Laboratory 1 – CE 321, Fall 2014
Watershed Dynamics

Purpose: This laboratory has been designed to demonstrate the fundamental concepts behind the dynamic interactions of topography, land-use and water quality within a typical watershed.

Background

When we use the “watershed approach” in environmental engineering and science, it is essential to be able to accurately determine the drainage area (i.e. the watershed) for any point of interest along a stream. A watershed is defined as the land area from which all runoff will flow to the point of interest. In order to determine or delineate the watershed boundary, you must be able to read a topographic map. We can use this information to help track water quality issues within a watershed.

Grouping

Students will participate in four hands-on team activities (team = students) and seven group activities (group = entire class) that are used to demonstrate key concepts behind watershed dynamics.

1) Topography and Watershed Delineation
   a. Overview of topography (group) – 15 minutes
   b. Understanding the hydrologic features on a topographic map (team) – 15 minutes
   c. Visualizing in 3-D based on contours (team) – 20 minutes
   d. Delineate a small watershed (team) – 20 minutes

2) Water quality/hydrology interactions
   a. Mass Balance – (group) - 10 minutes
   b. Watershed Model
      i. Point/Nonpoint Source Pollution (group) – 10 minutes
      ii. Impact of Nonpoint Source Pollution (group) – 20 minutes
   c. Dissolved Solids (DS)/Conductivity
      i. Connection of DS to Conductivity (group) – 10 minutes
      ii. Total DS (TDS) Model (group) – 10 minutes
      iii. Measure Conductivity (group) – 5 minutes
   d. Group Activity
      i. Mass Balance activity involving conductivity (team) – 20 minutes

3) Review (group) - 10 minutes
Objectives

- become familiar with USGS topographic maps and learn how to delineate watersheds
- understand the difference between nonpoint source and point source pollution
- become familiar with basic mass-balance applications and relate them to real-world applications
- become familiar with connections between dissolved-solids and conductivity

Activities

1) Topography and Watershed Delineation

   a) Overview of topography: Typically we work with a 7.5-Minute Series Topographic Map from the United States Geological Survey (USGS) which are 2D representations of specific areas of land. These 7.5-Minute Series Topographic Maps are named by “Quadrangle” - usually the largest town on the map. These maps have a scale of 1:24,000 or 1” = 2000’ and a contour interval of 20 feet. The contours connect points of equal elevation and are shown in brown. Heavy brown lines are the 100-ft contours. Other features shown are rivers, streams, municipal boundaries, towns, roads, schools, buildings, forested areas, etc.

   The following figure is part of the Easton, PA Quadrangle. It shows Easton, Lafayette College, and the lower reaches of Bushkill Creek winding around campus and emptying to the Delaware River. Quads like this would be used to represent the watershed model that will be used to demonstrate nonpoint source and point source pollution.

Look carefully at the contour lines on the map and verify the following:

- Based on the contours shown, elevations here at Lafayette College range from less than 300 ft at the stadium to above 360 ft (note the survey benchmark marked BM 350 near Pardee Hall)

- By looking at the contours surrounding the campus area, one can determine that our campus sits on a hill – you also know this from first-hand experience

- The ground surface slopes steeply downward (note the closely spaced contours) to the west and south (toward Bushkill Creek) and to the east (toward the Delaware River). To the north, the land dips and then rises up to a ridge at about 600 feet.
b. Understanding the hydrologic features on a topographic map
The closer the contours are spaced on the map, the steeper the slope; the farther apart the contours, the flatter the slope – mark a steep slope SS and mark a mild slope MS.

Drainage divides: these topographic features divide one watershed from the next, thus the name – they are shown as wide loops in the contours representing hills; or narrow loops in the contours represent ridges – mark a drainage divide DD.

Permanent (perennial) streams may not be labeled but are always shown with solid blue lines – intermittent streams (not shown above) are marked with dash-dot line – mark a perennial stream PS.

If the V or U shape in the contours points uphill, the topographic feature is a valley - streams often connect these points – mark an upward pointing U or V shape as UV or UU.

If the V or U shape in the contours points downhill, the feature is the nose of a hill – you will never see a stream here – mark a downward pointing V or U shape as DV or DU.

Contours never cross – if you see a line crossing contours, it is a stream or man-made feature such as a road – mark one of these crossings XC.

Sometimes you may see a loop with tic marks along the inside – this is a depression – mark one of these with a D.

b) Visualizing in 3-D based on contours: For the following two topographic features, use Play-Doh to create a 3-D model of the contours shown.
c) *Delineate a small watershed* - Delineate the watershed of the small stream at the point shown (i.e. draw a line that encloses all the area from which runoff will flow to the point):

Tools: Pencil & eraser

General method (as they say, practice makes perfect):

- Locate the “drainage divides”, the topographic features such as hills and ridges that divide flow between adjacent streams – rough sketch in these boundaries first so you know the general shape of the watershed
- Sketch your way uphill from the point of interest, *always perpendicular to contour lines*
- For hills and other contour loops or bends, draw the boundary such that it divides these features in half
- Check that the watershed boundary is everywhere perpendicular to contour lines and does not cross any drainage divides
- Finally, check that there are (1) no areas inside your delineated watershed where the contours indicate flow going away from the point of interest, (2) no areas outside your delineated watershed where contours indicate flow toward the point of interest
2. **Water quality/hydrology interactions**

a) **Mass Balance**
   - Simple way to quantify the inputs and outputs of chemicals within a watershed
   - Total Maximum Daily Load (TMDL) - a calculation of the maximum amount of pollutant that a body of water can receive; generally measured as a mass.

   Common mass relationships used in the control and modeling of chemicals in watershed management

   \[ V_1C_1 + V_2C_2 = V_3C_3 \]  
   = Mass Relationship  
   (Equation 1)

   \[ Q_1C_1 + Q_2C_2 = Q_3C_3 \]  
   = Mass Rate Relationship  
   (Equation 2)

b) **Watershed Model**

   - Point/Nonpoint Source Pollution - A watershed model will be used to demonstrate point/nonpoint source interactions within a typical watershed; water flow dynamics through residual developments, across farmland, over roadways, and from an industrial site.
     - **Point Source Pollution**: The U.S. Environmental Protection Agency (EPA) defines point source pollution as “any single identifiable source of pollution from which pollutants are discharged, such as a pipe, ditch, ship or factory smokestack” (Hill, 1997).
     - **Nonpoint Source Pollution**: Most nonpoint source pollution occurs as a result of runoff. When rain or melted snow moves over and through the ground, the water absorbs and assimilates any pollutants it comes into contact with (USEPA, 2004b). Following a heavy rainstorm, for example, water will flow across a parking lot and pick up oil left by cars driving and parking on the asphalt. When you see a rainbow-colored sheen on water flowing across the surface of a road or parking lot, you are actually looking at nonpoint source pollution.

   - Discussion about salt and how they relate to Chemicals (Nutrients)
     - Salt composted of a anion and cation
       - A general definition – a metal combined with a single nonmetal other than oxygen. Many salt are often one metal combined with more than one nonmetal, including oxygen.
       - Various Salts - NaCl, CuCl₂, NaNO₃, MgCO₃, NaHCO₃, Na₃PO₄

   - Demonstrate the Physical Watershed Model
     - Sprinkle a measured amount (grams) of salt over roads, farms, factories and homes – Use a weigh boat.
     - Have it rain for a period of one day and collect the sample.
c) **Dissolved Solids/Conductivity**
   - Now how do we develop and understanding of the impact
     - Certainly the impact of excessive nutrients can be seen through evidence such as eutrophication and impacts on habitat...even evidence through the death of fish.
     - Point Sources were a relatively easy fix, but Nonpoint SOURCE pollution has become a growing problem and **not** an easy fix.
     - Quantification has become an important way to control and regulate the impact and that is being done by TMDLs for various chemical on concern (chemicals that are toxic and/or impact habitat...etc.)
     - For this exercise let’s consider Salt – NaCl that contaminated our watershed.

- **Conductivity – Total Dissolved Solids (TDS) Connection**
  - A simple way to measure the impact of salts is through conductivity (In science, as in business, we are always looking for inexpensive ways to measure, evaluate, and test.)
    - Conductivity in water is a result of Dissolved Solids
    - Conductivity = \( f(\text{ion concentration, ion charge}) \)
    - Conductivity (in \( \mu\text{S/cm} \)) / 1.8 = TDS mg/L (empirical)
      - A short discussion of why 1.8
      - Empirical – derived without using scientific method or theory
    - \( S \) = Siemens, a measurement related to electrical conductivity; \( S = \) to the reciprocal of Ohm (Resistance)
    - 1 cm is the distance which conductance is measured across. *Not the slit in the probes used to measure conductivity – the slit is an opening of 1 cm.*
    - \( R = V/I \rightarrow \) Ohm’s Law
      - \( V = \) voltage
      - \( I = \) Current (measured in units of amperes)
      - \( R = \) Resistance (Ohm (\( \Omega \)))
    - \( S = R^{-1} = 1/R = \Omega^{-1} = I/V \)
      - \( S \) is also referred to mho (ohm spelled backwards)
  - Measure Conductivity of
    - Rain Water – De-ionized (DI) Water
    - Runoff – Water with dissolved salt

**d) Group Activity**

a. 250 ml DI water and weighed amount of table salt (about 50 milligrams) – calibrate model, adjust 1.8 for pure system of NaCl
   - Conductivity (in \( \mu\text{S/cm} \)) / **1.8** = TDS mg/L

b. Calculate the mass of salt (TMDL) that entered the watershed and collected in the bay.
   - i. Convert Conductivity from \( \mu\text{S/cm} \) to mg/l
   - ii. Measure volume of water collected in graduated cylinder
   - iii. Concentration of salt water times Volume = **Mass**

c. Using a measured amount (250 ml) of a **Prepared Salt Solution** perform a simple mass balance exercise. With the use of a conductivity meter, measure the conductivity of
the prepared salt solution. NOW predict the mixed concentration of salt (mg/L and uS/cm) - 250 ml of prepared salt solution + 100 ml of DI water.

i. \( V_1 C_1 + V_2 C_2 = V_3 C_3 \)

d. Carry out actual mixing and test final solution with conductivity meter

i. How did you do?

ii. Calculate % error with respect to calculated – Predicted = Theoretical

1. \( \frac{(\text{Actual} - \text{Predicted})}{\text{Predicted}} \times 100 = \% \text{ Error} \)

Apparatus and Supplies

1) Topographic Maps (Bushkill Quads)
2) Play-Doh
3) Weigh-boats
4) Conductivity Meters
5) Table Salt
6) Watershed Model
7) 3 Beakers per team (500 ml)
8) Supply about 10 liters of Salt Water (~ 3,000 – 5,000 uS/cm)
9) Supply of about 10 liters De-ionized (DI) Water
**Equations (One worksheet from each GROUP is to be handed in):**

| Concentration in a solution: | \( C = \frac{M}{V} \)  
|                             | C: Concentration [mg/L]  
|                             | M: Mass of dissolved [mg]  
|                             | V: Volume of solvent [L]  
| Conductivity:               | \( \kappa /X = \text{TDS} \)  
| (or Specific Conductance,  | \( \kappa \): Conductivity, or specific conductance of solution  
| Empirical relation)         | \( [\mu \text{S/cm} = 10^{-3} \text{ mS/cm}] \)  
|                             | X: Conversion constant  
|                             | TDS: Total dissolved solids, concentration [mg/L]  
| Conservation of Mass:       | \( V_1C_1 + V_2C_2 = V_3C_3 \)  
|                             | (Under given conditions \( V_1 + V_2 = V_3 \))  
|                             | \( Q_1C_1 + Q_2C_2 = Q_3C_3 \)  
|                             | Q: Volumetric flow rate (Volume/Time)  

### a. Calibrate Model (Obtain Conversion factor, X):

Volume of DI water (V): ____________ (            ),  
Mass of Salt (M): __________________ (          )  
Calculated concentration of this solution (C): _____________________________ (                   )  
Measured Conductivity (κ):___________ (          ),  
*Calculate Conversion factor (X): ___________

### b. Watershed Model Data:

Conductivity of the runoff (κ): __________(          ),  
Volume of runoff: __________________ (          )  
Conversion factor* (X): ______________( unitless ),  
Calculated TDS: ______________ (            )  
Calculated amount of salt entering watershed (TMDL): _____________________________ (               )  

*Need to first obtain X from calibration above!

### c. & d. Concentration of Mixtures/% Error:

Volume of prepared salt solution (V1):_________ (        ),  
Conductivity of prepared solution (κ1):_______(          )  
Calculated concentration of prepared salt solution (C1): ______________ (          ) – Provided by instructor  
Volume of DI water (V2):_______ (        ),  
Conductivity (κ) & Concentration (C2) of DI water: _______ ______

*For Predicted Calculation we will ASSUME DI to have 0 conductivity and 0 concentration of salts (Why - ?)*  

Volume of the mix (V3): __________ (          ),  
Calculated Conc. of mix (C3-Predicted?) __________  
Measured Conductivity of V3 (κ3): _______ (          ),  
Measured Conc. Of mix (C3-Actual?) __________  
Calculated % Error with respect to Predicted (Theoretical): __________________________
Lab Homework Assignment

*Due date* - one week from your assigned laboratory session by 4pm. To be delivered to faculty mailbox. Everyone is to turn in this assignment.

1) Use the pencil and eraser method to delineate the Mud Run watershed for the point shown (a color map is in the `S:\CEE_Drive\CE321` folder). Once you are done, trace your pencil line with a highlighter so that it is clear to your instructor.
2) Walkabout! Relax and take a walk around campus as well as around the city of Easton and identify three examples of nonpoint pollution and three examples of point source pollution. Document with pictures and provide a brief summary (100 words or less) with each picture describing the picture and your findings. (Stop by the purple cow and enjoy an ice-cream cone (http://www.thepurplecowcreamery.com/).)

3) A lake has a constant volume of 100,000 m$^3$. As a result of geologic influence (i.e., limestone) the lake an average conductivity of 300 uS/cm. During a typical winter event when road salting takes place a volume of 10 m$^3$ water with high a salt concentration enters the lake. The salt concentration measured as conductivity, uS/cm is 10,000. As an engineer concerned with the lake ecosystem your job is to regulate lake conditions. In this case you would want to predict the salt influence on the lake and make sure it does not rise above 500 uS/cm. (Draw a diagram similar to the one in Problem 4 to represent the problem presented.)

   a. Based on the information given, what would you predict the conductivity in the lake to be just after a typical winter storm, assuming road salting takes place?
   b. Predict the concentration (mg/L) of salt in the lake after a typical winter storm.
   c. As the town environmental engineer, do need to impose any restrictions on road salting? Explain your answer.
   d. Is this an example of point source pollution or nonpoint source pollution?

4) There is a concern with the quality of water downstream of a wastewater treatment plant (WWTP), in particular the BOD. ($Q = \text{million-gallons/day (MGD)}$) and $C = \text{concentration (mg/L)}$

   a. With the following information please solve for the water flow ($Q$) and concentration of BOD ($C$) for the point identified just downstream of the WWTP.
   b. What the mass rate at point downstream of the WWTP
   c. What is the TMDL of BOD.
   d. Is this an example of point source pollution or nonpoint source pollution?