

**CVEG 4303
WATER RESOURCES ENGINEERING
SPRING 2022**

**HOMework
06**

ABOVE
AVERAGE

CVEG 4303 P01

Water Resources Engineering

Spring 2022

Dr. Nzewi

Homework 06

Assigned: 04/26/2022

Due: Tuesday, May 03, 2022 at 1:00 PM (In CLASS) Closes 05/02/2022 11:30 PM

SUBMIT THIS as cover sheet with your work

Name [PRINT]

MAALWIKA - AGGARWAL

Instructions:

IN ALL THE PROBLEMS YOU MUST PROVIDE ENOUGH DETAILS AND DESCRIPTION OF THE SOLUTION METHOD TO DEMONSTRATE YOUR KNOWLEDGE OF THE SOLUTION METHOD. A SUBSTANTIAL PORTION OF THE GRADE WILL BE BASED ON YOUR METHODS.

Problem 1 [150]

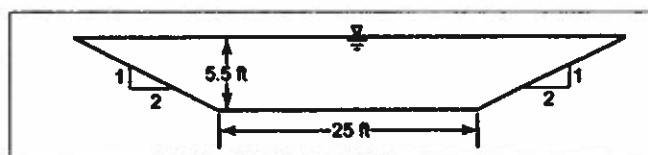
850
900

Determine the following channel parameters for the channel shown.

The Manning's $n = 0.011$ and the slope is $4.0 \text{ ft}/1200 \text{ ft}$.

- Area of flow $[\text{ft}^2]$
- The hydraulic radius $[\text{ft}]$ and hydraulic depth $[\text{ft}]$.
- The critical flow section factor, $Z_c [\text{ft}^{5/2}]$ and the normal flow section factor, $Z_n [\text{ft}^{8/3}]$
- The flowrate in the channel $[\text{ft}^3/\text{s}]$ for the given conditions.

Show your work fully.



Problem 2 [150]

A very rough circular open channel has a diameter of 60 in and the depth of flow is 15.0 in. The Manning's $n = 0.025$ and the slope is $3.0 \text{ ft}/1500 \text{ ft}$. Determine the following:

- Area of flow $[\text{ft}^2]$.
- The hydraulic radius $[\text{ft}]$ and hydraulic depth $[\text{ft}]$.
- The critical flow section factor, $Z_c [\text{ft}^{5/2}]$ and the normal flow section factor, $Z_n [\text{ft}^{8/3}]$
- The flowrate in the channel $[\text{ft}^3/\text{s}]$ for the given conditions.

Show your work fully.

Problem 3 [100]

Problem 14.6 - with a flowrate of 20 cfs.

Show your work fully

Problem 4 [150]

A right-angled triangular channel carries a flow of 16,000 l/s. The Manning's $n = 0.020$ and the slope is $2 \text{ m}/3000 \text{ m}$.

- Determine the critical depth $[\text{m}]$ for this flow.
- Determine Froude number for the flow when the depth of flow is 0.6 m.
- Determine the normal depth of flow $[\text{m}]$.

Show your work fully.

Problem 5 [150]

A grass-lined trapezoidal channel is to be designed to carry a flow of 260 cfs. Determine a suitable Manning's n . The slope of the channel is $1.5 \text{ ft}/2000 \text{ ft}$. The side slopes (same both sides), $z = (1 \text{ vertical} : 2 \text{ horizontal})$. Use a b/y ratio of 1.25 and a maximum channel width $b = 12 \text{ ft}$.

Determine the design depth of flow for the channel $[\text{ft}]$

- Determine the other design parameters including the freeboard.
- Is the flow in the channel under sub-critical or super-critical flow conditions? Why?
- Sketch the profile cross-section of the channel with all necessary dimensions.

Show your work fully.

Problem 6 [200]

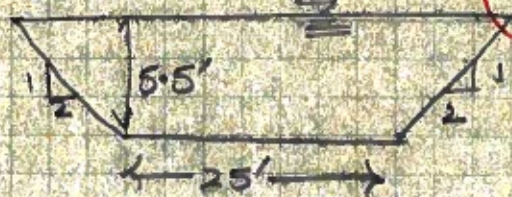
Problem 14.15

- Determine all the design parameters of the channel including the freeboard.
- Is the flow in the channel under sub-critical or super-critical flow conditions? Why?
- Sketch the profile cross-section of the channel with all necessary dimensions.

Show your work fully

Problem 1

$$n = 0.011, \quad B = \frac{4}{1200}$$

a) Area of flow (ft^2)

$$\begin{aligned} A &= by + \frac{1}{2} y^2 (m_1 + m_2) \\ &= (25)(5.5) + \frac{1}{2} (5.5)^2 (2+2) \\ &= \boxed{198 \text{ ft}^2} \end{aligned}$$

b) Hydraulic radius and depth (ft)

$$\begin{aligned} \text{Perimeter (P)} &= b + y (\sqrt{1+m_1^2} + \sqrt{1+m_2^2}) \\ &= 25 + 5.5 (\sqrt{5} + \sqrt{5}) = 49.5967 \text{ ft} \end{aligned}$$

$$\begin{aligned} \text{Top Width, T} &= b + y(m_1 + m_2) = 25 + 5.5(4) \\ &= 47 \text{ ft} \end{aligned}$$

$$\text{Hydraulic radius} = \frac{A}{P} = \frac{198}{49.5967} = \boxed{3.992 \text{ ft}}$$

$$\text{Hydraulic depth} = \frac{A}{T} = \frac{198}{47} = \boxed{4.2127 \text{ ft}}$$

c) $\bar{R}_c (\text{ft}^{5/2})$ and $\bar{R}_h (\text{ft}^{2/3})$

$$\bar{R}_c = A \sqrt{D} = 198 \sqrt{4.2127} = \boxed{406.395 \text{ ft}^{5/2}}$$

$$\bar{R}_h = AR^{2/3} = (198)(3.992)^{2/3} = \boxed{498.28 \text{ ft}^{2/3}}$$

d) Flow rate (ft^3/s)

$$\begin{aligned} Q &= \frac{1.486}{n} AR^{2/3} \sqrt{S} = \frac{1.486}{0.011} (498.28) (\sqrt{4/1200}) \\ &= \boxed{3886.32 \text{ ft}^3/\text{s}} \end{aligned}$$

Problem 2

$$d = 80 \text{ in} = 5 \text{ ft}$$

$$y = 15 \text{ in} = 1.25 \text{ ft}$$

$$n = 0.025$$

$$S = 3/1500$$

(150)

2/9

a) Area of flow, A

$$\frac{y}{d_0} = \frac{1.25}{5} = 0.25$$

$$\frac{A}{d_0^2} = 0.1535$$

$$\text{So, } A = (0.1535)(5)^2 = \boxed{3.8375 \text{ ft}^2}$$

b) Hydraulic radius and depth (R)

$$\frac{R}{d_0} = 0.1466$$

$$\frac{D}{d_0} = 0.1774$$

$$\text{So, } R = (0.1466)(5) = \boxed{0.733 \text{ ft}}$$

$$D = (0.1774)(5) = \boxed{0.872 \text{ ft}}$$

c) $\bar{Z}_C$ & $\bar{Z}_n$

$$\frac{A \bar{Z}_D}{d_0^{5/2}} = 0.0646$$

$$\frac{A R^{2/3}}{d_0^{8/3}} = 0.0427$$

$$\text{So, } \bar{Z}_C = A \bar{Z}_D = (0.0646)(5)^{5/2} = \boxed{3.611 \text{ ft}^{5/2}}$$

$$\bar{Z}_n = A R^{2/3} = (0.0427)(5)^{8/3} = \boxed{3.121 \text{ ft}^{8/3}}$$

d) Flowrate

$$Q = \frac{1.486}{n} A R^{2/3} \sqrt{S} = \frac{1.486}{0.025} (3.121) (3/1500)$$

$$\boxed{Q = 8.2974 \text{ ft}^3/\text{s}}$$

Problem 3

$$Q = 20 \text{ cfs}$$

$$d = 40 \text{ cm} = 3.33 \text{ ft}$$

$$Z_c = \frac{Q}{\sqrt{g}} = \frac{20}{\sqrt{32.2}} = 3.5245 \text{ ft}^{5/2}$$

$$\text{Also, } Z_c = A \sqrt{D}$$

So,

$$\frac{A \sqrt{D}}{d_0^{5/2}} = \frac{Q / \sqrt{g}}{d_0^{5/2}}$$

$$\frac{A \sqrt{D}}{d_0^{5/2}} = \frac{3.5245}{3.33^{5/2}} = 0.1737$$

$$\text{At } 0.1603, y/d_0 = 0.40$$

$$\text{At } 0.2011, y/d_0 = 0.45$$

$$\text{So, at } 0.1737 = 0.40 + \frac{0.45 - 0.40}{0.2011 - 0.1603} (0.1737 - 0.1603)$$
$$= 0.4164$$

$$\text{So, } \frac{y}{d_0} = 0.4164$$

$$\text{So, } y = (0.4164)(3.33)$$

$$y = 1.386 \text{ ft}$$

Problem 4

$$Q = 16000 \text{ l/s} = 16000 \times 0.001 = 16 \text{ m}^3/\text{s}$$

$$n = 0.02, S = 2/3000 \text{ m}$$

a) Now, $R_c = \frac{Q}{\sqrt{g}} = \frac{16}{\sqrt{9.81}} = 5.1084 \text{ m}$

$$\text{Area} = y^2$$

$$\text{top width} = 2y$$

$$R = \frac{A}{P} = \frac{y^2}{2y} = y/2$$

Now, $R_c = A/\sqrt{D} = y^2 \sqrt{y/2}$

$$5.1084 = y^2 \sqrt{y/2}$$

$$y^{2.5} = 7.2243$$

$$y_c = 2.2056 \text{ m}$$

(critical depth)

b) $y = 0.6 \text{ m}$

$$Fr = \frac{Q}{A \sqrt{gD}} = \frac{16}{0.6^2 (\sqrt{9.81 \times 0.6})}$$

$$= 1.8819 \text{ m}^2/\text{s}$$

review formula
& calculation

c) $R_n = AR^{2/3}$

from $Q = \frac{1}{n} AR^{2/3} \sqrt{S}$

$$AR^{2/3} = \frac{Qn}{\sqrt{S}} = \frac{(16)(0.02)}{\sqrt{2/3000}} = 12.894 \text{ m}$$

Now, $A = y^2$

$$R = \frac{1}{4} 2\sqrt{y}$$

So, $R_n = AR^{2/3}$

$$R = \frac{A}{P} = \frac{y^2}{2\sqrt{2y^2}}$$

$$= \frac{y^2}{y(2\sqrt{2})} = \frac{y}{2\sqrt{2}} \sqrt{2y^2}$$



120

4/9

50

50

$$12.394 = (y^2) (44.2 J y)^{2/3}$$

$$12.394 = (y^2) \left(\frac{J y}{2} \right)^{2/3}$$

$$12.394 = \frac{y^{2+2/3}}{1.58} = 0.524$$

$$\text{So, } \boxed{y = 3.585 \text{ m}}$$

normal
depth

Problem 5

a/b
 $Q = 260 \text{ cfs}, S = 1.5/2000, z = 1:2, b/y = 1.25$
 $\text{Max } b = 12 \text{ ft}$

now, $\frac{b}{y} = 1.25$

$$y = \frac{12}{1.25} = 9.6 \text{ ft}$$

$$A = (b + zy)y$$

$$= (12 + 2(9.6))9.6$$

$$= 1299.52 \text{ ft}^2$$

$$R = \frac{(b + zy)y}{b + 2y\sqrt{1+z^2}} = \frac{(12 + 2(9.6))9.6}{12 + 2(9.6)\sqrt{1+2^2}}$$

$$R = 5.4525 \text{ ft}$$

now, $Q = \frac{1}{n} AR^{2/3} \sqrt{S}$

so, $\frac{AR^{2/3} \sqrt{S}}{Q} = n = \frac{(299.52)(5.4525)^{2/3} \sqrt{1.5/2000}}{260}$

$$n = 0.0977$$

$$T = b + y(2z) = 12 + 9.6(2 \times 2)$$

$$= 50.4 \text{ ft}$$

now, at 20 cfs, $C = 1.5$

at 3000 cfs, $C = 2.5$

so, at 260 cfs,

$$C = 1.5 + \frac{2.5 - 1.5}{3000 - 20} (260 - 20)$$

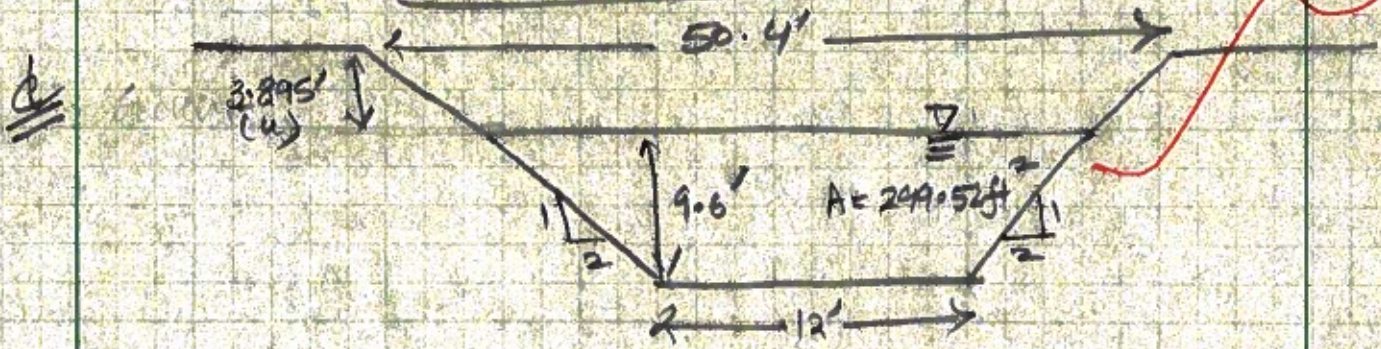
$$= 1.581$$

So, freeboard,

$$h = \sqrt{cy}$$

$$h = \sqrt{1.581 \times 9.6}$$

$$h = 3.895 \text{ ft}$$



$$Q = VA$$

$$\text{So, } V = \frac{Q}{A} = \frac{260}{299.52} = 0.8681 \text{ ft/s}$$

$$D = \frac{A}{T} = \frac{299.52}{50.4} = 5.9428 \text{ ft}$$

$$\text{So, } Fr = \frac{V}{\sqrt{gD}} = \frac{0.8681}{\sqrt{32.2 \times 5.9428}}$$

$$Fr = 0.0627$$

Since Fr is less than 1 ($0.0627 < 1$), the flow is SUB-CRITICAL

200

Problem 6

$S = 0.002$, $n = 0.015$, $z = 1:1.5$, $b/y = 2$, $Q = 500$ cfs

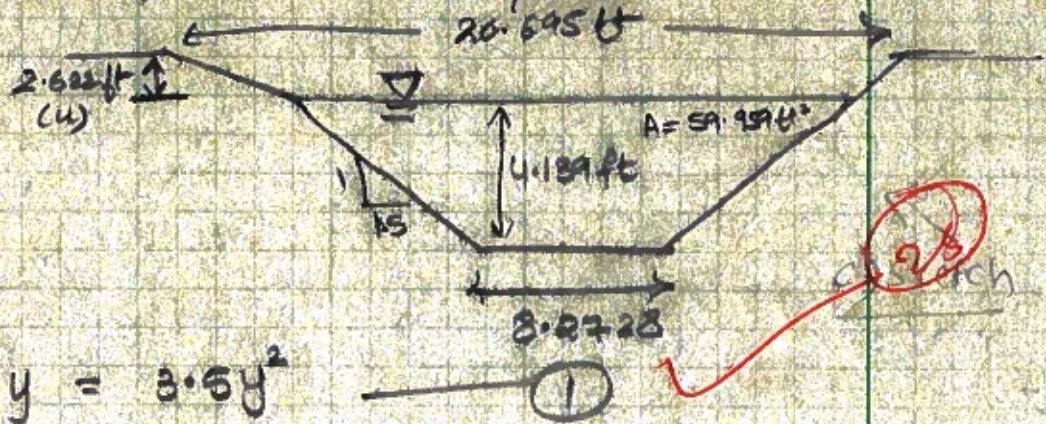
are

$\frac{b}{y} = 2$

so, $b = 2y$

$$A = (b + zy)y$$

$$= (2y + 1.5y)y = 3.5y^2$$



check

$$R = \frac{(b + zy)y}{b + zy\sqrt{1 + z^2}} = \frac{(2y + 1.5y)y}{2y + 2y\sqrt{1 + 1.5^2}}$$

$$R = \frac{3.5y^2}{5.61y} = 0.624y$$

$Q = \frac{1.486}{n} A R^{2/3} \sqrt{S}$ Substitute (1) & (2)

$$500 = \frac{1.486}{0.015} (3.5y^2) (0.624y)^{2/3} \sqrt{0.002}$$

$$500 = (99.067) (2.184y^{2.67}) (0.0447)$$

$$y^{2.67} = 51.67$$

$$y = 4.139 \text{ ft}$$

$$\text{so, } b = 2(4.139) = 8.278 \text{ ft}$$

$Q = 500$ cfs, so cfs

At 20 cfs = 1.5

" 3000 cfs = 2.5

$$\text{So, at } 500 = 1.5 + \frac{2.5 - 1.5}{3000 - 20} (500 - 20)$$

$$= 1.661$$

26

50

So, freeboard

$$u = \sqrt{cy}$$

$$= \sqrt{1.661 \times 4.139}$$

$$= \boxed{2.622 \text{ ft}}$$

$$A = 3.5y^2 = \boxed{59.959 \text{ ft}^2} \quad (\text{from } ①)$$

$$R = 0.62y = \boxed{2.5827 \text{ ft}} \quad (\text{from } ②)$$

$$T = b + y(2z) = (8.778) + 4.139(20.5) = \boxed{20.695 \text{ ft}}$$

$$Fr = \frac{Q}{A \sqrt{gD}}$$

$$D = \frac{A}{T} = \frac{59.959}{20.695} = 2.897 \text{ ft}$$

$$\text{So, } Fr = \frac{500}{59.959 \sqrt{32.2 \times 2.897}}$$

$$\boxed{Fr = 0.863}$$

So, since the Fr is less than 1 ($0.863 < 1$), the flow

is SUB-CRITICAL

AVERAGE

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Name [PRINT] Armando Gomez

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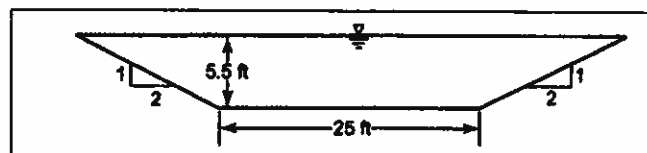
710
900

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Problem 14.6 - with a flowrate of 20 cfs.

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- Determine the normal depth of flow [m].

Show your work fully.

Problem 5 [150]

A grass-lined trapezoidal channel is to be designed to carry a flow of 260 cfs. Determine a suitable Manning's first. The slope of the channel is $1.5 \text{ ft}/2000 \text{ ft}$. The side slopes (same both sides), $z = (1 \text{ vertical} : 2 \text{ horizontal})$. Use a b/y ratio of 1.25 and a maximum channel width $b = 12 \text{ ft}$.

Determine the design depth of flow for the channel [ft]

- Determine the other design parameters including the freeboard.
- Is the flow in the channel under sub-critical or super-critical flow conditions? Why?
- Sketch the profile cross-section of the channel with all necessary dimensions.

Show your work fully.

Problem 6 [200]

Problem 14.15

- Determine all the design parameters of the channel including the freeboard.
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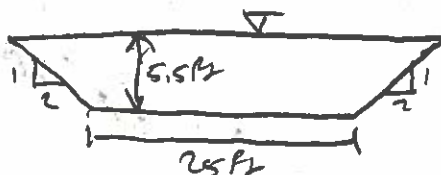
Show your work fully



Given.

$$n = 0.011$$

$$S = 4 \text{ ft} / 1200 \text{ ft} = .003$$



Find:

- Area A in ft^2
- Hydraulic Radius R (ft) and Hydraulic Depth D (ft)
- Critical Flow Section Factor, Z_c ($\text{ft}^{5/2}$) and the normal flow section factor, Z_n ($\text{ft}^{4/3}$)
- The Flow rate in the channel (ft^3/s) for the given conditions

Solution

$$\begin{aligned} a) A &= b \cdot y + \frac{1}{2} y^2 (m_1 + m_2) \\ &= (25)(5.5) + \left(\frac{1}{2}\right)(5.5)^2 (2+2) \\ &= 198 \text{ ft}^2 \end{aligned}$$

$$b) \text{ Hydraulic Radius } R = \frac{A}{P} = \frac{198}{49.6} = 3.99 \approx 4 \text{ ft}$$

$$\begin{aligned} \text{Wetted Perimeter} &= b + y(\sqrt{1+m_1^2} + \sqrt{1+m_2^2}) \\ &= 25 + 5.5(\sqrt{1+2^2} + \sqrt{1+2^2}) \\ &= 49.6 \text{ ft} \end{aligned}$$

$$\text{Hydraulic depth } D = \frac{(b + m_1 y) y}{b + 2m_1 y} = \frac{(25 + (2)(5.5)) 5.5}{25 + (2)(2)(5.5)} = 4.21 \text{ ft}$$

$$\begin{aligned} c) \text{ Critical flow section factor } Z_c &= A \sqrt{D} \Rightarrow (198) \sqrt{4.21} = 406.26 \text{ ft}^{5/2} \\ \text{normal flow section factor } Z_n &= A R^{2/3} \Rightarrow (198) (4)^{2/3} = 498.93 \text{ ft}^{4/3} \end{aligned}$$

$$d) Q_n = \frac{1.486}{n} Z_n \sqrt{S} = \frac{1.486}{0.011} (498.93) \sqrt{0.003} = 3,691.7 \text{ cfs}$$

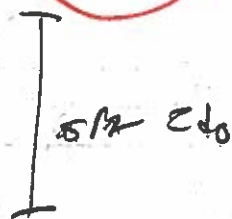
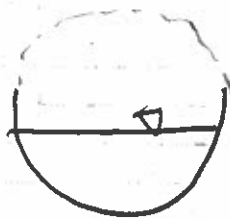
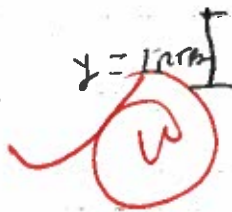
② Given

$$d_o = \text{Diam} = 60 \text{ in} = 5 \text{ ft}$$

$$y = \text{depth} = 15 \text{ in} = 1.25 \text{ ft}$$

$$n = 0.025$$

$$S = 3 \text{ ft} / 1500 \text{ ft} = 0.002$$



Solution

$$\frac{y}{d_o} = \frac{1.25}{5} = 0.25$$

a) $\frac{A}{d_o^2} = (1.535) \Rightarrow A = (1.535)(5) = \boxed{3.8325 \text{ ft}^2}$

b) $\frac{R}{d_o} = (0.1446)(d_o) = (0.1446)(5) = \boxed{0.723 \text{ ft}}$

$$\frac{D}{d_o} = (0.1774)(d_o) = (0.1774)(5) = \boxed{0.887 \text{ ft}}$$

c) $z_c = A \sqrt{D} = (3.8325) \sqrt{0.887} = \boxed{3.61 \text{ ft}^{5/2}}$

$$z_n = A R^{2/3} \Rightarrow (3.8325)(0.723)^{2/3} = \boxed{3.12 \text{ ft}^{8/3}}$$

d) $Q_{\text{cfs}} = \frac{1.49}{n} A R^{2/3} \sqrt{S} = \frac{1.49}{0.025} (3.12) \sqrt{0.002} = 9.99 = \boxed{10 \text{ cfs}}$

3

Prob

Given:

$$d_m = (40 \text{ in} \times \frac{1}{n}) = 3.33 \text{ ft}$$

$$Q = 20 \text{ cfs}$$

Find:

critical depth

Solution:

$$Z_c = \frac{Q}{\sqrt{g}} = \frac{20}{\sqrt{32.2}} = 3.52 \text{ ft}^{5/2}$$

$$\frac{A\sqrt{D}}{d_o^{5/2}} = \frac{Z_c}{d_o^{5/2}} \Rightarrow \frac{3.52}{(3.33)^{5/2}} = 0.174$$

Table 14.1

$$\frac{y}{d_o} = \frac{(0.174 - 0.1603)(.45 - .40)}{(0.2011 - 0.1603)} + .40 = .4169$$

$$\frac{y_c}{3.33} = 0.4169 \Rightarrow y_c = 1.39 \text{ ft}$$

④ Gauss

$$Q = 16,000 \text{ m}^3/\text{s} \approx 16 \text{ m}^3/\text{s}$$

$$n \approx 0.020$$

$$S = \frac{2 \text{ m}}{3000 \text{ m}} = 0.00067$$



Solution

$$\frac{\sigma}{2} = 45^\circ \Rightarrow m = \tan(45) = 1 \text{ m} = 1$$

$$P = 2y\sqrt{1+1} = 2\sqrt{2}y$$

$$A = \frac{1}{2}(2m+y)y = \left(\frac{1}{2}\right)(2+y)y = y^2$$

$$R = \frac{A}{P} = \frac{y^2}{2\sqrt{2}y} = \frac{y}{2\sqrt{2}}$$

$$D = \frac{A}{T} = \frac{y^2}{2y} = \frac{y}{2}$$

$$y_c = \left(\frac{2Q^2}{g m^2}\right)^{1/3} = \left(\frac{(2)(16)^2}{9.81(1)}\right)^{1/3} = 2.21 \text{ m}$$

$$b) F_r = \frac{V}{\sqrt{gD}} \Rightarrow$$

$$D = \frac{y}{2} = \frac{1.5}{2} = 0.75 \text{ m}$$

$$V = \frac{1}{n} R^{2/3} S^{1/2} = \frac{1}{0.02} \left(\frac{0.5}{2.483}\right)^{2/3} \left(\frac{1}{1500}\right)^{1/2}$$

$$V = 0.41 \text{ m/s}$$

$$F_r = \frac{0.41}{\sqrt{9.81(0.75)}} = F_r < 1$$

Sub critical flow

c)

$$Q = AV \Rightarrow Q = y^2 \frac{1}{0.02} \left(\frac{y}{2.483}\right)^{2/3} \left(\frac{1}{1500}\right)^{1/2}$$

$$16 \text{ m}^3/\text{s} = y^{8/3} (1.456)$$

$$y^{8/3} = 35.08$$

$$y = 3.79 \text{ m}$$

(125)

(50)

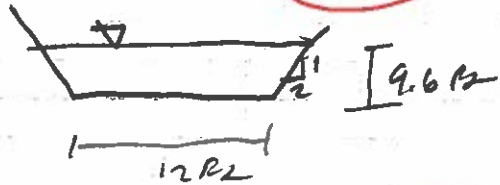
(50)

Q. 100

$$Q = 260 \text{ cfs}$$

$$S = \frac{1.5}{2000} = 0.00075$$

$$b = 12 \text{ ft}$$



$z = 1$ vertical, 2 horizontal

$$\frac{b}{y} = 1.25 \Rightarrow y = \frac{b}{1.25} = \frac{12}{1.25} = 9.6 \text{ ft}$$

Solution:

a) $\frac{b}{y} \Rightarrow y = 9.6 \text{ ft}$

b) $A = b_1 y + \frac{1}{2} y^2 (m_1 + m_2) = (12)(9.6) + \frac{1}{2} (9.6)^2 (2+2) = 299.52 \text{ ft}^2$

$P = b + y(\sqrt{1+m_1^2} + \sqrt{1+m_2^2}) \Rightarrow 12 + 9.6(\sqrt{1+2^2} + \sqrt{1+2^2}) = 54.93 \text{ ft}$

$R = \frac{A}{P} = \frac{299.52}{54.93} = 5.45 \text{ ft}$

$n = \frac{AR^{2/3} \sqrt{S}}{Q} = \frac{(299.52)(5.45)^{2/3} \sqrt{0.00075}}{260} = 0.0977$

$T = b + y(m_1 + m_2) \Rightarrow 12 + 9.6(2+2) = 50.4 \text{ ft}$

$u = \frac{V}{\sqrt{C_x}} \Rightarrow \sqrt{(5)9.6} = 2.2 \text{ ft}$

c) $z_c = A \sqrt{\frac{A}{T}} \Rightarrow 299.52 \sqrt{\frac{299.52}{50.4}} = 730.17 \text{ ft}^2$

$D = \frac{299.52}{50.4} = 5.94 \text{ ft}$

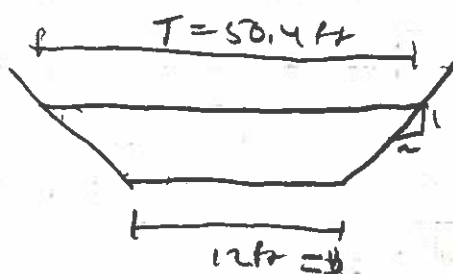
$V = \frac{260}{299.52} = 0.868 \text{ ft/s}$

$F_r = \frac{0.868}{\sqrt{(2)(5.94)}} = 0.1628$

less than $F_r < 1$

Sub-critical flow

d)



$u = 2.2 \text{ ft}$
 $9.6 \text{ ft} = y$

6
11.5

GIVEN:

Concrete-lined Trapezoidal channel

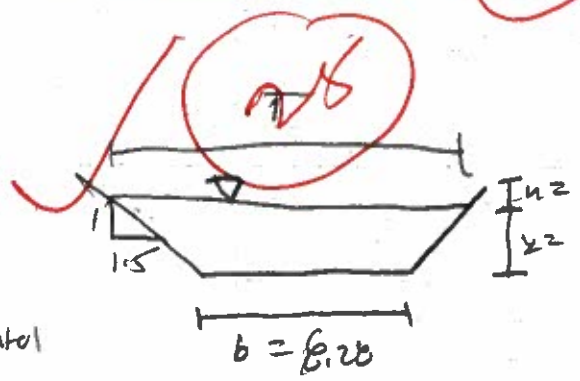
$$Q = 500 \text{ cfs}$$

$$\text{Bed slope} = 0.002$$

$$n = 0.015$$

Side slope, $z = 1$ Vertical, 1.5 Horizontal

$$b/y \text{ rule} = 2 \Rightarrow b = 2y$$



SOLUTION:

$$A = by + \frac{1}{2} y^2 (1.5 + 1.5) = (2y)(y) + 1.5y^2(3)$$

$$= 2y^2 + 4.5y^2 = 6.5y^2 = 54.99 \text{ ft}^2$$

$$P = b + y \left[\sqrt{1 + 1.5^2} + \sqrt{1 + 1.5^2} \right] = 2y + 3.6y = 5.6y$$

$$= 23.184 \text{ ft}$$

$$T = 2y + 3y = 5y = 20.7 \text{ ft}$$

$$R = \frac{3.5y^2}{5.6y} = 0.625y = 2.5825 \text{ ft}$$

$$Q = \frac{1.486}{n} A R^{2/3} \sqrt{S} \Rightarrow 500 = \left(\frac{1.486}{0.015} \right) (3.5y^2) (0.625y) \sqrt{0.002}$$

$$y = 4.14 \text{ ft}$$

$$u = \sqrt{3.1(4.14)} = 3.58 \text{ ft/s}$$

$$D = \frac{54.99 \text{ ft}^2}{20.7} = 2.69 \text{ ft}$$

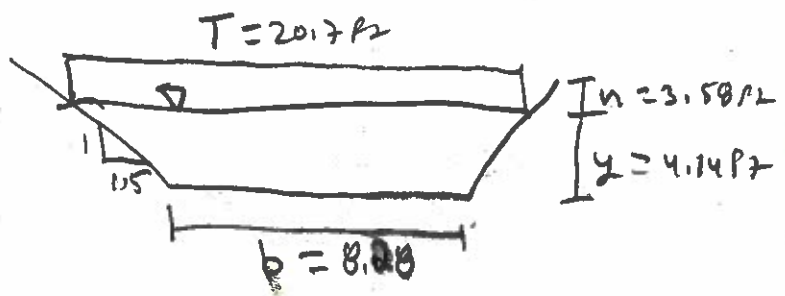
$$V = \frac{500}{54.99} = 8.33 \text{ ft/s}$$

$$Fr = \frac{8.33}{\sqrt{(2.2)(2.69)}} = 2.49$$

$$Fr > 1$$

Super-critical flow because $Fr > 1$

C



BELOW
AVERAGE

CVEG 4303 P01

Water Resources Engineering

Spring 2022

Dr. Nzewi

Homework 06

Assigned: 04/26/2022

Due: Tuesday, May 03, 2022 at 1:00 PM in CLASS

SUBMIT THIS as cover sheet with your work

Name [PRINT]

Sydney Jones

Instructions:

IN ALL THE PROBLEMS YOU MUST PROVIDE ENOUGH DETAILS AND DESCRIPTION OF THE SOLUTION METHOD TO DEMONSTRATE YOUR KNOWLEDGE OF THE SOLUTION METHOD. A SUBSTANTIAL PORTION OF THE GRADE WILL BE BASED ON YOUR METHODS.

Problem 1 [150]

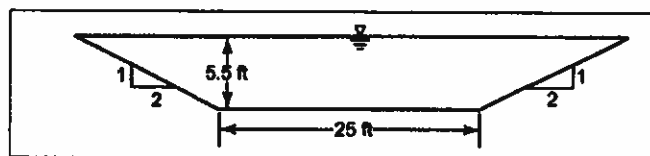
530
900

Determine the following channel parameters for the channel shown.

The Manning's $n = 0.011$ and the slope is $4.0 \text{ ft}/1200 \text{ ft}$.

- Area of flow $[\text{ft}^2]$
- The hydraulic radius $[\text{ft}]$ and hydraulic depth $[\text{ft}]$.
- The critical flow section factor, $Z_c [\text{ft}^{5/2}]$ and the normal flow section factor, $Z_n [\text{ft}^{4/3}]$
- The flowrate in the channel $[\text{ft}^3/\text{s}]$ for the given conditions.

Show your work fully.



Problem 2 [150]

A very rough circular open channel has a diameter of 60 in and the depth of flow is 15.0 in. The Manning's $n = 0.025$ and the slope is $3.0 \text{ ft}/1500 \text{ ft}$. Determine the following:

- Area of flow $[\text{ft}^2]$.
- The hydraulic radius $[\text{ft}]$ and hydraulic depth $[\text{ft}]$.
- The critical flow section factor, $Z_c [\text{ft}^{5/2}]$ and the normal flow section factor, $Z_n [\text{ft}^{4/3}]$
- The flowrate in the channel $[\text{ft}^3/\text{s}]$ for the given conditions.

Show your work fully.

Problem 3 [100]

Problem 14.6 – with a flowrate of 20 cfs.

Show your work fully

Problem 4 [150]

A right-angled triangular channel carries a flow of 16,000 l/s. The Manning's $n = 0.020$ and the slope is $2 \text{ m}/3000 \text{ m}$.

- Determine the critical depth $[\text{m}]$ for this flow.
- Determine Froude number for the flow when the depth of flow is 0.6 m.
- Determine the normal depth of flow $[\text{m}]$.

Show your work fully.

Problem 5 [150]

A grass-lined trapezoidal channel is to be designed to carry a flow of 260 cfs. Determine a suitable Manning's n . The slope of the channel is $1.5 \text{ ft}/2000 \text{ ft}$. The side slopes (same both sides), $z = (1 \text{ vertical} : 2 \text{ horizontal})$. Use a b/y ratio of 1.25 and a maximum channel width $b = 12 \text{ ft}$.

Determine the design depth of flow for the channel $[\text{ft}]$

- Determine the other design parameters including the freeboard.
- Is the flow in the channel under sub-critical or super-critical flow conditions? Why?
- Sketch the profile cross-section of the channel with all necessary dimensions.

Show your work fully.

Problem 6 [200]

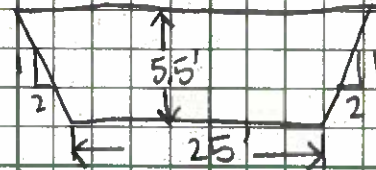
Problem 14.15

- Determine all the design parameters of the channel including the freeboard.
- Is the flow in the channel under sub-critical or super-critical flow conditions? Why?
- Sketch the profile cross-section of the channel with all necessary dimensions.

Show your work fully

Problem 1

50



$$a) \frac{1}{2} (25 + (2 \cdot 2 \cdot 5.5)) \cdot 5.5 = 198 \text{ ft}^2$$

$$b) \text{ radius} = \frac{A}{P}$$

$$P = 25 + 5.5 \sqrt{3+3} = 44.05 \text{ ft}$$

$$R = \frac{198}{44.05} = 4.49 \text{ ft}$$

$$\text{Hydraulic Depth } B = \frac{A}{P} = \frac{198}{44.05} = 4.49 \text{ ft}$$

$$c) Q = \frac{1}{0.011} \cdot 198 (4.49)^{2/3} \cdot \left(\frac{4.49}{1200}\right)^{1/2} = 12962.11 \text{ ft}^3/\text{s}$$

$$Fr = 1$$

$$\frac{Q^2}{g} = \frac{A^3}{T}$$

$$\frac{(12962.11)^2}{32.2} = \frac{(25 + 2(y_c) y_c)^3}{(25 + 4y_c)}$$

$$182.38 (25 + 4y_c)^{3/2} = (25 + 2y_c) y_c$$

$$y_c = 14.7 \text{ ft}$$

$$Z = A \sqrt{y_c} = 198 \sqrt{14.7} = 464.35 \text{ ft}$$

$$Z_c = (25 + 2 \cdot (14.7) \cdot 14.7) \cdot \sqrt{14.7} = 3066.02 \text{ ft}$$

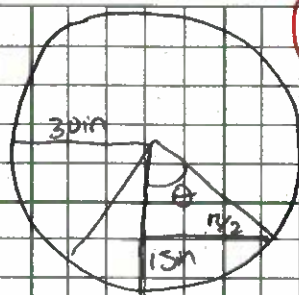
$$d) Q = \frac{1}{n} A R^{2/3} S^{1/2}$$

$$= \frac{1}{0.011} (198) (4.49)^{2/3} \left(\frac{4.49}{1200}\right)^{1/2} = 12962.11 \text{ ft}^3/\text{s}$$

Problem 2

a)

$$A = \frac{r^2(\theta - \sin\theta)}{2} = \frac{30^2(2.093 - .866)}{2} = 3.834 \text{ ft}^2$$



1.04

b)

$$R = \frac{A}{P}$$

$$P = 30 \cdot 2.093 = 62.79'' = 5.23'$$

$$R = \frac{3.83}{5.23} = .73 \text{ ft}$$

c)

$$D = \frac{A}{T} = \frac{3.834}{4.32} = .885 \text{ ft}$$

$$\frac{T}{2} = 30 \cdot \sin 60^\circ = 25.98''$$

d)

$$Q = \frac{1}{\pi} A R^{\frac{2}{3}} S^{\frac{1}{2}}$$

$$= \frac{1}{.025} \cdot 3.834 \cdot (.732)^{\frac{2}{3}} \left(\frac{3}{1500}\right)^{\frac{1}{2}}$$

$$Q = 5.57 \text{ ft}^{\frac{3}{5}}$$

e)

$$Z_n = 3.834 \sqrt{.885} = 3.606 \text{ ft}^{\frac{5}{2}}$$

$$Z_c = \frac{Q}{\sqrt{g}} = \frac{5.57 \text{ ft}^{\frac{3}{5}}}{\sqrt{32.2}} = .981 \text{ ft}^{\frac{5}{2}}$$

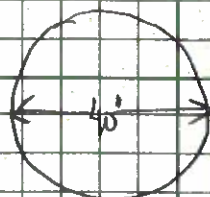
Problem 3

10

$$Q = \frac{20}{40/12} = 6 \text{ ft}^3/\text{s} \quad 3.5 \text{ ft}^{3/2}$$

$$Z_c = \left(\frac{Q^2}{g} \right)^{1/3} = \left(\frac{6^2 \text{ ft}^3/\text{s}}{32.2} \right)^{1/3}$$

$$= 0.57 = \boxed{16.85''}$$



$$Q = 20 \text{ cfs}$$

Problem 4



$$Q = 16 \text{ m}^3/\text{s}$$

$$n = .02$$

$$S = .000667$$

50

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

$$= \frac{1}{.020} y \left(\frac{y}{2\sqrt{2}} \right)^{2/3} (.000667)^{1/2}$$

$$= \frac{16 \cdot .02 \cdot (2\sqrt{2})^{2/3}}{.0258} = y^2 \cdot y^{2/3}$$

a) $y^{2.66} = 24.787 \quad y = 3.33 \text{ m}$ ✗

b) $\frac{Q^2 T}{g A^3} = 1 \quad y_c = \left[\frac{2Q^2}{g m^2} \right]^{1/5} = \left[\frac{2 \cdot 16^2}{9.81 \cdot 1^2} \right]^{1/5} = 2.206 \text{ m}$ ✗

$$Fr = \frac{V}{\sqrt{gR}}$$

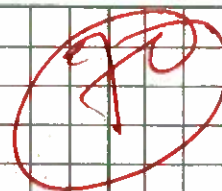
$$R = \frac{A}{P} = \frac{y^2}{2y\sqrt{2}} = \frac{y}{2\sqrt{2}} = .212$$

$$V = \frac{Q}{A} = \frac{16}{y^2} = 44.4 \text{ m/s}$$

$$Fr = \frac{V}{\sqrt{gR}} = \frac{44.44}{\sqrt{9.81 \cdot .212}} = 30.8$$

Super critical

Problem 5



$$Q = 260 \text{ cfs}$$

$$S = 7.5 \times 10^{-4}$$

$$m_1 = m_2 = 2$$

$$\frac{b}{y_0} = 1.25$$

$$b = 12 \text{ ft max}$$

$$A = (10)(5) + \frac{1}{2} (2)(4) = 100 \text{ ft}^2$$

$$P = 10 + (5)\sqrt{3} + \sqrt{3} = 27.3 \text{ ft}$$

$$T = 10 + 5(4) = 30 \text{ ft}$$

$$R = \frac{100}{27.3} = 3.66 \text{ ft}$$

$$u = \sqrt{C_y} = \sqrt{(1.58)(5)} = 2.81 \text{ ft}$$

$$\frac{(2.5 - 1.5)}{2000 - 20} = \frac{x}{2600 - 20}$$

$$x = 1.08$$

$$C = 1.58$$

$$D = \frac{100}{20 + 10} = 3.3$$

$$V = 2.6$$

$$Fr = \frac{V}{\sqrt{gD}} = \frac{2.6}{\sqrt{32.2 \cdot 3.3}} = 0.25$$

Subcritical

Problem 6

$$A = (b + zy)y$$

$$by = 2$$

$$b = 2/y$$

$$A = 3.5y^2$$

$$R = \frac{(b + zy)y}{b + zy\sqrt{1+z^2}} = \frac{(2/y + 1.5y)y}{2/y + 2y\sqrt{1+1.5^2}} = .624y$$

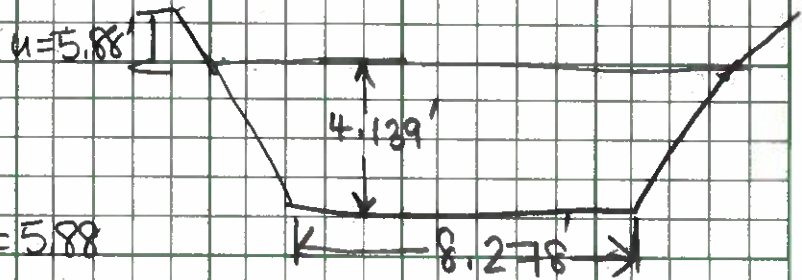
$$Q = \frac{1.486}{n} A R^{\frac{2}{3}} S^{\frac{1}{2}}$$

$$500 = \frac{1.486}{.015} \cdot 3.5y^2 (.624y)^{\frac{2}{3}} (.002)^{\frac{1}{2}}$$

$$y = 4.139 \text{ ft}$$

$$b = 8.278 \text{ ft}$$

$$u = \sqrt{cy} = \sqrt{142 \cdot 4.139} = 5.88$$



$$\frac{2.5 - 1.5}{2000 - 20} = \frac{x}{2600 - 500}$$

$$x = -.08$$

$$C = 1142$$

$$Ff = \frac{V}{\sqrt{gd}} = \frac{8.34}{\sqrt{32.2 \cdot 2.4}} = .948$$

Subcritical

$$D = \frac{59.96}{24.834}$$

1.50

V.

DESIGN
PROJECTS

[02]

CVEG 4303
WATER RESOURCES ENGINEERING
SPRING 2022

PROJECT
01



Department of Civil & Environmental Engineering

CVEG 4303 PO1

WATER RESOURCES ENGINEERING

SPRING 2022

Dr. Ngweni

REVISED: 04/19/2022

RATIONAL METHOD APPLICATION: STORMWATER SEWER DESIGN PEAK FLOWS IN A SMALL WATERSHED

PROJECT DETAILS POSTED IN CANVAS

This project involves the determination of the peak runoff flowrates for stormwater sewer design in a small catchment. Students will be required to work in groups. Students may consult the Instructor for help and for project clarification.

PROJECT OVERVIEW

CVEG 4303 student groups are charged with the design of a drainage system for a watershed at the Harris County, TX location shown in the accompanying map. The scale of the map (with 2-foot contour lines) is noted (see map). Land use practices have been identified – see the accompanying land use practices table.

The primary task is to generate engineering information necessary for determining the size the sewers. This information should be presented in a tabular format. The Rational Method will be implemented in the determination of peak runoff flowrates at drainage inlets (manholes). The system to be designed should adequate for a 5-, 10- or 25-year rainfall event. The actual return period of the design storm event will be specified for each student group. The pertinent Intensity-Duration-Frequency (IDF) curve data/graphs have been supplied in the Appendix.

Group	Location	Watershed Sub-areas	Design Return Period [Years]	Minimum t_c [minutes]	Slope []	Channel flow Velocity [ft/s]
	Harris County Region I	A (left of ditch) & C	25	20.0	Based on ground elevation. Circular pipe	3.0
	Harris County Region II	B (right of ditch+A024) & C	10	17.0	Based on ground elevation. Circular pipe	4.0
	Harris County Region III	A (left of ditch) & C	5	10.0	Based on ground elevation. Circular pipe	3.5
	Harris County Region II	B (right of ditch+A024) & C	25	14.0	Based on ground elevation. Circular pipe	3.0
	Harris County Region I	A (left of ditch) & C	5	18.0	Based on ground elevation. Circular pipe	4.0
	Harris County Region III	B (right of ditch+A024) & C	10	11.0	Based on ground elevation. Circular pipe	2.0

REQUIREMENTS

1	Determine the areas [acres] using two clearly defined methods. Provide, in tabular format, a comparison of your results. The 2 alternative area determination methods are necessary for ensuring the accuracy (consistency) of area calculations. The <i>Triangular Method</i> must be one of the methods used.
2	Determine an appropriate (hydraulic) length [ft] for each sub-watershed. This is the length for the calculation of time of overland flow travel (used for t_c determination). <u>Tabulate the results.</u>
3	Calculate the average slope of each sub-watershed. Assume that the length [ft] used in design calculations is a straight line from the farthest point in the catchment to the outlet in each sub-watershed. <u>Tabulate the results.</u>
4	Calculate the time for overland flow travel using the <u>Kirpich</u> formula. Perform the checks to show your values are reasonable. Use Figure 16.7 (textbook-Gupta) to determine a ballpark estimate. Tabulate and compare the results.
5	Determine the runoff coefficients for each sub-watershed (based on land use for each sub-area). <u>Tabulate the results.</u>
6	For the design storm return period (based on Group assignment): a) Calculate the peak discharge from <u>each</u> sub-watershed. b) Calculate the peak flow that will be used to size each segment of the storm sewer line – identify the sewer segments and manholes (drainage inlets) by numbering them appropriately on the map c) Present a schematic of the storm sewer layout on your area. Provide a separate, properly annotated, map. d) Provide a table with the required details for the sewer system design.

EACH GROUP WILL SUBMIT A BOUND REPORT (WITH MAPS) AND EACH MEMBER WILL SUBMIT 2 POWERPOINT SLIDES DESCRIBING THE PROJECT COMPONENT IN WHICH THEY WERE LEAD.

ADDITIONAL PROJECT INSTRUCTIONS

STUDENT DESIGNATIONS: STUDENT 1 – GROUP LEADER [SUBMITS REPORT FOR GROUP]

TASK NO.	DESCRIPTION OF REQUIREMENT	LEAD** STUDENT
1	Determine an appropriate length [ft] for each sub-watershed. Please state any assumptions you have made in determining this value. Indicate the path designated for this watershed linear measure on the map (drawing) you were provided by the instructor.	STUDENT1
2	Calculate the average slope [] of each sub-watershed. Assume that the length to be used is the straight line distance to the farthest point in the catchment (from the outlet in each sub-catchment. This distance (length [ft]) was determined in #1. Slope = [maximum elevation – minimum elevation]/[sub-watershed length].	STUDENT2
3	Calculate the time of concentration using the Kirpich formula for overland flow segment of travel time.	STUDENT2
4	Determine the Runoff Coefficient (C) for each sub-watershed (The value of C depends on the land use determined for each sub-watershed section.) Consult appropriate references to obtain appropriate values of C and specify your references. See the Appendix for tables of C values.	STUDENT3
5	For each sub-catchment, calculate the peak runoff rate [cfs] using the Rational Method	STUDENT3
6	Compute the peak flowrate that would be used in the design of each segment of the storm sewer <u>system</u> as runoff is channeled (routed) toward the outlet of the system.	STUDENT1
7	For the peak flow in 6, design a lined trapezoidal concrete channel for the purple segment (see map) using the discharge at the outlet of sub-watershed C061 and the slope of the storm sewer segment along sub-watershed C061.	STUDENT1
8	Provide a sketch of your storm drainage system including the location of the open channel.	STUDENT1

****LEAD STUDENT = STUDENT HAVING PRIMARY RESPONSIBILITY FOR COMPLETING TASK [FOR PROJECT GRADE DETERMINATION]**

LAND USE PRACTICES

A Sub-watersheds are **West** of Hammond Ditch B sub-watersheds are **East** of Hammond Ditch

Sub-Watershed	Land Use
A011	30% grassed; 70% commercial
A012	20% Gravel trailer park; 80% business
A013	Office buildings with paved areas
A021	30 % residential (sparse); 70% lawn with dense soil
A022	Pasture with 10% woodland
A023	70% soy bean field with grassed swale
A024	Grassed area with pond
C061	90% grassed area; rest is soy bean field. (Location of future detention pond)
B031	50% lawn with dense soil, 50% residential
B032	30% Residential; 70% playground
B033	20% Residential; 80% playground
B034	Apartment complexes
B041	Light Commercial
B042	40% grassed lawn; 60% commercial development
B043	Primary school area
B044	Commercial development

APPENDIX I

IDF CURVES

Atlas 14 IDF Curves

Assistance with NOAA Atlas 14 Updates to the Harris County Flood Control District Policy Criteria & Procedure Manual (PCPM)

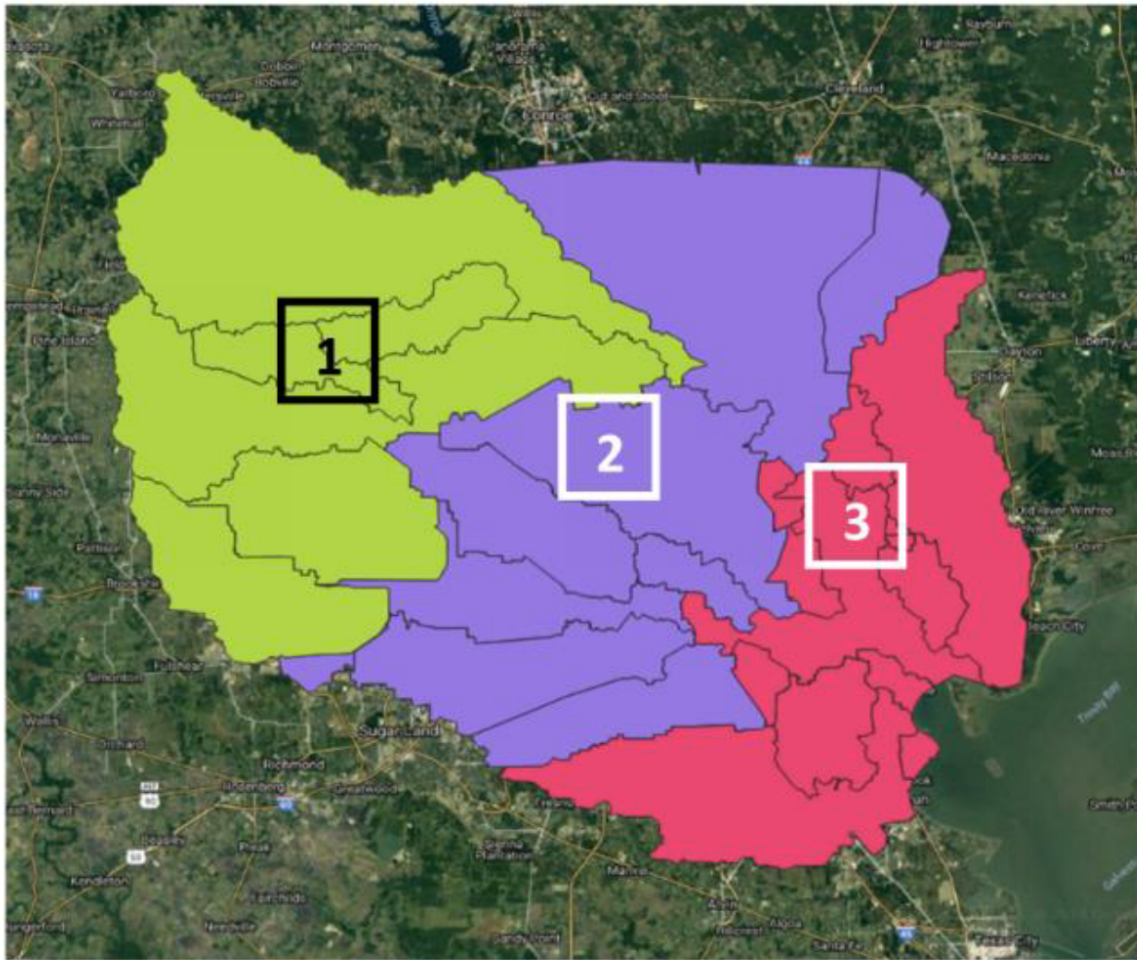


Figure 1. Harris County Regional Watersheds

$$I = \frac{b}{(t_c + d)^e}$$

Equation 1. IDF Relationship Equation

where:

I = design rainfall intensity (inches/hour)

t_c = time of concentration (minutes)

e , b and d = coefficients based on rainfall frequency-duration curves

Table 1. Updated Rainfall IDF Coefficients for Harris County

Coefficient	50 % AEP	20 % AEP	10 % AEP	4 % AEP	2 % AEP	1 % AEP	0.2 % AEP
	2-Year	5-Year	10-Year	25-Year	50-Year	100-Year	500-Year
<i>Region 1</i>							
e	0.7372	0.7058	0.6819	0.6446	0.6170	0.5870	0.5111
b (in.)	48.27	51.78	54.26	54.97	54.84	53.93	50.89
d (min.)	9.30	8.19	7.44	6.27	5.45	4.53	2.69
<i>Region 2</i>							
e	0.7263	0.7051	0.6752	0.6397	0.6166	0.5857	0.5129
b (in.)	47.25	54.09	55.26	56.72	57.94	56.68	54.26
d (min.)	8.94	8.34	7.30	6.12	5.47	4.46	2.72
<i>Region 3</i>							
e	0.7244	0.6900	0.6623	0.6294	0.6096	0.5797	0.5196
b (in.)	48.35	52.32	54.68	57.79	61.00	60.66	62.17
d (min.)	9.07	7.88	6.96	5.89	5.46	4.44	2.95

AEP - annual exceedance probability

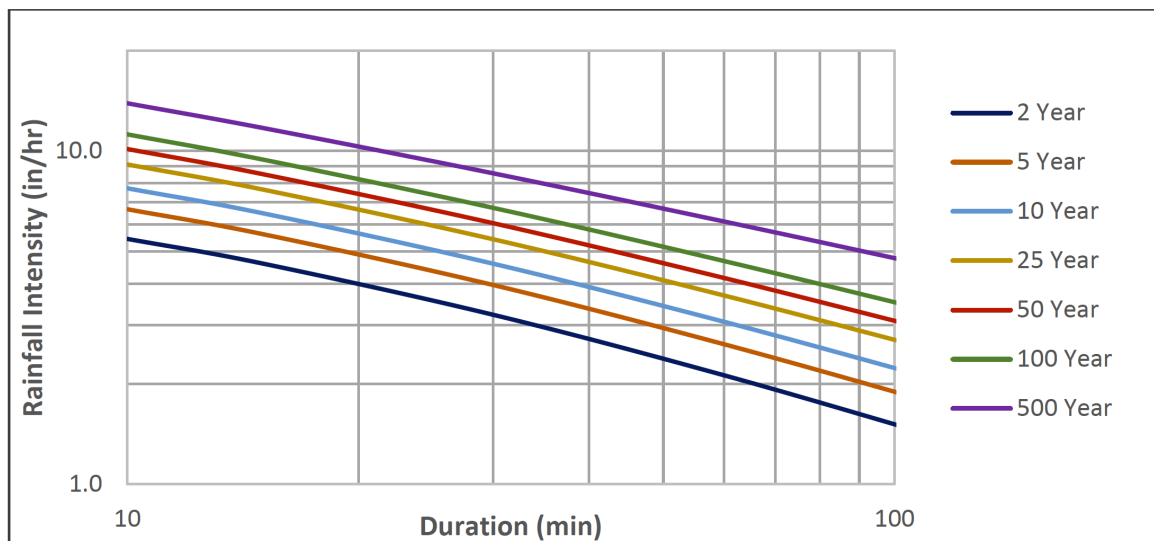


Figure 3. Region 1 Updated IDF Curves, 2-year through 500-year

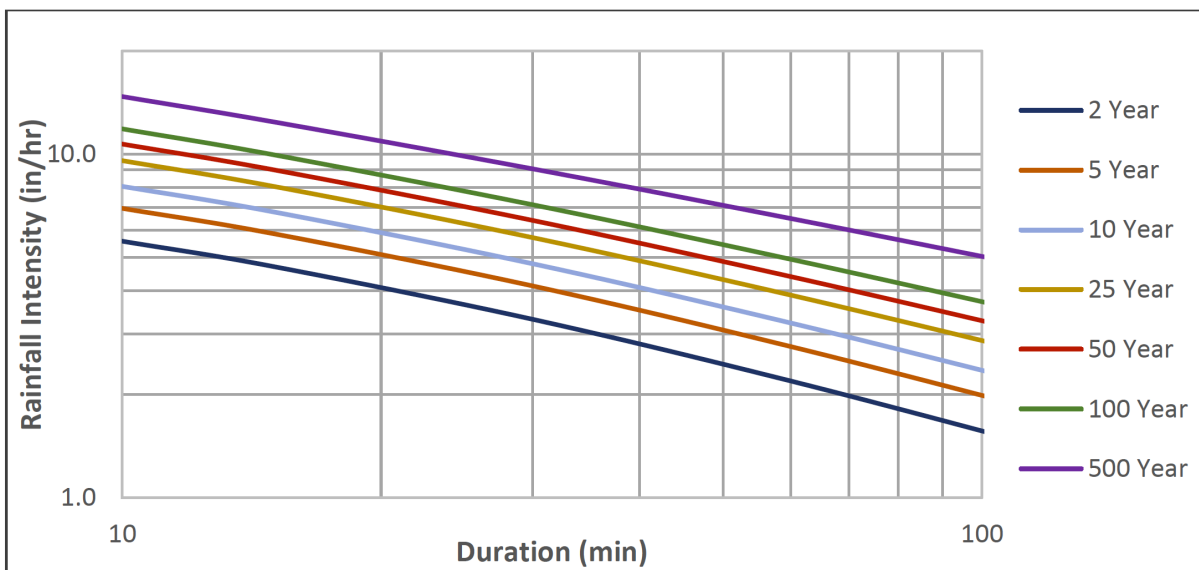


Figure 4. Region 2 Updated IDF Curves, 2-year through 500-year

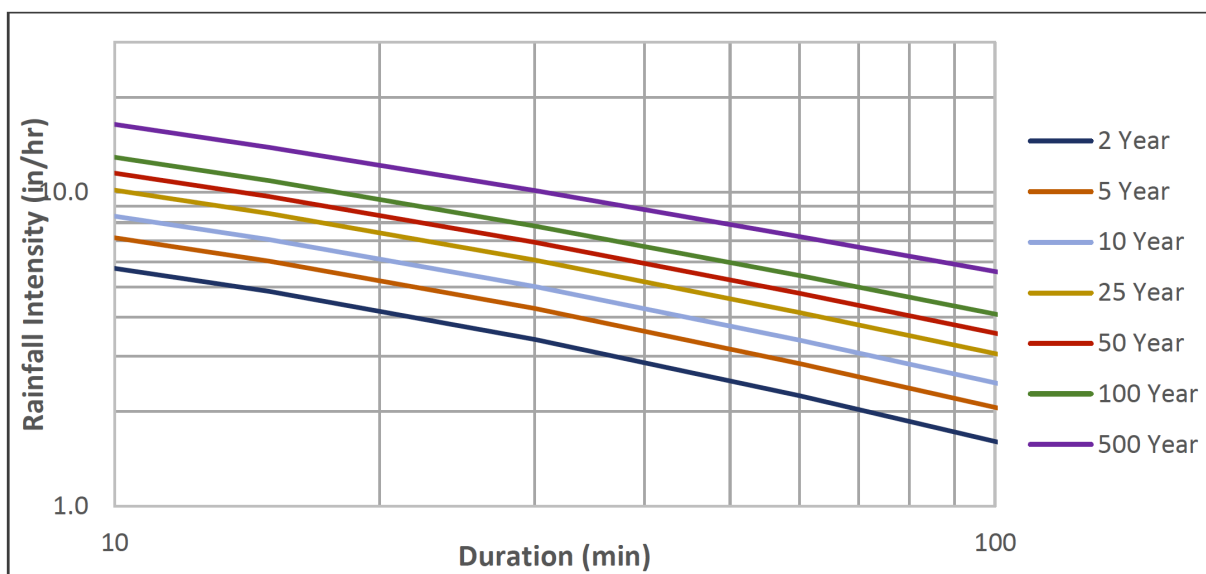


Figure 5. Region 3 Updated IDF Curves, 2-year through 500-year

APPENDIX II

RUNOFF COEFFICIENTS (SAMPLE)

RUNOFF COEFFICIENT, C

[HYDRAULIC DESIGN MANUAL, TXDOT, 2019)

Table 4-10: Runoff Coefficients for Urban Watersheds

Type of drainage area	Runoff coefficient
Business:	
Downtown areas	0.70-0.95
Neighborhood areas	0.30-0.70
Residential:	
Single-family areas	0.30-0.50
Multi-units, detached	0.40-0.60
Multi-units, attached	0.60-0.75
Suburban	0.35-0.40
Apartment dwelling areas	0.30-0.70
Industrial:	
Light areas	0.30-0.80
Heavy areas	0.60-0.90
Parks, cemeteries	0.10-0.25
Playgrounds	0.30-0.40
Railroad yards	0.30-0.40
Unimproved areas:	
Sand or sandy loam soil, 0-3%	0.15-0.20
Sand or sandy loam soil, 3-5%	0.20-0.25
Black or loessial soil, 0-3%	0.18-0.25
Black or loessial soil, 3-5%	0.25-0.30
Black or loessial soil, > 5%	0.70-0.80
Deep sand area	0.05-0.15
Steep grassed slopes	0.70
Lawns:	
Sandy soil, flat 2%	0.05-0.10
Sandy soil, average 2-7%	0.10-0.15
Sandy soil, steep 7%	0.15-0.20
Heavy soil, flat 2%	0.13-0.17
Heavy soil, average 2-7%	0.18-0.22

RUNOFF COEFFICIENT, C

[HYDRAULIC DESIGN MANUAL, TXDOT, 2019]

Table 4-10: Runoff Coefficients for Urban Watersheds

Type of drainage area	Runoff coefficient
Heavy soil, steep 7%	0.25-0.35
Streets:	
Asphaltic	0.85-0.95
Concrete	0.90-0.95
Brick	0.70-0.85
Drives and walks	0.75-0.95
Roofs	0.75-0.95

Table 4-11: Runoff Coefficients for Rural Watersheds

Watershed characteristic	Extreme	High	Normal	Low
Relief - C_r	0.28-0.35 Steep, rugged terrain with average slopes above 30%	0.20-0.28 Hilly, with average slopes of 10-30%	0.14-0.20 Rolling, with average slopes of 5-10%	0.08-0.14 Relatively flat land, with average slopes of 0-5%
Soil infiltration - C_i	0.12-0.16 No effective soil cover; either rock or thin soil mantle of negligible infiltration capacity	0.08-0.12 Slow to take up water, clay or shallow loam soils of low infiltration capacity or poorly drained	0.06-0.08 Normal; well drained light or medium textured soils, sandy loams	0.04-0.06 Deep sand or other soil that takes up water readily; very light, well-drained soils
Vegetal cover - C_v	0.12-0.16 No effective plant cover, bare or very sparse cover	0.08-0.12 Poor to fair; clean cultivation, crops or poor natural cover, less than 20% of drainage area has good cover	0.06-0.08 Fair to good; about 50% of area in good grassland or woodland, not more than 50% of area in cultivated crops	0.04-0.06 Good to excellent; about 90% of drainage area in good grassland, woodland, or equivalent cover
Surface Storage - C_s	0.10-0.12 Negligible; surface depressions few and shallow, drainageways steep and small, no marshes	0.08-0.10 Well-defined system of small drainageways, no ponds or marshes	0.06-0.08 Normal; considerable surface depression, e.g., storage lakes and ponds and marshes	0.04-0.06 Much surface storage, drainage system not sharply defined; large floodplain storage, large number of ponds or marshes
Table 4-11 note: The total runoff coefficient based on the 4 runoff components is $C = C_r + C_i + C_v + C_s$				

RUNOFF COEFFICIENT, C FOR RETURN PERIODS

Description of area	Runoff Coefficient (C)			
	Up to 10 yr Frequency		25 yr Frequency	
	minimum	maximum	minimum	maximum
Business:				
Downtown areas	0.75	0.95	0.83	1.00
Neighborhood areas	0.50	0.70	0.55	0.77
Residential areas:				
Single family	0.30	0.50	0.33	0.55
Multiple units, detached	0.40	0.60	0.44	0.66
Multiple units, attached	0.60	0.75	0.66	0.83
Residential, suburban	0.25	0.40	0.28	0.44
Apartment dwelling areas	0.50	0.70	0.55	0.77
Industrial areas:				
Light	0.50	0.80	0.55	0.88
Heavy	0.60	0.90	0.66	0.99
Parks, cemeteries	0.10	0.25	0.11	0.28
Playgrounds	0.20	0.35	0.22	0.39
Railroad yards	0.20	0.40	0.22	0.44
Unimproved areas	0.10	0.30	0.11	0.33

Character of Surface	Up to 10 yr Frequency		25 yr Frequency	
	Minimum	Maximum	Minimum	Maximum
Pavement:				
Asphalt	0.70	0.95	0.77	1.00
Concrete	0.80	0.95	0.88	1.00
Brick	0.70	0.85	0.77	0.94
Roofs	0.70	0.95	0.77	1.00
Lawns, sandy soil:			0.00	0.00
Flat (2 %)	0.05	0.10	0.06	0.11
Average (2 - 7 %)	0.10	0.15	0.11	0.17
Steep (7% or more)	0.15	0.20	0.17	0.22
Lawns, heavy soil:			0.00	0.00
Flat (2 %)	0.13	0.17	0.14	0.19
Average (2 - 7 %)	0.18	0.22	0.20	0.24
Steep (7% or more)	0.25	0.35	0.28	0.39

Compiled from data obtained from "Design and Construction of Sanitary and Storm Sewers" (1969) ASCE and WPCF, pp 50-51

RUNOFF COEFFICIENT, C

(GUPTA, 2017 – PAGE 714)

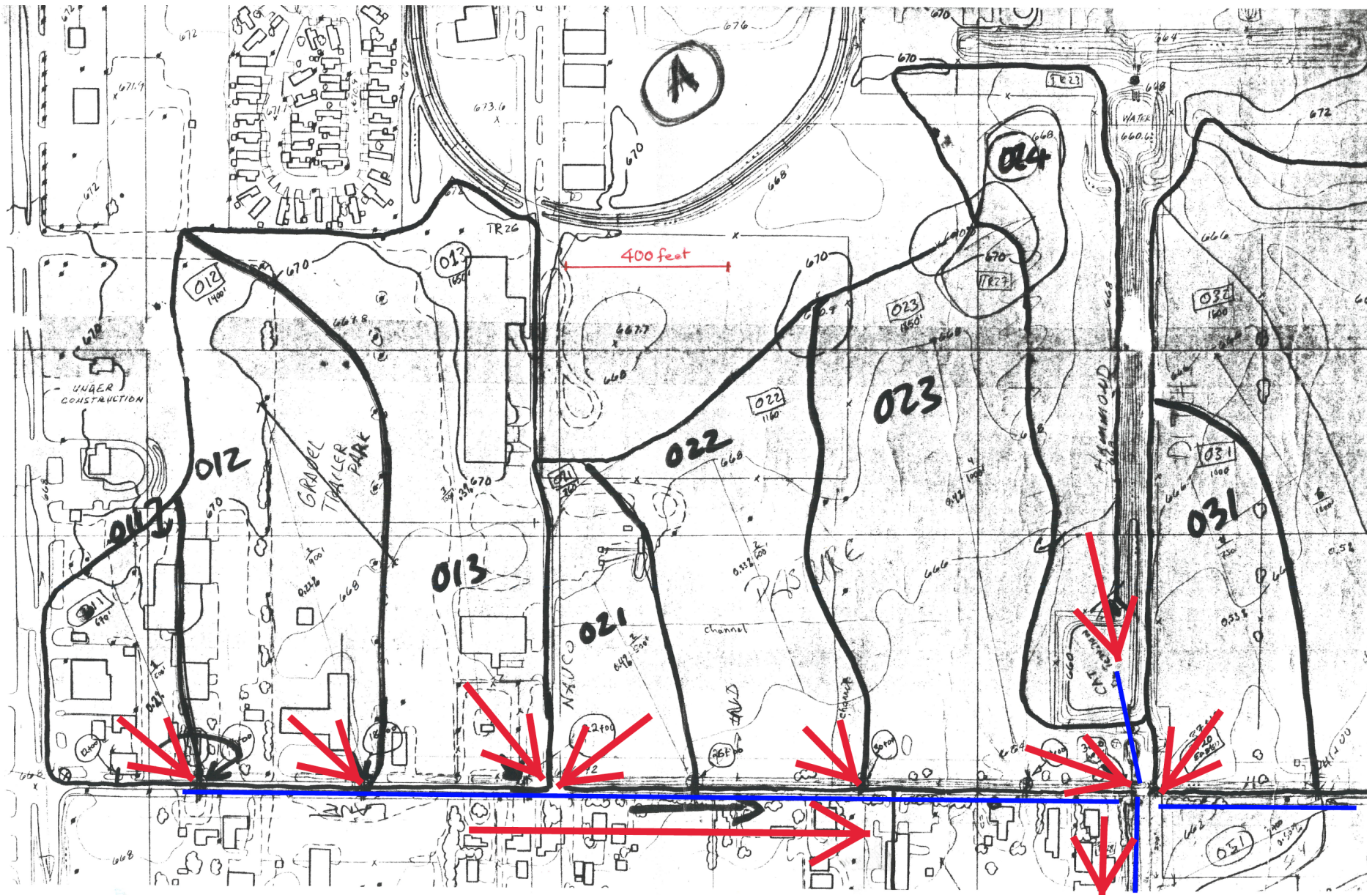
Table 16.5 Rational Runoff Coefficient

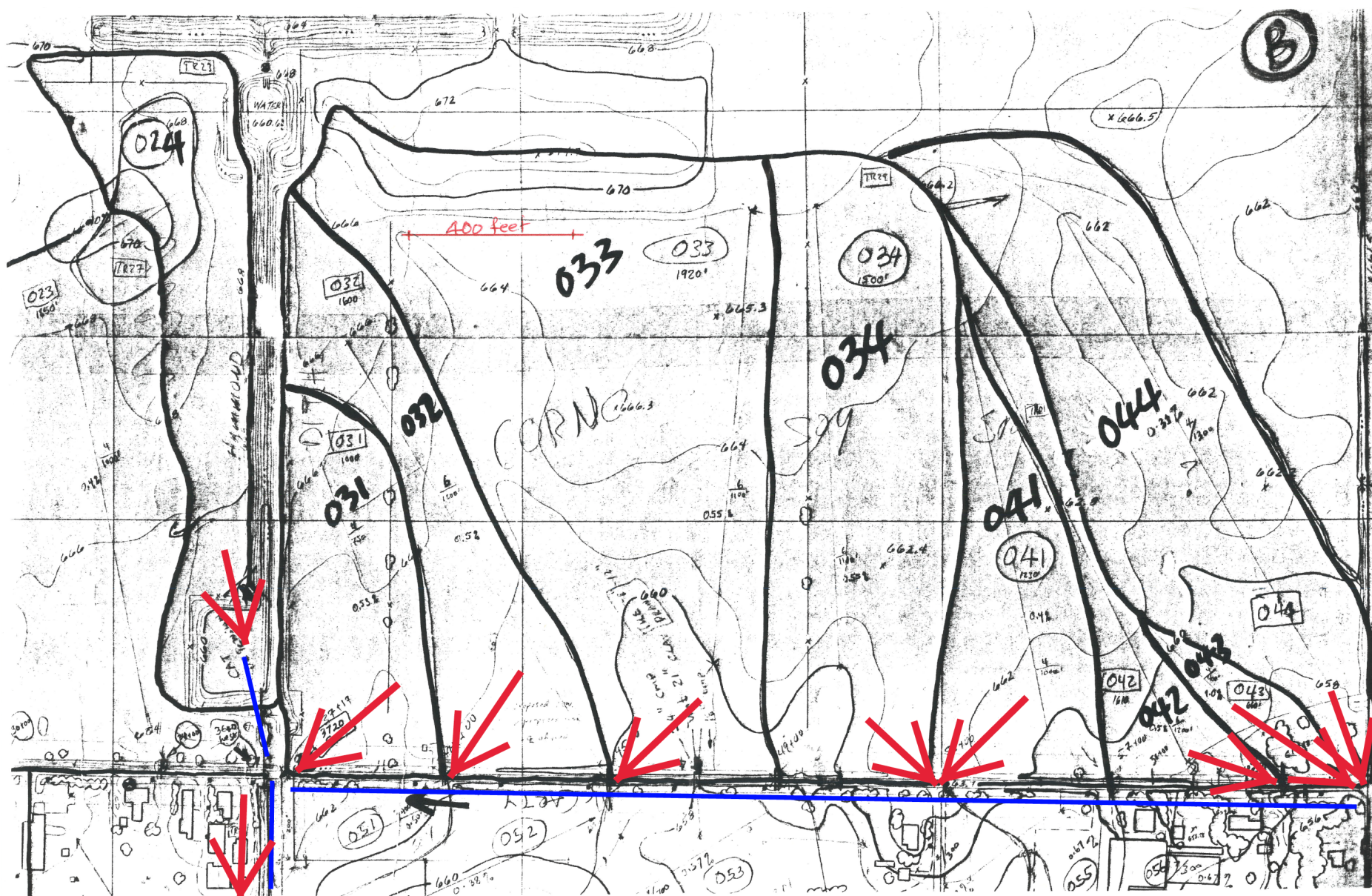
Urban Catchments			
General Description	C	Surface	C
City	0.7–0.9	Asphalt paving	0.7–0.9
Suburban business	0.5–0.7	Roofs	0.7–0.9
Industrial	0.5–0.9	Lawn heavy soil	
		>7° slope	0.25–0.35
Residential multiunits	0.6–0.7	2–7°	0.18–0.22
Housing estates	0.4–0.6	<2°	0.13–0.17
Bungalows	0.3–0.5	Lawn sandy soil	
		>7°	0.15–0.2
Parks, cemeteries	0.1–0.3	2–7°	0.10–0.15
		<2°	0.05–0.10
Rural Catchments (less than 10 km ²)			
Ground Cover	Basic Factor	Corrections: Add or Subtract	
Bare surface	0.40	Slope < 5%: –0.05	
Grassland	0.35	Slope > 10%: +0.05	
Cultivated land	0.30	Recurrence interval < 20 yr: –0.05	
Timber	0.18	Recurrence interval > 50 yr: +0.05	
		Mean annual precipitation < 600 mm: –0.03	
		Mean annual precipitation > 900 mm: +0.03	
Source: Stephenson (1981).			

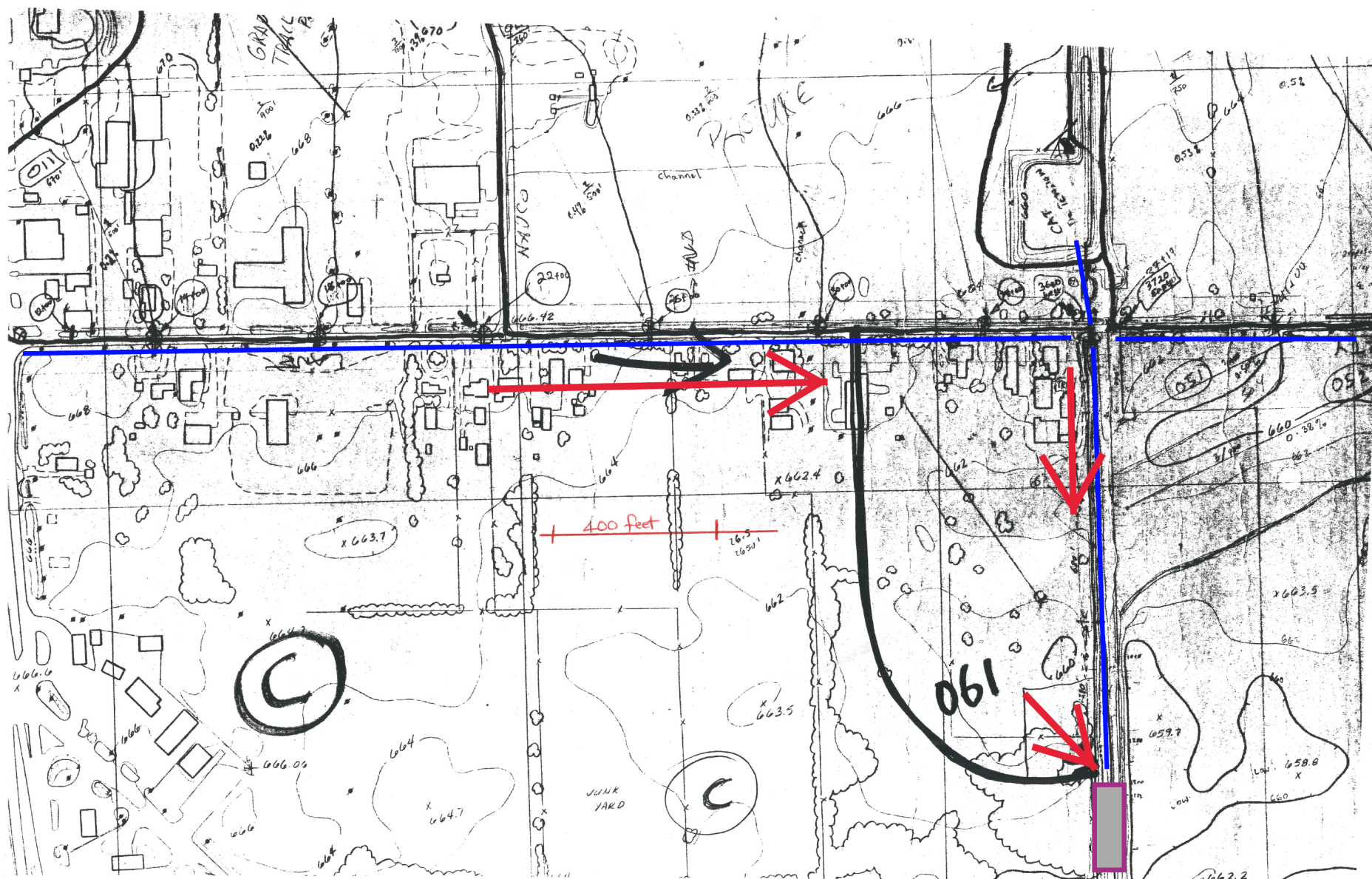
APPENDIX III

PROJECT MAPS

SMALL HARRIS COUNTY WATERSHED







ABOVE
AVERAGE

**Prairie View A&M University
Roy G. Perry College of Engineering
Civil & Environmental Engineering Department**

6

H



CVEG 4303: Water Resources

Section: P01

Title: Watershed Analysis and Design

Submitted By: Armando Gomez, Allyssa Reynolds

Submitted To: Dr. Nzewi

Due Date: April 28, 2022 – 1:00PM

Prairie View A&M University
Department Of Civil & Environmental Engineering

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Letter of Transmittal

Dr. Nzewi
Professor of Civil & Environmental Engineering
C.L. Wilson Engineering Building
Prairie View, Texas, 77446

April 27, 2022

Dear Dr. Nzewi,

Good

We submit the proposed report titled "Watershed Analysis and Design," as a fulfillment of the required design project for the Water Resource Engineering course.

The purpose of this report is to successfully analyze and design a watershed and trapezoidal channel providing the necessary parameters to showcase the knowledge and efficacy of the course. Components such as finding the runoff coefficient and time of concentration, and the analysis of a Harris County watershed in Region III, have all been observed and designed adequately. The following report reflects how the watershed was analyzed, and how the trapezoidal channel was designed.

Please review our report, and provide all constructive feedback. If there are any questions, please contact the Team Lead, Allyssa Reynolds, via email at areynolds18@pvamu.edu, or by phone at (314)-677-7306. We hope this report is sufficient in providing all of the necessary data and design.

Sincerely,

Allyssa Reynolds & Armando Gomez

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You forgot to number
the pages

1 Abstract

The objective of this project was to analyze Harris County watershed, develop a drainage system network to the left of Hammond ditch, and to design a lined concrete trapezoidal channel based on the drainage system analysis. Data such as the land use for each watershed, direction of flow, elevation of the land site, and boundary of each watershed have all been provided by the client.

2 Introduction

R&G Engineering Firm was contracted by Dr. Nzewi of Prairie View A&M University to analyze the Harris County Region III watershed, and to design a lined concrete trapezoidal channel based on the analysis. The design included the calculations for runoff coefficient, time of concentration, rainfall intensity, and subsequent peak runoff rates. A drainage system-network was also developed to create the channel. This drainage system will be able to ~~withstand a~~ 10-year rainfall event, and is located to the left of Hammond ditch. *drain*

3 Data Presentation

3.1.0 Task 1

For the first task, our team had to establish an adequate length for each sub-watershed. Our client provided a known length, and the team was able to convert the known length in feet to inches. In this project, 2 inches were equivalent to 400 feet. By breaking this conversion further, $\frac{1}{2}$ inches were equivalent to 100 feet. The length would represent where the farthest droplet of water would travel and was determined by measuring the distance between the highest and lowest elevation closest to the runoff pipe. The following table represents the lengths found for each sub-watershed:

Sub-Watershed	Length (ft)
A024	1375
B031	1000
B032	1560
B033	1500
B034	1600
B041	1100
B042	1500
B043	600
B044	1800
C061	1000

Table 1.0: Sub-watershed Lengths, L

3.1.1 Task 2

For the second task, our team had to calculate the average slope of each sub-watershed. The following equation was utilized to find the slope:

$$\text{Slope, } S = \frac{\text{Elevation}_{\text{maximum}} - \text{Elevation}_{\text{minimum}}}{\text{Sub-watershed Length}}, \text{ Equation 1}$$

All equations were provided from the client, and the sub-watershed length was determined in the previous task, task 1. The following table represents each slope for each sub-watershed:

Sub-Watershed	Change in Elevation (ft)	Length (ft)	Slope
A024	10	1375	0.0073
B031	2	1000	0.0020
B032	2	1560	0.0013
B033	10	1500	0.0067
B034	6	1600	0.0038
B041	4	1100	0.0036
B042	6	1500	0.0040
B043	2	600	0.0033
B044	8	1800	0.0044
C061	2	1000	0.0020

Table 2.0: Slope, S, for each Sub-watershed

3.1.2 Task 3

For the third task, our team determined the time of concentration. This is the overland flow segment of travel time, the time it takes for a droplet of water to travel from the farthest point of the catchment to the pipe. The time of concentration was calculated by using the Kirpich formula. This equation can be found below:

$$t_c = \frac{0.0078L^{0.77}}{S^{0.385}}, \text{ Equation 2}$$

The length, L, was determined from task 1, and the slope, S, was determined from task 2. All other values are constants due to English units being utilized.

The following table represents the time of concentration for each sub-watershed:

Sub-Watershed	Length, L (ft)	Slope (S)	t_c (min)
A024	1375	0.0073	13.55
B031	1000	0.0020	17.43
B032	1560	0.0013	29.12
B033	1500	0.0067	14.98
B034	1600	0.0038	19.65
B041	1100	0.0036	14.90
B042	1500	0.0040	18.23
B043	600	0.0033	9.66
B044	1800	0.0044	20.15
C061	1000	0.0020	17.43

Table 3.0: Time of Concentration, t_c , for each Sub-watershed

3.1.3 Task 4

For the fourth task, our team determined the runoff coefficient, C, for every sub-watershed. The client provided the land use for each sub-watershed and various sources to determine C. Thus, we were able to determine the runoff coefficient for each sub-watershed. The following table represents this data:

keep to 2 decimal places
Good detail!

Sub-Watershed	Runoff Coefficient (C)	General Description (Handout)
A024	0.300	High C_r + High C_i + Normal C_v + Normal C_s
B031	0.28 0.280	Lawns, Heavy Soil Single Family
B032	0.32 0.320	Single Family Playground
B033	0.300	Single Family Playground
B034	0.600	Apartment Dwelling Area
B041	0.68 0.675	Light Industrial
B042	0.420	Lawns, Flat Neighborhood area
B043	0.600	Neighborhood area
B044	0.600	Neighborhood area
C061	0.345	Grassland

Table 4.0: Runoff Coefficient, C, for each Sub-watershed

The watershed to the left of Hammond ditch was determined to be an urban and suburban area. The area South of Hammond ditch was determined to be rural due to its land use. These assumptions allowed the team to determine the runoff coefficients effectively. Averages for each range of the runoff coefficients were obtained and used as C.

3.1.4 Task 5

For the fifth task, the peak runoff rate was determined for each sub-catchment by utilizing the Rational Method. Since the client wanted us to use the Rational Method, the following assumptions were made:

1. The area of the analyzed catchment is less than 200 acres.
2. Rainfall intensity is uniform during a storm.
3. Rainfall is distributed uniformly across the drainage area.

With these assumptions, we were able to complete the Rational Method:

1. Determine the area of each sub-watershed, and verify that the area is less than 200 acres.
 - a. Area was calculated using two methods to ensure validity of results. Methods included the triangular and square method.
 - b. Square method can be found in Appendix A.
2. Determine the time of concentration for each sub-watershed.
3. Determine rainfall intensity based on each time of concentration.
4. Solve for the peak runoff rate.

The following equation was utilized to find the peak runoff rate:

$$Q = CIA, \text{ Equation 3}$$

The equation for runoff coefficient is as follows:

$$C = \frac{\sum a_i \cdot c_i}{\sum a}, \text{ Equation 4}$$

The equation for rainfall intensity was provided by the client. This equation is located below:

$$I = \frac{b}{(t_c + d)^e}, \text{ Equation 5}$$

Where b , in. = 54.68, d , min. = 6.96, and $e = 0.6623$. These values were obtained by utilizing the updated rainfall coefficient table. This table is located in Appendix B under Figure 1.

The following table represents the peak runoff rate for each sub-watershed:

Sub-Watershed	C	t_c (min)	Intensity, I (in/hr)	Area, A (ac)	Flow, Q (cfs)
A024	0.300	13.55	5.26	8.82	13.93
B031	0.280	17.43	4.20	4.99	6.13
B032	0.320	29.12	5.17	22.10	35.39
B033	0.300	14.98	4.50	7.93	10.99
B034	0.600	19.65	4.37	11.31	18.18
B041	0.675	14.90	4.16	7.00	11.73
B042	0.420	18.23	4.28	4.50	7.77
B043	0.600	9.66	3.66	2.00	2.99
B044	0.600	20.15	3.78	16.25	27.36
C061	0.345	17.43	6.51	13.75	38.65

Table 5.0: Peak Runoff Rate, Q, for each Sub-watershed

3.1.5 Task 6

For the sixth task, we determined the peak flow rate that was used to design the segment of the storm sewer system, also named the drainage system-network. This was calculated by utilizing the segment that held the largest time of concentration value. To determine the maximum time of concentration, though, the travel time for each pipe was found. The client provided the velocity, 2 feet/s, and the length of each pipe was determined by the team. The following equation represents this:

$$\frac{\text{Length of Pipe, ft}}{\text{Velocity, ft/s}} \cdot \frac{60 \text{ s}}{1 \text{ min}}, \text{ Equation 6}$$

The time of travel was converted into minutes to provide uniformity of dimensions. The following table represents the peak flow rate determined:

Excellent detail

Sub-Watershed	Length (ft)	Travel Time (min)	Time of Concentration (min)
061->G	0	0.000	17.43
031->A->G	1100	9.17	26.59
024->I->A->G	1325	11.04	40.17
032->B->A->G	1500	12.50	27.48
033->C->B->A->G	1900	15.83	35.48
034->D->C->B->A->G	2700	22.50	37.40
041->D->C->B->A->G	2700	22.50	40.73
042->E->D->C->B->A->G	3500	29.17	38.83

043->F->E->D->C->B->A->G	3700	30.83	50.98
044->F->E->D->C->B->A->G	3700	30.83	48.26

Table 6.0: Peak Runoff Rate, Q, for the Storm Sewer System

The peak floor rate that was would be used for the design of the watershed using equations 3 - 5 as follows:

$$C = \frac{\sum a_i \cdot c_i}{\sum a}$$

$$C = 42.59 / 98.65$$

$$C = 0.432$$

$$I = \frac{b}{(t_e + d)^e}$$

$$I = 54.68 / (50.98 + 6.96)^{0.66623}$$

$$I = 3.6582$$

$$A_{SumTotal} = 98.65 \text{ Acres}$$

$$Q = CIA$$

$$Q = 0.432 * 3.6582 * 98.65$$

$$Q = 156 \text{ cfs}$$

3.1.6 Task 7

For the seventh task, we designed a concrete-lined trapezoidal channel using the peak flow from Task 6. The discharge at each outlet of the sub-watershed C061 and the slope of the storm sewer segment along sub-watershed C061 was utilized. Several equations were used to determine the appropriate design, including the Manning's equation. Through the trial-and-error method, the design was developed and provided.

To begin the design, the area of the channel was determined to be: 22.61 ft^2 . The following equation was utilized:

$$\text{Area, } A = by + zy^2, \text{ Equation 7}$$

Where bottom width, $b = 10$, depth of the channel, $y = 1.8$, and side slope, $z = 1.6$.

Since b and y were determined, the perimeter of the channel and channel top width, T , were found to be 16.79 ft and 15.76 ft by utilizing the following two equations:

$$\text{Perimeter, } P = b + 2y\sqrt{(1 + z^2)}, \text{ Equation 8}$$

$$T = b + 2zy, \text{ Equation 9}$$

Next, the hydraulic radius, R, was determined to be 1.50 ft. The following equation was used:

$$R = \frac{A}{P}, \text{ Equation 10}$$

Next, the hydraulic depth was determined to be 1.43 ft by utilizing the following:

$$D = \frac{A}{T}, \text{ Equation 11}$$

Next, the channel flow rate was determined to be 164.52 cfs by using the following equation:

$$Q = \frac{1.486}{n} AR^{2/3} \sqrt{S}, \text{ Equation 12}$$

Where Manning's roughness coefficient, $n = 0.012$, and land slope, $S = 0.0020$.

Note, n value of 0.012 is sufficient for pipes with a max diameter of 35 inches.

Finally, the freeboard for the channel was determined to be 1.66 ft. This was found using the following equation:

$$u = \sqrt{cy}, \text{ Equation 13}$$

Where freeboard coefficient, $c = 1.53$.

Although the freeboard for the channel was found to be 1.66, the value was rounded to the next whole number, 2 ft. If this channel were to be designed within Harris County, it would be more economical and feasible to obtain a freeboard of 2 ft rather than 1.66 ft.

The following table provides the channel characteristics:

Channel Flow Rate, Q, cfs	164.52
Channel Side Slope, z	1.6
Channel Bottom Width, b, ft	10.0
Depth of Channel, y, ft	1.8
Channel Freeboard, u, ft	2.0
Channel Velocity, ft/s	2.0

Table 7.0: Design Channel Characteristics

3.1.7 Task 8

For the seventh task, we sketched the drainage system design and provided the location of the open channel.

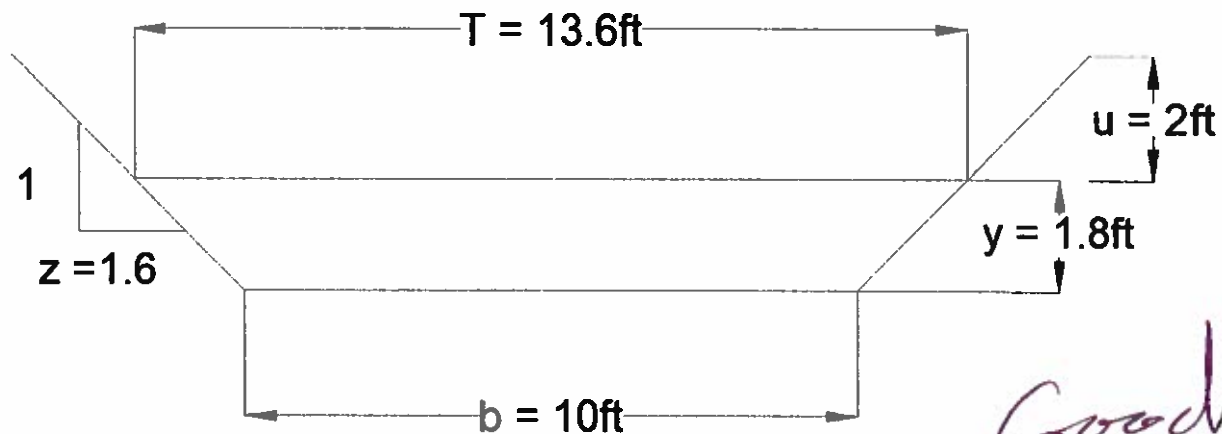


Figure 1.0: Drainage Channel

4 Conclusion

The objective of the project was to analyze the Harris County Region III watershed and to design a lined concrete trapezoidal channel based on the analysis. By completing eight tasks, the design was able to be developed appropriately. The flow used to design the channel was 156 cfs. The channel characteristics included a bottom width of 10 feet, a depth of 1.8 feet, and a slide slope of 1.6. With these dimensions, the channel has a flow capacity of 164.52 cfs. This is above the needed flow rate of 156 cfs, and thus verifies that the channel is adequate. Recommendations include utilizing a Water Resources Engineering software to develop the design, as this would aid in understanding the project better.

References

1. Gupta, Ram S. *Hydrology & Hydraulic Systems.* , 2017. Print.

Appendix A

Raw Calculations

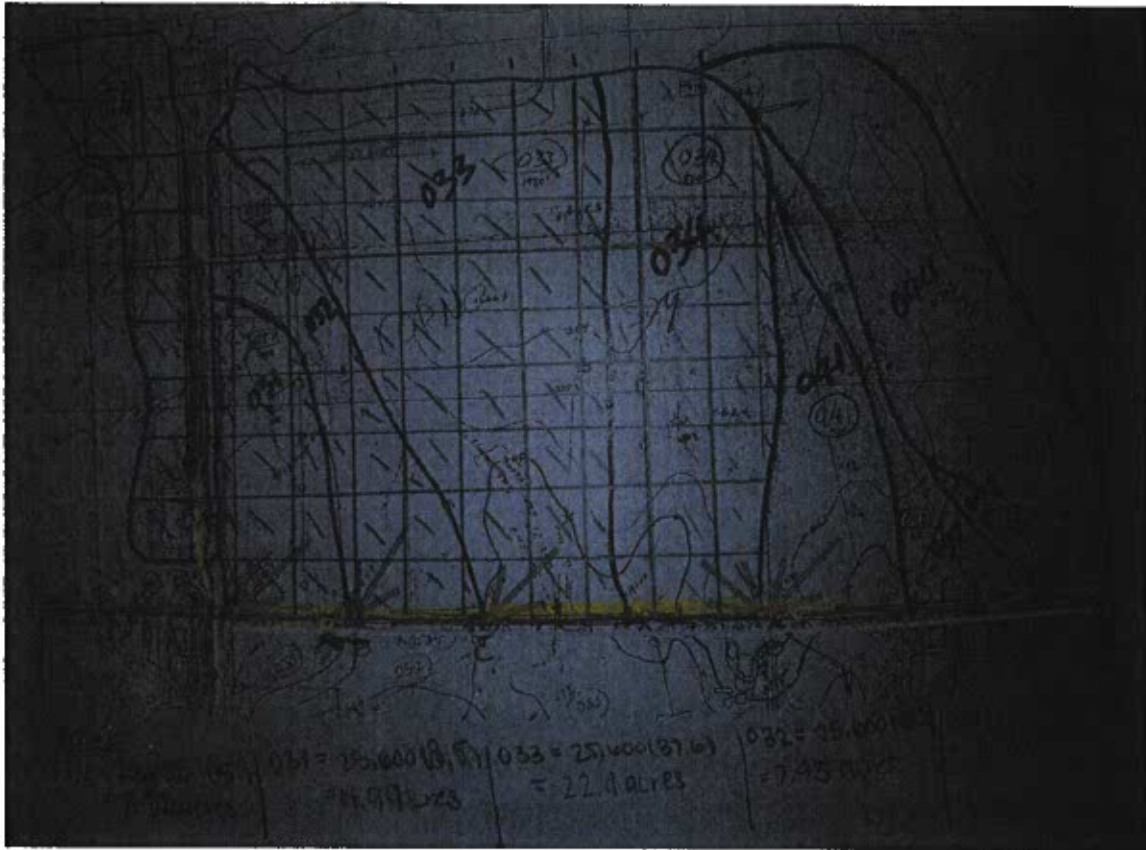


Figure 1.0: Area Calculations reflect calculations of the area via the squares method for sub-sheds 024-034.

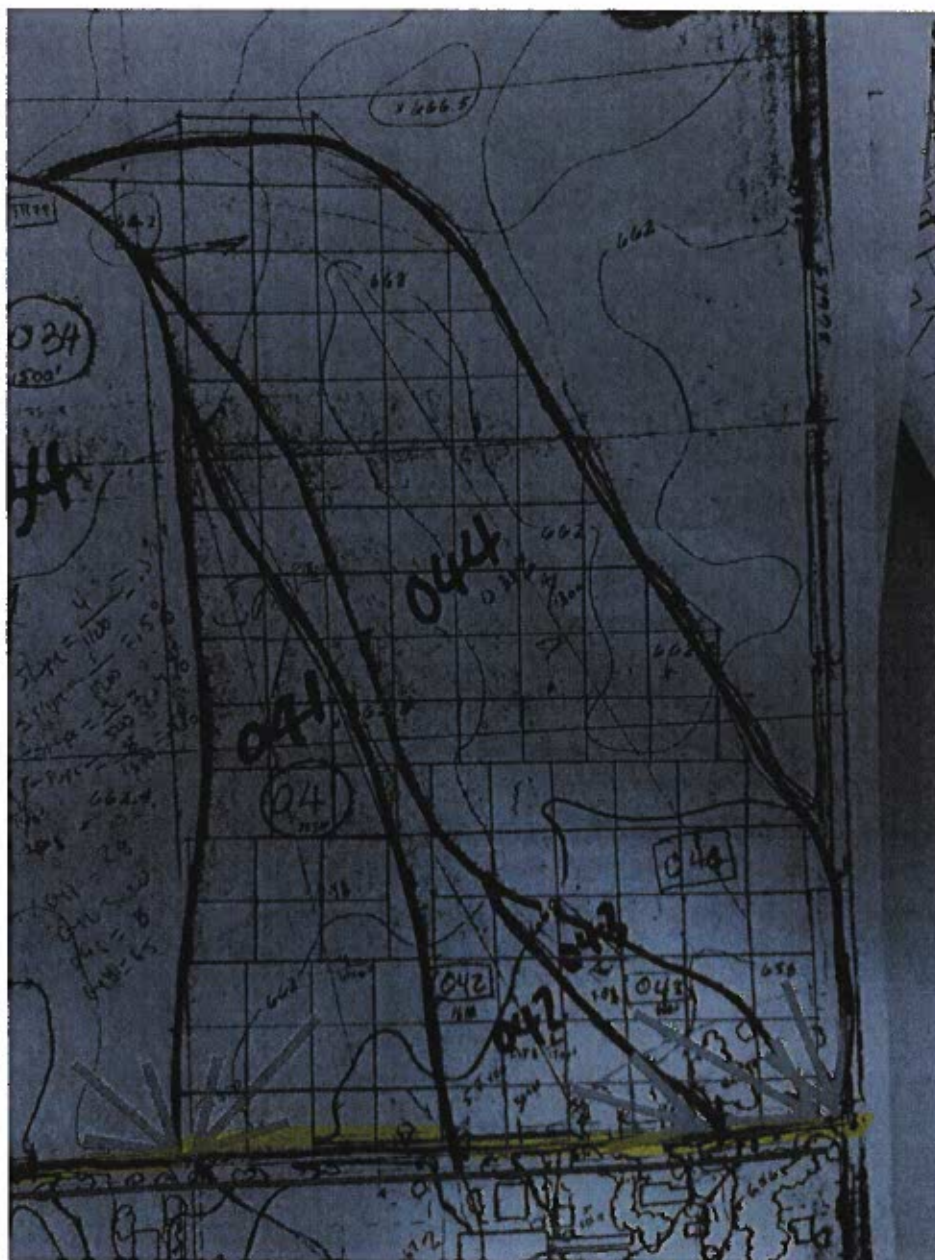


Figure 2.0: Area Calculations reflect calculations of the area via the squares method for sub-sheds 041-044.

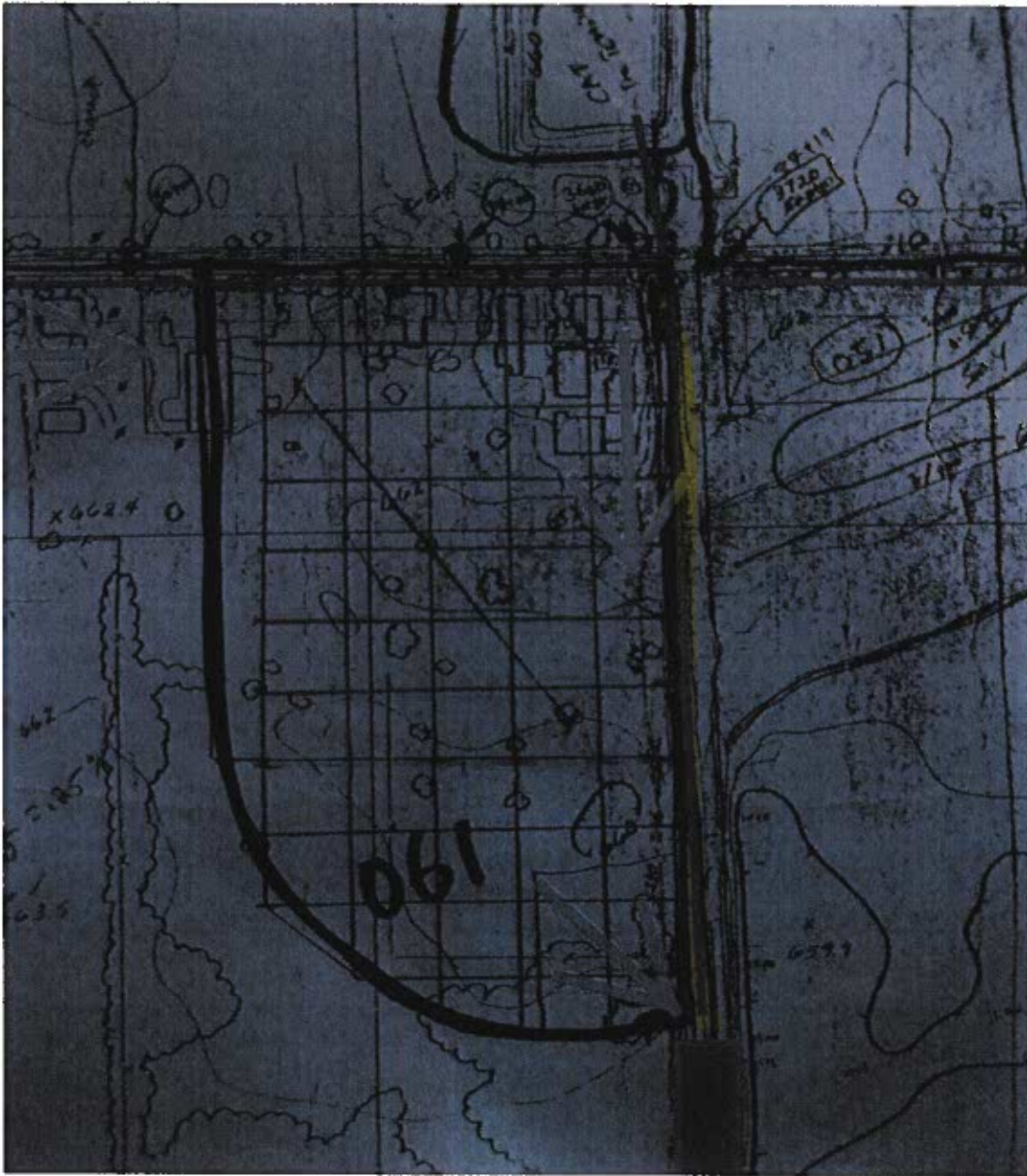


Figure 3.0: Area Calculations reflect calculations of the area via the squares method for sub-sheds 061 .

Appendix B

Tables and Figures Used

Table 1. Updated Rainfall IDF Coefficients for Harris County							
Coastal Zone	10 % AEP 2-Year	20 % AEP 5-Year	10 % AEP 10-Year	4 % AEP 25-Year	2 % AEP 50-Year	1 % AEP 100-Year	0.2 % AEP 500-Year
Region 1							
<i>K</i>	0.7372	0.7058	0.6819	0.6446	0.6170	0.5870	0.5111
<i>C</i> (in.)	48.27	51.78	54.26	54.97	54.84	53.93	50.89
<i>C</i> (mm)	9.30	8.19	7.44	6.27	5.45	4.53	2.69
Region 2							
<i>K</i>	0.7263	0.7051	0.6752	0.6397	0.6166	0.5857	0.5129
<i>C</i> (in.)	47.25	54.09	55.26	56.72	57.94	56.68	54.26
<i>C</i> (mm)	8.94	8.34	7.30	6.12	5.47	4.46	2.72
Region 3							
<i>K</i>	0.7244	0.6900	0.6623	0.6294	0.6096	0.5797	0.5196
<i>C</i> (in.)	48.35	52.32	54.68	57.79	61.00	60.66	62.17
<i>C</i> (mm)	9.07	7.88	6.96	5.89	5.46	4.44	2.95

AEP = annual exceedance probability

Figure 1.0: Rational Runoff Coefficient reflects the runoff coefficient used for the analysis

Table 16.3 Rational Runoff Coefficient			
Urban Catchments			
General Description	C	Surface	C
City	0.7-0.9	Asphalt paving	0.7-0.9
Suburban business	0.5-0.7	Roofs	0.7-0.9
Industrial	0.5-0.9	Lawn heavy soil	
		>7° slope	0.25-0.35
Residential multiunits	0.6-0.7	2-7°	0.18-0.22
Homeing estates	0.4-0.6	<2°	0.13-0.17
Suburbs	0.3-0.5	Lawn sandy soil	
		>7°	0.15-0.2
Parks, cemeteries	0.1-0.3	2-7°	0.10-0.15
		<2°	0.05-0.10
Rural Catchments (less than 10 km ²)			
Ground Cover	Basic Factor	Corrections: Add or Subtract	
Bare surface	0.40	Slope < 5%: +0.05	
Grassland	0.35	Slope > 10%: +0.05	
Cultivated land	0.30	Recurrence interval < 20 yr: -0.05	
Timber	0.18	Recurrence interval > 50 yr: +0.05	
		Mean annual precipitation < 600 mm: -0.03	
		Mean annual precipitation > 900 mm: +0.03	
Source: Frehse (1961)			

Figure 2.0: Rational Runoff Coefficient reflects the runoff coefficient used for the analysis.

RATIONAL RUNOFF COEFFICIENTS	
Surface Description	Runoff Coefficient
Asphalt pavement	0.70-0.95
Concrete pavement	0.50-0.90
Gravel	0.30-0.50
Grass, mowed	0.40-0.60
Grass, rough	0.60-0.75
Grass, steep	0.35-0.40
Grass, steep, rough	0.30-0.70
Grass, steep, rough	0.30-0.80
Grass, steep	0.60-0.90
Grass, rough	0.10-0.25
Grass, rough	0.30-0.40
Grass, rough	0.30-0.40
Grass, rough	
Grass, rough, steep	0.15-0.20
Grass, rough, steep	0.20-0.25
Grass, rough, steep	0.18-0.25
Grass, rough, steep	0.25-0.30
Grass, rough, steep	0.70-0.80
Grass, rough, steep	0.05-0.15
Grass, rough, steep	0.70
Grass, rough, steep	
Grass, rough, steep	0.05-0.10
Grass, rough, steep	0.10-0.15
Grass, rough, steep	0.25-0.30
Grass, rough, steep	0.15-0.20
Grass, rough, steep	0.15-0.20

Figure 3.0: Rational Runoff Coefficient reflects the runoff coefficient used for the analysis.

Runoff Coefficient	Runoff Coefficient
0.25-0.35	0.25-0.35
0.45-0.55	0.45-0.55
0.50-0.95	0.50-0.95
0.70-0.85	0.70-0.85
0.75-0.95	0.75-0.95
0.75-0.95	0.75-0.95

Table 4-11: Runoff Coefficients for Rural Watersheds

Watershed Characteristics	Extreme	High	Normal	Low
Land Use - C_p	0.25-0.35 Steep, rugged terrain with average slopes above 30%	0.20-0.28 Hilly, with average slopes of 10-30%	0.14-0.20 Rolling, with average slopes of 5-10%	0.08-0.14 Relatively flat land with average slopes of 0-5%
Soil Infiltration - C_i	0.12-0.16 No effective soil cover, either rock or thin soil mantle of negligible infiltration capacity	0.08-0.12 Slow to take up water, clay or shallow loam soils of low infiltration capacity or poorly drained	0.06-0.08 Normal, well drained light or medium textured soils, sandy loams	0.04-0.06 Deep sand or other soil that takes up water readily, very light, well drained soils
Vegetation Cover - C_v	0.12-0.16 No effective plant cover, bare or very sparse cover	0.08-0.12 Poor to fair, clean cultivation, crops or poor natural cover, less than 20% of drainage area has good cover	0.06-0.08 Fair to good, about 50% of area in good grassland or woodland, not more than 50% of area in cultivated crops	0.04-0.06 Good to excellent, about 90% of drainage area in good grassland, woodland, or equivalent cover
Surface Water - C_s	0.10-0.12 Negligible surface depression, low soil shallow, drain away, steep and small, no ponds	0.08-0.10 Well-defined system of small drainageways, no ponds or swamps	0.06-0.08 Normal, considerable surface depression, a few swamps, small ponds and marshes	0.04-0.06 Much surface storage, drainage system not properly drained, large floodplain area, large number of ponds or swamps

Note: C_p , C_i , C_v , C_s are the runoff coefficients based on the 4 runoff components: $C = C_p + C_i + C_v + C_s$

Figure 4.0: Rational Runoff Coefficient reflects the runoff coefficient used for the analysis.

Rational Runoff Coefficient (C)				
Type of Surface	1 yr Frequency		25 yr Frequency	
	Minimum	Maximum	Minimum	Maximum
Roofs				
Asphalt	0.75	0.95	0.83	1.00
Shingles	0.30	0.70	0.55	0.77
Residential areas				
Grass	0.30	0.50	0.33	0.55
Grass, detached	0.40	0.60	0.44	0.66
Grass, attached	0.60	0.75	0.66	0.83
Grass, detached	0.25	0.40	0.28	0.44
Grass, attached	0.50	0.70	0.55	0.77
Industrial areas				
Grass	0.50	0.80	0.55	0.80
Grass	0.60	0.90	0.66	0.96
Grass, attached	0.10	0.25	0.11	0.28
Grass	0.20	0.35	0.22	0.36
Grass	0.20	0.40	0.22	0.44
Grass	0.10	0.30	0.11	0.33
Character of Surface	Up to 10 yr Frequency		25 yr Frequency	
	Minimum	Maximum	Minimum	Maximum
Pavement				
Asphalt	0.70	0.95	0.77	1.00
Concrete	0.80	0.95	0.88	1.00
Grass	0.70	0.85	0.77	0.94
Grass	0.70	0.85	0.77	1.00
Grass, sandy soil				
Grass	0.05	0.10	0.06	0.09
Grass	0.10	0.15	0.11	0.17
Grass	0.15	0.20	0.17	0.22
Grass, heavy soil				
Grass	0.15	0.17	0.14	0.09
Grass	0.16	0.22	0.20	0.19
Grass	0.25	0.35	0.28	0.24

Figure 5.0: Rational Runoff Coefficient reflects the runoff coefficient used for the analysis.

AVERAGE

Prairie View A&M University
Roy G Perry College of Engineering
Civil & Environmental Engineering Department

3



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CVEG 4303 P01 – Water Resources
Spring 2022

Project Report 1- Rational Method: Peak Flows
for Sewer Design in a Small Watershed

Submitted to:

Dr. Nzewi

Submitted by: Group 3

Sydney Jones, Sophie Tuke, Maurice Bettis

Date Due: April 28, 2022

Letter of Transmittal

April 26, 2022

Dr. Nzewi

Civil Engineering Department

Prairie View A&M University

Dear Dr. Nzewi:

The attached technical laboratory report contains the detailed results of The Rational Method Application: Stormwater Sewer Design Peak Flows in a Small Watershed. The report contains detailed sample calculations, the results, and design of the storm water drainage needed for our provided region.

Please contact me at 512-586-4461 or by e-mail at sjones117@pvamu.edu if you have any questions on the report.

Sincerely,

Sydney N Jones

✓ 850
Good.

Abstract

The Rational Method is used to estimate the peak surface runoff rate for the design of drainage structures. It is, most suitably, and often used for small catchments and urban watersheds, and is determined based on three components- the runoff coefficient, the rainfall intensity, and the catchment or drainage area. Determining the peak flow rate and volume of storm water runoff produced in a watershed for a given storm period is a vital step in assessing suitable and effective drainage design. In this project, the Rational Method was applied in order to find the peak runoff rate of the given area on the map of Harris County Region III watersheds. Through the measurement of the designated areas, and calculations of its rainfall intensities and coefficients, the runoff rate for the sewer system design for the Watershed Sub-areas of A (left of ditch) & C were found, under the specified parameters for Group 3.

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List of Equations

Task 1 : No equation utilized

Task 2 : Slope = $\frac{\text{Maximum elevation} - \text{minimum elevation}}{\text{Length}}$

Task 3 : $t_c = \frac{.0078 L^{.77}}{S^{.385}}$

Task 4 : Runoff Coefficient = based on table, multiplied per percentage given

Task 5 : Rational Method (Q) = CIA, 1 acre = 43,560 square feet, 1 (in/hr) = 1/43,200 cfs

Task 6 : Average Runoff Coefficient, $C = \frac{\Sigma C \times A}{\Sigma A}$

Task 7 : Area, $A = by + zy^2$

Wetted Perimeter, $P = b + 2y\sqrt{1 + z^2}$

Hydraulic Radius, $R = \frac{A}{P}$

Flow Rate, $Q = \frac{1.49}{n} AR^{2/3} \sqrt{S}$

Freeboard, $U = \sqrt{Cy}$

Task 8 : No equation utilized

Good!

Results and Calculations

Task 1:

For task 1, we were asked to calculate the appropriate length for each subwatershed in feet. Below are the lengths in order based on the watershed, found by measuring in inches and utilizing the available scale on the provided map. The lengths can be found on the map in the appendix.

Table Length of each sub-watershed

Sub-Watershed Region	Length (in)	Scaled length (ft) 2 inches= 400 feet
A011	3.0	600
A012	7.0	1400
A013	7.2	1440
A021	4.5	900
A022	5.4	1080
A023	6.6	1320
A024	8.75	1750
C061	6.0	1200

Task 2:

For task 2, we were asked to calculate the average slope of each subwatershed. The way we calculated the slope using the slope formula (maximum elevation - minimum elevation/ sub-watershed length) below is a data table showing the results after using the formula for each region.

Sub-watershed region	Scaled length (ft) 2 inches = 400 feet	Maximum elevation	Minimum elevation	Average slope
A011	600	670	666	.0066
A012	1400	670	668	.0014
A013	1440	672	668	.0027
A021	900	670	666	.0044
A022	1080	670	664	.0037
A023	1320	670	664	.0045
A024	1750	670	660	.0057

C061	1200	662	660	.0016
------	------	-----	-----	-------

Task 3:

For task 3, we were asked to calculate the time of concentration utilizing the Kirpich formula for the overland flow segment of travel time. The first step was to find the lengths after we find the length for each region we must find the slopes of each region and after we find both values. We can plug in them in the equation to find the tc of each region

$$\text{Equation 1.1: } t_c = \frac{.0078 L^{.77}}{S^{.385}}$$

KEEP TABLES TO 1 page
Substitute the value

Sub-watershed	length	slope	Time of concentration
A011	600	.0066	7.42 min
A012	1400	.0014	25.9 min
A013	1440	.0027	20.5 min
A021	900	.0044	11.86 min
A022	1080	.0037	14.59 min
A023	1320	.0045	13.53 min
A024	1750	.0057	17.92 min
C061	1200	.0016	21.85 min

Task 4:

For task 4, we were asked to calculate the runoff coefficient, C, for each sub- watershed based on the land use determined for each region. The Runoff Coefficient is a dimensionless factor that is used to convert the rainfall amounts to runoff. To calculate the coefficient, the reference appendix for Runoff Coefficients, (Hydraulic Design Manual, TxDOT, 2019) was used to find the standard coefficients, and later applied, whether directly, or as a percentage of the watershed's value based on physical characteristics given.

Task 5:

For task 5, we were asked to calculate the peak runoff rate in cubic feet per second (cfs) using the Rational Method.

$$Q = CIA$$

Where we have previously found the C, runoff coefficient, the I, rainfall intensity, and the area based on the length and height.

The area was found using the triangular method, $\frac{1}{2}bh$, and later converted to acres, as 1 acre = 43,560 square feet.

sub-watershed	b	tc	d	e	i
A011	52.32	7.42 min	7.88	.69	7.96 in/hr
A012	52.32	25.9 min	7.88	.69	4.61 in/hr
A013	52.32	20.5 min	7.88	.69	5.20 in/hr
A021	52.32	10.14 min	7.88	.69	7.12 in/hr
A022	52.32	14.59 min	7.88	.69	6.11 in/hr
A023	52.32	13.53 min	7.88	.69	6.32 in/hr
A024	52.32	17.92 min	7.88	.69	5.55 in/hr
C061	52.32	21.85 min	7.88	.69	5.10 in/hr

sub-watershed	C Value	Q, runoff rate (cfs)
A011	0.205	0.002 cfs
A012	0.62	0.000836 cfs
A013	0.95	0.00149 cfs
A021	0.239	0.00032 cfs

Same # of ~~digits~~ decimals

too small!
something is wrong

A022	0.4	0.00018 cfs
A023	0.121	0.00021 cfs
A024	0.22	0.00095 cfs
C061	0.163	0.0007 cfs

Task 6:

For task 6, we were asked to calculate the peak flow rate that would be used in designing each segment of the storm sewer system towards the outlet. First the total runoff coefficient was calculated using the equation below:

$$\text{Equation 1.2: } C = \frac{\sum C \times A}{\sum A}$$

Section	C value
1	.35
2	.18
3	.16

Next, the rainfall intensity was calculated. The time of concentration, t_c , was found first by utilizing the Kirpich formula, equation 1.1. The lengths were found using the following method (nodes can be found labeled in appendix):

Length from node to node	Distances
Section 1 (A→B→C→D→E)	600'+400'+480'+750'+680'=2310'
Section 2 (L→E)	280'
Section 3 (E→F)	1080'
011+(A→B→C→D→E→F)	600'+400'+480'+750'+680'+1080'=3390'
012+(B→C→D→E→F)	1400'+480'+750'+680'+1080'=4390'
013+(C→D→E→F)	1440'+750'+680'+1080'=3950'
021+(C→D→E→F)	900'+750'+680'+1080'=3410'

*Good!
detail*

022+(D→E→F)	1080'+680'+1080'=2840'
023+(E→F)	1320'+1080'=2400'
024+(L→E→F)	1750'+280'+1080'=3110'
061	1200'

Region III

Utilizing the t_c that was calculated above, the rainfall intensity can be calculated with the IDF Coefficients for Harris County seen in the table below. The 5 year return period is used for region 3.

Table 1.2: Updated Rainfall IDF Coefficients for Harris County (region 3, 5 year return period)

e	.0069
B (in.)	52.32
D (in.)	7.88

0.6900 typ0

the detail for

The equation to find rainfall intensity in inches per hour is as follows:

$$I = \frac{B}{(t_c + D)^e} = \frac{52.32}{(33.2 + 7.88)^{.69}} = 4.03 \text{ in/hr}$$

i don't see this

I = design rainfall intensity (inches/hours)

t_c = time of concentration (minutes)

E, b and d = coefficients based on rainfall frequency-duration curves

too low!

Finally, the total area for the first portion (011+012+013+021+022) is added up and found to be 59.81 acres. For the second portion (023+024) the area summed together is 23.61 acres. Finally for the last segment of storm sewer the area is 18.24 acres.

Table 1.3: Flow rate calculations

Section	Runoff Coefficient	Rainfall Intensity(in/hr)	Total Area (acres)	Calculated Flow Rate (cfs)
A	.35	4.03	59.81	84.36
B	.18	7.15	23.61	30.39
C	.16	7.15	18.24	20.87
Combined				135.6

high

Task 7:

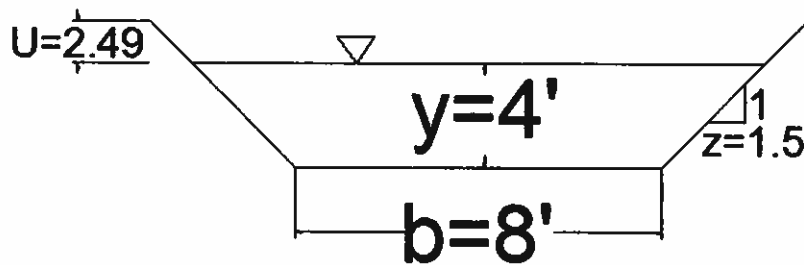
For task 7, we were asked to design a lined trapezoidal concrete channel for the watersheds. By using the combined flow rate found in table 1.3 above, the concrete channel can be designed efficiently to contain water from each storm water sewer section. Below is a table showing each equation used to find different dimensions of the channel and the final computed value:

$$Q = CIA$$

Assumed values: $n=.03$, $b=8'$, $z=1.5'$ and $y=4'$	Calculated value
Area, $A = by + zy^2 = 8 \times 4 + 1.5 \times 4^2$	56 ft^2
Wetted Perimeter, $P = b + 2y\sqrt{1 + z^2} = 8 + 2 \times 4\sqrt{1 + 1.5^2}$	22.4 ft
Hydraulic Radius, $R = \frac{A}{P} = \frac{56}{22.4}$	2.5 ft
Flow Rate, $Q = \frac{1.49}{n} AR^{2/3} \sqrt{S} = \frac{1.49}{.03} (56) 2.5^{2/3} \sqrt{.0016}$	204.4 cfs ✓
Freeboard, $U = \sqrt{Cy} C = 1.5 + (204 - 20) \frac{2.5 - 1.5}{3000 - 20} = 1.56$	$2.49 \approx 2.5 \text{ ft}$

Task 8: Below is a cross sectional sketch of the storm sewer drain. The location can be found on the map in the appendix.

Figure: Sketch of Storm Drain



What is your design flow?

Conclusion

Based on the calculations completed for the design of the storm sewer and trapezoidal concrete channel, the ditch will end at the bottom of sub-section 061. This design is the best option for the flowrate that was calculated.

give value

Appendix

- Calculations for the task 2

TASK 2	
Slopes	
Regions	
A011	$= \frac{670-666}{600} = .0066$
A012	$= \frac{670-668}{1400} = .0014$
A013	$= \frac{672-668}{1440} = .0027$
A021	$= \frac{670-666}{900} = .0044$
A022	$= \frac{670-664}{1080} = .0056$
A023	$= \frac{670-664}{1320} = .0045$
A024	$= \frac{670-660}{1750} = .0057$
C061	$= \frac{662-660}{1200} = .0016$

Scanned with CamScanner

- Calculations for time of contraction

TASK 3

Time of contraction

$$A011 = \frac{.0078(600)^{.77}}{(.0066)^{.385}} = 7.92 \text{ min}$$

$$A012 = \frac{.0078(1400)^{.77}}{(.0014)^{.385}} = 25.1 \text{ min}$$

$$A013 = \frac{.0078(1440)^{.77}}{(.0027)^{.385}} = 20.3 \text{ min}$$

$$A021 = \frac{.0078(900)^{.77}}{(.0099)^{.385}} = 11.56 \text{ min}$$

$$A022 = \frac{.0078(1080)^{.77}}{(.0037)^{.385}} = 14.59 \text{ min}$$

$$A023 = \frac{.0078(1320)^{.77}}{(.0045)^{.385}} = 13.33 \text{ min}$$

$$A024 = \frac{.0078(1750)^{.77}}{(.0057)^{.385}} = 17.92 \text{ min}$$

$$C061 = \frac{.0078(1200)^{.77}}{(.0016)^{.385}} = 21.85 \text{ min}$$

Nodes are labeled, the design length used to compute time of concentration and the different sections for the storm water sewer.



BELOW
AVERAGE

CIVIL ENGINEERING DEPARTMENT
PRAIRIE VIEW A&M UNIVERSITY



CVEG 4303 Water Resources Project 1
Spring 2022

Project Report On

**“Rational Method Application: Stormwater Sewer Design
Peak Flows in a Small Watershed”**

Submitted by

Layla Ogletree, Johnathon Chevalier, & Caleb Ross

On

April 28th, 2022

To

Dr. Nzewi

Letter of Transmittal

April 28th, 2022

Dr. Nzewi, P.E.

Civil Engineering Department

Prairie View A&M University

Good

Dear Dr. Nzewi,

The attached report contains information on a newly built drainage system for a watershed in Harris County, Texas. This report contains the task requirements, a representation of an open channel design, and the professionalism of civil engineers to ensure proper design development.

LJC Corporation is available to provide any answers to any questions that may concern the output of our product. The primary contact for these questions will be our team, Layla Ogletree, Sincerely,

Layla Ogletree

Johnathon Chevalier

Caleb Ross

Good

700

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Pages not numbered

Report should be
one-sided

Abstract

This project was prepared by group 5, LJC corporation, collectively. There is special consideration and acknowledgment to Dr. Nzewi for providing the necessary data and values to successfully complete the project. This group of engineers was tasked with designing a watershed in region one of Harris county. The watershed is adequate for five-year rainfall with a minimum of 18 minutes in time of concentration with a 4 feet per second channel flow. Our design is to involve sections A and section C of the given map of the project. In the given project report below you will see the difference in flow rate and flow time as well as a drawn design of our drainage system.

Task 1

Two methods were used to calculate the areas of the sub-watershed section. The first was the soiree methods. The map was placed over gridded engineering paper. The number of squares was then counted and estimated to find the area of the section. Because the paper was under the map and therefore not directly on the map, this method was not as accurate. The second method used was the triangle method. The legend on the graph was used to measure out several triangles on the map. The areas were calculated and added up to estimate the total area of the section.

Task 2

As engineer two, I was projected with calculating the average slope of each sub watershed. In this we are given the length of each sub watershed from engineer one and use that value along with elevations from the topography map to create the slope of each section of the watershed. In the table below, we see the values that were calculated by such formulas that are also given below.

Equation 2.1 – Equation for Slope calculations

$$\text{Slope} = \frac{(\text{Maximum Elevation} - \text{Minimum Elevation})}{\text{Sub - Watered Length}}$$

Equation 2.2 – Equation for Time of concentration calculations

Kirpich Time Of Concentration Calculator

Watershed Hydrology Equations Formulas

Solving for time of concentration.

$$t_c = 0.0078 \left(\frac{L^{0.77}}{S^{0.385}} \right)$$

Table 2.1- Slope and Time of Concentration calculations

Water Resources	Sub-Watershed	Max Elevation	Min Elevation	Length (given in step 1) (feet)	Average Slope	Time of Concentration (Minutes)	Time of Concentration (Seconds)	Value Check by Velocity (feet/seconds)
	A011	670.00	668.00	400.00	0.01	6.05	362.85	1.10
	A012	670.00	668.00	400.00	0.01	6.05	362.85	1.10
	A013	678.00	669.80	400.00	0.02	3.51	210.77	1.90
	A021	668.00	666.00	300.00	0.01	4.34	260.27	1.15
	A022	670.00	666.00	400.00	0.01	4.63	277.86	1.44
	A023	670.00	664.00	600.00	0.01	6.33	379.68	1.58
	A024	670.00	660.00	200.00	0.05	1.46	87.69	2.28
	C061	664.00	659.70	600.00	0.01	7.40	431.64	1.39
Total Flow time:						39.56	2373.62	

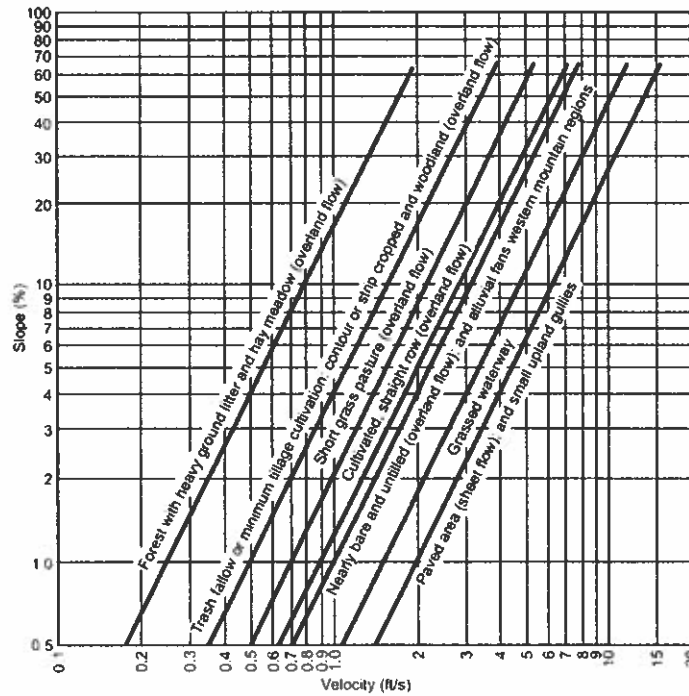
Not the correct method

Task 3

Inclusively as engineered two, we are also given the prompt to find the time of concentration amongst the watershed and determine exactly how accurate they are compared to a standard graph. Below happens to be figure 16. Seven from our hydrology book which helps us determine how accurate we are when it comes to our slope of the sub watersheds and the velocity of the section. As you can see from calculation and plotting on the graph that there happens to be some miscalculations asked to our points on such apply to graph don't seem to edit.

Make direct reference to figure or data

Figure 16.7 Average velocity of overland flow (from U.S. SCS 1975b).



Task 4

Runoff Coefficient

For the watershed c-values below were estimated referencing the land use

Sub -watershed	Land use	Estimated C-value
A011	Suburban business	.6
A012	Tesidnetal multi-unit	.5
A013	City	.7
A021	Grassland	.35
A022	Unimproved grassland	.2
A023	Unimproved (pasture)	.3
A024	Unimproved (pasture)	.2
C061	Sandy Unimproved <1% grade	.3

Task 5

Peak runoff rate using rational method

$$\text{Minimum } t_c = .0078(L).77S.385 = 18$$

$$Q = CIA$$

$$I = b(tc + d)e$$

$$I = 51.78(tc + 8.19).7058$$

This is Kippich eqn for calculating overland flow

Travel time Not tc

Task 6

The peak flowrate was calculated using the Rational Method. The C was found through the summation of the Area times the C for each section and divided by the total area. The area was the total area calculated from task one, using the triangle method. Lastly, the I was calculated by first estimating the longest path. In this case the longest path was from section 011 to section 061. This cumulative time was then used to calculate I using the equation given. Then all three numbers were multiplied to estimate the peak flow, which was found to be 100.84 cfs.

Task 7-8

From the previous tasks, the information was applied to design a concrete trapezoidal channel. The Q, S, and C, the information from section 061 was used. The Manning Equations for Q and V were used to find A & R. This information was applied to the dimensions of a hydraulically efficient open channel for a trapezoid. Lastly, the b, by, and B of the channel was calculated.

Results and Discussions

Engineer 1: Layla Ogletree

For this design, I believe the methodology as well as the application was complete and correct. For Task 3, t_c should have also been calculated using the velocity given and the lengths calculated from the first task. For the results for the design of the channel, in comparison to similar calculation and designs done in class, these numbers seem to align. Though, I am not sure if the application of the dimensions of a hydraulically efficient open channel for a trapezoid was the method that was supposed to be applied in regards to this design project.

Engineer 2: Johnathon Chevalier

Based on my calculations and my results, it is determined that a few of the sub watersheds don't necessarily align with what graph 2.1 is indicating. And I think that the margin of error is that on the graph given the elevations that were needed to calculate the slope aren't clearly defined. In order to receive a more accurate and adequate finding, if the proper elevations

You must summarize your results with tables. The narrative is inadequate

were given to accurately determine the slope than the rest of the values that are determined upon calculating the slope will result in a more accurate result.

Engineer 3: Caleb Ross

by rectangle

$H \times W$

Section 011:

$$700\text{ft} \times 400\text{ft}$$

$$= 280,000 \text{ ft}^2 = 6.43 \text{ ac}$$

Section 012:

$$1400\text{ft} \times 400\text{ft}$$

$$= 560,000 \text{ ft}^2 = 12.86 \text{ ac}$$

Section 013:

$$1400\text{ft} \times 400\text{ft}$$

$$= 560,000 \text{ ft}^2 = 12.86 \text{ ac}$$

Section 021:

$$800\text{ft} \times 300\text{ft}$$

$$= 240,000 \text{ ft}^2 = 5.51 \text{ ac}$$

Section 022:

$$1200\text{ft} \times 400\text{ft}$$

$$= 480,000 \text{ ft}^2 = 11.02 \text{ ac}$$

Section 023:

$$1300\text{ft} \times 600\text{ft} =$$

$$= 780,000 \text{ ft}^2 = 17.91 \text{ ac}$$

Section 024:

$$1700\text{ft} \times 200\text{ft}$$

$$= 340,000 = 7.81 \text{ ac}$$

Section 061:

$$1000\text{ft} \times 600\text{ft}$$

$$= 600,000$$

$$= 13.77 \text{ ac}$$

total length

3,300 ft

Rough

Sketch



by triangle

O 11:

$$A = \left(\frac{400 \times 300}{2}\right) + \left(\frac{200 \times 200}{2}\right) + \left(\frac{200 \times 200}{2}\right) + \left(\frac{200 \times 100}{2}\right) + \left(\frac{100 \times 100}{2}\right) \\ + \left(\frac{100 \times 300}{2}\right) + \left(\frac{100 \times 200}{2}\right) + \left(\frac{100 \times 100}{2}\right) \\ = 145000 \text{ ft}^2 = 3.33 \text{ ac}$$

O 12:

$$A = \left(\frac{400 \times 400}{2}\right) + \left(\frac{400 \times 500}{2}\right) + \left(\frac{350 \times 500}{2}\right) + \left(\frac{250 \times 500}{2}\right) + \left(\frac{400 \times 500}{2}\right) \\ + \left(\frac{400 \times 100}{2}\right) + \left(\frac{150 \times 450}{2}\right) + \left(\frac{150 \times 200}{2}\right) \\ = 436250 \text{ ft}^2 = 10.01 \text{ ac}$$

O 13:

$$A = \left(\frac{400 \times 400}{2}\right) + \left(\frac{400 \times 400}{2}\right) + \left(\frac{400 \times 400}{2}\right) + \left(\frac{400 \times 400}{2}\right) \\ + \left(\frac{400 \times 400}{2}\right) + \left(\frac{400 \times 400}{2}\right) + \left(\frac{150 \times 200}{2}\right) + \left(\frac{150 \times 200}{2}\right) \\ + \left(\frac{400 \times 500}{2}\right) = 610000 \text{ ft}^2 = 14.00 \text{ ac}$$

O 21:

$$A = \left(\frac{400 \times 300}{2}\right) + \left(\frac{500 \times 200}{2}\right) + \left(\frac{200 \times 200}{2}\right) + \left(\frac{150 \times 200}{2}\right) + \\ \left(\frac{100 \times 150}{2}\right) + \left(\frac{100 \times 150}{2}\right) = 160000 \text{ ft}^2 = 3.67 \text{ ac}$$

O 22:

$$A = \left(\frac{500 \times 400}{2}\right) + \left(\frac{600 \times 400}{2}\right) + \left(\frac{600 \times 400}{2}\right) + \left(\frac{400 \times 500}{2}\right) \\ + \left(\frac{100 \times 400}{2}\right) = 460000 \text{ ft}^2 = 10.56 \text{ ac}$$

O 23:

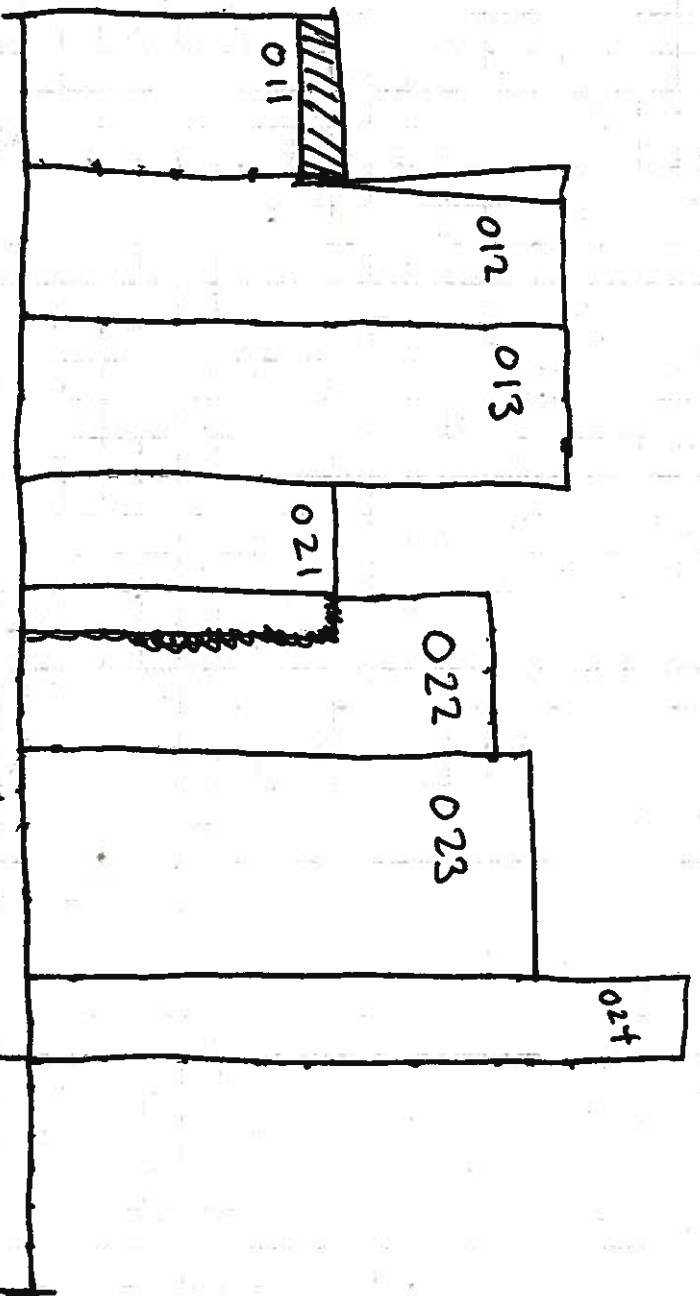
$$A = \left(\frac{200 \times 200}{2}\right) + \left(\frac{200 \times 200}{2}\right) + \left(\frac{400 \times 200}{2}\right) + \left(\frac{400 \times 200}{2}\right) \\ + \left(\frac{400 \times 400}{2}\right) + \left(\frac{400 \times 600}{2}\right) + \left(\frac{400 \times 600}{2}\right) + \left(\frac{400 \times 600}{2}\right) \\ + \left(\frac{500 \times 200}{2}\right) + 2\left(\frac{300 \times 150}{2}\right) + 2\left(\frac{150 \times 200}{2}\right) = 685000 \text{ ft}^2 \\ = 15.73 \text{ ac}$$

024:

$$\begin{aligned}
 A &= \left(\frac{200 \times 400}{2} \right) + \left(\frac{150 \times 400}{2} \right) + \left(\frac{150 \times \overset{150}{\cancel{200}}}{2} \right) + \left(\frac{150 \times \overset{150}{\cancel{200}}}{2} \right) \\
 &+ \left(\frac{150 \times 200}{2} \right) + \left(\frac{150 \times 200}{2} \right) + \left(\frac{200 \times 200}{2} \right) + \left(\frac{200 \times 200}{2} \right) \\
 &+ \left(\frac{200 \times 400}{2} \right) + \left(\frac{400 \times 200}{2} \right) + \left(\frac{300 \times 150}{2} \right) + \left(\frac{150 \times 200}{2} \right) \\
 &+ \left(\frac{150 \times 200}{2} \right) = 295,600 \text{ ft}^2 = 6.77 \text{ ac}
 \end{aligned}$$

061:

$$\begin{aligned}
 A &= \left(\frac{600 \times 600}{2} \right) + \left(\frac{600 \times 600}{2} \right) + \left(\frac{400 \times 400}{2} \right) + \left(\frac{200 \times 400}{2} \right) \\
 &+ \left(\frac{400 \times 200}{2} \right) = 520,000 \text{ ft}^2 = 11.94 \text{ ac}
 \end{aligned}$$



using triangle method

each box $\approx 100\text{ft}$

Values

Station	Area (ac)	Length (ft)
011	3.33	400
012	10.01	400
013	14.00	400
021	3.67	300
022	10.56	400
023	18.73	600
024	6.77	200
061	11.94	600

$$t_c = 18 \text{ minutes}$$

$$Q = C I A$$

$$= \left(\frac{\sum a \cdot C}{\sum C} \right) ($$

all

travel paths

* longest path

$$011 \rightarrow 012 \rightarrow 013 \rightarrow 021 \rightarrow 022 \rightarrow 023 \rightarrow 024 \rightarrow 061$$

$$6.05 + 6.05 + 3.51 + 4.43 + 4.63 + 6.33 + 1.46 + 7.19 = 39.85 \text{ min}$$

$$\text{024} \rightarrow \text{061}$$

$$1.46 + 7.19 = 8.65 \text{ min}$$

att there are no other paths that could be longer

$$Q = \left(\frac{\sum a C}{\sum a} \right) (\sum A) (3.38) = 100.84 \text{ cfs}$$

$$I = \frac{51.78}{(39.85) + 8.19} \bigg)^{0.7058}$$

$$= 3.38 \text{ in/hr}$$

$$Q = 100.84 \text{ cfs}$$

Q From
061

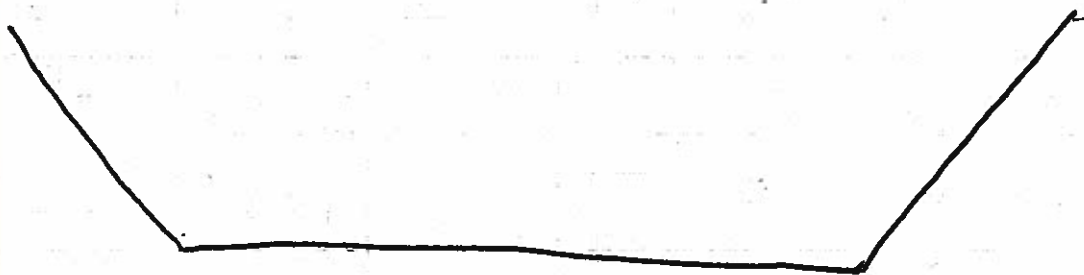
$$Q = 12.05956$$

$$C = 0.3$$

$$S = 0.01$$

~~1000000~~

$$V = 4 \text{ ft/s}$$



$$A = by + \frac{1}{2} y^2 (m_1 + m_2)$$

$$Q = \frac{1.486}{n} A R^{2/3} \sqrt{S}$$

$$n = 0.12 \text{ for concrete}$$

$$12.06 = \frac{1.48}{0.12} (A R^{2/3}) (\sqrt{0.01})$$

$$120.6 = \frac{1.48}{0.12} (A R^{2/3})$$

$$\frac{14.472}{1.48} = A R^{2/3} = 9.78$$

$$V = \frac{1.486}{0.12} (R^{2/3}) (\sqrt{0.01}) = 4$$

$$40 = \frac{1.486}{0.12} R^{2/3}$$

$$R^{2/3} = 3.23$$

$$A(3.23) = (9.78)$$

$$A = 3.03 \text{ Ft}^2$$

$$\therefore 3.03 R^{2/3} = 9.78$$

$$R = (3.23)^{3/2}$$

$$R = 5.805 \text{ Ft}$$

$$A = 3.03 \quad P = 0.52$$

$$R = 5.85$$

~~$$A = \frac{1}{2} h (b_1 + b_2)$$~~

$$A = \frac{1}{2} h (b_1 + b_2)$$

$$5.85 = \frac{3.03}{P} \quad P = \frac{3.03}{5.85} = 0.52 \text{ ft}$$

~~Let's~~ ~~assum~~ using dimension of h eff cross section

$$b = 2 + \frac{\sqrt{3}}{3} y$$

$$P = 2\sqrt{3} y$$

$$A = \sqrt{3} y^2 \Rightarrow \sqrt{\frac{3.03}{\sqrt{3}}} = y = 1.32 \text{ Ft}$$

$$b = 2 + \frac{\sqrt{3}}{3} (1.32) = 1.523 \text{ Ft} \quad z = \sqrt{3}/3$$

$$A = \frac{1}{2} h (b_1 + b_2) \Rightarrow 3.03 = \frac{1}{2} (1.32) (1.53 + b_2)$$

$$\frac{3.03 \times 2}{1.32} = 1.53 + b_2 \Rightarrow b_2 = 3.053 \text{ Ft}$$

Channel Design

$$A = 3.03 \text{ ft}^2$$

$$D = 0.52 \text{ ft}$$

$$R = 5.85 \text{ ft}$$

$$Q = 12.06 \text{ cfs} \quad V = 4 \text{ ft/s}$$

$$C = 0.3$$

$$S = 0.01$$

$$B = 3.05 \text{ ft}$$

