

Living with Streams – Engineer and Build Your Own Levee

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Next Generation Science Standards (NGSS) related to this lesson

Earth and Human Activity

- MS-ESS3-3.** Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment.

Earth Science Disciplinary Core Ideas

ESS3.B: Natural Hazards

- Mapping the history of natural hazards in a region, combined with an understanding of related geologic forces can help forecast the locations and likelihoods of future events.

Engineering Design

- MS-ETS1-1.** Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solution.
- MS-ETS1-2.** Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.
- MS-ETS1-3.** Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.
- MS-ETS1-4.** Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.

List of the first and second dimensions of the NGSS Framework

Science and Engineering Practices	Cross-Cutting Concepts
Asking questions and defining problems	Patterns
Developing and using models	Cause & Effect
Planning and carrying out investigations	Scale, Proportion, & Quantity
Analyzing and interpreting data	Systems and Systems Models
Using mathematics and computational thinking	Energy and Matter
Constructing explanations and designing solutions	Structure and Function
Engaging in argument from evidence	Stability and Change
Obtaining, evaluating, and communicating information	

Introduction

One way that people protect property from flooding is to build levees on either side of a stream to keep the water from overflowing the channel. Levees are earthen structures designed to reduce the risk of flooding by controlling the flow of water during periods of high discharge (FEMA, 2012). No levee is completely flood-proof, but sound engineering can improve a levee's chances of withstanding a flood.

This activity is split into three parts: (1) Read About Flooding In Your Local Area, (2) Preliminary Earth Materials Testing, (3) Engineer and Build Your Own Levee.

READ ABOUT LOCAL FLOODING

Have the students do a short reading exercise to learn about the potential for flooding in their local area. Provide a graphic organizer to allow them to extract information out of the article, then have them share what they found in pairs or tabletop groups.

A graphic organizer for the article *California’s Next Nightmare* (by New York Times reporter Alex Prud’homme), is provided to the right. This one sets the students up for understanding the two scenarios for levee disasters (and their consequences) that will be addressed during the build-your-own levee activity:

1. levee failure due to a dramatic increase in discharge, and
2. levee failure due to ground motion associated with a major earthquake.

California’s Next Nightmare is available at this url:

<http://www.nytimes.com/2011/07/03/magazine/sacramento-levees-pose-risk-to-california-and-the-country.html?_r=0>

California’s Next Nightmare

New York Times – July 1, 2011

Sacramento Flooding (paragraph 3)

Two location factors related to the flood-prone nature of Sacramento	

Two events that could cause a <i>megaflood</i>	

Consequences of a megaflood in Sacto	Consequences beyond Sacto

Chance of a Megaflood (paragraph 5)

Is a Sacto megaflood possible?	What evidence is given?

PRELIMINARY EARTH MATERIALS TESTING

The Scenario

Give your students this scenario:

You live in a lovely home next to a stream. Unfortunately, it has been raining nonstop upstream for the last three days; discharge has been rising steadily and the resultant floodwaters are approaching your town. You decide to build your own levee in order to protect your home from this flood. To save time and money, you must build your levee from local materials (they are easier to access and cost less). Luckily you have a little time to test the available materials before designing and building your levee.

Earth Materials Testing Procedures

Set the materials out at each station, and make sure that each student has a copy of the *Earth Materials Testing Chart* to record their observations. Explain that this phase of the levee project is to model how each individual earth material behaves if used by itself to build a levee. Limit the duration of this testing phase to just enough time to get a feel for the behavior of each earth material, about 15 to 20 minutes.

For each trial, have them create a hill of the earth material in the center of the small tub so that it extends from one side to the other (a miniature levee). If needed, they may use the spray bottle to moisten the material and stir with a spoon before building their miniature levee. Once built, add water from the jug into one side of the tub to see how well the material holds back the water. Do this for each material making observations and recording those observations on the *Earth Materials Testing Chart*. Ask them to dump out each earth material after each trial taking care not to mix the earth materials (so that it is easier for you to clean up later). If time remains after testing each material individually, then encourage them to try different mixtures of the materials to see how the combined materials might behave.

After testing is complete, run a short discussion about **permeability** (a measure of the ability of a material to allow fluids to flow through it). Water will flow faster and more easily through earth materials with a high permeability. If a material is **impermeable**, then fluids cannot pass through it.

Allow time for clean up before moving on. Have them scrape mixed materials into a single bucket, and “pure” materials into designated containers. Rinse small tub and spoon, wipe clean and return.

BUILD YOUR OWN LEVEE

Teacher Preparation

Measure out earth materials and fill jugs and spray bottles with water. Mark the land side and water side of each large container as shown in figure 1. In addition, mark

Earth Materials Testing Each group should have:

- ½ cup of each earth material (fire clay, sand, pea gravel, pebbles)
- small tub (~4"x6"x2½")
- spray bottle filled with water
- jug of water
- small metal spoon
- bucket of water for rinsing
- 4 trays or containers for dumping each used earth material types
- towels for clean up

a horizontal line one-inch from the bottom on each side of the container, and then mark four ½-inch increments above this base level (see figure 1).

Prepare a 3:2 mixture of sand to gravel and fill each container with a pre-moistened (but not saturated), compacted 1-inch layer of this mixture (about 4 cups of the mixture per container should do it). Each container now should be filled with a compacted base layer of sand and gravel up to the one-inch mark, and there should be four more horizontal marks at ½-inch intervals above the base level. Prepare the perforated cups for simulating rainfall. Arrange a table with the priced materials for building the levee. Separate the play money into bundles of \$3000 for each group.

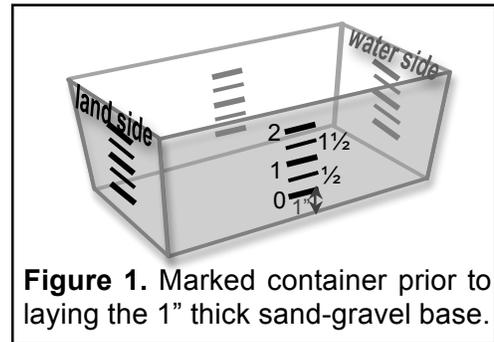


Figure 1. Marked container prior to laying the 1" thick sand-gravel base.

Procedure for Levee Design and Construction

Initial Information

Give each group a container prepared with the sand-gravel base layer, and a lego block (their house). Tell the students that now that they have a feel for how the different locally available earth materials behave, they can begin to plan how to go about building their levee. Point out the 1-inch thick base layer in the container (a mixture of sand and gravel), and tell them that their house (the lego brick) was built on this base layer next to the stream.

Go over what a successful levee must do, in particular their levee must:

- minimize cost
- be built from local materials.
- withstand the forces of standing water as well as flowing water during a flood.
- be resistant to erosion (from rainfall for example), even when the channel is not at flood stage.
- withstand shaking from an earthquake.

Point out that they will be using “tools” to build their levee, and once construction begins, they will not be able to touch the earth materials with their hands (only with their tools). In addition, a single person may not operate two tools at the same time (only one tool per person at a time). Tools include:

Materials for Levee Construction

- earth materials (fire clay, sand, pea gravel, pebbles)
- cups to measure and store earth materials for “purchase”
- bowls for mixing materials/water
- spray bottles filled with water
- small tub (~4”x6”x2½”) for further testing as needed
- shoebox size plastic container (~13”x8”x4”)
- buckets
- small water scooping cups (or baster)
- jugs of water
- large metal serving spoons
- small metal spoons
- small plastic spoons
- ~6” long 1” diameter dowels for compacting
- pieces of bathroom rug cut into ~1-1/2 squares
- flat plastic sheeting cut to fit the container
- lego bricks to represent houses
- perforated cups to simulate rainfall (set inside cups without perforations)
- overhead transparency strips, tape, and a vis-à-vis pen
- rulers and protractors

- **Dump Truck** (bowl – for mixing earth materials, water)
- **Bulldozer** (large metal spoon for lifting, carrying, digging, stirring)
- **Backhoe type 1** (small metal spoon for lifting, carrying, digging, stirring)
- **Backhoe type 2** (small plastic spoon for lifting, carrying, digging, stirring)
- **Water Truck** (spray bottle of water, unlimited refills)
- **Compactor** (large wood dowel, used only for compacting - not stirring or digging)

To clarify the tool use, explain that if they are the bulldozer operator (using the large spoon), then they may not operate the dump truck or backhoe at the same time – in other words if they are using the spoon (bulldozer) to stir up the material, they may not hold the bowl (dump truck) as they do this, nor may they use more than one spoon at a time. This mimics reality and encourages full participation of all group members during the construction process. You also may suggest that the tools be used in shifts so that everyone has a chance to be involved in the different aspects of construction.

The Design Process

Once they have seen the available materials and are aware of how the tools must be operated, ask the students to take some time to brainstorm some potential levee designs with their group. Hand out the *Preliminary Levee Design* worksheet and the *Levee Budget Worksheet* to help them with this process. Discuss the constraints that their design needs to satisfy:

- The **levee crown** (the top of the levee) should be centered at the midpoint of the container and rise at least to the topmost horizontal line (this is 2-inches above the container's base level and will be the maximum flood level in the container).
- The location of the **levee toe** (edge of the levee where the levee base meets the natural ground) depends on how wide the levee's base is. The wider the levee base, the less yard space there will be and the more the levee will disturb the animals and plants that live alongside the stream. It would be preferable to have a strong levee that also maximizes yard space and minimizes environmental impact.
- Once completed, the levee should be aesthetically pleasing – remind them that they will have to live with the levee year round in their yard.
- This stream is in California, so the levee must be stable enough to withstand the shaking of an earthquake at any time (not just during a flood). *Earthquake vibrations will be simulated by drumming on the table both prior to flooding and again during maximum flooding.*
- The levee must be stable enough to withstand erosion all times of the year (for example during periods of local rainfall). *Rain falling on the levee will be simulated with water-filled perforated cups.*
- The levee must be stable enough to hold back the slowly rising flood waters of a **regional flood**. *To simulate a regional flood, water will be added slowly in ½" increments up to the flood level.*

- The levee must be stable enough to hold back the rushing flood waters of a **flash flood**. *To simulate a flash flood, water will be added all at once and as fast as possible.*
- The levee must be built with the available funds (\$3000), so carefully pick and choose what materials and tools would work the best for the design.
- If the equipment breaks, it will be out of commission (can not be used anymore)

The students should discuss how to address all of these constraints as they complete the *Preliminary Levee Design* worksheet. Explain that cost is always an important consideration in any engineering project. If a project can be completed at 30% of the cost with the same effect, then that is a much better investment. The best levee designs balance stability, visual impact, environmental impact, and cost. When they have completed their design, post them around the room so that their ideas can be shared during the design-level iteration.

Design-Level iteration

Although the students will be eager to forge ahead at this point, tell them that another important aspect of any engineering project is the **iteration process**. During the iteration process, engineers use data from analysis and/or testing to modify designs to improve their product. In this activity, the first iteration will be at the design level. They will compare their design ideas with those of the other groups. Direct the groups to circulate around the room to view all of the designs. They should be sure to:

- Note the positive and negative aspects of each design.
- Consider how well their design is likely to behave compared to the others.

Once they have finished looking at all of the proposed designs, have them reclaim their *Preliminary Design* worksheets and return to their stations. Each group should discuss any ideas they might have gained that would improve their levee and modify their original designs as needed.

Levee Construction

Give each group \$3000 in play money, have them finalize their *Levee Budget Worksheet*, and proceed to the 'store' to purchase their materials. As the students move into the construction phase, be sure to emphasize that once construction begins they may not touch the earth materials with their hands (only their tools), AND only one person per tool at a time.

The construction phase will take some time, allow at least 45 minutes to an hour and issue a "flood warning" about 15 minutes prior to the end of the allotted time. As the construction phase is ending, hand out the tape, strips of overhead transparency, vis-à-vis pens, and *Levee Dimensions/Levee Observations* charts. They should tape the overhead transparency to the side of their container and use a vis-à-vis pen to trace the cross-sectional outline of their levee as a record of its shape and size (for later use). In addition, have them measure their levee's dimensions and record their data in the table on the *Levee Dimensions* chart.

Procedure for Rainfall, Earthquake, and Flooding Events

Rainfall

To simulate the rainfall event, give each group a rainfall cup (with perforations in the bottom) set inside an unperforated cup. Demonstrate how the rain will be simulated and have the students decide who will make the rain and who will observe the levee. Once everyone is set, direct the students to fill their rainfall cup with water, and on your mark remove it from the unperforated cup and allow the 'rain' to fall on their levees for 30 to 60 seconds. Note: if you allow the rain to fall for too long, then water may pond up on the landside of the levee, which will confuse later observations during the flooding events.

Earthquake

To simulate the earthquake, have the groups pair up – one group drums all around the table for 30 seconds while the other group observes their levee, then reverse the roles. Have them do the 'earthquakes' on your mark so that they all shake for the same amount of time. Allow time after each quake for the students to record their observations.

Levee Modification

If their levees failed in some way during either the rainfall or earthquake event (or both), then allow them time to complete a second iteration by evaluating the problem, designing a fix for their levee, purchasing additional materials, and making the fix.

Flooding

To ensure that every levee is subjected to the same general flood, you will need to coordinate the timing of the flooding events. Explain in general how the flooding will proceed for both the **regional** and **flash** floods. Demonstrate how to use a small cup to scoop out the water between the regional and flash flood events. Finally, have group members choose duties for each event:

- **flood maker** (pours water into the water side of the container as directed)
- **levee crown observer** (observes the top area of the levee)
- **water side observer** (observes the levee on the water side of the container)
- **land side observer** (observes the levee on the land side of the container)

During the **regional flood**, the flood maker will pour water into the far end of the water side of the levee (along the edge of the container). The water should be added slowly ½ inch at a time with as little turbulence as possible. After each half-inch of water is added, allow the students one minute to record observations. When the final flood stage is reached (two inches above the base level), they should observe the levee for about 2 minutes and then use a small cup to scoop out as much water as possible without damaging the levee. If there is time, allow for another redesign. If not, then proceed with the flash flood.

During the **flash flood** the students will raise the water directly to the flood stage level (2 inches above the base) by upending the water jug and adding the water as fast as possible to the center of the "stream area" on the water side of the container. To be

fair, all groups should have the same amount of water in their jugs before they start to flood. When the final flood stage is reached (two inches above the base level), they should observe the levee for about 2 minutes and record their observations.

COMMUNICATING THE RESULTS

Give the students about 30 minutes to incorporate their findings into a do-it-yourself levee brochure (using butcher paper and markers) that they will present to the class. Tell them that they are civil engineers designing a “Build-Your-Own Levee” brochure for people who live in a floodplain. Their brochure should use simple language that the general public would understand.

Materials

- butcher paper
- markers

Their brochure should include:

- A title that catches the attention of the reader (the general public)
- A brief description of what a levee is (its function and of what it is constructed)
- Pictures and words describing how levees are constructed
 - present their design with further options for improvement based on their observations
 - explain why theirs is a superior design (what constraints does it meet?)
- A description of the ways that a levee might fail (based on your observations)

LEVEES AND FLOOD PROTECTION DISCUSSION

Although students plan and construct their levee in their own way, it is quite likely that much of the engineering principles related to levee construction will be touched upon.

Concepts that could emerge include:

- The coarser the grain size, the more permeable the material.
- Fine grain sizes are more impermeable (with clay being the most impermeable).
- Mixing fine-grains with coarser grains allows the finer grains to fill in the otherwise large spaces between the coarser grains, and lowers permeability.
- Voids allow for seepage and threaten the strength of the levee structure.
- The earthen material in a levee must be well-compacted to be most effective.
- Compaction works best if done layer by layer (lay down in relatively thin “lifts” of material and compact each lift prior to laying down the next one).
- The more massive the levee, the higher it’s strength.
- Coarser-grained materials provide more strength to a levee structure than do finer-grained materials, because they have more mass.
- Levees built with a wide base are more stable than narrow more vertical levees.

- Levees become less stable as the flood level rises.
- Levees fail by:
 - **overtopping** (water flowing over the levee crown)
 - **breaching** (water flowing through the levee), and
 - **underseepage** (water flowing under the levee).
- Prior to failing a levee may exhibit:
 - **pipng** (water seeping through the levee and seeping out on the land side), slumps, and cracks may appear prior to breaching
 - **sand boils** (water pooling or bubbling up on the landward side of the levee) signal underseepage
- The natural foundation surrounding a stream may have to be excavated and filled with a core of impermeable material (like clay) to prevent underseepage
- Installing a **cut-off wall** (concrete usually) prevents water from seeping through a levee (protecting against piping and underseepage if founded below the base of the levee).
- Coverings of grass, gravel, rip rap, concrete or other stonework protects a levee against erosion and scouring.

EARTH MATERIALS RECOVERY FOR REUSE

Used mixed earth materials can be separated into their constituent grain sizes by allowing them to dry and then passing them through a series of sieves of with smaller and smaller mesh openings. The largest openings catch the pebbles, the next size down catches the gravel, and the final mesh catches the sand allowing clay and silt to filter through. Wire mesh of different sizes can be purchased at the hardware store and stapled to a wood frame, or you can use colanders, wire mesh kitchen strainers, and/or sand toy sieves. Separating the clay will be the most problematic. Fabric can be used for the finest mesh to filter out sand from clay, however that is time-consuming. Alternatively, you can wash the sand with water to suspend the clay, and then decant the muddy water into trays and evaporate to retrieve the clay.

FOLLOW-UP

This activity could be followed up by a discussion about the negative consequences of building a levee, both to people and the surrounding environment. Floodplains are natural parts of a stream's pathway. During periods of high discharge in a natural stream, water is temporarily stored in its floodplain, which reduces flooding in downstream areas. In addition, floodplains commonly comprise wetlands that support a wide diversity of life, improve water quality, and absorb the impact of flood events. Unfortunately, once a levee is built, its presence promotes a false sense of security and encourages development in floodplains, which destroys wetlands and puts more people at risk during floods. When levees are built on a stream, they stop the stream from occupying its own floodplain, which adversely affect the wetlands, and causes discharge to build up to higher than normal levels in the stream channel. As the

discharge builds without release, this large volume of water is funneled downstream by the levees. If the downstream levees fail, then highly destructive floods result. Such floods are much more destructive than would be the case if there were no levees. Thus, although levees do protect people from small to moderate floods, levees actually increase the risk of *major* floods. When a levee finally fails, the resultant flood will be much worse than it would have been if the river had been unleveed and allowed to flood earlier further upstream.

RESOURCES ON THE WEB

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Earth Materials Testing Chart

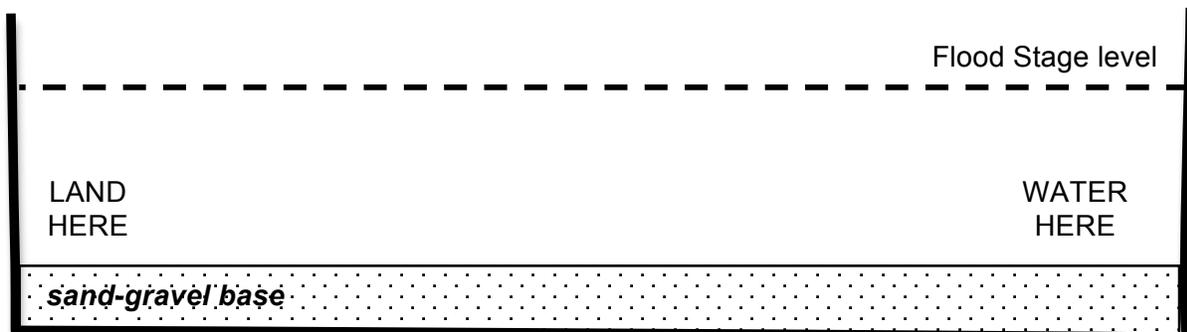
My Observations			
Pebbles	Gravel	Sand	Clay
Mixtures?			

Our Preliminary Levee Design

1. Brainstorm some ideas for your design – come up with as many ideas as possible – no idea or suggestion silly, the more ideas you have, the more choices you will have when you make your final design.

Ideas for Basic Levee design	
How might you make your levee:	Write down and/or sketch your ideas here
earthquake resistant	
resistant to the fast-flowing water of a flash flood	
resistant to normal erosion, like from rainfall	

2. Read through your ideas and choose the ones that you think will work the best. Use the side-view outline of your container provided below as a starting point to sketch the basic design of your levee based on your ideas sketch, OR make your own sketch on a separate piece of paper. Be sure to include what earth materials you will be using and where you will place them.



Levee Budget Worksheet

Use this sheet to determine what materials you will spend your money on in order to build your levee. You have an initial budget of \$3000. You will probably need approximately 3 to 4 cups of earth materials for the bulk of the levee. Everyone will need a dump truck. Although the unit cost of the levee material is given in cups, you may purchase in fractions (for example $\frac{1}{2}$ cup or $\frac{1}{4}$ cup).

Levee Material	Price per unit	Amount Needed	Total Price
Clay	\$500 per $\frac{1}{2}$ cup		
Sand	\$100 per cup		
Gravel	\$100 per cup		
Pebbles	\$100 per cup		
Cut-Off-Wall	\$1000 per sheet		
Sod grass	\$20 per square		
<i>Subtotal:</i>			
Equipment	Price per unit	Number Needed	Total price
Dump Truck	\$500	1	\$500
Water Truck	\$300		
Bulldozer	\$500		
Backhoe type 1	\$300		
Backhoe type 2	\$200		
Compactor	\$250		
<i>Subtotal:</i>			
Total Cost (levee materials plus equipment):			

Levee Dimensions

When construction is complete, use an overhead transparency and a vis-à-vis pen to trace the cross-sectional outline of your levee as a record of the shape and size of your levee. Measure the dimensions of your levee and record your data in the table below:

Height of levee crown (above the base level)	
Width of levee crown	
Width of the levee base	
Slope angle from crown to toe on land side	
Slope angle from crown to toe on water side	

Levee Observations

<i>Event</i>	<i>Land Side</i>	<i>Water Side</i>
Rainfall		
Earthquake		
Regional Flood		
Flash Flood		