Laboratory 1 – CE 321, Fall 2016
Watershed Delineation & Hydrology/Water Quality Interaction

SOLUTIONS

Objectives

- become familiar with USGS topographic maps and learn how to delineate watersheds
- investigate water quality and mass-balance applications using a model 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. As we have discussed, water quality at any location along a stream or river depends upon land use (point and non-point sources of pollution) within the watershed draining to that location. In order to delineate the watershed boundary, you must be able to read a topographic map.

Logistics

There are two parts to the lab: topography and watershed delineation, and water quality mass balance on a watershed. You will work in teams of 2-3 students for the second part of the lab.

I. Topography and Watershed Delineation

Typically we work with a 7.5-Minute Series Topographic Quad Map from the United States Geological Survey (USGS). These 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. On the next page is a portion of the Easton, PA Quadrangle. It shows downtown Easton, Lafayette College, and the lower reaches of Bushkill Creek winding around campus and emptying to the Delaware River.

Look carefully at the contour lines on the map (next page) and verify the following:

- Based on the contours shown, elevations here at Lafayette College range from less than 200 ft down at the Arts Campus on 3rd Street to above 360 ft (note the survey benchmark marked BM 350 near Pardee Hall)
- By looking at the contours surrounding the campus area, it is clear that our campus sits on a hill – of course 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 down along Hamilton Street by the stadium to ~280 ft, and then rises up to ~380 ft at Sullivan Park, and farther up to a ridge that exceeds 600 ft.
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 a flat area FA

- 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 UU or UV

- 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 (a bit hard to find) with a D
**Visualizing in 3-D based on 2-D contours**

For the following two topographic features, use Play-Doh to create an accurate 3-D model of the contours shown (note, this can now also be done using a digital elevation map and 3D printer):

*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 (NOT pen!) & a good eraser

General method (practice makes perfect):

- Draw small arrows all over the map indicating the direction of maximum slope at each point
- Based on your arrows, 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
- Now carefully 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, based on your arrows, 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

Note:

In practice delineation is now typically done digitally using a “DEM”. A digital elevation model (DEM) is a regularly-spaced grid of elevation values that is the digital equivalent of a contour map. DEMs at various spatial resolutions (90-m, 30-m, 10-m) are available free of charge from the USGS website nationalmap.gov.

Pennsylvania and other states now also have LiDAR elevation data at an amazing 1-m spatial resolution. LiDAR measures distance optically by imaging the ground surface with a laser and analyzing the reflected light.

DEM can be delineated by computer programs such as ArcGIS Spatial Analyst. You will learn how to do this in CE 351 Water Resources Engineering.
II. Water quality/hydrology interactions

For this part of the lab we will use table salt (NaCl) as our pollutant, and will work with a small model of a watershed. Road salt is in fact a common “nonpoint source” pollutant to freshwater streams in northern latitudes where it is used for deicing. As you may recall from chemistry class, salts in general are ionic compounds that dissociate in water into cations and anions. Other common salts include CaCl$_2$, CaCO$_3$, MgCO$_3$, NaHCO$_3$. We will measure the salt concentration indirectly by measuring the electronic conductivity of the salt solution.

The watershed model is used to demonstrate the difference between point and nonpoint source pollution as well as the mechanism for transporting pollution to a waterway.

- **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). Most such sources are required to have a discharge permit, i.e. a NPDES permit. NPDES is an acronym for National Pollutant Discharge Elimination System.

- **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. For obvious reasons, this type of pollution is much more difficult to regulate and control, but can cause significant problems. For example, excess nutrients (N and P) cause large algae blooms – when the algae dies off and decays, its decomposition can consume all the oxygen in the water, making it unable to support life (e.g. the dead zone in the Gulf of Mexico). EPA is applying a TMDL approach (TMDL = total maximum daily load) to regulate nonpoint pollution. This is a calculation of the total amount (mass) of pollutant that a waterbody can receive and still meet its water quality standard. The TMDL is then allocated to various sources in the watershed so that a limit on the amount coming from each source can be determined.

a. Measuring salts

A simple indirect way to measure salts is through a conductivity measurement. In science, as in business, we are always looking for inexpensive ways to measure, evaluate, and test. The conductivity of a solution is a function of its ion concentration and the ion charges. We measure this by applying a current across a small gap filled with solution and measuring the voltage difference (recall that V=IR). Conductivity is the reciprocal of resistance. The SI unit of conductivity is siemens per meter (S/m). Another common unit is mhos per cm (note that “mhos” is “ohms” spelled in reverse and ohms is a measure of electrical resistance). Cm is the distance across which the voltage difference is measured.
A basic, *empirical approximation* is the following:

\[
\text{Conductivity (}\mu\text{S/cm}) / 1.8 = \text{total dissolved solids (TDS) (mg/L)}
\]

Note that in practice the value 1.8 will depend on the specifics of the solution involved. We will check this value for a system of NaCl dissolved in water. [*Worksheet part a*]

Using 250 mL DI water and a weighed amount of table salt (~50 mg), determine the conductivity of the salt solution, and then determine the constant X.

**Using an unknown sample supplied by the instructor, check your calibrated X value with the unknown sample.**

**b. Demonstrate the Physical Watershed Model (group effort)**

- Use a weighing boat to measure out a bit of salt (record the weight)
- Sprinkle the salt over roads, farms, and homes
- Now simulate rain by sprinkling the model with distilled water and allow sufficient time to drain to the bay. The runoff is collected in a beaker under the model

Measure the following [*Worksheet part b*]

- Volume of the runoff captured
- Conductivity of the rain water – De-ionized (DI) Water
- Conductivity of the runoff

Determine the amount (mass) of salt that exited the watershed

**c. Mixing/Dilution Mass Balance**

Using a measured amount of a Prepared Salt Solution (250 ml) and DI water (100 ml), perform a simple mass balance/dilution exercise [*Worksheet part c*]

Measure the volume and conductivity of the prepared salt solution. Based on the volumes of water and the measured concentrations, predict the mixed concentration of salty solution (uS/cm and mg/L) when you add them together and mix. Conduct the mixing and test the final solution with the conductivity meter

Calculate % error between the predicted and actual measurements and comment on the result

\[
((\text{Predicted} - \text{Actual}) / \text{Actual}) \times 100 = \% \text{ Error}
\]

Recall from class that we can write a mass balance for two sources that completely mix as
\[ V_1C_1 + V_2C_2 = V_{\text{mix}}C_{\text{mix}} \]

where \( V \) are volumes of solution and \( C \) are concentrations (mg/L)

**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
**Worksheet – one per group** (hand in after lab) Names:

### Equations

| Concentration in a solution: | \( C = \frac{M}{V} \)  
|-------------------------------|------------------|
| M: Concentration [mg/L]  
V: Volume of solvent [L] | C: Mass of dissolved [mg] |

### Conductivity:

| Empirical relation | \( \kappa /X = \text{TDS} \)  
|--------------------|-----------------|
| \( \kappa \): Conductivity, or specific conductance of solution  
(\( \mu S = 10^{-3} \text{mS, so mS/L X 1000 = \mu S/L} \)) | X: Conversion constant |
| TDS: Total dissolved solids, concentration [mg/L] |

### Conservation of Mass:

| Equation | \( V_1C_1 + V_2C_2 = V_3C_3 \) (Under given conditions \( V_1 + V_2 = V_3 \))  
k_1C_1 + k_2C_2 = k_3C_3 |

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**a. Calibrate TDS/Conductivity Equation (Obtain conversion factor, X):**

Volume of DI water (V): __________ ( ), Mass of Salt (M): ________________ ( )

Calculated concentration of this solution (C): ____________________________ ( )

Measured Conductivity (\( \kappa \)):___________ ( ), *Calculate Conversion factor (X): __________

**b. Watershed Model Data:**

Conductivity of the runoff (\( \kappa \)): __________( ), Volume of runoff: ________________ ( )

Conversion factor* (X): ________________ ( unitless ), Calculated TDS: ________________ ( )

Calculated amount of salt entering watershed (TMDL): ____________________________ ( )

(*use the class average from part a)

**c. Concentration of Mixtures/% Error:**

Volume of prepared salt solution (\( V_1 \)):_________ ( ), Conductivity of prepared solution (\( \kappa_1 \)): ______( )

Calculated concentration of prepared salt solution (\( C_1 \)): ________________ ( )

Volume of DI water (\( V_2 \)):_______ ( ), Conductivity (\( \kappa \)) & Concentration (\( C_2 \)) of DI water: ______

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

Volume of the mix (\( V_3 \)): __________ ( ), Predicted Conc. of mix (\( C_3\text{-Predicted} \) )

Measured Conductivity of the mix (\( \kappa_3 \)): _____ ( ), Measured Conc. of mix (\( C_3\text{-Actual} \) )

Calculated % diff between predicted and measured: __________________________
Worksheet – one per group (hand in after lab)

Names: Kara, Matt, Amanda, Rosenthal, Marchese, Grisanti

Equations

<table>
<thead>
<tr>
<th>Concentration in a solution:</th>
<th>( C = \frac{M}{V} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>C: Concentration [mg/L]</td>
<td>M: Mass of dissolved [mg]</td>
</tr>
<tr>
<td>V: Volume of solvent [L]</td>
<td></td>
</tr>
</tbody>
</table>

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<tr>
<th>Conductivity: (Empirical relation)</th>
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<tr>
<td>( \kappa ): Conductivity, or specific conductance of solution</td>
<td>( (\mu S = 10^{-3} \text{ mS}, \text{so mS/L} \times 1000 = \mu S/L) )</td>
</tr>
<tr>
<td>X: Conversion constant</td>
<td>TDS: Total dissolved solids, concentration [mg/L]</td>
</tr>
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<tr>
<th>Conservation of Mass:</th>
<th>( V_1C_1 + V_2C_2 = V_3C_3 ) (Under given conditions ( V_1 + V_2 = V_3 ))</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \kappa_1C_1 + \kappa_2C_2 = \kappa_3C_3 )</td>
<td></td>
</tr>
</tbody>
</table>

**a. Calibrate TDS/Conductivity Equation (Obtain conversion factor, \( X \))**:

Volume of DI water (V): \( \frac{250 \text{ mL}}{} \) ( ), Mass of Salt (M): \( 0.05 \text{ g} \) ( )

Calculated concentration of this solution (C): \( \frac{200 \text{ mg/L}}{} \) ( )

Measured Conductivity (\( \kappa \)): \( \frac{425 \text{ uS/cm}}{} \) ( ), *Calculate Conversion factor (X): \( 2.125 \)

**b. Watershed Model Data:**

Conductivity of the runoff (\( \kappa \)): \( 3215 \text{ uS/cm} \) ( ), Volume of runoff: \( \frac{770 \text{ mL}}{} \) ( )

Conversion factor (X): \( 2.125 \) (unitless), Calculated TDS: \( \frac{1513 \text{ mg}}{} \) ( )

Calculated amount of salt entering watershed (TMDL): \( 1165 \text{ mg} \) ( )

(*use the class average from part a)

**c. Concentration of Mixtures/\% Error:**

Volume of prepared salt solution (V₁): \( 250 \text{ mL} \) ( ), Conductivity of prepared solution (\( \kappa_1 \)): \( 425 \text{ uS/cm} \)

Calculated concentration of prepared salt solution (C₁): \( \frac{200 \text{ mg/L}}{} \) ( )

Volume of DI water (V₂): \( \frac{100 \text{ mL}}{} \), Conductivity (\( \kappa \)) & Concentration (\( C_2 \)) of DI water: \( \frac{1.5 \text{ uS/cm}}{} \), \( 0.7059 \text{ mg/L} \)

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

Volume of the mix (V₃): \( \frac{350 \text{ mL}}{} \), Predicted Conc. of mix (\( C_3 \)-Predicted): \( 143 \text{ mg/L} \)

Measured Conductivity of the mix (\( \kappa_3 \)): \( \frac{306.5 \text{ uS/cm}}{} \) ( ), Measured Conc. of mix (\( C_3 \)-Actual): \( 144.2 \text{ mg/L} \)

Calculated % diff between predicted and measured: \( 0.856 \% \)
Lab Assignment – Due (XXXX)

1) Delineate the Mud Run watershed for the point shown below (Copied from Bangor Quad). When you are done, highlight your pencil line so that it is easily visible.
In-Class Delineation Exercise – Mud Run Watershed
CE 351

Delineate the contributing area for the point shown:
2) Walkabout! Relax and take a walk around campus and neighboring Easton and identify two examples of nonpoint pollution and two examples of point source pollution. Document with pictures and provide a few sentences with each picture describing your findings.

3) A lake has a volume of 100,000 m$^3$. As a result of geologic influence (i.e., carbonate bedrock or limestone) the lake has a background conductivity value of 300 uS/cm. During a typical winter event when road salting takes place, a volume of 100 m$^3$ water with high salt concentration enters the lake. The salt concentration measured as conductivity is 10,000 uS/cm. As the town engineer you know that DEP has established a limit of 500 uS/cm for the lake. (Draw a diagram to represent the problem presented.)

   a. Based on the information given, what would you predict the conductivity and concentration (mg/L) in the lake to be just after a typical winter storm, assuming full mixing of the lake? As the town environmental engineer, do need to impose any restrictions on road salting? Explain your answer.
   b. Suppose half of the salty runoff enters a isolated cove of the lake with a volume of 5,000 m$^3$, rather than mixing into the entire lake. What would you predict the conductivity and concentration to be in this cove?
   c. Is this scenario an example of point source pollution or nonpoint source pollution?
I took this picture when I was on the bus heading to New York City. There are several power plants and factory buildings located nearby the water. There are plenty of roads crossing this area and numerous cars running on the road because New York is such a busy city. The runoff of the highways, roads and vehicle fluids would go into the river, which would make this area is nonpoint source pollution.

I was walking along the College Avenue, and saw the pipe on the riverbank. Since here is a residential area, the pipe might discharge the sewage directly to the river. This is point source pollution.
The road on the picture below is the College Avenue. There are cars running on the road everyday and people living near by the river. The pollution from them will directly go into the river. Therefore, this is nonpoint source pollution.

This is a pipe coming out of the bank. It might be one of the dead sewage pipes because there was no water coming out. People can say it is point source pollution because the pollution was just coming from the wastewater discharge pipe.
The pipe on the upper center of the picture is a pipe coming from a car wash shop. This pipe may go to discharge the wastewater from washing cars. So this would pollute the Bushkill water that is on the bottom of the picture. So, it is point source pollution.

On the left side of the river is a parking lot and on the right side are two buildings. I took this picture when I was standing on the bridge that is crossing the river. The runoff of the parking lot, buildings, roads and cars are going to pollute the river. So, it is also a good example of non point source pollution.
Problem 2

Find
Identify two examples of nonpoint source pollution and two examples of point source pollution.

Solution
Nonpoint source pollution:

March Field Parking Lot
This is an example of nonpoint source pollution because cars often leak oil or other fluids, which then gets swept into bodies of water from rain runoff. Because this pollution cannot be traced back to a single car, it is nonpoint source.

Easton Construction Site
Construction sites often produce nonpoint source pollution because of the loose debris and excess soil on site. Like the car oil, this debris can enter water sources through rain runoff.
Problem 2

Solution Cont.
Point source pollution:

Stream at the bottom of the hill.

This pipe, which empties directly into a small stream, is an example of point source pollution. Although it is unclear where it originates from, it is possible that it expels some sort of contaminant into the water. Because these contaminants come from a specific location, it is point source pollution.

Facility along Delaware River.

This air vent is another example of point source pollution because, similarly to the drain pipe, whatever contaminants this vent may be expelling can be traced specifically back to this point.
Problem 3

**Given**
A lake has a volume of 100,000 m$^3$. The background conductivity value is 300 μS/cm. During a typical winter event when road salting takes place, a volume of 100 m$^3$ of water with a high salt concentration enters the lake, which has a conductivity value of 10,000 μS/cm. The DEP has established a limit of 500 μS/cm for the lake.

**Find**
(a) The conductivity and concentration in the lake after a winter storm, assuming full mixing of the lake. As the town engineer, do you need to impose road salt restrictions?
(b) Suppose half of the runoff enters an isolated cove with a volume of 5000 m$^3$, rather than mixing into the entire lake. What is the concentration and conductivity in the cove?
(c) Is this scenario an example of point source pollution or nonpoint source pollution?

**Solution**
(a) Lake, pre storm: $V_1 = 100,000$ m$^3$
   \[ k_1 = 300 \text{ μS/cm} \]

   Road salt salin: $V_2 = 100$ m$^3$
   \[ k_2 = 10,000 \text{ μS/cm} \]

   \[ 300/8 = C_1 \]
   \[ 10000/8 = C_2 \]

   \[ C_1 = 166.7 \text{ mS/L} \]
   \[ C_2 = 1250 \text{ mS/L} \]

   \[ 100000 (166.7 + 100000000000) = 1001000 C_2 \]

   \[ C_2 = 172.1 \text{ mS/L} \]

(b) Lake, post storm: $V_3 = 100,000 + 100$ m$^3$
   \[ V_3 = 101000 \text{ m}^3 \]

   \[ k_3 = \frac{V_1 k_1 + V_2 k_2}{V_3} = \frac{100000 	imes 300 + 10000 	imes 10000}{101000} \]

   \[ k_3 = 309.8 \text{ μS/cm} \]

   No restriction on road salt is necessary because the conductivity in the lake after a typical winter storm (309.8 μS/cm) does not exceed the DEP's limit of 500 μS/cm.
Problem 3

Solution Cont.

(b) half of salty runoff: \( V_2 = 50 \text{ m}^3 \)
\[ k_2 = 10,000 \text{ m}^3/\text{cm} \]
\[ C_2 = 555.5 \text{ mg/L} \]

cove, pre storm: \( V_1 = 5000 \text{ m}^2 \)
\[ C_1 = 166.7 \text{ mg/L} \]

cove, post storm: \( V_2 = V_1 + V_2 \)
\[ V_2 = 5050 \text{ m}^3 \]

\[ 5000 \times 166.7 + 50 \times 555.5 = 5050 \times C_2 \]
\[ C_2 = 220.1 \text{ mg/L} \]

\[ k_2/1.8 = 220.1 \]
\[ k_2 = 396.1 \text{ m}^3/\text{cm} \]

(c) This scenario is an example of nonpoint source pollution, as most runoff problems are. Because the lake is accumulating road salt runoff from the whole town, it is impossible to pin down one specific point where this pollution is originating.