Connecting Industry to Mathematics Instruction

NSF ATE Award # 1954291

Student Activity Sheet

Stormwater Runoff & Hydraulics

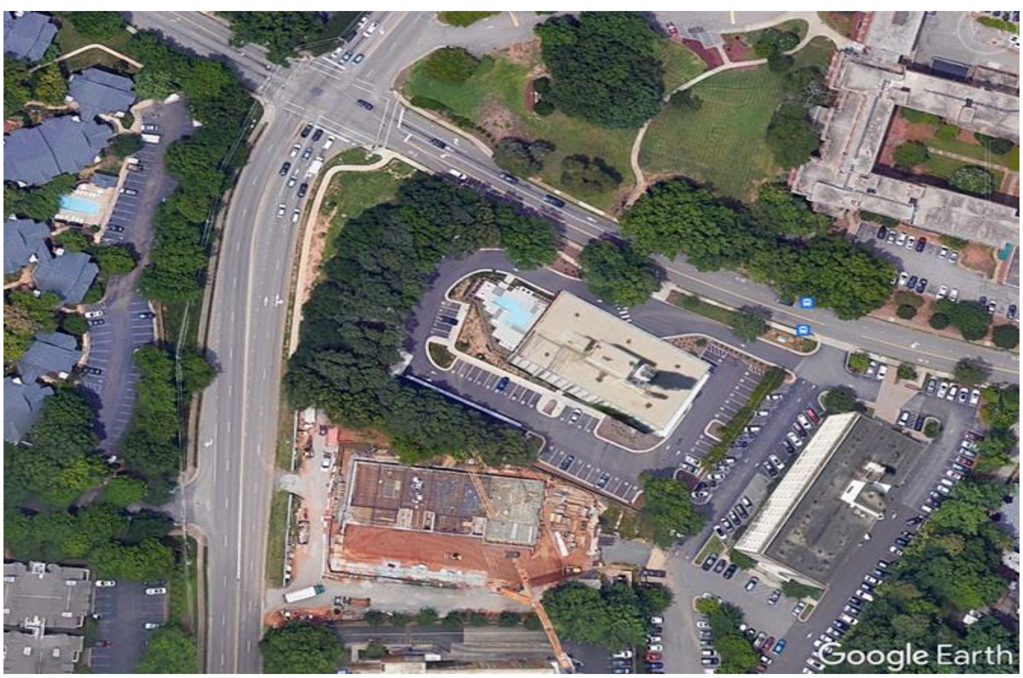
In partnership with

Background: A new development is planned for a 5-acre site adjacent to a roadway maintained by NCDOT. This site will be graded to suit the needs of the owner, but the site is subject to an encroachment agreement for driveways and any other connections to existing infrastructure within the NCDOT right-of-way, such as the storm drainage network.

Tasks Objective:

You are tasked by NCDOT to determine the amount of stormwater flow that can be added to an existing drainage network from a newly developed site, evaluate the potential for erosion in a ditch leaving the site, and redesign a pipe due to increased flow from an upstream roadway widening project.

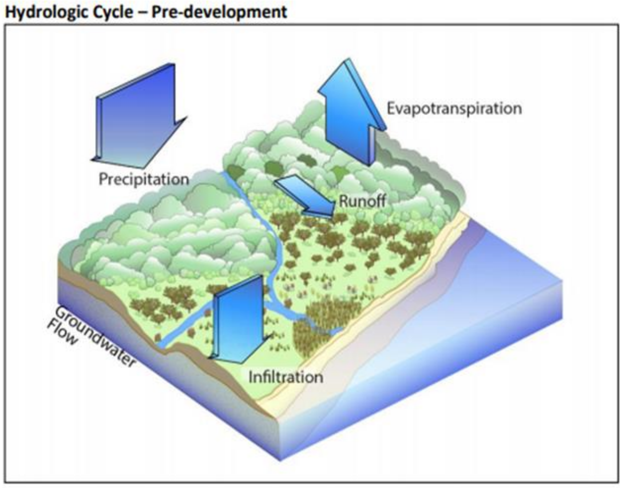
The image of the 5-acre site below taken from Google Earth and shows the construction area that is being built, which will increase the amount of rainwater runoff.



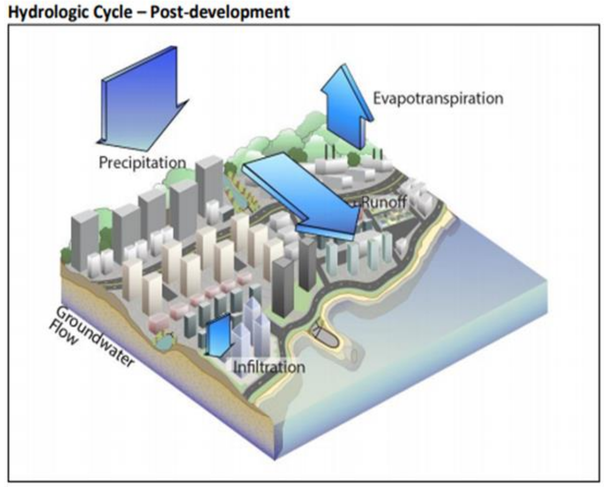
Task 1: **Determining the rain water runoff from the new development**

1. Based on the two images below, what conclusions can you draw about how development impacts the amount of stormwater runoff? Explain the reasoning for your conclusions?

Hydrologic Cycle – Pre-development



Hydrologic Cycle – Post-development



2. A runoff coefficient is the percent of rainfall that will runoff of the surface and not absorb into the ground. Determine the weighted average rainfall runoff coefficient for the 5-acre new development site that is comprised of 65% pavement, 10% woods, and 25% steep sloped grass surface. Use the midpoint of the intervals given for C in the table below.

Table 3. Typical Rational Runoff Coefficients

Type of Surface	C
Pavement	0.7 - 0.9
Gravel surfaces	0.4 - 0.6
Industrial areas	0.5 - 0.9
Residential (Single-family)	0.3 - 0.5
Residential (Apartments, etc.)	0.5 - 0.7
Grassed, steep slopes	0.3 - 0.4
Grassed, flat slopes	0.2 - 0.3
Woods / Forest	0.1 - 0.2

$$C = \frac{\Sigma(A_i C_i)}{\Sigma(A_i)}$$

C: Weighted Average of **Runoff Coefficient**

A_i: *Area of Surface Type* [*acre*]

C_i: Runoff Coefficient of Individual Surface Type

	A	B	C	D
1		Areas A	Runoff C	A_i*C_i
2	Pavement			
3	Woods			
4	Grass			
5	Sums			
6	Weighted C			

3. Explain the contextual meaning of the C value you computed above.

4. NCDOT design plans are based on the rainfall rate that occurred during a 10-year period for a 10-minute duration. The chart below gives the expected rainfall rates that could occur. What rate (including units) should be used for this design plan?

5. How does the estimated rainfall change if the average recurrence interval increases? Explain why.

6. How does the estimated rainfall change if the duration were to increase? Explain why.

POINT PRECIPITATION FREQUENCY ESTIMATES

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PF_tabular | PF_graphical | Maps_&_aerials

PF tabular

PDS-based point precipitation frequency estimates with 90% confidence intervals (in inches/hour)[1]

Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	4.90 (4.48-5.35)	5.70 (5.23-6.23)	6.54 (6.00-7.14)	7.30 (6.67-7.96)	8.06 (7.36-8.80)	8.65 (7.86-9.43)	9.19 (8.29-10.0)	9.65 (8.65-10.5)	10.2 (9.04-11.1)	10.6 (9.35-11.6)
10-min	3.91 (3.58-4.27)	4.56 (4.18-4.99)	5.23 (4.80-5.72)	5.83 (5.34-6.36)	6.43 (5.86-7.01)	6.89 (6.26-7.51)	7.30 (6.58-7.95)	7.64 (6.86-8.34)	8.03 (7.15-8.77)	8.35 (7.36-9.12)
15-min	3.26 (2.98-3.56)	3.82 (3.50-4.18)	4.41 (4.05-4.82)	4.92 (4.50-5.36)	5.43 (4.95-5.92)	5.82 (5.28-6.34)	6.15 (5.55-6.70)	6.43 (5.77-7.02)	6.74 (6.00-7.36)	6.98 (6.16-7.63)
30-min	2.23 (2.04-2.44)	2.64 (2.42-2.89)	3.14 (2.88-3.42)	3.56 (3.26-3.89)	4.02 (3.67-4.38)	4.38 (3.98-4.77)	4.71 (4.25-5.13)	5.01 (4.49-5.46)	5.37 (4.77-5.85)	5.65 (4.99-6.18)
60-min	1.39 (1.27-1.52)	1.66 (1.52-1.81)	2.01 (1.84-2.19)	2.32 (2.12-2.53)	2.68 (2.44-2.92)	2.97 (2.69-3.24)	3.24 (2.93-3.53)	3.51 (3.15-3.83)	3.85 (3.42-4.20)	4.13 (3.64-4.51)

7. Using the 10-year 10-minute Design Storm rate, determine the peak amount of runoff for this newly developed site. Show the conversions needed to change *in-acre/hour* into *cfs*.

$Q = C \cdot i \cdot A$

Q is the peak runoff (cfs)

C is the weighted average runoff coefficient

i is the Rainfall intensity of Design Storm (in/hour)

A is total area (acres)

Task 2: **Determining if the existing drainage is sufficient for the new development**

1. Determine which of the below drainpipe images will allow (a) the least amount of water to flow through and (b) the most amount of water to flow through. Also, state at least 3 pipe characteristics that you considered in making your decisions.

2. If the radius of a drainpipe increases, what changes would occur in the flow rate of water through the pipe?

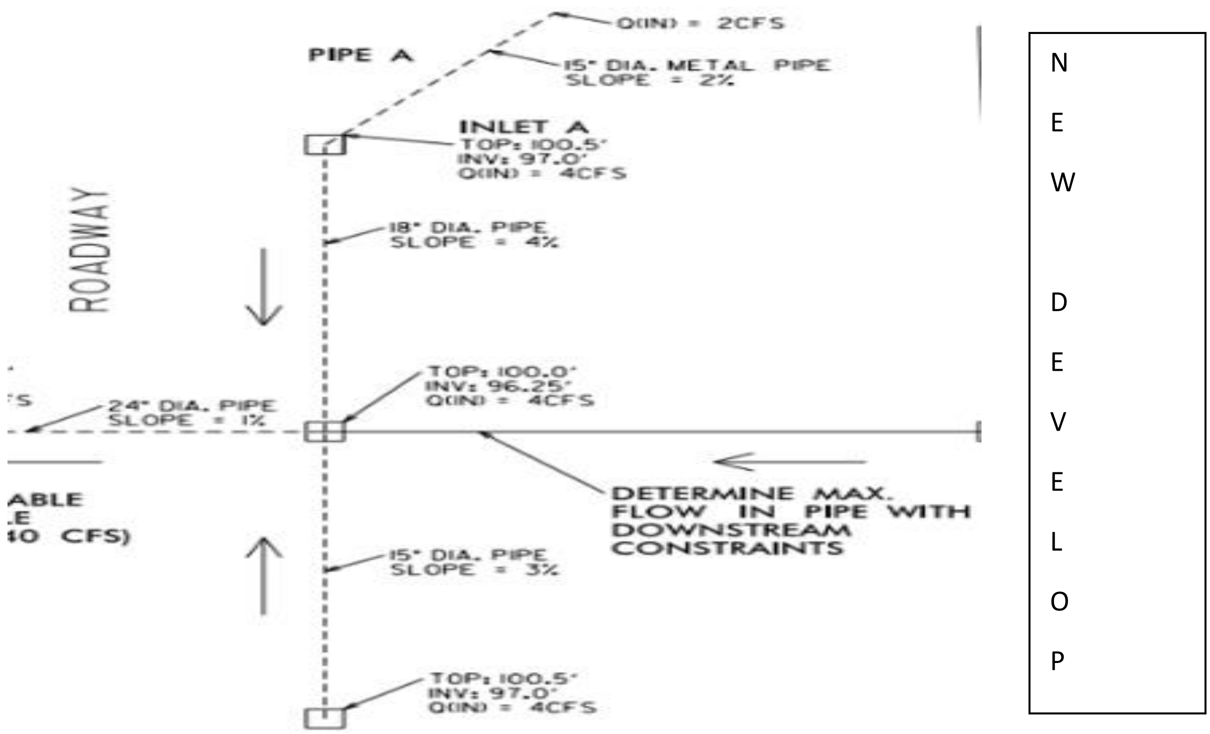
3. If the slope of a drainpipe increases, what changes would occur in the flow rate of water through the pipe?

4. Manning's Equation, $Q = \frac{1.49}{n} \cdot A \cdot R^{\frac{2}{3}} \cdot S^{\frac{1}{2}}$, where Q is the flow through the pipe, n is Manning's roughness of the pipe interior wall, A is the pipe cross sectional area, R is the hydraulic radius which is $\frac{Area}{Wetted\ Perimeter}$, and S is the pipe slope is used to determine the flow rate through drainpipes. As variables A and S each increase, what changes occur in Q? Does this support your pipe characteristics listed in #1 above and explain why?

5. Create an excel spreadsheet with the same column titles as below and make changes to the radius and slope values to confirm your conclusions to the question above. Include your excel formulas in the table below.

n-value	Pipe Radius	Area	Perimeter	Hyd Radius	Slope	Flow Rate Q
0.012	1 ft				0.01	

6. The diagram below shows the existing drainage network. Use Manning's Equation to determine the maximum flow rate for the existing 24-inch concrete pipe crossing beneath the ROADWAY in the existing drainage network below. (n = 0.012).



7. What is the flow rate in Pipe A before INLET A and after INLET A in the existing drainage network?

8. What is the combined flow rate needing to enter the 24-inch diameter pipe going under the ROADWAY including the existing drainage network and the runoff flow rate from the new development?

9. Is the existing 24 in diameter drainage pipe large enough to attach the existing drainage incoming flow rate and the new drainage from the runoff of the new 5-acre development? Why or why not? How many cfs are we short or in excess?

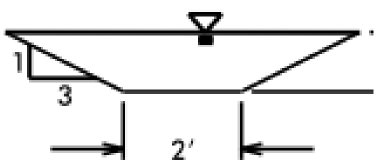
Task 3: **Designing the new drainage system**

1. Shear stress is the force applied by flowing liquid to its boundary. In this case, the liquid is stormwater and the boundary is the channel surface. Basically, shear stress describes the force of water that is trying to drag the channel surface downstream with it. Determine which of the below drain ditch images will experience (a) the least amount of shear stress and (b) the largest amount of shear stress. Also, state at least 3 characteristics that you considered in making your decisions.






2. Your remaining on-site flow must leave the site through an outlet trapezoidal channel (ditch) as shown below. If the longitudinal ditch slope is 5.0%, the sides are sloped 3:1, the base is 2 feet, and the depth of flow is 0.56 feet, what is the maximum shear stress in the ditch? Include units on your result.



$\tau = \gamma \cdot d \cdot S_0$ where

$\tau = maximum\ shear\ stress\ of\ the\ flow$

$\gamma = weight\ of\ water\ in\ \frac{pounds}{cubic\ ft}$

$d = depth\ of\ water\ flow\ in\ feet$

$S_0 = channel\ longitudinal\ slope$

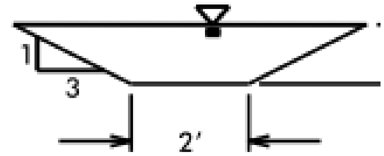
3. What qualities do you believe would create more shear stress in a ditch that is not included in the maximum shear stress flow formula above? Explain.

4. Using the chart below, what class of riprap would you recommend protecting this ditch from erosion?

Table 1. Permissible Shear Stress

Liner	d50 (in)	τ_p (lb/ft^2)
Class A riprap	4	1.6
Class B riprap	8	3.2
Class I riprap	10	4.0
Class II riprap	12	4.8

5. Manning's Equation also applies to trapezoidal channels. If the trapezoidal channel from #2 above was designed to a depth of 1-foot, determine the flow rate that the trapezoidal channel could convey. Use Manning's constant n =0.035. Will the trapezoidal ditch be able to remove the excess water runoff? (The wetted perimeter is only the length where the water contacts the ditch bottom and sloped sides.)



6. Is Class B riprap still appropriate for this ditch? Why or why not?

Task 4: **Adding in a new turn lane**

1. The image below shows the new turn lane that is needed following the new 5-acre site development. The addition of the turn lane will add 5.5 cfs additional rainwater flow to the pipe labeled "A" in the existing drainage network schematic. Pipe "A" is a corrugated metal pipe (CMP) with a Manning's Roughness Coefficient n = 0.024. Will Pipe "A" be able to handle the additional flow at the current slope of 2%? If it cannot, make a pipe recommendation assuming the network downstream of "Inlet A" is adequate and Pipe A can be removed and replaced. You can increase Pipe A slope up to 5%, change the pipe material to concrete, or change the pipe size (cannot be larger than the pipe immediately downstream). Determine the best solution for handling the additional 5.5 cfs runoff and make your recommendation with supporting mathematical documentation.