Lea: Environmental Engineer Career Pathway Lesson

Slope, Surge, and Erosion Fundamentals

Storm Water Career: Engineer

All Careers Full- Course Lesson Plan #: 5 of 15

Next Lesson Plan Title (Full-Course): Trash Pollution & Engineering Solutions

Select Career Short-Course Lesson Plan #: 3 of 6

Next Lesson Plan Title (Short-Course): Trash Pollution & Engineering Solutions

SUMMARY

This lesson explores designing effective drainage structures, focusing on the importance of select design features that impact water flow dynamics. Through hands-on activities, students investigate the relationship between curve design, slope, roughness, and erosion, while applying principles of fluid dynamics to develop and propose a drainage system design that addresses both immediate and long-term storm water management needs.

FOCUS & GOALS

In practicing storm water management, students will:

- Learn various factors that affect drainage system design
- Review drainage design features and their influence on flow rates
- Assess impacts of drain system runoff in various storm conditions

MATERIALS NEEDED

- Individual student worksheets and maps (double-sided)
- Classroom/group shared maps (double-sided)
- Calculator
- Paper plates, paper cups, ball bearings or small round beads, foil tray, masking tape, and scissors
- Sand and gravel or small stones
- Water

LEARNING OBJECTIVES

- Design drainage structures by applying principles of fluid dynamics
- Experimenting with track designs and utilizing Manning's Equation to analyze flow rates and drainage system efficacy
- Understand erosion mitigation by comparing different materials and techniques to assess their effectiveness

VOCABULARY

Flow Rate - Measures how fast water moves, usually in cubic feet per second (CFS).

Erosion - The geological process in which earthen materials are worn away and transported by natural forces such as wind or water.

Riprap - Loose stone used to form a foundation for a breakwater or other structure.

Specifications - Detailed descriptions of the requirements for a specific product, service, or process.

Standards - Established norms or requirements that provide guidelines and criteria to ensure consistency, quality, safety, and interoperability in products, services, and processes.

Background

The design of drainage structures is a critical component of civil engineering, tasked with the essential goal of managing water flow effectively to ensure safety, functionality, and sustainability within communities. Engineers encounter a variety of challenges in this field, one of the most significant being the consideration of flow rate—the measurement that defines slope, shape, area, and surface texture of a design. Selecting the appropriate parameters are vital; if the slope or area is too small, water can struggle to maneuver through a channel, leading to pooling or overspill. Conversely, an area that is too large can render constructions impractical or excessively costly and a slope too steep can cause hazardous conditions..

Understanding the dynamics of water movement in relation to drainage designs is fundamental for constructing safe and sustainable communities. As water flows around through structures, the principles of gravitational forces play a crucial role. Water, due to its inertia, tends to continue in a straight line, while gravitational forces pull it toward the outer edge of the curve or down a slope. This interaction can present significant challenges, especially during heavy rainfall when water volumes increase, potentially resulting in flooding or erosion if not managed properly.

Moreover, engineers must balance immediate needs, such as preventing flooding, with long-term goals that aim to protect environmental integrity by minimizing erosion and runoff. This requires careful planning and analysis, including factors such as the strategic placement of inlets, the sizing of conduits, and appropriate outfall locations that prevent excessive backwater or soil erosion.

This lesson provides students with hands-on opportunities to explore key design factors that influence fluid flow dynamics in drainage infrastructure. Through various experiments, students will solidify their understanding of concepts such as water flow speed, volume, and slope, while considering the real-world implications of their design choices. For instance, the selection of area and slope affects how water navigates channels before reaching outfalls located near receiving waters. Additionally, students will examine the effects of water flow on soil integrity around these outfalls and investigate appropriate erosion mitigation strategies by modeling and comparing different flow diffusion materials.

In the first activity, students will investigate how slope dimensions impact water flow. They will use beads or ball bearings as representations of water and will be tasked with designing a track system that transports the beads from a high point to a low point. Success in this challenge will depend on their ability to adjust slope designs that effectively keep the beads on course.

Next, students will analyze the dynamics of slopes and volume at a previously introduced mock project site as they finalize a culvert design suitable for typical storm drainage demands. They will utilize Manning's Equation, a standard formula in fluid dynamics, to calculate how slope affects flow rates in an open channel design. Using the Rational Method, student then determine the volume and rate of flow of runoff draining into the culvert. These calculations will then be applied to assess the system's performance during larger storm events.

Finally, students will explore the impacts of drainage design on water flow and subsequent erosion at outfalls. Through a hands-on comparison of materials designed to mitigate erosional effects, they will apply their findings to enhance their channel designs. Students will also reflect on previous lessons concerning RUSLE (Revised Universal Soil Loss Equation) parameters used in the PLET (Pollutant Loading Evaluation Tool) model, considering how specific site conditions might necessitate adjustments to model assumptions.

As a culmination of the lesson, students will have the opportunity to apply the principles of drainage design they have learned, along with supplementary resources, to their project site. They will reflect on potential best management practices (BMPs) identified in earlier lessons and determine how these practices can be integrated into their proposed drainage structure designs.

I. Roll with it! Activity

1. Announce to students:

   Exciting news, team! The Storm Patrol engineer is stepping in to tackle a pressing challenge in our Waikele watershed. With heavy storms becoming a regular occurrence, the administrative building is facing flooding after intense downpours. Funds have been secured to install a culvert that will direct water away from the building, channeling it toward a natural depression in a nearby open field where it can safely infiltrate or flow into the stream. First, let's look at how water flows through channels so we can apply our findings to drainage designs.

2. Distribute paper plates and cups, scissors and tape, and beads or ball bearings. Explain to students that they will be creating a model of a channel, and the beads or bearings will represent water. Their goal is to create a track within the design parameters that will allow the "water" to flow well without slowing, pooling, or spilling over.

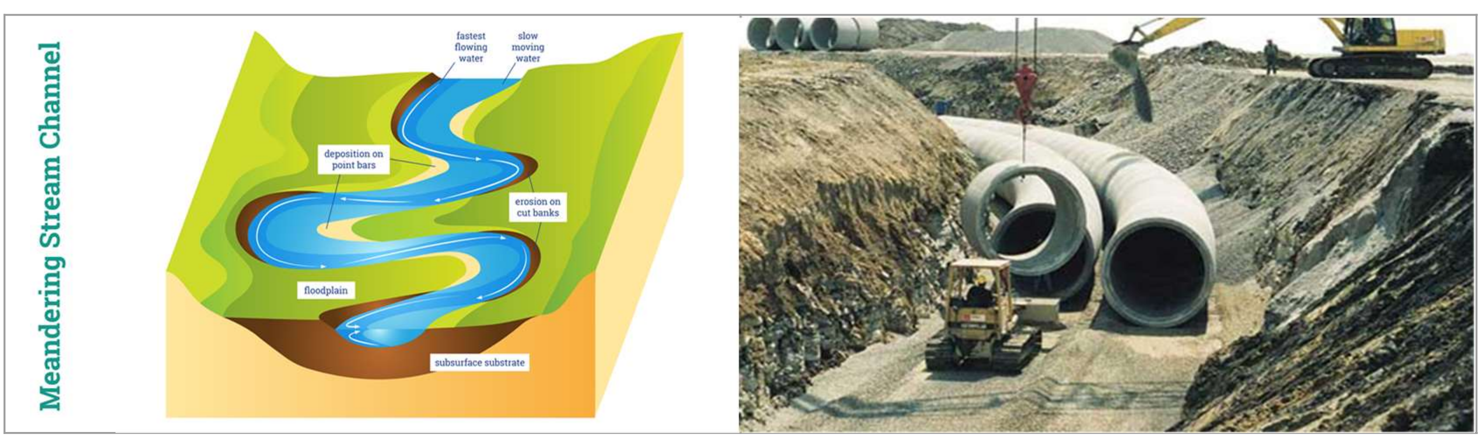
I. Roll with it! Activity Continued

3. Demonstrate how students will use paper plates to cut out the inner section, leaving a U-shaped circular channel. Cut this and then make small slits every inch or so along the edges. This will allow the edges to be manipulated into different curvatures.
4. As needed, connect more channels together.
5. Demonstrate how they can use cups as pillars to create different elevations in their channel course.
6. Determine specifications for a course, such as distance and change in height (EXAMPLE: 2’ starting at 8” high and ending at 0” in height.)
7. Have students use their imagination to design a channel with these specifications.
8. Show them examples of how they are going to make the tracks with the paper plates and cups.
9. Challenge them to design a channel course that will successfully keep the “water” in the channel without falling off.
10. Once they have their channel course created, have the students test if the “water” flows through correctly. They do this by placing a cup at the end of the course and slowly pouring their beads or ball bearings into the channel at the top of the course.

TIPS: Set up a working area with “bumpers” to help contain wayward beads. These could be a perimeter of books or other objects. Have students bend in the curve of the plate to make a well-formed U shape throughout their “channel”. Instruct students to use one bead at a time when trialing the runs for their set-up. Share with them that it is easier to start at the exit and place the elevation of the “channel” in short sections, trialing with a bead as they go. Finally, larger beads are easier to find and clean up. However, small beads work better to mimic water flow and trial in spoonful quantities.

II. Storm Water Drainage Design Activity

1. Share with students that they will be adding to what they have learned from previous lessons to finish an open channel drainage project for the same mock site they created their SWPPP for in Lesson 2. This mock site is a portion of the Waikele campus site they used to calculate runoff and pollutant loads in Lesson 4.
2. Provide students with the Mock Site Drainage Plans and Storm Water Drainage Design worksheet.
3. Share with students that an open channel is a waterway, canal, conduit, or culvert in which a liquid flows with a free surface. A culvert is a short conduit that conveys storm water runoff but may also be used to restrict flow and reduce downstream peak flows. In addition to the hydraulic function, a culvert must also support the embankment and protect traffic and adjacent property owners from flood hazards to the extent practicable. Most culvert design is empirical and engineers must design using local Standards & Specifications. Their worksheet shares some of the design standards for open channels and the channel plans for their mock site have incorporated these standards into the design.



Examples of drainage structures. Left: natural water channels, erosion occurs as the force of inertia competes with the soil structures as water bends around a curve; right: underground pipes requires strategic designing and construction.

II. Storm Water Drainage Design Activity Continued

To clarify what these terms mean, read these definitions:

- Standards are established norms or requirements that provide guidelines and criteria to ensure consistency, quality, safety, and interoperability in products, services, and processes.
- Specifications are detailed descriptions of the requirements for a specific product, service, or process. They outline the necessary features, characteristics, and performance criteria that must be met to satisfy the needs of a project or organization.

4. Share the sample portion of a real-world highway channel design and ask students to review it and identify a parameter from the plan that involves one of the standards on their worksheet (hint: slopes). Ask them to then find one of the specifications (several are highlighted, but include width of concrete and inclusion of weep holes along the bottom on the cross-section view of the channel).
5. Explain to students that the slope of the designed channel has not been determined. They will calculate flow rates using Manning's equation for the minimum slope of 0.5%, as indicated in the standards, which helps to prevent sediment buildup within a channel. Then they will consider what the maximum slope can be to keep under the standard maximum flow rate of 16 ft/s. With their findings, students will provide their recommendations for the slope of the channel.
6. Another aspect considered in designing the channel for the mock site is how much runoff would need to move through the channel during a 50-year storm. This was determined by considering runoff calculations that they made in their previous lessons, as noted on the worksheet.
7. Explain to students that they now need to make sure the design can accommodate the quantity of runoff from the drainage area that will flow into the channel during both typical and large storms. A typical storm is usually considered to be a storm event with a precipitation rate of one inch per 24 hours.
8. Ask them what they think that means. Ensure they understand this means that a total 1" depth worth of rain fell over a given area throughout the length of the storm event. For example, rain falling for 8 hours at a rate of ⅛ inch per hour would equal a 1" rain event. This is a light drizzle over most of the day. Conversely, rain falling at 1" per hour is a fairly heavy rain and prolonged storms at this rate would then be greater than a 1" storm, which is not common.
9. Ask students what they think a 50-year storm means. Ensure they understand that this is a storm size that has an average recurrence or repeats every 50 years.
10. Ask students to look at the graph on their worksheet and share what the size of a 50-year storm is for their mock site (around 3.4 inches per hour).
11. Then ask them to share what the size of a 100-year storm is for their mock site (around 3.8 inches per hour).
12. Have the students then complete their worksheet and calculate how much runoff would need to flow through during a typical storm as well as a 50 and 100-year storm. Then, have them discuss if the channel as designed would be adequate and what may happen during such a storm.

III. Water's Path to Erosion Activity

1. Share with students that another important factor to consider when calculating runoff and pollutant loads is the type of soil and other factors that influence soil erosion and infiltration. In this next activity, they will explore how the water flows out of their channel, the outlet, and can disrupt the ground through erosion. The extent of erosion depends on a number of factors, including the rate of flow, the type of soil, and what's on top of the soil. In their activity, they will model an outfall and explore how rip rap, large chunks of rock, dissipates flow and can help reduce erosion at outfalls.
2. Distribute the Water's Path to Erosion worksheet along with activity materials, including the foil trays, sand, fine and coarse gravel, water bottles, and scissors.
3. Create a "channel" using 1-2 paper cups. Cut in half and then cut off the bottom. Overlap edges and tape together on the inside and outside.
4. Create the "outfall" site by filling ¼ of the foil tray with sand and then wedging it to start at the top edge of the tray, becoming a thin layer at the middle-bottom of the tray (See Figure 1).
5. Set up your materials (See Figure 2), first by placing the tray filled with sand on top of another tray or book. Then place the top end of the channel on a box or inverted cup and the outfall end of the channel on the top edge of the tray with sand. Secure with tape. The top end of the channel should be slightly higher than the outfall end.

III. Water's Path to Erosion Activity Continued

6. Punch a hole in the corner of the tray and place a bowl under the hole.
7. Instruct students to measure out 1 cup of water into a pre-marked cup. Pour the water all at once into the top of the channel. Wait 3-5 minutes to allow the water to drain out of the channel. The exact wait time is not critical, but should be about the same amount for each trial. Students record results and observations on their worksheet.
8. Between each trial, students should make sure the bowl is under the hole, tilt the tray, and drain out the water.
9. Students then follow their worksheet, repeating the trials using different surface components and recording results and observations on their worksheet.
10. At the conclusion of their trials, lead them in assessing what they observe. Are there clear paths to how the water flows? Did they notice any difference between the trials? What do they think would be the best design to protect the soil around the outfall of the mock site channel?
11. Next, share with students that they will use the Revised Universal Soil Loss Equation (RUSLE) to assess the impact of flow rates on the existing soils at the Mock Site Drainage outfall area. Explain that RUSLE is a modeling tool to estimate soil erosion rates. The worksheet lists the coefficients used in the calculation and their relative association. A number of complicated calculations, estimations, and assumptions go into determining each of these coefficients.

   Invite students to recall what they learned about modeling in Lesson 4, where they used the PLET model to determine pollutant loads in runoff. The PLET actually incorporates RUSLE into its assumptions. The coefficients for urban areas are provided on their worksheet. Using these coefficients, they will calculate the erosion rate of the outfall area of their drainage channel. They will assume the outfall area is equal to the drainage length, width, and slope.
12. Guide students as they complete the worksheet and reflect on how design considerations impact pollutant loads and overall watershed health.


Example set up for Activity III. Left: Figure 1; right: Figure 2.

Right examples of rip rap around outfalls to prevent erosion.
Top left: example of rill erosion; bottom left : example of erosion at an outfall.

RUSLE2, or the Revised Universal Soil Loss Equation, is a tool used to estimate soil erosion from factors like rainfall and surface runoff, focusing on two main types of erosion: rill erosion, which occurs in small channels, and interrill erosion, found in the spaces between those channels. It takes into account four key factors that influence erosion rates: climate, soil type, topography, and land use. RUSLE2 uses a computer program with a database of site-specific data to calculate erosion by allowing users to select conditions that match their location. This flexible tool can be applied in various settings, such as farms, construction sites, and disturbed lands, and helps land managers implement practices like planting cover vegetation or using gravel or rip rap to reduce soil loss.

Adaptations and Resources

Storm Patrol Project Based Learning Track:

- Students reflect on their previous site walk-through and map to determine if there are similar issues concerning drainage or erosion on their site or if their site contributes to these issues.
- As a team, students select an issue to address within their project.
- Given their assigned patrol role, students research how professionals in this role can use their specialized skills to address the selected issue.
- Students work on completing Parts 1 -3 of Section 4 of their workbook.

Activity-Centric Learning Track:

Conduct Activities I , II, and II.

Tips to Truncate Lesson:

- Prepare materials for Roll with It ad Water's Path to Erosion ahead of time for students to use.
- Create only one example and demonstrate the activity for Roll with It and/or Waters Path to Erosion.
- Skip sharing the real world design plans in the Storm Water Drainage Design activity.

Tips to Extend Lesson:

- Provide additional challenges to the Roll with It activity, such as including a steep slope or sequential curves.
- Have students explore how a trapezoidal shape would affect the Mock Site Drainage Design (**TIP:** Use the Open Channel Flow Calculator from the resources section).
- Have students research other erosion control measures used at outfalls or along steep slopes.

Resources:

- Sample portion of a real-world highway channel design, https://drive.google.com/file/d/1LwhOVz34owE9Kblmm3zsQmQyeJZ-imF5/view?usp=sharing
- Stage Discharge Relationships, https://kacv.net/brad/nws/lesson2.html#:~:text=The%20hydraulic%20radius%2C%20R%20is,rectangular%20channel%2C%20T%3Db.
- Knox County,*Stormwater Drainage Design, Chapter 7*, https://www.knoxcounty.org/stormwater/manual/Volume%202/knoxco_swmm_v2_chap7_jan2008.pdf
- California Department of Transportation, *Chapter 860*, https://dot.ca.gov/-/media/dot-media/programs/design/documents/chp0860-a11y.pdf
- Virginia Department of Transportation, *Chapter 9*, https://www.vdot.virginia.gov/media/vdotvirginiagov/doing-business/technical-guidance-and-support/technical-guidance-documents/location-and-design/migrated/drainagemanual/chapter9_acc10172023_PM.pdf
- City of Bella Vista, Arkansas, *Chapter 6*, https://cms7files.revize.com/bellavista/Document%20Center/City%20Departments/Street/Drainage%20and%20Stormwater%20Runoff/Drainage%20Manual/Chapter-6-Open-Channel-Flow.pdf
- Omni Calculator, https://www.omnicalculator.com/physics/open-channel-flow
- U.S. Department of Agriculture (USDA), https://www.ars.usda.gov/southeast-area/oxford-ms/national-sedimentation-laboratory/watershed-physical-processes-research/research/rusle2/revised-universal-soil-loss-equation-2-overview-of-rusle2/
- USDA, https://www.nrcs.usda.gov/sites/default/files/2022-10/RUSLE2%20Handbook_0.pdf
- USDA, https://efotg.sc.egov.usda.gov/references/public/KS/RUSLE2slideset051603.pdf
- Roadex Network, https://www.roadex.org/e-learning/lessons/drainage-of-low-volume-roads/components-of-road-drainage-system/