Student Name: Date:

Connecting Industry to Mathematics Instruction
NSF ATE Award # 1954291

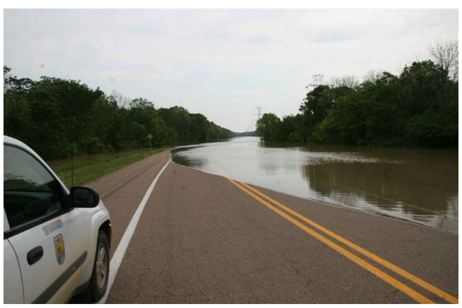
Road Drainage
Student Activity Sheet

In partnership with WAKE TECH, WAKE COUNTY PUBLIC SCHOOL SYSTEM, WakeEd PARTNERSHIP

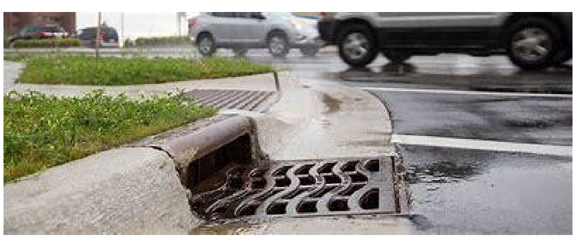
SEPI, Inc is an engineering company started by Sepi Saidi in 2001 here in Wake County. They helped teachers develop this project.

This project explores the following question:
How does the design of inlets along a specific stretch of road relate to the total flow rate (and per inlet flow rate) for a given drainage area?

Drainage systems are important to the safety of drivers on the road. When the drainage system is not sufficient or functioning properly, water will pool on the roadways making it impossible for drivers to pass through as shown in the images below.



source: https://commons.wikimedia.org/wiki/File:Water_on_highway_road.jpg



source: http://emea.ejco.com/am/en/resource-center/product-briefs/product-drainage-grates

Introduction and Prediction:

Think about the following Initial Discussion Questions. Be ready to informally discuss these questions when you are placed in a group for this project.

- Have you ever seen a road flood?
- When you observed this did all the roads flood?
- Why did some flood when others did not?
- What factors contribute to whether a road floods or not?
- How does each factor contribute?
- Do they increase or decrease the likelihood of a flooded road?

For this project, you are an Engineer Intern at SEPI, Inc and are tasked with determining how many drainage inlets (as shown in the previous image) are needed to prevent unsafe amounts of water from pooling on the roadways.

In this activity:

- The drainage area is given as 50.0 acres
- We assume that during rain events, water will flow from this entire 50-acre area to the roadway and so the entire 50 acres will need to be drained by the inlets.
- You will specifically look at a 0.36 mile stretch of Old Honeycutt Rd (in the town of Fuquay-Varina) and the surrounding area outlined in red on page 2.

Prediction:

Though you don't have all the details yet, you know that the length of the road is 0.36 miles, this is a 50-acre drainage area, <u>and the end goal is to determine the number of inlets needed to control the spread of water on the highway</u>.

How many inlets do you think will be required to ensure safe travel on the highway for those traveling the speed limit? Predicted number of Inlets = ___________________

Part 1: Determine the weighted runoff coefficient for the given 50-acre drainage area, A, in Fuquay Varina.

1. Examine the Runoff Coefficient table below. Answer the following questions:
   What relationship do you notice between the type of ground cover (listed as *Slope*) and the corresponding runoff coefficient values? Explain your answer in the context of the types of ground cover.

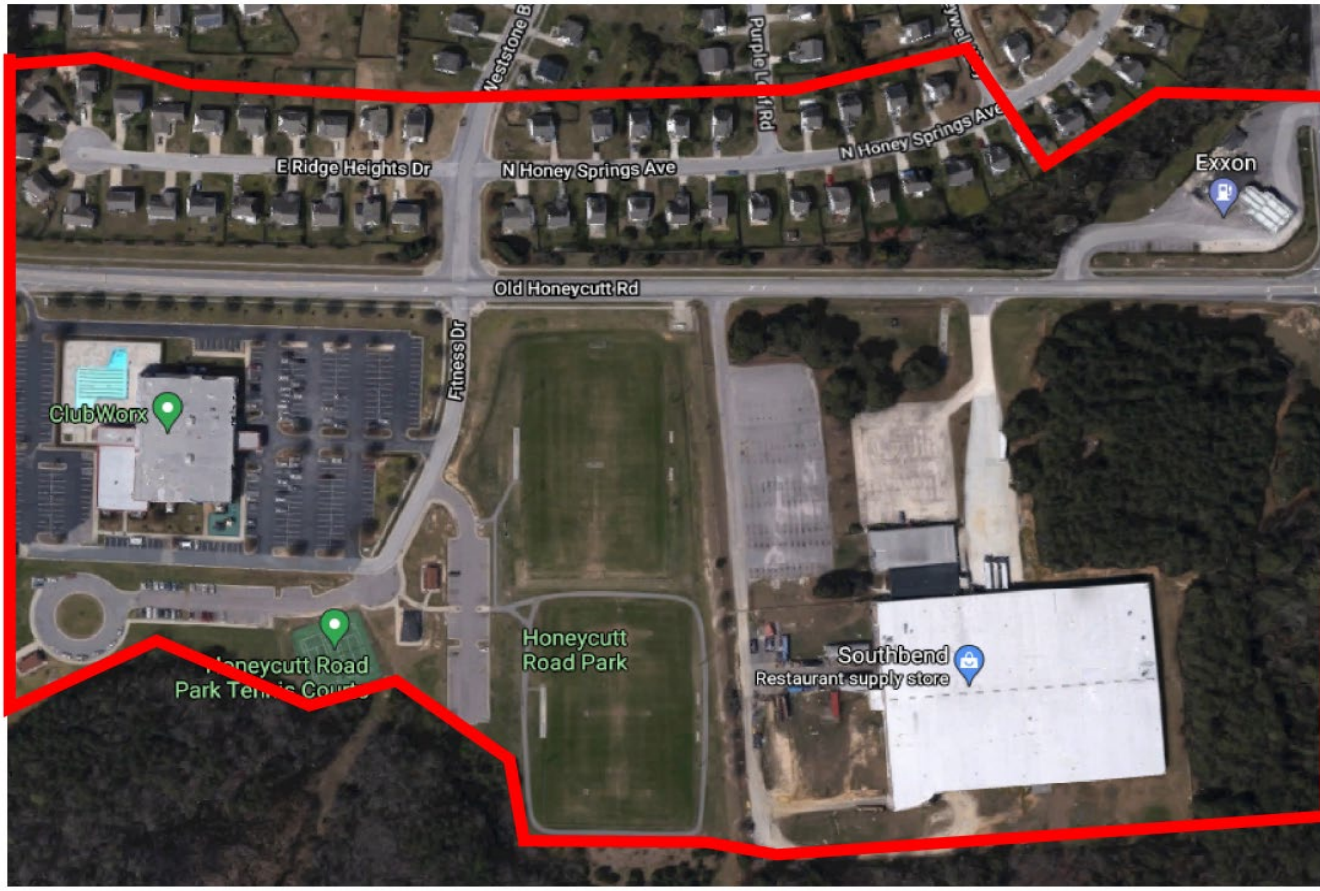
	Runoff Coefficient, C					
	Soil Group A			Soil Group B		
Slope :	< 2%	2-6%	> 6%	< 2%	2-6%	> 6%
Forest	0.08	0.11	0.14	0.10	0.14	0.18
Meadow	0.14	0.22	0.30	0.20	0.28	0.37
Pasture	0.15	0.25	0.37	0.23	0.34	0.45
Farmland	0.14	0.18	0.22	0.16	0.21	0.28
Res. 1 acre	0.22	0.26	0.29	0.24	0.28	0.34
Res. 1/2 acre	0.25	0.29	0.32	0.28	0.32	0.36
Res. 1/3 acre	0.28	0.32	0.35	0.30	0.35	0.39
Res. 1/4 acre	0.30	0.34	0.37	0.33	0.37	0.42
Res. 1/8 acre	0.33	0.37	0.40	0.35	0.39	0.44
Industrial	0.85	0.85	0.86	0.85	0.86	0.86
Commercial	0.88	0.88	0.89	0.89	0.89	0.89
Streets: ROW	0.76	0.77	0.79	0.80	0.82	0.84
Parking	0.95	0.96	0.97	0.95	0.96	0.97
Disturbed Area	0.65	0.67	0.69	0.66	0.68	0.70

Rational Method Runoff Coefficients - Part I

	Runoff Coefficient, C					
	Soil Group C			Soil Group D		
Slope :	< 2%	2-6%	> 6%	< 2%	2-6%	> 6%
Forest	0.12	0.16	0.20	0.15	0.20	0.25
Meadow	0.26	0.35	0.44	0.30	0.40	0.50
Pasture	0.30	0.42	0.52	0.37	0.50	0.62
Farmland	0.20	0.25	0.34	0.24	0.29	0.41
Res. 1 acre	0.28	0.32	0.40	0.31	0.35	0.46
Res. 1/2 acre	0.31	0.35	0.42	0.34	0.38	0.46
Res. 1/3 acre	0.33	0.38	0.45	0.36	0.40	0.50
Res. 1/4 acre	0.36	0.40	0.47	0.38	0.42	0.52
Res. 1/8 acre	0.38	0.42	0.49	0.41	0.45	0.54
Industrial	0.86	0.86	0.87	0.86	0.86	0.88
Commercial	0.89	0.89	0.90	0.89	0.89	0.90
Streets: ROW	0.84	0.85	0.89	0.89	0.91	0.95
Parking	0.95	0.96	0.97	0.95	0.96	0.97
Disturbed Area	0.68	0.70	0.72	0.69	0.72	0.75

Rational Method Runoff Coefficients - Part II

2. Classify the different types of ground cover in the image outlined in red below using the types of ground coverage listed in the Runoff Coefficient tables provided.
   List the different types of ground cover you see here:



3. Using the table below, estimate (roughly) the percent of the total 50 acres for each type of ground coverage. NOTE: This is YOUR ESTIMATION. There is NO exact correct or wrong answer here, but you need to make an informed estimate. You should find at least 6 types of ground cover, but up to 8 can be used. Also be sure that your acreage percentage numbers all SUM to 100%.

Type of Ground Cover	**Percent of Total Acreage**

Part 2: Determine the Weighted Average Runoff Coefficient, C_W.

Discuss your answers to the following questions with your group members.
This step is important to develop context for your final solution to the project. **Do NOT skip this step!**

Initial Discussion Questions:

- Have you ever seen a road flood?
- When you observed this did all of the roads flood?
- Why did some flood when others did not?
- What factors contribute to whether a road floods or not?
- How does each factor contribute?
- Do they increase or decrease the likelihood of a flooded road?

	Runoff Coefficient, C					
	Soil Group A			Soil Group B		
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Res. 1/2 acre	0.25	0.29	0.32	0.28	0.32	0.36
Res. 1/3 acre	0.28	0.32	0.35	0.30	0.35	0.39
Res. 1/4 acre	0.30	0.34	0.37	0.33	0.37	0.42
Res. 1/8 acre	0.33	0.37	0.40	0.35	0.39	0.44
Industrial	0.85	0.85	0.86	0.85	0.86	0.86
Commercial	0.88	0.88	0.89	0.89	0.89	0.89
Streets: ROW	0.76	0.77	0.79	0.80	0.82	0.84
Parking	0.95	0.96	0.97	0.95	0.96	0.97
Disturbed Area	0.65	0.67	0.69	0.66	0.68	0.70

Rational Method Runoff Coefficients - Part I

	Runoff Coefficient, C					
	Soil Group C			Soil Group D		
Slope:	< 2%	2-6%	> 6%	< 2%	2-6%	> 6%
Forest	0.12	0.16	0.20	0.15	0.20	0.25
Meadow	0.26	0.35	0.44	0.30	0.40	0.50
Pasture	0.30	0.42	0.52	0.37	0.50	0.62
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Res. 1/8 acre	0.38	0.42	0.49	0.41	0.45	0.54
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Streets: ROW	0.84	0.85	0.89	0.89	0.91	0.95
Parking	0.95	0.96	0.97	0.95	0.96	0.97
Disturbed Area	0.68	0.70	0.72	0.69	0.72	0.75

Rational Method Runoff Coefficients - Part II

Determine the weighted runoff coefficient for the given 50-acre drainage area, *A*, in Fuquay Varina.

1. **Compare and discuss your estimates of the percent of the total 50 acres for each type of ground coverage from Part 1 with those of other group members. Based on your discussion, as a group, come up with a final estimation. Use the Excel template provided and complete columns B and C.**

2. In column D, use the percentages that you estimated to calculate how much acreage there is of each ground type. Remember, this land totals 50 acres. Each of the values in this column is an area of soil type measured in acres. Because there are more than one, we use the notation, A_i. Show at the bottom of your table that the sum of the acreage is 50 acres. This represents the value $\sum A_i$.
3. Examine the tables of runoff coefficients above. In column E, enter the runoff coefficient for each type of ground cover, **using Soil group *C*, slope <2%**. Each of the values from the table is a *C* value. Because there are more than one, we use the notation C_i.

4. Complete column F by using Excel to multiply each portion of land acreage by its corresponding runoff coefficient type. At the bottom of this column, calculate the sum of all the values in the column, $\sum C_i * A_i$

5. In Excel, below the $\sum C_i * A_i$ value, calculate the weighted runoff coefficient, C_w, for this area using the listed formula below.

$$C_w = \frac{\sum(A_i C_i)}{\sum(A_i)}$$

C_w: Weighted Average of Runoff Coefficient C
A_i: Area of Soil Type [acre]
C_i: Runoff Coefficient for Soil Type

Report your C_w value here:

C_w = ___________________________

6. Based on all your work above, write a sentence explaining what the C_w value means in terms of runoff. Do NOT explain how it was calculated, explain what the value means in the context of this problem.

Part 3: Determine the Total Rate of Discharge, Q_T, in cfs.

$$Q_T = C_w * i * A \text{ where}$$

$$C_w = your\ weighted\ runoff\ coefficient, \quad i = inensity\ of\ rainfall, \quad A = area\ in\ acreage$$

Assume an intensity of rainfall, *i*, of 4 inches/hour. An intensity of 4 in/hr is assumed to be the hardest rainfall occurrence before the average driver will begin to slow down due to poor visibility. It is common practice to accept this intensity value when determining inlet spread requirements only. Spread design applies when drivers are traveling the speed limit. This value is used for calculating spread and determination of appropriate locations for inlet placement to collect roadway pavement runoff.

1. Research online and explain here, using a complete sentence, what the units “cfs” represents (these are the commonly accepted units used for total rate of discharge, Q_T).

2. Show that 1 inch/hr *acre is approximately equal to 1 cfs.

3. Calculate the Total Rate of Discharge (Q_T). This Q_T value will drive the design phase of the project and will be the primary value used for the total drainage network for the proposed stretch of road.

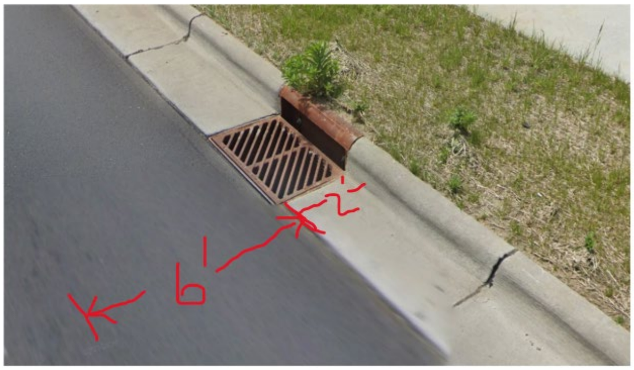
   Report your Q_T value here:

   Q_T = ___________

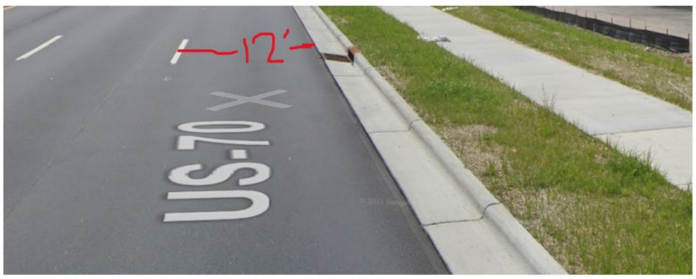
Part 4: Calculate the Spread and Inlet Spacing

Spread is defined as the ponded width of discharge into a vehicular travel lane. Spread is the main factor in inlet spacing design. Inlet spacing shall be sufficient to limit spread as required for safe vehicle maneuverability.

The acceptable industry standard for the acceptable spread of discharge onto the road is half of the width of the travel lane added to shoulder width, as shown in the picture below (for a 12 ft travel lane).



12 foot travel lane.



Half of the width of the travel lane added to shoulder width.

The proposed roadway design will assume a 2 foot 6-inch curb and gutter pan with 12 ft travel lanes per the typical section, as deemed necessary by the project.

For clarification, the curb and gutter section described above represents a 2 foot gutter width, which equates to a 2 foot shoulder width, also shown above. The 6 inches in the “2 foot 6-inch curb and gutter pan” mentioned above represents the curb height.

The equation for spread, *T* (width of flow in feet) is:

$$T = \left(\frac{Q \cdot n}{0.56 S_x^{1.67} S_L^{0.5}} \right)^{0.375}$$

Where:

T is spread (width of flow), ft

Q is per inlet flow rate, ft^3/sec (note that this differs from the total rate of discharge/flow rate for the whole drainage area from Part 3)

n is Manning’s roughness coefficient for sheet/overland flow (see Table 15-1 below), we use this value since it’s used generally for up to 100 ft of water course over a plane surface which suits our meaning of *Q* above

NOTE: *Q* is NOT the same as Q_T from Part 3.

For activity calculation purposes, please make the following assumptions:

- Since the water is flowing over asphalt, assume an *n*-value of 0.011 from Table 15-1, below.

Table 15–1 Manning's roughness coefficients for sheet flow (flow depth generally ≤ 0.1 ft)

Surface description	n [1]
Smooth surface (concrete, asphalt, gravel, or bare soil)	0.011
Fallow (no residue)	0.05
Cultivated soils:	
Residue cover ≤ 20%	0.06
Residue cover > 20%	0.17
Grass:	
Short-grass prairie	0.15
Dense grasses [2]	0.24
Bermudagrass	0.41
Range (natural)	0.13
Woods: [3]	
Light underbrush	0.40
Dense underbrush	0.80

1 The Manning's *n* values are a composite of information compiled by Engman (1986).
2 Includes species such as weeping lovegrass, bluegrass, buffalo grass, blue grama grass, and native grass mixtures.
3 When selecting *n*, consider cover to a height of about 0.1 ft. This is the only part of the plant cover that will obstruct sheet flow.

- Assume a cross slope, S_x , of 2.5% (0.025 ft/ft) per the typical section. This captures the angle of the road perpendicular to the gutter
- Assume a longitudinal slope, S_L , of 1.0% (0.010 ft/ft) for the entire length of the highway.
- Assume that the overall drainage area for the project site will be equally distributed between the inlets placed along the proposed roadway and the entire drainage area will be captured within the inlet design.

1. Substitute the above parameters to express the spread equation in terms of Q.

   T =

2. Use DESMOS to graph T as a function of Q from the equation you wrote above. What do you notice about the graph (just make general observations about how T and Q are related)? Why do you clearly need to stay in quadrant 1?

3. What happens to *T* as S_L gets larger? Use that information to explain how water pools differently on a road that is not very steep compared to one that is steeper? How does the formula represent this?

4. What happens to *T* as S_L gets smaller? Use that information to explain what would be the implications of making a road perfectly flat? What would the formula say about such a road?

5. If the width of spread for this curb/inlet design is chosen as 8 ft as shown in the first picture on page 1 with the 2 ft shoulder width plus half the 12 ft travel lane. Find the inlet flow rate, Q. Show all steps to solve this equation. How can you check your work using DESMOS?

   Q=__________________

6. Explain what the value you found for Q represents in the context of this problem.

Part 5: Calculate the number of Inlets

Determine the number of inlets needed throughout the project site of the proposed 4-lane highway to meet the design criteria. HINT: You will need a value calculated in PART 2 of this project to find the number of inlets. Look at the units!

Once satisfied, this will allow for safe passage of vehicles during large storm events by sufficiently draining the roadway enough that the spread will not create a driving hazard or safety concern for the traveling public.

1. Number of inlets required = __________

Use complete sentences below to explain how you found your answer.

2. Explain in a complete sentence how you would place the inlets on the road.