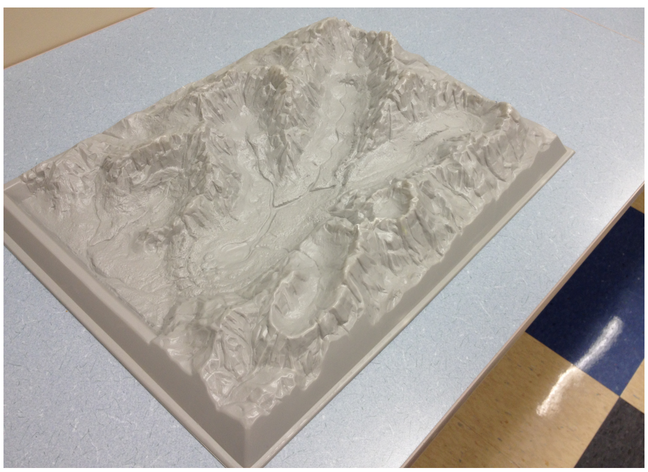
Exercise 2: Teacher Notes

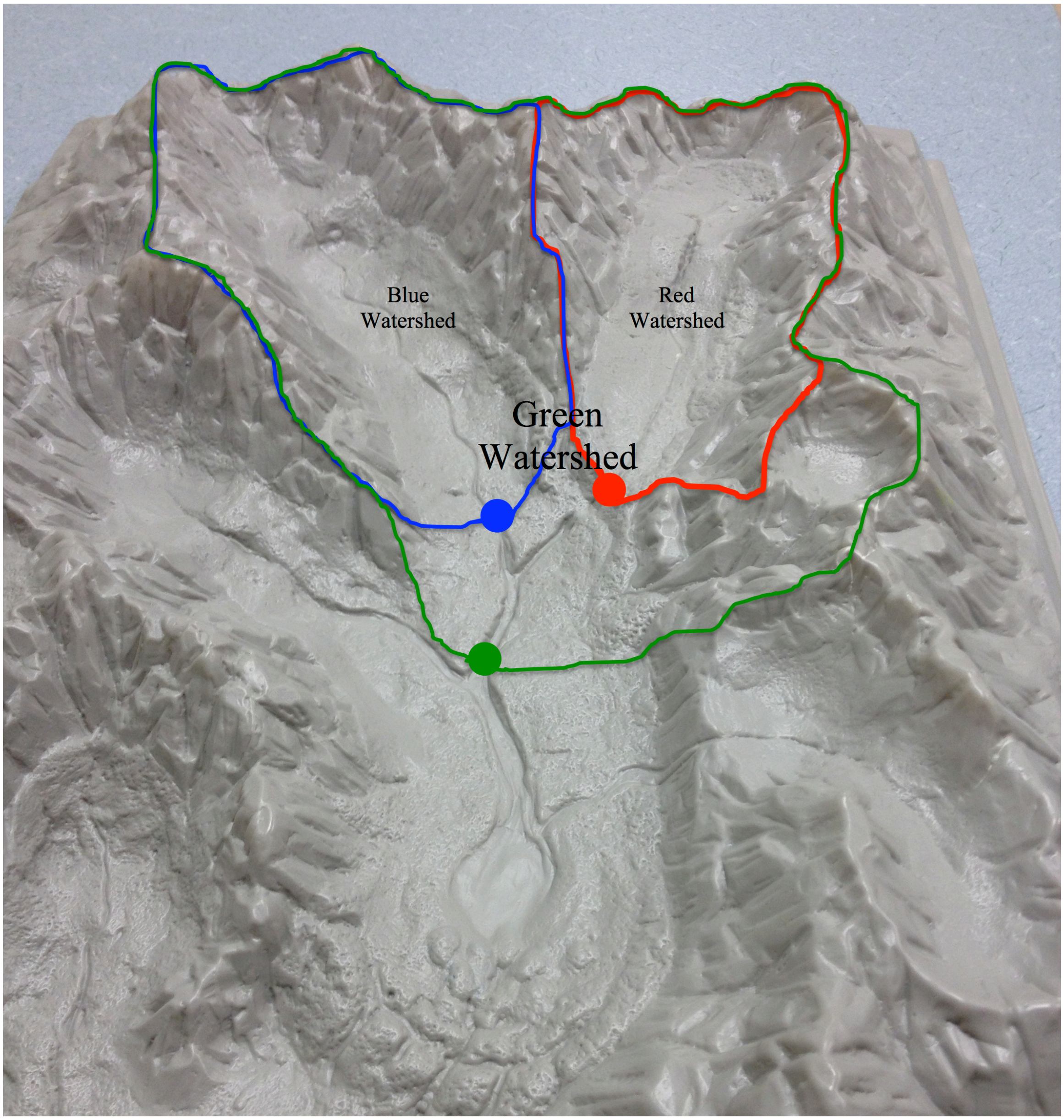
Background Information

Watersheds are simply the area of land that drains to a particular point on Earth's surface. The movement of water through a landscape is ultimately controlled by gravity and topography. In the case of naturally flowing watersheds, water cannot move uphill without work being applied to the system (by a pump for instance). In its simplest form, water flows from higher elevation areas to lower elevation areas because of the effect of gravity. Therefore, watersheds are primarily identified by their boundaries - higher areas represent the boundaries between adjacent watersheds.

Watersheds can be large or small depending on how much area drains to the particular point on Earth's surface that is selected. Depending in the reason for studying a watershed, we can elect to look at large or small areas; the only difference is the size of the system. In fact, all large watersheds are composed of smaller watersheds. The topography, substrate material, and precipitation pattern affect the movement of water through and storage of water within a watershed. It is important to note that watersheds may store water or be sources of water to other watersheds.

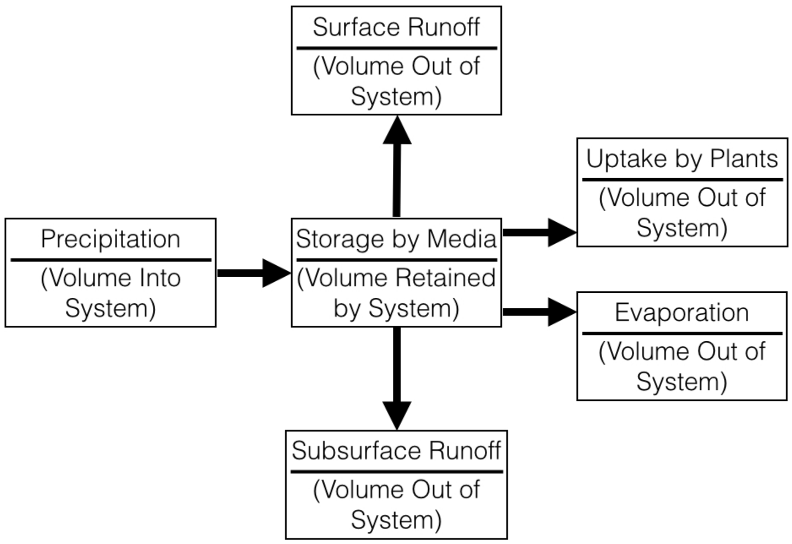


While landform models, such as the one pictured here, are more difficult to come by today, they provide a tangible way to identify watersheds, discuss the boundaries between watersheds, and show how large watersheds are composed of smaller watersheds. This model is approximately 2 foot by 2 foot. If a plastic landform model is not available, one can be created with furniture, balled up newspaper, and a large piece of black plastic that is arranged to drain to a bowl.



Plastic landform models can be misted with water from a spray bottle to track the path that water takes from higher to lower elevations. Students can be asked to identify the boundaries of the watershed that drains to the red dot (in fact, a wet erase marker can be used to trace the boundary before it is misted). They can be asked to do the same for the blue and green dots. In essence, the watershed is everything "upstream" of the dot. This brief demonstration allows students to see that the boundaries of a watershed are defined by its highest points and that large watersheds are made of smaller watersheds.

As we saw in Exercise 1, a water budget model can be used to account for water moving into a system, being stored within a system, and moving out of a system. A system can be simple, such as our coffee can from Exercise 1, or of moderate complexity, such as our GeoSandbox in this exercise or, highly complex, such as entire watersheds that will be seen in later exercises.



A water budget approach may be used to simply describe the magnitude of water storage and transmission within a watershed. Precipitation is the way that water enters a watershed. The transmission of water in a watershed can occur over the surface or through the subsurface. Runoff is the amount of water that leaves a watershed over the surface. Infiltration is the process, driven by gravity, by which water enters the substrate from the surface. Other natural processes that affect the water budget include: evaporation of water from the soil and transpiration of water through vegetation after having been drawn up through the soil.

As stated earlier, the storage of water in a watershed is determined from the porosity of the materials that comprise the watershed. Water can be stored at the surface, in lakes and rivers, or in the subsurface, within the substrate as groundwater.

In the exercise described here, we will look at a watershed water budget. We will not have time for evaporation or uptake by plants since these processes are rather slow. Therefore, the precipitation will either become runoff (surface or subsurface) or will be stored in the GeoSandbox:

Total Precipitation = Surface Runoff + Subsurface Runoff + Change in Storage

Surface runoff contributes to streamflow and does so in the fastest manner because the transmission of water over the surface has the least resistance to flow. Groundwater is often discussed in terms of the depth of the water table (depth from the surface to groundwater) and transmission occurs more slowly because there is greater resistance to flow from the substrate. Depending on many features of a watershed, the water table can be close to or far from the surface. Streams in a watershed may be referred to as gaining or losing streams. Gaining streams are streams that experience an increase in surface discharge due to the contribution of groundwater to surface flow. Losing streams are streams that lose water to groundwater primarily due to infiltration through the streambed. Thus, it is clear that hydrology of watersheds is a complex system, with many parts that can significantly affect how and where water is stored and transmitted.

Introduction

To improve elementary, middle, and high school-aged students' understanding of watershed processes, it is essential to provide structured learning experiences that build a conceptual model for the input, output, storage, and movement of water and materials in the surface and subsurface. Since watersheds are often large and complex, Exercise 2 will use a small-scale model, called a GeoSandbox, to facilitate understanding and serve as a common platform for discussing watersheds in later exercises. Since measurements are an integral component of science, in general, and geosciences in particular, Exercise 2 will use the GeoSandbox to discuss options for measurements and demonstrate how they are taken. If students have no prior experience with watersheds and a plastic landform models is available, it would be beneficial to begin the unit with the demonstration discussed in this unit's introduction.

The GeoSandbox provides a model for students to visualize a watershed in three dimensions, observe and account for the movement of water within the watershed, and develop a water budget to account for water entering, leaving, and being stored within the watershed. Precipitation will be simulated with six pump sprayers and surface and subsurface drainage simulated through two drainage points cut into the container with valves installed. The quantity of water entering and leaving the system will be measureable. Since the sandbox container is clear plastic, geologic layering and water subsurface storage can be visibly seen. Surface features can show topography.

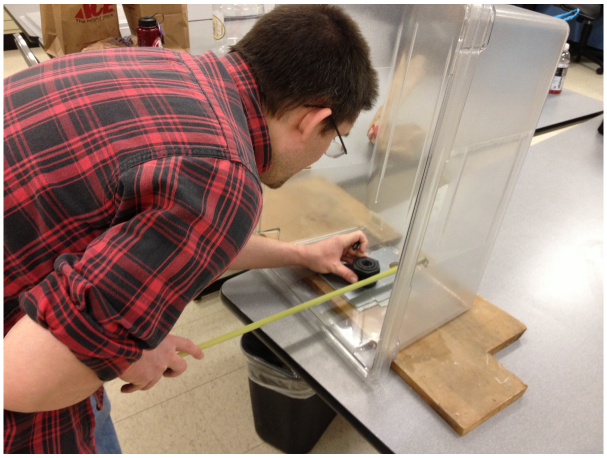
Materials

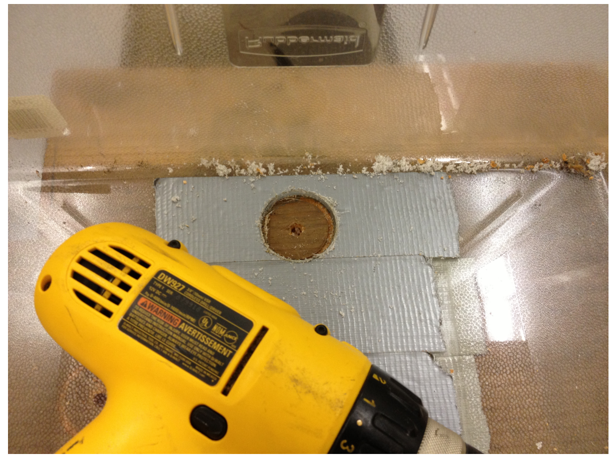
- Transparent Container. The container's volume should be at least 15 gallons to provide an adequate demonstration (smaller containers also work and, while not as dramatic, are significantly less expensive). The recommended composition of the container is polycarbonate. Food service supply companies have an excellent stock of such containers at reasonable prices. Glass containers should be avoided because they may not be strong enough to withstand the pressure of the substrate and water once the substrate is saturated. In addition, holes cannot easily be cut in glass.
- Approximately 50 Pounds of Pea Gravel. This amount should be adequate to provide a four-inch layer.
- Approximately 50 Pounds of Sand. This amount should be adequate to provide a four-inch layer.
- Approximately 10 Pounds of Topsoil. This amount should be adequate to provide a four-inch layer.
- 2 Plastic Ball Valves (construction may be polyvinyl chloride (PVC))
- 2 Plastic Bulkheads for Attaching Valve to Sandbox

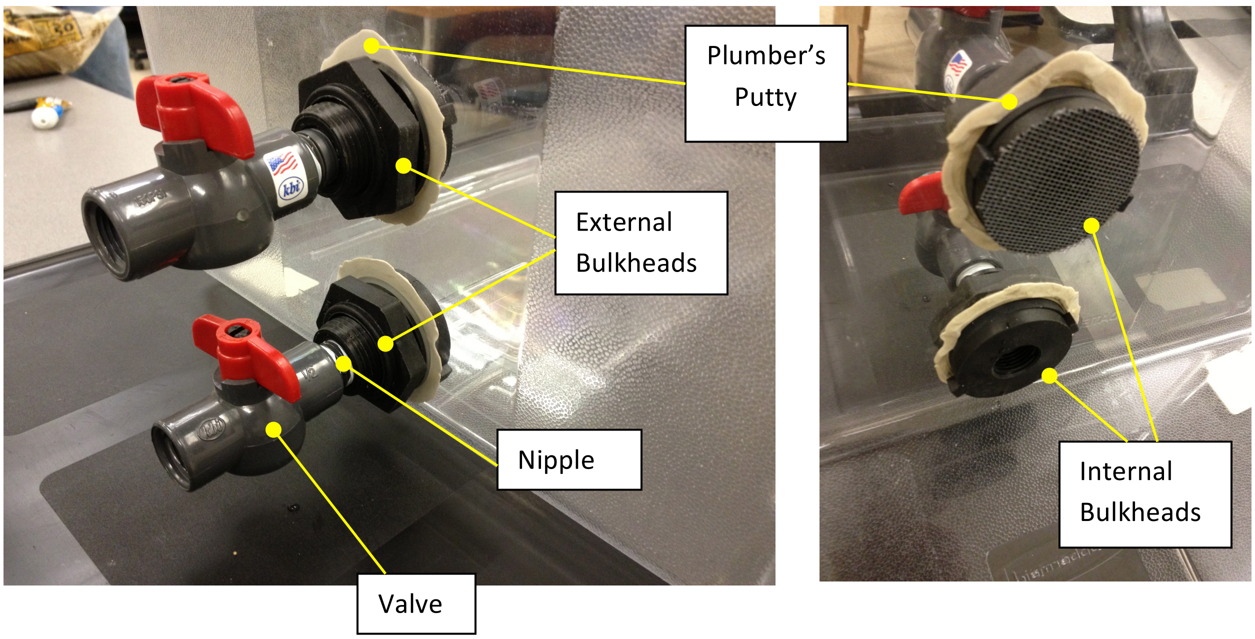
- Plastic Tubing Compatible with Nipple
- 2 Nipples Threaded on Both Ends (to connect ball valve and bulkhead)
- 2Nipples Threaded on One End and Barbed on the Other (to connect ball valve with tubing)
- Teflon Tape
- Waterproof Sealant (plumber's putty or silicon sealant)
- Screening
- Drill and Hole-Saw Bit for Drilling Holes in the Container
- 6 Spray Bottles (each should hold at least one liter of volume)
- Stopwatch
- 2 Buckets to Collect Water from Upper and Lower Openings
- 2 100-mL Graduated Cylinders to Measure Water Collected in Buckets
- Wooden Shims or Other Means of Elevating One End of the Sandbox. This can be achieved using any material (block of wood, book, brick).
- Plastic Sheeting (serves as demonstration of parking lot or roof)
- Small, Shallow Plastic Container with a Small Hole Punched in Bottom (serves as demonstration of lake or pond)
- Plastic Houses (such as those used in Monopoly for perspective)
- Cart for Transport of the Assembled GeoSandbox (the final weight will be substantial and transport on a cart will ensure that the device is not broken or someone injured)

For optional experiments

- PVC Caps for the Piping
- Hacksaw or PVC Pipe Cutter for Cutting Piping







Care should be taken when measuring, drilling, and assembling the GeoSandbox. Testing that the GeoSandbox is watertight before adding substrate is highly recommended.

Advanced Preparation

Clean and dry the sandbox container. In one of the short sides of the rectangle, drill one hole approximately one-third of the distance from the sandbox bottom. Drill a second hole approximately two inches above the first hole. The holes should be centered on the sandbox wall. Ensure that the area around the holes is free of any debris or burrs prior to working.

Place a layer of the sealant (plumber's putty or silicon) on both the outer and inner walls of the sandbox around the holes. Plumber's putty is a waterproof, clay-like material that provides a pliable, water-tight seal. The advantages of plumber's putty over other sealants is that plumber's putty remains soft after application and does not require a curing period after application. Thus, seals created from using plumber's putty can be used immediately after application and plumber's putty can also be removed and re-applied, if needed.

Bulkheads are devices that attach to the GeoSandbox through the wall of the GeoSandbox. Bulkheads provide a means of attaching other threaded devices (e.g. valves, nipples) without requiring the attachment of the devices directly to the GeoSandbox wall. The attachment of threaded devices directly to the GeoSandbox wall runs the risk of the device's threads wearing out the GeoSandbox wall at the point of attachment, which would render the wall useless. Thus bulkheads ensure that the threads of other devices do not work themselves loose and leak. The bulkheads may be provided intact. Take one of the bulkheads apart and seat the outer portion of the bulkhead onto the outer wall sealant layer. A short, threaded pipe that is part of the bulkhead will extend into the sandbox. This short, threaded pipe is the attachment point for the inner portion of the bulkhead. Screw the inner portion of the bulkhead onto the short, threaded pipe. The bulkhead should be tightened so that the seal is firm. This will result in a small amount of sealant being squeezed out onto both the outer and inner walls of the sandbox. However, if it is apparent that large amounts of sealant have been lost due to the tightening of the bulkhead, the bulkhead should be removed and the sealant should be re-applied, as the seal will likely not be watertight. If plumber's putty is used, the next step may be immediately followed. If silicon sealant is used, permit the sealant to cure as prescribed by the sealant's directions. This could take up to 24 hours.

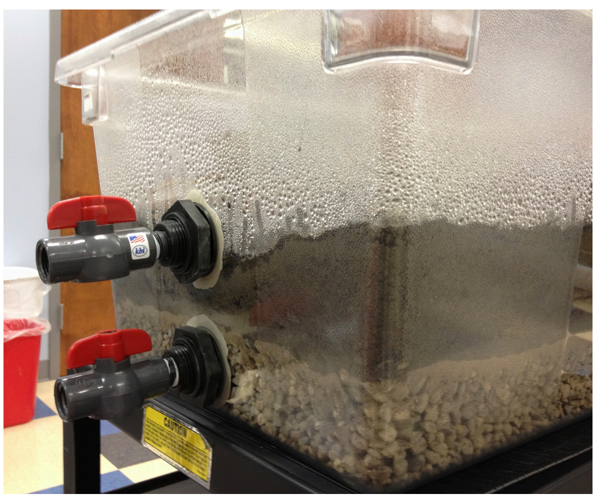
Cut a circle of screening large enough to cover the opening to the bulkhead. This is recommended to keep excessive amounts of fine material from being flushed from the sandbox into the bulkhead and clogging it. Fasten the screening to the bulkhead using water-resistant glue. Permit the glue to dry for the amount of time prescribed by the glue manufacturer before exposing it to water. (Please note, use of soil with large amount of fine sediment will cause this material to accumulate in front of the screening and restrict water flow. This fine sediment can be removed with a spoon or the screening can be removed and sediment allowed to flow out of the GeoSandbox.)

The threaded nipple is a short, threaded segment of pipe that provides a means of attaching other threaded devices (e.g. valves) to the bulkhead. Place Teflon tape onto the threads of the nipple. Teflon tape is a non-tacky sealing tape that ensures that a water-tight seal exists between the threads in an attachment. Screw the nipple into the external portion of the bulkhead. Take your time in screwing the nipple into the bulkhead, as cross-threading of the nipple into the bulkhead could ruin the threads on the nipple, the bulkhead, or both. Take note of any Teflon tape that may be lost during the fastening of the nipple into the bulkhead. If a large amount of Teflon tape is lost during the attachment, the seal between the nipple and bulkhead may be poor. If this is the case, remove the nipple and re-apply the Teflon tape.

Repeat this procedure for the second bulkhead in the second hole. At this point, it is best to fill the GeoSandbox with water and test the seals and performance of the valves. Once the substrate is added, making alterations will be significantly more difficult. The barbed nipple can be attached to the ball valve by applying Teflon tape and threading it in place. Plastic tubing can be cut to length and pushed onto the barb.

When you are ready to load the GeoSandbox with substrate, place an approximately 4-inch layer of pea gravel into the sandbox. Gently tamp the gravel layer with a wide, flat object so that the layer is approximately level and packed. Next, place an approximately 4-inch layer of sand into the sandbox on top of the gravel layer. Gently tamp the sand layer with a wide flat object so that the layer is level and packed. Last, place an approximate 4-inch layer of soil on top of the sand layer. The soil layer will subside when moistened, thus it is not necessary to pack the soil layer. Additional soil can be added to the top layer to simulate topographic high points. Pieces of wood, approximately 5 inches in height, should be placed under the side of the non-drain end of the GeoSandbox to enhance the topographic gradient. A small, shallow plastic container with a hole punched in the bottom can be installed to simulate a pond and plastic sheeting can be installed to simulate an impervious surface, such as a parking lot. Small plastic house (such as those from monopoly) can be placed in the GeoSandbox to provide students with perspective on scale.

Before use, water needs to be introduced to the GeoSandbox. This will take time (approximately ½ hour) and involve gently pouring water into the top of the box and allowing it to infiltrate the substrate until the water table has reach the desired level. Enough water should be placed into the sandbox so that a layer of water is evident in the gravel and sand layers. This will be gallons of water. The soil layer should be moist but not saturated (muddy). Allow the sandbox to come to equilibrium for 24 hours prior to any experiments. If the water table is not at the right level (you should be able to see it through the side of the clear container in the gravel and sand layers), introduce more water into the sandbox or drain water from the sandbox until desired level is achieved. Please note, the substrate and water will add significant weight and the GeoSandbox should be transported on a cart to protect it from damage and avoid injuries.



Wood is placed beneath the non-drain end of the GeoSandbox to create a topographic gradient. Misting the GeoSandbox simulates precipitation.

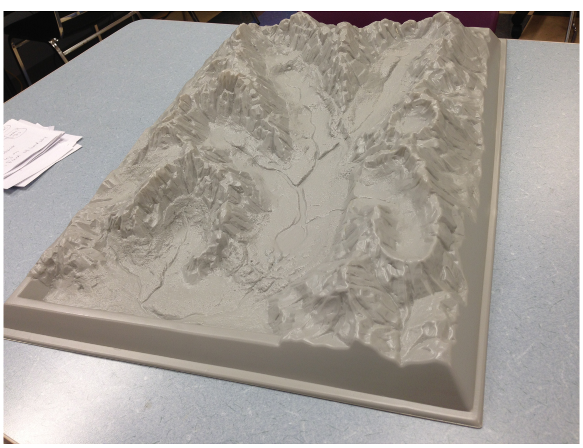
Classroom Procedure

Exercise 2.1: 3D Observations & Descriptions of a Watershed and Water Budget of Precipitation, Surface Runoff, and Subsurface Runoff

Start by asking students what they know about watersheds. Depending on their awareness from driving, they might see signs identifying watersheds along the road. If they live on a farm, they might know about their water district or work to reduce runoff. Students who hike, especially in mountainous areas, will be familiar with crossing from one “drainage” to another. Drainage is essentially another name for watershed.

Start by explaining that watersheds are the upland areas that drain to one particular point on Earth. Since watersheds are often large, and it is often difficult to see all of their features at once, students need practice with a more tangible, small-scale model. This can be accomplished by starting with a three-dimensional, plastic landform model, such as the one shown below.

You can start by having the class gather around the landform model. Next, place a red dot along the landform and ask, “where would rain need to land in order to eventually pass by this location.” (An example is shown earlier in this document using the landform model). Students will suggest various places, most of them accurate. Ask students how they are selecting their locations. Most will indicate that they are above the dot and that the water will eventually run downstream from the locations that they select toward the dot. Have a student use a wet erase marker to draw the watershed boundary. As the boundary is being drawn, the student should be asked to explain how he or she is deciding on its location. There will undoubtedly be a few places that are difficult to determine and he or she might ask for help from the class or the teacher.



Additional photographs of this landform model, including one with watershed boundaries labeled, are provided at the beginning of the unit.

As the student draw the boundary, it should become more apparent to students that the boundary is the high point and that a drop of water that strikes one side of the highpoint drains into the watershed and on the other side drains away from the watershed. Once the student is done drawing the boundary, the true test is to spray the landform with water and watch to see if drops drain the way that is predicted. It is also important to state that a watershed is any area that drains to a particular area. In this case, the entire area that drains to the red dot.

Next, students should be asked to complete the same task for the blue dot and then the green dot. Comparing the watershed for the blue dot with the watershed for the red dot allows students to see how watershed boundaries abut one another. Comparing the blue and red dot watersheds with the green dot watershed allows students to see that watersheds can vary in size and that larger watersheds are made of smaller watersheds. In closing, students should be asked why this model does not accurately represent the movement of water through substrates that we learned about in the Exercise 1. Since the landform model is plastic, it represents impervious surface and demonstrates runoff rather than runoff and infiltration.

Now it is time to introduce the GeoSandbox. Ask students to make observations of this new watershed and why it better represents what we learned from Exercise 1. They should be able to identify where water could enter the watershed (above – representing precipitation), leave the watershed (two pipes form the side – one is surface and one is subsurface), and be stored in the watershed (plastic cup and within the pebbles and sand – lake and groundwater). All of these facets need to come up in discussion. Students might also mention that water could evaporate back into the atmosphere or get taken up by plants; both of these will be processes that are slower and not captured by the GeoSandbox.

For this demonstration, place the GeoSandbox in a central location where students can gather around it. Students will see that there are different layers of substrate. They will notice the topographic features at the surface and see a visible line through the side of the container that denotes the water table. Water can be introduced to the watershed through the top. If you want to suggest a method for introducing water to the system, set out the six spray bottles. They will note the two valves as ways that water can leave. Remember, students have a difficult time conceptualizing subsurface flow. It is important that student realize water could leave at the surface or subsurface and which routes into and out of the GeoSandbox represent concepts already studied. You are connecting the tangible with the abstract using the GeoSandbox as a bridge.

Ask students to trace the fate of a raindrop that falls onto the GeoSandbox. Answers should be that some soaks into the ground (infiltration), some flows into streams (run off), and some evaporates back into the atmosphere. Next, ask if they have any idea, on average, how much of the world's precipitation turns into runoff? (The answer is just about 30%). Next, ask them if they have any idea if they rain on the GeoSandbox watershed, how much will run off?

The first measurements will involve water input (precipitation) and water output (surface and subsurface). Depending on the level of students, only volumes will be measured or volumes and rates can be measured. Fill six spray bottles with tap water. The total volume of water before spraying should be measured with graduated cylinders. Open both valves on the sandbox; the water that was stored should have been drained previously. Two vessels will be used to collected water from the top and bottom bulkheads and the volumes measured using a graduated cylinder following the spraying.

Begin spraying the surface of the sandbox with all of the spray bottles and start the stopwatch. Continue spraying the sandbox until all six bottles are empty at which point the time on the stopwatch should be noted. Using the stopwatch, observe the time when water begins and stops draining from the surface bulkhead AND when water begins and stops draining from the subsurface bulkhead. Please note, the times might take a few minutes to collect but the information is conceptually important. In addition to times, measure the volumes of water collected for both the surface and subsurface flow.

There are some qualitative and quantitative questions to address following this demonstration.

Basic Questions

- How much water (volume) fell during the rainfall event?
- What depth fell at any one point? What was the rate of rainfall in inches per hour? (This question connects with measurements made using a rain gauge.)
- Was the rate of rainfall uniform? How could we simulate different rates of rainfall and why would this matter? (This can be demonstrated with faster/slower spraying and the results examined.)
- How would you take these measurements in the real world? (You would use a rain gauge and calculate the volume.)
- How much water (volume) left via the surface and subsurface?
- How would we measure each of these in a real watershed? (This question connects with measurements using a stream gauge or flow meter.)

More Advanced Questions

- What percentage of water left the system via surface and subsurface flow? (Students are generally surprised by the high volume that leaves via subsurface as they never see this process. Globally it is thought that subsurface contributes more to streams and rivers than surface flow).
- Compare the total volume of water you added to the watershed to the total volume of water that left the watershed. Were the two numbers the same? If not, what does that tell us about the watershed? (Not all the water that was added left the system, so some was stored within the system. They will be able to see some water in the shallow cut if it was added and additional water can be seen at the bottom of the GeoSandbox below the subsurface bulkhead.)
- How long did it take for surface and subsurface water to flow after the rainfall event began? Why were there delays? (The demonstration is very realistic because water does not reach the bulkheads immediately and surface runoff always occurs more quickly than subsurface flow.)
- Did the surface and subsurface flows last the same amount of time? What do you think explains this? (This is an extension of the previous question; since the water must move between the substrate particles, it takes longer to begin and continues for a longer period of time).

The GeoSandbox watershed with water being introduce to and removed from the system.

Since not all of the water that entered the system left, students can be asked to identify where the excess water is stored in the watershed and how it could be measured. For the GeoSandbox, measuring is relatively easy. The plastic cup that represents the pond at the surface can be emptied into a graduated cylinder and its volume measured. Water in a subsurface layer can be drained by lifting the elevated portion of the GeoSandbox higher and using the lower valve. Its volume can also be measured. Students might suggest that some water is still in the bottom of the GeoSandbox. This is true but we have no easy way to extract and measure them directly. Since we know the total water we added, the difference between what is introduced and what is removed must be what is stored (surface and subsurface). Lastly, ask students how these measurements would be taken in an actual watershed. They will quickly realize that draining a lake or groundwater system is neither feasible nor desirable. It is easy to see that estimating the volume of the lake is much easier because two dimensions can easily be measured using aerial photographs and the third determined with a boat, string, and weight. Subsurface water storage is much more difficult as it involves drilling multiple wells to determine each of the three dimensions.

Students can be asked if they will collect the same amount of water if they add the same volume a second time using the spray bottles. Students should be asked to write a hypothesis, backed with evidence. Then, the same experiment will be completed a second time and the same measurements will be made with the graduated cylinders and stopwatches.

- What was different about the GeoSandbox watershed this time? Did it appear to change our data? How did it change the data? What do you think is the underlying reason for the changes?

There are additional features that can be added to the GeoSandbox depending on the size of the container. For instance, we installed gravel in the shape of a streambed on part of the surface of the sandbox. This made it easier to observe the surface runoff and stream flow. We also placed a plastic sheet on a portion of the sandbox surface. A plastic sheet is an impermeable layer and simulates the construction of a parking lot or other impermeable surface in a real-world application. The surface area of the plastic sheet and the location of placement of the plastic sheet are at the discretion of the teacher. Students will see that water collects on the plastic sheet and drains to the lowest point but does not flow through the plastic. This is reinforced by placing the plastic sheet along the edge of the container so that students can see water does not reach the soil below the plastic.

If more time is available, more detailed investigations can be conducted by noting the proportion of the total area of the sandbox that is now impermeable and compare it to the total area of the sandbox that is receiving precipitation. This experiment could be repeated multiple times with plastic sheets of varying areas. Note the differences in runoff versus groundwater flow for different plastic sheet areas. What effect did adding an impermeable layer have on the amount of runoff? What effect did the impermeable layer have on the amount of groundwater collected?

After each use, we recommend draining the GeoSandbox, removing the lid, and opening the valves to allow it to dry out. Thus, you will avoid the odor that comes with anaerobic respiration.