<u>Exercise 1: Teacher Notes</u>

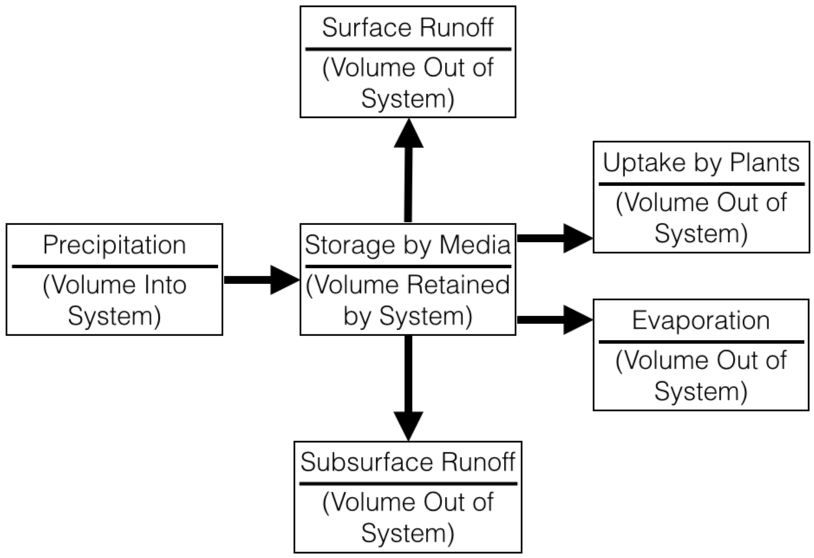
Background Information

A water budget, based on volumes, is used to account for the fate of water that enters and leaves a soil system. Water that enters a system may either be stored within the system or leave the system. While the water may leave the system via percolation through the soil, runoff over the soil, evaporation from the soil, and transpiration from plants that took water from the soil, Exercise 1 will only focus on the water that is stored within the soil or percolates through the soil (this percolated water would be added to groundwater).

In real world conditions, vegetation, surface runoff, and evaporation may also affect the destination of precipitation. Surface vegetation may uptake water and emit water vapor via transpiration. Surface vegetation may also physically trap surface precipitation, preventing water from entering the soil column. However, because there is no vegetation in the soil samples used in this exercise, the effects of vegetation will be ignored (this exercise could be extended by including vegetation). Surface runoff may occur due to surficial areas of low soil permeability, but because the soil samples used in this exercise are captive inside an exposure chamber, namely a steel can, runoff is not possible but should be demonstrated to and discussed with students. Evaporation of water from the surface of the soil can occur but takes more time to occur than what will be permitted in this exercise. Thus, the effects of evaporation will also be considered negligible and will be ignored but could be investigated as an extension. Lastly, the amount of water already stored in the soil system can limit how much additional water can be stored. For simplicity, we will be starting with dry soil. Exercise 2 provides an opportunity to compare water storage in soils that are unsaturated and saturated.

The volumes of water that enter, are stored within, and leave soil systems are often measured by scientists. While these volumes can change slightly with temperature (due to water's density depending on its temperature), this change will be considered minor and outside the scope of this exercise.

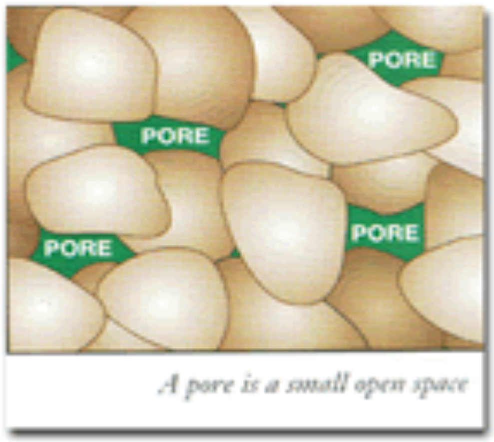
General Water Budget for the Soil System



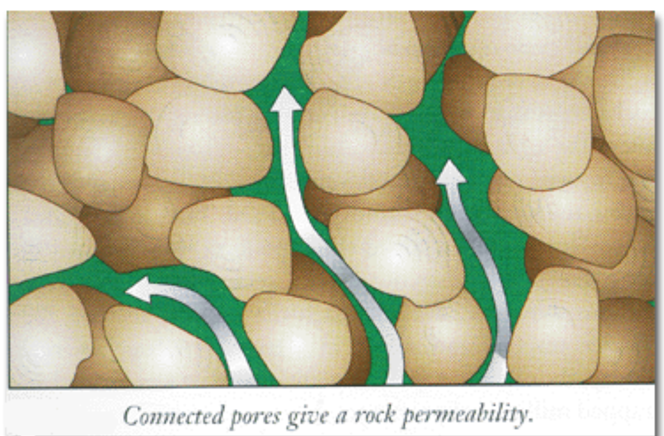
All water that enters the soil system must either be stored within the system or exit the system. Just like other matter, water can neither be created nor destroyed.

The assumptions made as part of this exercise will permit an accounting of water using a simple budget model (volume water input via precipitation = volume of water storage in soil + volume of water output via subsurface flow) based on the Conservation of Mass. Around the world, water is accounted for via measurements of volume. It is important to note that while this water budget is simple, it can be increased in complexity to account for other variables such as output via vegetation, surface runoff, and evaporation if these are appropriate to the class.

The amount of water stored within and transferred out of soil is dictated by many geological and geographical features. Geological features of the landscape are primarily defined by the soil substrate of the watershed (e.g. gravel, sand, clay, soil, and/or bedrock). The storage of water will be primarily determined by the porosity of the material. Porosity is the measure of the volume of voidspace in a material. Highly-porous material has a greater storage capacity for water when compared to a material with low porosity. The transmission of water will be determined by the permeability of the material. Permeability is a measure of the connectedness of porespace. Thus, if a material has a high permeability, many of that material's pores are connected, permitting the pores to "communicate" with each other. It is important to note that porosity and permeability are independent properties. A highly-porous material may have a low permeability, if the pores are simply not connected. This could occur for a variety of naturally-occurring reasons, such as fine material clogging pores. Conversely, a material with low porosity may have a significant permeability, if the few pores are well-connected. This is seen in fractured natural materials, where the fractures in a rock may be the only appreciable porespace found in the rock. If the fractures are continuously connected, then a low porosity rock may transmit fluids by way of the fractures.



Conceptual Model of Porosity



Conceptual Model of Permeability
Source: http://mpgpetroleum.com/fundamentals.html

Introduction

This activity is critical to student understanding as it provides a small-scale, concrete example of processes that occur on a larger scale and, to many students, are far removed from their everyday experiences. With the recent nationwide droughts, a question that should be relevant to students is: “How much water is enough when watering your lawn or garden?” Many students will see their parents, a park, or a local business watering their lawn, and see water running off the grass surface onto the street and into the gutter. Or some may know a farmer who has had to irrigate more than normal in a drought. Students will not be thinking about what happens to that water once it reaches the soil-water system. Students might have heard that it is best not to water in the middle of the day or that watering too much is a waste of money, but not know the basis for these recommendations.

Equipment (Per Group)

- 3 - #10 Cans (commercial-size cans containing coffee, tomato sauce, or pudding)
- Fiberglass or Metal Fine Mesh Screen (preferably 100-mesh or smaller)
- Duct or Electrical Tape
- 7 to 8 Measuring Cups of each Substrate (4 inches depth of each pea gravel and topsoil)
- Ruler or Tape Measure
- 100 mL Graduated Cylinder (with 1 mL increments)
- Stopwatch

**The volume of the cans is at the discretion of the experimenter. However, the cans must be of identical, measurable dimensions and must have a large opening to avoid sampling error (the sprinkler might not distribute the water uniformly and #10 cans have a 6 inch opening). As well, they should be clean and dry. Half of the cans should have the tops cut off and the other half should have the tops and bottoms cut off.*

***Additional substrates could be used but should be tested by the teacher in advance. We selected pea gravel and topsoil as they retain different volumes of water and students can easily see and feel the differences between them.*

Equipment (Shared)

- Hose
- Sprinkler
- Milk Crate or Other Elevated Surface for Sprinkler
- Plastic Containers for Transporting Assembled Cans and Leveling Them on the Lawn

*We recommend using an oscillating sprinkler, similar to the one shown below, but strongly recommend the teacher test the sprinkler in advance. While the sprinkler will distribute different volumes of water different distances from the sprinkler, cans placed the same distance away should receive the same volumes of water. This pattern holds true except for along the edges of the area being watered. Oscillating sprinklers should allow one class of student groups to run their experiments if the cans are placed the same distance away on both sides of the sprinkler.

This is an example of the recommended sprinkler and arrangement of cans during the exercise. Cans may be placed on both sides of the sprinkler with larger classes.

Advanced Preparation

It is important to use a band-cutting can opener (also called a smooth-edge can opener) so that sharp metal edges are removed from the cans. To save time and ensure safety, cans can be cut in advance of the laboratory exercise. While not required, mesh screening could be cut to size in advance.

It is recommended that the sprinkler be tested in advance to make sure that it distributes water evenly. From our experience, an oscillating sprinkler that moves back and forth has uniform distribution for any set distance away from the sprinkler. It is recommended that cans be placed the same distance from the sprinkler. One simple way to test if a sprinkler will work is to setup empty cans, let the sprinkler run for an hour, and determine if each can has collected the same volume. This test also allows you to see the rate of water distributed by the sprinkler; from our experience, one hour with an oscillating sprinkler yielded a sufficient amount of water.

The heights of the cans should be the same and tilt on the cans should be avoided. Subtle differences in height and tilt can impact the volume of water that enters the cans. Watch for heavy winds the day of the exercise that might cause water to be blown away from the sprinkler in inconsistent ways.

A plastic container can be used to transport the assembled cans and level them when placed on the lawn as they will tend to tilt. A milk crate can be used to elevate the sprinkler to allow more water to fall into the cans.

Classroom Procedure for Exercise 1.1: Measurements of Water Entering, Leaving, and Being Retained Within a Soil-Water System

Start with the question, “How much water is enough when watering your lawn?” This is a difficult question to answer and we often do not think carefully about it because water is relatively plentiful in the Midwest. Depending on the students, the teacher might need to reframe the question in a way that is conceptually similar but more concrete and easier for students to see such as, “How much water is enough when watering a flowerpot?” In this case, it is easy to see that excess water eventually starts to pool on the top (if there is no hole) or flow through the bottom (if there is a hole). In addition, students are not surprised that some water is retained by the substrate in the pot. Students will be constructing an experiment, using a flowerpot as a mental model, to determine how much water is enough for watering a lawn.

The teacher needs to make a decision how to approach this exercise. With more advanced students that are comfortable with experimental design and data collection, students can generate experimental designs (using the list of materials) and collect subsequent data with the teacher periodically providing insight and “seeding” ideas. For students that need more structure, a design can be provided and students, through a class discussion, determine what measurements they need to take before and after exposure to precipitation from the sprinkler. In both cases, there will be time to discuss what each measurement tells students about water entering or leaving the soil system and for students to explain limits of their measurements.

For advanced students, teams will be provided with the list of materials and given time to brainstorm a way to design their experiment to collect data on how much water is enough. At this point, they should be shown the equipment, sprinkler, and photograph of the location with the sprinkler in place. In addition, they should be told, “a local expert recommends watering to a depth of four inches in order to adequately expose plant roots to water.” During the brainstorming phase, students will create whiteboard designs that will be shared with the class. Whiteboard designs should include a labeled diagram and a list of the measurements that will be taken. These whiteboards will be shared with the class followed by a discussion during which a common design and data collection method will be agreed to.

A few instructional notes should be mentioned here. First, while the original question asks about grass, many students have difficulty thinking about what happens to water when it is sprayed on a surface. The flowerpot system was introduced because students get a chance to see water being stored and passed through. Second, there will be a second iteration of this experiment using different substrates later. So, student designs and data collection methods can be improved later and results do not need to be perfect the first time around.

While there are different ways to collect data, students need to be headed in the direction of measuring the volume of water. Students should measure the volume of water that reaches a separate “rain gauge” and the amount that passes through their device (devices are cans with soil, mesh screening, and a separate can to collect water). The difference between the volume of water in the rain gauge and the volume of water in the bottom can on the device allows us to calculate the volume of water that is stored within the substrate.

Before students begin collecting data, student teams should agree on a specific plan for their data collection. Discussion should happen around what measurements will be taken so that each team knows the **quantity of water that entered their containers (the volume of water in their rain gauge), that left the substrate in their device (the volume of water in the bottom can of their device), and that was retained within the substrate in their device (the difference between the volume in the rain gauge and the volume in the bottom can)**. Groups need to clearly understand the measurement they are taking before and after exposure to the water from the sprinkler. Also, groups will need to discuss and decide how best to stop the substrate from falling or flowing out of the can (this is the reason for the mesh screen and tape). During the brainstorming phase, the teacher might need to "seed" design ideas to various groups and allow these ideas to be presented to the entire class during a classroom discussion.

Example Design Ideas for Volume Measurements

Using one of the cans as a template, cut one circle of fine mesh screen to fit the bottom of the can. Ensure that the mesh circle is large enough so that excess screen will protrude upward along the outside diameter of the can. This excess screening will provide ample footing for the tape to grip, which will permit the tape to hold the screen in-place on the bottom of the can without the mesh slipping off. The addition of 1 to 1.5 inches to the mesh circle radius (an extra 2 to 3 inches in diameter) should be sufficient to permit a strong grip by the tape. Duct tape will affix the mesh to the can. Groups will likely need to double-up the mesh to avoid having excessive substrate fall through. While we do not want to lose too much substrate during the exercise, this process of erosion is often seen after heavy rainstorms when soil is washed into rivers, and it presents an opportunity to discuss a real-life problem with students.

When taping mesh screen to cans, use enough tape so that the screen is attached to the outside of the can with sufficient confidence that the mass of the wet substrate will not pull the screen from the can outer wall (resulting in the failure of the can and loss of data). Test the screen by pulling on the screen with hand pressure. If the screening slips from the can wall, remove the tape and re-attach the screen using more tape.

The choice of medium (pea gravel or topsoil) is at the discretion of the teacher. The amount of substrate to be used is also at the discretion of the experimenter. However, we found that 7 to 8 cups of pea gravel or packed topsoil (a depth of about 4 inches in a #10 can was optimal). It is best to test this in advance (as it depends on the sprinkler, water pressure, and substrate composition) in order to determine how long to run the sprinkler.

*Note: While it might be tempting to introduce water to the substrate using spray bottles rather than a sprinkler so that the entire experiment can be performed within the classroom, we found that the delivery of water was at an artificially high rate and that the substrate was wet in some areas and left dry in others.

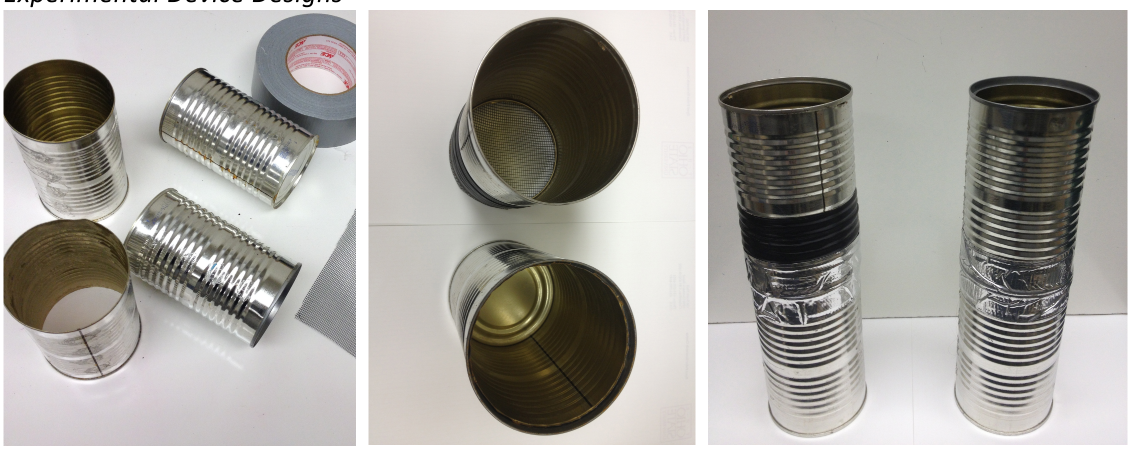
Sample Designs and Data Collection Methods

Volume will be used to measure the water.

Sample Data Recording

_____ Volume of Water Collected in Rain Gauge (Water That Enters Substrate)
_____ Volume of Water Collected in Bottom Can of Device (Water Transferred Through Substrate)
_____ Volume in Gauge – Volume in Bottom Can = Volume of Water in Soil (Water Stored in Substrate)

Experimental Device Designs



Materials used to create the rain gauge and device can be found at most hardware stores. (above left) The rain gauge and device are each made of two cans, joined by duct tape, with wire mesh placed between them. The top and bottom have been removed from the top can and the top has been removed from the bottom can. The duct tape was also used to affix the wire mesh to the can. (above center, above right) Adding the second can to the bottom of the rain gauge ensures that both devices are receiving water at the same height. All measurements are made post-sprinkler.

Sprinkler Exposure

Students might want to take a few minutes to observe the sprinkler and determine where best to place their cans. If no one observes that the distribution of water is different depending on the distance from the sprinkler, point this out. This would be a great time to discuss controlled variables. It is important that each team places their devices the same distance away.

Turn the sprinkler on and start the stopwatch. After approximately 25 minutes has passed (time interval depends on the flow rate of the sprinkler and should be tested in advance), turn the sprinkler off, retrieve the cans, and take measurements. The cans should be permitted to collect a moderate amount of water. In fact, the ideal amount of water is just before the substrate is saturated and water begins to reach the bottom can. This will make it easier for students to confront the fact that a certain amount of water can be stored in the system and, once exceeded, excess water passes through the substrate. After measurements are made, return the cans to their locations and turn on the sprinkler for an addition 25 minutes (once again, time interval depends on the flow rate of the sprinkler) before taking a second set of measurements. If class time runs out, you can bring all of the cans into the classroom, cover the entire set with foil (to stop evaporation), and take measurements during the next class period.

Remember, the following principle underpins Exercise 1.1 and 1.2.

Water Added to Substrate = Water Retained by Substrate (stored in soil) + Water Lost by Substrate (transferred through the soil)

Compare all pre-exposure and post-exposure measurements.

Measurements being taken from the devices following use of the sprinkler.

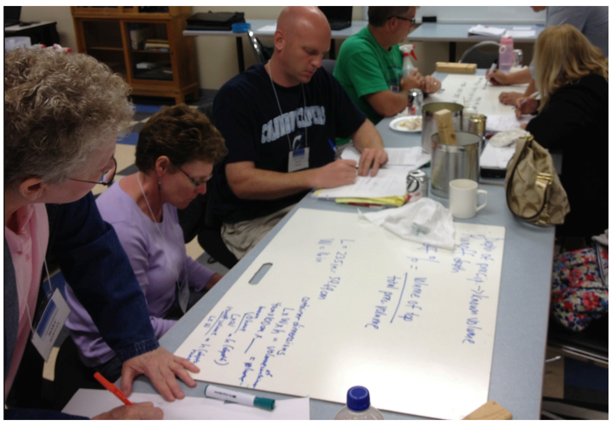
Post Exercise Whiteboards & Discussion

Each group should create a whiteboard sharing a diagram of their design, their measurements, and a conclusion sentence (How much water would be enough?). Groups might elect to answer the question in terms of volume or the number of minutes the sprinkler should run (To determine this, students will need to calculate the volume water that fell on the system each minute. This is a great application of rates.). Remember, the goal at this level is to identify where the water can go and show that the water is measureable. Groups should also be able to identify area of improvement should the exercise be done again. Groups will briefly share their boards with the class in a presentation or roundtable format. In addition to sharing their results, the following concepts should be discussed:

- How did this experiment represent real-life conditions? How did it not represent real-life conditions?
- Where could the water have gone under real-life conditions? Student should be made to think about plants taking up the water and water evaporating. This experiment did not investigate those variables. How would they design an experiment to test them (Note: Designing an investigation to measure evaporation is probably easier than water being taken up by plants). We will discuss surface runoff during Exercise 1.2.

- As a class, what method would we agree to use if we did this experiment again?

Regardless of the method used, some soil substrate will pass through the mesh. While this does introduce some uncertainty to the measurements of volume of water, it is unavoidable. This is an ideal situation to discuss real-life circumstances, such as topsoil loss and sediment loads in rivers. Many students have seen how muddy rivers can be after heavy rainfall events. When measurements are taken, these sediments are included in the volume of water (although, like the experiment, they are a relatively minor part). Ideas can be brainstormed for how to eliminate this uncertainty (evaporate the water and determine the volume of the evaporated water).



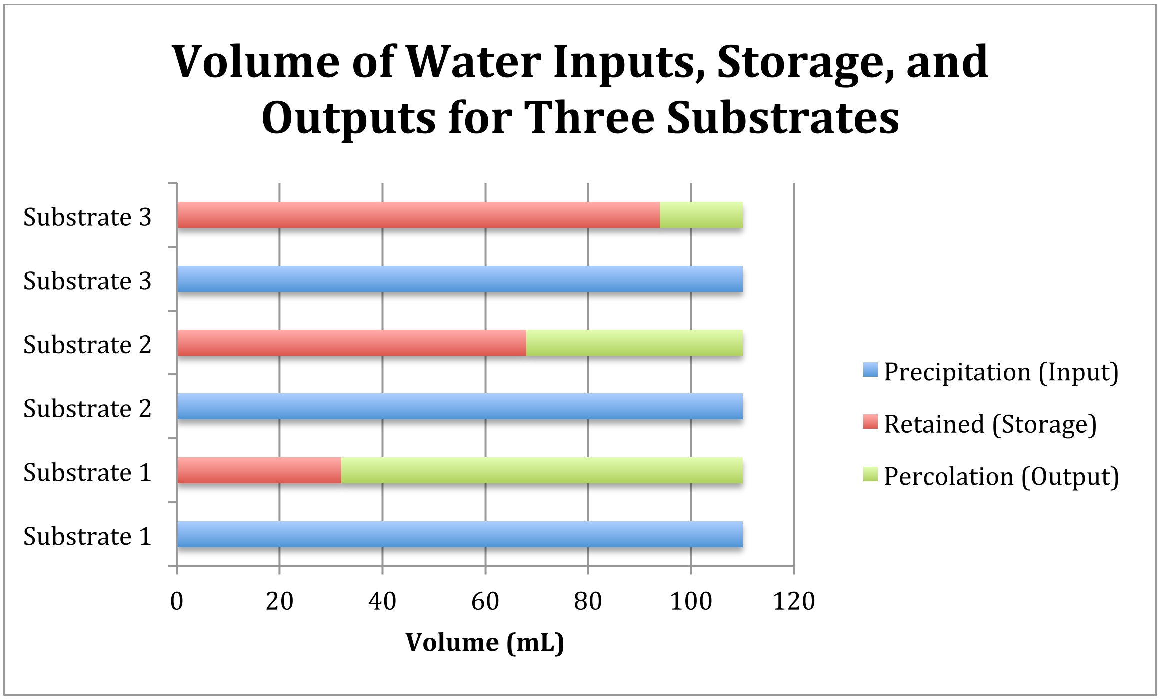
Whiteboards being created to share measurements and facilitate discussion of results with the class.

Classroom Procedure for Exercise 1.2: Impact of Types of Soil Movement of Water Through a Soil-Water System

Repeat the experiment, using the agreed upon method, for two different substrates (both pea gravel and topsoil). Students should be guided by the question, "Do all of these substrates need the same amount of water?" Realize that the sprinkler will be used again. The goal of this second exercise is to better understand that substrates store different amounts of water. In addition, students will be able to improve on their procedure from Exercise 1.1. The detail to which permeability and porosity are discussed is at the discretion of the teacher.

- Which substrate stores the most water? The least?
- Which substrates correlate with water storage and transmission?
- Is there anything else that appears to impact water storage or transmission? (Students might discuss the amount of soil used or how compact or dry it was when starting.)

If time is limited, this second exercise can be conducted in conjunction with the first exercise by providing different groups with different substrates or having all groups test both substrates. We recommend using no more than three substrates for simplicity (all should be tested in advance). For easy comparison, groups can be asked to create bar graphs depicting the amount of water that entered their system and stacked bar graphs depicting the amount of water that was stored in each of their substrates and passed through each of their substrates. An example is provided below. Results should be shared out using brief group presentations or a roundtable format.



Sample measurements for three substrates displayed using a bar graph.

Lastly, the teacher should fill a device with substrate, place a sheet of rubber membrane (such as rubber roofing) cut to the size of the can on top of the substrate, and seal the edges using caulk. A large quantity of water should be poured into the device and students made to observe that no water is transmitted. After a few minutes, the water is neither stored nor does it pass through (this is easily demonstrated by pouring the water back into the original container and seeing that it takes up the same amount of space). At this point, students can be shown the material inside the can. Students should be asked to consider, “Do all materials allow water to be stored or transmitted?”

Generally, materials like rubber roofing, concrete, and asphalt do not allow storage and transmission. Precipitation that lands on them moves via surface runoff. This demonstration is a dramatic and extreme example of surface runoff. Students might also have noticed that if they pour water quickly into their containers that substrates like the soil had ponding along the top whereas sand did not. Large rainfall events over short periods of time can result in surface runoff, even over topsoil. Evidence of this can be seen at construction sites with slopes where there are erosion patterns in the soil. Construction companies are required to mitigate this by erecting barriers and installing plants.

Barrier designed to reduce surface runoff.

Closing Thoughts for More Advanced Classes

It is important to note that an unknown amount of water is already present in the soil. However, determining this unknown amount of water requires additional laboratory analysis, such of drying the soil. Accounting for this water storage is outside the scope of this exercise. It is important to note that the water budget model we have been using only provides insight on the *change* in water storage, not how much was originally there.

In real life conditions, the loss of water by the soil sample is dependent on complex environmental processes, such as the transpiration rate for the specific vegetation, temperature, relative humidity, wind velocity, and soil composition. Quantifying these processes is possible, but difficult, and is also considered outside the scope of this exercise.