Connecting Industry to Mathematics Instruction
NSF ATE Award # 1954291

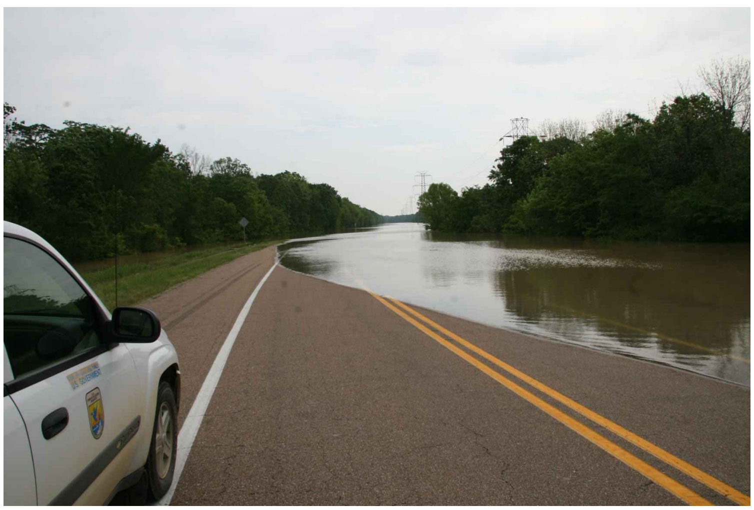
Solutions: Road Drainage - Stormwater Inlet Design Based on Flow Rates
Student Activity Sheet

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

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?

SEPI, Inc is an engineering company started by Sepi Saidi in 2001 here in Wake County.

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.



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

You are an Engineer Intern at SEPI, Inc and are tasked with determining how many drainage inlets are needed to prevent unsafe amounts of water from pooling on the roadways. In this activity, the drainage area for today's activity will be given as 50.0 acres. For the purposes of this activity, 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.

Introduction and Prediction:

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?

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, and the end goal is to determine the number of inlets needed to control the spread of water on the highway. How many inlets do you think will be required to ensure safe travel on the highway for those traveling the speed limit? Predicted Inlets = ____________________

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

1. 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 just below this image.

   Residential, Forest, Pasture, Commercial, Parking, Streets

2. Estimate (roughly) the percent of the total 50 acres for each type of ground coverage.

   Student values may differ but should be close to the percentages given:
   20% Residential
   15% Forest
   15% Pasture
   25% Commercial
   15% Parking
   10% Streets

3. Compare and discuss your estimates with those of other group members. Based on your discussion, you or another group member may deem it appropriate to adjust your answers to #1 and #2. Please use the space below to list any adjustments made to your answers to #1 and #2 and support your decision with complete sentences below.

   Student answers will vary here. Not looking for the response for this to be punitive but to be informative.

4. Examine the tables of runoff coefficients below. What relationship do you notice between the type of ground cover and the corresponding values?

   We did not use the terms pervious and impervious so students may not but the more impervious a road is, the less water it absorbs or the more runoff it has. Higher runoff is associated with a higher runoff coefficient in the table. Whereas a surface that is pervious would have a lower runoff coefficient and will absorb more water during storms.

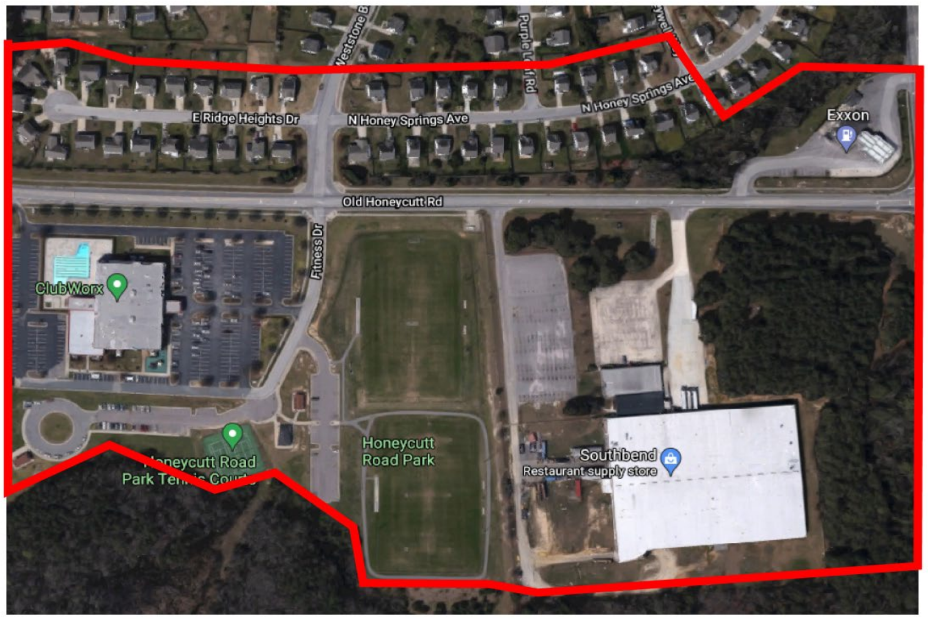
5. Calculate the weighted runoff coefficient, C_w, for this area using the listed formula below and choosing C_i values from the table (Use Soil group C, slope <2%). Use the website [Rational Method Runoff Coefficient Tables for Storm Water Runoff Calculation - Bright Hub Engineering](https://www.brighthubengineering.com/hydraulics-civil-engineering/93173-runoff-coefficients-for-use-in-rational-method-calculations/) (url is https://www.brighthubengineering.com/hydraulics-civil-engineering/93173-runoff-coefficients-for-use-in-rational-method-calculations/) to research the different soil groups and explain why soil type C is appropriate for this project.

$$C_w = \frac{(.2 * 50 * .38) + (.15 * 50 * .12) + (.15 * 50 * .3) + (.25 * 50 * .89) + (.15 * 50 * .95) + (.1 * 50 * .84)}{50}$$

$$C_w = \frac{3.8 + 0.9 + 2.25 + 11.125 + 7.125 + 4.2}{50}$$

$$C_w = \frac{29.4}{50}$$

$$C_w = 0.588$$



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

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

	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

C_w = 0.588

6. Based on all your work above, write a sentence explaining what the C_w value means in terms of runoff.

   In terms of runoff, 0.588 means that slightly more than half of the water when it rains will not soak into the ground cover and will need to be managed using a series of inlets.

Part 2: Determine the Total Rate of Discharge, Q_T, in cfs for the given 50-acre area, *A,* using the C_w value found in part 1, the i-value specified below, and the given formula: $Q_T = C_W \cdot i \cdot A$

7. Explain using a complete sentence what cfs represents.
   This represents cubic feet per second which is a rate of discharge for a particular area when it rains. This gives us an idea of how many cubic feet need to be managed for every second it is raining.

Assume an intensity of rainfall, *i*, of 4 inches/hour should be used for calculating spread and determination of appropriate locations for inlet placement to collect roadway pavement runoff. It is common practice to accept this intensity value when determining inlet spread requirements only. 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. Spread design applies when drivers are traveling the speed limit.

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.

8. Calculate the Total Rate of Discharge.

$$Q_T = C_w * A * i$$

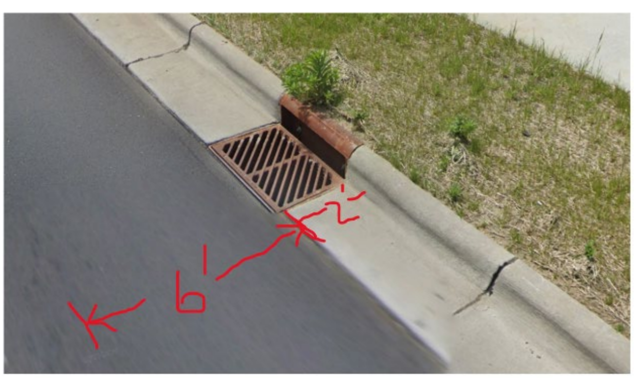
$$Q_T = 0.588 * 50 * 4$$

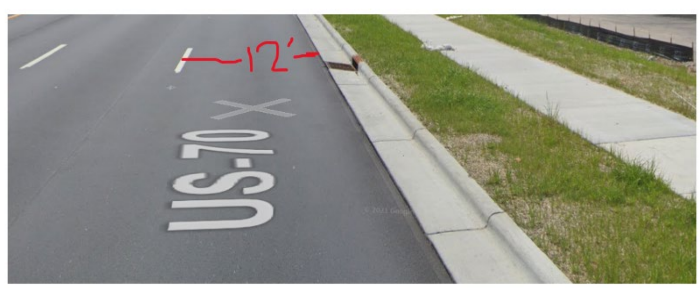
   Q_T = 117.6 cfs

Part 3: 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. 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). Inlet spacing shall be sufficient to limit spread as required for safe vehicle maneuverability. 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, shown below. The 6 inches represents the curb height.





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

T: spread (width of flow), ft

n: Manning's roughness coefficient that describes water movement over different surfaces (Table 15-1)

Q: 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 2)

For activity calculation purposes, please make the following assumptions:

1.) Since the water is flowing over asphalt, assume an n-value of 0.011 from Table 15-1, below.
2.) 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
3.) Assume a longitudinal slope, S_L, of 1.0% (0.010 ft/ft) for the entire length of the highway.
4.) 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.

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.

9. Why do you think Table 15-1 is only used for flow depth generally less than or equal to 0.1 ft?

10. How does water pond differently on a road that is not very steep compared to one that is steeper? How does the formula represent this?

11. What would be the implications of making a road perfectly flat? What would the formula say about such a road?

12. If the width of spread for this curb/inlet design is chosen as 8 ft, find the inlet flow rate, Q. Show all steps to solve this equation and compare your final answer with all group members.

Q=2.75cfs

13. Explain what the value you found for Q represents.

For this design activity, please determine the number of inlets needed throughout the project site of the proposed 4-lane highway to meet the design criteria. Use a sentence to explain how you found your answer.

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.

14. Number of inlets required = 43