Appendix: Answers to Module Work Problems

Module 7 Work Problem Answers

7a. SEDIMENT TRAP CALCULATIONS ESCH III-70-76

1. **Given a total drainage area of 2.5 acres, what is the total volume (V) of sediment trap required?**

$$\mathrm{V} = \mathrm{A} \times 134$$

V (Total Volume, cubic yards) = A (Total Drainage Area, acres) x 134 (cubic yards/acres)

V = (**2.5**) acres x 134 (cubic yards/acres) = (**335**) cubic yards

2. **If the drainage area is 1.5 acres, what volume (V) is required for the permanent pool for wet storage?**

$$\mathrm{V} = \mathrm{A} \times 67$$

V (Perm. Pool Vol., cubic yards) = A (Total Drainage Area, acres) x 67 (cubic yards/acre)

V = (**1.5**) acres x 67 (cubic yards/acres) = (**100.5**) cubic yards

3. **For a total drainage are of 2.8 acres, how much volume (V) is required for the temporary pool or drawdown volume for dry storage?**

$$\mathrm{V} = \mathrm{A} \times 67$$

V (Temp. Pool Vol., cubic yards) = A (Total Drainage Area, acres) x 67 (cubic yards/acres)

V = (**2.8**) acres x 67 (cubic yards/acres) = (**187.6**) cubic yards

4. **If the sediment trap receives drainage from 0.75 acres of disturbed area onsite and receives runoff from 1.5 acres of undisturbed area offsite, at what volume (V) should sediment be removed?**

$$V = A \times \frac{67}{2} = A \times 33.5$$

V (Sediment Vol., cubic yards) = A (Total Drainage Area, acres) x 33.5 (cubic yards/acres)
V = (**2.25**) acres x 33.5 (cubic yards/acres) = (**75.4**) cubic yards

5. **What is the minimum length (L) of outlet required for a sediment trap with a drainage area of 1.9 acres?**

$$L = A \times 6$$

L (Outlet Length, feet) = A (Total Drainage Area, acres) x 6 (feet/acre)

L = (**1.9**) acres x 6 (feet/acres) = (**11.4**) feet

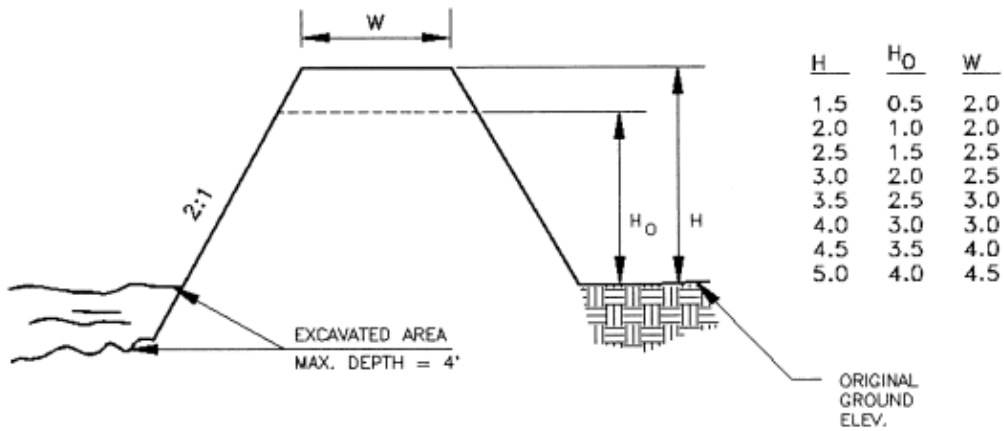
6. **If a sediment trap has a 4.5 feet high embankment, what is the minimum top width required on the embankment?**

From ESCH III-74, Plate 3.13-1

Embankment Height, H = (**4.5**) feet Top Width, W = (**4.0**) feet

1992 3.13

MINIMUM TOP WIDTH (W) REQUIRED FOR SEDIMENT TRAP EMBANKMENTS ACCORDING TO HEIGHT OF EMBANKMENT (FEET)



H	H_O	W
1.5	0.5	2.0
2.0	1.0	2.0
2.5	1.5	2.5
3.0	2.0	2.5
3.5	2.5	3.0
4.0	3.0	3.0
4.5	3.5	4.0
5.0	4.0	4.5

Source: VESCH, Chapter 3.13

Plate 3.13-1

7b. SEDIMENT BASIN CALCULATIONS ESCH III-77-115

1. **For a total drainage area of 25 acres, what volume (V) sediment basin is required?**

$$V = A \times 134$$

V (Total Volume, cubic yards) = A (Total Drainage Area, acres) x 134 (cubic yards/acre)

V = (**25**) acres x 134 (cubic yards/acre) = (**3,350**) cubic yards

2. **If the total drainage area is 18 acres, what is the volume (V) of the permanent pool or wet storage?**

$$V = A \times 67$$

V (Perm Pool Vol., cubic yards) = A (Total Drainage Area, acres) x 67 (cubic yards/acres)

V = (**18**) acres x 67(cubic yards/acres) = (**1,206**) cubic yards

3. **Given 5 acres of disturbed area onsite and 10 acres undisturbed above the site but draining to the sediment basin, what is the required volume (V) of the temporary pool or drawdown volume?**

$$V = A \times 67$$

V (Temp. Pool Vol., cubic yards/acres) = A (Total Drainage Area, acres) x 67 (cubic yards/acres)

V = (**15**) acres x 67(cubic yards/acre) = (**1005**) cubic yards

4. **Given that the sediment cleanout level shall be no more than one foot below the dewatering device, determine the maximum volume (V) of sediment that will require removal from the permanent pool of a sediment basin serving 27 acres?**

$$V = A \times \frac{67}{2} = A \times 33.5$$

V (Sediment Vol., (cubic yards) = A (Total Drainage Area, acres) x 33.5 (cubic yards/acres)

V = (**27**) acres x 33.5(cubic yards/acres) = (**904.5**) cubic yards

5. **If a plan shows a sediment basin with a flow length of 125 feet, what is the maximum effective width required such that no baffles are required?**

$\frac{L}{W_e} = x$, *x ≥ 2 ... no baffles required; x < 2 ... baffles required*

L (Flow length, feet) / W_e (Effective Width, feet) ≥ 2 (no baffles; < 2 (baffles required)

$$\frac{L}{W_e} = 2 \qquad or \quad W_e = \frac{L}{2}$$

W_e (feet) = L (feet) / 2 = (**125**) feet / 2 = (**62.5**)

6. **What is the minimum top width of a sediment basin embankment with a height of 15 feet?**

From ESCH III-80:

Embankment Height	**Minimum Top Width**
< 10 feet	6 feet
10-14 feet	8 feet
15 feet (max)	10 feet

H (Embankment Height, feet) = (**15**) feet

T (Minimum Top Width, feet) = (**10**) feet

7. **What is the size of two anti-seep collars given a 3 feet diameter barrel with a saturated length of 85 feet?**

From ESCH III-106, Plate 3.14-12:

On the lower chart, select the saturated length.

Saturated Length, Ls = (**85**) feet

Read across chart to number of collars.

Number of Collars = (**2**)

Read up to top of chart to pipe diameter.

Pipe Diameter, D = (**3**) feet

Read across chart to size of anti-seep collars.

Size of Anti-Seep Collars = (**7.3**) feet x (**7.3**) feet

BONUS

More Sediment Basin Problems and Answers

1. **What is the diameter in inches of the dewatering orifice for a sediment basin draining 15 acres?**

   A. **Determine temporary pool or dry storage volume.**

$$V = A \times 67$$

V (Temp. Pool Vol., cubic yards) = A (Drainage Area, acres) x 67 (cubic yards/acres)

V = (**15**) acres x 67(cubic yards/acres) = (**1005**) cubic yards

   B. **Convert temporary pool volume from cubic yards to cubic feet.**

cubic feet = cubic yards x 27

V (Temp. Pool Vol., cubic feet) = V (Temp. Pool Vol., cubic yards) x 27

V (cubic feet) = (**1005**) cubic yards x 27 = (**27,135**) cubic feet

   C. **What is the flow rate through the orifice for a 6 hour drawdown?**

$$Q = \frac{V}{t}$$

where

t = drawdown time in seconds (6 x 60 x 60) or $Q = \frac{V}{21{,}600}$

Q (Flow Rate, cubic feet/second) = V (Temp. Pool Volume, cubic feet) / 21,600 (seconds)
Q (cubic feet/second) = (**27,135**) cubic feet / 21,600 (seconds) = (**1.26**) cfs

   D. **If the maximum possible head is 2 feet, what is the average driving head?**

$$h = \frac{H}{2}$$

h (Average Driving Head, feet) = H (Maximum Possible Heat, feet) / 2
H (feet) = (**2**) feet / 2 = (**1**) feet

E. Given the Flow Rate, Q, from C and the Average Driving Head, h, from D, what is the orifice area?

$$A = \frac{Q}{\left(\sqrt{64.32 \times h}\right) \times 0.6}$$

or

$$A = \frac{Q}{(64.32 \times h)^{\frac{1}{2}} \times 0.6}$$

A (Orifice Area, square feet) = Q (Flow Rate, cfs) / {[64.32 x h (average driving, feet)]$^{1/2}$ x (0.6)}
A = (**1.26**) cfs / {[64.32 x (**1**) feet]$^{1/2}$ x (0.6)} = (**0.263**) square feet
A = (**1.26**) cfs / {[8.02] x (0.6)}= (**0.263**) square feet

F. What is the orifice diameter?

$$d = 2 \times \sqrt{\left(\frac{A}{3.14}\right)}$$

or

$$d = 2 \times \left(\frac{A}{3.14}\right)^{\frac{1}{2}}$$

d (Orifice diameter, feet) = 2 x [A (Orifice area, square feet) / 3.14]$^{1/2}$
d (feet) = 2 x [(**0.263**) square feet / 3.14]$^{1/2}$ = (**0.578**) feet

G. What is the orifice diameter in inches?

$$D = d \times 12$$

D (Orifice diameter, inches) = d (Orifice diameter, feet) x 12 (inches/foot)
d (inches) = (**0.578**) feet x 12 (inches/foot) = (**6.94**) inches **≈ 7"**

H. For this size orifice, what is the diameter of the perforated drainage tubing?

$$D_t = D + 2$$

D_t (Diameter of tubing, inches) = D (Orifice diameter, inches) + 2 (inches)
D_t (inches) = (**7**) inches + 2 (inches) = (**9**) inches

2. **What diameter riser is required for a principle spillway with a peak flow of 25 cfs and 1.0 feet head?**

From ESCH III-97, Plate 3.14-8:

On horizontal axis, select head, h (feet), and read up.

On vertical axis, select peak flow, Q (cfs), and read across.

At intersection of two lines, read riser diameter.

Riser Diameter = (**33**) inches

3. **Given an 80 feet long, corrugated metal pipe, what is the diameter of the barrel required for a peak flow, Q = 25 (cfs) and head, H = 10 (feet) on pipe outside embankment.**

From ESCH III-98 (corrugated metal pipe):

On the left vertical column, select the head, H (feet) = (**10**) feet

Read across the table, select the pipe peak flow, Q70 (cfs) = (**25.3**) cfs ... **34.9**

Read up the table to determine the pipe diameter, D (inches) = (**21**) inches **... 24"**

If pipe length is other than 70 feet long: L (feet) = (**80**) feet

Read from bottom of chart for the pipe length, the Conversion Factor, CF = (**0.96**) ... **0.96**

The pipe capacity for this length pipe is determined:

$$Q_L = CF \times Q_{70}$$

Q_L (Pipe Capacity, cfs) = CF (Conversion Factor) x Q_{70} (Pipe Peak Flow, cfs)

Q_L = (**0.96**) x (**25.3**) cfs = (**24.3**) cfs

[Q_L = (**0.96**) x (**34.9**) cfs = (**33.5**) cfs]

If pipe capacity flow rate, Q_L (cfs) is less than the required peak flow rate, Q (cfs), select the next larger pipe size and repeat above calculation.

Pipe Diameter, D = (**24**) inches

4. **For a 50 cfs peak flow rate, what diameter of 100 feet long reinforced concrete pipe is required given a head of 11 feet on the pipe outside embankment?**

From ESCH III-99 (reinforced concrete pipe):

On the left vertical column, select the head, H(feet) = (**11**) feet

Read across the table, select the pipe peak flow, Q70 (cfs) = (**52.7**) cfs ... **86.2**

Read up the table to determine the pipe diameter, D (inches) = (**24**) inches ... **30**

If pipe length is other than 70 feet long: L (feet) = (**100**) feet

Read from bottom of chart for the pipe length, the Conversion Factor, CF = (**0.93**) ... **0.95**

The pipe capacity for this length pipe is determined:

$$Q_L = CF \times Q_{70}$$

Q_L (Pipe Capacity, cfs) = CF (Conversion Factor) x Q_{70} (Pipe Peak Flow, cfs)

Q_L = (**0.93**) x (**52.7**) cfs = (**49**) cfs

[Q_L = (**0.95**) x (**86.2**) cfs = (**82**) cfs]

If pipe capacity flow rate, Q_L (cfs) is less than the required peak flow rate, Q (cfs), select the next larger pipe size and repeat above calculation.

Pipe Diameter, D = (**30**) inches

5. **Given a 21 inch corrugated metal pipe riser, what is the diameter, thickness, and height of the trash rack and anti-vortex device?**

From ESCH III-104, Table 3.14-D: Read

Riser Diameter, D = (**21**) inches

Read horizontally across table to determine:

Cylinder Diameter = (**30**) inches

Cylinder Thickness = (**16**) gage

Height = (**11**) inches

6. **For a sediment basin embankment less than 10 feet high, what size concrete base is required for a riser of 24 inches diameter to prevent floating?**

From ESCH III-110, Plate 3.14-14:

$$CBD = 2 \times D$$

CBD (Concrete Base Dimension, inches) = 2 x D (Diameter of Riser, inches)

CBD = 2 x (**24**) inches = (**48**) inches

7. **What size steel plate is required to anchor the principal spillway of a sediment basin with an embankment less than 10 feet high and a riser of 36 inches diameter?**

From ESCH III-110, Plate 3.14-14:

$$SBD = 2 \times D$$

SBD (Steel Base Dimension, inches) = 2 x D (Diameter of Riser, inches)
SBD = 2 x (**36**) inches = (**72**) inches

8. **For a sediment basin, what are the bottom width, slope and minimum length of the emergency spillway requiring a flow capacity, Q = 30 cfs, given a water surface 1.0 foot above the spillway, referred to as Stage, Hp = 1.0 foot.**

From ESCH III-100, Table 3.14-C:

Read the Stage, Hp (feet) in the first column, Hp = (1.0) feet

Read across the table on line for Q (capacity) cfs to meet required capacity, Q = (33) cfs

Read across the table on line for V (velocity) fps, V = (4) fps

Read across the table on line for S (slope) %, S = (3) %

Read across the table on line for X (channel length) feet, X = (51) feet

Read up column to Bottom Width, b = (14) feet

9. **What is the Saturated Length, Ls(feet), of a sediment basin barrel given the depth of water at the principal spillway crest, Y = 10 feet, slope of the barrel, S = 0.08 feet/foot, (8%) and the slope of the upstream face of the embankment is 3:1, where Z feet horizontal to one foot vertical, Z = 3 feet/foot.**

$$Ls = Y \times (Z + 4) \times \left(1 + \frac{S}{0.25 - S}\right)$$

Where:
Y = Depth of water at the principal spillway crest (feet)
Z = Slope of upstream face of the embankment (feet/foot)
S = Slope of the barrel (feet/foot)

Ls (Saturated Length, feet)

$$Ls = Y \times (Z + 4) \times \left(1 + \frac{S}{0.25 - S}\right)$$

$$Ls = 10 \times (3 + 4) \times \left(1 + \frac{0.08}{0.25 - 0.08}\right)$$

$$Ls = 10 \times 7 \times 1.47 = 102.9$$

Ls = (**102.9**) feet

10. **Given a depth of water at the principal spillway crest, Y = 8 feet, slope of barrel, S = 10%, the slope of the upstream face of the embankment is 2.5:1, what is the Saturated Length, Ls (feet), of the barrel?**

From ESCH III-105, Plate 3.14-11:

On the bottom of the chart, read on the vertical axis the depth of water at the principal spillway crest:

Y = (**8**) feet

Read across chart to slope of pipe:

S = (**10**) %

Read up to top of the chart to upstream embankment slope: (**2.5**): 1

Read across chart to saturated length:

Saturated Length, Ls = (**85**) feet

11. What is the maximum spacing between anti-seep collars which are 4 feet by 4 feet and attached to a 24 inch diameter barrel?

Given Collar Size, V = (**4**) feet

Given Barrel Diameter, D = (**2**) feet

$$P = \frac{V - D}{2} \; and \; Lm = 14 \times P$$

P (Projection of Collar above barrel, feet) = (V – D) / 2

P = [(**4**) – (**2**)] /2 = (**1**) feet

Lm (Maximum Spacing between Anti-Seep Collars, feet) = 14 x P (feet)

Lm = 14 x (**1**) feet = (**14**) feet

Module 8 Work Problem Answers

8a. Outlet protection trap work problems ESCH III-154-165

1. **Given a discharge of 20 cfs from a 15 inch pipe into water depth less than half the pipe diameter (Minimum Tailwater Condition), what is the apron length, La (feet); median stone size of riprap, d(50); upstream apron width, Wu (feet); and downstream apron width, Wd (feet), required for outlet protection?**

From ESCH III-164, Plate 3.18-3 (Minimum Tailwater Condition)

On the bottom horizontal axis, select the given Discharge, Q = (**20**) cfs

Read up to bottom chart to given Pipe Diameter, D = (**15**) inches

Read over to right for median size riprap stone, d (**50**) = (**0.8**) feet

From Discharge, Q = (**20**) cfs, read up to top chart to Pipe Diameter, D = (**15**) inches

Read to left for Minimum Apron Length, La = (**19**) feet

$$Wu = 3 \times D$$

Wu (Upstream Apron Width, feet) = 3 x D (Pipe Diameter, feet)

Wu = 3 x (**1.25**) feet = (3.7**5**) feet

$$W\,d = D + L\,a$$

Wd (Downstream Apron Width, feet) = D (Pipe Diameter feet) + La (Apron Length feet)

Wd = (**19**) feet + (**1.25**) feet = (**20.25**) feet

2. **From a 24 inch pipe flows 50 cfs into water depth greater than half the pipe diameter (Maximum Tailwater Condition), what is the apron length, LA (feet); median stone size, d(50); upstream apron width, Wu (feet); and downstream apron width, Wd (feet), required for outlet protection?**

From ESCH III-165, Plate 3.18-4 diameter (Maximum Tailwater Condition)

On the bottom horizontal axis, select the given Discharge, Q = (**50**) cfs

Read up to bottom chart to given Pipe Diameter, D = (**24**) inches

Read over to right for median size riprap stone, d (50) = **(0.7**) feet

From Discharge, Q = (**50**) cfs, read up to top of chart to Pipe Diameter, D = (**24**) inches

Read to left for Minimum Apron Length, La = (**56**) feet

$$Wu = 3 \times D$$

Wu (Upstream Apron Width, feet) = 3 x D (Pipe Diameter, feet)

Wu = 3 x (**2.0**) feet = (**6**) feet

$$Wd = D + 0.4 \times La$$

Wd (Downstream Apron Width, feet) = D (Pipe Diameter, feet) + 0.4 x La (Apron Length, feet)

Wd = (**2**) feet + 0.4 x (**56**) feet = (**24.4**) feet

Module 10 Work Problem Answers

Time of Concentration ESCH V-4

1. **What is the Time of Concentration, T (minutes), for a Length, L (feet) = 200 feet, over an average grass surface, with a 4% slope?**

From ESCH V-11, Plate 5-1 (Seelye Chart)

Select on left vertical axis the Length = (**200**) feet

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

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

Read on right vertical axis, Time of Concentration, T= (**15**) minutes

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

From ESCH V-11, Plate 5-2

Convert slope in % to slope in feet/foot:

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

Where:

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 lope equality 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 1000 feet?**

   From ESCH V-54, Plate 5-24

   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 (**1000**)/ [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 = (**15**) + (**3**) + (**2**) = (**20**) minutes

Rational Formula ESCH V-3

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

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

C, Runoff Coefficient, is found from (ESCH V-29, Table 5-2)

T (minutes), Time of Concentration, is calculated for:
overland flow (ESCH V-11, Plate 5-1) shallow
concentrated (ESCH V-12, Plate 5-2) channel
flow (ESCH V-13, Plate 5-3)

i, (inches/hour), Average Rainfall Intensity, from (ESCH V-14 to V-280

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

1. **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 woodlands, 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 ESCH V-29, Table 5-2:

Land use:	**Runoff Coefficient**	**x**	**Area(acres)**	**=**	**C x A**
Roof	(**0.95**)	x	(**10.0**)	=	(**9.5**)
Asphalt Paving	(**0.95**)	x	(**5.74**)	=	(**5.45**)
Woodlands	(**0.25**)	x	(**4.0**)	=	(**1.0**)
Lawn	(**0.35**)	x	(**5.26**)	=	(**1.84**)
				Total C x A =	**(17.79)**

C, Weighted Average Runoff Coefficient = Total C x A / Total A(acres) = (**0.71**)

2. 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 ESCH V-14:

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) = (**4.1**) in/hr.

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

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

Q (Peak rate of runoff, cfs) = (**0.71**) x (**4.1**) x (**25**) = (**72.8**) cfs

Module 11 Work Problem Answers

Graphical Peak Discharge Method (TR-55) ESCH V-31

$$q_p = q_u \times A_m \times Q \times F_p$$

Where:

q_p = Peak Discharge (cubic feet / second)
q_u = Unit Peak Discharge (csm / in)
A_m = Drainage Area (square miles)
Q = Runoff (inches)
F_p = Pond and Swamp Adjustment Factor

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 Tables 5-4, ESCH V-32:
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 5-5, ESCH V-56 to 59: 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 Table 5-4, ESCH V-32: Hydrologic Soil Group = (**A**)

From Table 5-5, ESCH V-56 to 59:

Land use:				=	CN x A
Impervious	(98)	x	**(3)**	=	**(294)**
Grass	(49)	x	**(2)**	=	**(98)**
Woods	(36)	x	**(4)**	=	**(144)**
				Total CN x A =	**(536)**

CN, Weighted Average Runoff Curve Number = Total CN x A / Total A(acres) = (**60**)

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 5-10, ESCH V-65, Fp = (**0.75**).

5. **Example Project: Defiance Ridge:**

   40% of the 250 acres is ½ acre lots on the Appling soil;
   10% is commercial on the Appling soil;
   30% is ½ acre lots on the Helena soil; and
   20% is open space on the Helena soil.
   All hydrologic conditions are good cover.

   The streets are paved with curb and gutter. They are laid out in such a way as to decrease overland flow to 100' in a lawn. Then water flows onto the streets and paved gutters and continues until it reaches the natural channel. (This is the same point at which channel flow began in pre-developed conditions.) Total length of street and gutter flow is 700' at an average of 3% grade.

Find: The post-development runoff curve number for the drainage area, the runoff for the 2-year and 10-year storms, the time of concentration, and the peak discharges for the 2-year and 10-year storms.

[Assume the project must meet compliance with the technical criteria of Part IIC under the Virginia Stormwater Management regulations (9VAC25-870-93 et seq.)]

See next three pages for the completed project worksheets 2, 3, and 4 ***(Developed Condition)***.

Since the development of Defiance Ridge will increase the peak discharge of the 2-year storm over the pre-developed conditions, provisions must be made to address the increase in runoff.

The site design could include measures that would reduce the volume of runoff (by using infiltration and retention), reduce the peak discharge rate (detention), or improve the receiving channel to convey the increased runoff. Note that any improvements to the channel should be based on the post-development hydrology. Detention storage can be provided at the lower end of the development to store and release the post-development 2-year storm peak. See Chapters 4 and 5 of the VESCH for more information.

Worksheet 3 (Runoff curve number and runoff): Use VESCH V-56, Table 5-5 for curve

Worksheet 2: Runoff curve number and runoff 1992

Project Defiance Ridge By ESC Date 2-4-91

Location Campbell County, Virginia Checked SWM Date 2-5-91

Circle one: Present (Developed) D.A. 250 acs.

1. Runoff curve number (CN)

Soil name and hydrologic group Appendix 6C	Cover description (cover type, treatment, and hydrologic condition; percent impervious; unconnected/connected impervious area ratio)	CN 1/ Table 5-5	CN 1/ Fig. 2-3	CN 1/ Fig. 2-4	Area ☐ acres ☐ mi² ☑ %	Product of CN x area
Appling, B	1/2 Ac. Lots, Good Condition	70			40	2800
Appling, B	Commercial	92			10	920
Helena, C	1/2 Ac. Lots, Good Condition	80			30	2400
Helena, C	Open Space, Good Condition	74			20	1480
				Totals =	100	7600

1/ Use only one CN source per line.

CN (weighted) = $\frac{\text{total product}}{\text{total area}} = \frac{7600}{100} =$ 76 ; Use CN = 76

2. Runoff

	Storm #1	Storm #2	Storm #3
Frequency ..... yr	2	10	
Rainfall, P (24-hour) (Plates 5-19,5-20) in	3.5	5.5	
Runoff, Q ..... in (Use P and CN with table 5-6, Plate 5-20 or eqs. Plate 5-22)	1.36	2.95	

Source: VESCH,V - 46

Worksheet 3: Time of concentration (T_c) or travel time (T_t) 1992

Project Defiance Ridge By ESC Date 2-4-91

Location Campbell County, Virginia Checked SWM Date 2-5-91

Circle one: Present (Developed)

Circle one: (T_c) T_t through subarea

NOTES: Space for as many as two segments per flow type can be used for each worksheet.

Include a map, schematic, or description of flow segments.

Sheet flow (Applicable to T_c only)		Segment ID	AB		
1. Surface description (table 5-7)			Lawn		
2. Manning's roughness coeff., n (table 5-7) ..			0.24		
3. Flow length, L (total L ≤ 300 ft)	ft		100		
4. Two-yr 24-hr rainfall, P_2 ..(Worksheet 2)..	in		3.5		
5. Land slope, s ..(From Problem # 5-3).....	ft/ft		0.02		
6. $T_t = \frac{0.007\,(nL)^{0.8}}{P_2^{0.5}\,s^{0.4}}$ Compute T_t	hr		0.23	+	= 0.23

Shallow concentrated flow		Segment ID	BC		
7. Surface description (paved or unpaved)			Paved		
8. Flow length, L	ft		700		
9. Watercourse slope, s	ft/ft		0.03		
10. Average velocity, V (Plate 5-23).....	ft/s		3.5		
11. $T_t = \frac{L}{3600\,V}$ Compute T_t	hr		0.06	+	= 0.06

Channel flow		Segment ID	CD	DE	
12. Cross sectional flow area, a	ft^2		8	27	
13. Wetted perimeter, p_w	ft		7.6	21.6	
14. Hydraulic radius, $r = \frac{a}{p_w}$ Compute r	ft		1.05	1.25	
15. Channel slope, s	ft/ft		0.02	0.005	
16. Manning's roughness coeff., n			0.08	0.06	
17. $V = \frac{1.49\,r^{2/3}\,s^{1/2}}{n}$ Compute V	ft/s		2.70	2.04	
18. Flow length, L	ft		1500	2500	
19. $T_t = \frac{L}{3600\,V}$ Compute T_t	hr		0.15	+ 0.34	= 0.49
20. Watershed or subarea T_c or T_t (add T_t in steps 6, 11, and 19)	hr				0.78

Source: VESCH, V - 47

Worksheet 4: Graphical Peak Discharge method

1992

Project Defiance Ridge By ECC Date 2-4-91

Location Campbell County, Virginia Checked SWM Date 2-5-91

Circle one: Present (Developed)

1. Data:

Drainage area ..... A_m = 0.39 mi^2 (acres/640)

Runoff curve number .... CN = 76 (From worksheet 2)

Time of concentration .. T_c = 0.78 hr (From worksheet 3)

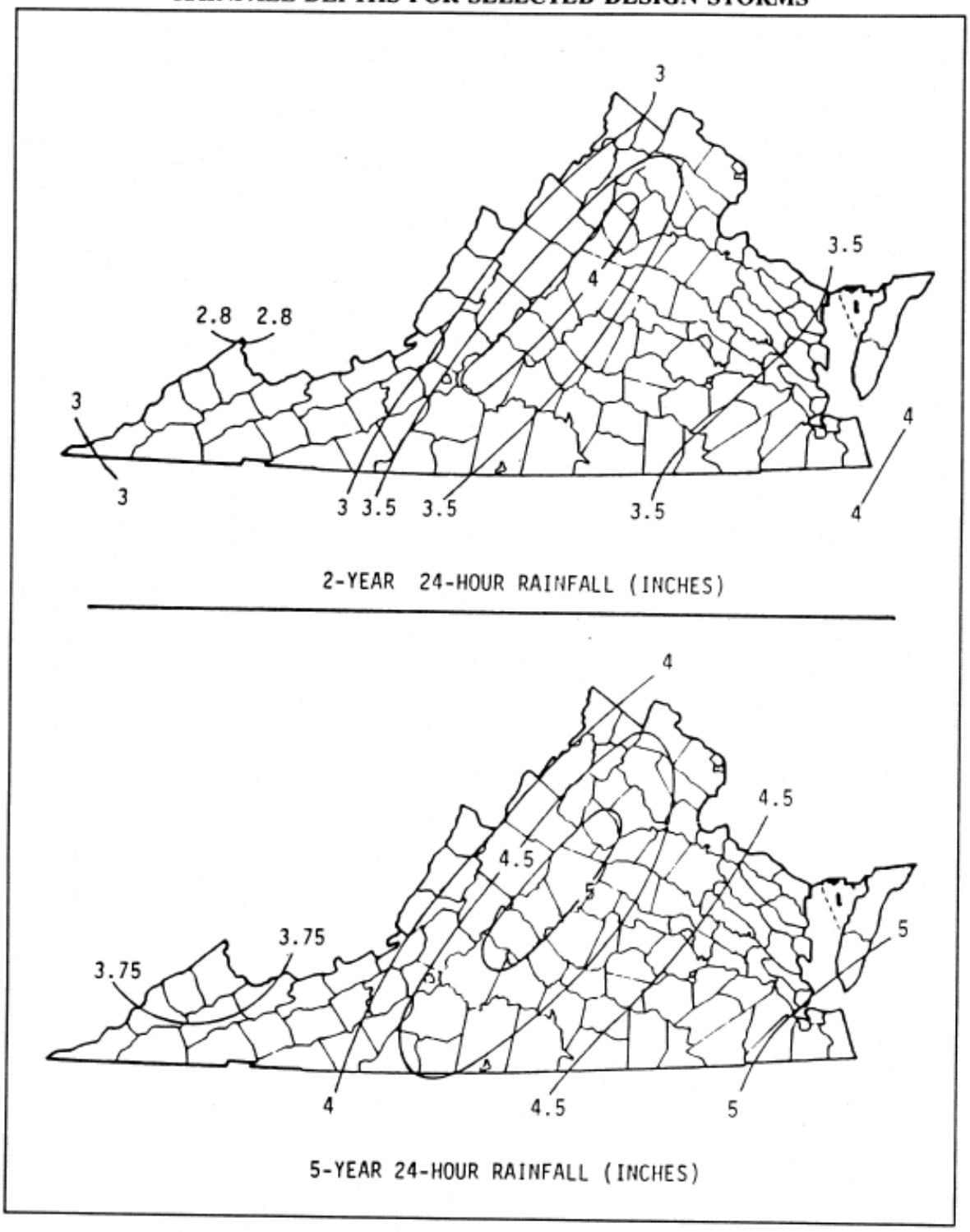
Rainfall distribution type = II (I, IA, II, III)

Pond and swamp areas spread throughout watershed ..... = 0 percent of A_m (0 acres or mi^2 covered)

		Storm #1	Storm #2	Storm #3
2. Frequency	yr	2	10	
3. Rainfall, P (24-hour) ..(Worksheet 2)...	in	3.5	5.5	
4. Initial abstraction, I_a ..... (Use CN with table 5-5)	in	0.632	0.632	
5. Compute I_a/P		0.18	0.11	
6. Unit peak discharge, q_u ..... (Use T_c and I_a/P with Plate 5-25)	csm/in	380	410	
7. Runoff, Q ..... (From worksheet 2).	in	1.36	2.95	
8. Pond and swamp adjustment factor, F_p .... (Use percent pond and swamp area with table 5-10. Factor is 1.0 for zero percent pond and swamp area.)		1.0	1.0	
9. Peak discharge, q_p ..... (Where $q_p = q_u A_m Q F_p$)	cfs	202	472	

Source: VESCH,V - 48

RAINFALL DEPTHS FOR SELECTED DESIGN STORMS

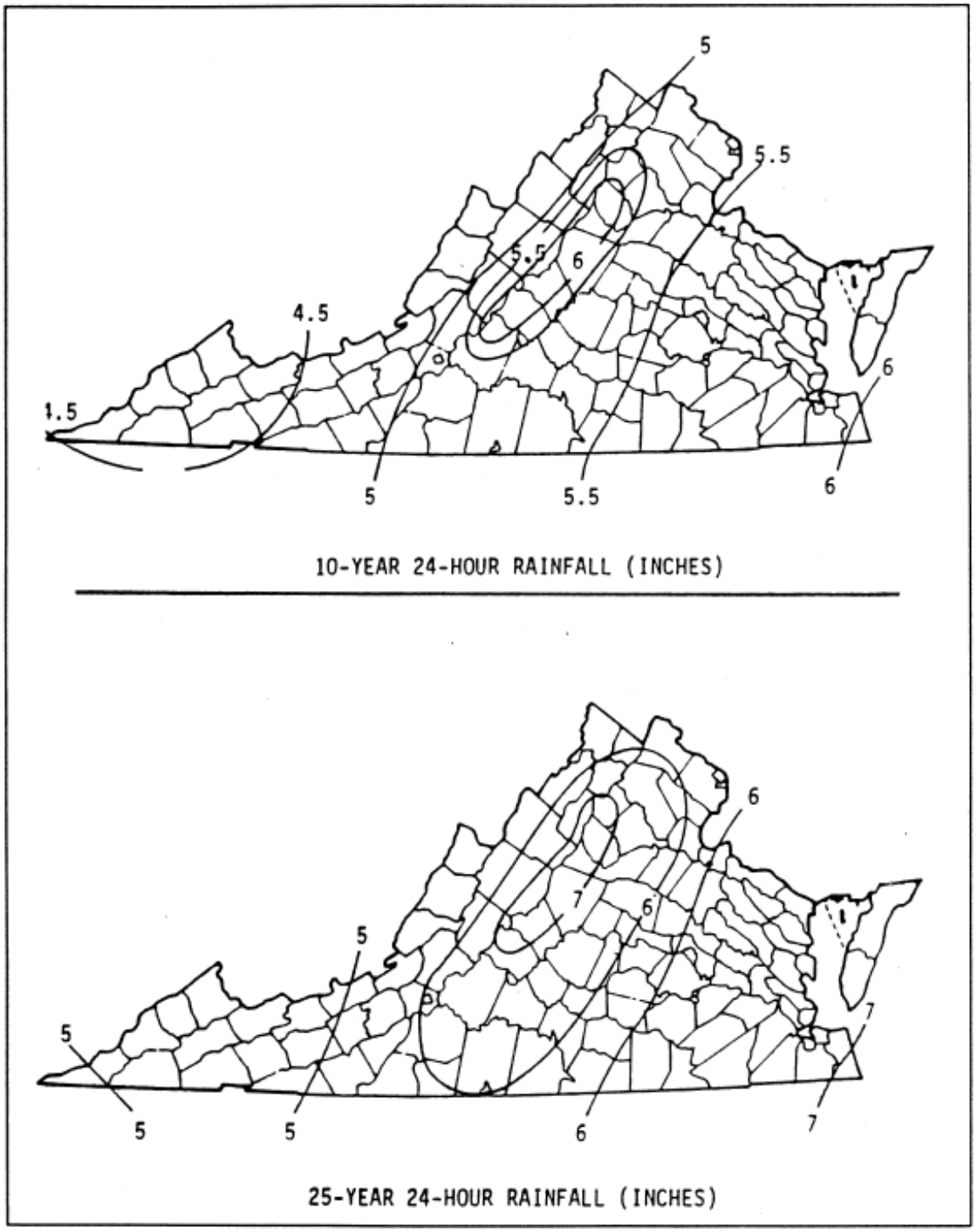


Source: USDA-SCS and U.S. Weather Bureau

Plate 5-19

Source: VESCH, V - 49

RAINFALL DEPTHS FOR SELECTED DESIGN STORMS (continued)

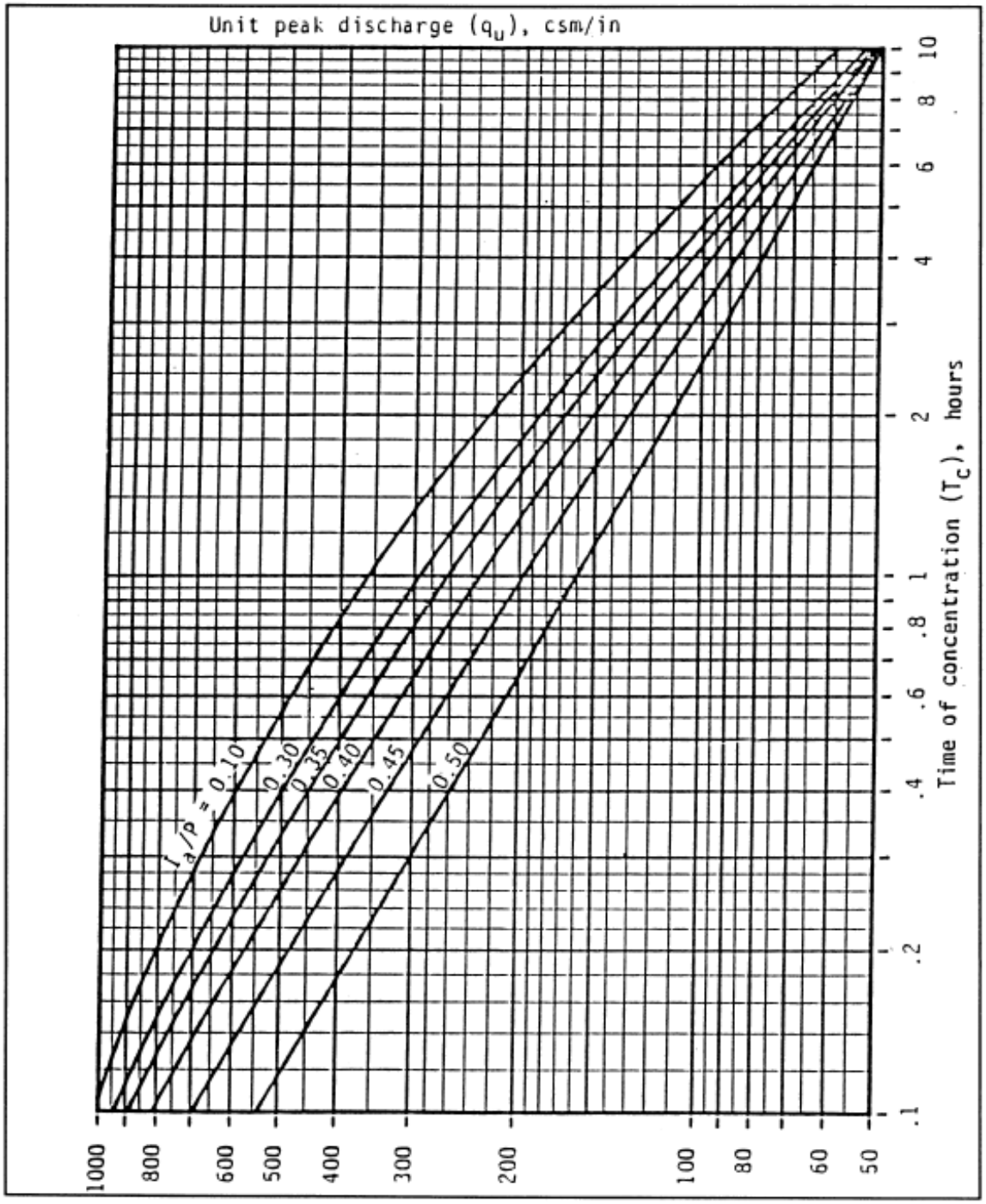


Source: USDA-SCS and U.S. Weather Bureau

Plate 5-20

Source: VESCH,V - 50

UNIT PEAK DISCHARGE (q_u) FOR SCS TYPE II RAINFALL DISTRIBUTION



Source: USDA-SCS

Plate 5-25

Source: VESCH, V - 55

TABLE 5-5*

RUNOFF CURVE NUMBERS FOR GRAPHICAL PEAK DISCHARGE METHOD

COVER DESCRIPTION			HYDROLOGIC SOIL GROUP			
			A	B	C	D
Fully Developed Urban Areas (Vegetation Established)						
Open Space (lawns, parks, etc.)	Poor Condition; Grass		68	79	86	89
	Fair Condition; Grass 50 - 75% cover		49	69	79	84
	Good Condition; Grass > 75% cover		39	61	74	80
Impervious Areas	Paved parking lots, roofs, driveways		98	98	98	98
Streets and Roads	Paved; curbs and storm sewers		98	98	98	98
	Paved; open ditches (w/right-of-way)		83	89	92	93
	Gravel (with right-of-way)		76	85	89	91
	Dirt (with right-of-way)		72	82	87	89
Urban Districts		Average % Impervious				
	Commercial and Business	85	89	92	94	95
	Industrial	72	81	88	91	93

* Refer to the TR-55 document for a complete table of runoff curve numbers and additional information on selecting the runoff curve number.

Source: USDA-SCS

Source: VESCH, V - 56

TABLE 5-5* (continued)
RUNOFF CURVE NUMBERS FOR
GRAPHICAL PEAK DISCHARGE METHOD

COVER DESCRIPTION			HYDROLOGIC SOIL GROUP			
			A	B	C	D
Residential Districts (by average lot size)		Average % Impervious				
	1/8 acre (town house)	65	77	85	90	92
	1/4 acre	38	61	75	83	87
	1/3 acre	30	57	72	81	86
	1/2 acre	25	54	70	80	85
	1 acre	20	51	68	79	84
	2 acres	12	46	65	77	82
Urban Areas - Development Underway, No Vegetation Established						
Newly graded area			81	89	93	95
Pavement and Roofs, Commercial & Business Areas			98	98	98	98
Row Houses, Town Houses and Residential w/lot sizes:	1/8 acre or less		93	96	97	98
	1/4 acre		88	93	95	97
	1/2 acre		85	91	94	96
	1 acre		82	90	93	95
	2 acres		81	89	92	94
Cultivated Agricultural Lands						
Fallow:	Bare Soil		77	86	91	94
	Crop Residue (CR) poor		76	85	90	93
	Crop Residue (CR) good		74	83	88	90

* Refer to the TR-55 document for a complete table of runoff curve numbers and additional information on selecting the runoff curve number.

Source: VESCH,V - 57

TABLE 5-5* (continued)

RUNOFF CURVE NUMBERS FOR GRAPHICAL PEAK DISCHARGE METHOD

COVER DESCRIPTION		HYDROLOGIC SOIL GROUP			
		A	B	C	D
Cultivated Agricultural Lands (continued)					
Row Crops:	Straight row (SR) poor	72	81	88	91
	Straight row (SR) good	67	78	85	89
	Contoured (C) poor	70	79	84	88
	Contoured (C) good	65	75	82	86
	Contoured and Terraced (C&T) poor	66	74	80	82
	Contoured and Terraced (C&T) good	62	71	78	81
Other Agricultural Lands					
Pasture, grassland or range	poor	68	79	86	89
	fair	49	69	79	84
	good	39	61	74	80
Meadow		30	58	71	78
Brush - brush, weed, grass mix	poor	48	67	77	83
	fair	35	56	70	77
	good	30	48	65	73
Woods - grass combination	poor	57	73	82	86
	fair	43	65	76	82
	good	32	58	72	79

* Refer to the TR-55 document for a complete table of runoff curve numbers and additional information selecting the runoff curve number.

Source: VESCH,V - 58

TABLE 5-5* (continued)

RUNOFF CURVE NUMBERS FOR GRAPHICAL PEAK DISCHARGE METHOD

COVER DESCRIPTION		HYDROLOGIC SOIL GROUP			
		A	B	C	D
Other Agricultural Lands (continued)					
Woods	poor	45	66	77	83
	fair	36	60	73	79
	good	30	55	70	77
Porous Pavement**					
	Gravel Subbase Thickness (inches)				
Porous Pavement (Properly Maintained)	10	57	66	69	75
	18	53	61	64	69
	24	52	58	61	66
	36	47	52	55	58
Porous Pavement (Not Properly Maintained)	10 - 36	98	98	98	98

* Refer to the TR-55 document for a complete table of runoff curve numbers and additional information on selecting runoff curve number.

** This information is not intended for design purposes.

Source: VESCH,V - 59

TABLE 5-6
RUNOFF DEPTH FOR SELECTED CN's AND RAINFALL AMOUNTS[1]

	Runoff depth for curve number of ____												
Rainfall	40	45	50	55	60	65	70	75	80	85	90	95	98
	inches												
1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.08	0.17	0.32	0.56	0.79
1.2	.00	.00	.00	.00	.00	.00	.03	.07	.15	.27	.46	.74	.99
1.4	.00	.00	.00	.00	.00	.02	.06	.13	.24	.39	.61	.92	1.18
1.6	.00	.00	.00	.00	.01	.05	.11	.20	.34	.52	.76	1.11	1.38
1.8	.00	.00	.00	.00	.03	.09	.17	.29	.44	.65	.93	1.29	1.58
2.0	.00	.00	.00	.02	.06	.14	.24	.38	.56	.80	1.09	1.48	1.77
2.5	.00	.00	.02	.08	.17	.30	.46	.65	.89	1.18	1.53	1.96	2.27
3.0	.00	.02	.09	.19	.33	.51	.71	.96	1.25	1.59	1.98	2.45	2.77
3.5	.02	.08	.20	.35	.53	.75	1.01	1.30	1.64	2.02	2.45	2.94	3.27
4.0	.06	.18	.33	.53	.76	1.03	1.33	1.67	2.04	2.46	2.92	3.43	3.77
4.5	.14	.30	.50	.74	1.02	1.33	1.67	2.05	2.46	2.91	3.40	3.92	4.26
5.0	.24	.44	.69	.98	1.30	1.65	2.04	2.45	2.89	3.37	3.88	4.42	4.76
6.0	.50	.80	1.14	1.52	1.92	2.35	2.81	3.28	3.78	4.30	4.85	5.41	5.76
7.0	.84	1.24	1.68	2.12	2.60	3.10	3.62	4.15	4.69	5.25	5.82	6.41	6.76
8.0	1.25	1.74	2.25	2.78	3.33	3.89	4.46	5.04	5.63	6.21	6.81	7.40	7.76
9.0	1.71	2.29	2.88	3.49	4.10	4.72	5.33	5.95	6.57	7.18	7.79	8.40	8.76
10.0	2.23	2.89	3.56	4.23	4.90	5.56	6.22	6.88	7.52	8.16	8.78	9.40	9.76
11.0	2.78	3.52	4.26	5.00	5.72	6.43	7.13	7.81	8.48	9.13	9.77	10.39	10.76
12.0	3.38	4.19	5.00	5.79	6.56	7.32	8.05	8.76	9.45	10.11	10.76	11.39	11.76
13.0	4.00	4.89	5.76	6.61	7.42	8.21	8.98	9.71	10.42	11.10	11.76	12.39	12.76
14.0	4.65	5.62	6.55	7.44	8.30	9.12	9.91	10.67	11.39	12.08	12.75	13.39	13.76
15.0	5.33	6.36	7.35	8.29	9.19	10.04	10.85	11.63	12.37	13.07	13.74	14.39	14.76

[1] Interpolate the values shown to obtain runoff depths for CN's or rainfall amounts not shown.

Source: USDA-SCS

Source: VESCH, V - 60

TABLE 5-9

I_a VALUES FOR RUNOFF CURVE NUMBERS

Curve Number	I_a (inches)	Curve Number	I_a (inches)	Curve Number	I_a (inches)
40	3.000	60	1.333	80	0.500
41	2.878	61	1.279	81	0.469
42	2.762	62	1.226	82	0.439
43	2.651	63	1.175	83	0.410
44	2.545	64	1.125	84	0.381
45	2.444	65	1.077	85	0.353
46	2.348	66	1.030	86	0.326
47	2.255	67	0.985	87	0.299
48	2.167	68	0.941	88	0.273
49	2.082	69	0.899	89	0.247
50	2.000	70	0.857	90	0.222
51	1.922	71	0.817	91	0.198
52	1.846	72	0.778	92	0.174
53	1.774	73	0.740	93	0.151
54	1.704	74	0.703	94	0.128
55	1.636	75	0.667	95	0.105
56	1.571	76	0.632	96	0.083
57	1.509	77	0.597	97	0.062
58	1.448	78	0.564	98	0.041
59	1.390	79	0.532		

Source: USDA-SCS

Source: VESCH, V - 64

TABLE 5-10

ADJUSTMENT FACTOR (F_p) FOR POND AND SWAMP AREAS SPREAD THROUGHOUT THE WATERSHED

Percentage of pond and swamp areas	F_p
0	1.00
0.2	0.97
1.0	0.87
3.0	0.75
5.0	0.72

Source: USDA-SCS

Source: VESCH, V - 65

APPENDIX 6C

LISTING OF SOIL TYPES IN VIRGINIA

The majority of soils currently found in Virginia along with their corresponding Hydrologic Soil Group designation are listed on the following pages.

The following key explains some of the abbreviations found the on attached soils list. For abbreviations not listed here, consult your local soil survey.

CL	-	clay loam	LS	-	loamy sand
FS	-	fine sand	SICL	-	silt clay loam
FSL	-	fine sandy loam	SIL	-	silt loam
L	-	loam	SL	-	sandy loam
LFS	-	loamy fine sand	VFSL	-	very fine sandy loam

WTDEPL and WTDEPH refer to range of depths to the surface of the groundwater.

Source: VESCH,VI - 50

Soil name	surftex	hydgrp	kfact	wtdepl	wtdeph
ABELL	FSL	B	0.28	2.00	3.50
ABELL	L	B	0.32	2.00	3.50
ABELL	SIL	B	0.32	2.00	3.50
ABELL	SL	B	0.28	2.00	3.50
ABELL VARIANT	L	B	0.32	2.00	3.50
ACKWATER	SICL	D	0.37	1.50	3.00
ACKWATER	SIL	D	0.43	1.50	3.00
ACREDALE	SIL	D	0.37	0.00	1.00
ADEN	SIL	C	0.43	0.00	1.00
AIRMONT	FLV-L	C	0.10	1.50	3.00
ALAGA	FS	A	0.10	6.00	6.00
ALAGA	LS	A	0.10	4.00	6.00
ALAGA	LS	A	0.10	6.00	6.00
ALAGA	S	A	0.10	6.00	6.00
ALBANO	SIL	D	0.37	0.00	1.50
ALBEMARLE	FSL	B	0.20	6.00	6.00
ALBEMARLE	L	B	0.32	6.00	6.00
ALBEMARLE	STV-FSL	B	0.20	6.00	6.00
ALDERFLATS	SIL	D	0.43	0.00	1.00
ALDIE	SIL	D	0.37	1.50	2.50
ALDINO	SIL	C	0.43	1.50	2.50
ALLEGHENY	CB-FSL	B	0.20	6.00	6.00
ALLEGHENY	CB-L	B	0.20	6.00	6.00
ALLEGHENY	FSL	B	0.28	6.00	6.00
ALLEGHENY	L	B	0.32	6.00	6.00
ALLEGHENY	SIL	B	0.32	6.00	6.00
ALONZVILLE	CB-L	B	0.20	6.00	6.00
ALONZVILLE	CB-L	B	0.32	6.00	6.00
ALONZVILLE	FSL	B	0.20	6.00	6.00
ALONZVILLE	L	B	0.32	6.00	6.00
ALTAVISTA	FSL	C	0.24	1.50	2.50
ALTAVISTA	FSL	C	0.37	1.00	2.50
ALTAVISTA	L	C	0.24	1.50	2.50
ALTAVISTA	LS	C	0.17	1.50	2.50
ALTAVISTA	SIL	C	0.32	1.50	2.50
ALTAVISTA	SIL	C	0.37	1.00	2.50
ALTAVISTA	SL	C	0.24	1.50	2.50
ALTAVISTA VARIANT	L	C	0.24	1.50	2.50
ALTICREST	FSL	B	0.24	6.00	6.00
ALTICREST	RB-FSL	B	0.24	6.00	6.00
ALTICREST	SL	B	0.24	6.00	6.00
ANGIE	L	D	0.32	3.00	5.00
ANGIE VARIANT	L	D	0.32	3.00	5.00
APPLING	CL	B	0.24	6.00	6.00
APPLING	CL	B	0.28	6.00	6.00
APPLING	FSL	B	0.24	6.00	6.00
APPLING	GR-COSL	B	0.15	6.00	6.00
APPLING	GR-FSL	B	0.24	6.00	6.00
APPLING	GR-SL	B	0.15	6.00	6.00
APPLING	L	B	0.32	6.00	6.00
APPLING	SCL	B	0.28	6.00	6.00
APPLING	SL	B	0.24	6.00	6.00
APPLING	SL	B	0.28	6.00	6.00
APPLING	VFSL	B	0.24	6.00	6.00

Source: VESCH, VI - 51

Module 12 Work Problem Answers

Open Channel Flow ESCH V-96 to 141

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 = ( ) feet x ( ) feet = ( ) 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 = ( ) feet + 2 x ( ) feet = ( ) 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 = ( ) square feet / ( ) feet = ( ) 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 = ( ) feet x [( ) feet] ^{2} = ( ) square feet

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

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

or

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

$$p = 2xd(z^2 + 1)$$

Where:

p= Wetted Perimeter (feet)

d = channel depth (feet)

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

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

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

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

or

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

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

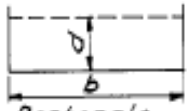
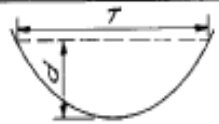
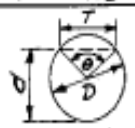
9. **For this same channel, what is the Hydraulic Radius, r(feet)?**

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

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

r = ( ) square feet / ( ) feet = ( ) feet

HYDRAULICS: ELEMENTS OF CHANNEL SECTIONS

Section	Area a	Wetted Perimeter p	Hydraulic Radius r	Top Width T
Trapezoid	$bd+zd^2$	$b+2d\sqrt{z^2+1}$	$\frac{bd+zd^2}{b+2d\sqrt{z^2+1}}$	$b+2zd$
 Rectangle	bd	$b+2d$	$\frac{bd}{b+2d}$	b
Triangle	zd^2	$2d\sqrt{z^2+1}$	$\frac{zd}{2\sqrt{z^2+1}}$	$2zd$
 Parabola	$\frac{2}{3}dT$	$T+\frac{8d^2}{3T}$ [1]	$\frac{2dT^2}{3T^2+8d^2}$ [1]	$\frac{3a}{2d}$
Circle - < 1/2 full [2]	$\frac{D^2}{8}\left(\frac{\pi\theta}{180}-\sin\theta\right)$	$\frac{\pi D\theta}{360}$	$\frac{45D}{\pi\theta}\left(\frac{\pi\theta}{180}-\sin\theta\right)$	$D\sin\frac{\theta}{2}$ or $2\sqrt{d(D-d)}$
 Circle - > 1/2 full [3]	$\frac{D^2}{8}\left(2\pi-\frac{\pi\theta}{180}+\sin\theta\right)$	$\frac{\pi D(360-\theta)}{360}$	$\frac{45D}{\pi(360-\theta)}\left(2\pi-\frac{\pi\theta}{180}+\sin\theta\right)$	$D\sin\frac{\theta}{2}$ or $2\sqrt{d(D-d)}$

[1] Satisfactory approximation for the interval $0<\frac{d}{T}\leq 0.25$
When $d/T>0.25$, use $p=\frac{1}{2}\sqrt{16d^2+T^2}+\frac{T^2}{8d}\sinh^{-1}\frac{4d}{T}$

[2] $\theta=4\sin^{-1}\sqrt{d/D}$
[3] $\theta=4\cos^{-1}\sqrt{d/D}$
} Insert θ in degrees in above equations

REFERENCE

U. S. DEPARTMENT OF AGRICULTURE
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H. H. Bennett, Chief
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STANDARD DWG. NO.
ES - 33
SHEET 1 OF 1
DATE 6 - 6 - 50