PERSPECTIVES ON WATER USAGE IN MICHIGAN AND THE GEOLOGY OF THE ICE MOUNTAIN SITE

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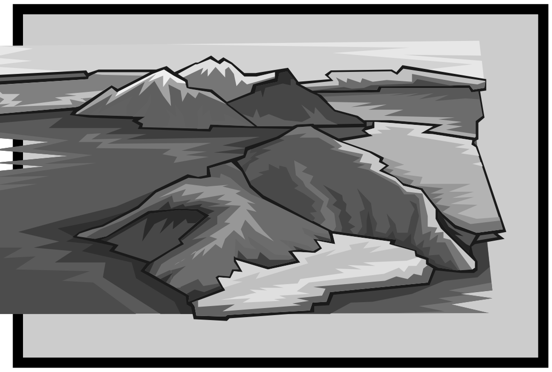
Introduction



Protection of water resources is vital to the economic well-being of Michigan. Potential out-of-basin water diversion projects and the ongoing controversy of the Ice Mountain bottled water plant receive considerable attention. Although society asks us to judge the merits of water use, the public and our students commonly lack a broader view of water resources and a realistic image of groundwater resources.

In this article we provide three perspectives on water in Michigan. We start with a simple engage activity to assess students' prior knowledge regarding water sources, usage, and volumes. In the second activity, we balance the hydrologic budget of the upper Muskegon River watershed and compare Ice Mountain's withdrawal to the overall budget. In the third activity, we use a geologist's set of field notes to construct a geologic cross-section of the unconfined aquifer at the Ice Mountain site. We conclude by suggesting activities to make the lesson relevant to your watershed.

Perspectives on Water Use in Michigan: How Much is Too Much Water?

Students and the public often carry naïve conceptions regarding the volumes and usage of water resources. To access students' knowledge as they enter the lesson we developed a simple activity, How Much is Too Much Water?, that could be used as a handout or overhead (Figure 1). We selected a variety of water uses. They reflect several orders of magnitude in water consumption. Instruct your students to match the users to the appropriate daily volume. Since the students' prior knowledge is probably limited, do not require the correct answers. The goal of the activity is to engage the students' interest and introduce them to how water is used and in what volumes. Answers. The main sources of water in Michigan are surface water from Lake Michigan or Huron and groundwater from shallow, unconfined aquifers. To check your local source visit the U.S. Environmental Agency's Michigan Drinking Water website (www.epa.gov/ogwdw/dwinfo/mi.htm). 1.F, 2.A, 3.D, 4.C, 5.B, and 6. E.

The Hydrologic Cycle

How many gallons of water moves through a typical Michigan watershed? Estimating the amounts in each part of the water cycle can be done relatively easily but the numbers can get large very quickly. The general formula is:

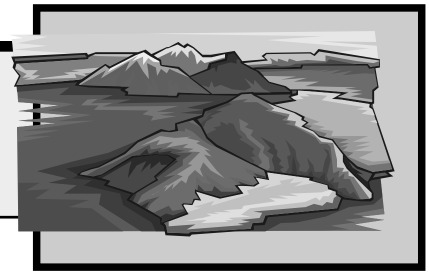
+ precipitation = – evaporation/transpiration – groundwater recharge – river discharge – consumed

We started by selecting the watershed of the upper Muskegon River and visiting the U.S. Geological Survey's Surface-Water Data for Michigan (waterdata.usgs.gov/mi/nwis/sw). This watershed contains the Ice Mountain site. To estimate the amount of precipitation we visited the National Weather Service website (www.nws.noaa.gov/). Data was available for Big Rapids, the largest city in the watershed. Big Rapids receives 34.95 inches of rain per year.

According to the U.S. Geological Survey the area of the watershed is 2,313 square miles above Croton. It takes three steps to determine how many gallons of water are received per year.

1. Calculate the area of the watershed in square inches:

$$2{,}313\ \text{mi}^2 \times \frac{5{,}280^2\ \text{ft}^2}{1\ \text{mi}^2} \times \frac{12^2\ \text{in}^2}{1\ \text{ft}^2} = 9.285 \times 10^{12}\ \text{in}^2$$



2. Calculate the volume of water the watershed receives each year:

$$9.285 \times 10^{12}\ in^2 \times \frac{34.59\ in}{yr} = 3.211 \times 10^{14}\ \frac{in^3}{yr}$$

3. Convert cubic inches to gallons:

$$3.211 \times 10^{14}\ \frac{in^3}{yr} \times \frac{0.004329\ gal}{in^3} = 1.390 \times 10^{12}\ gal$$ (a bit over a trillion gallons per year)

Where does all this water go? The U.S. Geological Survey (Hanson, 1991) has studied the distribution of water to different parts of the water cycle. On average, for the conterminous United States, 67% is lost to evapotranspiration, 29% goes to surface water outflow, 2% supplies ground water, and 2% is consumed (Table 1). Although these data serve as a starting point for understanding the water cycle they lack detail specific to our state or watershed.

Fortunately, more accurate data exist for each component in the water cycle in Michigan (see Table 1 for compilation). Evapotranspiration rates for individual states are detailed in Hanson (1991). The rate for Michigan is "less than" 15 inches per year (similar to the rates for most western states). We used 13 inches per year as a starting estimate in our calculations. The surface water outflow from the basin can be estimated by the using online historical data for the Muskegon River at Croton, Michigan provided by the U.S. Geological Survey (water.usgs.gov/cgi-bin/daily_flow?mi). We averaged the eight years of data for annual mean steam flow ($9.988 \times 10^{13}\ in^3/yr$) and compared it to the volume of water the watershed receives each year to determine that 31% of the rainfall (equivalent to 10.72 inches of rain) leaves the watershed as surface water. An estimate of groundwater recharge is provided by Holtschlag (1996). He reported a recharge rate of 10.5 inches of water per year near the town of Morley in southwest Mecosta County (equivalent to 32.3% of the water budget). U.S. Environmental Protection Agency (cfpub.epa.gov/surf/state.cfm?statepostal=MI) provides online data for water usage for the Muskegon River watershed (data for 1990). In the watershed, about 0.8% of the water is consumed for human use.

A quick glance at our models shows our water losses, 34.49 inches per year, is just less than the 34.59 inches of rain the watershed receives in an average year (Table 1). Of the five parameters listed the evapotranspiration rate is the most poorly constrained. Hanson (1991) reported a rate of "less than" 15 inches per year and we conservatively used a value of 13inches per year. If the actual value is a bit greater than the 13 inches per year our estimates of the gains and losses within the watershed would be balanced.

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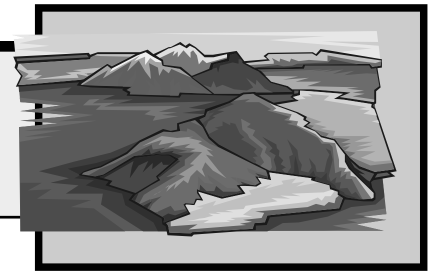


	+ precipitation	–evaporation/ transpiration	- surface water outflow	– ground water recharge	– consumed
U.S.G.S. national average[a]		67%	29%	2%	2%
Percents for upper Muskegon River watershed		37.54%	31%[b]	30.4%	0.8%[d]
Water budget for watershed (in/yr)	+34.59	-13[a]	-10.72	-10.5[c]	-0.27
Water budget for watershed (gallons/yr)	1.390×10^{12}	5.22×10^{11}	4.31×10^{11}	4.23×10^{11}	1.11×10^{10}
Approximately (gallons/yr)	1.39 trillion	522 billion	431 billion	423 billion	11 billion
Compared to Ice Mountain	8×10^{-5} of rainfall or 0.008%	2.1×10^{-4} of evap/trans or 0.021%	2.6×10^{-4} of surface or 0.026%	2.7×10^{-4} of groundwater or 0.027%	1.0×10^{-2} of consumed or 1%

Table 1. Distribution of water within the water cycle of the upper Muskegon River watershed.

Consumed means the water is used by people, animals, plants, and industrial and commercial processes. Sources of data: a = Hanson (1991), b = U.S.G.S. online historical data for the Muskegon River at Croton, MI, c = Holtschlag (1996) for Morley, MI, d = U.S. E.P.A. online data for Muskegon River watershed, data for 1990. Bold numbers were the published or estimated values used to approximate the water budget.

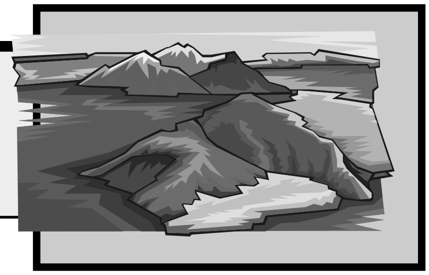
A visual scale might help students better grasp the relative amounts of water. Table 1 also shows the distribution of rainfall between these different parts of the water cycle from the perspective of inches per year. Figure 2 shows a photograph of a column of water 34.59 inches tall, the amount of rainfall the watershed receives each year. If we distributed the rainfall between the different parts of the water cycle, 13 inches would be lost to evapotranspiration, 10.5 inches would recharge aquifers, 10.72 in would flows across the surface, and 0.27 in would be consumed. The amount of water removed by Ice Mountain, drawn at this scale, would be 2.85×10^{5} in., a tiny fraction of the thickness of the period at the end of this sentence.

How does the groundwater removed by Ice Mountain compare to other parts of the water cycle in the watershed? The company currently removes 313,920 gallons per day or 114,580,000 (1.14×10^{8}) gallons per year. Table 1. shows the amount of water Ice Mountain removes compared to the overall water budget. Ice Mountain is using about 0.008% of the rainfall that lands within the water shed. It is removing a small percent (0.027%) of the groundwater in the basin.

Geologic Cross-section of an Unconfined Aquifer: Insights into Ice Mountains Geology

The geology at the Ice Mountain site is typical of many of the shallow, unconfined aquifers in the state. By using a hypothetical set of geologist's field notes to construct a geologic cross-section of the aquifer, students will gain insights into shallow aquifers near their homes. The exercise will also provide a better understanding of where the water in Ice Mountain bottles comes from.

Students need to read the field notes (see page 59) and plot the data on figure 3.



Generalized Geologic Cross-Section of Ice Mountain Well Sites

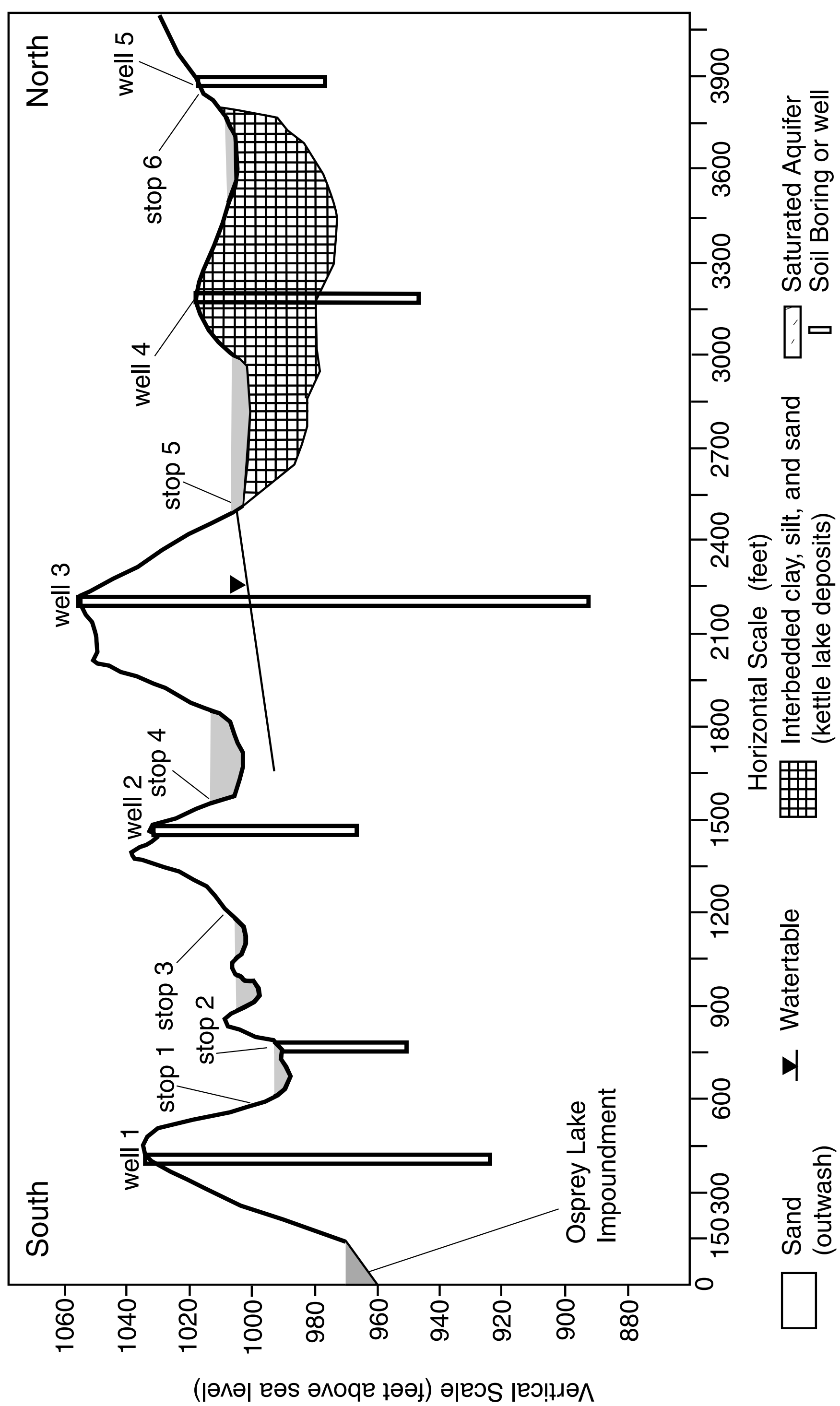


Figure 3. Incomplete cross-section of the shallow, unconfined aquifer at the Ice Mountain site.

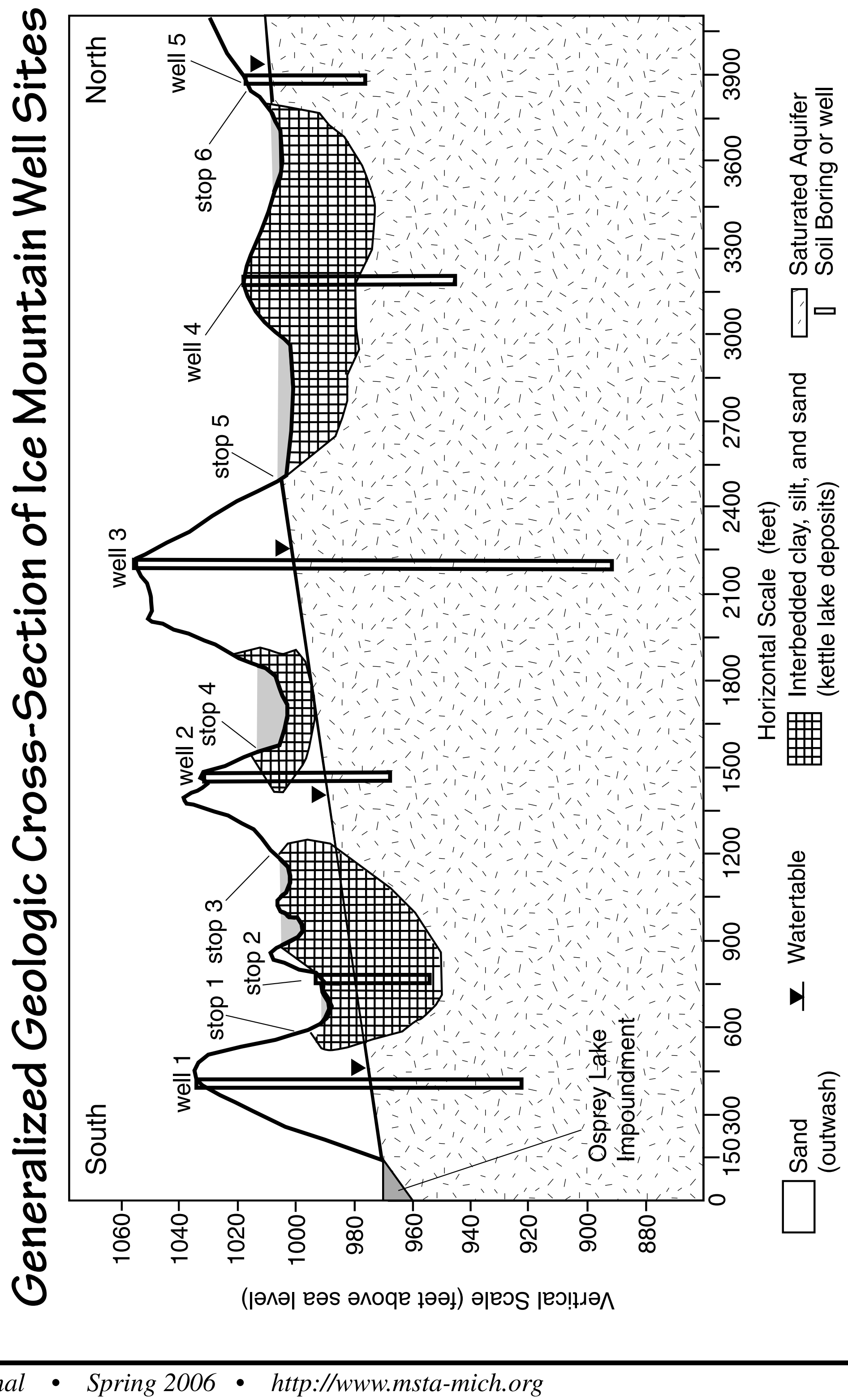


Figure 4. Complete cross-section of the shallow, unconfined aquifer at the Ice Mountain site. Cross-section courtesy of Malcolm Pirnie

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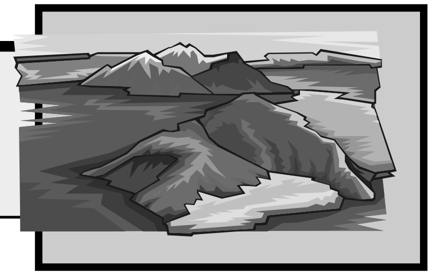

An incomplete cross-section of the geology beneath the Ice Mountain site, Mecosta County, Michigan. Based on data from Malcolm Pirnie Inc.

A complete cross-section of the geology beneath the Ice Mountain site, Mecosta County, Michigan. Based on data from Malcolm Pirnie Inc.

The geologist started to compile some of her data on the cross-section. Her information demonstrates how to plot the field data. A completed cross-section is shown in figure 4. The exercise assumes basic knowledge of geologic cross-sections, unconfined aquifers, the water table, and perched water or aquifers. Additional background on shallow, sand and gravel aquifers is available at the U.S. Geological Survey web site "Aquifer Basics" (capp.water.usgs.gov/aquiferBasics/). Note: some of the small lakes in the area are "perched" above the water table. Perched conditions arise when an impermeable layer (such as clay) prevents surface water from migrating downward to the water table. Also, the wells shown in this cross-section are not at the location of wells for Ice Mountain. We provide a set of questions (see below) to guide students towards some of the more relevant observations in the exercise.

Extensions

Our description of the hydrologic cycle was specific to the watershed of the upper Muskegon River. The web resources provided in that section apply to nearly all the major watersheds in Michigan. Teachers could guide their students through a similar exercise designed specifically for their own watershed. To check water usage in your watershed visit the U.S. Environmental Agency's Surf Your Watershed website (cfpub.epa.gov/surf/state.cfm?statepostal=MI). Students' might match the water usage to parts of the water cycle and suggest potential actions to reduce water loss.

The exercises raise other interesting questions. Why is Michigan's evapotranspiration rate lower than the national average? We suspect our longer winters and cooler climate plays a role. Why is Michigan's groundwater recharge rate higher than the national average? The abundance of glacial material that blankets most of the state probably enhances recharge. What water losses might be modified to increase the availability of water for human consumption? Answers will vary but we suggest examining ways of reducing water loss from evapotranspiration and water consumed by human activities.

Conclusions

The Content Standards in the Michigan Curriculum Framework call for all students to explore and understand the hydrosphere. Our lesson addresses how water moves below the Earth's surface; relationships between the hydrosphere, regional climates, and human activities; and rate of water use. We hope these exercises guide students to an understanding of critical knowledge regarding groundwater in Michigan.

Acknowledgements

This paper was improved by the thoughtful reviews of Greg Foote of Malcolm Pirnie Inc and Larry Fegel and John Weber of Grand Valley State University.

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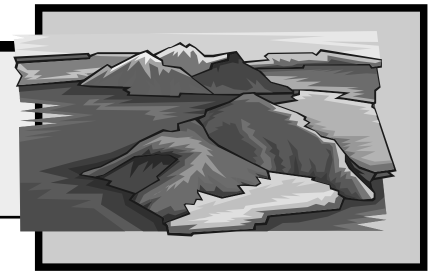

Figure 1. How Much is Too Much Water?

Ice Mountain is bottling water right here in our own back yard! You may think that is great, it will create new jobs and revenue for our region. These facts may be true, but have you considered the environmental side of the argument over Ice Mountain's bottling plant here in West Michigan? Let's take a look and see what we discover!

What is the main source of the water that your family uses?

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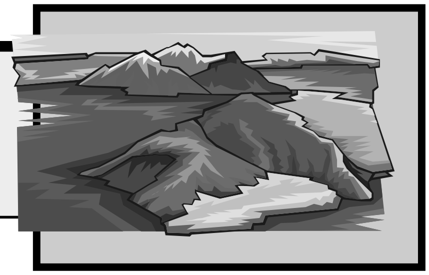

Match the following water users with the correct amount of water usage.

1. ________	Volume of Lake Michigan	A.	88 Gal./Day
2. ________	Average water used by a family of four.	B.	313,900 Gal./Day
3. ________	Groundwater used by a Michigan pharmaceutical company.	C.	1,500,000 Gal./Day
4. ________	Groundwater used by a Michigan baby food company.	D.	28,270,000 Gal./Day
5. ________	Groundwater used by Ice Mountain.	E.	588,816,000 Gal./Day
6. ________	Flow over Tahquamenon Falls.	F.	1,427,000,000,000 Gal.

Figure 2. Using a cylinder of water as a visual scale of the components of the water cycle. The column of water is 34.6 inches high, the same as the precipitation in the watershed. Most of the water in the watershed is lost to evaporation/transpiration. About one-third of the water recharges groundwater or is discharged through surface water. A small percent is consumed. The relative amount of water bottled by Ice Mountain is about three one-thousandths (0.003) of an inch at this scale.

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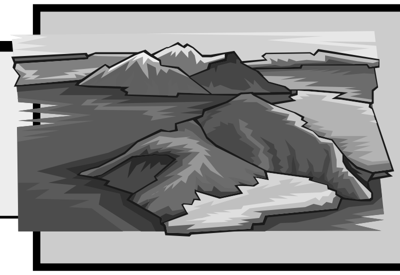

Field Notes for Ice Mountain Site

A geologist is exploring the surface and groundwater near the Osprey Lake Impoundment. She starts on the north shore of the impoundment and plans to hike to the north. The following information is from her field notebook. She has started to compile her observations on a geologic cross-section. Complete the cross-section using her data and complete the questions.

Stop 1: **Since Last Stop:** Climbed up and over hill. Saw numerous sand outcrops. Might be glacial outwash. **At This Stop:** Five feet of interbedded clay, silt and sand just above the lake. Might be old kettle lake deposit.

Stop 2: **Since Last Stop:** Walked around small wetland. **At This Stop:** On north bank of wetland. Took soil boring to depth of 952 feet. Found interbedded clay, silt and sand just like at Stop 1. Water table located just below 980 feet.

Stop 3: **Since Last Stop:** Climbed a small sandy hill and descended to two small lakes; lakes seem to be in interbedded clay, silt and sand. **At This Stop:** Sand on top of clay and silt.

Stop 4: **Since Last Stop:** Up and over another sandy hill. **At This Stop:** Find interbedded clay, silt and sand just above lake; looks like mirror image of the other side of hill.

Stop 5: **Since Last Stop:** Around the lake. Interbedded, clay, silt and sand on the other side of lake for about 10 feet above lake. Up and over a sandy hill. **At This Stop:** Sand over interbedded clay, silt and sand.

Stop 6: **Since Last Stop:** Around the lake (again). Over a small hill of interbedded clay, silt and sand. At second lake, a bit of interbedded clay, silt and sand on shore. **At This Stop:** Sand.

End Traverse: Return to office. Call drill team. Plan on five wells. Driller says best to drill from sandy hills where possible. Drilling done one month later.

Drilling Results

Well 1: Drilled 60 feet of sand to water table. Continued another 50 feet in saturated sand.
Well 2: Start in 20 feet of sand, drilling slows through 10 feet of silt and clay. Then another 10 feet of sand to water table. Well continues another 25 feet, all in saturated sand.
Well 3: Start in sand. After 50 feet, all in sand, hit water table. Continue another 105 feet, all saturated sand.
Well 4: Interlayered, clay, silt and sand for 40 feet. Intersected water table only 12 feet below surface. Drilling continued for an additional 40 feet below the interlayered, clay, silt and sand, all in saturated sand.
Well 5: Start in sand. After only 7 feet hit water table. Drill another 30 feet, all sand.

QUESTIONS

1. What type of sediment is associated with the lakes?
2. What type of sediment is associated with the hills?
3. Indicate the location of the water table by placing a "∇" at the appropriate depths. Draw a line connecting the water table in the wells and the appropriate surface lakes. Are all the lakes connected to the water table?
4. Lightly shade the shallow-water aquifer (the saturated sediment).
5. Explain the origin of the lakes near Well 4.
6. Explain the origin of the lakes near Stops 1-4.
7. What direction does groundwater flow at the Ice Mountain site?
8. What is one source of water for Osprey Lake Impoundment?

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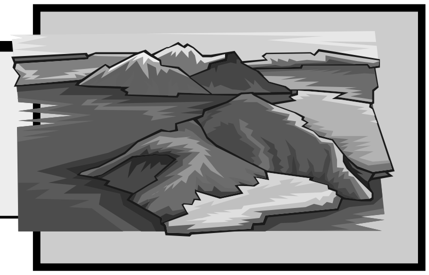

Answers

1. The lakes form on interbedded clay, silt and sand.
2. The hills are made of sand (except the hill at Well 4).
3. See geologic cross-section (figure 4). No, lakes at Stops 1-4 are perched above the water table.
4. See geologic cross-section (figure 4).
5. The lake level is the surface of the water table and fed by groundwater.
6. The lakes perched above the water table are fed by precipitation.
7. Groundwater flows from the north to the south.
8. Some water for the impoundment is groundwater (also surface water).

References:

Hanson, R.L., 1991, Evapotranspiration and Droughts, in Paulson, R.W., Chase, E.B., Roberts, R.S., and Moody, D.W., Compilers, National Water Summary 1988-89--Hydrologic Events and Floods and Droughts: U.S. Geological Survey Water-Supply Paper 2375, p. 99-104. (available at geochange.er.usgs.gov/sw/changes/natural/et/)

Holtschlag, D.J., 1996, A generalized estimate of ground-water recharge rates in the Lower Peninsula of Michigan: U.S. Geological Survey Open-file report No. OF 96-0593, 37 p.