The Hydrology of Allegheny County

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Overview

This unit will introduce students, taking Earth and Space Science, to the hydrology of the region in which they live, Pittsburgh and the surrounding Allegheny County. It begins with a classification of the forms that water is found in on earth and what per cent of the earth's total water is represented by these classes.

This will be followed by an overview of the water cycle, water budgets, and the movement of water above and below ground. During this section students will be introduced to the representative characteristics of these topics found in Pennsylvania and more specifically, Allegheny County.

The unit will conclude with an examination of the formation and classification of Pennsylvania rivers.

Rationale

The science course, Earth and Space Science, is characterized by four independent units each nine weeks long. These four units are Geology, Geomorphology, Astronomy, and Meteorology. These units stand by themselves and require no previous knowledge on the part of the students. This paper supplements the material in the first two units on Geology and Geomorphology.

The students who take this subject are typically mainstream students, who have had problems with abstract thinking in other subjects. They typically have problems with higher math. Many of these students take the course as an alternative to Physics or to make up for a failed year in chemistry.

This is a population which benefits from concrete science that is real, immediate, and relevant. If they can see examples of the concepts being presented to them, they can learn the material. What is more significant, they are able to synthesize their new knowledge and apply it to the higher level of understanding indicated by problem solving and critical thinking.

This unit, on the Hydrology of Allegheny County, will give the students concrete examples of the processes they will be learning. The learning will be further enhanced by the unit's relevance to the students, in that they will understand the source and significance of the water they see and use each day.

The proposed curriculum will be applicable to the 11th grade course, Earth and Space Science, which uses the text book "Earth and Space Science" by Spaulding and Namowitz, published by Heath in 1994. The chapters to which this material will be applied are:

Chapter 9	Water moving underground
Chapter 10	Running Water

Why study hydrology?

We all depend on fresh water for life. We need it to drink and to raise the food we live on. We need it for manufacturing, recreation, and sanitation. And yet, despite the fact that roughly 70% of our planet is covered by water, it remains a limited resource.

This is because only 3% of the earth's water is fresh water, most of which is frozen. Only .5 % of the world's water is usable by man. The rest is salt water, which contains too much dissolved salt and other minerals to be drinkable.

Pennsylvania is fortunate in the amount of fresh water it has available. One only needs to look at a map of the state to see more miles of streams per square mile than almost any other state. Yet this surface water is only a fraction of the total fresh water to be found in the state.

There is 30 times more freshwater located underground in Pennsylvania than in all the streams, lakes, and rivers combined. If it were pumped to the surface, Pennsylvania would be covered by fresh water to a depth of 8 feet! Below the fresh water lies even more salty groundwater called brine. This water contains much more salt than sea water and is found at depths from 200 feet to 1000 feet. This brine is left over from seas that covered the state millions of years ago.

Who uses the groundwater?

All of us who live in Pennsylvania depend on groundwater for drinking and other uses. For some, it is well water that they draw directly from the ground of their property. In fact, about half of the households in this state get at least part of their water directly from the ground. This places the state second in the nation for the total number of wells and the total number of household wells. It is third in the nation for the number of public water wells.

But what about the other half of the households? These families get their water from public water suppliers who draw the water from streams and lakes. However, most of the water that is found in streams and lakes came from groundwater flowing to the surface.

Groundwater is also used for agriculture, industry, mining, and commercial purposes. In total, Pennsylvanians use over 1 billion gallons of groundwater per day! In Allegheny County we use up to 63 million gallons of groundwater each day.

The water cycle.

All of the water found in the ground, lakes, oceans, and running water make up the *Hydrosphere.* The movement of water between these places is called the *water cycle*. This movement is powered ultimately by the sun. This cyclic movement has not start or end point, it is continuous.

However, books will generally start the cycle with evaporation of ocean water caused by the heating of the sun. Much of the precipitation that falls on Pennsylvania began as ocean water. Although the average precipitation varies across the state, (fig. 1) the average is 42 inches per year.

Here in Allegheny County we typically will get between 36 and 40 inches of precipitation a year. Precipitation includes rain, snow, and hail. What happens to this total amount on reaching the ground is very important to the state of the groundwater.

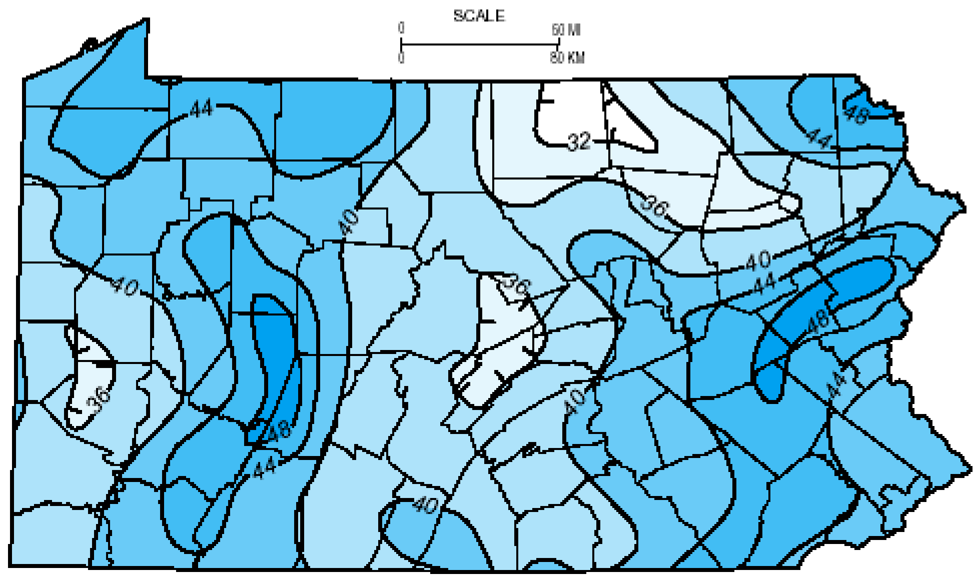
Scientist who study what happens to this precipitation are called *Hydrologists.* They examine precipitation, stream flow, evaporation, transpiration, groundwater, and usage. Evaluating all these measurements helps to determine an areas *hydrologic budget*.

During a rain, some of the water will flow on the surface as *surface runoff.* This water flows directly into the lakes, steams, and wetlands of Pennsylvania. The remainder will soak into the ground or evaporate back into the atmosphere.

Once water soaks into the ground some will be taken up by the roots of plants and be lost through the leaves as *transpiration.* This is often combined with the water lost by evaporation as *evapotranspiration.* With Pennsylvania's many trees, this adds up to a lot of moisture going back up into the atmosphere.

The remaining water flows downward into the ground through a layer which is partly saturated and into the water table. This is a boundary below which all the spaces in the rock and soil are filled with water. This water found in the water table is *groundwater storage.* The water that reaches the groundwater storage recharges it.

The depth of groundwater varies widely depending on geology and topography. Normally it is closer to the surface in valleys and deeper down under hills. Where it intersects the surface, groundwater discharges and becomes surface water. This groundwater discharge is called *baseflow,* and is what keeps the rivers and streams flowing even when there has been no rain.



Average annual precipitation in Pennsylvania in inches.

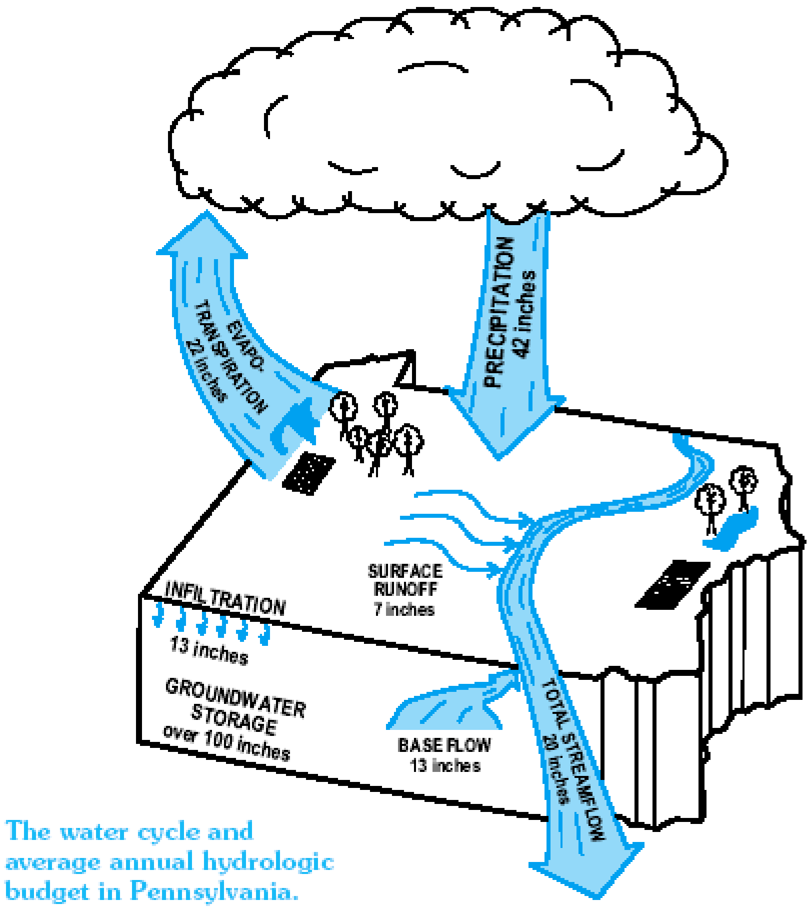
fig. 1

As can be seen in figure 2, Pennsylvania has an average base flow of 13 inches per year. This means that if a years worth of base flow were saved, it would cover the state with 13 inches of water. This figure also shows the average loss of precipitation to surface runoff and evapotranspiration.

The Hydrologic budget

Scientist look at the amounts of precipitation, evapotranspiration, runoff, infiltration, groundwater storage, base flow, and human usage to develop the hydrologic budget. This is important for determining whether we will have enough water to meet our needs.

The hydrologic budget can be looked at like a savings account in a bank. Precipitation would represent your income. Evapotranspiration and runoff represents your expenses, while infiltration is what you have left to put into your savings account. Groundwater storage is your current savings. Withdrawal from your savings occurs in the form of base flow and water withdrawn from wells.



The water cycle and average annual hydrologic budget in Pennsylvania.

fig. 2

Drought

During short periods of time (months to years), it is not unusual for the amount of water entering groundwater storage to be less than the amount leaving. During droughts, more water leaves groundwater storage through base flow and well withdrawal than enters it and groundwater levels drop. Lower water levels in wells and reduced stream flows indicate lower groundwater levels. If the water table drops below a streambed, that streambed will be dry.

Flooding

Flooding, a common situation in Pennsylvania is not related to high groundwater levels.
Rather, flooding is caused by high amounts of surface runoff. This may occur when rain fall rate exceeds the grounds ability to absorb the water or if the ground is saturated by previous rain fall. High runoff also occurs when the ground is still frozen in early spring which makes spring the most dangerous period of the year in Pennsylvania for flooding.

Factors altering the water budget

Human Factors

Humans affect the water budget through their actions. Infiltration is significantly reduced and runoff increased when the ground is covered by roads and parking lots. The runoff is directed to culverts that then carry the water directly to the rivers and streams. This bypasses the ground water storage entirely and ultimately reduces base flow.

Many communities have changed from on lot septic systems to public sewers. This reduces infiltration and recharge of the groundwater. Water that used to be slowly released into the soil from septic tanks is now carried away to sewer treatment facility and then released directly into the rivers after treatment. Once again this bypasses groundwater storage and ultimately reduces base flow.

Humans can also directly reduce groundwater storage by pumping water out of the ground with wells. If this water is not replaced at the same rate at which it is removed, the groundwater level will drop. This may cause wells and streams to run dry.

Natural Factors

Evapotranspiration varies widely through the year. In early spring, when the weather is still cool and the trees have not come in leaf, evapotranspiration is very low. This makes spring a period of maximum infiltration.

As the weather warms, evaporation increases. As the trees come out in leaf, their ability to take up groundwater and release it through their leaves by transpiration increases. Evapotranspiration moves 22 inches of precipitation back into the atmosphere of Pennsylvania each year, more than half the rain that falls.

Water Budget Graphs

Each location on earth has its own unique water budget which is summarized by a water budget graph. This graph shows moisture need and moisture supply. What makes these graphs valuable is their ability to forecast water usage, deficit, recharge, and surplus.

Water in the ground

Rocks and soil can hold water in spaces between particles called pores. The per centage of volume which is pore space is called *porosity.* If the particles are flat or the spaces have been filled in which mineral cement, the porosity is reduced

Rocks transmit water by having it pass through the connected pore spaces. The larger and better sorted the grain sizes are, the better the *permeability.* Sand and gravel have very good permeability because it is sorted and the particles are round. Clay and shale have poor permeability because the particles are flat. Clay and shale are said to be impermeable. However, if the shale has been cracked, the cracks will allow water to flow through the impermeable rock.

Forming the water table

1. Rain falls to the ground and enters the pores of the soil
2. When the upper layer is saturated, water begins to sink down until it hits an impermeable layer
3. From this impermeable layer, the pores fill up and the water piles up in a *zone of saturation*
4. The top of the zone of saturation will be the *water table*

Water table use

Seepage from the water table keeps streams and rivers flowing, even during dry periods. This seepage maintains the level of lakes and swamps as well as the water level in wells. Where the water table meets the surface on hill sides, springs are formed.

Pittsburgh Rivers

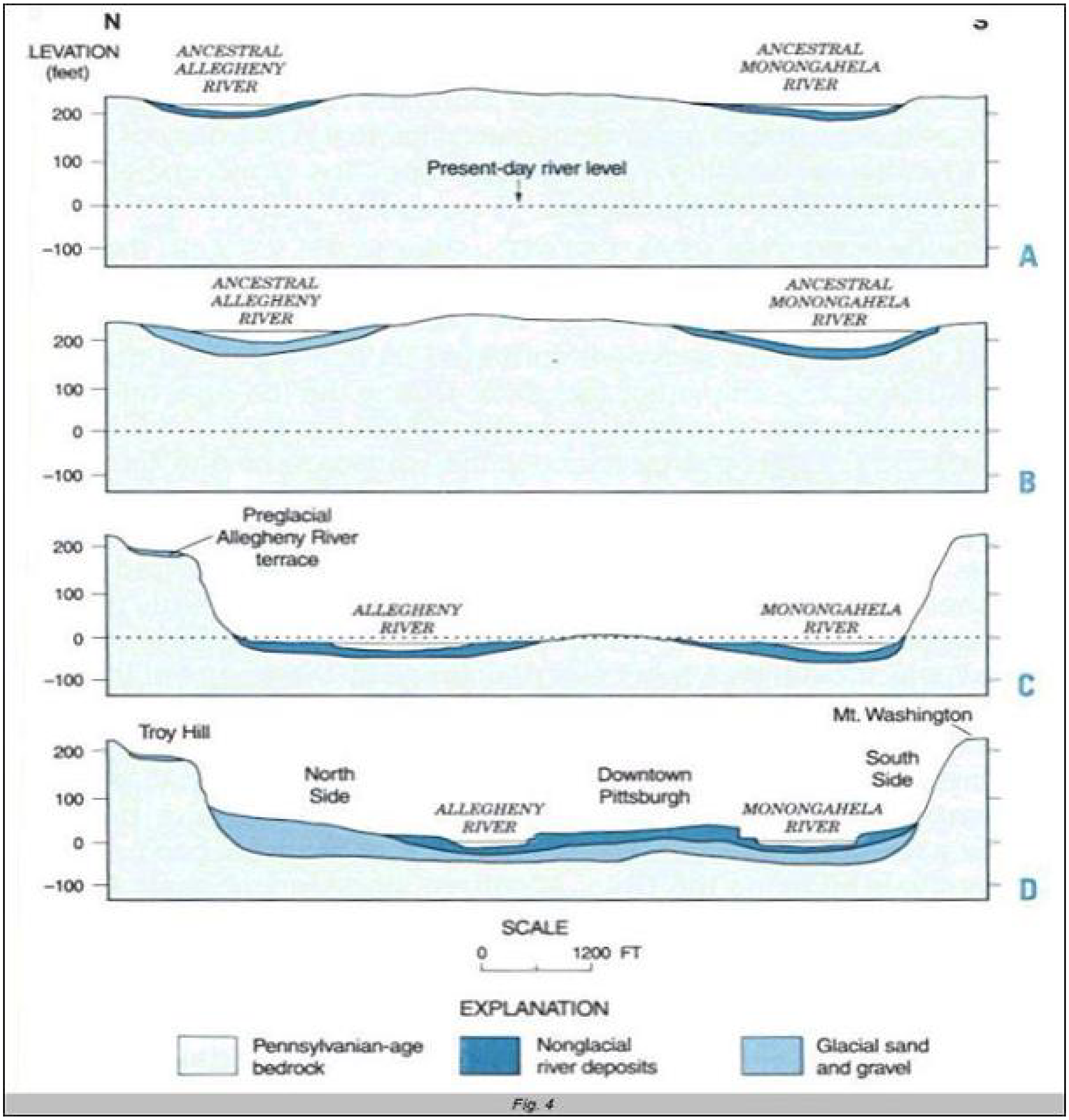
During the early Cenozoic, western Pennsylvania was a broad rolling plain. The rivers that exist now are mainly in the same courses they occupied then. Since the land was so flat, the rivers flowed in broad meandering flat valleys. Being close to their base level they widened rather than deepened their valleys. The remains of this flat plain are found on the top of the flattened hills in Squirrel Hill, the Allegheny airport, Mount Lebanon, and parts of East Wilkinsburg.

In the late Cenozoic the region was uplifted. This increased the gradient of the rivers, which caused them to flow faster. As a consequence, they began to cut down rapidly forming deep valleys 300 to 400 feet below the plains surface.

As the rivers cut down, their flow slowed and they began to cut sideways, enlarging and defining the valleys. These valleys then became stranded 200-330 feet above the present stream levels. These remnant valleys can be seen along side the rivers. This sequence can be seen in the cross section illustrated in figure 4.

Cross section A. Before the first glaciation about 770,000 years go, the rivers flowed in shallow valleys amid low relief plains.

Cross section B. During an early Nebraskan glaciation, increased runoff helped carve the river channels deeper while filling the Allegheny Valley with glacially derived sand and gravel.



Development of the Allegheny and Monongahela River valleys over the past 1 million years. From Pennsylvania Geology, Vol. 28, No. 3/4.

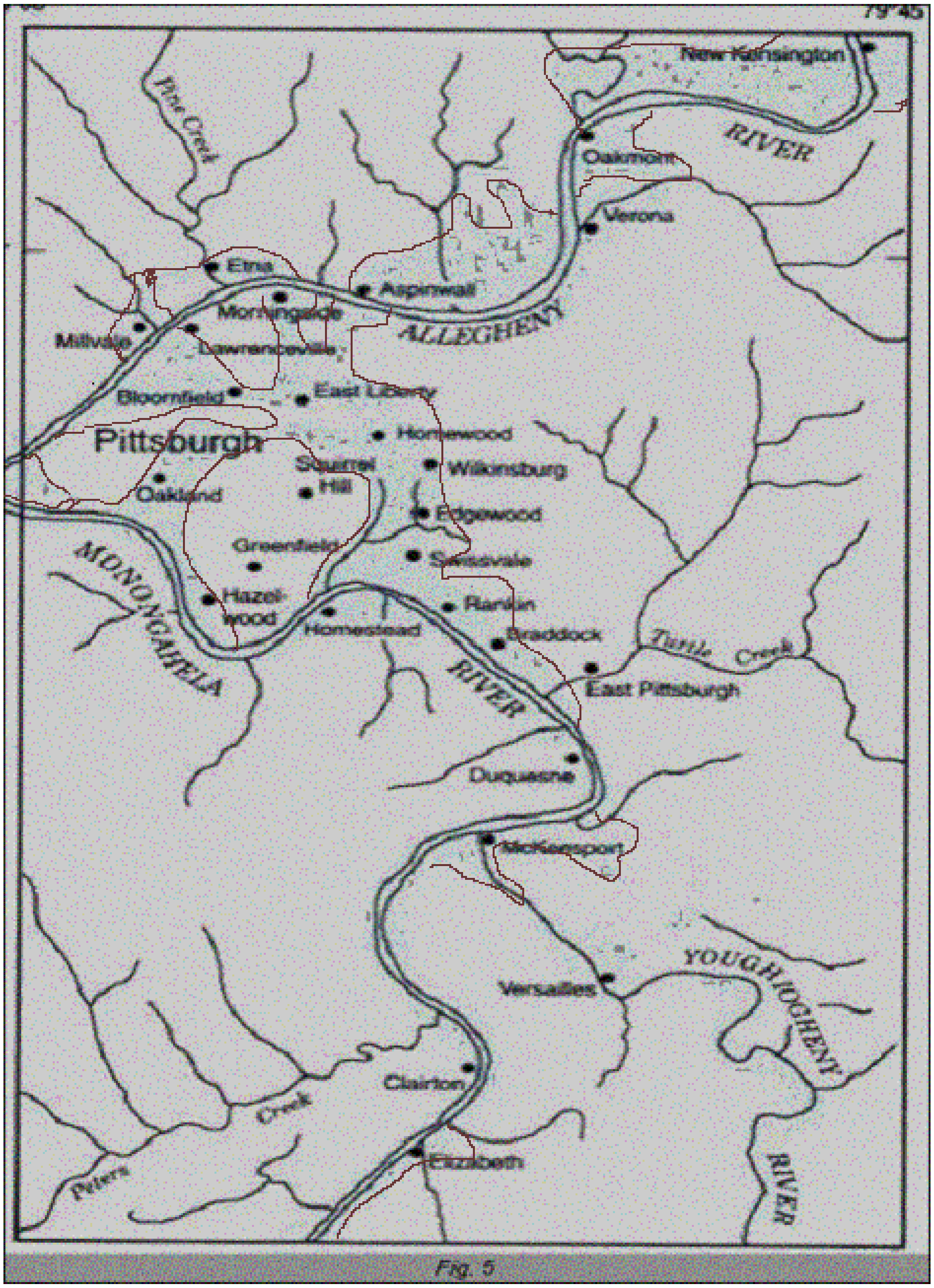
Cross section C. Following the initial glaciation, the rivers began to cut downward and laterally into bedrock as the land began to rise. During successive glaciations, this created a single very wide valley at present day Pittsburgh and left remnants of the old river valley floors 200 to 250 feet above the present river level.

Cross section D. During the last glaciation the Allegheny River cut down a little more and filled the entire valley with glacially derived sand and gravel.

The most important of these valleys is the one that leaves the Monongahela River at Rankin and loops up through Swissvale, Homewood, and Shadyside, back down through Oakland and back to the Monongahela River (fig. 5). This broad flat valley is the only direct path to Pittsburgh from the east. As such, the principal east-west streets of Pittsburgh, as well as the Pennsylvania railroad mainline follow this remnant valley.

Urbanization grew up first around this valley because of the desire for proximity to these routes. Only much later did settlements move onto the surrounding hills to the north and south of this valley. Excavations into this remnant valley reveal sediments up to 40 feet deep. These were deposited during the last glaciation.

Since these sediments are made up of loose sand and gravel sitting on top of bedrock, this area has plentiful ground water storage capacity. However, since most of this area is now paved over with streets and parking lots, most recharge runs off into storm sewers.



From Pennsylvania Geology, Vol. 28, No. 3/4.

Pittsburgh and the Glacier Age

As has been mentioned before, Pittsburgh was initially settled because of the strategic confluence of the three rivers. Only later did the mineral resources of the region become significant. The origin of these three rivers goes back to the last ice age when a great wall of ice stood to the north of Pittsburgh.

Before the last ice age, the major river in the region was the Monongahela River. It flowed in its present channel north to where Pittsburgh is now. It then turned into the current channel of the Ohio, up to Beaver, and then northwest past New Castle and into the Erie basin. The Ohio was but a tributary of the Monongahela River.

The Allegheny River was unrecognizable at this time since it was three separate rivers draining different parts of the state. All of these rivers eventually drained northward into the Erie basin.

Then, 770,000 years ago the ice advanced into Northwestern Pennsylvania. The great wall of ice blocked the rivers flowing northward, acting like a dam. A huge lake, called Lake Monongahela was formed and grew deeper and deeper. Eventually it became so high it overflowed the divides that separated the streams. This overflow could only go south.

And so the Upper Allegheny joined the Middle Allegheny and the two flowed southward to join the Lower Allegheny making one south flowing river. Meanwhile, the Monongahela backed up and overflowed down the Ohio tributary and cut the divide between the Ohio River and the Kanawha River. All the drainage in the area then headed south and west towards the Mississippi river.

As the glaciers melted, huge quantities of water and sediment were carried south deepening the river valleys. Before the ice age, the rivers in the area meandered back and forth on a flat plain. Afterwards, river valleys cut across the former plains. This cutting down continued at a rapid rate, even after the flow of water from the melting glaciers abated. This is because with the removal of the massive weight of the glaciers, the land literally rebounded upwards. This resulted in the maintenance of a steep gradient for the rivers to flow down, which gave them great erosional energy.

Two subsequent glacial advances, renewed periods of rapid cutting and deposition in the area. This has given Pittsburgh its unique terrain of multiple abandoned river channels up to 200 feet above the current riverbeds. These are the channels that became the prized areas of settlement and routes of transportation into Pittsburgh.

The last of these advances of ice ended 10,000 years ago, and left a large supply of sand and gravel from glacial runoff. Many of the rocks found in the gravel of the Allegheny may have been transported clear from northern Canada.

Objectives

Student will be able to:

Describe the distribution and quantity of freshwater on the earth

List the parts of the hydrosphere, and describe the movement of water in the water cycle.

Identify the conditions under which ground water surplus, usage, deficit, and recharge occurs.

Explain how the climate of Pennsylvania affects local ground water formation and flow.

Describe the effect of human activities on the formation of ground water.

Explain how ground water movement is affected by different materials.

Identify and describe underground regions above and below the water table, and describe the importance of the water table.

Strategies

Students will be given a series of lectures using the material provided in the rationales section to give them the background material needed for the learning objectives. Interspersed between lecture sections, classroom activities and assignments will be given. These will include hands on labs and written assignments.

Classroom Activities

I. Permeability and Porosity

Brief Description:
Students will conduct simple experiments to determine pore space and permeability of gravel, sand, and clay.

Key Terms:
Porosity of a rock or rock material indicates how much of the total volume is air.
Permeability of a material is its ability to transmit water and or other liquid.

Materials:
Gravel, sand, clay, funnel, filter paper, glass-marking pen, graduated cylinder, small test tubes, glass bottles, ring stand, stopwatch.

Procedure:
A. Porosity

1. Mark a bottle, beaker, or test tube about half way up the side.
2. Fill the bottle with water to this mark and measure the volume using a graduated cylinder. This measurement will be the total volume.
3. Dry the bottle and fill it to the mark with gravel.
4. Using a graduated cylinder, slowly pour water into the gravel until the water reaches the top of the gravel.
5. Note the volume of water added to the gravel. This measurement is the pore space.
6. To determine the total % pore space in the gravel, divide the pore space volume by the total volume times 100. (% Pore Space=Pore Space/Total Volume x 100)
7. Repeat with sand and clay.

B. Permeability

1. Fold a piece of circular filter paper into quarters, open it so it is a cone, and place it in a funnel.
2. Fill the cone with gravel to about half an inch from the top.
3. Place the stem of the funnel in a bottle or graduated cylinder.
4. Pour water into the gravel in the funnel and note how many seconds it takes to fill the glass bottle or graduated cylinder.
5. This gives you a comparative permeability rate.
6. Repeat with sand and clay.

Variations/Extensions:

1. Mix the sand, gravel and clay in various proportions and repeat the experiment.
2. Collect soil samples from various locations and depths and repeat the experiment.

II. Groundwater Flow Model

The activities in this section are designed to be used with a groundwater flow model. The flow model helps students to conceptualize the workings of an aquifer. Commercial models are available or inexpensive ones can be made. I have included instructions for constructing a flow model out of a two liter bottle.

A typical groundwater flow model

Concepts/Topics that can be demonstrated with a typical Groundwater Flow Model:

- Groundwater will flow from upland areas to low areas
- Groundwater and surface water are related
- Discharge/Recharge
- Zones of Saturation/Water Tables
- Materials in an aquifer affect rates of flow
- Percolation
- The affects on the water table due to pumping wells (cone of depression)
- Infiltration
- Contamination and leaching
- Movement of contaminants/Persistence of Contaminants

Inexpensive Groundwater Flow Model Plans
Materials:
2 liter clear plastic bottle, transparent straws, plastic syringe, washed pea gravel, sand, topsoil.

Procedure:

1. Cut the top off the two liter bottle
2. Place at least two inches of gravel on the bottom of the bottle.

3. Position the two straws into the container and layer three inches of sand on top of the gravel. Make sure you hold the straws in place as you pour in the sand.
4. Add two inches of top soil on top of the sand.

Please note that you can change the composition of the layers to make the ground flow model more consistent with your area.

Two liter groundwater flow model activity

Procedure:

1. Add water to the model slowly to saturate the sand and gravel layers.
2. Ask students to predict what will happen if the water is drawn off (using a syringe) through one of the straws.
3. Insert a syringe into one of the straws and withdraw some water. Observe what occurs.
4. Move the syringe to the other straw and remove water through it. Note the effect on the level of the groundwater (cone of depression).
5. Repeat the experiment.

Variations/Extensions:

1. Inject food coloring into one of the wells (straws) to represent a contaminant. Observe how the contaminant enters the groundwater and how pumping from the other well affects its movement.
2. Investigate how different soils influence the movement of contaminants.
3. Make two depressions representing land fill sites. Line one with plastic and fill both with sand. Pour colored water into both depressions and observe how the contaminant moves.

III. How Soils Affect Water Movement

Brief Description:
Students will measure soil volume and make visual observations about water movement through soil.

Key Terms:
Percolation is the downward flow or seepage of water through the pores of rocks and soil.
A **Zone of Saturation** is an area where all pore spaces are filled (saturated) with water.

Materials:
The following is a list of materials that should be distributed to each lab group participating in this activity.
4 Large Paper cups, sand, topsoil, gravel,4 plastic coffee can lids or similar objects, cheesecloth or nylon stockings, rubber bands, four 250 ml beakers, thumbtacks, stopwatch.

Procedure:

1. Students should use a paperclip to poke several holes in the bottom and lower portion of each. Each cup should have the same number of holes located approximately in the same spots.
2. Put a piece of cheese cloth over the bottom of each cup so that the holes are covered, and secure the cheese cloth with a rubber band.
3. Cut a hole in the coffee lid with a pair of scissors so the cup fits in the lid. Repeat with other lids and cups.
4. Place the cups so they sit with the lid resting on the top of a beaker. (The bottom of the cup should be inside the mouth of the beaker.) Label the cups A, B, C, and D.
5. Fill cup A half full with soil, cup B half full with sand, cup C half full with gravel, and cup D half full with equal amounts of soil, sand and gravel.
6. Tell the students to predict which soil will percolate the fastest and ask them to predict how long it will take for this to occur.
7. The students should measure 100 ml of water and pour it into cup A.
    - Students should record the time it takes for 50 ml of water to drain into the beaker.
    - Students should make observations about the appearance of the 50 ml of water recovered.
    - Students should allow the water to drip for a total of 20-25 minutes and record the total volume of water recovered.
8. Repeat the procedure for cups B, C, and D.
9. Compare and discuss results.

Variations/Extensions:

1. Have students calculate percolation rates and graph results. Students can also determine water retention for each sample.
2. Use different soil types and mixtures.
3. Compact the soil and repeat the experiment or ask the students to speculate how soil compaction might affect percolation.

Annotated Bibliography/Resources

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Appendix A

Content Standards

Pittsburgh Public Schools Science Standards Addressed

1. All students explain how scientific principles of chemical, physical, and biological phenomena have developed and relate them to real-world situations

2. All students demonstrate knowledge of basic concepts and principles of physical, chemical, biological, and earth sciences

3. All students explain the relationships among science, technology, and society

4. All students evaluate advantages, disadvantages, and ethical implications associated with the impact of science and technology of current and future life

5. All students evaluate the impact on current and future life of the development and use of varied energy forms, natural and synthetic materials, and production and processing of food and other agricultural products

Appendix B

Lecture Notes

These notes are designed to be used with sections 9-1 and 9-2 of the Earth science textbook being used in the Pittsburgh school system for 11th grade. But may be used as part of any unit on ground water. I prefer to print these on an overhead and have students copy them into their notebooks as visual organizers of the key concepts.

9-1

Fresh water and water budgets

Freshwater distribution

- 3% of the water on earth is freshwater
- 2/3's of the worlds freshwater is frozen
- only .5% of the earth's water is usable by humans

The water cycle

- The hydrosphere consists of water found in oceans, underground, in lakes, rivers, and the atmosphere
- The water cycle is the movement of this water from one part of the hydrosphere to another
- Sunlight provides the energy to drive the water cycle

The water budget

- Income consists of precipitation such as rain and snow
- Savings consists of lakes, groundwater, and dams
- Spending consists of evaporation, transpiration, runoff, and human usage.
- When income exceeds spending savings gets recharged and water is stored in the ground
- When savings is filled, the surplus becomes stream runoff
- If usage exceeds income, water is drawn from savings
- If the savings is used up, and usage still exceeds recharge, a deficit occurs

Water budget graphs

- Each location on earths has its own u unique water budget which is summarized by a water budget graph
- This graph shows moisture need and moisture supply
- Periods of water usage, deficit, recharge, and surplus can be determined from the graph

9-2

Water in the ground

Can rocks hold water?

- Rocks and soil hold water in spaces between particles called pores
- The per centage of volume which is pore space is called porosity
- Poor sorting, flat particles, and cement between the particles reduce porosity

Can rocks transmit water?

- Rocks can transmit water by having the liquid pass through connected pore spaces
- The larger and better sorted the grain sizes are, the better the permeability.
- Sand and gravel have very good permeability
- Clay and shale are impermeable because the particles are flat
- Non porous rocks may become permeable if the they are cracked

Forming the water table

- Rain falls to the ground and enters the pores
- When the upper layer is saturated, water begins sinking down until it hits an impermeable layer
- From this layer, the pores fill up and the water piles up in the zone of saturation
- The top of the zone of saturation is the water table

Water table use

- Seepage from the water table keeps streams flowing
- Seepage maintains the water level in lakes and swamps
- Drinking water from wells and springs are fed from the water table

Wells and springs

- Wells are holes dug down to below the water table, the top of the water in the well is at the water table top
- Springs appear at places where the water table meets the surface, such as on a hillside
- Water tables rise and fall depending on the amount of rain