ESI Environmental Science Institute
THE UNIVERSITY OF TEXAS AT AUSTIN

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Exploring Aquifers: Porosity and Permeability

Lesson plan for grades 9-12
Length of lesson: 50 minutes
Adapted by: Jesús Aguilar-Landaverde, Environmental Science Institute, November 2012
Authored by: Lynn Kirby (UTeach) [Originally*, Investigating Porosity and Permeability - Aquifer Study*]

SOURCES AND RESOURCES:

- *Science:* Taikan Oki and Shinjiro Kanae, "Global Hydrological Cycles and World Water Resources"
  http://www.sciencemag.org/content/313/5790/1068.abstract
- *USGS:* Aquifer Basics
  http://water.usgs.gov/ogw/aquiferbasics/
- Shinichi Hamasaki, Akira Tachibana, Daisuke Tada, Kiyoshi Yamauchi, Toshizumi Tanabe, "Fabrication of highly porous keratin sponges by freeze-drying in the presence of calcium alginate beads"
  http://sciencelinks.jp/j-east/article/200517/000020051705A0556008.php

POTENTIAL CONCEPTS TEKS ADDRESSED THROUGH THIS LESSON:

§112.32.c Aquatic Science, Grade 10, 11, 12: 4A, 4D
§112.35.c Chemistry, Grade 10, 11, 12: 4B
§112.37.c Earth and Space Science, Grade 11, 12: 15C

PERFORMANCE OBJECTIVES :

Students will be able to:

- In writing, define porosity as it relates to the ability of a material to hold fluid.
- In words, identify the units of porosity to be units of volume.
- In writing, define permeability as it relates to the ability of a material to permit the flow of fluids.
- In words, identify the units of permeability to be units of volume per unit time.
- In writing, calculate porosity and permeability values for three materials from collected empirical data.
- Compare and contrast different sediments (gravel, sand, clay) based on their measured porosities and permeabilities.

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RESOURCES, SUPPLIES, HANDOUTS: (per group of ~4 students)

- 1 set of Lab Instructions (separate document)
- 1 student data sheet (separate document)
- 1 100 mL graduated cylinder
- Rubber bands (at least two)
- 1 stop watch
- 50 mL of each of the following: coarse sand, gravel, art clay
- 1 ring stand
- Pitcher to hold water (may serve more than one table)
- 1 bucket to dispose of used water (only one necessary per class)
- Coffee filters
- 1 250 mL flask
- 1 set of measuring cups (metric, 25 mL and 15 mL)
- Student Pre-Test
- Student Post-Test
- PowerPoint Presentation
- Instructions and Datasheet

CONCEPTS:

An **aquifer** is a geologic formation that will yield water to a well in sufficient quantities to make the production of water from this formation feasible for beneficial use. It contains **permeable and porous** layers of underground rock or sand that hold or transmit groundwater below the water table. The **porosity** of a sediment or rock is the fractional volume of void space in the material. This void space may be filled by either air or fluid; the size and quantity of **pores** in these materials determines their **porosity. Gravity, surface tension, adhesion, and cohesion** of water molecules contribute to the flow of water through **permeable** materials. Artesian aquifers are confined on the top and bottom by **non-permeable** rock layers, sometimes called **aquitards**, which put the aquifer under pressure and allow springs and wells to flow without being pumped.

BACKGROUND:

In this lesson, the students will be introduced to the properties of porosity and permeability by measuring selected materials' ability resist flow of water and also to resist saturation. The students will record their data and use their results and the class's to make inferences about the kinds of materials needed to form different parts of an aquifer including the confining layers (aquitards) and vadose zones.

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PREPARATION:

ADDITIONAL MATERIALS (Instructor):

- 1 kitchen sponge (any size)
- Supplemental PowerPoint (separate document)
- Projector ready for instruction display

ENGAGE (Est. Time: 5-10 minutes)

**First: distribute the student pre-test (see MATERIALS).

Prior to the lesson the instructor should measure the saturation volume for an ordinary household sponge; it will serve as an introduction to the lesson to challenge students' perceptions of porosity and permeability.

Teacher and Student Activity:

As option, the instructor could present the students with an estimation challenge. That is presented with a flask of an unknown volume of water (measured by the teacher to be within the saturation limit of the dry sponge), would the water pass through the sponge if poured directly on the sponge? The engagement in this brief opening section is in the uncertainty of estimation. Students will almost certainly have had experiences with sponges, but this task allows them to quantify their capacity in terms of water volume.

Probing Questions, Answers, Misconceptions:

- Will the water pass through the sponge if poured directly on the sponge? Why/why not?
- The teacher could ask for shows of hands or maybe even for precise estimates (in mL) of just how much water is in the flask.
    - "Give me some numbers! How much *volume* of water do you think is in this flask?"
- If it does pass through, will all of it pass by?
- If it doesn't, then *how much* does the teacher need to pour before it does?
- **(After pouring the water)**
- How could we *as scientists and engineers* explain what just happened to someone what we just witnessed?
    - "It's a sponge; it's absorbent/porous."
    - *What does that/those words mean? What are pores?*
- What if I'd tried this with a brick?

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- "No water would pass through, but you'd have a big mess on the floor."
- *Tell me more about that. Why wouldn't the water pass through? Why* would it fall on the floor instead?
- "Bricks don't have holes like sponges do."
- *All right. That's something very good to think about, and you bring up a good point. How do we know that the brick doesn't have just a bunch of smaller holes that we can't see?*
- "Because you'd see the water not go through. It wouldn't get absorbed like the sponge."
- *Those are very good qualitative observations. We'll come back to that. For now, let's do some quantitative measurements….*

TRANSITION…

Note to instructor: This is *critical* for beginning to emphasize the learning objectives throughout this lesson. In past teaching of this lesson, students have had difficulty connecting the qualitative and quantitative definitions of porosity and especially permeability.

"The question now becomes: how can we today, *as scientists and engineers*, *compare,* say, the absorbency of this sponge with, maybe, a bathroom towel, or an actual sea sponge? >> To answer this question, let's conduct an experiment and see what we can learn."

Materials Management

At this point, the instructor should distribute the materials necessary for the laboratory portion of this lab. One suggestion is to display the required materials per each group on an overhead and assign one "materials manager" per group to retrieve these from a center table or center. Ring stands should already be assembled and on the students' desks.

EXPLORE (Est. Time: 15 minutes)

Refer to and review the student instructions and data sheet (see MATERIALS).

Teacher and Student Activity:

The instructor should gain the students' attention in order to review the experiment procedure. Careful note should be made on explaining the importance of tightly securing the coffee filter to each funnel using the rubber bands. Failure to do this may result in excessive spilling. See the figure below

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for a sketch of this setup. While demonstrating this procedure, the instructor should quiz the students on crucial steps such as the one below.

Also, the instructor should **project** the instructions (separate document) on an overhead, a document camera, or a projector so that the students have ample opportunity to follow along.

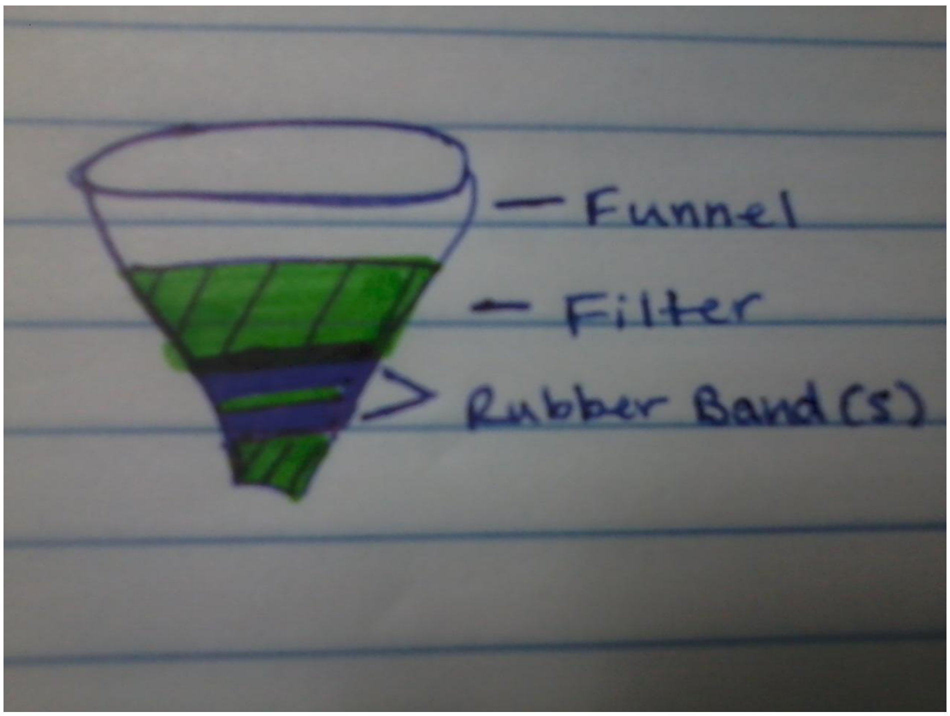

Figure 1: A sketch of how to secure the provided coffee filters to the funnel.

The authors of this lesson have empirically found that saturating the filter in the above configuration effectively eliminates volume loss effects due to absorption by the filter. The filters are a modification from the original lesson, which required pantyhose. The instructor should demonstrate to the students this saturation procedure of pouring 100 mL of water through an empty funnel and collecting the flow in a flask. In the trials run by the authors, a single coffee filter was able to withstand over a dozen trials of different samples, so this initial filter should suffice for the remainder of the experiment. If not, have extra filters handy for students.

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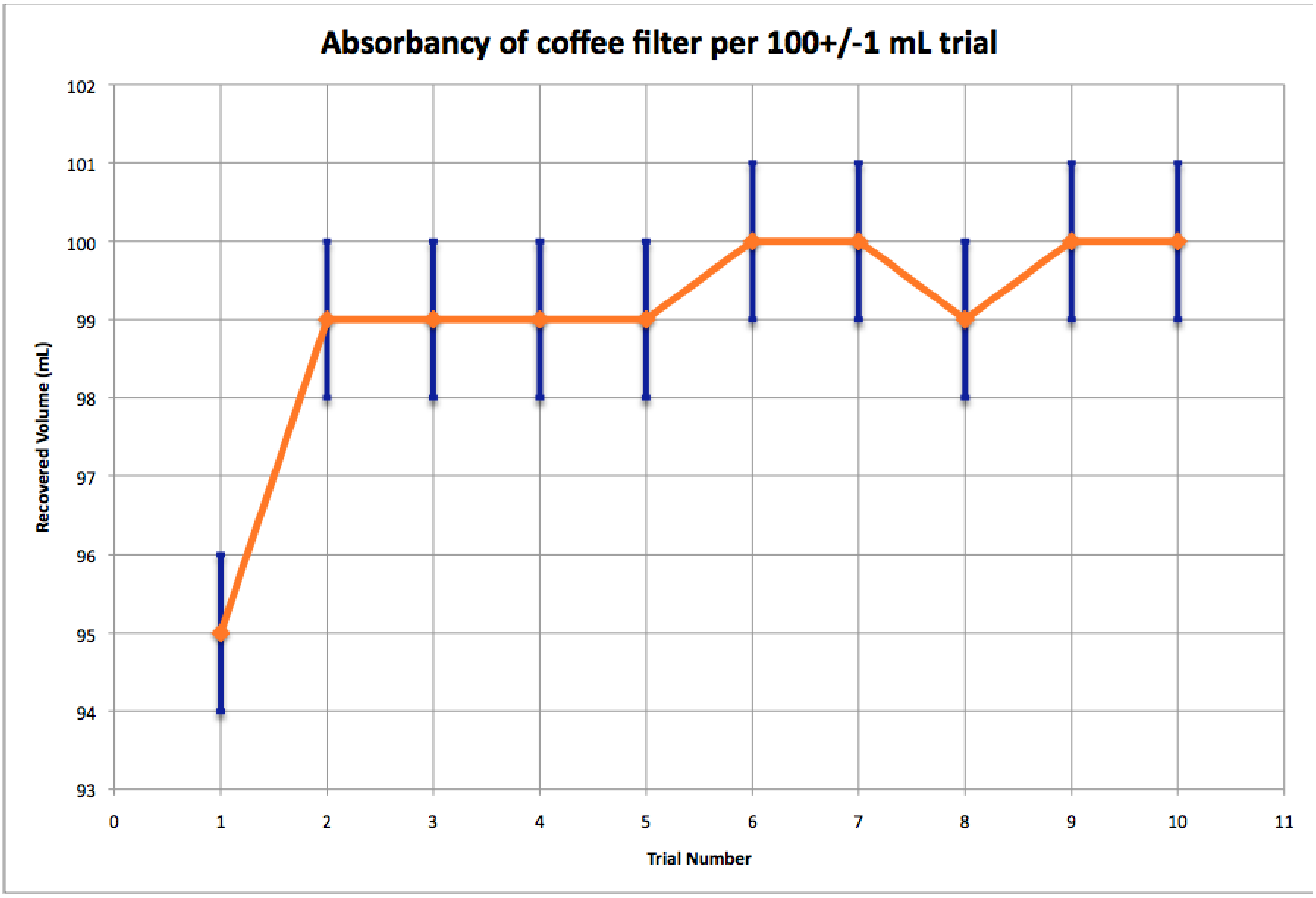

Figure 2: Pouring 100 mL through an empty filter-funnel apparatus reduces effects of absorption for subsequent trials.

Also, the instructor should clearly explain how to perform the porosity and permeability measurements. For the **porosity** measurements, students will measure 50 mL of water in the graduated cylinder. For each sample, they will use the 25 mL spoon and place 50 mL of the sample into the filter-funnel apparatus. They will use the **15 mL** spoon as a stopper at the bottom of the funnel (see sketch). Taking the graduated cylinder, they will ***slowly*** pour water onto the surface of the sample until the sample becomes saturated. (**N.B.** In teaching this lesson, some groups began this process *as instruction was going on*. While this is sometimes desirable, the author of this lesson implores the teacher to first demonstrate this step to the students, to have the students repeat this procedure, and then to have the students perform it independently. This is to minimize error in measuring porosity (and soon permeability), to reduce unnecessary repetitions of this step, and to leave as much time for later discussion).

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The volume required to saturate the solution should be recorded for the porosity value (50 mL – volume left after pouring). This experiment was modified from the original lesson plan such that each sample (50 mL each) should have a saturation volume less than or equal to 50 mL.

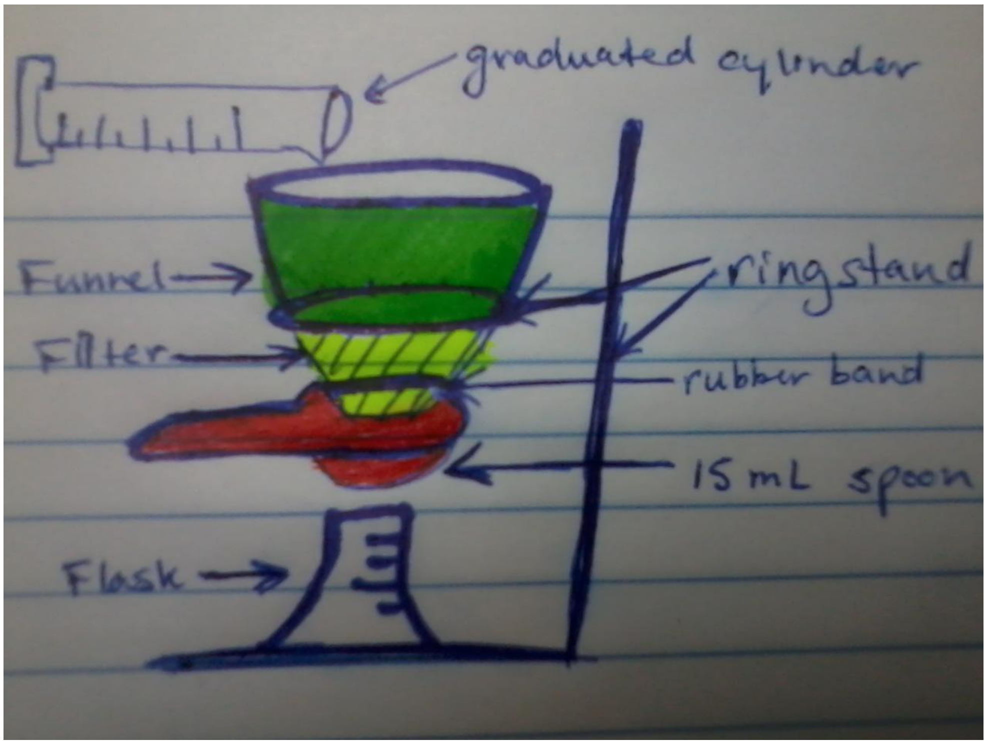

Figure 3: A sketch of the porosity measurement procedure. One student will be holding the stopping cup (red) in place while another pours the liquid into the funnel (green)-filter (yellow) setup.

For the **permeability** measurement, students will record the amount of time it takes for 50 mL of water to flow through each sample as well as the volume of recovered water after each flow. To do this, students will *pour the remainder of the volume from the porosity measurement* into the funnel. In the case of the more porous gravel, it is almost certain that water will have begun to overflow slightly into the stopping 15 mL spoon. The 250 mL flask should be placed underneath the end of the funnel but below this spoon.

From here, students will simultaneously remove the stopping spoon and begin the chronometer on the stopwatch. (**N.B.** Again, it may be most advantageous to demonstrate the *entire* collection process to the students, also emphasizing strongly this point of simultaneity. Messes and repetitions

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can be greatly reduced using this approach. It is recommended to quiz these students formatively before letting them work independently).

Water will begin to drip (in the case of the gravel, flow) into the flask. If during the porosity measurement, water has accumulated into the 15 mL stopper, then this volume should be poured back into the top of the funnel, and *not* directly into the flask so as to not skew permeability measurements. The **ratio** of recovered water to flow time will serve as a measure of (mean) **permeability** in units of **milliliters per second.**

Stopping criterion: Students should repeat this for each of the three samples in the following order: gravel, sand, clay (to reduce mess). Students should cease flow time measurements once the rate of flow has fallen **below one drop per ten seconds.** This lesson was empirically modified such that the time of flow per each sample is no more than about five minutes. (**N.B.** This process was empirically calibrated to keep the total measurement time within ten minutes; at the teacher's discretion, this stopping criterion can and should be modified to fit with the allotted class period and to leave room for discussion afterward.)

If necessary, it should be reviewed with the students how to convert from the chronometer's interface to seconds:

Because of this, the instructors may wish to review **significant digits** with students when calculating permeability.

The students will be working in groups with *assigned roles* (see attached instructions) and will be recording their hypotheses prior to the experiment. They will also then record the saturation volumes (porosity), flow times (FT), recovered water (RW) volumes, permeability (RW/FT) for each sample **in a provided data table** (included in student instruction sheet file, see MATERIALS)**.**

There should be a bucket in the center of the class for students to dispose of their used sand, clay, and water samples during and after the experiment. Additional water should be provided in quart-sized pitchers.

Probing Questions, Answers, Misconceptions:

- What sediment do you predict the water will travel faster through? (This is actually a hypothesis the students will write down as part of the experiment)

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- "The gravel"
  - *Tell me more. Why do you think the gravel?*
  - "The particles rocks are bigger than the sand grains"
  - *And what does that tell you?*
  - "There is more space between the rocks than between the sand grains, so water will be able to pass through more easily."
  - *That sounds very reasonable to me. Let's test it and find out.*

- "The sand"
  - *And why do you believe the sand?*
  - "When waves reach the sand on a beach, the water doesn't just sit there."
  - *So where does it go?*
  - "It seeps through the sand to lower layers."
  - *And how far does it go? Do you know?/How could you check?*
  - *How <u>fast</u> does it seep through? Do you think it would be faster or slower than gravel or clay? Why?*

- Which sediment do you think will hold the most water and why? (Another hypothesis to be recorded and tested)
  - "The sand because that is how you make sand castles. It won't work if you don't have water, but also the water stays in the sand castle the entire while you build with it."
    - *That's a very good observation. And what about clay? If clay gets too dry, we sometimes add water to be able to mold it—just like molding wet sand—so how does this compare to the sand?*
    - "The sand is wet throughout, but the clay only gets wet on the outside."
    - *These are great observations. Today, we'll have an opportunity to put these hypotheses to the test.*
  - "The gravel because that is what many roads/(or playgrounds) are made of. These roads soak up rainwater well."
    - *Fair enough. And, if these roads soak up rainwater efficiently, where does the water go in the gravel?*
    - "It goes into the soil."
    - *Ah, it goes into the soil? So is the gravel soaking up the water or the soil?*
    - "The soil."
    - *You've made a really good observation, though! What role does the gravel play in all of this?*

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- *What if instead I had just a bare dirt road and it rained? What would be different?*

- Are your measurements agreeing or disagreeing with your predictions so far? How so?
- What do your numbers look like so far? How do they compare?
- *Why* was it important to pour the water before the experiment began?

Materials Management

At this point, the instructor should have the students return their gravel samples back to their corresponding bags. Used water, sand, and clay samples should be discarded in the bucket. Due to the large amount of materials, roles should be again self-assigned within groups to return all materials. For example,

- 1 member should return the ring stand parts (instructor assistance may be required here with an appropriate wrench)
- 1 member should dispose of used water and samples, empty unused pitcher water in a sink, and dispose of each filter
- 1 member should return the flask, stopwatch, graduated cylinder, measuring spoons, pitcher, and funnel
- 1 member should wipe off each working space

TRANSITION…

"We've now had some scientific measurements, so let's see now what we can learn from them together in order to answer our questions at the beginning of class."
Again, the purpose here is to reinforce *why* the students are doing this lab and lesson.

EXPLAIN (Est. Time: 10-15 min)

In this section, the instructor will regain the attention of the students. Each group will be surveyed and asked to compare their empirical measurements. In a separate file, it may be beneficial to the instructor to create a spreadsheet with the appropriate scripts written to plot the *means* of each quantity per sample for the entire class. This will allow a clear group analysis of the measurements in order to identify the relationship of porosity to permeability. If for some reason data is severely affected by systematic errors, the instructor should have a pre-made sample data plot for discussion and comparison. Such an instance may be an opportunity to discuss some of the basic concepts of uncertainty in measurement. Too, at this time the instructor should present the formal definitions of both quantities measured in the lab as follows.

- **Porosity**: A measure of a material's ability to hold a fluid. It is measured in units of volume.

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- **Permeability:** A measure of the amount of fluid able to flow through a material. It is measured in units of volume per unit time.

Teacher and Student Activity:

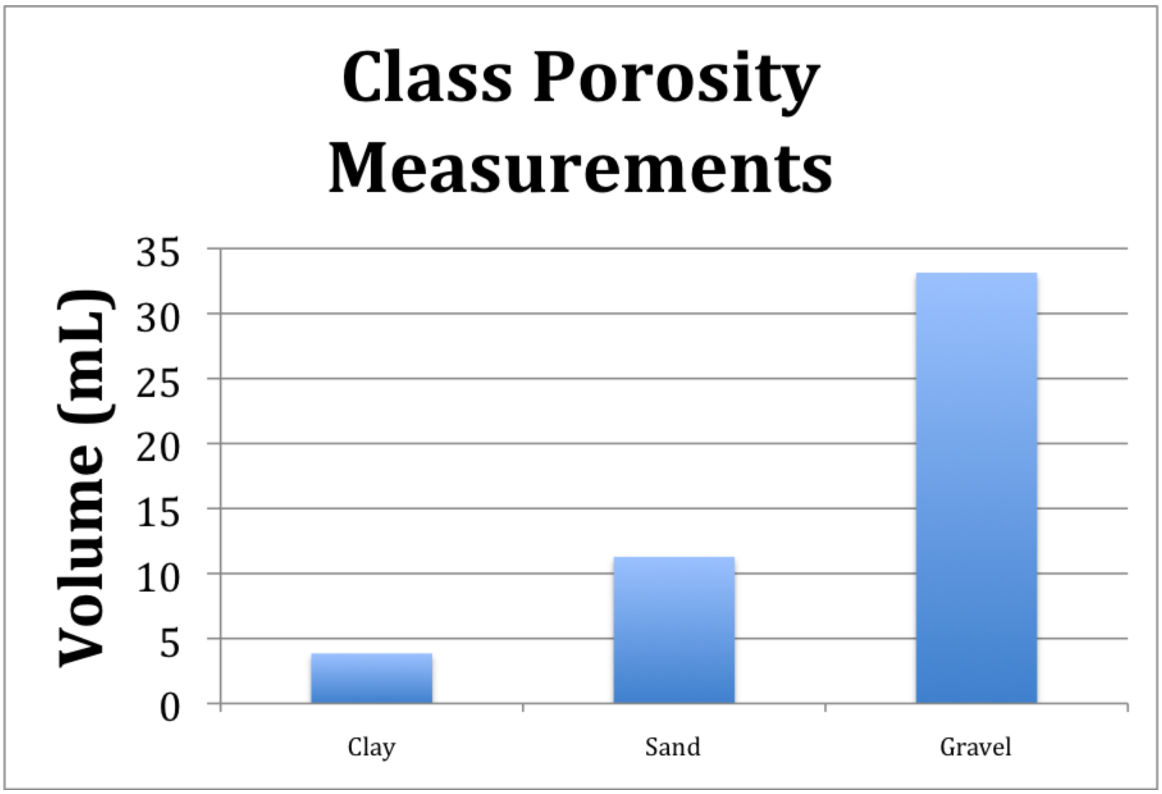

Figure 4: A generated line graph from an ensemble of theoretical measurements. The formatting is due a difference in excel and Word resolutions per page. Font sizes were enlarged for class legibility. The blue series corresponds to porosity. It is recommended that a similar plot be made for permeability for the students to see both trends. If it is appropriate for the classroom, it may help to plot both series in one window for emphasis.

Probing Questions, Answers, Misconceptions:

- So, what exactly *were* we measuring in this experiment? That is, what *are* porosity and permeability? What do these words really *mean?*

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- As a class, what can we say about our average values of porosity? Of permeability?
    - What is the *range* of values?
    - Which one was highest? Which one was lowest?
- Back to our friend, the sponge, did it have a high or low porosity? Permeability? Why?
- **Why exactly *are* different materials porous and permeable?**
    - What's the ***connection*** the sponge and the materials we measured today?
    - What makes them both porous (or not) and permeable?
    - Think of the brick, too. If we crushed up a brick and stuck it in this funnel, how do you think it would compare to these materials? Is it necessarily true that bricks are **non-permeable?**

TRANSITION…

"Believe it or not, everyone, the kind of work we've done so far and the questions we've answered/began to answer today are not unlike the types of measurements practicing scientists in hydrology, geology, climate science, biology, chemistry, physics, engineering have to do all the time with different parts of our nature. For today, let's focus on what's going on beneath our very feet."

ELABORATE (Est. Time: 10 min)

This section contains a PowerPoint slideshow (see MATERIALS) with very simplified schematics of aquifers such as the one shown below. Aquifers, confining layers, aquitards, and vadose zones will be introduced primarily in terms of their porosities and permeabilities. That is, it should be stressed that aquifers should have sufficiently *high* porosity to store water. Confining layers (including aquitards) should be of sufficiently *low* permeability to *confine* or *contain* water within the aquifer. Based on measurements made in the experiment earlier, students will be asked which materials might make suitable aquifers and which might better serve as confining structures. The final evaluation expands on this by varying the permeabilities and porosities of these structures.

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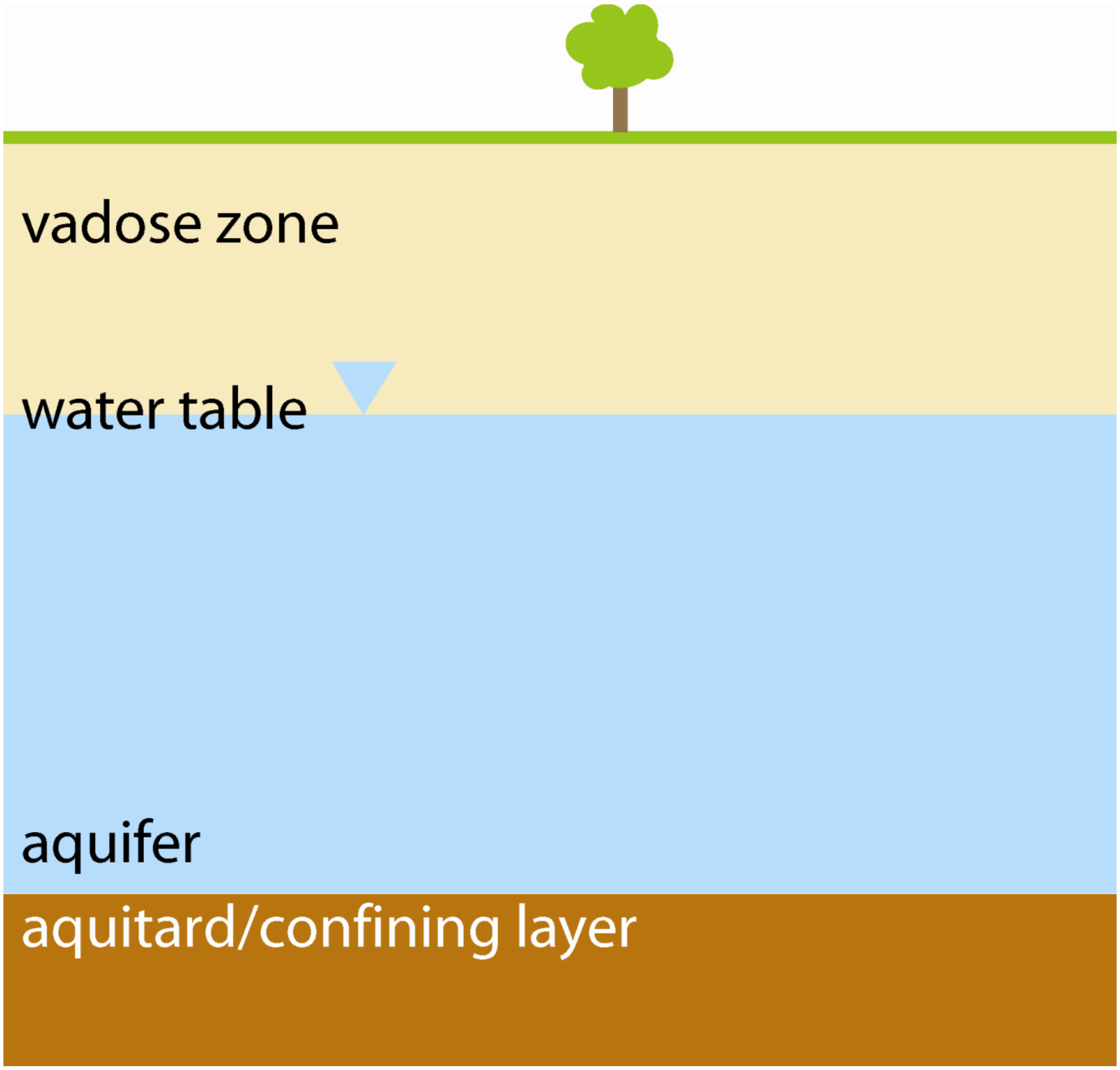

Teacher and Student Activity:

Probing Questions, Answers, Misconceptions:

- From our measurements, which material would make the best **aquifer**? Which would make the poorest one? Why?
- What about **confining layer?** Why?
- What can we *infer* about the porosity and permeability of the **vadose zone**? How do you know that?

EVALUATE (Est. Time: 10-15 minutes)

Administer student post-test (see MATERIALS).