Appendices

I: Module 2 Knowledge Check Answers

1. Which stage of erosion accounts for the highest erosion percentage?

   b. Raindrops

2. In which month would precipitation intensity have the greatest impact on soil?

   b. July

3. Vegetative controls are ________ costly than structural controls.

   b. Less

II: Module 3 Knowledge Check Answers

1. LDAs subject to VESMA must have what approved before a VESCP authority can authorize the start of land disturbance?

   d. Stormwater management plan

2. Localities may adopt ordinances that are more stringent if they are necessary to address TMDL requirements.

   a. True

3. How long does the VESCP authority have to review an ESC plan?

   d. 60 days from submission for adequate plans

III: Module 7 Outlet Protection Problem Solutions

Use Virginia Stormwater Management Handbook (VSWHB) Chapter 7.4 specification C-ECM-15.

Round final answers to one decimal place, when practical.

1. Tailwater condition and apron details.
   Step 1: This is a minimum tailwater condition since water depth is less than half the pipe diameter.

   Step 2: ***Figure C-ECM-15-3*** *in the VSWHB is used for* ***minimum*** *tailwater conditions.*

   Step 3: Find Q = 13 cfs on bottom horizontal axis.

   Step 4: Move to pipe diameter curve on the ***lower*** *half of the chart (d = 15 inches).*

   Step 5: Find median stone size (d_{50} riprap size) = 0.5 feet = 6 inches on the right-side vertical axis.

   Step 6: Move to the pipe diameter curve on the ***top*** *half of the chart (d=15 inches).*

   Step 7: Find L_a = 14 feet on the left side vertical axis.

   Step 8: Upstream apron width:

   $W_u = 3 \times \text{Pipe Diameter } (D_O) = 3 \times 1.25 \text{ feet} = 3.75 \text{ feet}$

   (d = 15 inches = 1.25 feet)

   Step 9: Downstream Apron Width:

   $W_d = \text{Pipe Diameter } (D_O) + \text{Apron Length } (L_a) = 1.25 + 14 = 15.25 \text{ feet}$

2. Apron details for maximum tailwater condition.
   Step 1: This is a maximum tailwater condition since water depth is more than half the pipe diameter. Use Figure C-ECM-15-4 in the VSWHB for maximum tailwater conditions.

   Find Q = 20 cfs on the bottom horizontal axis.

   Step 2: Move to the pipe diameter curve on the lower half of chart (d = 18 inches).

   Step 3: Find median stone size (d_{50} riprap size) on the right-side vertical axis = 0.5 feet = 6 inches because the answer read from the chart is less than the minimum recommended.

   Step 4: Move to the pipe diameter curve on the top half of the chart (d = 18 inches).

   Step 5: Find L_a = 34 feet on the left side vertical axis.

   Step 6: Upstream Apron Width = Wu = 3 × Pipe Diameter (D_0) = 3 × 1.5 feet = 4.5 feet (d = 18 inches =1.5 feet)

   Step 7: Downstream Apron Width = W_d = Pipe Diameter (D_0) + 0.4 × Apron Length (L_a) = 1.5 + 0.4 × 34 feet = 15.1 feet

IV: Module 8 Problem Solutions

8A SEDIMENT TRAP

Use the Virginia Stormwater Management Handbook (VSWHB), Chapter 7.4, C-SCM-11.

Round final answers to one decimal place, when practical.

1a. Total storage = 2.46 acres on site + 0.40 acres off site = 2.86 total acres to sediment trap (round to 2.9 acres)

> *2.86 acres (ac) × 134 cubic yards per acre (cy/ac) = 383.24 cubic yards (cy) (round to 383.2 cy)*

1b. Permanent pool (wet storage)

> *= 2.86 ac × 67 cy/ac = 191.62 cy (round to 191.6 cy)*

1c. Temporary pool (dry storage)

> *= 2.86 ac × 67 cy/ac = 191.62 cy (round to 191.6 cy)*

1d. Embankment height

> Use the sediment trap cross-section provided in Figure 8-1.
>
> *The existing grade at the top of the permanent pool (wet storage) is 279.0 feet and the grade at the top of the temporary pool (dry storage) is 282.0 feet. The difference (the depth for dry storage) is 3.0 feet. The embankment has to be at least 1 foot higher than the crest of the spillway, so we add 1 foot to the 3.0-foot depth provided for the temporary pool to get an embankment height of 4.0 feet.*

1e. Minimum top width of embankment

> Use the result from Question 1d (embankment height of 4.0 feet).
>
> *Use Table C-SCM-11-2, Chapter 7.4 of the VSWHB to find a width of 3.0 feet.*

1f. Stone outlet length

> *= 6 × 2.86 acres of drainage area = 17.16 feet (This is the minimum outlet length per C-SCM-11, so round up to 18 feet for practicality)*

8B SEDIMENT BASIN

Use the VSWHB, Chapter 7.4, C-SCM-12.

Round final answers to one decimal place, when practical.

1a. Total volume

= 12 acres (ac) disturbed + 3 ac undisturbed = 15 total acres to sediment basin

= 15 total ac × 134 cubic yards per acre (cy/ac) = 2,010 cy

1b. Permanent pool (wet storage) volume

= 15 ac × 67 cy/ac = 1,005 cy

1c. Temporary pool (dry storage) volume

= 15 ac × 67 cy/ac = 1,005 cy

1d. Cleanout volume

Remove sediment from the basin when the sediment level is no higher than 1 foot below the bottom of the dewatering orifice, or half of the permanent pool (wet storage) volume, whichever is lower:

Half wet storage volume = $\frac{1{,}005\ cy}{2} = 502.5\ cy$

(The designer would need to indicate the depth of this volume. That depth cannot be less than 1 foot to the bottom of the dewatering orifice.)

See Figure C-SCM-12-2 from VSWHB, Chapter 7.4: Sediment cleanout volume ≥ 1 foot below dewatering device.

2. Diameter of dewatering orifice for sediment basin receiving drainage area in Question 1.

Step 1: 15 acres (ac) × 67 cubic yards per acre (cy/ac) = 1,005 cubic yards (cy)

Step 2: 1,005 cy × $\frac{27\ cf}{1\ cy}$ *= 27,135 cubic feet (cf)*

Step 3: Required drawdown time in hours = 24 hours minimum

$$= 24\, hrs \times \frac{60\, minutes}{hour} \times \frac{60\, seconds}{minute} = 86{,}400\, seconds$$

$$Step\ 4{:}\ Q = \frac{S}{86{,}400\, seconds} = \frac{27{,}135\, cf}{86{,}400\, seconds} = 0.31\, cubic\ feet\ per\ second\ (cfs)$$

$$Step\ 5{:}\ A = \frac{Q}{(64.32 \times h_d)^{1/2}\,(0.6)} = \frac{3.4\, cfs}{(64.32\ x\ 2\ ft)^{1/2}\,(0.6)} = 0.046\, square\ feet$$

$$Step\ 6{:}\ d = 2 \times \left(\frac{A}{3.14}\right)^{1/2} = 2 \times \left(\frac{0.77}{3.14}\right)^{1/2} = 0.24\, feet = 2.9\, inches$$

(round to 3 inches)

Also see the note in the VSWHB, C-CSM-12, Appendix A Section XIII (Dewatering): Do not use a diameter of dewatering orifice less than 3 inches to help prevent clogging by soil or debris.

3a. Riser diameter to pass flow safely

Step 1: Choose the two-year storm (31 cfs) since Figure 8-3 shows an emergency spillway. The principal and emergency spillways must pass the peak runoff expected from the contributing drainage area for a 25-year storm. See Table C-SCM-12-1 Design Criteria Parameters (Spillway Design). Without an emergency spillway, the principal spillway must pass the entire 25-yr storm.

Step 2: Arrive at a diameter of 42 inches where $h_r = 1.0$ *feet on the x-axis and Q = 31 cfs on the y-axis meet (See VSWHB, Chapter 7.4, Figure C-SCM-12-8 Riser Inflow Curves, Section 9.0 Appendix A Design Procedure for Temporary Sediment Basins).*

3b. Riser diameter when discharge to conveyance system that is not adequate and no system improvements can be made

This sediment basin cannot discharge the 31 cfs flow rate since the receiving conveyance system is not adequate for this flow. For a temporary sediment basin that discharges to a stormwater conveyance system that is not adequate, without system improvements, water quantity compliance requirements (9VAC25-875-560) and GM 22-2012 dictate that the basin must be designed so that the two-year storm peak discharge flow rate (during construction) is less than or equal to the two-year predevelopment peak discharge flow rate. ***Therefore, using the peak flow rate of 5.47 cfs and*** h_r ***of 1 foot, per Figure C-SCM-12-8, the riser diameter should be 12" (diameter is between 12" and 15" on***

chart, but since the flow cannot be greater than 5.47 cfs, select the smaller diameter of 12").

4. Trash rack dimensions (Use Table C-SCM-12-7, Anti Vortex Device Design, VSWHB Chapter 7.4, Section 9.0 Appendix A).

Step 1: Use a riser diameter of 12 inches. Find in furthest left column on table.

Step 2: Move one column to the right to find the trash rack diameter size of 18 inches.

Step 3: Move two more columns to the right to find the trash rack height of 6 inches.

5a. Determine if baffles are required.

Step 1: 11 yards × 6 yards = surface area of 66 square yards

$W_e = \frac{A}{L} = \frac{66\ square\ yards}{4.5\ yards} = 14.67\ yards$

Step 2: $\frac{L}{W_e} = \frac{4.5\ yards}{14.67\ yards} = 0.307\ yards$

Since this ratio is less than 2, the sediment basin will require baffles.

5b. Determine if baffles shown are sufficient.

Step 1: New flow path (L) = 7 + 6.5 = 13.5 yards

Effective width = $W_e = \frac{A}{L} = \frac{66\ square\ yards}{13.5\ yards} = 4.89$

Step 2: Length-to-width ratio = $\frac{L}{W_e} = \frac{13.5\ yards}{4.88} = 2.77$ *which is >2*

The baffles provided are sufficient.

6. Embankment minimum width if height of embankment is 12 feet (See Embankment Cross-Section in Table C-SCM-12-1):

Embankment Cross-Section

For embankments of less than 10 feet:

- *Minimum top width of 6 feet*
- *Maximum side slopes of 2H:1V or flatter for embankments 10 to 14 feet in height*
- *Minimum top width of **8 feet***
- *Maximum side slopes of 2.5H:1V or flatter*

For 15-foot embankments (maximum allowed under these specifications):

- *Minimum top width of 10 feet*
- *Maximum of 2.5H:1V side slopes*

7. Basin sizing:

Step 1: Calculate total storage needed.

15 acres × 134 cubic yards per acre = 2,010 cubic yards = 54,270 cubic feet

Step 2: Determine wet storage volume (V_1) provided. Plan shows L = 138 feet, W = 84 feet, depth (D_1) = 6 feet

Surface area (A_1) = Length × Width = 138 feet × 84 feet = 11,592 square feet

$V_1 = 0.4 \times A_1 \times D_1 = 0.4 \times 11{,}592$ square feet × 6 feet = 27,820.8 cubic feet

Step 3: Determine dry storage volume (V_2) provided. Plan shows L = 164 feet, W = 100 feet

Surface area (A_2) = Length × Width = 164 feet × 100 feet = 16,400 square feet

D_2 = 8 feet – 6 feet = 2 feet

$V_2 = \frac{A1 + A2}{2} \times D_2 = \frac{11{,}592 + 16{,}400}{2} \times 2$ *feet = 27,992 cubic feet*

Step 4: Add the wet and dry storage volumes (in cubic feet).

Total Storage Volume provided = $V_1 + V_2$ *= (27,820.8 + 27,992) cubic feet = 55,812.8 cubic feet*

Step 5: Convert to cubic yards.

Volume (cubic yards) = 55,812.8 cubic feet × $\frac{1\ cubic\ yard}{27 cubic\ feet}$ *= 2,067.14 cubic yards provided*

Basin volume appears to be in compliance since the volume provided is larger than the volume required.

8. Barrel diameter

Step 1: Use the correct table based on the information in the question: (Use Table C-SCM-12-5, Chapter 7.4 of the VSWHB).

Step 2: Based on the information in the question, H = 10 feet.

Step 3: From the table, choose the value just above the peak flow given in the question. When using the 10-foot row, the next highest Q is 25.3 (can accommodate 25 cubic feet per second or cfs).

Step 4: Read up to find the diameter of pipe that accommodates 25.3 cfs: ***21 inches.***

Step 5: The barrel length provided in the question is not 70 feet, so proceed.

Step 6: Based on the information in the question, barrel length = 80 feet. Using the bottom part of the chart, find 80 feet, read over to the 21 inches column, and find the conversion factor is 0.96.

Step 7: Pipe capacity for this length (Q_1) *= CF ×* Q_{70} *= 0.96 × 25.3 cfs =* ***24.288 cfs This pipe capacity is less than the required peak flow rate.***

Step 8: Choose next larger barrel size = 24 inches and confirm capacity.

Q_1 *= 0.96 × 34.9 cfs =* ***33.504 cfs***

This pipe capacity is greater than the required peak flow rate*, so barrel size must be at least* ***24 inches****.*

V: Module 9 Problem Solutions

TIME OF CONCENTRATION

1. **What is the Travel Time, T (minutes), for a Length, L (feet) = 100 feet, over an average grass surface, with a 4% slope?**

   From VSWHB Appendix A, Section A.3.2.3 Travel Time (Velocity) Method (Seelye Chart)

   Select on left vertical axis the Length = (**100**) feet

   From that point, draw a line through Average Grass Surface to pivot line.

   Draw a line from pivot line through the Slope = (**4%**)

   Read on right vertical axis, Time of Concentration, T= (**11.5**) minutes

2. **For shallow concentrated flow over pavement for 500 feet (L) and 2% slope, what is the Time of Concentration, T (minutes)?**

   From Average Velocities for Estimating Travel Time for Shallow Concentrated Flow, NEH 2010

   Convert slope in % to slope in feet/foot:

$$S = \frac{s}{100}$$

s = slope (%)

S – Slope (feet/foot)

   Slope, S = (**2**) % / 100 = (**0.02**) feet/foot

   On the left vertical axis, select the Slope, S = (**0.02**) feet/foot

   Read over horizontally to line marked “Paved”, and read down to determine:

   Average Velocity, V = (**2.8**) feet/second

$$T = \frac{L}{60 \times V}$$

   T (Time of Concentration, minutes) = L (Length, feet)/ [60 x V (Velocity (feet/second)]

   T (Time of Concentration, minutes) = L (**500**)/ [60 x (**2.8**) (feet/second)]

   T (Time of Concentration) = **2.97** minutes or approximately **3** minutes

3. **Given a channel with a hydraulic radius of 2.0, a slope equaling 0.5%, and a Manning's Roughness Coefficient, n= 0.02, what is the Time of Concentration of flow through a channel over a length of 1,000 feet?**

   From Nomograph Solution of Manning Equation, VDOT

   On left vertical axis, select Hydraulic Radius = (**2.0**)

   Draw line through Slope = (**0.005**) feet/foot to pivot line

   From pivot line, draw through Manning's Roughness Coefficient, n = (**0.02**)

   Read from right vertical axis the Velocity, V = (**8.35**) feet/second

$$T = \frac{L}{60 \times V}$$

   T (Time of Concentration, minutes) = L (Length, feet)/ [60 x V (Velocity (feet/second)]

   T (Time of Concentration, minutes) = L (**1,000**)/ [60 x (8.35) (feet/second)]

   T (Time of Concentration) = **1.996** minutes or approximately **2** minutes

4. **What is the total Time of Concentration?**

   Time of Concentration,

   T = Overland Flow Time + Shallow Concentrated Flow Time + Channel Flow Time

   T = (**11.5**) minutes + (**3**) minutes + (**2**) minutes = (**16.5**) minutes

RATIONAL FORMULA

$$Q = C \times i \times A$$

Where:
Q (cubic feet/second), Peak Rate of Runoff, is calculated from above equation.

C, Runoff Coefficient, is found from (VDOT, Appendix 6E-2)

T (minutes), Time of Concentration, is calculated for:

overland flow (Seelye Chart)
shallow concentrated (NEH Average Velocity Graph)
channel flow (Kirpich Method, VDOT Appendix 6E-5)

i, (inches/hour), Average Rainfall Intensity for design storm frequency of interest (1-year, 2-year, 10-year), from NOAA-Atlas 14

A (acres), Drainage Area, determined from USGS maps or topographic survey

1 acre = 43,560 square feet

5. **For a Lynchburg commercial development of 25 acres, with 250,000 square feet of roof top, with 10 acres of asphalt paving for streets and parking, 4 acres of forest with a 4% slope, and with the remainder in lawn on heavy soils with slopes greater than 7%, what is the weighted average runoff coefficient based upon the highest values of individual runoff coefficients?**

   A (Area of roof top, acre) = square feet of roof top / 43,560 (square feet)

   A (acres) = (**250,000**) square feet / 43,560 square feet = (**5.74**) acres

   From VDOT, Chapter 6, Appendix 6E-2:

Land use:	**Runoff Coefficient**	**x**	**Area(acres)**	**=**	**C x A**
Roof	(**0.90**)	x	(**5.74**)	=	(**5.17**)
Asphalt Paving	(**0.90**)	x	(**10**)	=	(**9.0**)
Forest	(**0.25**)	x	(**4.0**)	=	(**1.0**)
Lawn	(**0.35**)	x	(**5.26**)	=	(**1.84**)
				Total C x A =	**(17.01)**

   C, Weighted Average Runoff Coefficient = Total C x A / Total A (acres) = (**0.68**)

6. **Given a total time of concentration of 20 minutes for the same development, what is the peak rate of runoff from a 10-year storm?**

   From IDF Chart for the City of Lynchburg (Module 9):

   Locate Time of Concentration, T (minutes) = (**20**) minutes on horizontal axis.

Locate curve for given storm frequency = (**10**) year.

From horizontal axis, read up to curve for given storm frequency, and read to left to vertical axis for rainfall intensity:

Rainfall intensity, i (in/hr) = (**3.8**) in/hr.

Weighted average runoff coefficient, calculated from previous problem, C = (**0.68**).

$$Q = C \times i \times A$$

Q (Peak rate of runoff, cfs) = (**0.68**) x (**3.8**) x (**25**) = (**64.6**) cfs

VI: Module 10 Problem Solutions

1. **If the soil is nearly impervious clay with a high-water table and has a high runoff potential, what is the Hydrologic Soil Group?**

   From TR-55, reproduced in Figure 10-2 in Module 10:

   Hydrologic Soil Group = (**D**)

2. **Given a residential district with 1/2 acre lots, what is the Runoff Curve Number for Hydrologic Soil Group C?**

   From Table 2-2a, from TR-55, reproduced in Figure 10-3 in Module 10:

   Runoff Curve Number, CN = (**80**)

3. **Given a site with soils consisting of deep well-drained sands with 3 acres of impervious area, 2 acres of grass in fair condition, and 4 acres of woods in fair condition, what is the weighted Curve Number?**

   From TR-55, reproduced in Figure 10-2 in Module 10: Hydrologic Soil Group = (**A**)

   From Tables 2-2a and 2-2c, TR-55, reproduced in Figures 10-3 and 10-4 in Module 10:

Land use:	CN	x	Area	=	CN x A	
Impervious	(**98**)	x	(**3**)	=	(**294**)	CN, Weighted Average Runoff Curve Number = Total CN x A / Total A (acres)
Grass	(**49**)	x	(**2**)	=	(**98**)	= 536/9
Woods	(**36**)	x	(**4**)	=	(**144**)	= **60**
				Total CN x A =	**(536)**	

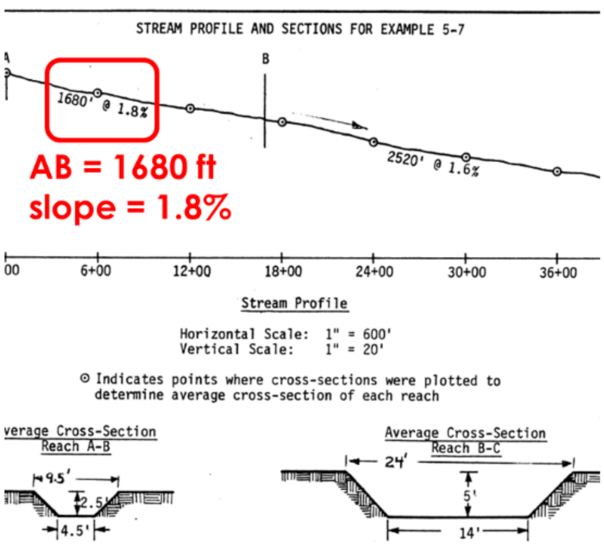
4. **If 3% of the watershed consists of ponds and swamps, what is the Pond and Swamp Adjustment Factor, Fp?**

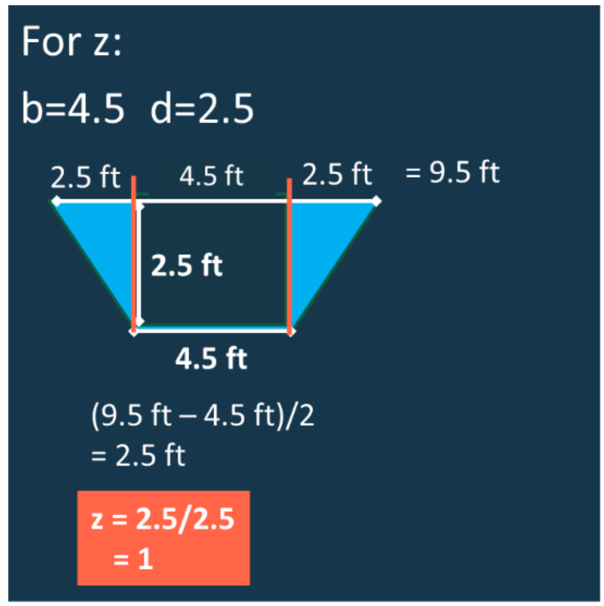
   Percentage of pond and swamp areas = (**3%**). From Table 4-2, TR-55, reproduced in Figure 10-19 in Module 10 F_p = (**0.75**).

VII: Module 12 Problem Solutions

CHANNEL ADEQUACY EXERCISE (P. 20-21)

(1) **Assume bankfull flow, earth bottom and rubble sides, and a Manning's Roughness coefficient (n) of 0.03. What is the velocity for reach AB and the velocity for reach BC?**





Use formula from Table 12-2, p. 10,

And b=4.5 d=2.5 z=1

$$R = \frac{(bd + zd^2)}{(b + 2d\sqrt{z^2 + 1})}$$

$$R = \frac{(4.5 \times 2.5 + 1 \times 2.5^2)}{(4.5 + 2 \times 2.5\sqrt{1^2 + 1})}$$

$$R = \frac{17.5}{11.57} = 1.5$$

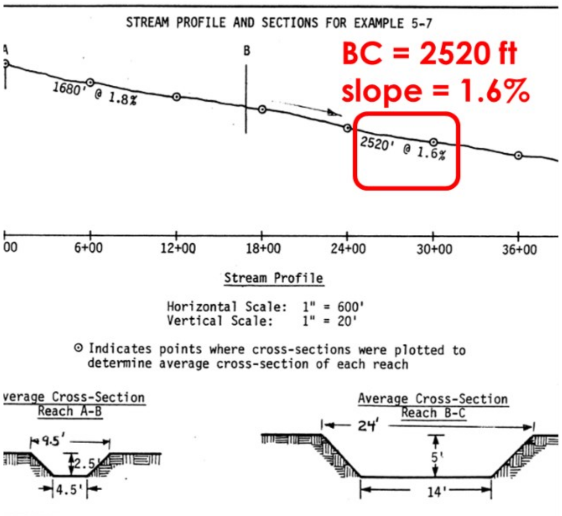
Use Manning's Equation, p. 6,

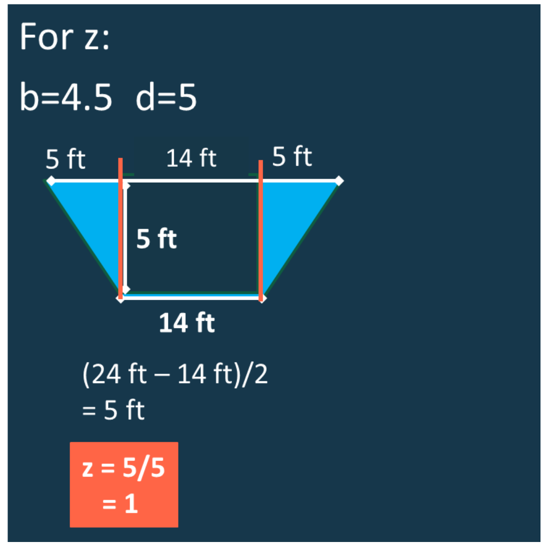
n=0.03 R=1.5 s=0.018 ft/ft

$$V = \frac{1.49}{n} \times R^{2/3} \times \sqrt{s}$$

$$V = \frac{1.49}{0.03} \times 1.5^{2/3} \times \sqrt{0.018}$$

$$V = 8.7\ ft/sec$$





Use formula from Table 12-2, p. 10,

And b=14 ft d=5 ft z=1

$$R = \frac{(bd + zd^2)}{(b + 2d\sqrt{z^2 + 1})}$$

$$R = \frac{(14 \times 5 + 1 \times 5^2)}{(14 + 2 \times 5\sqrt{1^2 + 1})}$$

$$R = \frac{95}{28} = 3.4$$

Use Manning's Equation, p. 6,

n=0.03 R=3.4 s=0.016 ft/ft

$$V = \frac{1.49}{n} \times R^{2/3} \times \sqrt{s}$$

$$V = \frac{1.49}{0.03} \times 3.4^{2/3} \times \sqrt{0.016}$$

$$V = 14.2\ ft/sec$$

(2) **If the channel lining is equivalent to coarse gravel, what is the permissible velocity?**

Permissible velocity is 6.0 ft/sec (Table 12-8, p. 18; VSWHB, Chapter 7, Section 7.4, C-ECM-15 Outlet Protection, Table C-ECM-15-3)

(3) **Would the channel erode under bankfull conditions?**

Reach velocities are:

AB velocity = 8.7 ft/sec BC velocity = 14.2 ft/sec

The channel would erode under bankfull conditions in both reaches since velocities within each is greater than the permissible velocity of 6.0 ft/sec.

(4) **Would the channel erode during the 2-year design storm flow? Assume the 2-year depths are 1.75 feet for reach AB and 3.5 feet for reach BC.**

Reach AB

Use formula from Table 12-2, p. 10,

And b = 4.5 ft d = 1.75 ft z = 1

Adjusted Hydraulic Radius:

$$R = \frac{(bd + zd^2)}{(b + 2d\sqrt{z^2 + 1})}$$

$$R = \frac{(4.5 \times 1.75 + 1 \times 1.75^2)}{(4.5 + 2 \times 1.75\sqrt{1^2 + 1})}$$

$$R = \frac{10.94}{9.45} = 1.16$$

Use Manning's Equation, p. 6,

n = 0.03 R = 1.16 s = 0.018 ft/ft

Adjusted velocity:

$$V = \frac{1.49}{n} \times R^{2/3} \times \sqrt{s}$$

$$V = \frac{1.49}{0.03} \times 1.16^{2/3} \times \sqrt{0.018}$$

$$V = 7.36\ ft/sec$$

> 6.0 ft/sec

<u>Reach BC</u>

Use formula from Table 12-2, p. 10,

And b = 14 ft d = 3.5 ft z = 1

Adjusted Hydraulic Radius:

$$R = \frac{(bd + zd^2)}{(b + 2d\sqrt{z^2 + 1})}$$

$$R = \frac{(14 \times 3.5 + 1 \times 3.5^2)}{(14 + 2 \times 3.5\sqrt{1^2 + 1})}$$

$$R = \frac{61.25}{23.9} = 2.56$$

Use Manning's Equation, p. 6,

n = 0.03 R = 2.56 s = 0.016 ft/ft

Adjusted velocity:

$$V = \frac{1.49}{n} \times R^{2/3} \times \sqrt{s}$$

$$V = \frac{1.49}{0.03} \times 2.56^{2/3} \times \sqrt{0.016}$$

$$V = 11.8\ ft/sec$$

> 6.0 ft/sec

(5) **What flow rate can the channel accommodate? Evaluate both reach AB and reach BC.**

Given:

<u>AB reach</u>

Pre-dev. Q_{10} *= 95 cfs*

Post-dev. Q_{10} *= 170 cfs*

<u>BC reach</u>

Pre-dev. Q_{10} *= 500 cfs*

Post-dev. Q_{10} *= 585 cfs*

Remember under bankfull conditions:

AB velocity = 8.7 ft/sec

$$A = (bd + zd^2)$$

$$A_{AB} = 17.5$$

Q_{AB} = 8.7 ft/sec x 17.5 sf

Q_{AB} = 152 cfs

BC velocity = 14.2 ft/sec

$$A = (bd + zd^2)$$

$$A_{BC} = 95$$

Q_{BC} = 14.2 ft/sec x 95 sf

Q_{BC} = 1,349 cfs

Post-development discharge will exceed channel capacity within reach AB and cause flooding during the 10-year storm

CHANNEL GEOMETRY

1. **What is the cross-sectional area (a) of a rectangular channel with a bottom (b) width of 4 feet and a depth (d) of 2 feet?**

$$a = b \times d$$

a (Rectangular Channel Area, square feet) = b (Bottom Width, feet) x d (Depth, feet)

a = (**4**) feet x (**2**) feet = (**8**) square feet

2. **For this same channel, what is the Wetted Perimeter, p (feet)?**

$$p = b + 2d$$

p (Wetted Perimeter, feet) = b (Bottom width, feet) + 2 x d (Depth, feet)

p = (**4**) feet + 2 x (**2**) feet = (**8**) feet

3. **For this same channel, what is the Hydraulic Radius, r (feet)?**

$$r = \frac{a}{p}$$

r (Hydraulic Radius, feet) = a (Area, square feet) / p (Wetted Perimeter, feet)

r = (**8**) square feet / (**8**) feet = (**1**) feet

4. **For a 3 feet deep triangular channel with side slopes of 3 feet horizontal to 1 foot vertical (3:1), what is the cross-sectional area?**

For Triangular Channel Area:

$$a = z \times d^2$$

Where:

d = channel depth (feet)

z = channel side slopes of Horizontal Distance [z =____________to vertical distance = 1]

a = (**3**) feet x [(**3**) feet] ^{2} = (**27**) square feet

5. **For this same channel, what is the Wetted Perimeter, p (feet)?**

$$p = 2 \times d\sqrt{(z^2 + 1)}$$

o r

$$p = 2 \times d\ (z^2\ + 1)^{\frac{1}{2}}$$

Where:
p= Wetted Perimeter (feet)

d = channel depth (feet)

z =channel side slopes of Horizontal Distance [z = (   ) to vertical distance=1]

p = 2 x (**3**) x [(**3**) ^{2} + 1] $^{1/2}$ = (**19**) feet

6. **For this same channel, what is the Hydraulic Radius?**

$$r = \frac{a}{p}$$

r (Hydraulic Radius, feet) = a (Area, square feet) / p (Wetted Perimeter, feet)

r = (**27**) square feet / (**19**) feet = (**1.4**) feet

7. **For a trapezoidal channel 3 feet deep, bottom width of 6 feet and 4:1 side slopes, what is the cross-sectional area (a)?**

For trapezoidal area:

$$a\ =\ (b\ \times\ d)\ +\ (z\ \times d^2)$$

Where:
b= bottom width (feet)

d = channel depth (feet)

z = channel side slopes of Horizontal Distance [z =____________to vertical distance = 1]

a = [(**6**) feet x (**3**) feet] + [(**4**) x { (**3**) feet } ^{2}]= (**54**) square feet

8. **For this same channel, what is the Wetted Perimeter, p (feet)?**

$$p = b + 2d\sqrt{(z^2 + 1)}$$

or

$$p = b + 2d\,(z^2 + 1)^{\frac{1}{2}}$$

p = (**6**) feet + 2 x (**3**) feet x [(**4**) ^{2} + 1] $^{1/2}$ = (**30.7**) feet

9. **For this same channel, what is the Hydraulic Radius, r (feet)?**

$$r = \frac{a}{p}$$

r (Hydraulic Radius, feet) = a (Area, square feet) / p (Wetted Perimeter, feet)

r = (**54**) square feet / (**30.7**) feet = (**1.76**) feet

MANNING'S EQUATION AND ROUGHNESS COEFFICIENTS

10. **What is the range of Manning's Roughness Coefficient for concrete pipe (Table 12-6)?**

n = (**0.011**) to (**0.013**)

11. **What is the range of Manning's Roughness Coefficient for a winding natural stream channel with some pools and shoals, and some weeds and stones (Table 12-5 in Module 12)?**

n = (**0.035**) to **(0.050**)

12. **Given a concrete lined triangular channel, with Manning's Roughness Coefficient, n = 0.015; Slope, S = 0.02 feet/foot slope; and Hydraulic Radius, R = 1.4, what is the velocity of flow in this channel?**

<u>Manning's Equation</u>

$$V = \frac{1.49}{n} \times R^{\frac{2}{3}} \times S^{\frac{1}{2}}$$

or

$$V = \frac{1.49}{n} \times \sqrt[3]{R^2} \times \sqrt{S}$$

Where:
V = Velocity (feet per second or fps)

n = Manning's Roughness Coefficient

R = Hydraulic Radius (feet)

S = Slope of the Channel (feet/foot)

V = [1.49 / (**0.015**)] x (**1.4**) $^{2/3}$ x (**0.02**) $^{1/2}$ = (**17.6**) fps

13. **For a Bermuda grass-lined channel (erosion resistant soils), with Manning's Roughness Coefficient, n = 0.05; Slope, S = 0.06 feet/foot slope; and Hydraulic Radius, R = 1.5, what is the velocity of flow in this channel? Does it exceed the permissible velocity for Bermuda grass (erosion resistant soils)?**

Manning's Equation

$$V = \frac{1.49}{n} \times R^{\frac{2}{3}} \times S^{\frac{1}{2}}$$

or

$$V = \frac{1.49}{n} \times \sqrt[3]{R^2} \times \sqrt{S}$$

Where:
V = Velocity (feet per second or fps)

n = Manning's Roughness Coefficient

R = Hydraulic Radius (feet)

S = Slope of the Channel (feet/foot)

V = [1.49 / (**0.05**)] x (**1.5**) $^{2/3}$ x (**0.06**) $^{1/2}$ = (**9.56**) fps

From VSWHB C-ECM-15, Table 15-2, Permissible Velocities for Grass-Lined Channels

S = s x 100

Where:
S = Channel Slope (%)

s = Channel Slope (feet/foot)

S (%) = (**0.06**) feet/foot x 100 = (**6**)%

Permitted Velocity for Bermuda Grass (erosion resistant soils) at Slope (**6**)% = (**5**) fps, **which exceeds allowed velocity (change lining from grass to riprap)**

14. **What is the flow rate of a channel with a velocity (V) of 4 feet/second and a cross-sectional area (A) of 50 square feet?**

Continuity Equation

$$Q = V \times A$$

Where:
V = Velocity (feet per second or fps)

A = Area (square feet)

Q = (**4**) feet/second x (**50**) square feet = (**200**) cubic feet/second