Lesson #3: Groundwater

Main Ideas: Accounts (From the Water Upper Anchor V. 3)
Structure of Systems: Water usually exists underground in the liquid state.

- Macroscopic (and microscopic) Scale: Water exists underground in cracks and spaces within rocks or in spaces between sediment grains. Some of these openings are tiny (microscopic). Different types of rock and sediment have different porosity (size of openings), permeability (connectedness of the openings), and transmissibility (capacity to transmit water) values. In general, well-sorted, unconsolidated sediments with larger grain sizes have higher permeability values. Well-sorted, unconsolidated sediments with smaller grain sizes have lower permeability values.
- Large Scale: Layers of rock or sediment from which water can be pumped or otherwise extracted are called aquifers. Layers of rock or sediment that store water but do not transmit water fast-enough for use are called aquicludes (or aquitards). Aquifers that are connected directly to the Earth's surface are called unconfined aquifers. The surface of the saturated zone in an unconfined aquifer is called the water table. Aquifers that are beneath aquicludes are called confined aquifers. Groundwater can be pumped out of the ground through a pipe called a well.

  Groundwater is not equally distributed. Some areas have more groundwater available than other areas.

Tracing Water: Water moves in and out and within the groundwater system. Water moves in and out at the boundaries with the surface water system or through the engineered system.

- Macroscopic (and microscopic) Scale: Water infiltrates into the ground from rain soaking into the ground and through rivers, streams, lakes, ponds, etc. are called recharge zones. Water leaves aquifers through discharge zones, usually springs, marshes, and many streams, rivers, lakes.

  Water moves through some layers (usually sands, gravels, sandstones, conglomerates, or fractured rocks) more easily than through other layers (usually clay, shale, unfractured rocks), depending on the porosity and permeability characteristics of the rock or sediment. In general, groundwater responds to gravity and flows in a downward direction, unless it encounters barriers.
- Large Scale: Groundwater in unconfined aquifers generally follows the flow of surface water. Water in unconfined aquifers stays within the surface watershed in which it originated. Water in confined aquifers can flow across surface watershed divides, depending on the characteristics of the aquifer.

Tracing Other Substances: Groundwater can often be a good source of drinking water. However, groundwater can contain other substances dissolved from the rocks underground (e.g. iron, fluoride, sulfur, salts). Sometimes, these naturally occurring substances make groundwater unsuitable for drinking. Groundwater can also become contaminated by human actions that introduce substances into the groundwater.

Humans can pollute groundwater. Water can dissolve substances and carry those substances with it as it moves underground. Anytime pollutants are left on the ground or buried, water coming in contact with them will carry some of the pollutants with it underground and potentially contaminate the aquifers. Polluted groundwater is very difficult and costly to clean up.

Performances:

Inquiry

P1--Extending experience: Through first hand collection of data related to groundwater (e.g., through groundwater modeling activities) students will develop personal experiences with water in environmental systems to the point where data about water quality and water movement are experientially real.

P2--Finding patterns in data on water systems: Students will use data to construct models of the movement of water and dissolved or suspended substances through environmental water systems.

Accounts

P3-Structure of systems: Students will connect
(b) macroscopic samples of water in different states as well as suspensions and solutions, and
(c) large-scale systems through which water moves and carries other substances.

P4--Tracing water and substances it carries: Students will trace water and substances it carries in suspensions and solutions through systems that include
(c) ground water

Module Overview:

Activity Number	Label	Estimated Time	Description
1	What Does Water Look Like Underground?	15 minutes	Teacher presents question and elicits ideas – Where is the water underground? What does it look like underground? Students complete the "before side" of a T-chart drawing
2	Permeability	15 minutes	Students pour water on gravel and clay to see what happens to the water. Students learn the definition of permeability.
3	Building the Groundwater Model	60 minutes total -30 minutes to build - 30 minutes to run & discuss	Students build groundwater models, then pump water through the groundwater model, making observations and noting patterns of water flow. The materials will guide students to examine the connection between surface water and groundwater.
4	Well Problem: Where would you put a well?	20-30 minutes	Given a new map/cross-section, students are asked to suggest a location for a new well and justify their answer based on the features on the map and cross-section.
5	Pollute the Groundwater Model	30-40 minutes	In their groups, students decide on a scenario to pollute their groundwater model. They carry out their pollution plan and observe where the pollution goes and how it moves through the groundwater system.
6	Clean-up the Groundwater Model	30-40 minutes	In their groups, students develop a plan to clean-up their groundwater model. They implement their plan and observe what happens.
7	Finish T-Chart	15 minutes	Students complete the T-Chart started in activity 1.1.

Materials:

Activity Number	Per Student	Per Group	Per Class
1	Student Pages 1.1		
2	Student Pages 1.2	• 1 clear plastic drinking cup filled with gravel • 1 clear plastic drinking cup filled with sand • 1 clear plastic drinking cup filled with powdered clay • 1 plastic cup of water • eye dropper or plastic pipette with narrow tip.	
3	• Student Pages 1.3 • Groundwater Model Cross-Section & Map	• Modeling tank, stopper & well http://www.mines.edu/outreach/cont_ed/esrc.shtml#pgwm • Gravel • Sand • Clay (powdered) www.wardsci.com 80 V 5719 Stress Clay, 20 lbs. • Rain cup (plastic cup with holes punched in the bottom) • Cup of water	• Teacher Demonstration Model • Overheads 1.3 Aquifer overhead Groundwater System Overview Groundwater Model Plan
4	• Student Pages 1.4	• Well Problem Cross-section and Map Overhead	• Teacher Demonstration Model • Well Problem Cross-section and Map Overhead
5	• Student Pages 1.5	• Student Groundwater Models from 1.3 • Colored pencils • Paper or plastic cups with holes poked in the bottom (rain cups) • Water • Paper towels	• Colored powdered drink mix • Pre-punctured film canisters (2 or 3) • Pre-punctured straws (2 or 3) • Pre-punctured paper cups (2 or 3)
6	• Student Pages 1.6	• Student Groundwater Models from 1.3 Clean-up materials: • Plastic spoons • Paper Dixie cups	

		• Paper Towel	
7	• T-Charts from Activity 1.1		

Activity 1: What Does Water Look Like Underground? (15 minutes)
Function/Rationale:
This activity serves as a pre-assessment of student ideas about groundwater.

Directions:
1. Explain to students that some people and some cities get water from wells that take water from underground. Ask students, "What does it look like underground? Where is the water?"
2. Have students share a few responses with the class to help students begin thinking about their own answers.
3. Distribute "Before & After" T-Charts.
4. Direct each student to draw a picture of where they think the water is underground. Have students label the important parts of their pictures.
5. Collect all pictures (make sure the students put their names on the sheets as you will return these later). The "After" part of the T-Chart will be completed at the end of lesson (Activity 1.7).

Activity 2: Permeability (15 minutes)
Function/Rationale:
This activity allows students to build an understanding of the relative meanings of permeable and impermeable. Students will use this understanding to understand aquifers (activities 3 –6)

Directions:
1. Before the class period, place 1 cup of gravel, 1 cup of sand, 1 cup of clay, and 1 cup of water on each table.
2. Have students pour half of the cup of water onto the gravel and the other half of the water onto the powdered clay.
3. Have students observe where the water goes in each cup and record their observations.
4. Define **permeability** - how easily water moves through the pore spaces. Permeability is relative. Gravel has a greater permeability than sand. Clay and shale have very low permeability, to the point that for the purpose of pumping water out of them, they are **impermeable**.
5. If necessary provide the following analogy: Imagine a room filled with beach balls. How much space is between the beach balls? Would water flow through these spaces easily? We would say this room is permeable. Now imagine a room filled with golf balls. How much space is between the golf balls? It would be harder for the water to flow through the golf balls. We would say this room is less permeable than the room with beach balls. Finally, imagine a room filled with ball bearings. There is still space between the ball bearings, but they are very, very tiny. It would be much harder, and take much longer for the water to flow through the ball bearings than the beach balls. We would say the ball bearing room is almost impermeable.
6. Note: Students may have trouble understanding later that rocks are impermeable in the short-term, but permeable in the long-term. Given enough time, some rocks like sandstone are permeable. That is why we have aquifers in some sandstone layers. However, during a rainstorm, water falling on rock will not soak in very much; most will run-off. So, permeability is also relative to time.
7. Introduce the term **infiltrate** - to soak in.

Activity3: Building Groundwater Model (30 minutes to build, 30 minutes to run & discuss)

Function/Rationale:

This activity:

1) helps students build understanding of how a groundwater system works and how groundwater and surface water are connected by constructing a model of a groundwater system.
2) introduces the idea of cross-section and illustrates the relationship between a cross-section and a map.
3) engages students in making observations and looking for patterns in the way water moves through a groundwater system.
4) serves as an embedded assessment of individual and whole-class progress on understanding groundwater systems.

Preparation:

1) Before class, build a teacher demonstration model. This model should not be the same as the model the students will build. You will use this model to introduce the idea of a model.
2) Label the following features on the teacher demonstration model using either sticky-notes, mailing labels, or grease pencil
   A) Confining layer (clay layer)
   B) Confined aquifer (below clay layer)
   C) Unconfined aquifer (above clay layer)
3) You will also use this teacher demonstration model to help students who are having trouble with the concepts of confined and unconfined layers.

Directions:

1) Introduce to students the concept of a model. Use the teacher groundwater model to explain what a model is. Explain that scientists build models to help them understand ideas and things they may not be able to see directly. Models also help scientists play with variables to see how things work. Students will be building groundwater models to see how groundwater systems work.
2) Demonstrate for students how to fold the Groundwater Model Plan.
   A) Fold the Groundwater Model plan in half along the line.
   B) Unfold the paper so that it makes a 90 degree bend. Hold the side labeled “map” horizontally and the side labeled “cross-section” vertically.
   C) Explain that the vertical side is like looking at the ground from the side through a window. It shows the layers underground. This is called the cross-section view. The horizontal side is what is on top of the ground. It is called the map view.
3) Explain that students will build a model in their Groundwater Model tanks that looks just like the drawing of the cross-section. Hints (from student pages):
   A) Insert the stopper tightly into the hole in the plastic tank.
   B) Put the well in first, up against the side of the tank so that you can see it through the tank wall.
   C) Pour the sand layer into the tank.
   D) Use a cup to pour just enough water into the tank to fill up the sand. There should be no water standing on top of the sand. The sand should just be wet.
   E) Pour in the rest of the sediments in layers carefully and evenly. Don’t mix the sediments.
4) Have students follow the materials to add water and pump water through their models.
5) Students should complete the cross-section of the Groundwater Model Plan by labeling the following features:
   A) Confining layer (clay layer)
   B) Confined aquifer (below clay layer)

  C) Unconfined aquifer (above clay layer)
  D) Top of the water table (∇)

6) Arrows that show the flow of water from the rain through to the well.
7) Hold a whole-class question session. Ask the following questions. Have students provide answers and explain their answers, referring to their groundwater models whenever possible. You may use the overhead of the Groundwater Model Plan to facilitate the discussion
   A) How does the water get into the unconfined aquifer? *Because there are no impermeable layers above it, water can infiltrate into the ground. Where it collects is the aquifer.*
   B) What is a confined aquifer? *A confined aquifer is under an impermeable confining layer.*
   C) What is a spring? *A spring is where the groundwater intersects the ground surface and spills out onto the surface.*
   D) How does the water get into the confined aquifer? *Water takes a very long time to fill a confined aquifer. The confining layers are relatively impermeable, but given a long enough time, water will eventually infiltrate through it. Water can also fill a confined aquifer from the side.*
   E) What is the relationship between the river and the water table? *The river and the water table are at the same level. The water can flow from the river into the groundwater and from the groundwater into the river.*

Activity 4: Where Would You Put A Well? (20-30 minutes)
Function/Rationale:
This activity:
1. allows students to use model-based reasoning skills to solve a problem
2. serves as a formative assessment for how well individual students understand the relationship between surface water and groundwater.

Preparation:
1. Build another demonstration model. This model should match the map and cross-section designed for this activity. (See Student Pages).

Directions:
1. Provide students with a map/cross-section.
2. Introduce the activity by showing the demonstration model to the class. Explain the task.

From Student Pages

1. You own all of the land in the picture. You need to drill a well for water for your house. You do not want to take the water directly from the river because the river water is not as clean as the groundwater.
2. Examine the picture of the cross-section below. Label the following features:
   A. Unconfined aquifer(s)
   B. Confined aquifer(s)
   C. Confining layer(s)
3. Remember, it costs about $9 per foot to drill a well. So, you don't want to have to spend too much money, but you also want to make sure you have enough water for your house.
4. Decide where would be the best place to drill the well so that you will have water all year long. Draw in your well. Be sure to show how deep your well should go.
5. Justify your well location below. Explain
   A. Why you chose to put it where you did.
   B. Why you drew it as deep as you did.
6. Share your answers with your group members.
7. If you decide to change your answer, draw in a second well in a different color from the first well. Be sure to use a key to identify which well was your first well and which well was you second well.
8. Justify your change below. Explain why you changed your well location and why the new location is better.

3. Remind students that they are to complete the first part of this activity (steps 1 – 5) individually. Students may share their answers after they complete step 5.
4. If students decide to change their answers, they must do it in a different color (do not erase) and explain why they changed their minds and why the new location is better.
5. Remind students how to fold the map/cross-section, like they did in activity 1.3.
6. Have students read the directions and use the information on the cross-section and map to determine where to locate a well.
7. Students must write out the justification for their choice for well location.
8. After students have made their decisions and answered the questions, lead a whole class discussion about students' various decisions. Ask for several groups to explain and justify their well decisions. Compare and contrast well locations and decide as a class which well location would be best and why. In general, locations that are closer to the river will provide a more reliable water supply.

Activity: 5 -- Groundwater Pollution Models (30-40 minutes)
Function/Rationale:
This activity:
1. continues the use of prior work from activity 3: students have a chance to use their models for further learning.
2. allows students to explore and test their ideas in order to build understanding of how pollution moves through groundwater systems.
3. develops group work skills.
4. provides embedded assessment opportunities.

Directions:
1. Students will work in groups to create and study a groundwater contamination scenario. Students will use the same groundwater models that they built in lesson #3. Your role in the activity is to check student understanding and help students think about how realistic their models are. Students should be free to choose the method of contamination from the list below and decide how they should attempt to clean it up. You should check in with each group as they clean-up their models to provide guidance.
2. Students can choose to model one of the following scenarios or make up their own scenario (must be approved by you). Provide a central supply station for materials. If you feel that the large number of choices might confuse some of your students, you may wish to choose one of the examples as a teacher directed model for discussion and assign the others to your students, one example to a group.

   Example #1: Fertilizer/Pesticides on Agricultural Fields - Use colored powdered drink mix to simulate contaminant. Observe the path of the contamination in the model.

   Example #2: Landfill - Bury a paper towel soaked in colored water. Observe the path of the contamination in the model.

   Example #3: Leaking Underground Storage Tank (Gasoline Station) - Bury a film canister punctured with holes and filled with colored water. Observe the path of the contamination in the model.

   Example #4: Abandoned Well - Insert a straw with holes into the model to represent an abandoned well. Pour colored water into the straw to represent pollution. Observe the path of the contamination in the model.

   Example #5: Unlined Sewage Lagoon or Surface Contamination Model - Place a paper cup with holes in the bottom on surface of the model. Pour colored water into the cup to simulate pollution leaking out of the lagoon. Observe the path of the contamination

3. Have the students draw a picture of what their model looks like before they run their simulation. This is an opportunity for them to see any changes as represented in their post-simulation drawing. It is also an opportunity for you to see if the students draw significant features of the model (confined and unconfined aquifers, confining layers, wells, etc.) – if they don't, it may be an opportunity to re-teach some of the important points of this lesson by referring back to the models and drawings they made in activity 3.
4. After helping the students obtain the necessary materials, make sure they don't flood their models by pouring the water too quickly while they are polluting their environment. You may need also to help them with the vocabulary they might need to accurately depict what happened.
5. Have students draw a picture of what actually happened. Provide colored pencils for students to show where the pollution went. Have students compare their predictions with their results.

Activity: 6 – Clean-Up of the Models (30-40 minutes)
Function/Rationale:
This activity:
1) elicits student ideas about potential methods of cleaning-up groundwater, and provides connections between student ideas and professional cleanup practices.
2) builds student understanding of the variety of techniques necessary for adequate pollution control.
3) helps students understand that solving an environmental problem may require a great deal more time, energy, and resources than preventing the problem in the first place.
4) Elicits students' ideas and creative problem-solving strategies.

Directions:
1) Conduct a group discussion of basic groundwater clean-up methods:
   A) Pumping pollutants out of the soil and rocks.
   B) Dig up and remove the contaminated soil.
   C) Bio-remediation - Introducing bacteria that can eat up the contaminants. Much slower than if human induced because the bacteria take a while to find the contamination, if ever.
   D) Natural processes - These processes happen naturally, without participation from humans. However, they take place very, very slowly.
   E) Dilution - Contamination eventually spreads far enough or additional water is added so that concentrations of the contamination are no longer a problem.
   F) Degradation - Some chemicals will break down into other chemicals. Sometimes, these new chemicals are less harmful than the original chemical, but not always.
2) Have groups develop a strategy for cleaning up their models. Encourage students to consider how feasible it would be to implement their clean-up solutions in real life. Point out that they should consider time, cost, disruption of people's lives, and materials necessary to carry out their plan. Have them consider how their models are similar to and different from real situations.
3) Students should implement their plan for cleaning up the pollution in their model. Again, you will need to be sure that students don't flood their models as they try to clean up the pollution.

After students have implemented their plan, the following questions will help them think about the results. You may wish to have the students look at all of the questions before beginning to answer them, in order to help them use their time more effectively. Note that question #6 and #7 are individual response questions.

From Student Pages

5. Did your plan work? _______ As a group, decide why your plan did or did not work.
6. In your group, discuss how your clean-up model is similar to and different from what might happen in real life?
7. Can you imagine this pollution event happening in real life? What kinds of effects could this type of pollution event have on human and other living organisms in a community?
8. Should people care about pollution? Why or why not? Write what you think.
9. How could we prevent this sort of pollution and clean-up problem from happening in the first place?

Activity 7: Wrap-Up & Finish T-Chart (15 minutes)

Function/Rationale:

1. This activity allows students to show what they learned about where water is located underground. It serves as a post-assessment.

2. This activity also allows students to compare what they have learned to their original ideas.

Directions:

1 You may wish to lead a wrap-up session. Make or draw out from students the following points.
   - A. Water exists underground in the spaces between sediment grains or in cracks in rocks.
   - B. Water moves through these spaces. Water moves more easily through larger, more connected spaces in gravel, as opposed to the small spaces in clay.
   - C. Layers of rock or sediment that hold lots of water that we can pump out of the ground are called aquifers. Layers of rock or sediment that water does not move through easily are called aquifers or confining layers.
   - D. Water soaks into the ground from the surface, including the bottoms of lakes and streams. Water can flow out of the ground at springs, and also in lakes and streams. Water can be pumped out of aquifers with wells.
   - E. Aquifers that are beneath confining layers are called confined aquifers. Aquifers that are not below confining layers are called unconfined aquifers.
   - F. Groundwater can be easily contaminated from the surface or underground. Once groundwater is contaminated, it is very difficult to clean-up

2 Re-distribute the "Before & After" T-Charts.

3 Have students draw the picture of what water looks like underground in the "After" side.

4 Have students write 5 complete sentences on the back summarizing what they learned about aquifers. Students should do this activity as homework if there is no time left in class.

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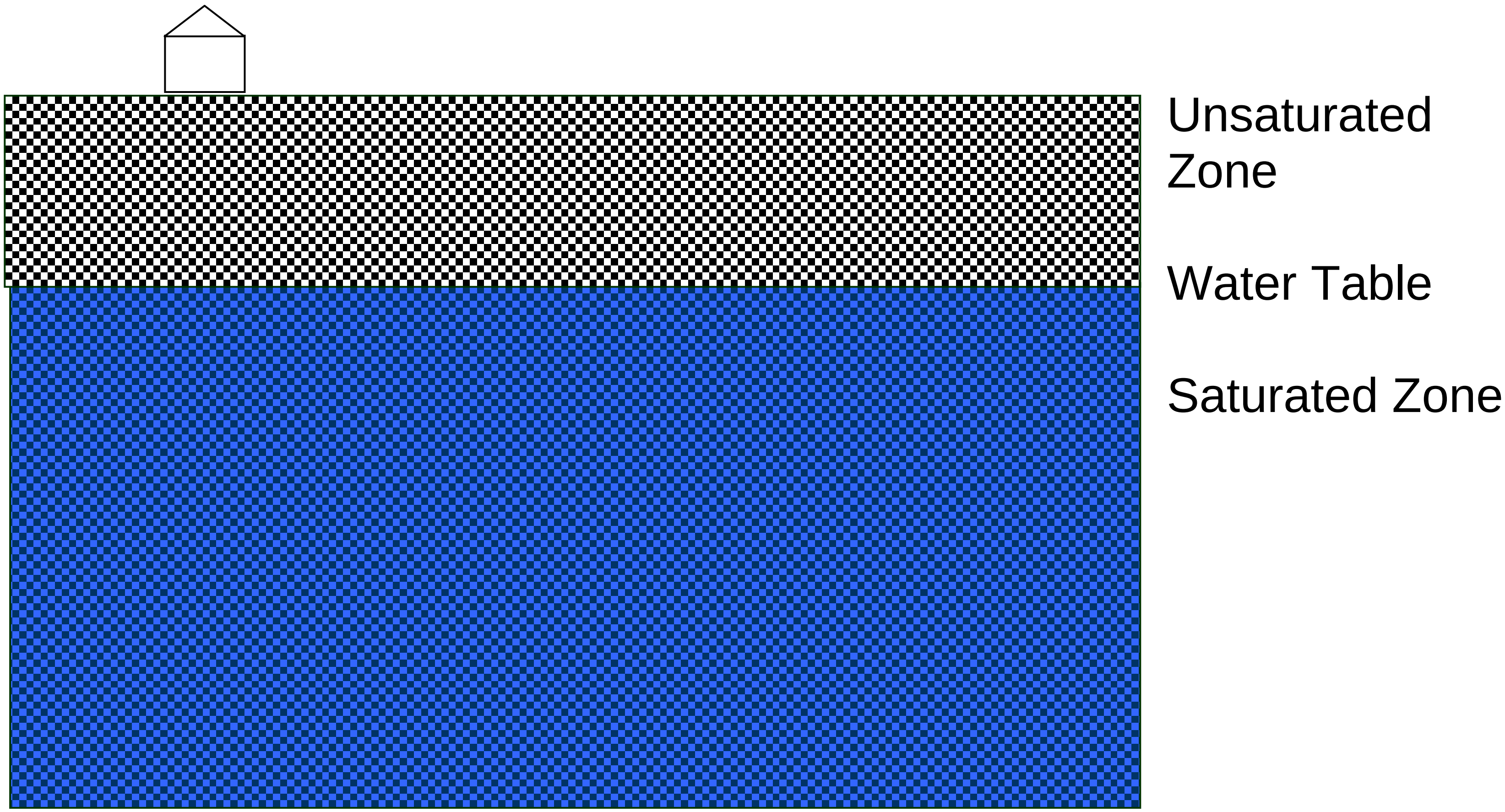
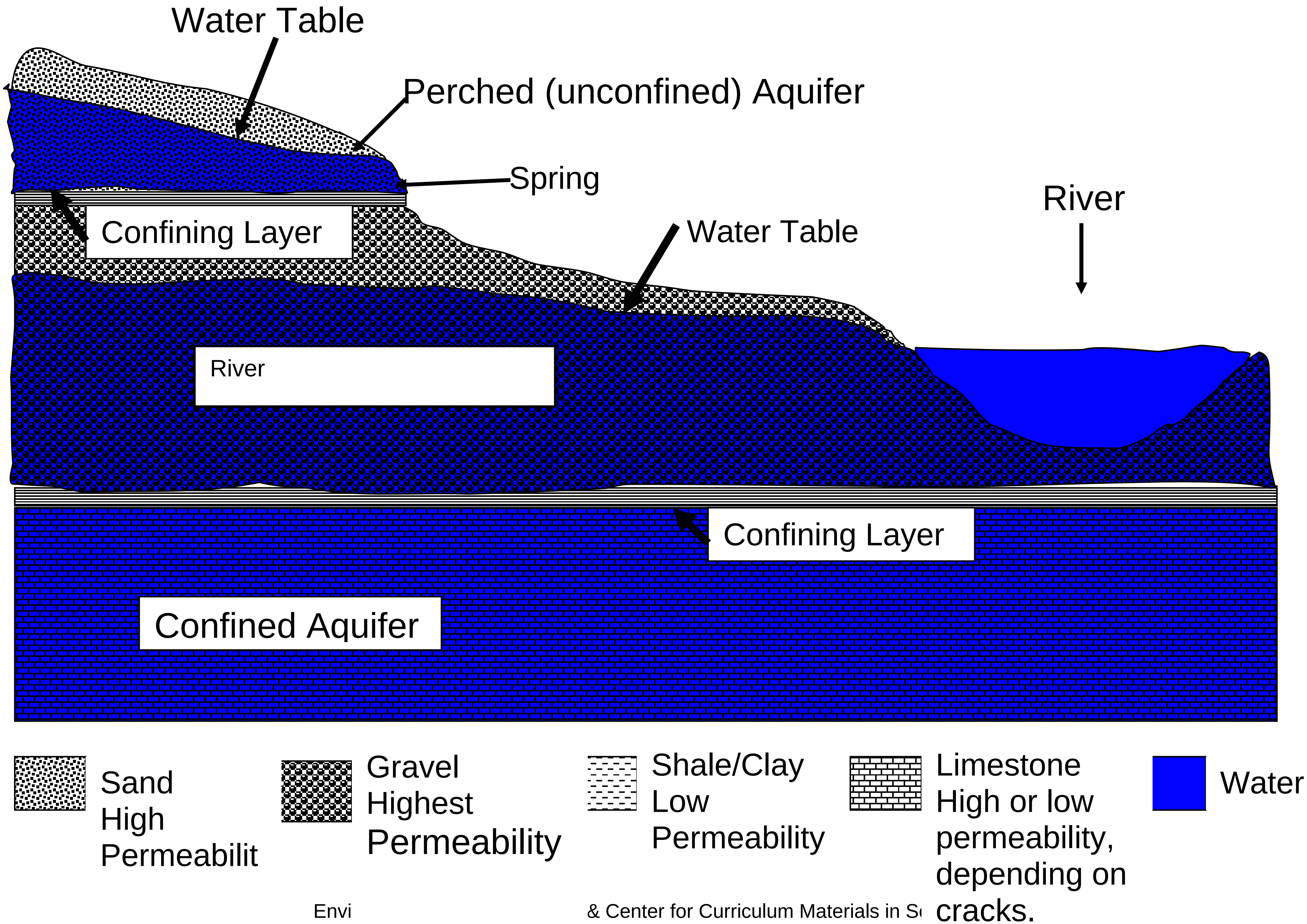
Activity 3 Aquifer Overhead

Aquifer

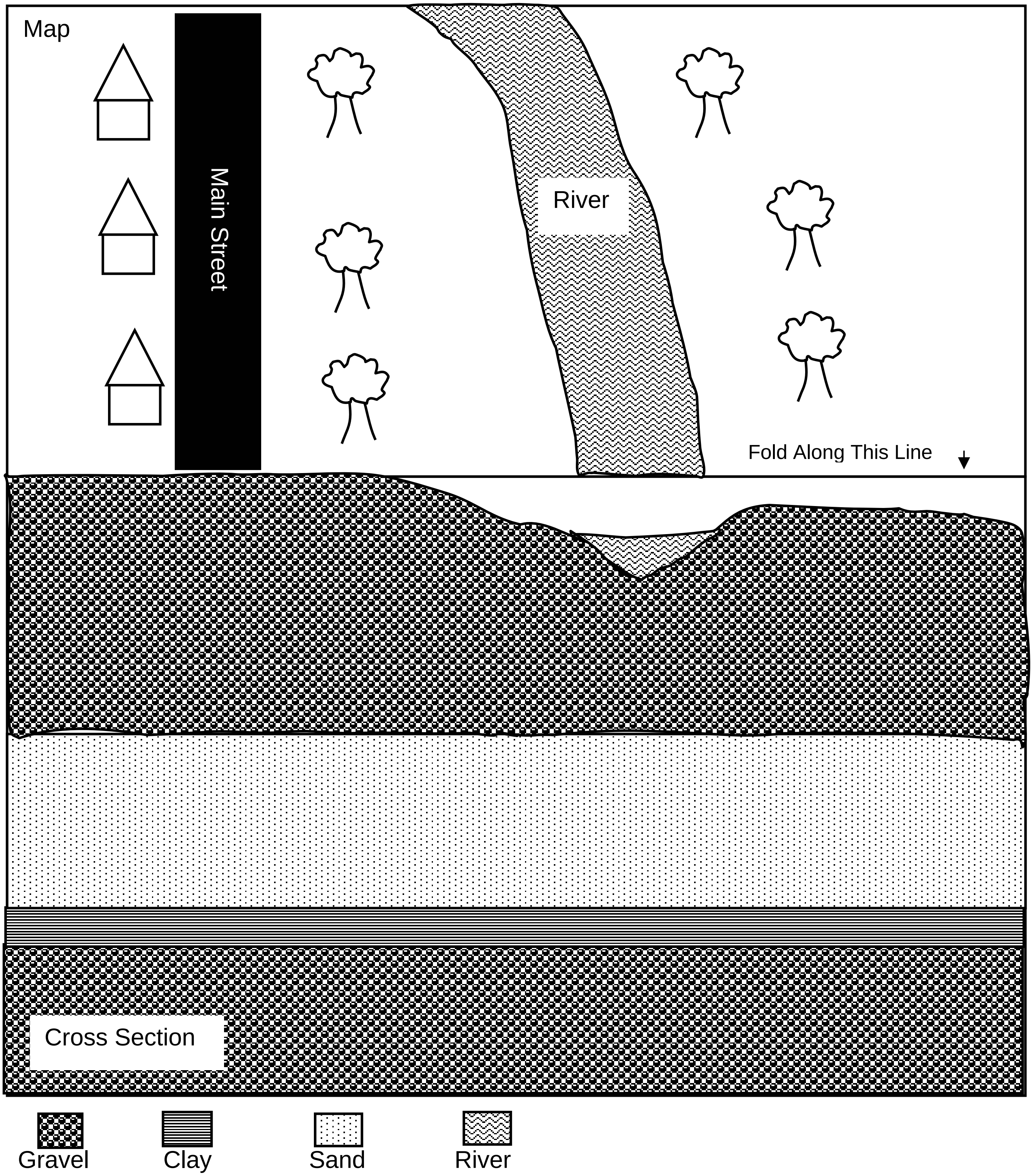
Rock, soil, or sediment that contains water that can be removed for use by pumping or natural flow.



Activity 3 Groundwater System Overview



3 Groundwater Model Plan Overhead



Activity 4 Overhead: Well Problem

Directions

1. You own all of the land in the picture. You need to drill a well for water for your house. You do not want to take the water directly from the river because the river water is not as clean as the groundwater.
2. Examine the picture of the cross-section below. Decide where would be the best place to drill the well so that you will have water all year long.
3. Remember, it costs about $9 per foot to drill a well. So, you don't want to have to spend too much money, but you also want to make sure you have enough water for your house.
4.