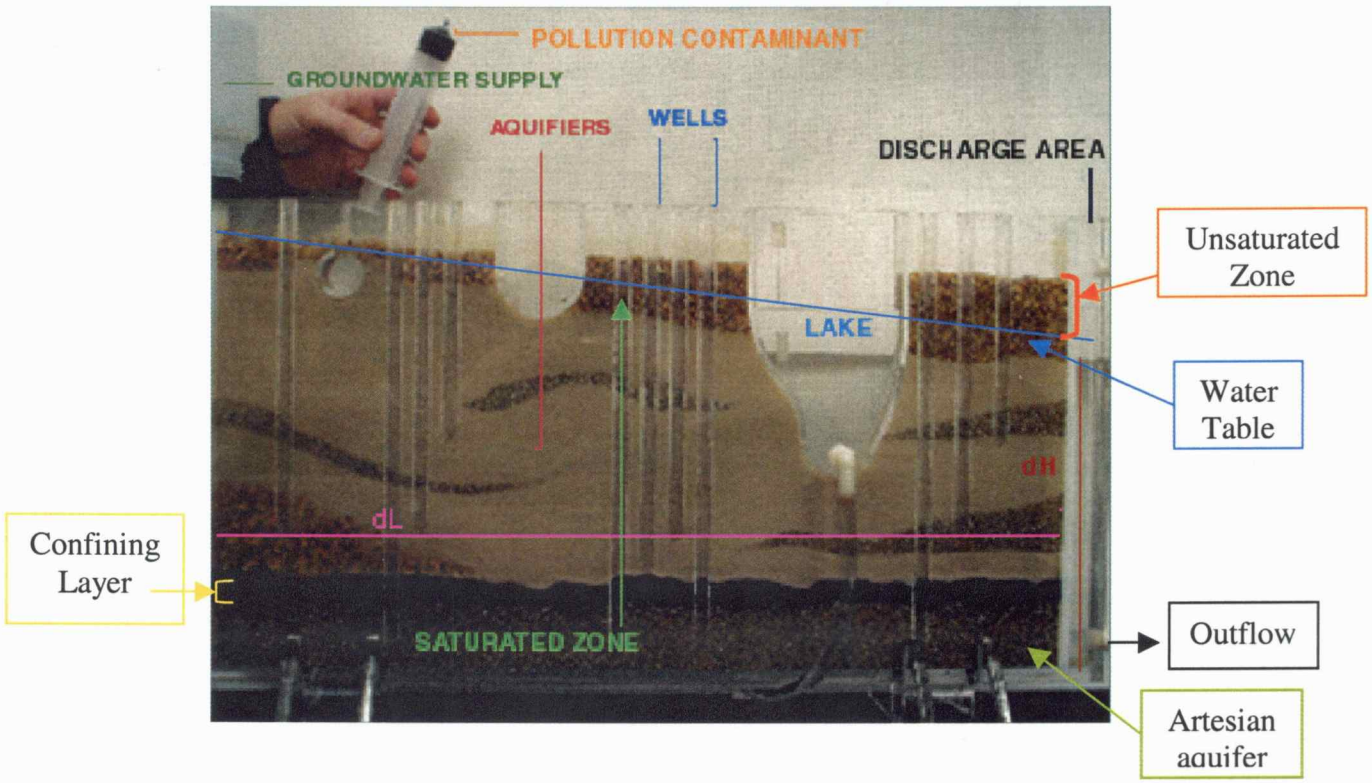


Figure 1. Labeled parts of ground water model. In dealing with Darcy's Law the dH is the distance in height between water table and discharge outflow point and dL is the length of travel.

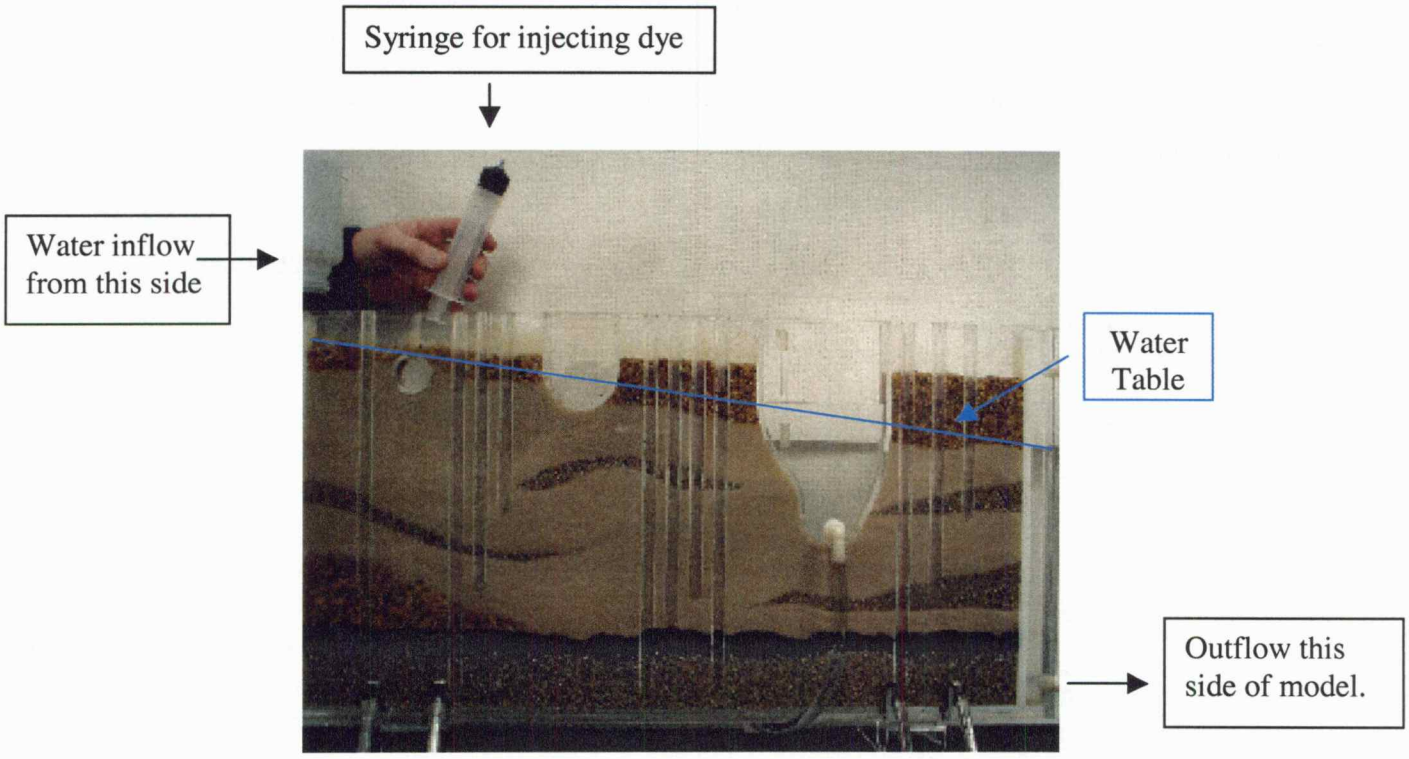


Figure 2. Model set up time before injection of dye.

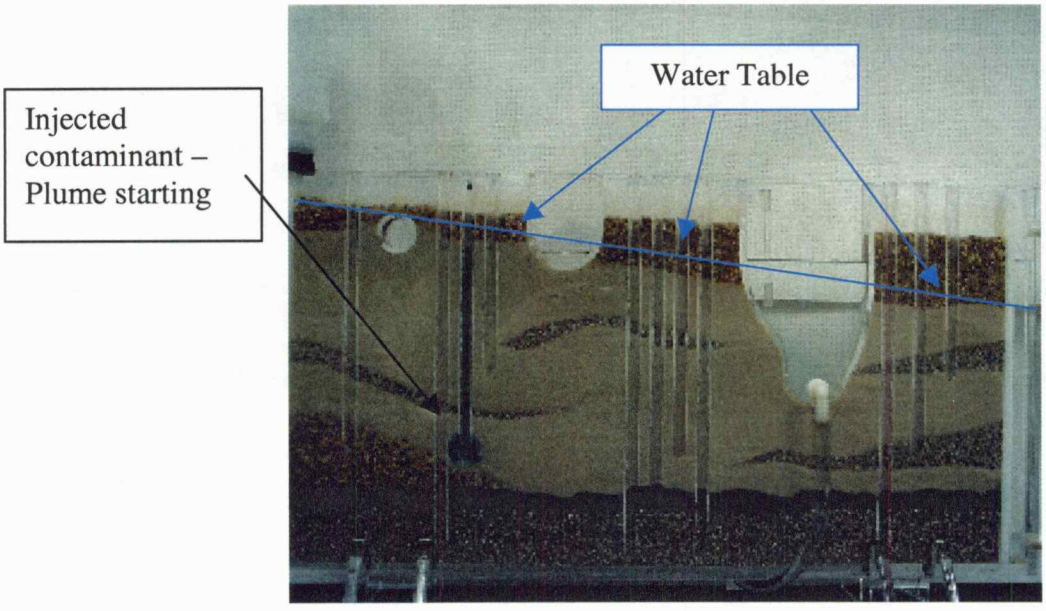


Figure 3. Model after injection of dye into well. Note circular spreading from bottom of well. This is called dispersion – pressure of injection from the syringe caused the contaminant to move away from the bottom of the well. Because the sand is porous the contaminant moved away in a roughly circular pattern. This figure is taken at time T_0.

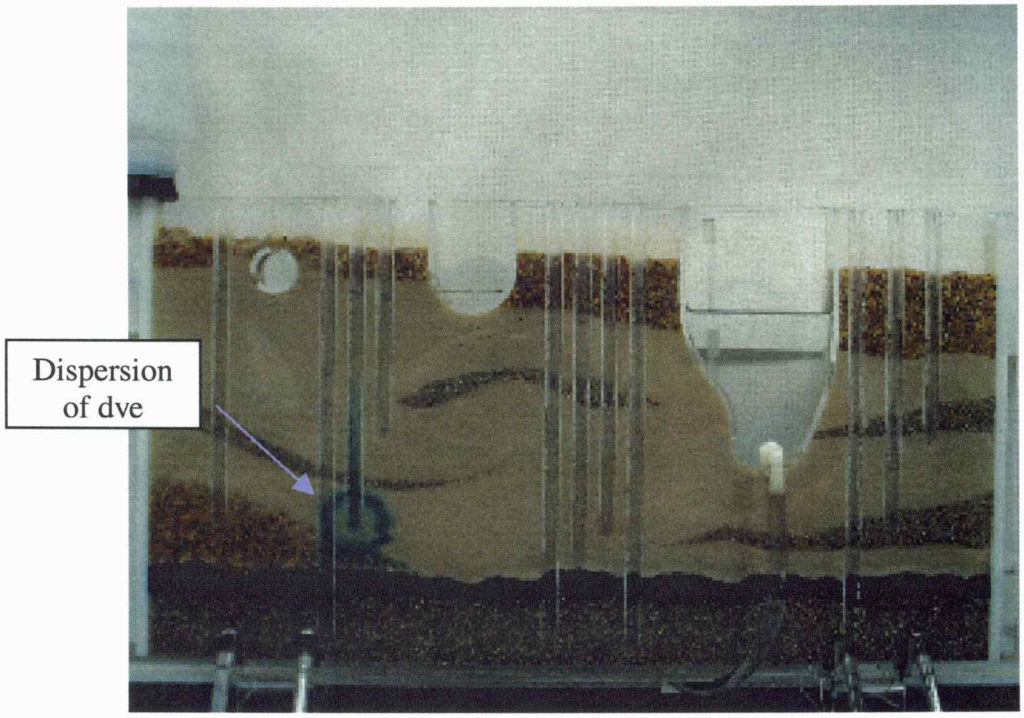


Figure 4. Time is T_{05} minutes. Model shows further dispersion of contaminant from well as pressure from injection disperses.

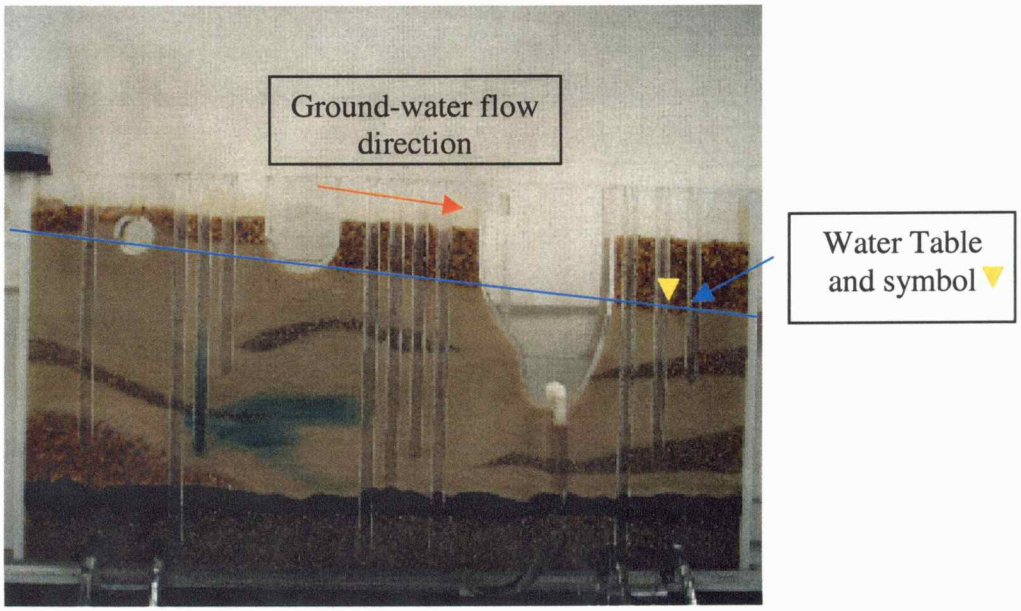


Figure 5. Time is T_{10}. Movement of plume downgradient from well following the flow in the aquifer from left to right (gradient shown by orange arrow).

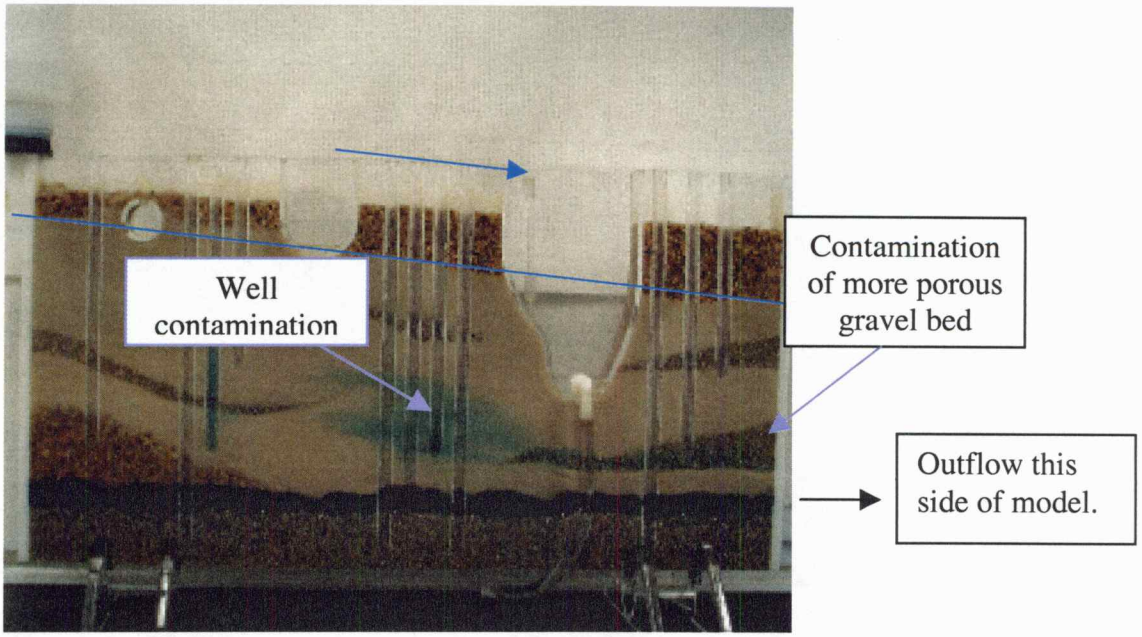


Figure 6. Movement of plume at time T_{15} minutes. Plume is dispersing upward and moving downgradient. Well that is sited in the sand is now contaminated by plume. Gravel bed is contaminated because gravel is more porous and water moves more easily in the gravel. Sand around gravel is somewhat higher pressure than the gravel so water moves into the gravel bed towards the discharge point.

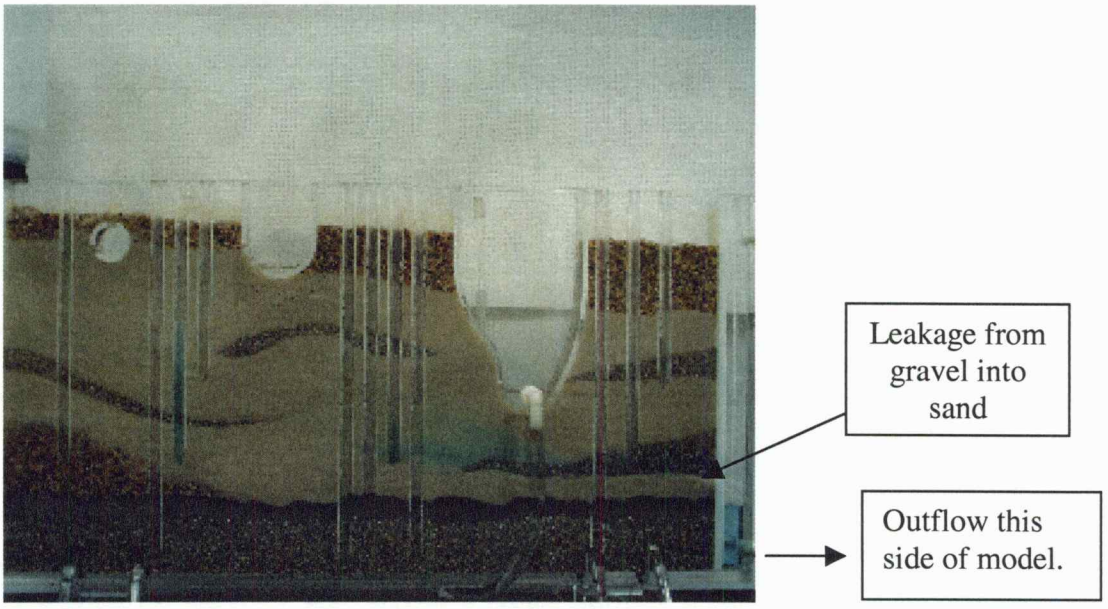


Figure 7. Movement of plume time T_{20} minutes. Contaminant has reached discharge to river. Layer below confining layer is not contaminated nor are the wells that intersect that layer. Some leakage from gravel into underlying sand and into discharge zone occurs. Time of arrival at discharge point appears to be 20 minutes.

More explanation of ground-water flow model

Definitions

Alluvium--deposits of clay, silt, sand, gravel, or other particulate material that has been deposited by a stream or other body of running water in a streambed, on a flood plain, on a delta, or at the base of a mountain.

Aquifer : Permeable layers of underground rock, sand or gravel capable of storing or conveying water below the surface of the ground, and that will yield water to a well or spring in sufficient quantities to produce water for beneficial use.

Aquifer (confined)--soil or rock below the land surface that is saturated with water. There are layers of impermeable material both above and below it and it is under pressure so that when the aquifer is penetrated by a well, the water will rise above the top of the aquifer. (see Artesian aquifer)

Aquifer (unconfined)--an aquifer whose upper water surface (water table) is at atmospheric pressure, and thus is able to rise and fall.

Artesian aquifer--ground water that is under pressure when tapped by a well and is able to rise above the level at which it is first encountered. It may or may not flow out at ground level. The pressure in such an aquifer commonly is called artesian pressure, and the formation containing artesian water is an artesian aquifer or confined aquifer.

Cone of depression - The depression of heads around a pumping well caused by withdrawal of water.

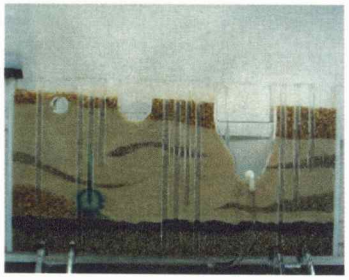
Confined aquifer (artesian aquifer) - An aquifer that is completely filled with water under pressure and that is overlain by material that restricts the movement of water.

Confining layer - A body of impermeable or distinctly less permeable (see permeability) material stratigraphically adjacent to one or more aquifers that restricts the movement of water into and out of the aquifers.

Permeability - The capacity of a rock or sediment (such as sand or gravel) for transmitting a fluid; a measure of the relative ease with which a porous medium can transmit a liquid.

Unsaturated zone - A subsurface zone above the water table in which the pore spaces may contain a combination of air and water.

Water table - The top water surface of an unconfined aquifer at atmospheric pressure.



Ground Water Plume Simulation

Image Processing Laboratory

Objectives (SOLs)

- Technologies, including computers, that are used to collect, analyze data and demonstrate concepts and simulate experimental conditions.
- Identification of groundwater zones, including water table, zone of saturation, and aquifers.
- Mathematical calculations using computer generate data.

Ground Water Plume Simulation

Image Processing Laboratory

http://www.isat.jmu.edu/users/klevicca/Image/#Laboratories #4 Plume

Groundwater is contained in saturated soil and rock material below the surface of the earth. The source of groundwater is precipitation. When rain falls, some of the water runs off into lakes and streams, and some of the water is absorbed into the ground, which is called *infiltration*. The *unsaturated zone* is where some of the soil is filled with water and some is filled with air. Below the unsaturated zone is the saturated zone. The *saturated zone* is where all of the cracks and spaces in the soil are completely filled with water.

Ground water moves down gradient, slowly between grains of soil or in the cracks of rocks until it reaches a discharge point at the surface. The areas where water enters the ground water system are called *recharged areas* and those where groundwater reappears at the surface of the ground is called *discharge areas*. *Aquifers* are underground units of soil or rock, which can yield a significant quantity of groundwater to wells.

This simulation shows how ground water moves through the soil. This movement depends on soil conditions. These are the soil condition: *Porosity* is the ratio of the volume of the void space in the material to the total volume of the material. Porosity is influenced by the size and shape of the individual grains that make up the

Formula to know:

Darcy Law

$V = -K(dh/dl)$

V= Darcy's velocity: groundwater movement (e.g. pipe in the river that discharges water)

K= hydraulic conductivity (K is a constant that depends on the soil characteristics)

dh/dl= change of H/ change in L (called hydraulic gradient)

soil. *Permeability* is the capacity of a material to transmit fluids, which is mainly controlled by the size of the pore space and the degree to which they are connected. Groundwater carries pollutants that it has pickup as it flows through the system. Some pollutants move faster than others in the groundwater, this is due to the soil's absorption rate or the pollutants solubility.

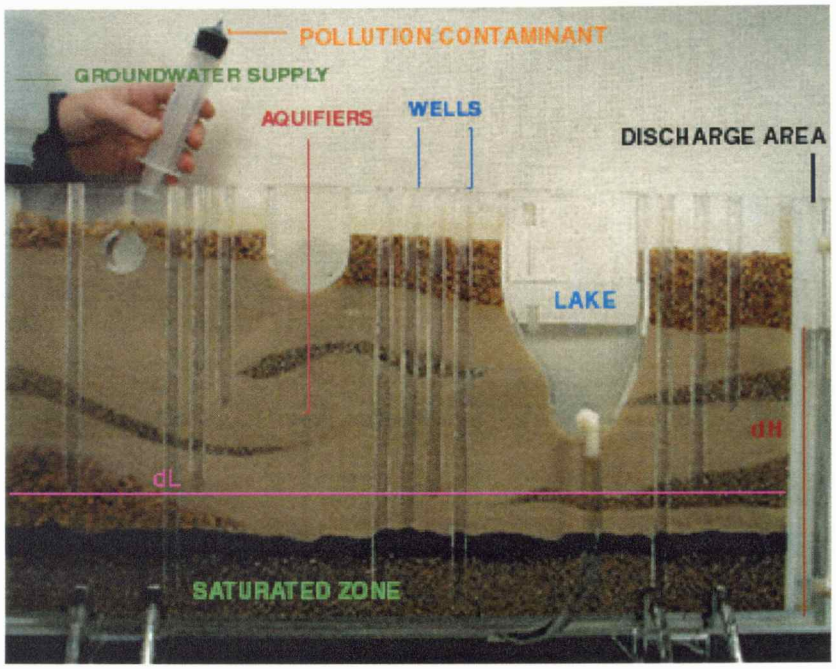
Darcy's Law was founded on the aspects of the movement of water through porous materials such as those found in groundwater aquifers. Darcy discovered that the amount of water that flowed through porous materials in a cylinder was directly related to the cross sectional area of the cylinder (A) and the differences in height at the two ends of the cylinder, and inversely related to the length of the cylinder (I). He also found that the flow was directly proportional to the hydraulic conductivity (K) of the material. Hydraulic conductivity relates to both the physical properties of the porous material itself and the physical properties of the fluid that is passing through it. The actual velocity of groundwater is changed by the hydraulic gradient, or the change in water elevation between the recharge and discharge areas.

Figure 1 gives a description of the model and its features.

Note: The setup image shows what the groundwater setup looks like without any pollution running through the model.

Note: Step 2 is a good time to view all the images and notice how the pollution moves through the aquifer to a discharge area. The syringe in the picture has colored solution (representing pollution) being dumped into a well.

Figure 1: Ground Water Model



Procedures

1. Open Plume Bitmap folder. Select first image. Check the Open All box then click Open.

2. Pull down Windows Menu. Highlight Tile Images. (see Note)

3. Go to Options Menu. Highlight Color Tables and choose Fire-1. Repeat this step for each tiled image.

4. Using double-sided arrow on image T05.bmp drag the image from the corners about an inch to make it bigger.

5. Use the segmented line tool and place it on one side of the image and drag it to the other side. Then go to the Analyze Menu and select Measure. This will give you the dl value as length in the info window.

6. Use the segmented line tool to measure the height of the well head (or the discharge area) on the right. (Refer to *Figure 1* for further explanation.) Drag the segmented line from the one end of the well to the other. Return to the Analyze menu and select Measure. This will give you your dh value in the info window.

7. Record the values for dh and dl and close Scion Image.

Questions

1. What would happen to the conductivity value if the soil was made of clay instead of sand?

2. If the pollution is in the saturated zone, it will take longer to get to the well, explain why this is.

3. If the polluted material is denser, would it reach the well faster or slower?

4. If the values for dh and dl changed to dh= ??? and the dl=??? what would Darcy's Velocity be?

5. Could weather conditions effect how a pollution plume moves underground? If yes, how would it effect the movement?

Using Groundwater Flow Models in 8th grade Earth Science
Kiran Purohit, Manhattan Academy of Technology

In 8th grade science at Manhattan Academy of Technology, we have worked to plan a curriculum in which different themes recur throughout the year, as students learn more about different earth processes, science concepts, and types of mathematical patterns. As a result, general concepts such as cyclical processes in the earth, composition of matter, and relationships of lithosphere/hydrosphere/biosphere come up in the context of many different projects.

A major scientific idea that we re-visit throughout the year is the usefulness of models. In the course of different projects, we look at the kinds of mathematical or visual models that might help with understanding or explaining something, as well as the good and bad points of various models. As beautiful models of groundwater flow, the sand tanks are useful for helping students not only to understand groundwater better, but also to understand how to manipulate models well.

One way to impress upon students the effectiveness and relevance of good models is to look at them in terms of the stories they can explain or clarify for us. In this unit, students work on writing short scenarios or narratives that could be modeled on the sand tanks. As a class, they read selections from Rachel Carson s *Silent Spring*, then go on to do group research into other kinds of groundwater phenomena that could be modeled using the sand tanks. In other words, by going back and forth between the sand tanks as models and the stories of real life, students can come to understand the usefulness of the models for explaining phenomena in nature.

Other than model-construction, a number of themes from other projects in earth science surface in this unit. In this outline, I try to indicate where I am either drawing on prior knowledge students should have, or gaps that I would plan to fill in future units. This way, a teacher can plan accordingly depending on where the students are when she does this sand tank unit!

TIME NEED-ED	BIG IDEAS OR CONCEPTS	CONNECTIONS TO CURRICULUM	DRIVING QUESTIONS	ACTIVITIES	MATERIALS	ASSESSMENT
2-3 days	-How the water cycle works -Relative time periods for each part of the cycle	-builds on idea of cyclical processes in earth science -depends upon an understanding of states of matter and phase changes -relate to other cycles in which humans intervene	-How does water cycle through the earth s lithosphere, hydrosphere, and atmosphere? -How do humans alter this cyclical process?	**Re-creating the water cycle** — in which students add to their idea of how the water cycle works.	-markers and chart paper -appropriate readings about the water cycle and ways water is used by humans	Can students -explain different parts of the water cycle? -show why water spends more time in some parts? -demonstrate why the amount of water in the world stays constant?
1 day	-Parts of the groundwater system -processes in the groundwater system	-builds on the idea that groundwater components (like other features of the land, like soil horizons) can look differently from one place to another	-What are some different aspects of the groundwater system? -How does water move from being underground water to surface water?	**Demonstration of the groundwater system** —in which the teacher models for students the parts of the groundwater flow model, how to inject dyes, etc. Students make a labeled diagram of the model.	-groundwater flow model -dye, syringes, etc. -science notebooks	Students develop working definitions of the parts of the groundwater model (aquifer, well, confining layer, etc.), as well as working ideas for how the model operates.

TIME NEED-ED	BIG IDEAS OR CONCEPTS	CONNECTIONS TO CURRICULUM	DRIVING QUESTIONS	ACTIVITIES	MATERIALS	ASSESSMENT
4-5 days	-Water budgets for NYC and other places -Causes/chain of events for drought -Ways in which water enters groundwater storage	-draws on knowledge of climate, biomes, and regions -different kinds of precipitation; life of a river -soil levels/horizons and soil formation	-What caused the water shortage in NYC, and do we have that problem this year? -What are the income and expenses in terms of water for a region? -How does water use and income relate to the climate? -Where does our city water come from, and what factors affect its availability?	**Modeling Water Budgets** in which students look at how income and expenses of water (through irrigation, evapotranspiration, precipitation, etc.) affect the amount of water **Studying different water budgets** Students look at water budgets for different climates; predict water usage, etc.	-water -droppers, graduated cylinders -containers for holding water -water budget graphs for different regions	Write up the results of this activity. Can students: -use/develop water budget graphs? -work with terminology like deficit, surplus, recharge, etc.? -show they understand the way water budget graphs work?

TIME NEED-ED	BIG IDEAS OR CONCEPTS	CONNECTIONS TO CURRICULUM	DRIVING QUESTIONS	ACTIVITIES	MATERIALS	ASSESSMENT
2-3 days	Modeling drought using the groundwater flow models		-What factors related to drought show up in a groundwater model? How could we manipulate those factors to show why drought would happen?	**Predicting occurrence of drought** — in which students use this year s conditions to predict the water availability for the summer.	-articles about 2002 water shortage and drought emergency -internet access, to get information for current year	Make a prediction about drought this year. Can students: -justify their predictions about drought, based on this year s weather and climate conditions?
				Designing a drought scenario that works on the sand tanks	-sand tanks **-sand tank materials**	Create a write-up of plan and its results that shows: -an understanding of how water flows in the sand tank **-an understanding of how to change the total amount of water in the system**
2 days	-The direction and rate of water flow underground -Causes for water to move	-relevance of gravity to this process	-Which direction does the water flow in underground streams? -How do	**Playing with and getting to know the sand tanks** — in which students become	-groundwater flow model -dye, syringes, etc. -science notebooks	Students write stories/narratives of the phenomena they modeled using the sand

TIME NEED-ED	BIG IDEAS OR CONCEPTS	CONNECTIONS TO CURRICULUM	DRIVING QUESTIONS	ACTIVITIES	MATERIALS	ASSESSMENT
	(pumping from wells, more water coming in, etc.)		pollutants/ toxins move through the system?	familiar with how to use the sand tanks, as they develop a scenario for the spread of some substance underground.		tanks. Do the stories reflect an understanding of how the tanks work? Can the student relate what they modeled to a real-life scenario?
1 day	-Types of pollution (point vs. non-point source)	-reading different kinds of sources from different perspectives	-What are the ways scientists classify pollution sources?	**Read different sites about pollution** — look at different government, environmental, and academic sources for definitions of pollution	-articles selected by the teacher or -internet access	Homework: Make a graphic organizer with 2-3 examples of point-source and non-point source pollution
2 days	-Runoff and pollution -Different ways that water can enter the groundwater		-What are different ways that water can enter the groundwater? -Where does water on the street go when it rains? If the land was not paved, where would it go?	**Visit to the East River** in which students go to the portion of the river near school, to see the different sources of runoff, precipitation, etc.	-digital cameras -science notebooks	Create a map of our school s section of the river. Show the following: -how roadway runoff could enter the river -how precipitation enters the river -other sources

TIME NEED-ED	BIG IDEAS OR CONCEPTS	CONNECTIONS TO CURRICULUM	DRIVING QUESTIONS	ACTIVITIES	MATERIALS	ASSESSMENT
						of pollution in the river.
2 days	Reading *Silent Spring* — probably not the whole text just some relevant parts selected by the teacher.		-What were the issues with pollution that Rachel Carson was trying to document?	**Discussion of *Silent Spring*** - focus on the chapter Surface Waters and Underground Seas, or other parts of the book	-copies of the text	Write about the book in terms of how it relates to ideas of pollution that the class has been covering.
1 day	Biomagnification of toxic materials	-connect back to previous work with food chain, etc.	-How do toxic substances build up in different animals in the food chain?	**Modeling the food chain** — Students play the role of primary, secondary consumers	-colored beans or paper for students to collect	Write an explanation of why animals at the top of the food chain might be more affected by some pesticides.
3-4 days	Using groundwater models to understand phenomena from the book	-how models are useful or problematic as representations	-Which scenarios from *Silent Spring* is it possible to model? -What are some problems that come up with modeling a complex system?	**Developing and implementing plans** — student groups come up with plans and present them to the class; then implement those plans on the sand tanks	The usual sand tank materials (syringes, dye, etc.)	Write a report on the model. Demonstrate the following: -an understanding of the groundwater phenomena being modeled -An understanding of how the

TIME NEED-ED	BIG IDEAS OR CONCEPTS	CONNECTIONS TO CURRICULUM	DRIVING QUESTIONS	ACTIVITIES	MATERIALS	ASSESSMENT
						model does/does not represent the phenomenon
2 days	Other topics related to groundwater and groundwater contamination		-What kinds of issues come up in different parts of the world related to groundwater contamination? -How are these related to what we learned in *Silent Spring*?	**Writing a brief research report on a new groundwater issue** — Students prepare these reports based on 2-3 sources, individually or in groups		The research must represent an understanding of a new event, as well as the relevant information about groundwater flow.
3 days	Modeling other groundwater topics using the sand tanks		-How can you model a scenario in a way that will help other people to understand it better?	**Developing and implementing plans** — student groups come up with plans and present them to the class; then implement those plans on the sand tanks **Presenting results to the class** — Using both a presentation medium	-sand tank materials -presentation materials (laptops, markers and posterboard, etc.)	Students should demonstrate that they can make connections between the different topics in the unit, and the specific situation they were studying. This is assessed through the material they present to the class.

Time Needed	Big Ideas or Concepts	Connections to curriculum	Driving questions	Activities	Materials	Assessment
				(powerpoint, poster, etc.) and a sand tank, prepare a presentation for the rest of the class		

The Incorporation of Groundwater Flow Models into a Middle School Earth Science Curriculum

Megan Roberts, East Side Middle School

Various environmental themes are woven throughout the 8th grade Earth Science curriculum at East Side Middle School. For example, when students are investigating the how the Water Cycle, we also look at the impact that humans are having on the worlds' water and explore the laws and ethics surrounding preservation and clean-up responsibilities. The main focus of this unit is a month long water quality assessment of the East River where students collect and analyze water samples. In addition, the students read "A Civil Action" (Jonathan Harr, 1996, Vintage Books, New York) as a case study by analyzing the science and environmental issues in the book. The book offers students an insight to the complexity of environmental issues and helps them to understand the various perspectives of those involved.

The Groundwater Flow models were used to simulate the Woburn stratigraphy in this book. They helped to illustrate the interaction of groundwater, surface water, and the pollutants in the context of the Woburn case and also helped students to grasp how groundwater can carry pollutants. The students attempted to demonstrate how the trichloroethylene contamination migrated from the point source to the towns' water supply by simulating both the Aberjona River and wells G and H.

As students read the book, class seminars were held to discuss the scientific issues and debate the issues surrounding the ownership of the groundwater. Students drew maps and used the flow models in order to illustrate their points to the class.

WHAT IMPACT DO HUMANS HAVE ON THE ENVIRONMENT?

TIME NEEDED	CONCEPTS, BIG IDEAS	TOPICS OF DISCUSSION	DRIVING QUESTIONS	RELATED ACTIVITIES	MATERIALS	ASSESSMENT
1-2 days	-Students will understand the formation of watersheds	-formation of watersheds -how watersheds feed into larger watersheds	-Where do rivers flow? - What separates watersheds from each other? - what watershed is NYC in?	**Internet Mapping Activity** where students explore how rivers form the contours of watersheds in the US.	1.Laptops 2.Photocopies of New York contour maps for students 2. overhead transparency of map	Students write an explanation of how a particular watershed is formed. (ie. The boundaries of the Croton Watershed are..)
2-3 days	- Students will understand how the water cycle works and will be able to see how humans can intervene in this cycle	-formation and location of aquifers and water tables - water recharge rates -tracking the path of fresh water	-How does rain water make its way to the ocean? -What can effect the rate of recharge in groundwater? - How do scientists know where groundwater is?	**A Rain Drop's Journey:** An activity where students follow the journey of a drop of water through the water, clouds, condensation, etc.	1. Station cards from PLT. 2. student score card 3. science journals	- For homework, students make a visual supplement to their rain drop journey's.

TIME NEEDED	CONCEPTS, BIG IDEAS	TOPICS OF DISCUSSION	DRIVING QUESTIONS	LAB WORK & ACTIVITIES	MATERIALS	ASSESSMENT
2-3 days	-Students will understand how humans interact with the water cycle	-building of dams and reservoirs - building of sewers and waste water treatment plants	-Can humans control or alter the water cycle? -How do humans obtain water? -How is water cleaned?	**Internet research on major dams** **NYT Article on River DAMS** Article discusses how salmon are harmed because of the dam on the Ohio River.	1. Laptops for research 2. NYT Article	Read NYT article for homework
	-Students will understand how different types of pollution can affect fresh water	-the formation of acid rain -the effects of fertilizers, sewage, pesticides, electrical plants, etc..	-How can air pollution effect the water in the area?	**Visit to East River and first collection of visual observations**	1. digital camera 2. students need journals	None
1-2 days	- Students will begin using flow models to simulate Woburn case	Looking at the interaction of groundwater, surface water, and pollutants	-How did the TCE travel from well G to well H? -How is the model different from the stratigaraphy in Woburn?	**Use Groundwater Flow Models and write up directions for use.**	1. Models 2. Dye, water, syringes, buckets, etc.	None

TIME NEEDED	CONCEPTS, BIG IDEAS	TOPICS OF DISCUSSION	DRIVING QUESTIONS	LAB WORK & ACTIVITIES	MATERIALS	ASSESSMENT
1 week	-Students will investigate the water quality of the East River	-the effects of nitrates, phosphates and dissolved oxygen in the East River	-What do high levels of Nitrates indicate? -What do high levels of phosphates indicate?	**2nd and 3rd Trips to the East River**	-H20 monitoring kits -H20 collection kits -Temperature probes -Student journals	Teach students to use Excel and then plot data. Begin to formulate conclusions about levels of chemical pollutants in the water.
1 d ay	-Students will discuss how groundwater travels	A Civil Action, by Jonathan Harr The use of maps and models to help visualize underground flow dynamics	-How does Pollution Travel? -Who is responsible for Groundwater Pollution?	**Class Seminar From both perspecitves**	Flow Models, Student Maps, A Civil Action, journals	Participation
	-Students will investigate the water quality of the lower Hudson River and compare it to the East River	-the effects of nitrates, phosphates and dissolved oxygen in the Hudson River	-What do high levels of Nitrates indicate? -What do high levels of phosphates indicate?	**Internet Research at EPA.gov to look for pollution limits on dissolved Oxygen, phosphates, DO, nitrates, and chloride.**	-Water monitoring kits -Water collection devices -student journals	Plot data and formulate conclusions about the levels of chemical pollutants in the water.

TIME NEEDED	CONCEPTS, BIG IDEAS	TOPICS OF DISCUSSION	DRIVING QUESTIONS	LAB WORK & ACTIVITIES	MATERIALS	ASSESSMENT
1-2 days	-Student will explore different cleanups techniques for river systems		-Who is the EPA and how do they make sure that public water is kept clean? -How can I make a difference in my community?	**Class visit from EPA official** **Internet research on the EPA (more specific)**	3. laptops 4. memory stick	Student lab reports and data charts are due. Post data analysis on school web page.

POROSITY I: Is something ever empty?

Is something ever empty? If you take a glass from the shelf, is it empty or full of air? If you fill the glass with sand, is the glass now full or can you still put materials (like water) into it?

Procedure

1. Put the screen into the model bottle and put a cap on the bottle.
2. Fill your model bottle with sand to the 1,000 ml. mark.
3. Fill the collection bottle with water to the 1,000 ml. mark. This is the start volume.
4. Slowly pour 100ml of water at a time from the collection bottle into the sand until you can see water standing on the surface of the sand.
5. Read the current volume on the collection bottle and record it as the finish volume.
6. Remove the cap from the model bottle and let the water drain and the sand dry. Then dump your sand into the waste bucket.
7. Perform the appropriate calculations to obtain the Pore Space Volume.
8. Obtain the other groups' data and fill in Group Data Table.
9. Make a folder on the desktop, using your name as the title.
10. Open a new workbook in Excel and save it as "Porosity1". Enter your data into the workbook, making a table similar to the ones we have used.

POROSITY I:

Explain

Porosity refers to materials (like sand, rocks, marbles, or molecules) which have enough open spaces for water to move through. These spaces are called pores. Each material has a unique number of pores, or pore volume, which cause the water to move through it at different rates. Pore volume is the measure of the pores between the sand. In this activity you measured the pore volume in a one liter sample of sand. The sand in this activity represents an **aquifer**. An **aquifer** is the porous rock structure that holds water underground. If we know the **porosity** of our **aquifer** and how big the aquifer is we can calculate the volume of water stored in that aquifer. In an actual aquifer, porosity will decrease with depth because overlying rock layers cause compaction.

Read

- Earth's water distribution (http://ga.water.usgs.gov/edu/waterdistribution.html)
- KS Map showing aquifer by county (http://mapster.kgs.ukans.edu/dasc.cfm?servername=mapster ...)

- Real Time Water Data
- Streams X state (http://water.usgs.gov/realtime.html); H
- Drought X state X month (http://www.ncdc.noaa.gov/oa/climate/research/prelim/drought)

Porosity I: DATA AND CALCULATIONS

Start Volume-Finish Volume=Pore Space Volume

1000 milliliters - _____ =
_____ milliliters (Pore volume in a liter of sand)

Group Data Table

Group Number	Student's Names	Pore Volume/liter of sand
1		
2		
3		
4		
5		
6		
7		
	Mean pore volume=	

Create your own definition of pore volume:

What are some factors affecting porosity?

Porosity II How do various soil materials differ in pore volume?

Materials containing a fairly large proportion of space are considered "high porosity." "That fraction of the pores through which water can flow is called effective porosity. Total porosity may range from near zero to over 50%, depending on the material, while effective porosities are typically somewhat smaller" (Buchanan & Buddemeier, 1993, p.3). The effective porosity is like the interconnecting network streets of a town and result in one's easy movement through town. This network of streets would not include cul de sacs and dead end streets.

Before you complete the procedures, rank each soil material from most pore volume (1) to least pore volume (6), and explain your reasoning.

Prediction		Hypothesis: How did the porosity data help you make your predictions?
Rank	Soil Material	
1		
2		
3		
4		
5		
6		

POROSITY II: Procedures

11. Put the screen into the model bottle and put a cap on the bottle.
12. Fill your model bottle with another soil material to the 1,000 ml. mark.
13. Fill the collection bottle with water to the 1,000 ml. mark. This is the start volume.
14. Slowly pour 100ml of water at a time from the collection bottle into the material until you can see water standing on the surface.
15. Read the current volume on the collection bottle and record it as the finish volume.
16. Remove the cap from the model bottle and let the water drain and the material dry.
17. Perform the appropriate calculations to obtain the Pore Space Volume.
18. Repeat steps 7-10, using your ALREADY MADE FOLDER. INSTEAD of using the title "Porosity1" USE "Porosity2".

POROSITY II: Data and Calculations

Group Table Chart

Group name	Pea Gravel	Gravel	Red Clay	Coarse Sand	Peat Moss	Lawn Soil
1						
2						
3						
4						
5						
6						
7						
Mean Pore Volume						

Porosity is actually documented as a percentage. Mean pore volume represents a fraction of the starting soil volume. Calculate the percentage for each soil type and complete the following chart.

Write the equation you will use to calculate porosity:

Soil Type	Mean Pore Volume (in ml)	Total Soil Volume (in ml)	Porosity %
Fine Sand			
Pea Gravel			
Gravel			
Red Clay			
Peat Moss			
Lawn soil			

19. Add this information to your Excel file, "Porosity2".
20. Make APPROPRIATE graphs for each chart. If you need help, please ask for assistance.

QUESTIONS

Using your graph, explain which soil materials you think would be used as an aquifer? Why?

Water is distributed throughout the earth and its atmosphere, what percentage is found in the ground as water?

As a class, using the Kansas Soil texture map, how many counties possess predominately clay soil?

References

Adapted from Porosity, U.S. Department of Energy, Office of Environmental Management.
http://www.em.doe.gov/soda/poros.html

Buchanan, R. and Buddemeier, R. W. (1993). Kansas Ground Water: An introduction to the state's water quantity, quality, and management issues. Educational Series 10, Lawrence, KS: Kansas Geological Survey.

Pre-Lab Construction

Materials

2 Clear Plastic Two-Liter Soda Bottles
1 Plastic Film Canister
1 Metric Ruler
Permanent Marker Pen
Marking Guides
Scissors
Rubber Band
Nylon Screen (10 cm X 10 cm)

In this activity you will create the bottles--model bottle/collection bottle--you will use for all the other activities.

Procedure:

1. Remove the labels from the bottles.
2. Select a bottle to become the model bottle with the bottom cut off and one to become the collection bottle with the top cut off.

3. Print and cut out the marking guides.

4. Place the cut out marking guides against the bottles, and using a permanent marker pen, label the bottles with the volumes on the marking guides.
5. On the collection bottle, cut off the top of the bottle 4 centimeters below the ring.
6. On the model bottle, cut off the bottom, 5 centimeters up from the bottom. (Note: save the bottom of this bottle for later activities.)
7. Fold or wad up the nylon screen and insert it into the neck of the model bottle.

Porosity and Permeability of Soils

AT A GLANCE:

Test the porosity and permeability of various soil types and relate soil types to ground water movement and aquifer protection.

TIME:
- One 50 minute class period to give prelab directions and background information.
- Two class periods are required to collect the individual data.
- One class session to collect, analyze and graph the class data.

MATERIALS:
- Porosity and Permeability of Soils Lab
- 100 ml beaker
- Grease pencil
- 100 ml graduated cylinder
- Funnel
- Filter papers
- Stopwatch
- Slock w/second hand
- Test tube

OBJECTIVES:

The student will be able to:

1. Use the terms porosity, permeability, aquifer, and confining layer appropriately in describing soils and rock layers.

2. Find the porosity and permeability of a soil, and then process and analyze class data including the average and range.

3. Explain how the porosity and permeability of soils affects the infiltration, movement, and storage of ground water.
   - Describe the type of soils that provide the best protection for aquifers or soils that make the best aquifers.

DEFINITIONS:

Aquifer: Any geologic formation containing water, especially one that supplies water for wells and springs. Porous rock layers under the ground that hold water.

Confining layers: Soil or rock layers that restricts ground water movement upward or downward. Also referred to as "aquitards."

Permeability: A measure of how fast water will flow through connected opening in soil or rock.

Porosity: The capacity of soil or rock to hold water.

PROCEDURE:

Review the movement of water through the cycle before doing this experiment. See lesson on "The Water Cycle and Local Sources of Contamination."

1. Use the "Porosity and Permeability of Soils Lab" sheet to guide the lesson.

2. Assign background reading (found in any earth science text).

3. Have students examine the various soils and predict the order of most to least porous and most to least permeable soils for their hypothesis. Note: The most permeable soil will take the least time. Students find this confusing.

4. Review the procedure on the lab sheet.
   - During the next two class periods have the students collect the data. The clay will take the most time for the porosity and permeability tests. You may want to assign only a few groups to do these if time is short.
   - Have labeled pans for wet sediment to be dumped in to keep it out of the sink. It can be dried and reused.
   - After the individual data is collected, write it on the board or an overhead to compare results and calculate a class average and range.
   - Discuss whether all the data should be included or if there are some obvious errors in measurements or calculations that should not be used in the class averages and ranges.

5. Groups can graph the class data to aid their analysis.

6. Have each student analyze the individual and class data in order to answer the discussion questions, write a conclusion that summarizes the findings, and explain if the data collected supported the hypothesis and background research.

OPTIONAL:

Other soil tests can be done such as:
- Calculate the percentage of sand, silt, clay and organic matter.
- Using with soil test kits to test for essential nutrients (N,P,K). Soil testing kit sources are identified in the "Resources" section.

- Test the ability of various soils to filter out pollutants such as vinegar (test with pH paper before and after filtering), food coloring and vegetable oil.
- Test the porosity of rocks by weighing and then soaking the rocks in water for a week and then reweighing them.

RESOURCES PROVIDED

"Porosity and Permeability of Soils Lab" sheet.

ADDITIONAL RESOURCES:

Soil Survey of Dakota County, US Department of Agriculture and Soil Conservation Service. Available in the Dakota County Library System and through the Natural Resource Conservation Service, 621-463-8665.

Soil testing kit sources:

- Flinn Scientific, Inc., 800-452-1261
- Forestry Suppliers, Inc., 800-647-5368.
- HACH Company, 800-227-4224
- LaMotte Company, 800-3434-3100, http://www.lamotte.com/ese.
- University of Minnesota Soil Test Kits, 612-891-7700. Processing done by University of Minnesota Soil Testing Lab.

Porosity and Permeability of Soils Lab

I. Purpose: To determine the porosity and permeability of various soils and relate this information to the infiltration, movement and storage of ground water.

II. Background: Write a paragraph that compares the relative sizes of the soil particles in the soils provided. Also define the terms porosity, permeability, confining layer and aquifer.

III. Hypothesis: Predict the rank order of the various soils from the most to the least permeable and from the most to the least porous soils.

IV. Procedure:

Part A: Porosity

1. Make a mark half way up a 100 ml beaker with a grease pencil or crayon.
2. Fill the beaker with water to the line drawn.
3. Pour this water into a graduated cylinder and record the volume to the nearest milliliter (ml) in the "Total Volume" column of your data table.
4. Dry the beaker.
5. Fill the beaker with gravel to the line drawn and fill a graduated cylinder to the 100 ml mark with water.
6. Slowly pour the water from the graduated cylinder into the gravel in the beaker until it just reaches the line.
7. Record the volume of water used to fill the pore spaces in the gravel in the "Pore Space" column on your data table.
8. Divide this volume by the total volume and multiply by 100 to get the percent pore space in your sample.
9. Repeat steps 4 - 8 with the other soils. Caution: - Pour the water in slowly to allow time for the water to soak into the pore spaces or you will overshoot your fill line!
10. Do not dump wet soils in the sink! Use the labeled pans provided for all used sediments. Clean and put away all glassware.

Part B: Permeability

1. Mark a test tube half way up with a grease pencil or crayon.
2. Prepare a funnel and filter paper apparatus.
3. Line the cone of the filter paper half full with gravel and put the test tube under the funnel.
4. Time the number of seconds it takes to pour water through the gravel in the funnel and fill the test tube to the half full mark. Caution: Do not overfill your funnel or the water will go down the sides of the filter paper rather then through the sediment.
5. Record the seconds in the "Permeability" column on your data table.
6. Repeat with the other available soils.
7. Do not dump wet soils in the sink! Use the labeled pans provided for all used sediments. Clean and put away all glassware.
8. Set up a class data chart on a separate sheet of paper with class data, average and range for porosity and permeability of the soils tested.

V. Data Table:

Individual Data Chart: Porosity and Permeability of Soils

Material	Total Volume (milliliters)	Pore Space (milliliters)	Porosity (% Pore Space)	Permeability (Seconds)
Gravel				
Sand				
Soil				
Clay				
Mixed				

VI. Discussion:

1. Using individual data and class averages, compare the porosity and permeability of the soils tested.

2. Using the ranges, discuss the reliability of the class data.

3. Discuss five possible sources of error with the procedure and how this experiment could be improved.

4. Explain which soils would work best as aquifers.

5. Explain which soils which work best as confining beds.

VII. Conclusion:

Restate the purpose of the lab.

Explain how the data supported or did not support your hypothesis and background research.

Summarize all major findings.

Identify ways different types of soil types, porosity, and permeability relate to ground water movement and aquifer protection.

Teaching Darcy's Law Through Hands-On Experimentation

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ABSTRACT

Darcy's Law is one of *the* essential concepts in hydrogeology. Before moving on to more complex problems, students must first thoroughly understand the basic principles of one-dimensional fluid flow through saturated porous media that are embodied in Darcy's Law. We believe that the best way for students to learn these principles is through experimentation. In this paper, we introduce an experimental apparatus and laboratory exercises designed to facilitate student exploration of Darcy's Law. Our permeameter design is simple and inexpensive to construct from readily available materials; it is also nearly indestructible and easy to use. The exercises we present are flexible and suitable for high-school or university students. Students performing the exercises will gain an understanding of the relationships among hydraulic gradient, pore size, porosity, fluid viscosity, particle size (mean and distribution), and volumetric flow rate.

Keywords: Apparatus; education – laboratory; education – undergraduate; engineering and environmental geology; hydrogeology and hydrology.

INTRODUCTION

Darcy's Law, which describes one-dimensional laminar flow through saturated porous media such as rocks and soil, is perhaps *the* essential concept in the study of hydrogeology. Providing students with hands-on laboratory experience helps them to develop an intuitive understanding of the relationship between hydraulic head and fluid flow in porous media that is embodied in Darcy's Law. Once the basic concepts are thoroughly understood, students have a firm foundation from which to move on to more complex and realistic problems. Here we begin by providing an introduction to Darcy's Law. We then identify a set of fundamental principles regarding flow in porous media that we believe are best learned through laboratory experimentation. After introducing a simple experimental apparatus capable of performing the relevant tests, we conclude by suggesting a series of student exercises with sample results.

DARCY'S LAW AND GROUND-WATER MOTION

Darcy (1856) performed his original experiments in the context of municipal water filtration for the city of Dijon, France. Unable to find an existing relation between flow rate and filter size, Darcy performed a series of experiments to aid in his design calculations (Hubbert, 1957). In Darcy's apparatus, pressurized water entered the top of a sealed vertical column filled with filtration sand and exited through a tap at the base of the column. Potential energy within the fluid was measured at the inlet and outlet using manometers and reported in meters of water above datum (base of the sand column). Darcy found that for a given sand, volumetric flow rate (Q) was proportional to the cross-sectional area of the column (A), the difference between fluid levels in the inlet and outlet manometers, and the inverse of column length ($1/L$). The coefficient of proportionality was found to vary with the type of sand used; coarse filtration sand was found to produce a larger coefficient of proportionality than finer sand.

In light of subsequent work by others, notably Hubbert (1940), Darcy's Law for steady, one-dimensional flow can be written in differential form as

$$Q=-KA\frac{dh}{dx} \quad , \qquad (1)$$

where K is the hydraulic conductivity (Darcy's coefficient of proportionality) and dh/dx is the hydraulic gradient or change in hydraulic head (h) with respect to distance along the sample (x). Hydraulic head describes the potential energy at any point within a homogeneous incompressible fluid and is given by

$$h=z+\frac{P}{\rho g} \quad , \qquad (2)$$

where z is elevation above datum, P is fluid pressure, ρ is fluid density, and g is gravitational acceleration. From a practical standpoint, hydraulic head can be defined as the height above datum to which the fluid will rise in an uncapped vertical tube (manometer). Fluid flows in response to decreasing hydraulic head; hence, the hydraulic gradient is inherently negative. The negative sign in (1) is, therefore, required to make volumetric flow rate (Q) a positive quantity. For steady, one-dimensional flow through a sample of length L and cross-sectional area A, (1) can be integrated to yield

$$Q=KA\frac{\Delta h}{L} \quad , \qquad (3a)$$

where

$$\Delta h=h_{inlet}-h_{outlet} \quad . \qquad (3b)$$

Subsequent to Darcy's original experiments, it was discovered that for a given porous medium, measured K increases with fluid density (ρ) and is inversely proportional to fluid viscosity (μ). Hubbert (1940) suggested there is an innate material property (k)

that relates hydraulic conductivity to ρ, μ, and the gravitational constant (g) as follows.

$$K=\frac{k\rho g}{\mu} \qquad (4)$$

As Hubbert suggested, k, which is now known as intrinsic permeability, must be determined by experimental means.

Based on classroom experience, we have identified the following principles as being crucial to a full understanding of Darcy's Law and its implications for flow in porous media.

1) Volumetric flow rate is linearly dependent on the hydraulic gradient.
2) Fluid properties combine with intrinsic permeability to determine hydraulic conductivity.
3) Particle size and size distribution help control intrinsic permeability.
4) Flow is controlled by the hydraulic gradient.
5) Sample orientation does not influence flow rate.
6) The medium with lower intrinsic permeability dominates system response in systems where flow passes from one medium to another.
7) Darcy's Law does not apply to flow at large Reynolds numbers.

In the remainder of this paper, we describe apparatus and laboratory exercises designed to enhance student understanding of these principles.

DEMONSTRATION APPARATUS

Quantitative laboratory measurements of hydraulic conductivity are typically made with an apparatus known as a permeameter. Such devices are commonly designed for batch operation rather than student experimentation. As a result, educators have developed demonstration permeameters to help students understand subsurface flow. Many such devices (for example, see Werner and Roof, 1994) are made of a transparent material so that introduction of a visible tracer (for example, food coloring) to the flowing water allows students to directly observe flow paths and tracer dispersion.

After reviewing commercially available designs and those described in the literature, we concluded that none was fully suitable for our specific needs. In addition to demonstrating principles 1-7 (above), we required that the apparatus be inexpensive, virtually indestructible, simple to construct, and easy to use. By forgoing the use of a transparent sample tube, we were able to design a simple permeameter that met our needs and could be constructed from hardware-store materials for around $10.

DESIGN AND CONSTRUCTION

The basic design of apparatus for measuring hydraulic conductivity has not changed significantly since Darcy's original experiments; a typical permeameter consists of a sample tube, end caps, manometers to measure hydraulic head, and inflow/outflow plumbing.

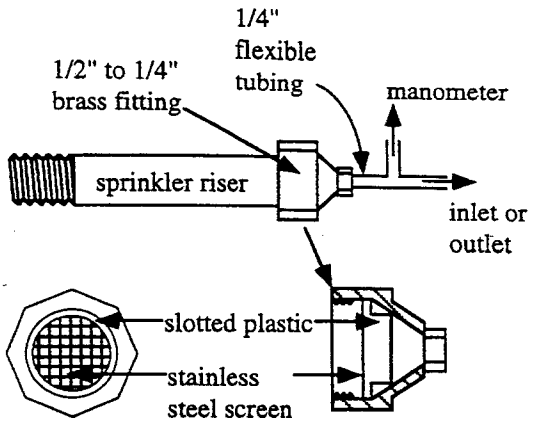


Figure 1: Diagram showing permeameter design. The sample tube consists of a length of pre-threaded plastic pipe (sprinkler riser). The sample is constrained between end caps (only one is shown) fastened onto each end of the sample tube. Plumbers' thread-sealing tape (PTFE) is used to obtain a watertight seal between the end caps and sample tube.

The end caps allow water to enter and exit the sample tube while preventing the sample from eroding. We employ commonly available plumbing items for the end caps and sample tubes; all other materials are standard laboratory supplies. A 1.27 cm (1/2 inch) diameter, pre-threaded plastic pipe (sprinkler riser) is used as a sample tube. Sprinkler risers are available in a variety of lengths; through trial and error, we have found the 20.3 and 25.4 cm (8 and 10 inch) lengths to be most convenient. Brass adapters that attach 1.27 cm (1/2 inch) pipe thread to 0.635 cm (1/4 inch) tubing (compression fitting or barbed) are used as end caps (see Figure 1). To prevent the sample from eroding, a piece of stainless-steel screen is inserted into the end cap. Fortuitously, we discovered that a common faucet aerator (*Plum Pak* part #PP28002) contained two properly sized round screens and a slotted piece of plastic that can be used to support the screen. To avoid restricting flow, we drill out the center of the slotted plastic. Although other arrangements could be easily developed, these end caps perform exceptionally well for materials down to the size of fine sand. It is important to note that this instrument is intended strictly for instructional purposes because the small diameter of the sample tube is expected to result in relatively large edge effects.

Measurement of K, using equation 3a, requires that Δh (and hence Q) be held constant. On the inlet side, a Mariotte bottle (see below) is used to supply fluid to the permeameter at a constant head, while the outlet tube is simply vented to atmospheric pressure. The constant-head boundaries (Mariotte bottle and drip point) are supported on common lab stands, as is the permeameter (Figure 2). Note that head loss is required to induce flow through the 0.635 cm (1/4 inch) flexible plastic tubing that connects the constant head boundaries to the sample. Therefore, it is necessary to measure head loss (Δh) across the sample using manometers (open-ended tubes) attached to T fittings adjacent to the permeameter (Figures 1

and 2). The T fittings should be located as close to the permeameter as is physically possible. A meter stick is used to measure hydraulic head in the inlet and outlet manometers.

Various methods (for example, pump, reservoir) can be used to supply fluid to the permeameter at constant head; however, we find a device known as a Mariotte bottle to be the most convenient (see McCarthey, 1934). A sealed reservoir is equipped with an outlet (siphon) and air inlet, both of which are submerged (Figure 3). When flow is initiated, air enters through the inlet tube to replace fluid leaving the reservoir; provided that fluid level in the reservoir does not drop below the bottom of the inlet or outlet tubes, fluid pressure at the bottom of the air inlet remains at atmospheric pressure. This effect produces flow at constant head, even though fluid level within the reservoir is dropping. Although one could construct such a device from standard glassware, for safety reasons we employ plastic wherever possible. The device illustrated in Figure 3 was constructed from a one-liter flat-sided plastic laboratory bottle. We found that larger plastic bottles tended to flex, which in turn led to small fluctuations in head at low flow rates. We chose a flat-sided bottle so that we could tap the inlet/outlet lines through the sides rather than the cap. Running the lines through the cap is easier but significantly complicates adding fluid during the course of an experiment. An alternative design and a straightforward discussion of the physics are provided by Cutler (1959).

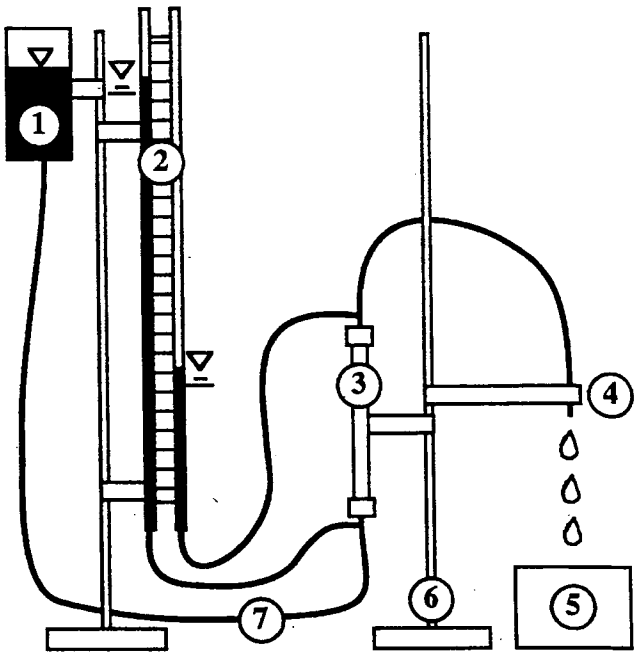


Figure 2. Apparatus for measuring hydraulic conductivity. Fluid levels are shown in black. Numbered components and additional details are as follows: (1) Fluid source (for example, Mariotte bottle, constant-head reservoir, pump). (2) Manometers – open-ended tubes of 0.95 cm (3/8") diameter clear plastic are attached to a vertical meter stick with clear tape or rubber bands. Note that capillary effects in small-diameter tubes will complicate reading the fluid levels. (3) Permeameter (see Figure 1 for details). (4) Drip point – vents flow to atmospheric pressure. (5) Outflow container – plastic cups are used to collect outflow for gravimetric measurement of flow rate (Q). (6) Standard laboratory stands and clamps are used to support the apparatus. (7) Clear flexible tubing is used for all lines to facilitate locating and purging air bubbles.

POROUS MEDIA

Sand is a convenient material for studying the properties of flow in porous media. Sand is easy to work with, and the relatively large hydraulic conductivity allows visible amounts of flow to occur in a short time span. In addition to providing students with visual evidence of the relationship between Δh and Q, high flow rates allow a number of experiments to be performed within a single laboratory session. We selected a standard washed play sand at the local building center. Although this material can be used as is, we chose to separate the sand based on grain size by passing it through a sieve stack consisting of #10, #20, #30, and #40 US Standard sieves. The fraction retained on the #20 sieve after passing through the #10 sieve (10-20 sand) has a grain size that ranges between 0.85 and 2 mm. Likewise, the 20-30 sand has diameters between 0.6 and 0.85 mm, and the 30-40 sand has diameters between 0.425 and 0.6 mm. The difference in grain size between these three sand fractions is readily apparent to the naked eye and helps students to understand the influence of pore size on hydraulic conductivity.

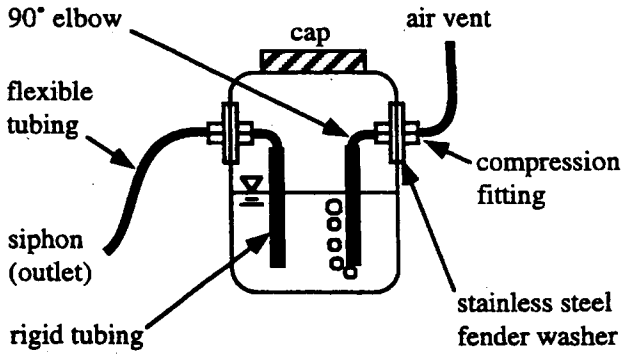


Figure 3. Mariotte bottle constructed for laboratory usage. Note that the cap must be tightly sealed in order for this device to function. Steady bubbling from the air inlet tube is a good indicator that the device is working properly.

SAMPLE PREPARATION

Sample preparation begins by fixing one end cap onto the sample tube, using plumbers' thread-sealing tape (PTFE) to attain a watertight seal. The sample can then be poured in through the open end. Tapping the sample tube against a hard surface will facilitate packing of the particles and minimize subsequent settlement. After filling, the second end cap is attached. An advantage to using the sands described above is that materials with a wide distribution of particle sizes will tend to segregate by size during filling. Students are encouraged to experiment with different filling methods using a clear graduated cylinder. If the dry sample mass (m) is measured during the filling process, sample porosity (n) can be obtained

from the sample volume (V_t) and material density (for example, ρ = 2.65 g/cm^3 for quartz). Porosity is defined as the ratio of void volume (V_v) to sample volume. For a dry sample, total volume is the sum of void volume and volume of solids (V_s), which in turn can be obtained from the sample mass and material density ($V_s = m/\rho$).

$$n=\frac{V_v}{V_t}=\frac{V_t-V_s}{V_t}=1-\frac{V_s}{V_t}=1-\frac{m}{V_t\rho} \qquad (5)$$

After the sample tube is filled with sand, it is connected to the inflow, outflow, and manometers as shown in Figure 2. While saturating the sample with water, it is important to minimize air entrapment within the sample. Trapped air lowers measured hydraulic conductivity by obstructing fluid flow; furthermore, the compressibility of air implies that the degree of obstruction will change with pressure (head). It is best to avoid these effects by saturating the sample from the bottom; tapping the sample tube after adding water will release any large trapped air bubbles. Air entrapment can also be reduced by adding a softening agent to the water (Werner and Roof, 1994) or employing coarse-grained samples. To prevent outgassing within the sample, tap water must be allowed to equilibrate to ambient pressure before use. Allowing the water to equilibrate to ambient conditions also minimizes temperature effects on viscosity.

EXAMPLE EXERCISES

Here we describe several sample exercises that students can perform during a laboratory session. Typically, we break the class up into arbitrarily assigned groups of three for laboratory sessions. Each group works on a given sample until they have completed the appropriate measurements and then moves to another station. To eliminate waiting time, we prepare more stations than there are groups.

Exercise 1 – Effects of Pore Size, Hydraulic Gradient, and a Material Boundary

In this exercise, students explore the linear relationship between Q and Δh, the influence of pore size on K, and the effect of a material boundary within the sample. Two homogenous samples are prepared, one containing 10-20 sand and the second 30-40 sand. A third sample is prepared by partially filling the sample tube with 10-20 sand and then topping it off with 30-40 sand to create a layered sample. Students measure Δh, Q, and outflow temperature for each sample at 5-10 different values of Δh. They are cautioned to allow the manometers to stabilize each time that Δh is changed. The time required for Δh to equilibrate will decrease with increasing mean grain size. Flow rate (Q) can be determined either volumetrically or gravimetrically. In the volumetric method, the outflow is captured in a graduated cylinder for a measured amount of time. The gravimetric method is similar, except that volume is estimated by weighing the outflow and dividing by the fluid density.

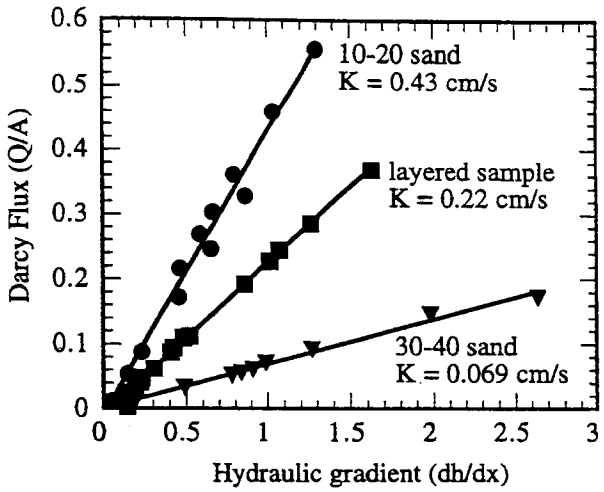


Figure 4. Linear relationship between Darcy flux and hydraulic gradient for three different granular materials. Slope of the best-fit lines through each data set gives the hydraulic conductivity (*K*).

Data are entered into a spreadsheet program as it is collected. We then rewrite (3) as

$$\frac{Q}{A}=K\frac{\Delta h}{L} \qquad (6)$$

The left hand side of (6) gives a quantity known as the Darcy flux (q), which is plotted as a function of the second term on the right hand side ($\Delta h/L$). The slope of a best fit line through the data gives K. As Q is expected to be 0 when Δh = 0, the best fit line must pass through the origin. Sample data (Figure 4) show the linear increase in Q with Δh as predicted by Darcy's Law, and the clear difference in K between the three samples. Standard tables for density and viscosity of water as a function of temperature (for example, Fetter, 1994) provide the data necessary to calculate K using (4).

After calculating K for the three samples, students use their data from the homogeneous samples (10-20 sand and 30-40 sand) to calculate the average hydraulic conductivity (K_{ave}) for a layered system and compare the result to their experimental measurement. Theoretical K_{ave} for one-dimensional flow perpendicular to the layering is given by (see, McWhorter and Sunada, 1977):

$$K_{ave}=\frac{LK_1K_2}{L_1K_2+L_2K_1} \qquad (7)$$

where L_1 and L_2 are the lengths of materials K_1 and K_2, respectively. The layered sample measured in the example (Figure 4) was filled 80% full with the 10-20 sand, and the 30-40 sand was used to fill the remaining 20%; (7) gives K_{ave} = 0.21 cm/s, which compares well with our experimental result of 0.22 cm/s.

Exercise 2 – Indifference of Flow to Sample Orientation

In this exercise, students learn that flow is driven solely by the difference in head across the sample

and, therefore, is indifferent to orientation and location of the sample with respect to the gravity gradient. In our system, the permeameter is mounted on a lab stand with a standard test-tube clamp (Figure 2). This design allows orientation and elevation of the permeameter to be easily changed. Each group of students works with a single sample and measures K (as per Exercise 1) with the sample in three different locations. First, the sample is oriented vertically, then it is rotated to horizontal, and finally, the sample is raised or lowered with respect to datum. Care must be taken not to introduce air into the sample or manometer tubes while the sample is being moved. Students observe that because flow is driven by Δh rather than h, it is insensitive to the orientation of the sample. We suggest that the exercise be concluded by asking students to describe natural systems where the principles demonstrated in this exercise would be relevant.

Exercise 3 – Effect of Fluid Viscosity

In this exercise, students explore the effect of fluid viscosity on hydraulic conductivity by using ice water as the flowing fluid. After measuring K (as per Exercise 1), using water at ambient temperature, ice cubes are added to the Mariotte bottle and the sample is submerged in ice water. We also submerge a length of the inlet tubing in the ice chest. The system is then allowed time to equilibrate to the new environment, and K is remeasured. In order to obtain a representative value, fluid temperature is measured at the outlet manometer connection. In our laboratory, this methodology lowers temperature of the flowing water to ~4°C from an ambient temperature of ~23°C. The viscosity of pure water increases by ~65% over this temperature range (Fetter, 1994), while the increase in density is negligible (~0.2%). Therefore, it is unnecessary to correct measured h for changes in fluid density as implied by (2). Test results (Figure 5) show the significant change in K that occurs when water temperature is reduced. Results are within 5% of predictions based on the measured temperature change.

Another approach to exploring the effects of fluid properties on hydraulic conductivity would be to measure K with water and then to repeat the measurement on that sample using a different fluid. However, for classroom experimentation, ice water has a number of advantages over alternative fluids (for example, dish soap, cooking oil, sucrose solution, or brine). Chilling the water changes viscosity significantly while having a negligible effect on fluid density; therefore, measured h can be used directly. As can be seen from (2), changes in fluid density will require that h be corrected to equivalent units (for example, Fetter, 1994). The density and viscosity of water as a function of temperature are also well known and readily available, hence calculation of K from (4) is straightforward. Changing water temperature is relatively easy and results in minimal down time while the system equilibrates. Adding a solute (for example, salt or sucrose) to change fluid properties requires that the system be thoroughly flushed with

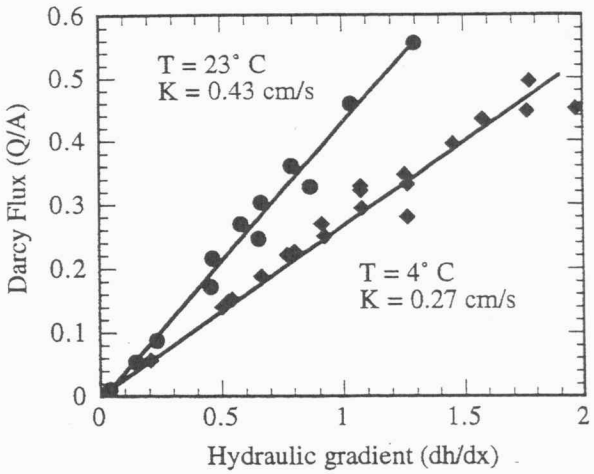


Figure 5: Effects of fluid viscosity on hydraulic conductivity. Water is considerably more fluid at 23°C (black circles) than at 4°C (black squares). As a result, measured hydraulic conductivity (slope of the best fit lines) increases with increasing water temperature.

the new fluid before taking measurements. Changing from water to an immisicble fluid (for example, cooking oil) cannot be done in a single laboratory session. To assure that the sample is fully saturated with the second fluid, the sample must be completely dried out before changing fluid; this is, at best, an overnight process. From a practical standpoint, chilled water is easy to work with; alternative fluids may be messy and difficult to clean up. Finally, using chilled water in this exercise serves to remind students that hydraulic conductivity measured at ambient laboratory temperature will differ significantly from field conditions, where shallow groundwater is expected to be close to the mean annual temperature.

Additional Possibilities

In addition to the activities described in Exercises 1-3, there are a number of other possible classroom exercises that could be performed with our apparatus.

1) The amount of water that empties from a unit volume of saturated porous media by gravity drainage is known as the specific yield (S_y). This quantity is important in evaluating water production from unconfined aquifers. Gravity will not provide sufficient force to drain 100% of the water from the pore space; some water will be held in place by capillary attraction. The amount of water retained in a unit volume of saturated porous media following gravity drainage is known as the specific retention (S_r). The sum of these two quantities is equal to porosity ($n = S_y + S_r$). If porosity is measured when filling the sample, our apparatus can be used to estimate S_r and S_y.
2) In describing our permeameter, we stated that hydraulic conductivity was measured under steady-state conditions; that is, all parameters in (3) are held constant during a given experimental trial. This approach works well for materials with relatively

high permeability such as sand. An alternative approach, known as the falling-head test, is commonly used to measure K in materials with low permeability such as silt or clay (for example, Fetter, 1994). Our apparatus can be reconfigured as a falling-head permeameter by eliminating the outlet tubing and manometer. Performing this exercise also provides students with insight on the basic principles of field slug tests. In our experience, the 30-40 sand is the most permeable material that can be used; coarser-grained sand results in an experiment that is too rapid to measure reliably.

3) Darcy's Law is only valid for laminar flow, which in turn implies that viscous forces dominate inertial forces. The upper limits on the validity of Darcy's Law can be explored by gradually increasing fluid velocity within the sample until inertial effects become significant. In order to do so, it is necessary to maximize fluid velocity by employing a short sample tube (for example, 10.2 cm long) and coarse sand. As the gradient is increased, the graph of Q/A vs. $\Delta h/L$ is expected to become non-linear when inertial forces become significant.
4) The linear relationship between L and Q can be explored by preparing 2-4 samples of different length, each with the same material. Theory suggests that a well sorted fine sand will probably show the least sample-to-sample variance in K.
5) In Exercise 1, the dominance of the lower-K material for flow in series was considered by using a layered sample. One could also arrange two or more permeameters in parallel to show the dominance of the higher-K material for flow through separate layered aquifers.

SUMMARY

After providing an overview of Darcy's Law, we have outlined several concepts that we believe are crucial to student comprehension of ground-water flow. We then introduced an inexpensive and durable apparatus designed for hands-on student experimentation. Finally, we have presented a series of laboratory exercises designed to help students develop an intuitive understanding of the fundamental mechanics of ground-water flow that are embodied in Darcy's Law.

ACKNOWLEDGMENTS

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Food for Thought

The standard account of the reasoning process within geology views it as lacking a distinctive methodology of its own. Rather, geology is described as a derivative science, relying on the logical techniques exemplified by physics. I argue that this account is inadequate and skews our understanding of both geology and the scientific process in general. Far from simply taking up and applying the logical techniques of physics, geological reasoning has developed its own distinctive set of logical procedures.

Robert Frodeman, 1995, Geological reasoning: Geology as an interpretive and historical science: *Geological Society of America Bulletin*, v. 107, p. 960-96 (from p. 960).

Integration of Field Observations with Laboratory Modeling for Understanding Hydrologic Processes in an Undergraduate Earth-Science Course

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ABSTRACT

Understanding how water is transported and stored in the subsurface is a difficult concept for introductory earth-science students. We have developed a hydrology minicourse that integrates field and laboratory experiences to help undergraduate students gain a better understanding of ground-water flow in aquifers. The centerpiece of the minicourse is an investigative field trip that permits analysis of a local aquifer that provides drinking water for the university community. Students collect qualitative and quantitative field data on grain size, thickness, and geometry of different stratigraphic horizons within the aquifer and then construct a small-scale laboratory model of the aquifer using boundary conditions determined from the field investigation. The aquifer model allows students to test hypotheses of ground-water flow by conducting a series of modeling experiments. The experiments test questions such as: "What is the influence of porosity and permeability on ground-water flow?" and "What is the effect of regional dip on ground-water flow?" Analysis of pre- and post-minicourse examinations demonstrates that students are able to better communicate fundamental hydrologic concepts after completing the minicourse.

Keywords: Education – geoscience; education – undergraduate; geology – field trips and field study; geology – teaching and curriculum; hydrogeology and hydrology.

INTRODUCTION

Recent science-education reform efforts have encouraged the development of "hands-on" laboratory and field activities to improve undergraduate science courses (for example, NSF, 1996; Boyer Commission, 1998). In addition, many science-education reform recommendations call for "active" learning styles that foster critical thinking and problem solving rather than "passive" learning (AAAS, 1993; NRC, 1997). This article outlines an innovative teaching approach that we developed at Purdue University to help students actively investigate ground-water flow in aquifers using "hands-on" field and laboratory activities. Various concepts in hydrology, particularly ground-water flow, have historically been difficult topics for undergraduate students to learn in a meaningful way. This difficulty can be attributed, in part, to the inherent complexity of the topic and the fact that hydrology is commonly not discussed in high-school science courses so students have no useful background preparation. As part of an introductory earth-science course for pre-service teachers, we have the students (1) participate in an investigative field trip that provides analysis of aquifers, watersheds, and watertables, (2) construct a small-scale laboratory model of an aquifer using boundary conditions determined during the field investigation, and (3) test working hypotheses of ground-water flow by conducting a series of laboratory experiments using the model. The field trip allows students to make direct observations, collect scientific data, experience the scale and complexity of geologic problems, think critically, and formulate field-based hypotheses. The laboratory modeling helps students discover fundamental hydrologic concepts that are difficult to observe in the field, such as regional fluid flow through an aquifer. This study presents results from an introductory geoscience course for pre-service teachers, but the hydrologic concepts and teaching approaches can be applied in a variety of introductory courses.

The approach used in the course is unique in that observations that students make in the field form the boundary conditions of their model and laboratory experiments. Numerous studies have demonstrated the educational effectiveness of field experiences (for example, Novak, 1976; Mason, 1980; Orion, 1989; Orion, 1993), but few studies have reported on the influence of integrating laboratory and field experiences (for example, deWet, 1994). In this article, we discuss how we attempt to have students connect field-trip observations with laboratory modeling in an introductory undergraduate course for pre-service teachers. In traditional classrooms, students are often provided with predetermined boundary conditions as part of a modeling exercise. Our approach allows the students to determine the appropriate boundary conditions themselves, through observing natural phenomena in the field. This method allows pre-service teachers to understand science as a process and, subsequently, to teach scientific concepts in a meaningful way.

The team that created and assessed the hydrology minicourse at Purdue University worked as part of the Collaborative Action Based Research (CABR) Pilot Program sponsored by the National Science Foundation. Individuals working on the CABR project made use of action research (Hamilton, 1995; Keating and others, 1998) to promote change in the instruction of undergraduate science courses, especially those taken by pre-service teachers, and to enhance students'

understanding of scientific concepts. The action research team for this study included faculty members in geoscience and geoscience education, an elementary-school teacher, a graduate teaching assistant in education, a graduate teaching assistant in geoscience, and two undergraduate students in education who had completed the course. This diverse team structure was designed to provide multiple perspectives for instruction of the course material as well as interpretation of research data collected to evaluate the educational effectiveness of the minicourse. We also discuss a variety of evaluation techniques that were used to determine how this integrated approach affected students' conceptual understanding of hydrologic processes.

Our teaching methods include: (1) having students make observations of natural phenomena, (2) prompting students to use their observations to develop scientific hypotheses, and (3) providing students an opportunity to construct a laboratory model to test their hypotheses. We emphasize students actively working as scientists rather than having them read about or listen to lectures about what scientists have already discovered. Students emulate scientists by making observations, developing hypotheses, and designing experiments to test their hypotheses. During the minicourse, the role of the instructor is to assist student exploration and discovery by providing opportunities for them to make scientific observations. Our approach also tries to change the expectations of elementary-education majors, many of whom expect scientists to simply provide them with the "right" answers. We hope that the future teachers will be able to teach science as a process by incorporating similar teaching approaches in their science courses (Manner, 1998). Finally, in an effort to improve student collaborative skills, they are required to work in small teams in each phase of the minicourse.

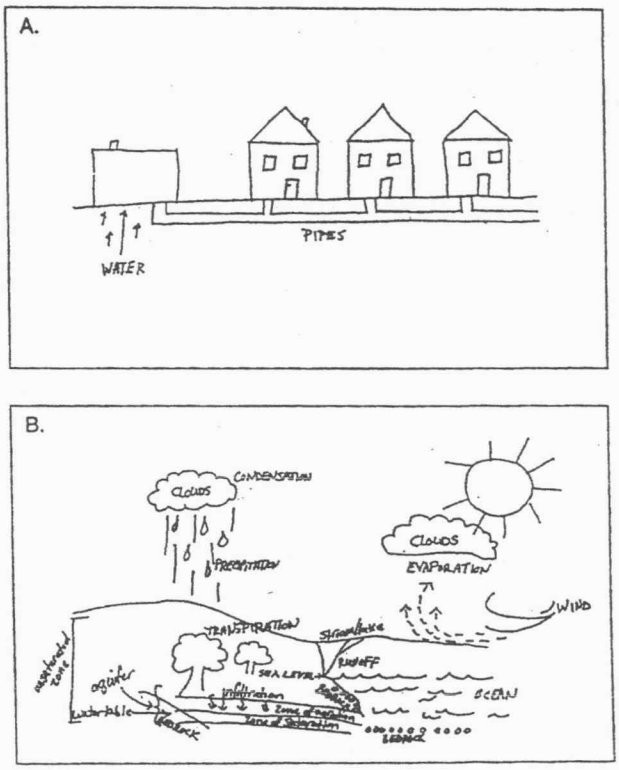


Figure 1. A) Actual pre-minicourse sketch by a student who was asked to explain the following questions: Where does ground water originate and how does it travel in the subsurface? B) Post-minicourse sketch by a student who was asked to explain the following questions: Where does ground water originate and how does ground water travel in the subsurface? The student was also asked to explain the entire hydrologic cycle, so the diagram includes more components of hydrology than the sketch in Figure 1A. Note the apparent improved understanding of the origin of ground water, the role of aquifers, and the impact of regional gradient on groundwater transportation.

FIELD TRIP

Procedure

The hydrology minicourse consists of four interrelated steps that are completed in six class periods: a preparatory unit, an investigative field trip, laboratory modeling exercises, and a classroom synthesis. Before the preparatory unit, students are interviewed individually by course instructors to determine their prior knowledge of hydrologic concepts. In addition to answering a series of questions about hydrology, students are asked to draw a sketch of how ground water migrates in the subsurface (Figure 1A). In the preparatory unit, students complete instructor-provided worksheets that introduce the fundamental concepts to be covered during the minicourse. To help students gain this basic knowledge, instructors also provide extensive resources, including journal articles, web-site addresses, and handouts that can be used throughout the minicourse. Students participate in the hydrology field trip as soon as they complete the preparatory unit. The main goals of the field trip are to have students: (1) actively collect, compile, and interpret geologic field data, (2) effectively experience the scale, complexity, and three-dimensional spatial characteristics of a watershed and an aquifer, (3) realize the limitations of real scientific data sets, (4) effectively communicate their observations and interpretations orally, (5) formulate and test working hypotheses in the field, and (6) propose additional laboratory investigations to evaluate hypotheses developed in the field.

The 22-km field-trip route is completed during the normal allotted classroom time (110 minutes). Instead of taking the entire class to the field at once, instructors conduct the same field trip multiple times with small groups of students. With two instructors and only six to eight students in the field at once, student-instructor interaction is frequent and group discussions involve each student. Although students are prompted through oral questioning by the instructors, observation- and inquiry-based learning is emphasized throughout the field trip. The field trip includes four stops that are outlined below.

Geologic Setting

Purdue University is located in west-central Indiana, a region that underwent multiple Pleistocene glaciations, which deposited gravel, sand, and mud

unconformably above Paleozoic strata (Figure 2). Pleistocene sediments were deposited by ice-contact processes and by eolian, fluvial, and lacustrine depositional systems located adjacent to ice margins. Repeated glacial advance and retreat resulted in depositional units that are laterally and vertically heterogeneous with abrupt changes in grain size, sorting, and bedding thickness. The unconsolidated Pleistocene deposits are the primary hosts for migration and storage of ground water in the study area. Subsurface aquifers within the Pleistocene glacial sediments supply most of the drinking-water that is used at Purdue University (Figure 2).

Field Sites

Stop 1 – *Purdue University water wells and chlorination facility.*
Purpose: Introduce students to basic hydrologic concepts including ground water, aquifers, and the source of local drinking water supplies.

Procedure: After hearing an overview of the main learning objectives and itinerary of the field trip, the students are taken to a campus water-well field located less than one mile from the classroom (Stop 1 on Figure 2). Inside unmarked brick buildings at this locality, there are water wells and chlorination facilities that supply most of the drinking water for the university community. Upon arrival at the well field, students are asked the following question: "Where do you think the water you drink on campus comes from?" Students are encouraged to discuss possible answers to this question in small groups. The most common answers from students are that water is taken directly from the Wabash River (Figure 2), from Lake Michigan (located 90 miles north of Purdue University), or from pipes originating from unknown sources. On the basis of this brief exercise, it is evident that prior to the field trip, the students are unaware that local drinking water is derived from shallow aquifers located directly beneath the campus. Instructors promote further discussion by demonstrating that the brick buildings contain water wells and chlorination facilities. This knowledge allows students to consider the following questions: "Where is the water being stored in the subsurface?" and "What are the physical characteristics of the subsurface (aquifer)?" Stop 2 is designed to help students answer these questions firsthand.

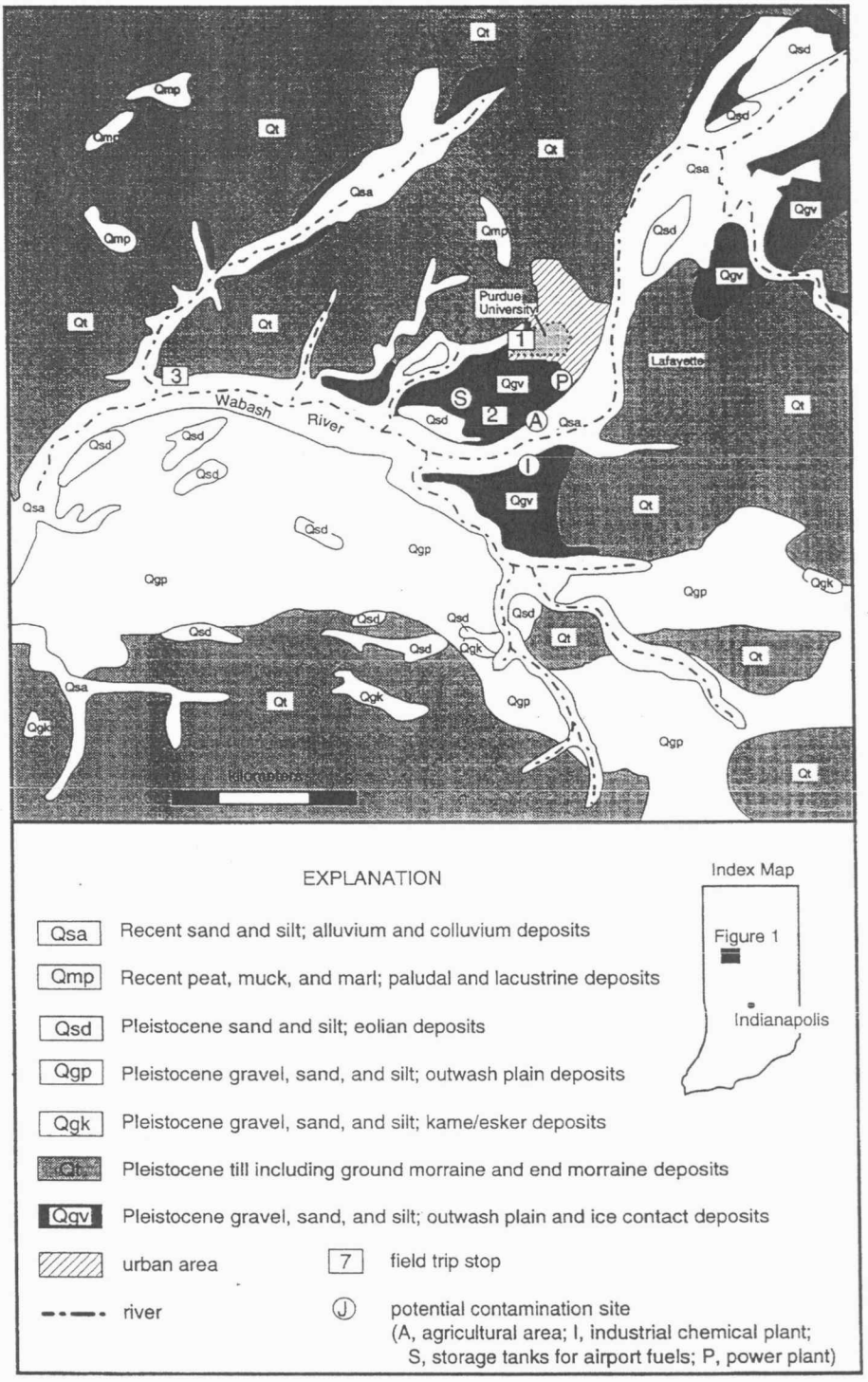
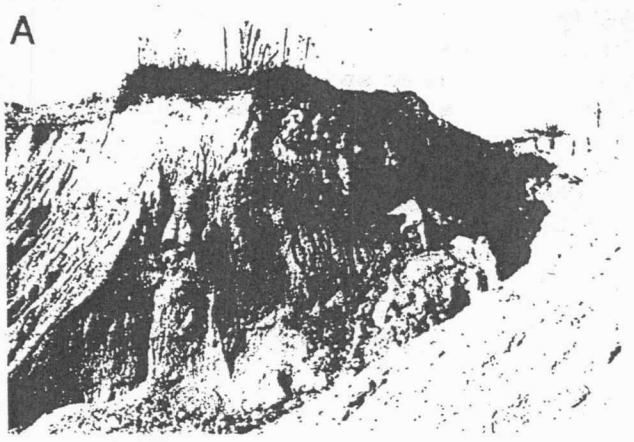
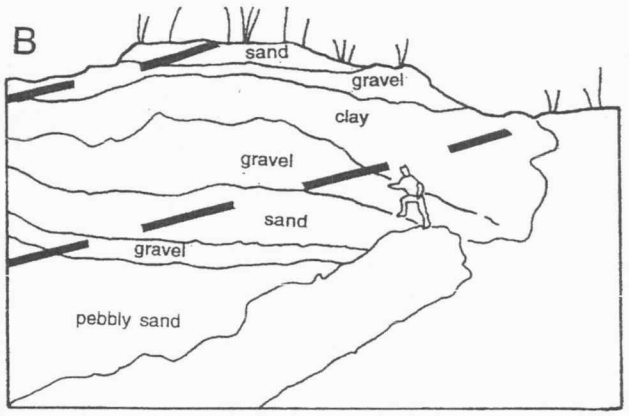


Figure 2. Generalized geologic map of part of the 1° x 2° Danville quadrangle, Indiana. Map location shown on index map of Indiana. Note that the study area is dominated by Pleistocene proglacial and ice-contact deposits and recent sediments. Geology adapted from Wayne and others (1966).

Stop 2 – *Pleistocene aquifer.*
Purpose: Have students make direct observations concerning the physical characteristics of an aquifer and develop working hypotheses as to the physical controls on groundwater migration within an aquifer.





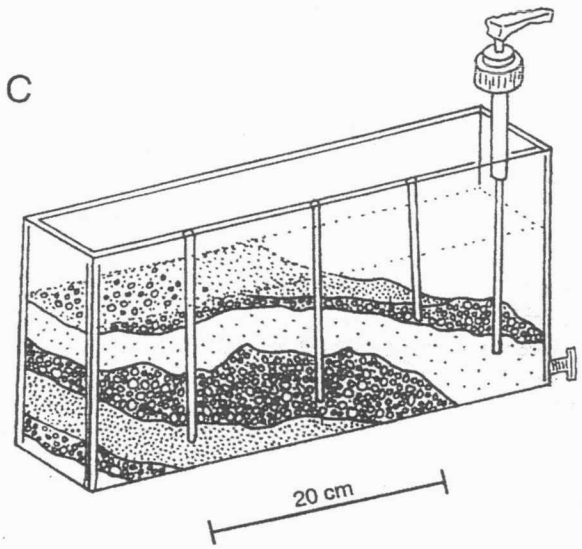


Figure 3 (right). A. Photograph of a typical outcrop face examined by students at Stop 2. Note the heterogeneity in the outcrop that is a product of variations in grain size and bed thickness. Person (right center) for scale. B. Line drawing interpretation of the outcrop face shown in Figure 3A. Dashed lines mark the part of the outcrop modeled in the laboratory (Figure 3C). C. Sketch of a hydrology model constructed by students for laboratory experiments. Students arrange grain sizes in the model according to their observations of an outcrop face examined in the field (aquifer at Stop 2). For example, in the model shown here, gravel, pebbly sand, sand, and clay are arranged from part of the outcrop face shown in Figures 3A, B. The part of the outcrop that is modeled is outlined by the heavy black dashed lines in Figure 3B. Water wells (four vertical cylinders) are installed at variable depths in the modeled aquifer. A moveable pump (shown in well on upper right) can be installed in the water wells to perform pump tests. A small plug (lower right) is used to drain the model in order to study ground-water-transport rates.

Procedure: Stop 2 is a sand and gravel quarry in which students inspect Pleistocene deposits that form the uppermost part of the aquifer that supplies drinking water to Purdue University (Stop 1 on Figure 2). The quarry is located at the southern edge of campus, four km from Stop 1 (Figure 2). The primary objective at the quarry is to have students make detailed observations concerning the lateral and vertical arrangement of unconsolidated sediment comprising the aquifer (Figures 3A, B). After dividing into small groups, students examine different sections of the well exposed quarry walls and make observations concerning the lateral and vertical variations in grain size (gravel, sand, and mud), sedimentary structures (cross-stratification, clast imbrication, and channels), and presence or absence of ground water. Students are provided with tape measures, graph paper, trenching materials, and hardhats and are encouraged to measure stratigraphic sections, construct detailed field sketches, make qualitative descriptions, and collect quantitative data (for example, percent gravel, sand, and shale). The excellent exposures and pronounced variations in grain size, bed thickness, bed geometry, and sedimentary structures permit first-order observations regardless of students' prior knowledge of geology (Figures 3A, B). The students are encouraged to dig into the sediment to determine whether fluids are actually present within the aquifer. Most students readily identify interbedded clay horizons that act as confining layers and partition sand- and gravel-dominated zones of high porosity and permeability. Water is often concentrated along the interface between clay horizons and overlying sand and gravel.

After the field data have been collected, student-led discussions allow them to share what they have discovered by comparing and contrasting the physical characteristics of different parts of the quarry. They are then encouraged to develop working hypotheses on how ground water would be transported through different parts of the aquifer. As part of a group discussion, they consider questions such as: "Is the aquifer lithologically homogeneous or heterogeneous?"; "Is ground water more prevalent in certain parts of the aquifer than others?"; "Why?" "What lithologies appear to transport and/or contain the most ground water?"; "Why?"; "Where in the quarry would a water well be installed to maximize intake of shallow ground water?"

After completion of the sedimentological analyses, the gravels layers are reexamined to determine the clast composition. The goal of this exercise is to have students collect and interpret quantitative data sets that encourage consideration of the role that variations in gravel-clast types might have on ground-water quality. Each group of students documents the gravel-clast composition of a representative portion of an outcrop face by identifying and recording each clast located within a delineated rectangle. At this point in the course, students have had experience identifying rocks and minerals using hand lenses, hydrochloric acid, and streak plates. Students will later compile and interpret the compositional data during the laboratory portion of the minicourse.

Stop 3 - *Regional traverse.*
Purpose: Expose students to hydrologic concepts concerning regional transportation and storage of ground water.

Procedure: After discovering that local water supplies are drawn from subsurface aquifers, the students consider the migration pathways of water from the surface to the subsurface as well as potential sources of ground-water contamination along the pathways. A traverse is taken through a local watershed, progressing downdip through the regional gradient, eventually ending at the Wabash River, the local water table (Stop 3 on Figure 2). As the traverse progresses towards the river, students are asked to identify sites where water is actively migrating or being stored at the surface (for example, streams, lakes, and marshes) and to hypothesize how it might be migrating in the subsurface in response to the regional gradient. The students also identify and discuss potential sources of ground-water contamination observed during the traverse, which include an industrial chemical plant, a power plant, agricultural lands, and gasoline storage tanks (I, P, A, and S on Figure 2).

As a related side project, at the end of the traverse, students study modern fluvial depositional systems near the confluence of a small stream with the Wabash River (Stop 3 on Figure 2). Students compare the arrangement of grain sizes and sedimentary structures in the modern fluvial depositional environment with those of the Pleistocene proglacial outwash deposits that they described at the aquifer (Stop 2). This exercise introduces the general concept that study of modern depositional systems may provide insight into ancient depositional processes and environments.

LABORATORY EXERCISES

Upon returning from the field trip, the students integrate their field observations with laboratory exercises by constructing a small-scale model of the aquifer that they observed in the field (Figure 3C). They are provided with a hydrologic-model kit (Figure 3C) and pre-sieved pebbles, coarse-grained sand, medium-grained sand, fine-grained sand, silt, and clay. After assembling the kit, students use their field sketches, measured stratigraphic sections, descriptions, and quantitative grain-size data to arrange sediment in the laboratory model in a manner similar to the outcrop that they studied in detail at the aquifer (Figure 3B, C).

The students then conduct a series of experiments that verify or refute their field-based hypotheses concerning the physical controls on ground-water transportation (for example, ground water migrates more rapidly through gravel than sand; clay interbeds act as vertical flow barriers in an aquifer). Students conduct experiments to evaluate the role of porosity and permeability on infiltration rates, examine aquifer recharge and discharge, and study the influence that regional dip has on ground-water transportation. The model has monitoring wells and an outlet that can be used to test flow rates through different lithologies and clear walls that permit visual inspection of fluid-migration pathways (fluids are mixed with a bright-colored dye). Detailed descriptions and step-by-step instructions of the laboratory experiments that were used with the hydrology model can be obtained from the Denver Earth Science Project (http://www.mines.edu/Outreach/Cont_Ed/esrc.shtml/pgwm). The students then compare the results of their simulations with those of other groups who observed and modeled different parts of the aquifer in the field. By comparing results, they are able to evaluate how lithology, bed thickness, and bed geometry may control the way fluids are transported and stored in an aquifer.

A second laboratory exercise involves compilation and interpretation of the gravel-clast composition data that the students collected from the aquifer during the field trip. The gravels include metamorphic and igneous clasts that were most likely derived from Precambrian source terranes exposed in Canada, northern Minnesota, and Wisconsin, in addition to clastic and carbonate rocks derived from local Paleozoic sources in Indiana and Illinois. By comparing data sets obtained from different lateral and vertical positions in the quarry, students document compositional variations in gravels within the aquifer. In considering the possible implications of ground water interacting with different rock types, students address the following questions: "What potential water-quality problems could result from aquifers comprised mainly of carbonate gravel clasts," "from igneous clasts rich in heavy minerals," "from poorly consolidated shale clasts"; "What gravels in the quarry might yield the highest quality ground water on the basis of its gravel-clast composition," "Why." The students discuss hypotheses relevant to these questions among themselves and are encouraged to seek additional information so they can understand these important concepts. After completion of the field trip and laboratory experiments, the students synthesize fundamental concepts by completing a series of worksheets and a final examination.

ASSESSMENT, REVISION, AND FUTURE DIRECTIONS

To test the educational effectiveness of integrating field observations with laboratory modeling, we investigated the following question: "Are students able to understand ground-water migration in an aquifer if they participate in a minicourse that integrates field-trip and laboratory experiences?" Our investigation of

this question included two main assessment strategies: (1) pre- and post-testing through oral and written questions answered during formal interviews and (2) post-testing through essay, short answer, and multiple-choice questions answered as part of a final written examination. Our analysis is based on assessment of 80 students from four classes taught in four consecutive semesters. In pre- and post-interviews, the students were asked questions concerning fundamental hydrologic concepts relevant to the minicourse and asked to demonstrate connectedness among these concepts (Table 1; Figure 1B). The key point from our analysis is that, after completing the course, they were more capable of effectively describing, both orally and with sketches, the connectedness between natural phenomena observed in nature (for example, aquifers, watersheds, lithologies, ground water) and abstract concepts that are difficult to observe directly but can be modeled in the laboratory (for example, regional fluid flow). In contrast to sketches drawn in pre-minicourse interviews, post-minicourse sketches illustrate aquifer heterogeneity, fluids migrating faster through more porous and permeable parts of an aquifer, and fluids migrating downdip in response to a regional gradient (Figure 1B). Analysis of students' written responses to final-exam questions suggests that they gained more knowledge from field and laboratory experiences than from worksheets or classroom lectures. The most frequently missed exam questions concerned concepts not experienced during the field trip or laboratory components of the course. Importantly, analyses of essay responses indicate that students understood what they were modeling in the laboratory and why the modeling was necessary to test their working hypotheses. Although our research methodology did not include rigorous statistical analyses, randomized field trials, or control groups that would better substantiate the effectiveness of our approach (Shea, 1999), we contend that the pre- and post-testing results clearly demonstrate that student learning occurred. Recent research indicates that despite the intensity or effectiveness of the teaching experience, learning is influenced by the amount of time students are exposed to the studied material (Gabel, 1994). To address the issue of the length of time of student involvement with this topic, the two-week minicourse has been infused into a five-week minicourse that builds upon the role of the field trip and its modeling via laboratory experiences. Future research will be conducted to assess the impact of a longer minicourse on student learning of the geosciences.

We also documented student opinions of the techniques used and monitored student attitudes towards learning during the minicourse (Table 1). Analysis of student e-mail journals, student-opinion surveys, and course evaluations reveals positive responses to the teaching techniques used in the hydrology minicourse. In response to student suggestions for improving the minicourse, we have increased the amount of time allowed to make observations in the field, reduced the complexity of some of the laboratory experiments, and added "wrap-up" sessions to both the laboratory and field experiments. Future minicourse modifications that we are planning include: (1) providing subsurface data (for example, well logs) from additional field sites in the study area on a web site so that students can make more regional observations, interpretations, and predictions, (2) retooling the laboratory component of the minicourse to include collection and analysis of more quantitative data sets to stress the interrelatedness of science and mathematics (for example, in addition to calculating porosity, permeability, and flow rates, students will determine the probability that one part of an aquifer will recharge faster than another), and (3) viewing of a videotape during the preparatory unit that shows each component of the minicourse from previous semesters to help students

Technique	Results
Assessment by instructors	
Pre- and post-minicourse examination (formal interviews with sketches)	After the minicourse, students were able to better communicate orally and with sketches the origin of ground water, how ground water migrates in the subsurface, and how the physical characteristics of the subsurface influence transportation and storage of ground water. Post-minicourse sketches provide direct evidence that students made fundamental connections between field observations and laboratory modeling exercises.
Post-minicourse final examination (written multiple-choice, short-answer, and essay questions)	The most frequently missed exam questions concerned topics that were not covered in the field or laboratory. Answers to essay questions strongly suggest that most students understood what they were modeling in the laboratory and why the modeling was necessary.
Assessment by students	
Student survey	A large majority of students stated that they learned the most by making field observations in association with "real" geoscientists and/or participating in group discussions while in the field. A smaller proportion indicated that they learned the most from the laboratory modeling experiences.
Course evaluation	Analysis of course evaluations suggest that students were interested in learning hydrology because they thought the minicourse was exciting and worthwhile. Pre-service teachers stated that they felt a sense of accomplishment and had more confidence in their scientific abilities.
E-mail journals	Although students were encouraged to document what they had learned during the minicourse in weekly journals, most students simply wrote that the minicourse was "interesting, exciting, fun, or cool."

Table 1. Assessment techniques used to evaluate student understanding of hydrology and attitude toward the hydrology minicourse.

better understand the expectations of the course and how each component is interrelated.

IMPACT OF ACTION RESEARCH

In outlining the curriculum for a two-week (10 classroom hours) hydrology minicourse, we faced the common dilemma of choosing from more available material than could be reasonably assimilated by students during the allotted time frame. We omitted material that could be easily obtained by students outside of the classroom and placed emphasis on "hands-on" experiences and inquiry-based learning activities. We tried to break down any instructor-student barriers by promoting active learning and discussion while minimizing formal lectures on course content. Instructors assisted student exploration and discovery in an attempt to dispel preconceived notions that science presents an absolute true/false duality (for example, see Perry, 1970).

In this study, our use of action research helped to (1) document the educational effectiveness of the hydrology minicourse, (2) determine the weaknesses of our approach, and (3) provide feedback for future improvement of the curriculum. By determining student pre- and post-minicourse understanding of fundamental concepts through multiple assessment strategies carried out by a diverse team, a thorough understanding of the strengths and weaknesses of the minicourse was gained. Students apparently benefitted from the involvement of a diverse instructional team that included scientists, educators, and students. Students regularly stated in e-mail journals, course evaluations, and informal conversations that having multiple perspectives during field and laboratory experiences was useful. They were also more comfortable discussing weaknesses of the minicourse with some instructors than with other instructors. Consequently, improvements of the minicourse were made based not only on our assessment strategies but from informal student-instructor conversations as well.

CONCLUSION

Integration of field-trip and laboratory experiences was an effective learning mechanism that allowed students to make connections between field observations and more abstract hydrologic concepts. We stress that the determinant of student understanding of hydrology gained during this minicourse was not by the volume or variety of course content but by how the content was actively discovered by students in multiple learning environments. The results of this study are consistent with previous research that demonstrates field experiences attract students to science (Karabinos and others, 1992) and make science learning more meaningful (Manner, 1995). This study also adds to a growing list of studies that indicate students are more likely to understand hydrologic concepts through "real-world" experiences (Harbor and McClintock, 1993; deWet, 1994; Fletcher, 1994).

ACKNOWLEDGMENTS

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Miscellaneous Announcements

A Proposal to Science Educators for Advanced Placement Geology

Geology is a science that is both fascinating and relevant to the lives of our students. Unfortunately, it is rarely offered at the high-school level. The existence of an advanced placement geology exam would encourage high schools to include geology in their curricula. Advanced placement courses are magnets that draw the best students around the country. Top science students enroll in AP Biology, AP Chemistry, and AP Physics classes. Colleges recognize the rigor of an AP course and will give preferential treatment to students enrolling in AP classes. Even if a rigorous geology course is offered in high school, the top students often avoid it because it does not carry the prestigious AP name. As a result, few college-bound students are exposed to the science of geology, and few will consider it in college. This affects both the quality and the quantity of students enrolling in college geology courses.

At this time, there is no advanced placement exam for geology. The people at the College Board believe that there is not enough interest in the exam to make it worthwhile to create the test. I am making this announcement to find out if that is the case. If you would like to teach an AP Geology course or you know someone who would, please contact me by e-mail or any other means convenient. If you or your institution would like to support this proposal, contact me as well.

Please forward this to other science educators who may be interested.

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37th Forum on the Geology of Industrial Minerals 2001 Victoria, British Columbia, Canada May 23-25

The conference will cover:

- Industrial Mineral Deposits of Western North America
- World-class Industrial Minerals Discoveries
- Evaluation of Industrial Mineral Deposits
- Natural Stone
- Synthetic and Energy-Intensive Minerals
- Value-added Industrial Minerals
- Diamonds in Canada

Field trips:

- Cordilleran geological transect with emphasis on industrial mineral deposits and operations
- Industrial mineral processing plants of the Vancouver area
- Limestone deposits of the Texada Island
- Crystar synthetic sapphire plant
- Diamond deposits of Northwest Territories
- Quaternary geology of the Victoria area and aggregate resources
- Dimension stone in Victoria

For information on the technical program contact:

George Simandl,
BC Geological Survey,
Tel 250-952-0413, Fax 250-952-0381,
George.Simandl@gems2.gov.bc.ca.

For Information on registration contact:

Susan Dunlop
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A Spreadsheet Approach to the Hydrological Cycle

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ABSTRACT

I have devised a spreadsheet approach that is designed to help students better understand the terrestrial or "basin" hydrological cycle. Students are assigned problems to create spreadsheets accounting for the flux in and out of the major surface and subsurface "reservoirs." The effects of hydroclimatic variation upon runoff are tested in the spreadsheet model. The assignment is given to upper-level undergraduates and graduate students in order to promote proficiency in the use of the spreadsheet, a potentially important tool in the geoscience curriculum.

Keywords: Education – computer assisted; engineering and environmental geology; hydrogeology and hydrology; miscellaneous and mathematical geology.

Introduction

The spreadsheet is becoming increasingly popular; however, it is not yet universally used as a tool for course assignments. The spreadsheet not only serves as a time-saving means of producing errorless calculations; it can also facilitate a better understanding of various geological, environmental and hydrological processes. Perhaps the most appealing aspect of using a spreadsheet is that it allows the student to readily find answers to his or her "what if" questions. I have observed that both undergraduate and graduate students are becoming progressively more proficient with the spreadsheet. However, there is a clear need for instructors to assign more spreadsheet problems in order to enhance these programming skills.

To meet this need, I have developed a simple spreadsheet assignment that can be used to promote better understanding of the various components of the terrestrial part of the hydrological cycle – particularly those involving subsurface and surface-water interactions. An additional objective of the assignment is to stimulate thinking regarding the effects of climate change on the hydrological cycle and water resources. I give the exercise to my undergraduate/graduate (400/600) level *Hydrogeology* course as a homework assignment.

Background
(presented as an introduction to the assignment)

Hydrological Cycle and Budgets: The hydrological cycle is a scheme employed to account for the flux of water from the oceans, to the atmosphere, to the hydrosphere (the earth's surface and shallow subsurface), and then back to the oceans. An estimated 1 x 10^{17} kilograms of water are transferred through the terrestrial or continental portion of the hydrological cycle annually (Chahine, 1992).

The hydrological cycle can be stated in the form of a budget or water balance as follows:

INFLUX = OUTFLUX or **[Equation 1]**

Precipitation = Evapotranspiration + Infiltration + Runoff.

This is a steady-state equation in that no water is accumulated or lost. The sum total of the global water budget remains constant. This is a good first-order approximation for the global cycle; however, it fails to account for important relationships between infiltration and runoff. After all, a great deal of streamflow is accounted for by water that has already infiltrated the earth's surface. How else could a stream flow on a perennial basis? We will return to this problem in our assignment.

A second, and more general, equation accounts for the input or output of water to and from "storage" [$\pm\Delta S$] (that is, water held within some storage "reservoir" such as rocks, soil, lakes or the oceans). This equation is stated as follows:

$$\sum \text{INFLUX} - \sum \text{OUTFLUX} = \pm\Delta \text{ STORAGE} . \quad \text{[Equation 2]}$$

The hydrological cycle is typically shown as a series of interrelated "reservoirs" with "flux" rates (mass/time, length/time, or volume/time) between each reservoir. Engineers call these "pot-and-pipeline" diagrams (Figure 1).

Residence Time: The mass of water within a reservoir divided by the flux in or out of the reservoir is known as the "residence time." This can be thought of as the average period of time a water molecule spends within a reservoir. For example, the total mass of water within the terrestrial atmosphere is 4.5 x 10^{15} kg. The flux rate is 107 x 10^{15} kg/yr (Chahine, 1992). The residence time is computed as follow:

$$\textit{Residence Time} = \frac{4.5 \times 10^{15}\, kg}{107 \times 10^{15}\, kg/yr} = 4.2 \times 10^{-2}\, year = 15\, days.$$

The shorter the residence time the more that particular reservoir is sensitive to perturbations within the hydrological cycle (for example, droughts) and pollution. In other words, low-residence time reservoirs are not "buffered" very well with respect to change.

The Basin Hydrological Cycle: The basic unit of landmass used to account for water on the continents is known as the "watershed" or the land area between two watershed divides. The hydrological budget for a basin can be accounted for by the

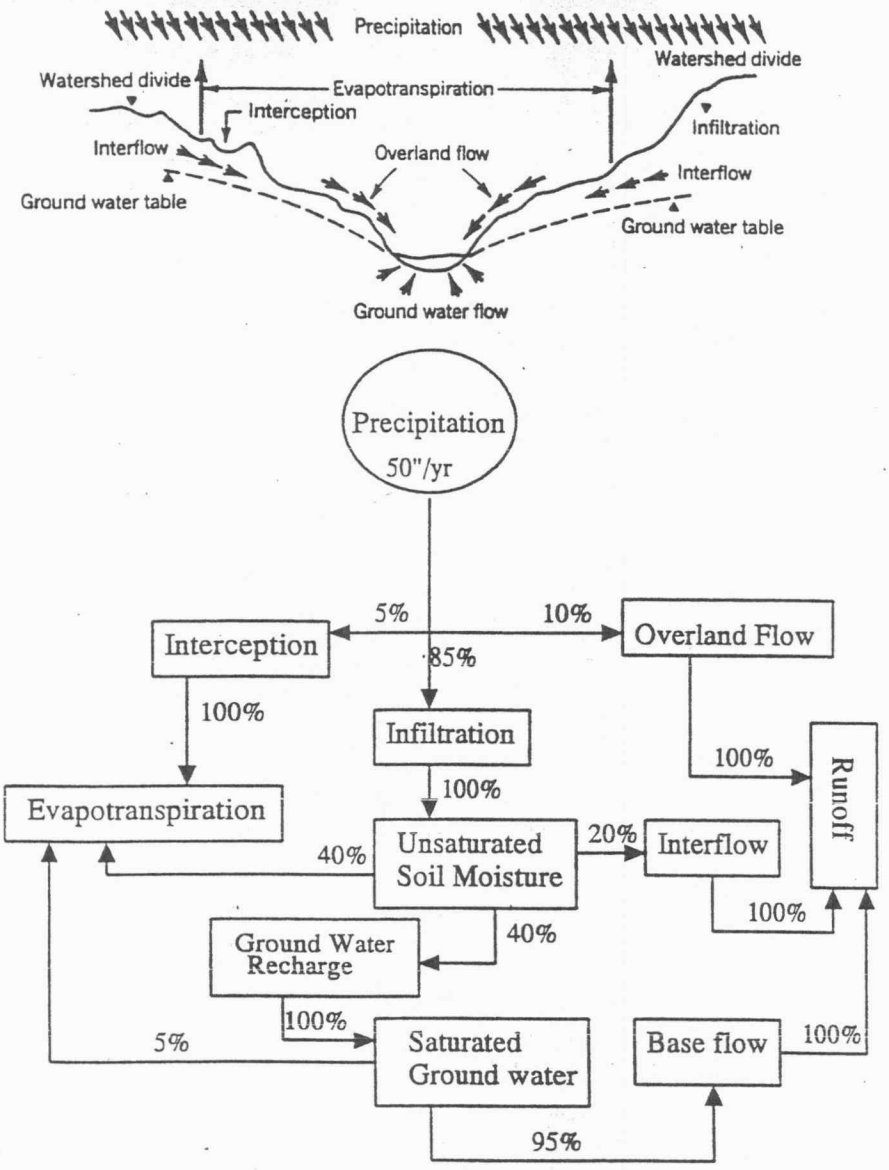


Figure 1. A schematic of the hydrological cycle for watersheds (slightly modified from Domenico and Schwartz, p.10, 1990, with permission of publisher). Note that the flux rates are given in percentage form and are only hypothetical (used for "Scenario 1").

scheme shown on Figure 1, slightly modified from Domenico and Schwartz (p. 10, 1990). Once again the sole influx is precipitation and the outflux is evapotranspiration (ET) and runoff. Water that infiltrates eventually outfluxes via ET and runoff. Ground water is also considered an active part of the cycle, although it might be held in storage for some time.

Calculating Flux (rate x area): Very often flux rates are given in the dimensions of length per time (for example, the average annual precipitation rate for Atlanta, Georgia is 48 inches/year). To convert these rates to volume/time, we simply multiply by the basin area. The following is a sample calculation using the "factor-label" approach (a must).

Sample Calculation: Convert 2.5 inches/year rainfall to cubic meters per day and then gallons per day given a basin area of 100 square miles.

$$\frac{2.5\,in}{year}\times 100\,mi^2\times\frac{1\,ft}{12\,in}\times\frac{(5{,}280\,ft)^2}{(1\,mi)^2}\times\frac{(.3048\,m)^3}{(1\,ft)^3}\times\frac{1\,year}{365.25}=\frac{4.50\times10^4\,m^3}{day}\times\frac{264\,gallons}{m^3}=\frac{1.19\times10^7\,gal}{day}.$$

Assignment

Part 1 (Scenario 1): The objective of this assignment is to devise and implement a spreadsheet solution for the basin hydrological cycle shown in Figure 1. The *input* to your model will consist of the hypothetical "percentage fluxes" to and from the various components or "pots." We also assume a net influx of 50 inches of rainfall per year and a basin area of 100 square miles. The primary *output* will consist of the total runoff generated from these inputs. Follow these steps and answer the related questions.

a) Set up a spreadsheet program and calculate the total ET. Your answer should be given in inches per year, cubic meters per day, gallons per day, and cubic feet per second. [Hint: These will all be columns in your spreadsheet. Build your conversion factors into the spreadsheet].

b) Do the same for runoff.

c) In order to complete "a" and "b" you must calculate all fluxes for all reservoirs shown on Figure 1.

d) From your spreadsheet calculations, compare the difference between precipitation rates and the sum of ET and runoff.

e) Let us assume the average person consumes 200 gallons of water per day. Given the total runoff, how many people can this basin support?

f) Calculate the volume of the ground water reservoir, assuming a basin area of 100 mi^2, a porosity of 25% and a saturated thickness of 10 meters. Given the calculated rate of ground-water recharge, calculate the residence time of ground water in this hypothetical basin.

g) Are ground water and surface water divides necessarily the same for a given watershed? Explain.

Precipitation Rate	50 in/yr					
				Volumetric Flux		
RESERVOIRS Flux sources	**% Flux[1]**	**Basin Area(mi^2)**	**Inches per year**	**Cubic meters per day**	**Gallons per day**	**Cubic feet per second**
INTERCEPTION precip.	0.05	100	2.50	4.50E+04	1.19E+07	1.84E+01
OVERLAND FLOW precip.	0.10	100	5.00	9.01E+04	2.38E+07	3.68E+01
INFILTRATION precip.	0.85	100	42.50	7.66E+05	2.02E+08	3.13E+02
UNSATD. SOIL MOISTURE infiltration	1.00	100	42.50	7.66E+05	2.02E+08	3.13E+02
G.W. RECHARGE unsatd. s.m.	0.40	100	17.00	3.06E+05	8.08E+07	1.25E+02
SATURATED GROUND WATER g.w. recharge	1.00	100	17.00	3.06E+05	8.08E+07	1.25E+02
ET.						
interception	1.00	100	2.50	4.50E+04	1.19E+07	1.84E+01
unsatd. s.m.	0.40	100	17.00	3.06E+05	8.08E+07	1.25E+02
satd. g.w.	0.05	100	0.85	1.53E+04	4.04E+06	6.25E+00
TOTAL ET		100	20.35	3.67E+05	9.68E+07	1.50E+02
BASEFLOW satd. g.w.	0.95	100	16.15	2.91E+05	7.68E+07	1.19E+02
INTERFLOW unsatd. s.m.	0.20	100	8.50	1.53E+05	4.04E+07	6.25E+01
OVERLAND FLOW precip.	0.10	100	5.00	9.01E+04	2.38E+07	3.68E+01
RUNOFF						
baseflow		100	16.15	2.91E+05	7.68E+07	1.19E+02
interflow		100	8.50	1.53E+05	4.04E+07	6.25E+01
overland		100	5.00	9.01E+04	2.38E+07	3.68E+01
TOTAL RUNOFF		100	29.65	5.34E+05	1.41E+08	2.18E+02

[1]The hypothetical percentage flux rates used are those given in Figure 1. Note also that the % flux in each box does not have to equal 1.0.

Table 1. Spreadsheet Solution to "Scenario 1."

Part 2 (Scenario 2): Assume that mean annual temperatures increase, resulting in a proportional increase in evapotranspiration. Now assume that 60%, rather than 40%, of the unsaturated soil moisture results in ET and that 10%, rather than 20%, of the soil moisture results in runoff. Furthermore, assume that 10%, rather than 5%, of the saturated ground water is "lost" to ET. Finally, assume that each reservoir within the model is in "steady-state." The rainfall rate will remain at 50 inches per year (perhaps a tenuous assumption if global warming occurs).

a) Complete a new "pot-and-pipeline" diagram for this scenario.

b) Modify the spreadsheet to account for these new flux rates.

c) Compare and contrast the resulting ET and runoff rates derived for Scenarios 1 and 2.

d) By what percent did streamflow decline in Scenario 2?

e) Explain why either Equation 1 or Equation is most relevant for the flux scheme shown o Figure 1. Which equation would be most relevan if only a total of 80% of the ground water re charge outfluxes through ET and baseflow? I other words account for the "missing" 20%.

***Spreadsheet Solution*:** A spreadsheet solutio to the problem posed as "Scenario 1" is given in Tab 1. I stress that the solution shown below is by r means unique nor is it likely the most efficient. Hov ever, it required less than a half hour to set up, ru

and check. A more sophisticated approach would involve the use of the Thornthwaite (1948) equation which relates evapotranspiration rates to mean monthly temperatures.

Acknowledgments

I thank the students of my *Hydrogeology* class for helping me to clarify some aspects of this exercise.

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Letters

Student Evaluations

I have enjoyed reading your inside-the-front-cover editorials for many years; however, the latest (on teaching evaluations) really "hit the spot." I could not agree more!

Although class attendance has not been required at our institution for many years, I check attendance several times each semester, require students in my introductory classes to sign their test papers to show that they personally picked up their graded exams (and penalize those who do not pick them up because I believe that discussing the corrected exam is at least as important as taking it in the first place), ask for questions about the previous lecture before each new class period begins, stop frequently to answer any questions, and stay for a few minutes after class in case there are any questions at that time. Yet I routinely get student evaluations that fall below others in my department. In spite of the fact that I post my office hours by my office door, give my home phone number to students in my classes, invite them to call me at home if they have any problems, and require individuals who are doing poorly on exams or in their lab work to come to my office for a conference, as many as one-third of those same students give me the worst possible ratings for those evaluation questions that ask whether I am available to answer their questions.

Typical daily attendance in introductory classes is roughly 50%, and only a fraction of those who attend do so on a regular basis. How much value do evaluations given by students who only attend class occasionally really have? Frankly, I put little faith in student evaluations. How can someone who is present only half of the time on average determine that I am or am not teaching that course well?

Even in upper division and graduate level classes, attendance has become more erratic and many students hardly give a thought to coming late to class or not coming at all. They often seem oblivious to the distraction they cause when they arrive late and talk to the students sitting next to them to find out what they missed, or fail to understand the material you are discussing because they were not present when you started your lecture.

You noted that your early morning class seemed to be the worst, that in your early morning class you were rated among the worst 20% of all the instructors at UW-Parkside. I can sympathize with you. I have had the same experience.

Your editorial concluded with, "What seems to be a simple and straightforward method evaluating instruction turns out upon examination to be fatally flawed." The major flaws in student evaluations are that the majority of students are still immature and have no sound basis for judging the quality of instruction. They are more likely to judge instructors on the basis of how well they are doing in class and other factors that are not related to how thorough or technically correct the instruction was. It is much more revealing to find out what students who took your class ten or more years ago think today about how good a teacher you were. Of course, by that time the "bean counters" don't really care.

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National Science Teachers Association

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Science Scope
November/December 2001, p. 20-26
Feature

Inquiry and Aquifers

Ted Leuenberger, Daniel Shepardson, John Harbor, Cheryl Bell, Jason Meyer, Hope Klagges, and Willie Burgess

Where does tap water in your house come from?

A question such as this is a good starting point for a discussion of water sources and the water cycle. Groundwater is the largest non-frozen fresh water resource on Earth, and wells have been used throughout history to retrieve water from the ground. Today many community water systems draw water from groundwater, and many homes in rural areas draw water directly from groundwater supply with little or no treatment before it is delivered through a tap for use. Thus it is important for students to understand the structure of the ground beneath them, which allows groundwater to exist in a state that provides safe, reliable supplies of fresh water.

Other important questions to address include: Are these supplies being recharged (naturally refilled) as we draw from them? Is that water safe to use? What might affect the quality of the water supply? Will communities and homes be able to continue drawing water from groundwater supplies directly beneath urban or rural areas? Do actions on the surface result in a change in ground water supplies? These types of practical questions reinforce the importance of studying groundwater.

Included in this article are activities that were designed to foster the understanding of Earth material permeability and groundwater movement. Through the use of a groundwater model and well logs, the possible movement of water in local groundwater systems may be investigated. Through these inquiry activities learners explore groundwater systems and issues, leading to the

development of citizens who will be better prepared to deal with issues surrounding local water supplies and the need to manage fresh water aquifers as sustainable resources.

Understanding the geology

Reviews of groundwater principles are provided in many science texts. By way of review we briefly describe some of the key points here. Earth materials consist of solid matter (rock, sand) and spaces between that are called *pores*. If the pores connect to each other, water can flow through the Earth material (it is permeable) and we call this geologic unit (rock or sediments) an *aquifer*. If the pores do not connect, water cannot flow into or through the material: it is impermeable. When the pores in a material are completely filled with water, we say that this material is *saturated*. If the pores are partly filled with air, then the material is *unsaturated*.

In many areas, the Earth materials very near the surface are unsaturated, but lie above a saturated zone. The uppermost level of the saturated zone marks the height of the water table in that area. If you were to dig a well, you would have to drill below the level of the water table before water would begin filling your well. You may have experienced this phenomenon at the beach when digging a hole in the sand and water began to fill your hole when you reached a depth below sea level.

Aquifers can exist in different ways. *Unconfined aquifers* exist where the upper boundary of the groundwater is the water table. A *confined aquifer* is bounded above and below by nonpermeable layers, so the water in the aquifer cannot rise as far as it would if there was no 'lid' on it. If you drill a well into a confined aquifer the water might come out at the surface (*artesian*).

In order to obtain fresh water, people drill wells to locate an aquifer that might best supply the need for fresh water. Because geologic layers are tilted, folded, and faulted in most areas and consist of both permeable and impermeable materials, there can be quite complex patterns of ground water movement. Water can only enter the ground when a permeable material is at the surface. At the site of a well, water can be drawn in sufficient quantities to cause a cone of depression. This *cone of depression* is a lowering of the water table in the area of the well. This causes a flow of groundwater toward the well site.

Determining permeability

To begin developing an understanding of how Earth materials might be suitable for the collection or transfer of water within a groundwater system, a simple activity can be used to examine the importance of porosity and permeability. Most students have prior experience playing with water,

sand, and mud, so they are comfortable making predictions about how well water might move through Earth materials.

Figure 1.

Permeability setup.



The first activity we describe asks students to develop simple experiments to compare the permeability of different materials. The equipment I provide students is basic. Each group receives several modified large-mouth sport drink bottles (see Figure 1), a supply of water, a piece of filter paper, and a variety of soil samples. I prepare the bottles by cutting off the bottom of one and drilling several holes through its lid. For the other bottle, I cut off the top half so that it can act as a base and water collector for the other bottle. The filter paper is cut to fit inside the lid of the first bottle. (See Figure 1 for setup.) Tape can be placed over the holes in the lid to prevent water from escaping, and removed once the students are ready to release the water from the apparatus.

The students are given two questions from which they develop a hypothesis and investigation to answer the questions:

1. Does the particle size of Earth material affect the amount of water that can be held within that material?
2. Does the particle size of Earth material affect the amount of water that Earth material can retain?

The students determine an answer for each question, identify the independent and dependent variables and, using the sport bottle apparatus, develop a procedure for testing the determined hypotheses. Figure 1A is an example of an investigation created by students. After testing, students present and defend their results, procedures, and conclusions, and are asked to consider what their results mean in terms of which Earth materials would make the best aquifer.

FIGURE 1a **A sample student-designed investigation**

1. Prepare each bottle by placing filter paper inside cap and covering holes on outside of cap with duct tape.
2. Place a 250-mL sample of each type of dirt in its own bottle.
3. Add water from a measured graduated cylinder until all of the spaces within the Earth material are filled and the water reaches the top of the Earth material sample.
4. Determine the amount of water added to the Earth material. This is the amount of water that the Earth material can hold. Record that data:

Amount of water held by each Earth material:
Sand:_____ Fine gravel:_____ Coarse gravel:_____

Include this data in the class data on the board.
5. Remove the duct tape from each bottle and allow water to drain into the bottom half for five minutes.
6. Measure the amount of water that drained out and subtract that from the amount of water originally held by the Earth material to determine the amount of water retained by the Earth material. Record this data:

Amount of water retained by Earth material:
Sand:_____ Fine gravel:_____ Coarse gravel:_____

Include this data in the class data on the board.
Calculate the class average for each and record below:

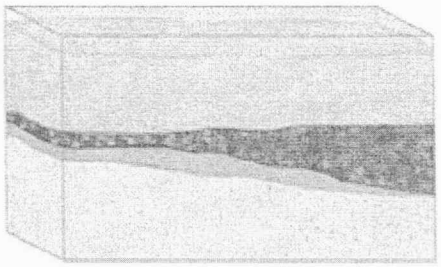
Amount of water held by each Earth material:
Sand:_____ Fine gravel:_____ Coarse gravel:_____

Amount of water retained by Earth material:
Sand:_____ Fine gravel:_____ Coarse gravel:_____

Investigating groundwater movement

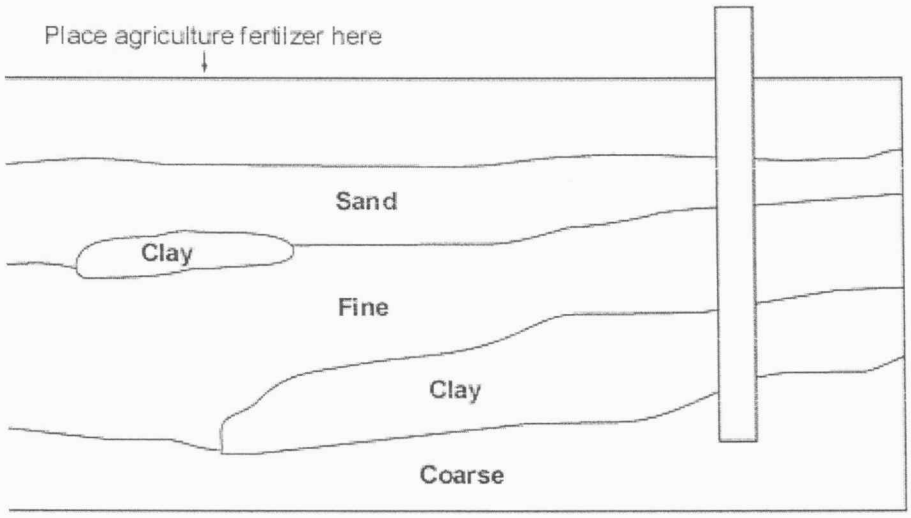
Surface water seeps into the ground and becomes part of the water table and existing aquifers. This activity examines the subsurface flow of groundwater through different Earth materials and demonstrates how pollutants reach our aquifers. Common potential groundwater pollutants include oil, road salt, fertilizer, human and animal waste, and pesticides. Near-surface items such as septic systems, landfills, and buried waste can also contribute to aquifer contamination. As surface water enters the ground and flows through an aquifer, these pollutants can be carried with it into the aquifer.

Figure 2. Tank for tracking groundwater movement.



To begin, students construct investigations to model possible situations of aquifer pollution and at the same time graphically demonstrate principles of groundwater movement. There are many fine groundwater models on the market. Most of them are suitable for demonstration or large group investigations. The Colorado School of Mines (CSM) offers a small, inexpensive groundwater model that can be used by individual students or small groups to investigate a variety of possible groundwater scenarios (see Resources). The model consists of a narrow plastic tank that can be filled with layers of different materials, and a pump and tube that simulates the operation of a well. (See Figure 2.)

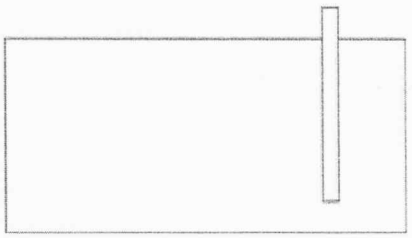
Figure 3. Diagram of layers and pollutants.



In small groups, students make a list of materials stored near the surface of the Earth that they would not like to have enter their drinking water supply. Each group shares this list with the class. Groups of students refine questions to investigate from this list. Students set up a situation, using a groundwater model, to test how surface or subsurface pollutants might enter an aquifer that is supplying water to a well system. Students prepare a diagram of how the layers and pollutants (typically simulated using food coloring or colored drink mix) will be positioned in the model. (See Figure 3.) Conversations with and between students help clarify how they are thinking about the physical processes involved in water movement in the different geologic layers. Students use this diagram to prepare for the construction of the groundwater model.

Students can devise ways of introducing a pollutant to the model that will be similar to real life situations. Sprinkling drink mix powder on the surface can test surface pollutants. Burying a paper towel soaked with food coloring, burying drink mix powder, or burying a film canister with food coloring can test sub-surface pollutants. The film canister needs to have some holes and be weighted down so that it will not float to the surface.

Figure 4. Blank observation diagram.



Students should simulate water being added and taken from the system over a specific time period. To produce a measurable situation, students can establish an amount of water to be added and removed that will represent one year (for example, add 50 mL of water to the surface and remove 50 mL from the well). Each year's sample can be placed in separate test tubes or clear plastic cups to compare the amount of contamination. In the case of surface pollution (fertilizer), different color pollutants can be added each year to see how several applications might affect the aquifer. A spray bottle can be used to simulate rain, or water can be carefully poured onto the surface. Students can diagram how the pollutant moves through the groundwater model using the Groundwater Observation Diagram (Figure 4).

Each group of students analyzes and transforms this data into a meaningful presentation. In this presentation, students explain the process of the investigation, identify limitations, justify explanations, respond to criticism, and generate related questions.

Practical considerations

Always place gravel in the layer from which the well will draw water. Sand tends to clog the end of the well. A confining layer may be made of clay. The best clay to use is Kaolin clay, probably available down the hallway in the art room. Ask the art teacher for porcelain grade clay, as it is about 90 percent kaolin.

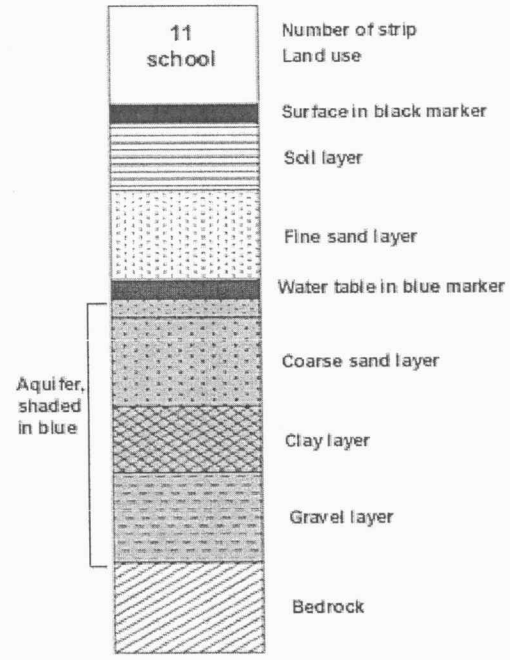
Using clay can be messy and difficult. To be a true confining layer, the clay must remain sealed to the side of the box. When additional Earth material is added, the box spreads out and often breaks the clay seal, so add the material with care. As each layer is added, water should also be added, otherwise air pockets will develop and air will be forced up, which will also break the seal of the confining layer.

Exploring groundwater systems

In this third activity, students work with the sort of data that geologists use to investigate directions of groundwater flow and pollution risks. Water wells are drilled for a variety of purposes. Whenever a well is drilled the well driller is required to produce a "well log." Each well log is simply a written record of the type and depth of each Earth material encountered during the drilling process. Well logs are submitted to a local or state agency, and in some states these records are available online (see samples at www.dnr.state.oh.us/odnr/water/maptechs/wellogs/app/default.html or www.state.in.us/dnr/water/wellwater/searchfield.htm l).

Looking at adjacent well logs will give students an idea of the arrangement of Earth materials in a given area (a geologic cross section). To get a "picture" of the geological structure that forms the aquifers available to a region, students can look at well logs, and then use them to construct a geologic cross section. This section can then be used to discuss local and regional groundwater sources and issues. By studying the location of existing aquifers and the geologic structures that form those aquifers, students can identify potential problems of existing land use and make decisions concerning future land use.

Sample well log.



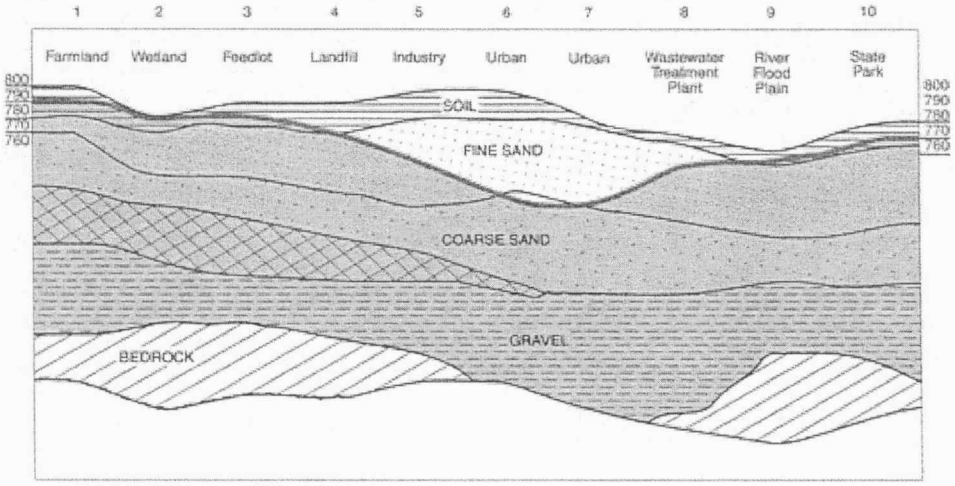
Before investigating actual local well logs, a hypothetical situation can be devised to motivate students and add interest as they assemble and interpret well log sets. In this case, students are told that they have been hired to locate the best location to draw water from for the city. The following activity has been adapted from a Project Wet groundwater investigation (see Resources). This activity uses English measures because elevations and well log depths are in feet. The well log depths are described in inches with each inch equal to 10 feet (see Figure 5). A variety of land uses are described to give the students an idea of how land use might affect aquifers.

Figure 5. Well log data table for student activity.

Elevation of surface	Well Number	Land use type	Depths, given as a number of inches below the surface to be used in drawing your diagram. 1inch = 10 ft.						
			Water table	Soil	Fine sand	Coarse sand	Clay	Gravel	Bedrock
800 ft	1	farmland	1	0–2	2–3	3–7	7–11	11–17	17–20
780 ft	2	wetland	0	0–1	1–4	4–6	6–10	10–14	14–20
790 ft	3	feedlot	1	0–1.5	1.5–5	5–8	8–12	12–15	15–20
790 ft	4	landfill	2	0–2	2–6	6–9	9–12	12–16	16–20
800 ft	5	industry	5	0–2	2–8	8–11	11–13	13–18	18–20
800 ft	6	urban area	7.5	0–2	2–7	7–13	13–14	14–20	
780 ft	7	urban area	6	0–0.5	0.5–6	6–12		12–20	
770 ft	8	wastewater treatment area	2	0–0.5	0.5–6	6–11		11–19	19–20
760 ft	9	river flood plain	1	0–1	1–6	6–9		9–14	14–20
780 ft	10	state park area	1.5	0–1	1–7	7–11		11–18	18–20

The activity below guides students through the plotting and analysis of well log data. Figure 6 is an example of the profile created by students using the well log data. By analyzing the data and information revealed by the profile (possible pollutants of surface activities, the cone of depression, the impermeable clay layer, the possible rate of flow within the different Earth materials) students can determine the best location to draw water for the city's water supply. As an extension, students can use actual well log information obtained from state or local agencies, and perform a similar analysis for a local area.

Figure 6. Sample profile using well log data from Figure 5.



I have found that students respond well to discovery of concepts through inquiry-based activities. These specific activities, used in succession, bring students to an understanding of groundwater systems and an awareness of the need to monitor and protect aquifers.

Ted Leuenberger *is a science teacher at Benton Central Junior/Senior High School in Oxford, Indiana.* ***Daniel Shepardson*** *and* ***Cheryl Bell*** *are professors in the Department of Curriculum and Instruction,* ***Jon Harbor, Hope Klagges,*** *and* ***Willie Burgess*** *are professors in the Department of Earth and Atmospheric Science, and* ***Jason Meyer*** *is a professor in the Department of Forestry and Natural Resources at Purdue University in West Lafayette, Indiana.*

Activity

Materials (for each group)

- 10 meter-long strips of adding machine tape
- large poster board
- well log data table

Procedure

1. Number the strips 1 through 10, with each number at the top.
2. Draw a line in black marker across each strip about 5 centimeters from the top to show the level of the surface on each strip. Label the land use at each well log above that line.
3. From the well log data table, fill in each log according to the sample strip. Use a blue marker to show the water table and shade in all empty spaces underneath in blue pencil.
4. Prepare the poster board with elevation lines (760, 770, 780,790, and 800) near the top at 1-inch vertical intervals.
5. Tape well logs on the poster board in order at the proper elevation, leaving a 4-inch gap between each well log.
6. Draw missing surface and water table lines and complete the questions below.

Questions

1. The horizontal scale of the cross section is 2 inches = 1 mile. The vertical scale is 1 inch = 10 feet. How many miles are horizontally represented in the cross section? How many feet are vertically represented in the cross section?
2. Look at wells 1, 2, 5, 7, and 9. How deep is the water table at each of these wells? Why are there differences? Is there a cone of depression?
3. Imagine a drop of water falling on the site at well 1. What pollutants might this water pick up as

it filters into the ground? How might this drop of water move down the column of strata at this site? (Where would it move slowest or fastest?) How might the water move when it encounters the clay layer?

4. What pollutants might be picked up by water at each of the well sites?

5. If you had to drill a well, which site would you consider most favorable and how deep would you want your well to be? Explain your answer.

Note

This article describes inquiry-based activities addressing groundwater and water supply, developed for ENVISION, a middle school teacher in-service program. The ENVISION project, funded by the National Science Foundation (award number 9819439-ESI), involves teachers in standards based inquiry investigations of local environmental issues. One of the major goals of ENVISION is to enhance teachers' inquiry skills and environmental science knowledge in order to successfully help their students learn concepts, skills and knowledge through inquiry-based studies of local environmental issues.

Resources

• Earth Science Resource Center
Office of Special Programs and Continuing Education
Colorado School of Mines
Golden, CO 80401
desp@mines.edu or (800) 446-9488, ext. 3621
Byron Jenkinson, Dept of Agronomy, Purdue University

• National Research Council 1996. *National science education standards*. Washington D.C.: National Academy Press

• Project WET (Water Education for Teachers). *Project WET curriculum and activity guide*. 1995. (pps. 136–142).

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Impact of Computer-Assisted Instruction in Hydrogeology on Critical-Thinking Skills

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ABSTRACT

Although studies demonstrate that computer-assisted instruction (CAI) can be effective for enhancing basic cognitive skills such as rote memory, the role of CAI in developing higher-order critical-thinking skills such as problem solving remains uncertain. Using principles from cognitive psychology, the impact of a hydrogeological CAI laboratory on student problem-solving skills is assessed. Problem-solving skill is measured by statistical analyses of the ability to transfer concepts across disciplinary domains. Results suggest that in comparison to traditional instruction, the CAI laboratory focuses student attention on fundamental principles and is effective in developing problem-solving skills, particularly for students with stronger backgrounds in math and science.

Keywords: Education – computer assisted; education – undergraduate; geology – teaching and curriculum.

Introduction

Well developed critical-thinking skills are important in all professions. In the geosciences, higher-order cognitive skills such as data interpretation, problem solving, and decision making are increasingly important as geologists become more involved in environmental problems. For example, geologists are now commonly asked to assess earthquake hazards (Mileti and others, 1994), evaluate volcanic risks (Stoopes and Sheridan, 1992), and analyze the suitability of potential waste-storage sites (Fairchild, 1991). Therefore, a successful earth science curriculum must include exercises that develop the higher-order cognitive skills required to analyze, interpret, and present scientific data (Reger, 1983; Bursik and others, 1994; Hodge and others, 1995).

Over the past decade, computer-aided instruction (CAI) has been increasingly promoted as a technique to improve geoscience education and promote critical thinking. For example, interactive CD-ROMs are now included with introductory textbooks (for example, Plummer and McGeary, 1996), and courseware is available for both introductory and advanced earth science courses (for example, Edwards and others, 1996). Some of the most recent geoscience CAI software combines traditional field and laboratory data acquisition and analysis with interactive numerical modeling of complex physical systems (Bursik and others, 1994; Hodge and others, 1995).

Because the technology is expensive, rigorous evaluation of the educational effectiveness of CAI is important. Further, CAI resources often come at the expense of other materials and programs. For example, a recent survey of school districts in western New York revealed that the significant *increase* in computer purchases over the past four years was accompanied by a significant *decrease* in the total number of books in school libraries (Cervantes, 1997).

Effective geoscience courseware should develop the ability to analyze and think critically about complex issues. Numerous studies demonstrate the effectiveness of CAI for rote memorization (for example, Bitzer and Bitzer, 1973; Boettcher and others, 1981; Duplass, 1995; Tjaden and Martin, 1995); a meta-analysis of 254 studies concluded that students exposed to CAI learned more material, learned faster, and liked their classes better than students in traditionally structured classes (Kulik and Kulik, 1989). However, the role of CAI in developing higher-order cognitive skills such as decision making, data analysis, and problem solving remains uncertain.

Evaluating the impact of CAI on critical thinking is more difficult than evaluating fact-based assessments due to the inherent difficulty in assessing higher-order cognitive skills. However, recent advances in the disciplines of cognitive science have advanced our understanding and ability to assess higher-order cognition to the point where such assessments are feasible. In this paper we use one well studied component of higher-order cognition, problem solving via knowledge transfer, to assess the impact of a geoscience CAI laboratory on students' critical-thinking skills. Our results suggest that the impact of the laboratory is generally positive, although the current version of the program may be more effective for students with stronger backgrounds in math and science.

Knowledge Transfer

Effective learning requires the acquisition of both domain-specific knowledge and higher-order thinking skills. These issues are linked in that long-term retention of domain-specific knowledge requires higher-order cognitive processes during learning (for example, Craik and Lockhart, 1972; Slamecka and Graf, 1978). Different theoretical explanations exist for this idea, such as the Depth of Processing Approach (Craik and Lockhart, 1972; Craik and Tulving, 1975). Similarly, greater cognitive processing also leads to greater success when learning to solve problems. For example, it has been shown that generating mental images of problems facilitates successful solutions (McIntosh, 1986) and that problem-solving attempts prior to learning the solution facilitates transfer to analogous problems (Needham and Begg, 1991).

Of particular interest in this work are higher-order cognitive skills associated with problem solving. Reed and others (1990) found that students given problem-solving exercises choose as aids sample problems that have high apparent similarity, overlooking problems with more useful properties, such as structural similarity. In general, students apply solutions to problems within the same disciplinary domain but fail to apply the solutions to similar problems in different domains (Gick and Holyoak, 1983). This phenomenon is referred to as a "failure of knowledge transfer" (Gick and Holyoak, 1983; Greeno, 1989; Reed and others, 1990; Bassok and Holyoak, 1993; Sternberg and Frensch, 1993). Gick and Holyoak (1983) found that students rarely transfer knowledge across domains spontaneously, even when the underlying principle was stated explicitly or a diagram was provided. Only when told explicitly that a previous solution would be helpful did the students successfully transfer knowledge. Research suggests that the tendency of students to transfer knowledge can be enhanced by the presentation of two (or more) analogs from different domains (Gick and Holyoak, 1983; Catrambone and Holyoak, 1989) or by pictorial analogs with both surface and procedural similarity (Chen, 1995).

Computer-Aided Instruction

In addition to possibly facilitating knowledge-transfer skills, computer-aided instruction has more direct advantages. In particular, CAI provides a self–paced learning tool which acts as a tireless tutor, providing immediate feedback and not becoming exhausted, exasperated, or judgmental. The additional practice provided by CAI is an important component of its educational effectiveness (Hannafin and others, 1986), as practice leads to automaticity of sub-skills which is required for more complex cognitive tasks (Salisbury, 1990). CAI software also frees instructors from tedious repetitive tasks to spend more time with students on difficult concepts and problem- solving skills (Ball and Hannah, 1984).

CAI provides a self-paced learning tool which acts as a tireless tutor, providing immediate feedback and not becoming exhausted, exasperated, or judgmental.

In addition, the interactive characteristics of CAI require learner participation, making this technique consistent with our intuitive notion that learning-by-doing is the most effective educational strategy (Dalton, 1986). Further, interaction promotes active rather than passive learning. As noted by Shlechter and others (1992), the advantages of active learning have been touted by instructional theorists from John Dewey (1910) to Merlin Wittrock (1974) and John Bransford (see Bransford and Vye, 1989).

CAI software takes on a variety of methodological formats. At the most basic level, CAI software is little more than an electronic textbook, enhanced with the equivalent of a series of electronic flash cards where the student is presented with a series of facts and answers a series of questions involving recall of the facts. However, there are significantly more complex, and potentially more educationally effective, CAI presentation formats. Of particular interest in this work is an advanced CAI methodology, here termed "experiment simulation."

Experiment simulators are designed as supplements to standard laboratory exercises and manuals. Except in extreme cases, where the laboratory exercises involve high risks of injury, expensive or inaccessible equipment, or the distinct possibility of damage to equipment (for example, Flaxman and Stark, 1987; Hays and Singer, 1989; Reigeluth and Schwartz, 1989), experiment simulators are not designed to replace actual physical measurements and analyses in the laboratory or field. Rather, experiment simulators provide both a multimedia introduction to the laboratory exercise and, after completion of the physical experiments, a framework for analyzing dynamic systems which are too complex to be easily demonstrated in the laboratory. By providing practice in basic laboratory skills, experiment simulators enable students to focus on the conceptual implications of their work (Martin and Szabo, 1990).

Computer simulations may promote the development of knowledge transfer skills for several reasons. First, multiple problems with similar underlying concepts can be rapidly presented. Second, surface similarities unrelated to the domain, such as computer interface options, can be maintained during presentation of similar concepts in different domains. Lack of surface similarity often distracts students as they deem this dissimilarity pertinent to the problem (Reed and others, 1990). Non-pertinent similarities may help focus attention on the similarity of underlying concepts (Chen, 1995).

A number of experiment simulators have been described in the literature, including those directed at concepts of Newtonian mechanics (Hennessy and others, 1995), the effects of biodegradable waste on the oxygen resources of streams (Ousey, 1993), and two-dimensional deformation (Tikoff and others, 1993). In our work we use experiment simulation to teach the fundamental principles of ground-water hydrogeology.

The Ground Water CAI Laboratory

Our CAI laboratory serves as an introduction to a traditional laboratory exercise in ground-water hydrogeology. The program contains a brief introduction to ground water, focusing on the distribution of Earth's water resources and the concept of the hydrologic cycle. In the main part of the laboratory, the program guides the student through an experiment simulation demonstrating the fundamental physical law of ground-water flow, Darcy's law. Darcy's law relates the rate at which ground-water flows to the external driving forces and physical characteristics of the aquifer, parameterized as the hydraulic conductivity. In a series of exercises, the students are directed to change the driving forces and physical characteristics and observe the resulting change in ground-water flow rate. For example, in one section the student is asked to change the length of the column containing

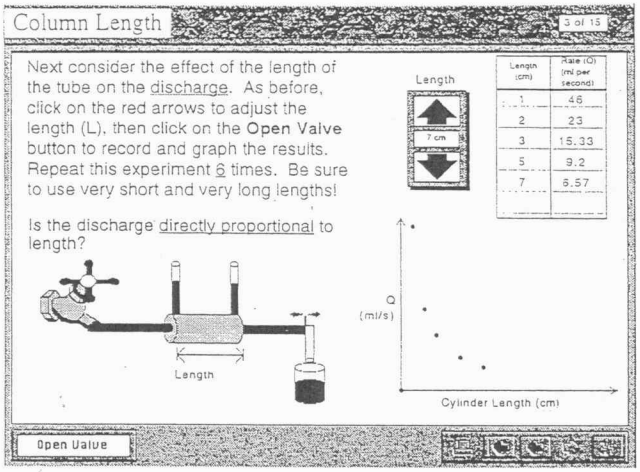


Figure 1. Hydrogeological CAI laboratory simulation of Darcy's experiment designed to understand the effect of a change in length of porous material on ground-water-flow rate.

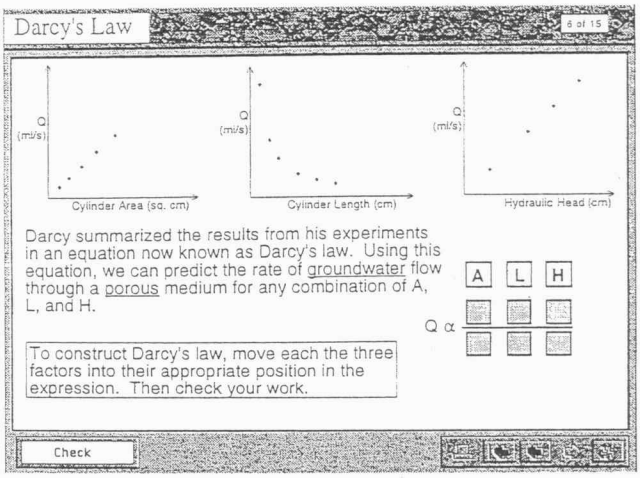


Figure 2. The CAI laboratory guides the student through an interpretation of their experimental results to derive Darcy's law.

the porous material and observe the change in flow rate (Figure 1). The laboratory provides both visual and auditory cues to indicate the ground-water flow rate. The result from each simulated experiment is dynamically graphed, allowing the student to observe the correspondence between the graph and the "physical" world.

The graphs created from each set of experiments are collected and used to guide the student through the development of Darcy's law (Figure 2). A brief discussion of inverse and directly proportional mathematical relationships is provided to aid the student in interpreting each graph. After the student successfully constructs Darcy's law using the experimental data, the student uses the law to determine the hydraulic conductivities of the hypothetical aquifer material. The CAI program concludes with a discussion of the typical range of hydraulic conductivities for various types of earth materials (sands, clays, granites, and so on).

Evaluation

In this study, one hundred thirty-eight undergraduates in an Introductory Geology course at Tufts University participated in conjunction with a scheduled laboratory session. Students were divided into two groups based on their lab sections. Lab sections were randomly assigned to a group. The same instructor taught all lab sections for this study. In the computer-instruction group (CI), students used the CAI software. In the traditional-instruction group (TI), students used informationally equivalent standard assignments.

Students in CI groups worked through the Groundwater CAI laboratory individually and at their own pace. Students in the TI group read an informationally equivalent handout. The handout contained most of the figures included in the CAI laboratory, and the text referred students to these figures. Students in the two groups spent approximately the same amount of time on their respective assignments. Then all students viewed a demonstration of a simple Darcy column and calculated the hydraulic conductivity of the porous material. Following the laboratory, all students filled out a four-part questionnaire, including 1) fact-based questions related to laboratory, 2) graph-interpretation questions (one couched within the ground-water domain and two addressing other domains), 3) questions using Darcy's law, and 4) questions using a cross-domain linear law (Okun's Law from economics). See Table 1 for a sample of questions of each type. Results from the questionnaire were tested for statistical significance using a multiple analysis of variance (Pagano, 1994).

The evaluation had two goals 1) assessment of acquisition of domain-specific knowledge and 2) assessment of higher-cognitive processing. Assessment of domain-specific knowledge had two components. First, students were evaluated for their understanding of the variables and their relationships within Darcy's law. For example, students were asked to indicate the directional change in ground-water flux if the distance between hydraulic heads increases and all other variables remain constant. Second, students determined the value of one of the Darcy's law variables, given the values of the other four variables.

The second assessment goal involves evaluating the impact of the CAI program on higher-order thinking skills such as problem solving. The essence of groundwater laboratory is the linear law describing ground-water flow ($Q = KAH/L$). The development and analysis of similar laws occurs within hydrogeology and in many other scientific disciplines. Thus the groundwater program is a natural candidate for evaluating the effectiveness of the program in promoting problem-solving skills by means of knowledge transfer. In this study, the ability of students to transfer their understanding of inverse and directly proportional relationships gained from studying Darcy's law to another domain was assessed using Okun's law in Economics ($U = CP/G$). This linear law is analogous

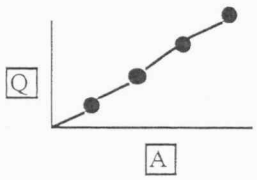
Question Type	Sample Question
Fact based	The cooling of water vapor in the atmosphere resulting inthe formation of clouds is the process of _____.
Graph Interpretation	What is the relationship between Q and A in the graph below? 
Darcy's Law	The water pressure coming into the tube increases the hydraulic head difference. What happens to the rate at which water is discharged?
cross-domain (Okun's Law)	If the Gross Domestic Product growth rate increased from 1990 to 1991, but all else remained equal, what happened to the unemployment rate for 1991 compared to 1990?

Table 1. Sample of fact-based questions related to laboratory and graph interpretation and questions using Darcy's law and a cross-domain linear law (Okun's Law from economics).

to Darcy's law and proposes that the civilian unemployment rate (U) is linearly related to the population growth rate (P) and inversely related to the gross domestic product growth rate (G) (McNess, 1984). Like questions on Darcy's law, students were asked to indicate the directional change in the civilian unemployment rate if the one of the variables increases and all other variables remain constant and to determine the value of one variable given the other relevant values.

Results and Discussion

Questions designed to assess acquisition of domain-specific knowledge were divided into two parts, those pertaining to briefly presented background facts and those investigating understanding of Darcy's law. The analyses showed a marginally significant interaction between question type and learning condition, $F(1, 134) = 3.50$, MSe = 1.30, p = .06. Participants in the CI group showed greater understanding of Darcy's law, while the TI group showed a greater ability to recall briefly presented facts. This suggests that the CAI

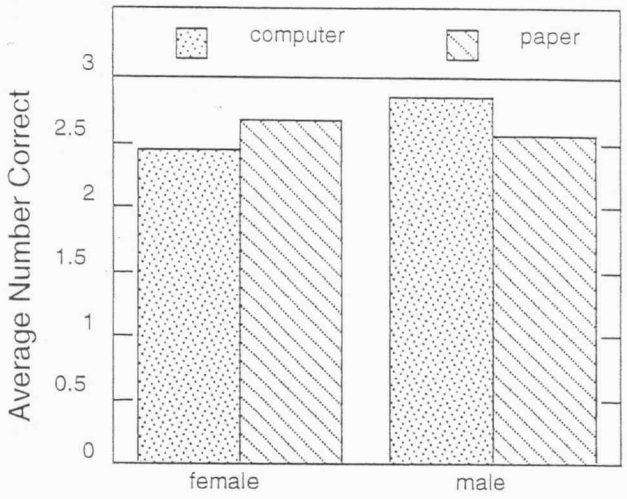


Figure 3. Interaction between learning condition for cross-domain knowledge transfer questions.

software helped to focus students' attention on the fundamental concept, Darcy's law, while those in the traditional instruction group were distracted by less important background information. Overall, the domain-specific questions showed a significant gender effect, $F(1, 134) = 4.89$, MSe = 2.25, $p < .05$. Females (M = 7.21) gave fewer correct responses than males (M = 8.02).

Analyses of the graph interpretation and use of Darcy's law questions showed no significant effects of either learning condition or gender.

Assessment of the impact of the CAI program on problem-solving skill by means of cross-domain questions indicated that for at least for some students, the ground-water simulation may have made principles underlying linear laws more apparent, thus facilitating transfer. This conjecture is supported by the significant interaction between learning condition and gender, $F(1, 134) = 4.39$, MSe = 0.52, $p < .05$. Males in the CI condition gave a greater number of correct responses than those in the TI condition, $t(72) = 2.04$, $p < .05$, while females did not differ based on condition. Analyzed alternatively, males in the CI condition gave more correct responses than females, $t(58) = -2.32$, $p < .05$, but males and females in the TI condition did not differ (see Figure 3). This suggests that the current version of the CAI laboratory was more effective in promoting knowledge transfer in males.

An additional factor, which unfortunately cannot be explored in this analysis, might explain the gender effects. Students in this particular Introductory Geology class at Tufts fell into two categories, Civil and Environmental Engineering students fulfilling prerequisites for major courses and science-phobic students fulfilling part of their science distribution. The demographics of the Civil and Environmental Engineering program predict that more male students fit into the former category. This prediction was supported by examining the demographic makeup of the course. Of the 138 students, approximately 42% were declared engineering majors, 65% of whom

were male. This may be a slight underestimate, as 25% of the students were first-year students or sophomores and had not yet declared a major.

Our results suggest that students with greater prior exposure to science and engineering gained more from the CAI laboratory. In future investigations, an assessment of major and number of math, science, engineering, and related courses, such as statistics or economics, should be made to better predict variance in performance and to adapt the software to be more effective for students with less prior exposure to math and science.

Conclusions

To our knowledge, the work presented here represents the first quantitative analysis of the impact of geoscience CAI software on higher-order cognitive skills. The results are encouraging and demonstrate that the hydrogeological CAI laboratory does promote improved problem solving, at least in students with greater prior exposure to math, science, and engineering. This suggests that further development of geoscience CAI software is warranted. However, further evaluation and software modification is required to understand why the CAI software is not more effective for some students. This understanding will aid in the development of future CAI software and assure that the next generation of geoscience software is as effective as possible.

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A pesticide applies selection pressure as surely as a drought or flood. The poison selects *against* traits that make a species vulnerable to it, because the individuals that are most vulnerable are the ones that die first. The poison selects *for* any trait that makes the species less vulnerable, because the least vulnerable are the ones that survive longest and leave the most offspring. In this way the invention of pesticides in the twentieth century has driven waves of evolution in insects all over the planet. *Heliothis* is only one case in hundreds. Flying scale insects have evolved strong resistance to buguinolate in only six generations. Nematode worms in the guts of sheep have evolved strong resistance to thiabendazole in three generations. Sheep ticks have evolved strong resistance to Hch-dieldrin in just two generations. In 1967, a distinguished entomologist announced in *Scientific American* the discovery of a "resistance-proof" family of insecticides. The poisons were variants of some of the insects' hormones. How could insects escape their own hormones? Yet within five years, flies had evolved one-hundred-fold resistance.

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Lesson Plans

Access Excellence Activities Collections: http://www.accessexcellence.org/AE/index.html Site has wide variety of lesson plans for different topics.

Australian Academy of Science The bitter-sweet taste of toxic substances lesson plan, activities, readings.http://www.science.org.au/nova/036/036key.htm

Australian Academy of Science Risk assessment information
http://www.curriculumsupport.nsw.edu.au/science/files/Sci_St6_risk_assess.pdf

CENTER FOR INNOVATION IN ENGINEERING & SCIENCE EDUCATION (CIESE) – lesson plans and workshops on topic for K-12. http://www.k12science.org/k12partnership/onlinematerials.html

Children's Water Education Council Ontario, Lesson plans http://www.cwec.ca/eng/Educators.htm

Environment Canada – Good information on ground water basics, water quality, contamination, hydrogeology. http://www.ec.gc.ca/water/en/nature/grdwtr/e_gdwtr.htm

Environmental Protection for Australia, Teachers Manual Good collection of lesson plans and environmental issues
http://www.deh.gov.au/education/publications/epa/modules/index.html

Environmental protection in Australia: a professional development manual for teachers
http://www.ea.gov.au/education/publications/epa/modules/module5.html#activities
Activities and discussion questions regarding risk assessment. There is a section on chemical risk assessment and the types of questions students need to ask in order to understand why limits are set on chemicals and the impacts on humans for different levels of toxic substances. 8 modules on different topics.

The Global Water Sampling Project http://www.ciese.org/curriculum/waterproj/index.shtml CIESE site for developing a ground water sampling project in your geographic area. Provides information on how to develop a project (hypothesis development), and a repository for collected

Ground water basics made easy
http://www.colorado.edu/geolsci/courses/GEOL2100/groundwater.html
University of Colorado site with definitions of basic groundwater concepts.

HACH Company's H2O University: Good water quality explanations http://www.h2ou.com/h2wtrqual.htm

Hamilton to New Baltimore Groundwater Consortium Hydrologic information to go will Wellhead editorials http://www.gwconsortium.org/index.html see readings section on CD).

HIPLAIN – High Plains Aquifer Information Network – http://www.hiplain.org/
links for information and education on the High Plains aquifer

MoDNR Communications and Education Office http://www.dnr.state.mo.us/oac/edpubs.htm Publications available from Missouri Dept. Natural Resources. Groundwater Protection Curriculum Guide, Booklet, and Video, Video can be checked out, copied and returned to EAO- **No charge**, 1994--PUB693 good source of

information. Discussion of basic ground water concepts plus includes discussion of karst and ground water flow in fractured limestone. Video is informative also.

National Geographic Map Machine Online map making site.
http://plasma.nationalgeographic.com/mapmachine/

Pike County Conservation District Learning Site http://www.pikeconservation.org/Home.htm Site with good information on ground water and surface water interactions

Science Junction - Water What Ifs - Water Related Web Sites
http://www.ncsu.edu/sciencejunction/depot/experiments/water/waterlinks.html Many links to other groundwater and water quality sites. Good information on basics and examples.

Stream Link http://www.streamlink.org/ Surface Water activities and water quality sampling

Subsurface Contamination of Groundwater
http://www.accessexcellence.org/AE/AEPC/WWC/1991/groundwater.html
The objective of this demonstration is to show students how difficult it is to study subsurface contaminants contained in underground storage tanks. Directions for building a model are given.

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

Toxic substances-Activities (Site may be inactive. Keep trying. Good information).
http://www.science.org.au/nova/036/036act.htm Links site for information on risk assessment and activities for demonstrating how difficult it is to define where a plume exists

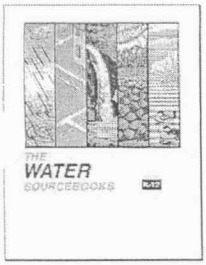
Univ. Wisconsin Stevens Point, Portage County, **Understanding Ground Water – Good site for ground water basics http://www.uwsp.edu/water/portage/undrstnd/index.htm**

US EPA Ground Water Primer EPA site http://www.epa.gov/seahome/groundwater/src/ground.htm
EPA site with basics on groundwater, hydrologic cycle, world consumption of groundwater, and other pertinent facts.

U.S. EPA New England Lesson plans 7-12 http://www.epa.gov/region01/students/teacher/groundw.html

US EPA education resources http://www.epa.gov/water/education.html
Links for adult and K-12 education resources. Information on water quality standards, watershed studies, and other activies.

U. S. EPA Superfund for Students and Teachers – curriculum, activities, resources, fact sheets http://www.epa.gov/superfund/students/clas_act/haz-ed/hazindex.htm. Excellent site for definitions of hazardous waste issues, terms, and activities to get the concepts across.



US EPA The Water Source Book – curriculum for K-12, fact sheets, good information of basics in ground water and hydrology http://www.epa.gov/safewater/kids/wsb/index.html#9-12

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.

USGS Aquifer Basics home page (index) http://capp.water.usgs.gov/aquiferBasics/index.html USGS site for information on aquifer types and geologic information and locations for different aquifers. Definitions and examples are well displayed in this website.

USGS Earthshots: Satellite Images of Environmental Change
http://edcwww.cr.usgs.gov/earthshots/slow/tableofcontents

USGS Toxics Hydrogeology Program fact sheets http://toxics.usgs.gov/pubs/factsheets.html

USGS 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.

Visionlearning – Web site with collection of upper level modules on various topics.
http://www.visionlearning.com/index.php

Water on the Web http://waterontheweb.org/index.html. Powerpoint presentations on water cycle, chemistry, field methods, emphasis on surface water and lakes but some concepts transferable to ground water.

Wellowner.org – Good information on well types, construction, water quality basics:
http://www.wellowner.org/awaterquality/basics.shtml

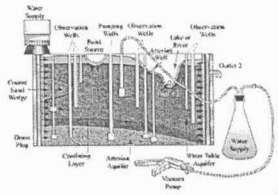
Wisconsin Department of Natural Resources Ground Water Education Study guides – practical lesson plans about ground water contamination and basic hydrology
http://www.dnr.state.wi.us/org/water/dwg/gw/education/study_guide.htm

Ground Water Flow

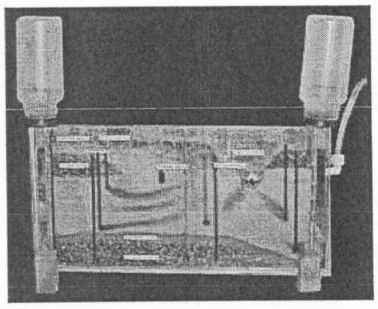
Models

About NIH Image Ground water flow model site - activities
http://www.isat.jmu.edu/users/klevicca/Image/#Laboratories Groundwater flow model demonstration of movement of a plume through an aquifer. Background on groundwater basics, equations for Darcy's Law, velocity, hydraulic conductivity, and hydraulic gradient. Excellent source of information.

Columbia EMSI Plumeflow Project – Curricula for use of groundwater flow models in the classroom
http://www.cise.columbia.edu/emsi/edout/sandtanks/curricula/



Univ. Nebraska Lincoln, Biological Systems Engineering: place to order a model
http://groundwater.unl.edu/standard.html



Univ. Wisconsin Stevens Point Chapter AWWA
http://www.uwsp.edu/stuorg/awra/h2omodel.html

Databases and Resources

Case Studies in Environmental Medicine Trichloroethylene Toxicity
http://www.atsdr.cdc.gov/HEC/CSEM/tce/ Site for information on TCE toxicity to humans, impacts on health, biological risks, and clinical testing information. Excellent resource.

Chemicool interactive Periodic Table: Info on chemical properties and uses of elements
http://www.chemicool.com/

Drugs Info File Information of various classes of drugs including health information.
http://www.drugsinfofile.com/solvents.html

The National Parks Service Environmental Contaminants Encyclopedia
http://www1.nature.nps.gov/toxic/index.html Listing of contaminants. PDF file available on tetrachloroethylene (tetrachl.pdf). Site gives background on uses and potential toxic levels to animals and humans. Long (63 pages).

Nevada Fish and Wildlife Service list of contaminant related websites
http://nevada.fws.gov/esoffice/Contam_links.html

North Carolina State University toxicology class notes
http://courses.tox.ncsu.edu/tox415demo/Lectures/Classes%20Folder/Lecture%20Notes/chemicals_environment_2.htm

Occupational Safety & Health Administration Safety and Health topics for different chemicals
http://www.osha.gov/SLTC/healthguidelines/index.html

Pesticide Action Network database http://www.pesticideinfo.org/Index.html

State of Washington Department of Ecology - Fecal Coliform
http://www.ecy.wa.gov/programs/wq/plants/management/joysmanual/fecalcoliform.html

Toxin Technical Information Index – Australian site. Chemical toxicity, environmental impacts.
http://nccnsw.org.au/member/tec/projects/tcye/tox/bytopic_index.html

U.S. EPA Ecotox – Ecotoxicology database single chemical toxicity data for aquatic and terrestrial life
http://www.epa.gov/ecotox/

US. EPA Local Drinking Water Analyses online: See if your city has a a water analysis online.
http://www.epa.gov/safewater/dwinfo.htm

US EPA Maximum Contaminant Levels (MCL) Drinking and ground water
http://www.epa.gov/safewater/mcl.html#mcls

U. S. EPA reports on remediation and other water issues http://www.epa.gov/ada/pubs/reports.html

US EPA Sources of Common Contaminants and Their Health Effects
http://www.epa.gov/superfund/programs/er/hazsubs/sources.htm
EPA website on common contaminants and their health effects.

US Geological Survey Toxic Substances Hydrology Program Lots of facts sheets and studies on toxic substances in the environment. Good source of information http://toxics.usgs.gov/

Water Quality Association - Water Contaminants Interactive Problem Solver
http://www.wqa.org/consumer/newindexNS.cfm

Includes the following tables as well as a Diagnose your water, Contaminant Researcher, and the following contaminant tables:

National Primary Drinking Water Standards: - Primary (Health Related) Inorganic Contaminants
National Primary Drinking Water Standards: - Primary (Health Related) Organic Contaminants
National Primary Drinking Water Standards: - Secondary Contaminants

World Health Organization Factsheets on disease and some metals (arsenic) world wide
http://www.who.int/mediacentre/factsheets/en/

Geology and Health NSF Workshp http://serc.carleton.edu/NAGTWorkshops/health04/components.html
Good source of reference for geologic contaminants – heavy metals, minerals, etc.

Sources for Readings

Environmental Defense Fund issue search: http://www.environmentaldefense.org/search_results_spider.cfm

Environmental Health News – Published by Environmental Health Sciences nonprofit group. Good source of articles on science and health. http://www.environmentalhealthnews.org/

Environmental News Network: News stories on environmental issues. http://www.enn.com/

National Geographic Publications search engine: Need to obtain articles from library or purchase. Good source for titles though. http://www.nationalgeographic.com/publications/

New York Times Daily Lesson Plan: Lesson Plan archives. Good environment related readings and lesson plans http://www.nytimes.com/learning/teachers/lessons/archive.html

Smithsonian Magazine: http://www.smithsonianmag.si.edu/

The Science Center – Clearing house for science related web sites.
http://science-education.org/gateway/gateway.html

Your Local Newspaper – frequently archives are available online.

GAMES

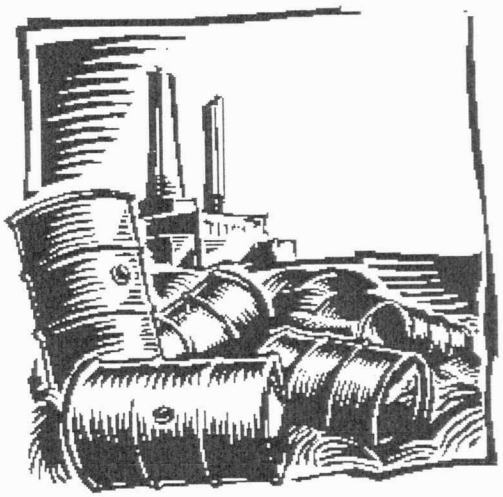
USGS Water Jeopardy http://ne.water.usgs.gov/Outreach/jeopardy/intro.htm
Contact Information:

Kathy Wilson, Outreach Coordinator
100 Centennial Mall North, Room 406
Lincoln, Nebraska 68508
Telephone: (402) 437-5663
Fax: (402) 437-5139
Email:kewilson@usgs.gov

Sciboard – online games and questions to further inquiry in science http://sciboard.louisville.edu/

Activity 2

Examining a Hazardous Waste Site



Duration	2 class periods
Grade Level	9-12
Key Terms/ Concepts	Aquifer Contamination Hazardous waste Superfund Water table
Suggested Subjects	Chemistry Earth Science Geology Physical Science

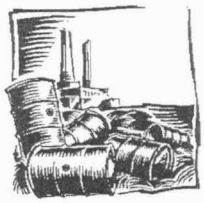
Purpose

This activity helps students understand how Superfund sites are created. They discuss what activities produce hazardous waste, and how contaminants are released and spread into the air, water, soil, and groundwater. Students learn what types of pollution can be cleaned up using Superfund authority and what types are addressed through other laws. Students construct a model to observe how contaminants move in groundwater.

Background

The U.S. Congress passed the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) in response to growing concern about health and environmental threats from hazardous waste sites. This law is commonly called **Superfund**. Working with states and Indian Tribal governments, Superfund requires the U.S. Environmental Protection Agency (EPA) to deal with abandoned, accidentally spilled, or illegally dumped **hazardous wastes** from the past, primarily from businesses and industry. Other types of pollution are handled by other environmental laws.

The Superfund program has a process for reporting and keeping track of potentially contaminated sites. Since the early 1980s when the law took effect, more than 37,000 hazardous waste sites have been reported. EPA must investigate each of the sites to determine the seriousness of the **contamination**. Only the most serious sites are cleaned up using Superfund authority; approximately four percent of reported sites are being cleaned up under Superfund. Sites not handled by the Superfund Program will be cleaned up by state governments or under other laws, or will require no cleanup because they pose no danger to people or the environment.



It is important to keep in mind that the Superfund Program deals only with abandoned, accidentally spilled, or illegally dumped hazardous substances. A number of other major environmental laws—such as the Resource Conservation and Recovery Act (RCRA), the Clean Water Act, the Clean Air Act, the Toxic Substances Control Act, and the Safe Drinking Water Act—were enacted to deal with other types of pollution.

To help prepare your students for this activity, use *Warm-Up 6: What is an Aquifer?* You can perform the entire Warm-Up or simply review the major points covered in it.

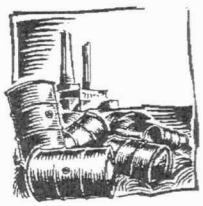
For more information on hazardous waste sites and cleanups, see the Suggested Reading list found at the end of the Haz-Ed materials. Other Haz-Ed materials that are related to the topic include *Warm-Up 2: EPA's Superfund Program—Overview.*

Preparation

1. Gather the following materials *(NOTE: You can split the class into 4 groups if desired and have each group do the experiment.)*

   - bottom part of a clear, plastic two-liter soda bottle
   - pump mechanism from a liquid soap dispenser
   - small piece of nylon fabric to cover the end of the pump tube
   - tape
   - resealable plastic sandwich bag with 2 cups of small pebbles or aquarium gravel (white or light-colored)
   - resealable bag with 2 cups of clean sand (white sand is best)
   - large coffee filter (round with a flat bottom, not cone-shaped)
   - clean spray bottle, the type spray window cleaner comes in
   - bottle of red food coloring
   - clear measuring cup (2-cup size)
   - copies for each student of:
     Fact Flash 1: Hazardous Substances and Hazardous Wastes
     Fact Flash 2: The Superfund Cleanup Program
     Fact Flash 5: Groundwater

   - copies for each student of the following maps from *Fact Flash 3: Flowing Railroad Hazardous Waste Site*
     Map 1, Flowing Railroad Site
     Map 2, Flowing Railroad Site Area
     Map 3, Diked Sludge Pond, Cross-Section



2. Read Fact Flashes 1, 2, 3 and 5 to prepare your lecture.

3. Distribute Fact Flashes 1 and 2 and assign students to read them as homework.

Procedure

Class #1

1. Review the main ideas from Fact Flashes 1 and 2.

2. Distribute Map 1, Flowing Railroad Site (from *Fact Flash 3: Flowing Railroad Hazardous Waste Site*). This is an overhead view of a fictional site showing where past industrial activities are thought to have taken place. Describe past site activities to the students, using the information in Fact Flash 3.

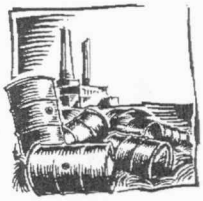
3. Distribute Map 2, Flowing Railroad Site Area (from Fact Flash 3). This is an overhead view of the towns, rivers, and some activities in the surrounding area. Describe the area to students using information from Fact Flash 3.

4. Ask students how they think contaminants might spread from the site. Possible answers include:

   - The wind can blow contaminant vapors.
   - The wind can blow small soil particles to which contaminants are attached.
   - Contaminants can be washed into the Flowing River by rainfall running off the site.
   - Liquid contaminants can flow down through the soil to the groundwater due to gravity.
   - Contaminants can be washed down through the soil to the groundwater by rainfall soaking into the soil.
   - Groundwater moving underground can spread contaminants in the aquifer.
   - Contaminated groundwater can move that uses the Flowing River.
   - Excavation or other activities that disturb the soil on the site can move contaminants.

5. Ask students how animals or plants may be exposed to contaminants from the site. Possible answers include:

   - The wind can blow contaminants to tree leaves, grasses, or crops.
   - Animals can eat contaminated plants.



- Fish and aquatic plants can be exposed to contaminants washed into the Flowing River.
- Farmland crops could be exposed to contaminants through the irrigation system that uses water from the Flowing River.

6. Ask students how people in Ruralville and Utopia may be exposed to contaminants from the site. Possible answers include:

   - Eating contaminated crops
   - Eating contaminated fish from the Flowing River
   - Utopia residents drinking contaminated water from their municipal wells
   - Ruralville residents drinking contaminated water from the Flowing River
   - Children playing on the site
   - Fishermen crossing the site to get to the Flowing River
   - Ruralville residents breathing air containing contaminated dust blown off the site
   - Ruralville and Utopia residents taking showers with contaminated water.

7. Ask students what factors would affect the amount of exposure from site contamination. Possible answers include:

   - Amount of contamination originally released at the site
   - Amount of dispersion of the contaminants
   - Amount of physical, chemical, and biological transformation of the contaminants into harmless compounds
   - Frequency of contact with contaminated water, soil, plants, and animals.

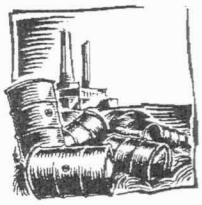
8. Explain to students that in a follow-up class, they will look more closely at how groundwater at the Flowing Railroad hazardous waste site may have been contaminated.

9. Distribute *Fact Flash 5: Groundwater* and assign students to read it prior to the next class.

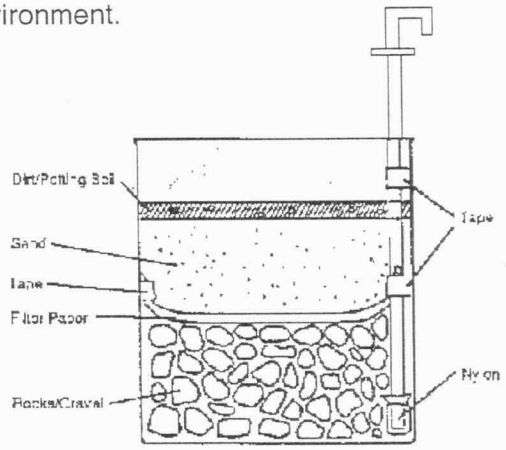
Class #2

1. Distribute Map 3, Diked Sludge Pond, Cross-Section (from Fact Flash 3). Briefly review with students the main points in *Fact Flash 5: Groundwater,* assigned for reading after the first class.

2. Explain that groundwater contamination is a major concern in the Superfund Program, and it is difficult to visualize how contaminants move underground. Therefore, the class is going to construct a small groundwater model to explore how groundwater and contaminants move in an aquifer.



3. Construct a miniature model of a groundwater environment. Choose 2 or 3 students to build the groundwater model at the front of the class. (If you have enough supplies, divide the class into 4 groups and have each group construct its own model.) Use the illustration shown on the next page as a guide.



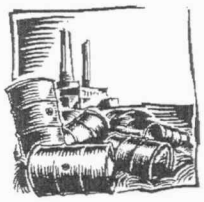
- Tape the pump mechanism, with the nylon fabric attached, to the inside of the container so that the nylon-covered end of the tube almost touches the bottom of the container.
- Fill the container about one-third full with the pebbles or gravel.
- Spread out the coffee filter and, if necessary, cut the paper to make a circle with a diameter larger than the diameter of the inside of the container. Place the filter paper on top of the pebbles and tape it to the sides of the container.
- Fill the rest of the container with sand. The filter paper will prevent the sand from falling down into the gravel and filling the spaces between gravel particles.

Your groundwater model is now ready for conducting experiments. Have students perform the following steps.

4. Spray water on the sand with the spray bottle, until the sand is saturated. The water will filter down through the sand and into the gravel. Keep spraying until the **water table** (the top of the portion of the ground that is completely saturated with water) is in the sand. Keep track of the amount of water that the container can hold at your selected water table level.

5. Push down on the pump mechanism and slowly draw a little water from the gravel through the tube and out of the pump. Make sure the pump empties into the measuring cup. Explain that the pump mechanism creates a vacuum to draw out the water. This is essentially the same method used to pump groundwater from **aquifers** (underground rock materials that are capable of storing and transmitting water in useful amounts).

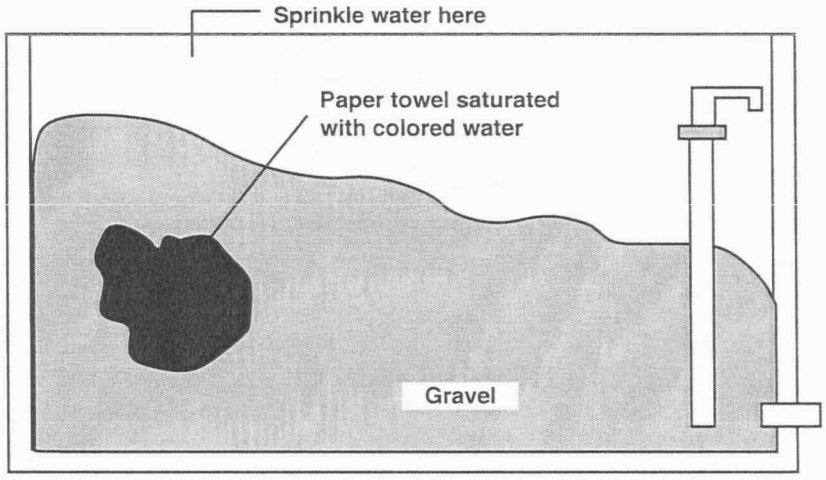
6. Spray more water on the sand until you reach your original water level. Then add a few drops of red food coloring on top of the sand. Place one of the drops near the edge of the sand, near the wall of the container. Explain to the students that the food coloring represents a hazardous waste, such as gasoline, that dissolves in water.



7. Make it rain on your aquifer model by pumping the spray bottle 5 times.

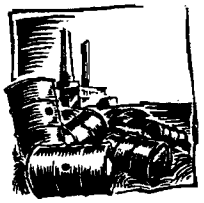
8. Continue pumping water from the container into the measuring cup. The water in the cup will eventually have a reddish hue. Keep track of how much water you have to pump from your groundwater model. Discuss with the students how the pollutant at the surface level has contaminated the groundwater. This is similar to rainwater carrying contaminants underground and into an aquifer. Can the students make any observations about how the pollutant moves downward through the sand from the drop placed by the wall of the container?

9. Ask students to guess how much clean water will have to be sprayed onto the sand to remove all of the food coloring. Continue adding water to the sand and removing water with the pump until the students believe your groundwater has been cleaned up. How much water did it take to clean the aquifer? Was this close to what the students guessed?



NOTE: Another way to illustrate this is to build your model using only gravel. Attach the pump mechanism the same way as for the other model. Roll a paper towel into a ball and saturate it with red food coloring. Bury it beneath the surface (in the gravel). The buried paper towel represents an abandoned waste site. Add water until 1/4 of the pump is submerged. Then spray more water on the surface until 1/2 the pump is under water. Press the pump 20 to 30 times, catching the water in another container. Have students discuss what they observe.

10. To simulate the addition and removal of other types of contaminants, you can put other additives into the water. For example, use molasses or maple syrup to represent a **dense non-aqueous phase liquid (DNAPL)**—a substance that is heavier than water and will not mix with water. Contaminants like TCE and PCB are DNAPLs. Use vegetable oil to represent a **light non-aqueous phase liquid**



(LNAPL)—a substance that is lighter than water and will not mix with water. Jet fuel is an LNAPL. The amount of water that will have to be flushed through the groundwater; model should be significantly greater to remove these contaminants than what was needed to remove the red food coloring.

11. Ask students how your small groundwater model represents contamination at a Superfund site. Answers could include:

    - Contaminants on the ground surface can be washed into groundwater by rainwater.
    - Contaminants in groundwater can be removed by pumping out contaminated groundwater; however, the amount of water needed to clean contaminants from groundwater is far greater than the amount of contamination added.

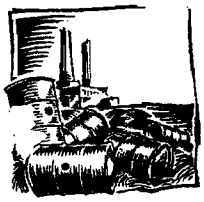
12. Ask students what is different between your experimental groundwater model and a real Superfund site. The following points could be made:

    - A Superfund site can have thousands of gallons of contaminants in the groundwater as opposed to a few ounces.
    - The subsurface at a Superfund site is far more complex than your groundwater model.
    - The water in your model is contained, but at a real Superfund site it almost always is flowing slowly in one direction. Flowing groundwater at a Superfund site can carry contaminants miles from where the contaminants were spilled on the surface. This can make it very difficult to locate a contaminant source once contaminated groundwater is detected.

13. Ask students to consider the situation at the fictional Flowing Railroad site. Would the residents of Utopia be in greater danger from contaminated groundwater if the groundwater beneath the Flowing Railroad site was flowing north toward Utopia or south away from Utopia? *(The answer is that residents would be in greater danger if the groundwater was flowing away from Utopia. This may sound surprising, but the reason is that, if the groundwater is flowing away from Utopia, it is flowing towards their drinking water wells located 3 miles south of the Flowing Railroad site.)*

Extensions (Optional)

- Separate the class into 3 groups. Have each group make a different model: (1) use red food coloring to simulate a water-soluble contaminant; (2) use the buried paper towel described in the note and illustration on previous page; and (3) use maple syrup to simulate a DNAPL and/or vegetable oil to simulate an LNAPL. Have students observe a demonstration of each model and discuss the differences.



- Consider inviting an EPA or state Superfund employee involved in overseeing hazardous waste cleanup projects to discuss a real Superfund site in your state and what made it a Superfund site.

- As an extra credit project, advanced students could use a computer model to predict the movement of contaminants in groundwater under various conditions. Check your local telephone directory for the nearest EPA or United States Geological Survey (USGS) office and contact them about obtaining a copy of the groundwater models they use on a personal computer disk.

Activity 4

Dealing with Chemical Emergencies



Duration	1 class period
Grade Level	7-12
Key Terms/ Concepts	Acute Chronic Emergency Exposure Hazardous material Release Residual Contamination Superfund
Suggested Subjects	Chemistry Physical Science

Purpose

This activity helps students understand how Federal, state, and local authorities respond to chemical emergencies. In a facilitated discussion, students identify activities that can result in spills and other emergency situations that may cause hazardous materials to be released. The difference between emergency situations and other times when hazardous substances may be released into the environment is explained. Students also discuss how Federal, state, and local authorities respond to spills and other releases of contaminants into the environment.

Background

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) directs the U.S. Environmental Protection Agency (EPA) and other Federal agencies to respond to **emergency** situations where **exposure** to **hazardous materials** poses an immediate risk of harm. Emergency situations covered by Superfund include chemical spills or fires. These situations require immediate action to reduce or remove toxic hazards and stabilize the contaminated area to prevent or minimize damage to people and the environment. Usually state and local authorities are the first at the scene of an emergency. After the immediate emergency has been addressed, the site is evaluated to determine whether additional work is necessary. If so, EPA, the state, or the responsible party will clean up the contamination.

For more information on emergency planning and response, see the Suggested Reading list found at the end of the Haz-Ed materials. Other Haz-Ed materials that are related to this topic include *Warm-Up 1: Defining Hazardous Waste* and *Warm-Up 2: EPA's Superfund Program—Overview.*



Preparation

1. Gather the following materials:

   - Copies for each student of:
     Fact Flash 1: Hazardous Substances and Hazardous Waste
     Fact Flash 2: The Superfund Cleanup Program

   - Copies for each student of the following Student Handout, *Hazardous Materials Emergencies.*

2. Read Fact Flashes 1 and 2 to prepare your lecture.

3. Distribute Fact Flashes 1 and 2 and assign students to read them for homework.

Procedure

1. Review the characteristics of hazardous substances and the strategy for emergency responses under the Superfund Program, using the information in the Fact Flashes students read for homework. Point out that this discussion will focus on situations involving brief exposures to uncontrolled hazardous materials as happens in emergencies.

2. Ask students to recall any emergencies that have occured in their community or state involving chemical spills, explosions, fires, or other incidents involving a **release** of hazardous materials . Examples include a highway accident involving an overturned truck carrying hazardous materials, derailment of railroad tank cars carrying hazardous materials, an explosion at an industrial plant, or an evacuation of a neighborhood because of a hazardous materials spill or leak.

3. Have a student list the incidents mentioned on the chalkboard. Have students discuss the circumstances surrounding these events. What happened? What chemicals were released? Were the chemicals explosive, toxic, ignitable, or chemically reactive? How was the emergency resolved?

4. Distribute copies of the Student Handout, *Hazardous Materials Emergencies.* Give them 5 or 10 minutes to read it.

   Use the incidents in the Student Handout as a basis for discussion.



5. Ask students what activities and situations could result in accidents involving the acute release of hazardous materials. Make a list of these activities on the chalkboard, noting the names of any actual occurrences the class can name. Ask what these types of activities have in common, besides the handling of hazardous materials. *(This discussion should point out that many such incidents occur at industrial plants or when hazardous materials are transported and that many pose a threat to people in the vicinity.)*

6. Go back to the list of incidents on the chalkboard. Ask students to suggest what kinds of things would have to be done to respond effectively in each case. (For example, a chemical spill that contaminates drinking water could require an alternative supply of drinking water, or a chemical fire could require evacuating a neighborhood or a whole community.)

7. Ask students who they would expect to respond to these incidents. Would the response be handled locally or would it require outside help? Who would decide on the "action plan" for responding? How would they know what types of hazardous materials are involved? If you were responsible for making such decisions, what other sorts of information would you want?

8. Ask students what makes an emergency different from any other incident. Is it the materials involved, the threat posed to the general population, or something else? Does an emergency require some sort of sudden event (for example, an explosion, fire, train wreck)? What sort of "emergency" might not involve a sudden event (for example, a slow gasoline leak into a river)?

9. Explain to students that whether an incident is considered an emergency under the Federal Superfund Program depends on the type of threat posed. For example, explosions or fires in a chemical plant require an immediate response which, in turn, requires quick decisions and immediate action to reduce or eliminate hazards and stabilize the environment. Other threats, such as a gasoline leak, once under control, allow for a longer planning and decision making process related to the cleanup.

   NOTE: You may want to point out to students that the quick decisions needed to deal with an "emergency" can sometimes result in more long-term problems. For example, hundreds of miles of Germany's Rhine River were polluted following a chemical fire at Basel, Switzerland. Firefighters used water to extinguish the blaze. The runoff from the firefighting washed tons of chemicals into the river.

10. Ask students how they would decide that the "emergency" is over? What if there is leftover contamination? Who would they expect to deal with it?



Extensions (Optional)

- Invite local firefighters or emergency medical technicians to speak to the class on how their departments respond to chemical emergencies and how they interact with other authorities in these situations. Encourage the speakers to bring along any special equipment used in those situations.

- Ask for three volunteers. Assign one to visit the local police department, another the local fire department, and the third the local emergency medical service (EMS), which may be part of the fire department in some communities. Have the students interview officials about their chemical emergency preparedness. Have them explore how emergency calls are received and what plans are set into motion. What would happen locally in the event of a hazardous material emergency? What actual emergencies has the department handled? What is their interaction with state and Federal authorities in these situations? Have the students prepare and present the results of their interviews to the class.

- Invite an EPA or state On-Scene Coordinator (OSC) involved in overseeing hazardous waste cleanup projects to discuss a real emergency cleanup in your state or region. Use the Contacts and Resources listed at the end of the Haz-Ed materials.



Hazardous Materials Emergencies

Charlotte, New York, April 1995. A fire started at a tire dump in Charlotte, Chatauqua County, New York, about 40 miles southwest of Buffalo. The dump covers about 15 acres and holds from 2 to 3 million tires, which are stacked 12-30 feet deep throughout the dump. The cause of the fire was unknown. About 33 local fire companies responded and began efforts to isolate and control the fire, which engulfed 4 to 5 acres. Response personnel set up a containment area for runoff. EPA's On-Scene Coordinator responded to the scene to provide air monitoring and technical support to local response personnel.

Lodi, New Jersey, April 1995. An explosion and fire at a plant that manufactures pharmaceutical chemicals killed at least 2 people, injured 12 others, and caused the evacuation of about 900 residents and schoolchildren in the area. EPA's On-Scene Coordinator and the Agency's Environmental Response Team responded to help local and state officials with air and water monitoring at the site. In addition, the U.S. Coast Guard sent a team to monitor the runoff of water used for firefighting into the Saddle River, where there were reports that fish had died.

Jackson, Mississippi, April 1995. More than 200 vials of the chemical phosgene and compounds used in tear gas were dug up during construction of a trench at the Mississippi State Fairgrounds. The vials reportedly came from World War I chemical warfare "test kits," buried in the 1930s in a pond that was later filled with dirt. EPA's On-Scene Coordinator provided on-site air monitoring and technical advice. U.S. Army teams inventoried the vials and packaged them for transfer to a military base for treatment and disposal.

Sargent Bluff, Iowa, December 1994. A rupture in a natural gas pipeline caused an explosion at a facility, about 15 miles south of Sioux City, Iowa, that manufactures urea and ammonium nitrate for fertilizer. The explosion reportedly killed 4 people and injured at least 30. The incident was initially reported by a nearby resident who said there was a strong ammonia smell in the area. Local firefighters and hazardous materials teams responded and evacuated the immediate area. Within an hour, the fire had been extinguished, but the release of contaminants into the air continued. EPA and state government officials were concerned about the additional release of materials, because the plant has large tanks of nitric acid, anhydrous ammonia, and ammonium nitrate that may have been impacted by the explosion. The facility is located along the banks of the Missouri River.

Activity 8

Hazardous Waste Cleanup Methods



Duration	1 class period
Grade Level	9-12
Key Terms/ Concepts	Cleanup method Treatment technologies
Suggested Subjects	Biology Chemistry Civics/Government Life Science Physical Science Physics

Purpose

This activity helps students understand some of the reasoning and science involved in choosing technologies for cleaning up hazardous waste sites. The students analyze the pros and cons of using various technologies for cleaning up specific hazardous waste problems, weighing factors such as contaminant-specific requirements, technological limitations, reliability, cleanup time, and cost.

Background

The Superfund Program was established by Congress in 1980 in response to growing public concern over the health and environmental risks posed by hazardous waste sites and other uncontrolled toxic hazards. The law is formally called the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). The U.S. Environmental Protection Agency (EPA) administers the Superfund Program in cooperation with individual states and Tribal governments. EPA is responsible for responding to chemical emergencies and investigating and cleaning up uncontrolled or abandoned hazardous waste sites throughout the United States.

In the Superfund Program, EPA uses a variety of processes and technologies, alone or in combination with each other, to clean up hazardous waste sites. Some processes are designed to physically remove the contaminated material from the site or confine contaminated materials to a specific area. Other processes and technologies are designed to treat the contaminated material—to destroy or permanently change their chemical structure; to extract or separate them from the soil, sludge, sediments, or the water they are contaminating; or to immobilize them and keep them from moving or spreading beyond the site.



The responsibility for selecting the most appropriate **cleanup method** for a specific site rests with the EPA Remedial Project Manager (RPM) or On-Scene Coordinator (OSC), with input from the affected community. An important step in this selection process is narrowing the field of alternatives and developing a list of options that make sense for dealing with the contamination at the site.

The RPM or OSC has to examine the range of available technologies and processes and find the ones that offer the best potential for reaching the cleanup goals that have been set for the site. This involves weighing several factors—whether a technology is capable of effectively treating the contaminants present at the site, how long it will take to clean up the contamination using the technology or process, how much it will cost, how complicated or difficult it is to use, and if it is safe for both the workers at the site and the surrounding community.

Many processes and **treatment technologies** are available for use at hazardous waste sites, and new technologies are constantly being developed. The state-of-the-art is changing continuously. For convenience, this activity is based on current information about the most commonly used technologies at Superfund sites.

For additional information on the topics covered in this activity, see the Suggested Reading list found at the end of the Haz-Ed materials.

Preparation

1. Gather the following materials:

    - Copies for each student of
      Fact Flash 3: Flowing Railroad Hazardous Waste Site
      Fact Flash 4: Flowing Railroad Site Investigation Results
      Fact Flash 8: Common Cleanup Methods
      Fact Flash 9: Common Contaminants.

2. Read the 4 Fact Flashes to prepare your lecture.

3. Distribute Fact Flashes 3, 4 and 9. Have students read Fact Flashes 3 and 4 for homework. They can get more information about the contaminants at the site in Fact Flash 9.



Procedure

1. Review the information in Fact Flashes 3 and 4 with the class.

2. Ask students to identify the contamination problems at the site. (Answers should include TCE, metals, PCBs, asbestos in the soil, and lead and TCE in groundwater.)

3. Divide the class into teams. Have each team discuss the options below and decide how the site should be used in the future:

   A. Should the site become a park, residential area, school, or playground?

   B. Should the site remain a restricted area for limited industrial use only?

   C. Should the site be zoned for a landfill or for hazardous waste storage since it already has been polluted?

4. Have each team record their decision on a sheet of paper.

5. Distribute copies of *Fact Flash 8: Common Cleanup Methods.* Have teams choose the one or two **cleanup methods** (from those listed in the Fact Flash) that would be most effective in protecting human health and the environment now and that make sense in light of their decision about the site's future use.

6. Instruct teams to discuss and record on a sheet of paper the reasons for their selections.

7. Reassemble the class and have students discuss and compare the various teams' selections.

Activity 9

Making Decisions About Hazardous Waste Cleanup



Duration	3 1/4 class periods
Grade Level	9-12
Key Terms/ Concepts	Cleanup Hazardous waste Potentially Responsible Party Superfund
Suggested Subjects	Health Life Science Physical Science Social Studies Drama Civics/Government

Purpose

This activity lets students assume roles and act out a situation that illustrates the process of decision making related to cleaning up a Superfund site. Students identify the participants in the Superfund decision making process, make judgments about the potential effect of site cleanup on the characters they portray, and learn that different people have different perspectives on the same cleanup issues. In addition, they practice writing statements, formulating questions, and articulating their views in a public meeting setting.

Background

Whether we are children or adults, our lives are influenced by a constant series of choices. Some choices we make for ourselves. Some are made by parents for their children, and many are made by people we don't even know. The combination of all these choices determines the quality of each of our lives. Making these choices is not easy because sometimes what one person perceives as the right choice for him or her as an individual may be perceived as the wrong choice for the neighborhood, community, or country.

For example, people living near an abandoned **hazardous waste** site may want the site cleaned up as fast as possible, no matter what the cost, because they fear for their own, as well as their children's, safety. On the other hand, people employed by a company that caused the contamination at the site (a **Potentially Responsible Party**) or the local government may favor alternatives that, while effective, take longer and cost less. They are concerned about the impact on jobs and the local economy if the government requires the company to pay too much for the **cleanup**.



The process of making decisions about **Superfund** site cleanup involves weighing and balancing a variety of technical and nontechnical factors, including the sometimes competing interests in the community. This activity provides a lesson about Federal policy-making that extends well beyond the Superfund Program.

To help prepare your students for this activity, use *Warm-Up 5: Hazardous Waste Issues in the News.* You may perform the entire Warm-Up or simply review the main points covered in it. As a follow-up, have your students perform *Activity 11: What the Community Can Do.*

For additional information on these topics, see the Suggested Reading list found at the end of the Haz-Ed materials. Other Haz-Ed materials that are related to this topic include *Fact Flash 8: Common Cleanup Methods* and *Fact Flash 10: Superfund Community Involvement Program.*

Preparation

1. Gather the following materials:

   - Copies for each student of Student Handout, *Analysis of Alternatives for Cleaning Up Flowing Railroad Site*
   - The *Character Background Sheets* included at the end of this lesson
   - Copies for each student of:
     Fact Flash 2: The Superfund Cleanup Program
     Fact Flash 4: Flowing Railroad Site Investigation Results.

Procedure

Class #1

1. Explain to students that in two successive follow-up sessions the class will act out a situation that illustrates the sometimes difficult process of making decisions about Superfund site cleanup. For this role-playing exercise, students will assume they live in the hypothetical area of the Flowing Railroad Superfund site. They will participate in a community meeting held to discuss and air community views about the site cleanup options under consideration.

2. Divide the class into nine teams. Explain that each team will represent one of the "players" in this drama: the U.S. Environmental Protection Agency's (EPA) **Remedial Project Manager (RPM)**, EPA's **Community Involvement Coordinator (CIC)**, a local Health Department official, the Mayor of Ruralville, the attorney for



FRR Enterprises, a local environmental activist, a person employed at Flow Automations, Inc., a local farmer, and a local carpenter.

NOTE: If you live in a community near a real Superfund site, you may choose to prepare Student Handouts using information about that site so the role-play will be more realistic for your students. Call the Community Involvement Coordinator in your state. Phone numbers are provided at the end of the Haz-Ed materials.

3. Assign a role to each team and explain that later each team will have to choose 1 team member to be the actor when the first part of the drama is played out at the next class. Team members should prepare a written statement for their character to deliver, as well as a list of questions the character may want to ask at the meeting.

4. Distribute the Student Handout, *Analysis of Alternatives for Cleaning Up Flowing River Site.* Give each team the *Character Background Sheet* that is appropriate for its assigned role. *NOTE: If you live in a community near a Superfund site, you may choose to adjust the roles and the background information for each to approximate the makeup and situation in your community.*

5. Distribute Fact Flashes 2 and 4. Explain to students that these Fact Flashes can be used as background information.

6. Explain that the information on these handouts can be used to develop their character's beliefs, attitudes, and point of view about the cleanup. Stress that this should go beyond what the character knows or has heard and should include identifying questions the character wants to ask about the cleanup. Encourage students to talk to their parents, local city or town government officials, business owners, and others to help develop their perspectives. Also remind students that some of their characters—EPA's RPM and CIC, the Mayor, and the official from the local Health Department, and possibly others—would probably consult with each other in real life to prepare for the meeting. Encourage teams responsible for these characters to do so.

7. Specify a specific date for the next class, allowing several days for preparation.

Class #2

1. For the role-play activity, have the students representing the Mayor and the CIC arrange desks or a table at the front of the room with chairs to accommodate 4 people, the Mayor, EPA's CIC, RPM, and the moderator/facilitator. Place a lectern, desk, or small table somewhere else in the room from which the other characters will make their statements.



NOTE: You may wish to assume the role of moderator/facilitator yourself or you can select a student to do so. The moderator/facilitator's only responsibilities are to maintain order, see that everyone has an opportunity to speak, direct questions to the appropriate person to answer, and see that people speak in turn rather than all at once.

2. At the conclusion of the meeting, explain to the students that the teams playing EPA's RPM and CIC will get together and consider the information presented in this meeting, make a decision, and present a Proposed Cleanup Plan at the next class (specify the date, allowing sufficient time for the RPM team to meet and prepare a plan). Students from the other teams will have an opportunity to discuss the decision among themselves and comment on it.

3. Have the Mayor speak first to welcome people to the meeting, then EPA's CIC. After that, have others (the assigned characters) raise their hands to be recognized as they would in a real meeting and call on them in turn. After all participants have made their initial statements, the various characters may be recognized to ask follow-up questions or make additional observations as often as time permits.

Class #3

1. Have the spokesperson for the RPM team present the team's Proposed Cleanup Plan, including the rationale for choosing the selected remedy. Allow no more than 10 minutes for this presentation.

2. Give students about 10 minutes to discuss the decision with their team members. Offer the teams an opportunity to comment on the decision. Is the decision clear? Do they agree with it? Why or why not? Do they understand the RPM team's rationale in making the decision?

3. After teams have made comments from the perspective of their characters, invite the class as a whole to discuss the role-play and the decisionmaking process illustrated. What were the various points of view expressed in the meeting? Which were similar? Which were different (competing)? Which would you have expected to carry more weight? Why? Did those points of view appear to influence the final decision? How do you think the decision will affect the quality of life in the community? Now that the decision has been made, do you think all the characters in this drama will accept it? Why or why not? What options do they have if they do not accept it? *(NOTE: An Instructor Fact Sheet,* Highlights about Roles, *is included in this lesson to help you ensure that the perspectives of all characters in the role-play are covered during the discussion.)*



Extension (Optional)

- Have students bring in examples throughout the year, from newspaper or local television news, of real Superfund cleanup or hazardous waste prevention decisions made by your local government or a major local business. Set aside time periodically to discuss the choices involved in these decisions and their impact on the quality of life in the community. *Warm-Up 5: Hazardous Waste Issues in the News* contains sample articles of the type students may find.

Instructor Fact Sheet – Highlights about Roles

NOTE: You may need to begin the discussion by identifying 1 or 2 of the actors' perspectives; try to make sure that perspectives of all the characters are covered during this discussion, encouraging the participants to identify as many as possible. You may want to write students' responses on the blackboard, or on a flip chart if you have one, to illustrate the range of perspectives presented and reinforce the idea that the decisionmaking process involves weighing and balancing many different, and sometimes competing, points of view.

- The **RPM** wants to learn more about the citizens' concerns so s/he knows what they are and how they can be addressed by the cleanup of the site and reflected in various written reports and other methods (e.g., fact sheets).

- The **CIC** also wants to learn more about the community's concerns, so s/he can begin identifying the kinds of information the community is seeking and ways it can be provided to them.

- The **local health official** wants more information about potential health hazards the community will be exposed to; the health official also sees this as an opportunity to increase his/her standing in the community.

- The **Mayor** of Ruralville has multiple perspectives. The mayor is concerned about the health and safety of the citizens and wants answers to questions. The mayor is also concerned about Ruralville's economic growth; its ability to attract future business; the danger of losing a major employer if FRR Enterprises goes bankrupt as a result of paying for cleaning up the site; and his/ her own reelection.

- The **attorney** for FRR Enterprises wants to protect his/her client's interests. If FRR Enterprises is being damaged financially due to incorrect or overly cautious studies, or is being asked to conduct site activities that go beyond reasonable measures for cleaning up the site, the attorney wants to know this so s/he can take action on behalf of the company.



- The local **environmental activist** is genuinely concerned about improving the environment and asks some very informed and appropriate questions in search for more information.

- The **plant worker** is worried about job security, as well as his/her family's health and safety.

- The **farmer** depends on the water from the Flowing River to irrigate the farm. The publicity surrounding this situation has already caused customers to be alarmed. The farmer wants to know exactly how serious this situation really is and how s/he can protect his/her farmland and economic future.

- The **carpenter** is concerned that the needs of poor people in the community won't be considered as decisions about the site are being made.

Analysis of Alternatives for Cleaning Up Flowing River Site

Alternative	Brief Description	Advantages	Disadvantages
#1 Provide Security	This alternative is used as a baseline against which to compare other alternatives. It allows for continuous monitoring of site conditions; action can be taken if conditions change. It includes fencing the contaminated area and erecting signs to indicate potential health hazards.	Because no threat to drinking water exists (the deep aquifer is not connected to the shallow aquifer), funds for this site may be used for more hazardous sites. The fence prevents direct contact with contamination.	It does not address the contamination. Contaminated water may continue to move toward the Flowing River. Asbestos particles may be released during windy weather if erosion continues to occur. The site is not available for future use.
#2 Only Cap	This alternative places layers of waterproof material like clay and plastic over the contamination. It reduces the amount of water reaching the contamination, and the contamination is slowed from moving and reaching water sources.	A short period of construction is required, so the site is addressed quickly. This technology is inexpensive, reliable, and commonly used. It will last with proper maintenance. The cap will reduce the rate at which the contamination in the shallow aquifer will move toward the Flowing River.	The cap does not neutralize or eliminate contamination. The cap requires maintenance and monitoring and is not always 100% effective. It limits the site's reuse; in order to maintain the cap, nothing can be built on top of it.
#3 Cap, Air Stripping, Chemical Precipitation	This alternative uses a cap to address soil contamination, as described in Alternative #2. Air stripping and chemical precipitation of contaminated water requires building a large tower on the site and drilling wells into the aquifer. Contaminated water is pumped to the top of the tower where the volatile pollutants can evaporate and form a gas. The gas is then filtered through a layer of carbon to remove the contaminants. After air stripping, the water is treated by chemical precipitation to remove the heavy metals. Chemicals are added to the water to create a sludge. The water is filtered from the sludge, treated, and pumped back into the environment. The sludge is sent off site to a licensed disposal facility.	The cap addresses the asbestos. See discussion of capping advantages in Alternative #2. This technology effectively removes most of the contamination from the shallow aquifer over 2-10 years. Most of the contamination is addressed through treatment, without having to move it from the site. An air stripper is relatively easy to operate and is not technically complex. Metals and PCBs are captured in the sludge. A licensed off-site facility can contain the sludge through extensive controls.	See the discussion of capping disadvantages in Alternative #2. The air stripping tower needs to be monitored carefully to ensure that any contamination released into the air meets State standards. Air stripping is 90% efficient and the tower needs to be monitored to prevent releases of contaminants. Contaminated sludge needs to be disposed of properly offsite.

Analysis of Alternatives for Cleaning Up Flowing River Site (con't.)

Alternative	Brief Description	Advantages	Disadvantages
#4 Incineration, Air Stripping, and Chemical Precipitation	This alternative involves digging up and burning contaminated soils at high temperatures in an on-site incinerator. The incinerator destroys TCE and PCB contamination. The remaining ash containing heavy metals is shipped off site to a landfill. As described in Alternative #3, air stripping and chemical precipitation of contaminated water require building a large tower on the site and digging wells into the aquifer. Contaminated water is pumped to the top of the tower where some of the pollutants can form a gas that may be filtered through carbon. Heavy metals are removed from the water by chemical precipitation.	The site is "clean" and available for reuse. The incinerator destroys at least 99.9999% of the organic (burnable) contaminants in the soil. An air stripper is relatively easy to operate.	Stringent permits are required to operate an incinerator. Hazardous emissions from incinerators have been associated with health risks, so careful monitoring is required. Public resistance to incineration often occurs. Treatment residuals from the incinerator must be managed and disposed of. Air stripping is 90% efficient. The air stripping tower needs to be monitored carefully to ensure that any contamination released into the air meets State standards. Asbestos is not addressed.
#5 Complete Excavation	This alternative requires digging up a large volume of the contaminated soil and shipping it to an off-site hazardous waste facility. Groundwater contamination is treated on site with air stripping and chemical precipitation, as described in Alternative #3.	This technology removes contaminated soil completely in a short period of time and requires no future maintenance. An air stripper is relatively easy to operate and is not technically complex. The site is safe for future use.	Trucks that carry contaminated soil (and those that deliver clean backfill) drive through town. A risk that something could go wrong during the removal and export of soil exists, which could result in public exposure to the contaminants through the air. Concerns may be raised over odor caused by excavation and transporting contaminated soil. Contamination is not addressed or treated on-site, but is passed elsewhere. Dust from excavation activities must be controlled. Roads may need to be repaired.



Character Background Sheet

EPA Remedial Project Manager (RPM)

You are the RPM assigned to the Flowing Railroad site. Your job is to direct the response effort and coordinate all cleanup activities at the site. You are responsible for coordinating not only with EPA Regional and Headquarters staff, but also with other Federal, state, and local agencies.

Although you live and work in the city where the EPA Regional Office is located, many of the sites for which you have been responsible were in small towns and rural areas like this one, so you can empathize with the concerns of the citizens of Ruralville. Your purpose at the community meeting is to tell people about the investigation of the problems at the site and the sort of cleanup options you are weighing as a result. In addition, you want to give them the opportunity to ask any questions and express any concerns they have about the cleanup in general or about specific cleanup options.

When the meeting is over, you will have to make a final decision about how to recommend that the site be cleaned up, balancing the data from your investigation and the other information at your disposal with what you hear in the meeting about what the community thinks. This is not an easy decision to make, because there are a lot of needs and interests you must try to satisfy—the requirements in the law, the needs of the people who live in the community, the wishes of those who run businesses in the community, the interests of FRR Enterprises which is a major employer in the community, etc.

You are responsible for choosing a cleanup option that:

1. protects human health and the environment
2. complies with existing Federal and state laws and requirements

Your choice also must:

1. be effective in the short-term, as well as over the long-term
2. reduce the toxicity, mobility, or volume of the contaminants
3. be realistic
4. be reasonably cost-effective
5. be acceptable to the community

You will prepare a Proposed Cleanup Plan describing your decision and discussing why you chose to proceed in this way. You will have to present that plan to the same group of people from the community and hear their reactions.

Character Background Sheet

EPA Community Involvement Coordinator (CIC)

You are the CIC assigned to the Flowing Railroad site. Your job is to manage all EPA's community involvement activities to provide an opportunity for public participation in the Superfund process.

You grew up in Ruralville but left to go to college. Now you live in the city where EPA's Regional Office is located. You still know a lot of people in Ruralville, and you are eager to help them understand what's involved in cleaning up the site and how the cleanup will—and will not—affect their lives.

Your purpose at the community meeting is to help explain the cleanup options being considered, answer citizens' questions, and listen to community concerns. You have already met most of the people at the meeting because your overall responsibility has been to ensure that the community knows what to expect and how to participate in Superfund decisionmaking. You have been sharing information about the Superfund process with the community and obtaining information from them since EPA's activities at the site began. You've visited with individuals, families, and business owners in the community, written fact sheets about various stages in the process, gathered and distributed information about the site itself and the data EPA collected during its investigation of the site. When the meeting is over and the RPM has made a final decision about how to clean up the site, you will prepare a fact sheet that summarizes the decision and help the RPM respond to comments from the community about the selected cleanup strategy.

You lead the meeting for EPA.



Character Background Sheet

Local Health Official

You are a Health Advisor for the Ruralville Health Department. Although you have more than 10 years of experience in the health field, this is the first time you have encountered a situation involving a hazardous waste site.

Your purpose at the community meeting is to learn as much as possible about any potential health effects that could result, now or in the future, from contamination at the site and from efforts to clean it up. You need this information to be able to accurately advise townspeople of any health-related dangers and how to avoid them.

Character Background Sheet

Mayor of Ruralville

You have been Mayor of Ruralville for six years. Your job is to protect the health and welfare of the community and its citizens and to make sure the interests of the community are considered as Superfund decisions are made.

You are a well-respected member of the community. Most of the townspeople believe you have done good things for Ruralville. Your purpose at the meeting is to demonstrate the leadership residents expect from their Mayor and to ensure the continuing economic well-being of the community, as well as the safety of its citizens.

You support town growth and have helped several small businesses get established in the community. Some people credit you with being instrumental in Flowing Railroad's decision to open its Flow Automations factory in Ruralville. The factory employs many of the people who work in Ruralville. In fact, some of them originally worked for the Flowing Railroad and were retrained so they could work at the new factory.

Your family is very important to you. You are especially close to your oldest child who happens to be married to the president of Flow Automations.

You lead the meeting.



Character Background Sheet

Attorney for FRR Enterprises

You are the general counsel for FRR Enterprises which owns the Flowing Railroad Company site and Flow Automations. Your purpose at the meeting is to protect the company's interests. You want to make sure the government and individual residents realize how the cleanup decisions in this case will affect the company and, in turn, the town's tax revenue and all the townspeople employed by the company.

You are concerned because FRR Enterprises already has spent more than $1 million on studies required to determine the extent of contamination at the site, and more bills are on the way. FRR Enterprises also will have to bear much of the cost of any cleanup remedy selected. You want people to understand that the contamination at the site resulted from activities that were legal at the time. You intend to argue that to make the company bear the financial burden for that is unfair, because the company did not do anything wrong. Besides, the Flowing Railroad was not the only business operated on the site, and if FRR Enterprises has to pay, even though they did nothing wrong, so should all the other businesses who operated on the site. FRR should not be penalized just because it is still around.

Although FRR Enterprises is financially stable now, company officials—your bosses—are concerned about the long-term impact of the cleanup since it is hard to predict what the total cost will be.

Character Background Sheet

Local Environmental Activist

You are a resident of Ruralville and the founder of the local chapter of Everlasting Earth. Everlasting Earth is a national advocacy organization dedicated to preventing pollution and fighting threats to public health and the environment. You are passionate in your belief that polluters should pay to clean up the problems they create.

Your purpose at the meeting is to make sure that no one lets FRR Enterprises off the hook. You believe they have damaged the environment and, as a result, the health of community residents could be in danger. You were one of the first people to learn (from your friend at the bank) about the environmental audit of the Flowing Railroad site. As soon as you heard the consulting firm's findings, you began lobbying to get the town to demand the site be cleaned up; you want the most stringent cleanup standards applied in this case.

You do not believe the town should be concerned with how much the cleanup might cost; FRR Enterprises must be made to pay, no matter what the cost. You also do not believe there is any danger that FRR Enterprises could go bankrupt or that Flow Automations could go out of business as a result of paying for the cleanup. You think the company is just trying to scare people.



Character Background Sheet

Worker at the Flow Automations Factory

You are employed as an assembler at the Flow Automations factory. Prior to this job, you worked for the Flowing Railroad.

Your purpose at the meeting is to learn as much as you can about the problems at the site and the cleanup being proposed. You feel like you are being asked to choose a "side" on this issue but you are confused. You have a number of concerns about the situation but no one answer seems to satisfy them.

You are a single parent with three young children. On the one hand, you need your job at Flow Automations; you have no other source of income. Besides that, Flowing Railroad was good to you; the company got you the job at Flow Automations and paid for the training you needed to do it. On the other hand, you and your children live near the site and you have the children's health and well-being to consider.

Character Background Sheet

Owner of a Farm near the Flowing River

You own 75 acres of farmland, some of which borders the Flowing River. The farm has been in your family for generations.

Your purpose at the meeting is to get some straight answers about the contamination from the site and how far it has spread. You want to know if it is affecting your crops and what can be done to stop it. You grow several crops and sell them to supermarkets in Ruralville and in several towns throughout the state. You depend on sales to stay in business and to pay your employees.

Your farm has had a number of hardships over the years. First, you lost many of your crops to a severe drought 2 years ago. Then, an electrical storm last June started a fire that burned several acres before it could be stopped. These things have cost you a lot of money. Now, some of your customers are asking you if your crops are contaminated because of what's happened at the Flowing Railroad site.

You feel like your farm's reputation and your whole future is at stake. You intend to let the Mayor and the people from the government know that and demand that they do whatever is necessary to solve the problem.



Character Background Sheet

Local Carpenter

You, your spouse, and your 4 children have lived in a rented cottage on the banks of the Flowing River for about a year. The Long Shot Cafe, where your spouse worked as a bartender, closed several months ago. Your spouse has not been able to find another job, so you have been the sole supporter for the family.

You earn money by doing odd jobs around town, but there haven't been many lately. You've had to depend on fishing in the river to feed your family; 3 of 4 main meals a week over the last few months have come from the river.

You have become increasingly frightened and angry over the last few weeks as you have heard more and more rumors about possible contamination of the river. You are convinced that, because you and your family are poor, your welfare will not be considered as the government makes decisions about how to deal with the Flowing Railroad site.

Your purpose at the meeting is to make them listen to your concerns.