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CE 365K Hydraulic Engineering Design **First Exam** **Spring 2016**

There are five questions on this exam. They are of equal credit. Please do all five questions.

1. Concepts and Definitions

(a) Write the equation for the Rational Method and define its variables including their units

$Q = C\,i\,A$

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Q = discharge (cfs)
C = runoff coefficient (0–1)
i = rainfall intensity (in/hr)
A = drainage area (acres)

(b) Draw a diagram showing an intensity-duration-frequency curve and label its axes.

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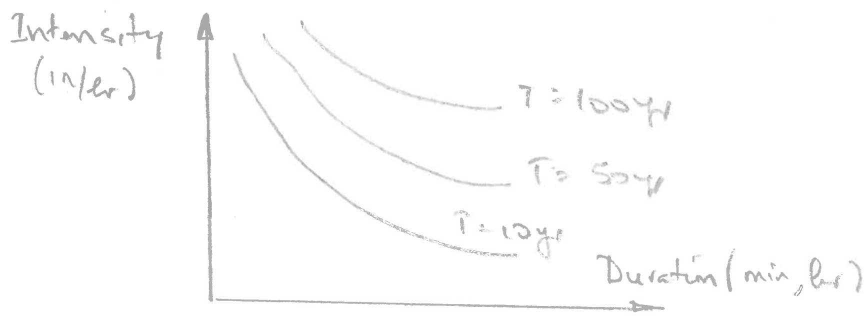

(c) Using a diagram, define the term "Time of Concentration" and explain how it is used with the idf curve in the Rational Method.

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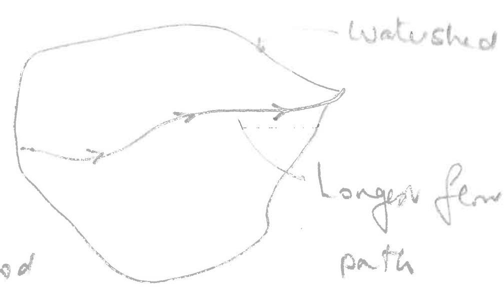
Time of Concentration is the time of travel along the longest flow path from the farthest point in the watershed to the outlet. The duration chosen for i in the rational method is equal to the time of concentration



(d) How can geographic information systems be used to support watershed delineation?

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A digital elevation model is used in which water flows from each cell to only 1 neighbor cell. The set of all cells that drain downstream to the outlet cell of the watershed defines its drainage area.

2. Channel Design

(a) A grassy swale channel (n = 0.03) has a longitudinal slope of 0.005 ft/ft. The shape is rectangular and the bottom width is 6 ft. Determine the discharge in the channel (cfs) if the depth of flow is 1ft.

$A = 6 \times 1 = 6\ ft^2$

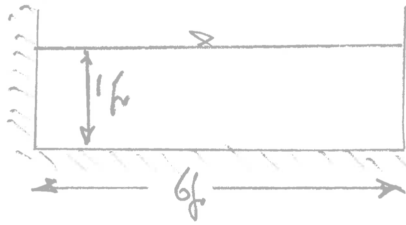
$P = 6 + 2 \times 1 = 8\ ft$

6 $R = A/P = 6/8 = 0.75$

$Q = \frac{1.49}{n} R^{2/3} S_o^{1/2} A$

$= \left(\frac{1.49}{0.03}\right)(0.75)^{2/3}(0.005)^{1/2} \times 6$

$Q = 17.4$ cfs (verified with FlowMaster – 17.35cfs)



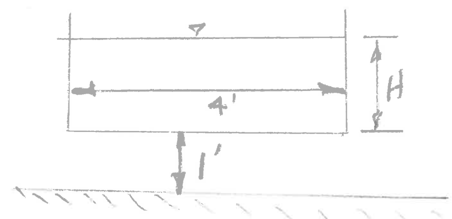
(b) Suppose a discharge of 20 cfs in this channel flows over a sharp crested rectangular weir whose crest elevation is 1ft above the channel bed, width is 4 ft and weir coefficient is 3.367. Determine the headwater elevation (ft) above the channel bed upstream of the weir.

$Q = CLH^{3/2}$

6 $20 = 3.367 \times 4 \times H^{3/2}$

$\therefore H = \left(\frac{20}{4 \times 3.367}\right)^{2/3} = \left(\frac{5}{3.367}\right)^{2/3} = 1.30\ ft$

$\therefore$ head water is 2.30 ft above stream bed



(c) The FlowMaster program allows you to solve channel design problems using a number of different approaches. Describe two of these approaches and for each approach give the variable to be determined and the variables that have to be specified as inputs

(i) To be determined: Discharge

4 Using inputs: Roughness, Channel Slope, Normal Depth, Channel geometry (bed width, side slope, diameter, etc)

(ii) To be determined: Normal Depth

4 Using inputs: Discharge, Slope, roughness, channel geometry

Can also solve for slope, roughness & channel geometry as targets.

3. Curve Number Method

(a) In the Curve Number methodology for design storm analysis the precipitation, P, in a storm event is partitioned into initial abstraction (I_a), retention (F_a), and effective precipitation, P_e. Write an equation connecting these variables.

2 $P = P_e + F_a + I_a \quad \ldots \quad (1)$

(b) The maximum retention or soil water capacity is S. What is assumed about the relationship between I_a and S?

2 $I_a = 0.2S$

(c) Show that if it is assumed that $\frac{F_a}{S} = \frac{P_e}{P-I_a}$ then the effective precipitation is given by

$$P_e = \frac{(P-0.2S)^2}{P+0.8S}$$

10 $\frac{F_a}{S} = \frac{P_e}{P-I_a} \quad \text{———} \quad (2)$

from (1) $F_a = P - P_e - I_a \quad \text{——} \quad (3)$

from (2) $F_a = P_e S/(P-I_a) \quad \text{——} \quad (4)$

(3) = (4) $\therefore P - P_e - I_a = \frac{P_e S}{P - I_a}$

$\therefore (P-I_a)^2 - P_e(P-I_a) = P_e S$

$\therefore P_e(P+S-I_a) = (P-I_a)^2 \quad ; \quad I_a = 0.2S$

$\therefore P_e = \frac{(P-0.2S)^2}{P+0.8S}$ as required

(e) The curve number CN and S are related by S = 1000/CN – 10.

2 What range does CN have? 0 – 100

How is the value of CN determined for a particular drainage area?

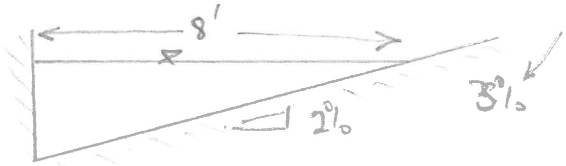
2 From the hydrologic soil group (A, B, C, D) and land cover characteristics (urban, rangeland, etc)

What role does GIS play in this?

2 GIS is used to map soil group and land cover and to resolve areas of particular soil group-land cover combinations so that the area-weighted value of CN can be found for the watershed

4. Inlet and Storm Sewer Design

(a) A street with one lane each way is 40 ft wide and at least 12 ft of free space in each lane is needed for driving during flooded conditions. If the longitudinal slope is 3%, the side slope on the street is 2%, and the surface material is asphalt with n = 0.016, determine the maximum discharge (cfs) that the gutter can carry.



$$Q = \frac{0.56}{n} S_x^{5/3} S_L^{1/2} T^{8/3}$$

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$$= \frac{0.56}{0.016} (0.02)^{5/3} (0.03)^{1/2} 8^{8/3}$$

$Q = 2.29$ cfs (verified with FlowMaster)

(b) Under these conditions if the flow in the gutter is 1.5 cfs, what percentage of the flow would be captured by a 10 ft curb inlet on grade?

$$L_T = 0.6 Q^{0.42} S_L^{0.3} \left(\frac{1}{n S_x}\right)^{0.6}$$

$$= 0.6 \times 1.5^{0.42} (0.03)^{0.3} \left(\frac{1}{0.016 \times 0.02}\right)^{0.6}$$

$L_T = 31.05$ ft (Verified with FlowMaster)

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$$E = 1-(1-L/L_T)^{1.8}$$

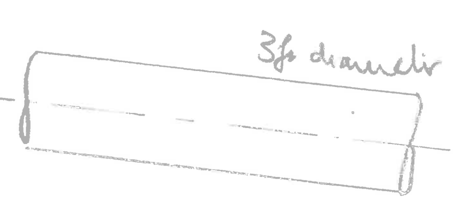
$$= 1-(1-10/31.05)^{1.8}$$

$E = 0.50$ from which we can say 50% of flow is captured

(c) If there is a 3 ft diameter circular concrete storm sewer pipe under this road (n = 0.013) what is its flow capacity (cfs) if it is just flowing full?

for circular pipe flowing full

$A = \pi/4\, D^2$, $P = \pi D$ $\therefore$ $R = A/P = \frac{\pi}{4} D^2 / \pi D = D/4$



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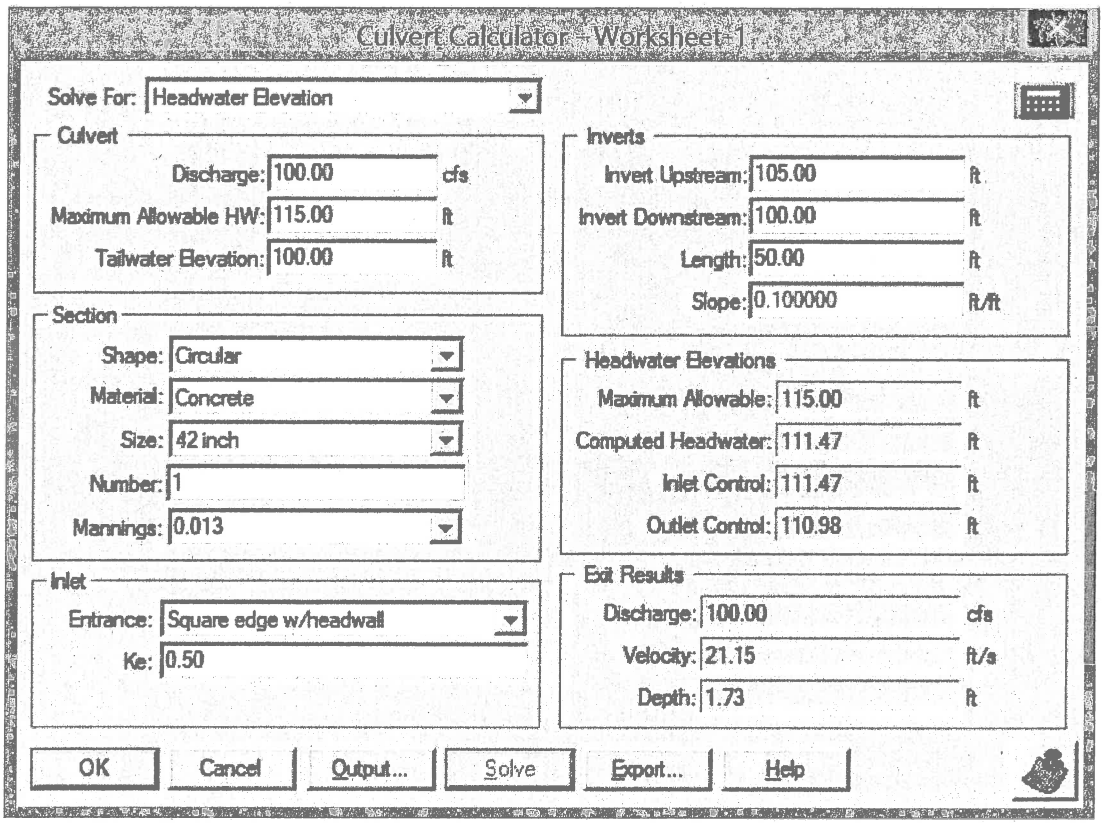
$$Q = \frac{1.49}{n} R^{2/3} S_o^{1/2} A$$

$$= \frac{1.49}{0.013} \times \left(\frac{3}{4}\right)^{2/3} (0.03)^{1/2} \times \pi/4 \times 3^2$$

$Q = 115.8$ cfs Verified with FlowMaster

5. Culvert Design



The image above shows the output of the Culvert Master program for a particular Culvert design.

(a) Describe in words the entrance conditions and flow conveyance system in this culvert.

2 Square-edged entrance to a 42" circular concrete culvert pipe

(b) Is the flow under inlet or outlet control? How deep is the headwater above the top of the pipe at the pipe entrance?

2 Inlet control. Top of pipe is invert + diameter = 105 + 3.5 = 108.5
∴ Headwater is 111.47 − 108.5 = 2.97' above pipe

(Problem 5 is continued on the next page)

(c) Draw a neat diagram of this culvert assuming that it passes under a road whose elevation is 115 ft. Label the pipe invert and water elevations at the upstream and downstream ends of the pipe.

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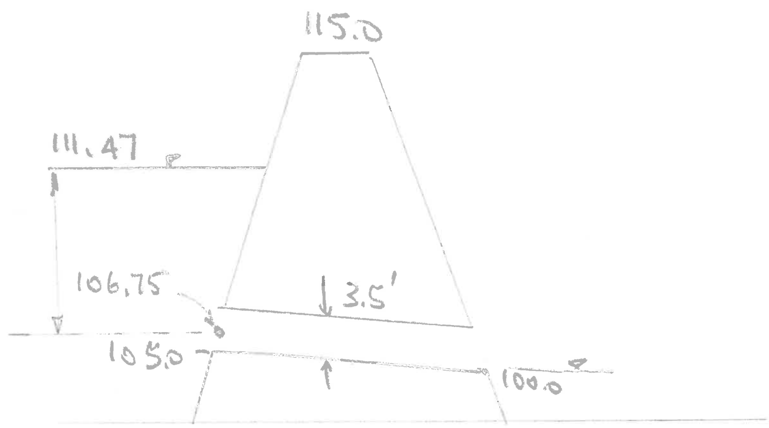

$h = 111.47 - 106.75$

$= 4.72'$

(d) If the flow at the upstream end is controlled as an orifice, determine the discharge through the orifice if the discharge coefficient is 0.6.

Center of pipe is at $105.0 + 3.5/2 = 106.75'$

$Q = C_d \sqrt{2gh}\, A$

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$= 0.6 \times \sqrt{2 \times 32.2 \times 4.72} \times \frac{\pi}{4} \times 3.5^2$

$= 100.65$ cfs (Verified with FlowMaster)

Also – this is the same as solution for inlet control on the culvert in Part (a) of question.