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July 2024

Virginia Department of Environmental Quality

Module 12

Channel Evaluation

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Module 12 Contents

12a. Channel Analysis and Inputs

12b. Continuity Equation

12c. Channel Computations Summary

12d. Reviewing Channel Design

12e. Designing Channels

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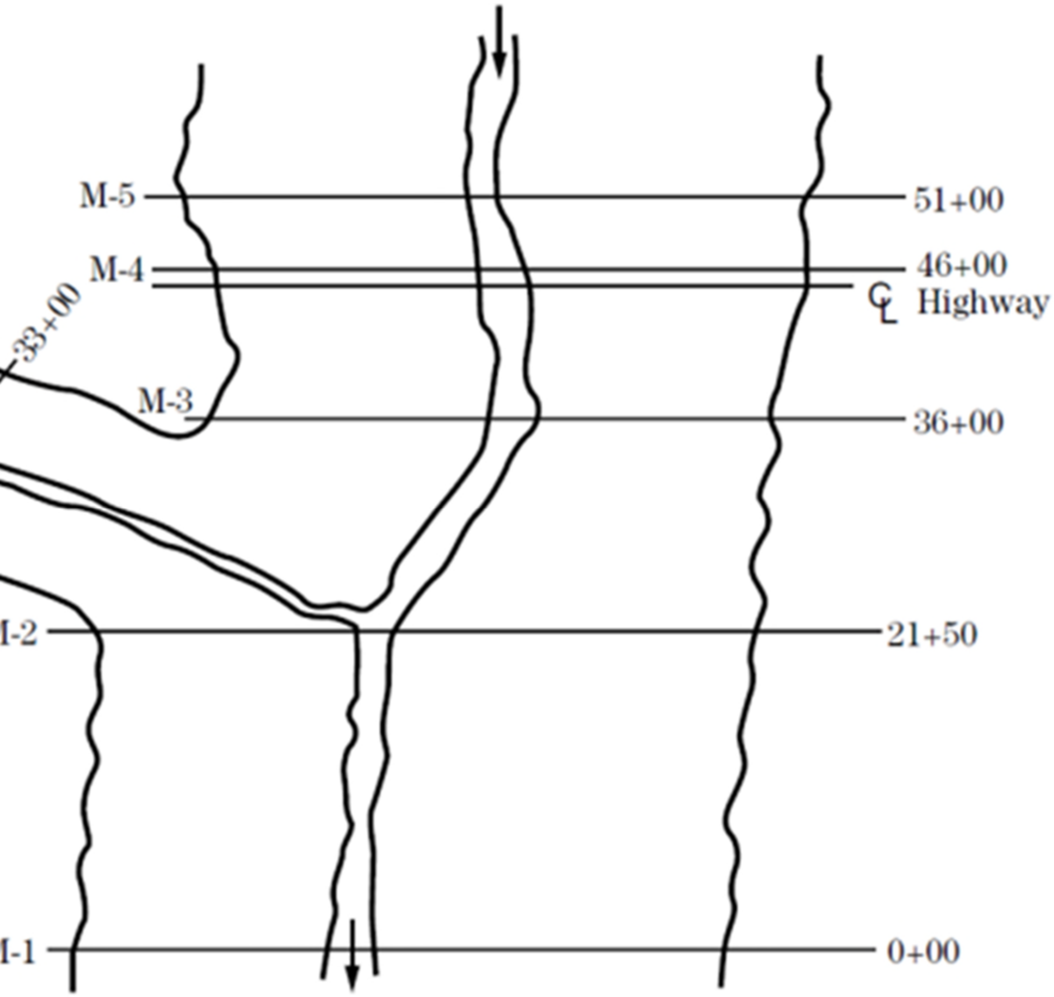
Module 12a.

Channel Analysis and Inputs

Channel Analysis and Inputs

- Compliance verifications may also be required:
  - Channel improvements
  - Restored channels
  - Natural channels (if required by VESMP authority)

Channel Survey



- Divide channel into fairly uniform segments where we can assume constant:
  - Flow depth
  - Cross-sectional area
  - Runoff velocity
  - Peak flow

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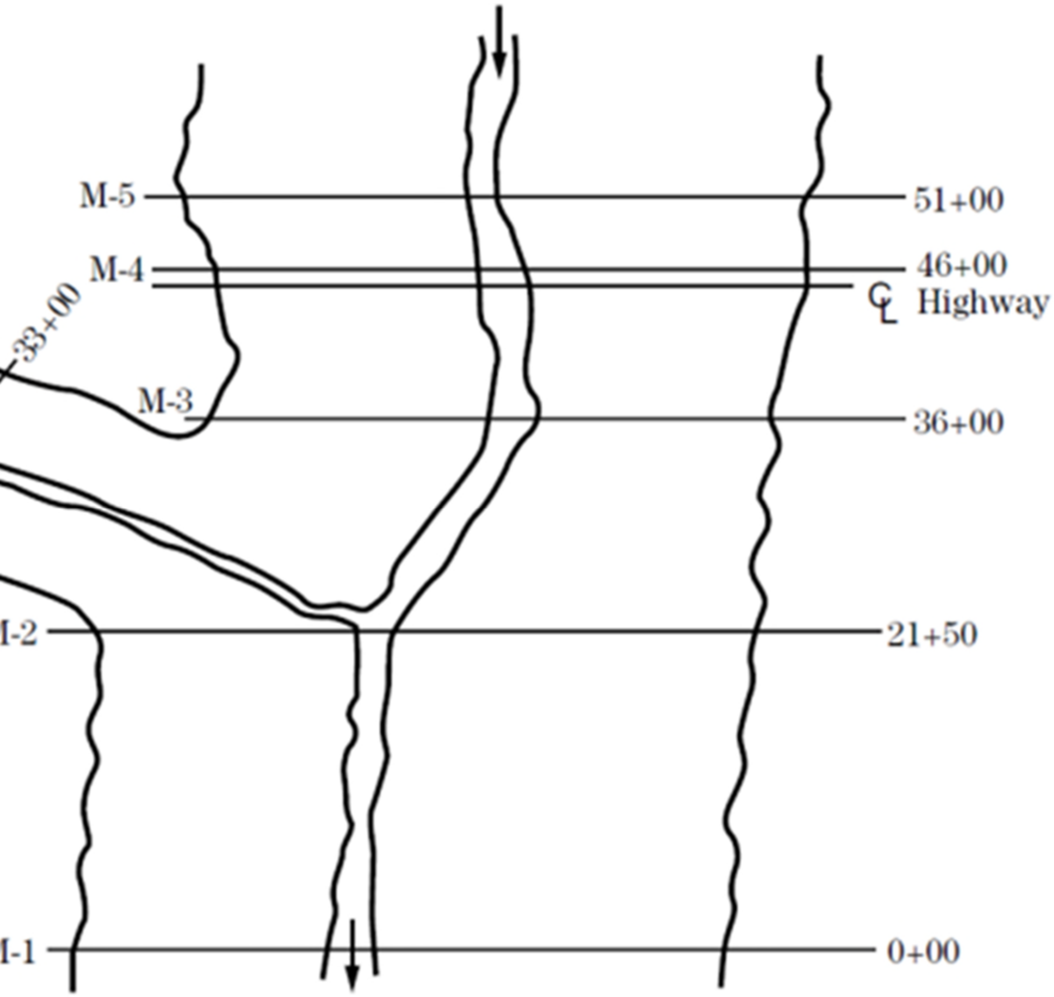
Channel Survey



- Evaluate each channel segment for channel characteristics
  - Slope
  - Representative cross-sectional area
  - Channel lining roughness
  - Downstream restrictions

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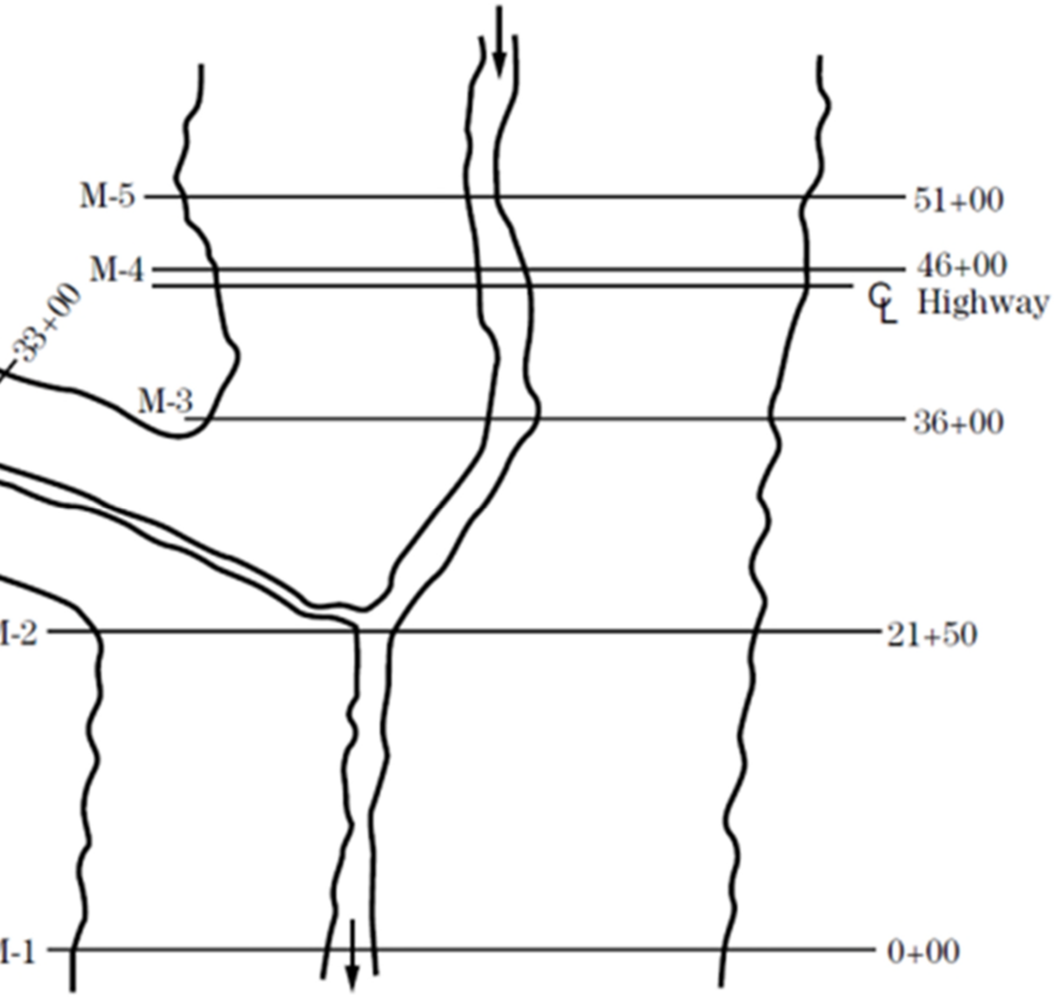
Channel Survey



- VSWHB recommends at the very minimum:
  - Three cross-sections minimum 50’ apart from discharge point

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Channel Survey

- Channel top of bank should be well defined and identifiable
  - Flattening or change in bank slope
  - Flattened vegetation in direction of flow
  - Soil types
  - Other obvious indicators of frequent flow levels

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Channel Survey

- When top of bank not obvious:
- Hydrologic analysis of contributing drainage area for 2-year pre-developed peak discharge flow
- Manning's equation used to define cross-sectional flow

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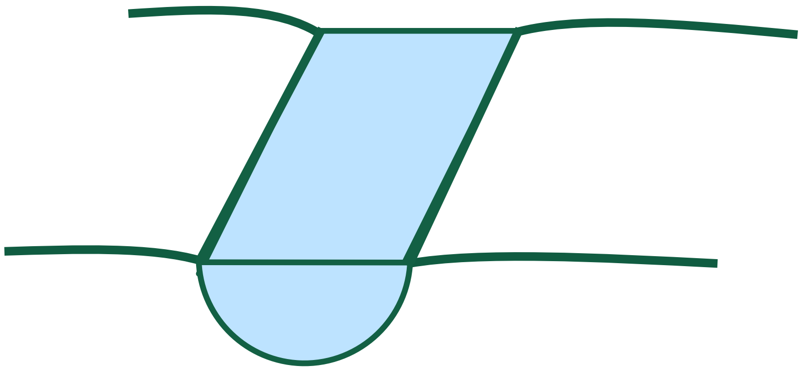
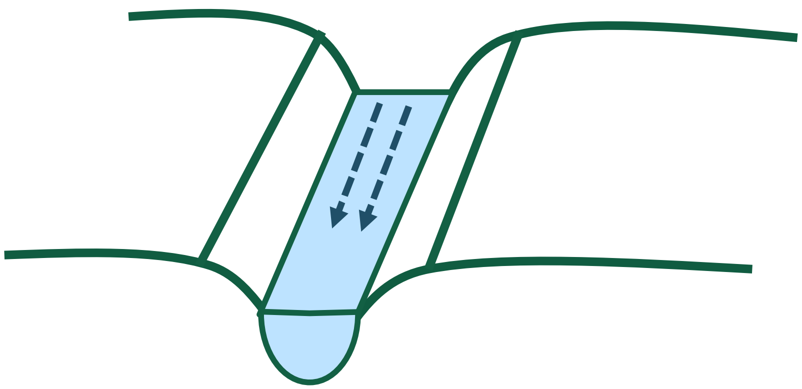
Permissible Tractive Force Method

- An alternative method for demonstrating channel protection also known as Permissible Shear Method
- Considers physical factors of bed material, channel geometry, depth, and velocity of flow
- Formulas for average tractive force as well as for shear stress in bends
- More information included in Chapter 7 of the VDOT Drainage Manual

Maximum Permissible Velocity Method



Capacity



Erodibility

- Both channel capacity and velocity of flow are functions of:
  - Channel lining
  - Cross-sectional area
  - Slope

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Maximum Permissible Velocity Method

Manning's Equation

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

V = velocity (fps)

n = Manning's roughness coefficient

R = hydraulic radius (A/P)

A = wetted cross-sectional area

P = wetted perimeter(ft)

s = slope (in ft/ft - NOT percent slope)

Two main equations:

Manning's Equation

Continuity Equation

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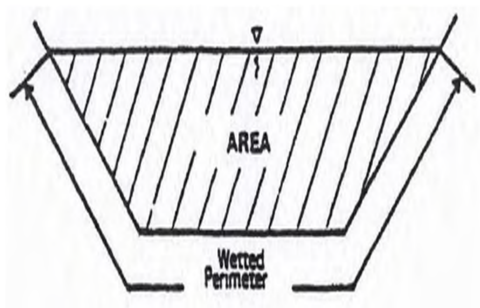
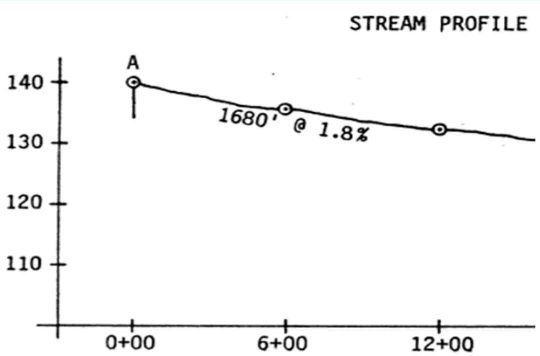
The Inputs



Channel Geometry (Cross-sectional)

- Area (A)
- Wetted Perimeter (P)
- Hydraulic Radius R=A/P



Channel slope (s)

(Gradient)

Channel Lining

(Manning's n)

Maximum Permissible Velocity Method

Manning's Equation

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

V = velocity (fps)

n = Manning's roughness coefficient

R = hydraulic radius (A/P)

A = wetted cross-sectional area

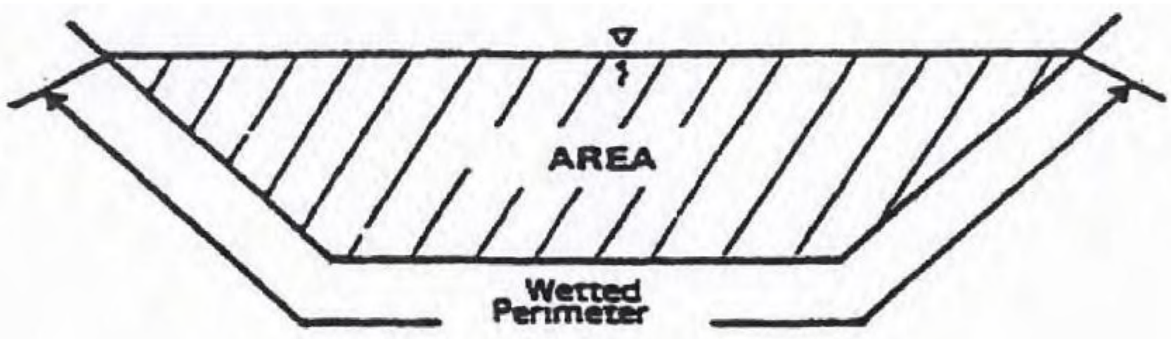
P = wetted perimeter(ft)

s = slope (in ft/ft - NOT percent slope)

The Inputs:

- Channel Geometry
  - Area (A)
  - Wetted Perimeter (P)
  - Hydraulic Radius (R=A/P)
- Channel slope (S)
- Channel Lining (Manning's n)

Maximum Permissible Velocity Method



<u>Note</u>:
Area (A) is actually cross-sectional area of flow within channel

The Inputs:

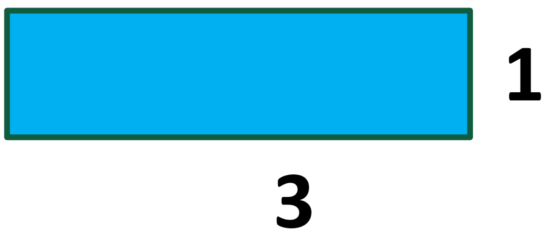
Area (A):
Cross-sectional area

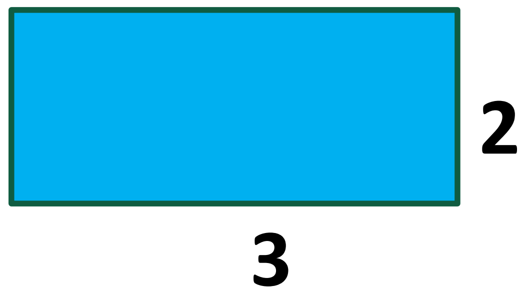
Wetted Perimeter (P)

Hydraulic Radius (r)
= A/P

Maximum Permissible Velocity Method

Calculate A, P and R for each:





A = 1x3 = 3
P = 1+3+1 = 5
R = A/P
= 3/5 = 0.6

A = 2x3 = 6
P = 2+3+2 = 7
R = A/P
= 6/7 = 0.86

The Inputs:

Area (A):
Cross-sectional area

Wetted Perimeter (P)

Hydraulic Radius (r)
= A/P

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Table 12-1: Equations for Primary Channel Cross-Sections

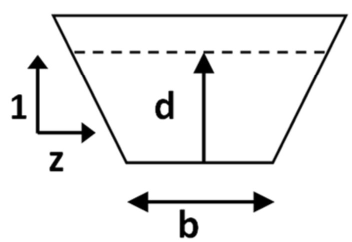
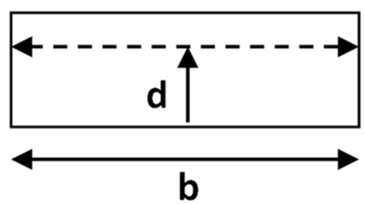
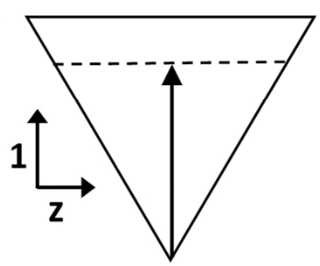
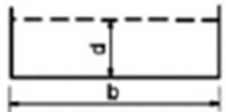
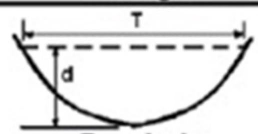
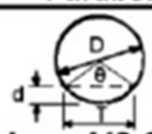
Section	Area A	Wetted Perimeter P	Hydraulic Radius r = A/P	Top Width T
	$bd + zd^2$	$b + 2d\sqrt{z^2 + 1}$	$\dfrac{bd + zd^2}{b + 2d\sqrt{z^2 + 1}}$	$b + 2zd$
	bd	$b + 2d$	$\dfrac{bd}{b + 2d}$	b
	zd^2	$2d\sqrt{z^2 + 1}$	$\dfrac{zd}{2\sqrt{z^2 + 1}}$	$2zd$

Table 12-2: Equations for Channel Cross-Sections

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

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

[2] $\theta = 4\sin^{-1}\sqrt{d/D}$

[3] $\theta = 4\cos^{-1}\sqrt{d/D}$

Insert θ in degrees in above equations

National Engineering Handbook, Section 5, ES-33

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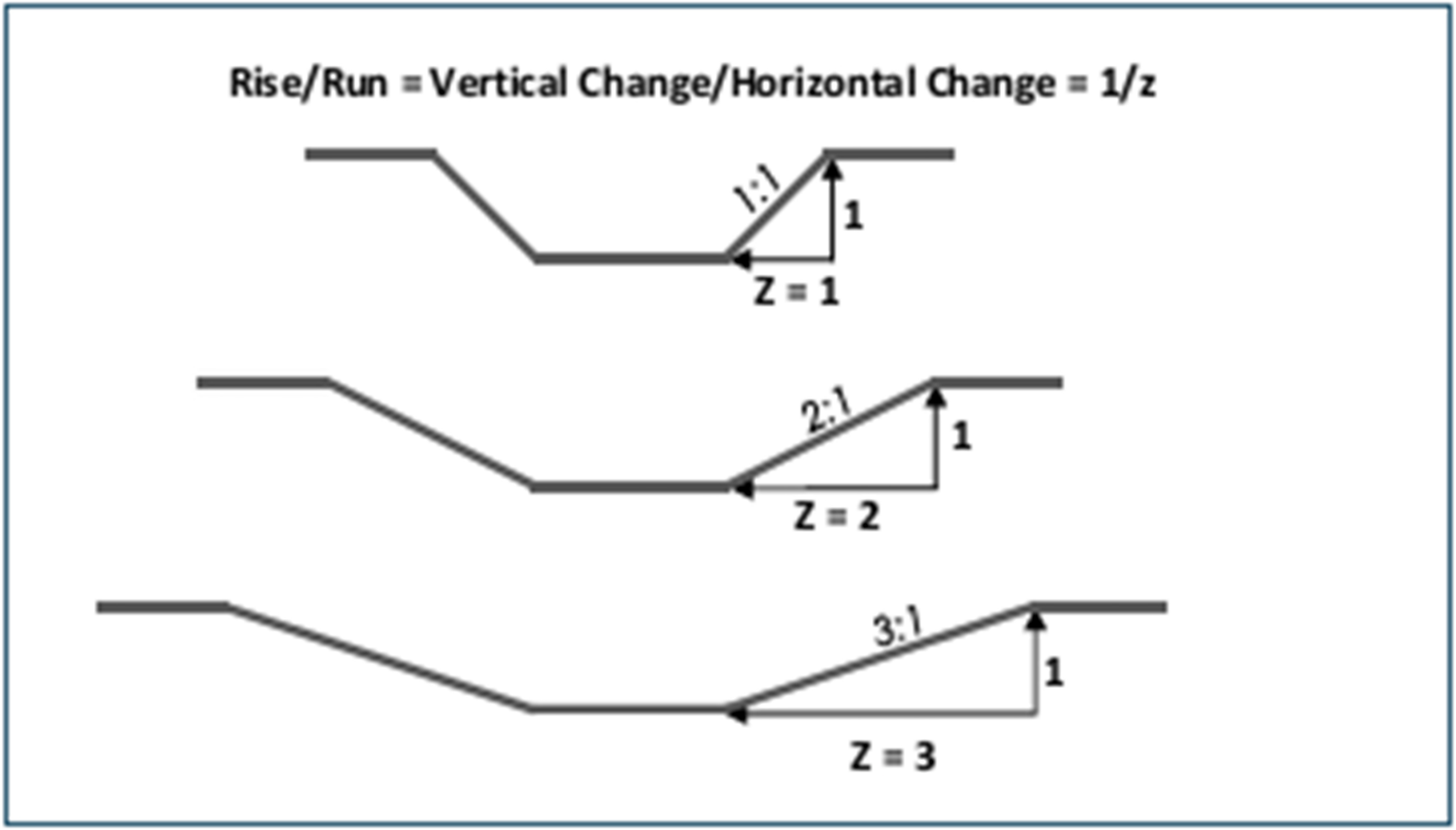
Channel Side Slopes



Input: Channel Slope (Longitudinal)

- *Rise/Run*
- *Elevation change (feet)/Channel Length (feet)*
- ***Channel slope*** – take along channel length at cross-sections for average longitudinal slope
- ***Energy slope*** - hydraulic grade line calculation should accompany analysis of existing or proposed pipe system (verify capacity for 10-year storm)

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Input: Channel Lining

- Susceptibility to erosion estimated using roughness coefficient
  – Manning’s “n” or Manning’s Roughness Coefficient
  – Some Manning’s n tables on pages 12-15
  – Available in many publications including the VDOT Drainage Manual

Table 12-3

I. Closed Conduits	Manning's n Range[2]
A. Concrete pipes	0.011-0.013
B. Corrugated-metal pipe or pipe-arch.	
1. 2 2/3 by 1/2-in. corrugation (riveted pipe):[3]	
a. Plain or fully coated	0.024
b. Paved invert (range values are for 25 and 50 percent of circumference paved):	
(1) Flow full depth	0.021-0.018
(2) Flow 0.8 depth	0.021-0.016
(3) Flow 0.6 depth	0.019-0.013
2. 6 by 2-in. corrugation (field bolted)	0.03
C. Vitrified clay pipe	0.012-0.014
D. Cast-iron pipe, uncoated	0.013
E. Steel pipe	0.009-0.011
F. Brick	0.014-0.017
G. Monolithic concrete:	
1. Wood forms, rough	0.015-0.017
2. Wood forms, smooth	
3. Steel forms	
H. Cemented rubble masonry walls:	0.012-0.013
1. Concrete floor and top	
2. Natural floor	
I. Laminated treated wood	
J. Vitrified clay liner plates	
II. Open Channels, Lined[4] (straight lignment):[5]	0.015
A. Concrete with surfaces as indicated:	
1. Formed, no finish	0.013-0.017
2. Trowel finish	0.012-0.014
3. Float finish	0.013-0.015
4. Float finish, some gravel on bottom	0.015-0.017
5. Gunite, good section	0.016-0.019
6. Gunite, wavy section	0.018-0.022
B. Concrete, bottom float finished, sides as indicated:	
1. Dressed stone in mortar	0.015-0.017
2. Random stone in mortar	0.017-0.020
3. Cement rubble masonry	0.020-0.025
4. Cement rubble masonry, plastered	0.016-0.020
5. Dry rubble (riprap)	0.020-0.030
C. Gravel bottom, sides as indicated:	
1. Formed concrete	0.017-0.020
2. Random stone in mortar	0.020-0.023
3. Dry rubble (riprap)	0.023-0.033
D. Brick	0.014-0.017
E. Asphalt:	
1. Smooth	0.013
2. Rough	0.016
F. Wood, planed, clean	0.011-0.013
G. Concrete-lined excavated rock:	
1. Good section	0.017-0.020
2. Irregular section	0.022-0.027
III. Open Channels, excavated[4] (straight alignment,[5] natural lining):	
A. Earth, uniform section:	
1. Clean, recently completed	0.016-0.018
2. Clean, after weathering	0.018-0.020
3. With short grass, few weeds	0.022-0.027
4. In gravelly soil, uniform section, clean	0.022-0.025
B. Earth, fairly uniform section:	
1. No vegetation	0.022-0.025
2. Grass, some weeds	0.025-0.030
3. Dense weeds or aquatic plants in deep channels	0.030-0.035
4. Sides clean, gravel bottom	0.025-0.030
5. Sides clean, cobble bottom	0.030-0.040
C. Dragline excavated or dredged:	
1. No vegetation	0.028-0.033
2. Light brush on banks	0.035-0.050
D. Rock:	
1. Based on design section	0.035
2. Based on actual mean section:	
a. Smooth and uniform	0.035-0.050
b. Jagged and irregular	0.040-0.045
E. Channels not maintained, weeds and brush uncut:	
1. Dense weeds, high as flow depth	0.08-0.12
2. Clean bottom, brush on sides	0.05-0.08
3. Clean bottom, brush on sides, highest stage of flow	0.07-0.11
4. Dense brush, high stage	0.10-0.14

IV. Highway Channels and Swales with Maintained Vegetation[6] (values shown here are for velocities of 2 and 6 f.p.s.):	Manning's n Range[2]
A. Depth of Flow up to 0.7 foot:	
1. Bermudagrass, Kentucky bluegrass, Buffalograss:	
a. Mowed to 2-inches	0.07-0.045
b. Length 4–6 inches	0.09-0.05
2. Good stand, any grass:	
a. Length about 12-inches	
b. Length about 24-inches	0.18-0.09
3. Fair stand, any grass:	0.30-0.15
a. Length about 12-inches	
b. Length about 24-inches	0.14-0.08
B. Depth of flow 0.7-1.5 feet:	0.25-0.13
1. Bermudagrass, Kentucky bluegrass, Buffalograss:	
a. Mowed to 2-inches	
b. Length 4–6 inches	0.05-0.035
2. Good stand, any grass:	0.06-0.04
a. Length about 12-inches	
b. Length about 24-inches	0.12-0.07
3. Fair stand, any grass:	0.20-0.10
a. Length about 12-inches	
b. Length about 24-inches	0.10-0.06
V. Street and Expressway Gutters:	0.17-0.09
A. Concrete gutter, troweled finish	
B. Asphalt pavement:	0.012
1. Smooth texture	
2. Rough texture	0.013
C. Concrete Gutter with asphalt pavement:	0.016
1. Smooth	
2. Rough	0.013
D. Concrete pavement:	0.015
1. Float finish	
2. Broom finish	0.014
E. For gutters with small slope, where sediment may accumulate, increase above values of n by	0.016
	0.002
VI. Natural stream channels:[8]	
A. Minor streams[9] (surface width at flood stage less than 100 ft):	
1. Fairly regular section:	
a. Some grass and weeds, little or no brush	0.030-0.035
b. Dense growth of weeds, depth of flow materially greater than weed height	0.035-0.05
c. Some weeds, light brush on banks	0.035-0.05
d. Some weeds, heavy brush on banks	0.05-0.07
e. Some weeds, dense willows on banks	0.06-0.08
f. For trees within channel, with branches submerged at high stage, increase all above values by	*0.01-0.02*
2. Irregular sections, with pools, slight channel meander; increase values given in 1a–e about	*0.01-0.02*
3. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stage:	
a. Bottom of gravel, cobbles, and few boulders	0.04-0.05
b. Bottom of cobbles, with large boulders	0.05-0.07
B. Flood plains (adjacent to natural streams)	
1. Pasture, no brush:	
a. Short grass	0.030-0.035
b. High grass	0.035-0.05
2. Cultivated areas:	
a. No crop	0.03-0.04
b. Mature row crops	0.035-0.045
c. Mature field crops	0.04-0.05
3. Heavy weeds, scattered brush	0.05-0.07
4. Light brush and trees:[10]	
a. Winter	0.05-0.06
b. Summer	0.06-0.08
5. Medium to dense brush:[10]	
a. Winter	0.07-0.11
b. Summer	0.10-0.16
6. Dense willows, summer, not bent over by current	0.15-0.20
7. Cleared land with tree stumps, 100–150 per acre:	
a. No sprouts	0.04-0.05
b. With heavy growth of sprouts	0.06-0.08
8. Heavy stand of timber, a few down trees, little undergrowth:	
a. Flood depth below branches	0.10-0.12
b. Flood depth reaches branches	0.12-0.16
C. Major streams (surface width at flood stage more that 100 ft.): Roughness coefficient usually less than for minor streams of similar description on account of less effective resistance offered by irregular banks or vegetation on banks. Values of n may be somewhat reduced. Follow recommendation in publication cited[8] if possible. The value of n for larger streams of most regular section, with no boulders or brush, may be in the range of	0.028-0.033

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Table 12-4: Manning's "n" Values for Pipes, Canals, and Ditches

MANNING'S "n" VALUES

Surface	Best	Good	Fair	Bad
Uncoated cast-iron pipe	0.012	0.013	0.014	0.015
Coated cast-iron pipe	0.011	0.012*	0.013*	
Commercial wrought-iron pipe, black	0.012	0.013	0.014	0.015
Commercial wrought-iron pipe, galvanized	0.013	0.014	0.015	0.017
Riveted and spiral steel pipe	0.013	0.015*	0.017*	
Common clay drainage tile	0.011	0.012*	0.014*	0.017
Neat cement surfaces	0.010	0.011	0.012	0.013
Cement mortar surfaces	0.011	0.012	0.013*	0.015
Concrete pipe	0.012	0.013	0.015*	0.016
Concrete-lined channels	0.012	0.014*	0.016*	0.018
Cement-rubble surface	0.017	0.020	0.025	0.030
Dry-rubble surface	0.025	0.030	0.033	0.035
Canals and ditches:				
Earth, straight and uniform	0.017	0.020	0.0225*	0.025
Rock cuts, smooth and uniform	0.025	0.030	0.033	0.035
Rock cuts, jagged and irregular	0.035	0.040	0.045	
Winding sluggish canals	0.0225	0.025*	0.0275	0.030
Dredged earth channels	0.025	0.0275*	0.030	0.033
Canals with rough stony beds, weeds on earth banks	0.025	0.030	0.035*	0.040
Earth bottom, rubble sides	0.028	0.030*	0.033*	0.035

* Values commonly used in designing.

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Table 12-5 Manning's "n" Values for Natural Stream Channels

MANNING'S "n" VALUES

Surface	Best	Good	Fair	Bad
<u>Natural Stream Channels</u>:				
1. Clean, straight bank, full stage, no rifts or deep pools	0.025	0.0275	0.030	0.033
2. Same as #1, but some weeds and stones	0.030	0.033	0.035	0.040
3. Winding, some pools and shoals, clean	0.033	0.035	0.040	0.045
4. Same as #3, lower stages, more ineffective slope and sections	0.040	0.045	0.050	0.055
5. Same as #3, some weeds and stones	0.035	0.040	0.045	0.050
6. Same as #4, stony sections	0.045	0.050	0.055	0.060
7. Sluggish river reaches, rather weedy or with very deep pools	0.050	0.060	0.070	0.080
8. Very weedy reaches	0.075	0.100	0.125	0.150

* Values commonly used in designing.

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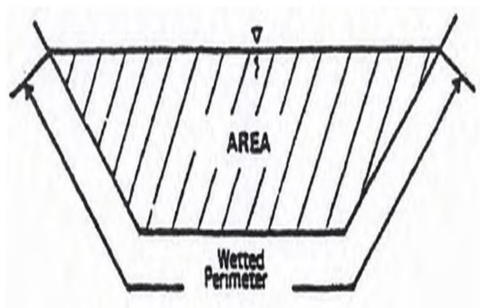
Table 12-6: Manning's "n" Values for Select Channel Lining Materials

MANNING "n" VALUES FOR SELECTED CHANNEL LINING MATERIALS

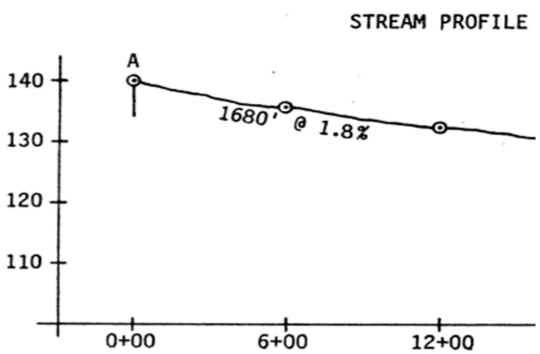
Material	Range of "n" Values
Concrete	
- Formed	0.013 - 0.017
- Trowel Finish	0.012 - 0.014
- Float Finish	0.013 - 0.015
- Gunite	0.016 - 0.022
Gravel Bed, Formed Concrete Sides	0.017 - 0.020
Asphalt Concrete	
- Smooth	0.013
- Rough	0.016
Corrugated Metal	
- 2-2/3" x 1/2" Corrugations	0.024
- 6" x 2" Corrugations	0.032
Concrete Pipe	0.011 - 0.013

Q&A: The Inputs



Channel Geometry (Cross-sectional)

- Area (A)
- Wetted Perimeter (P)
- Hydraulic Radius R=A/P



Channel slope (s)

(Gradient)

Channel Lining

(Manning's n)

Verifying Permissible Velocity

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

- Calculate velocity
- Compare to permissible velocity of lining
- Permissible velocities (C-ECM-15 Outlet Protection, VSWHB) or in manufacturer's specifications

Table 12-7: Permissible Velocities for Grass-Lined Channels, Table C-ECM-15-2, VSWHB

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

Channel Slope	Lining	Erosion-Resistant Soil Velocity (ft/s)	Easily Eroded Soil Velocity (ft/s)
0 – 5%	Bermudagrass	6	4.5
	Reed canarygrass Tall fescue Kentucky bluegrass	5	3.75
	Grass-legume mixture	4	3
	Red fescue Redtop Annual Lespedeza Small grains Temporary vegetation	2.5	1.875
5 – 10%	Bermudagrass	5	3.75
	Reed canarygrass Tall fescue Kentucky bluegrass	4	3
	Grass-legume mixture	3	2.25
>10%	Bermudagrass	4	3
	Reed canarygrass Tall fescue Kentucky bluegrass	3	2.25

Source: Schwab, G., et al., 1966

Table 12-8: Permissible Velocities for Unlined Earthen Channels, Table C-ECM-15-3, VSWHB

Table C-ECM-15-3 Permissible Velocities for Earth Linings	
Soil Types	**Permissible Velocities (ft/s)**
Fine Sand (non-colloidal)	2.5
Sandy Loam (non-colloidal)	2.5
Silt Loam (non-colloidal)	3.0
Ordinary Firm Loam	3.5
Fine Gravel	5.0
Stiff Clay (very colloidal)	5.0
Graded, Loam to Cobbles (non-colloidal)	5.0
Graded, Silt to Cobbles (colloidal)	5.5
Alluvial Silts (non-colloidal)	3.5
Alluvial Silts (colloidal)	5.0
Coarse Gravel (non-colloidal)	6.0
Cobbles and Shingles	5.5
Shales and Hard Plans	6.0

Source: Schwab, G., et al, 1966

STRAIGHT CHANNELS

Table C-ECM-15-2 Permissible Velocities for Grass-Lined Channels			
Channel Slope	Lining	Erosion-Resistant Soil Velocity (ft/s)	Easily Eroded Soil Velocity (ft/s)
0 – 5%	Bermudagrass	6	4.5
	Reed canarygrass Tall fescue Kentucky bluegrass	5	3.75
	Grass-legume mixture	4	3
	Red fescue Redtop Annual Lespedeza Small grains Temporary vegetation	2.5	1.875
5 – 10%	Bermudagrass	5	3.75
	Reed canarygrass Tall fescue Kentucky bluegrass	4	3
	Grass-legume mixture	3	2.25
>10%	Bermudagrass	4	3
	Reed canarygrass Tall fescue Kentucky bluegrass	3	2.25

Source: Schwab, G., et al., 1966

Table C-ECM-15-3 Permissible Velocities for Earth Linings	
Soil Types	Permissible Velocities (ft/s)
Fine Sand (non-colloidal)	2.5
Sandy Loam (non-colloidal)	2.5
Silt Loam (non-colloidal)	3.0
Ordinary Firm Loam	3.5
Fine Gravel	5.0
Stiff Clay (very colloidal)	5.0
Graded, Loam to Cobbles (non-colloidal)	5.0
Graded, Silt to Cobbles (colloidal)	5.5
Alluvial Silts (non-colloidal)	3.5
Alluvial Silts (colloidal)	5.0
Coarse Gravel (non-colloidal)	6.0
Cobbles and Shingles	5.5
Shales and Hard Plans	6.0

Source: Schwab, G., et al, 1966

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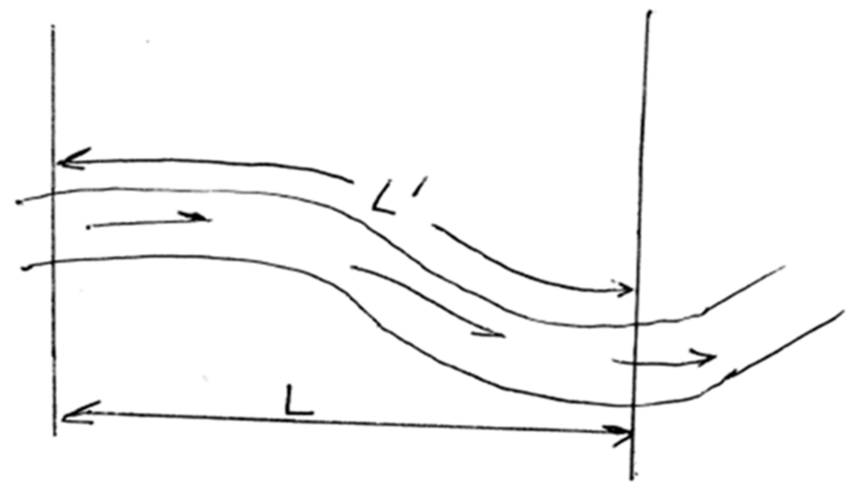
Table 12-9 Reduction in Permissible Velocity Based on Sinuosity

CURVED CHANNELS

REDUCTION IN PERMISSIBLE VELOCITY BASED ON SINUOSITY

Sinuosity*	Maximum Percent Reduction in Permissible Velocity
Slight (1.0 to 1.2)	5%
Moderate (1.2 to 1.5)	13%
Very Sinuous (1.5 and greater)	22%

* Sinuosity - degree of curvature of channel.



Sinuosity = L′/L

Source: Chow

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Q&A

TABLE 5-14

PERMISSIBLE VELOCITIES FOR GRASS-LINED CHANNELS

Channel Slope	Lining	Velocity* (ft./sec.)
0 - 5%	Bermudagrass	6
	Reed canarygrass Tall fescue Kentucky bluegrass	5
	Grass-legume mixture	4
	Red fescue Redtop Sericea lespedeza Annual lespedeza Small grains Temporary vegetation	2.5
5 - 10%	Bermudagrass	5
	Reed canarygrass Tall fescue Kentucky bluegrass	4
	Grass-legume mixture	3
Greater than 10%	Bermudagrass	4
	Reed canarygrass Tall fescue Kentucky bluegrass	3

* For highly erodible soils, decrease permissible velocities by 25%.

TABLE 5-22

PERMISSIBLE VELOCITIES FOR UNLINED EARTHEN CHANNELS

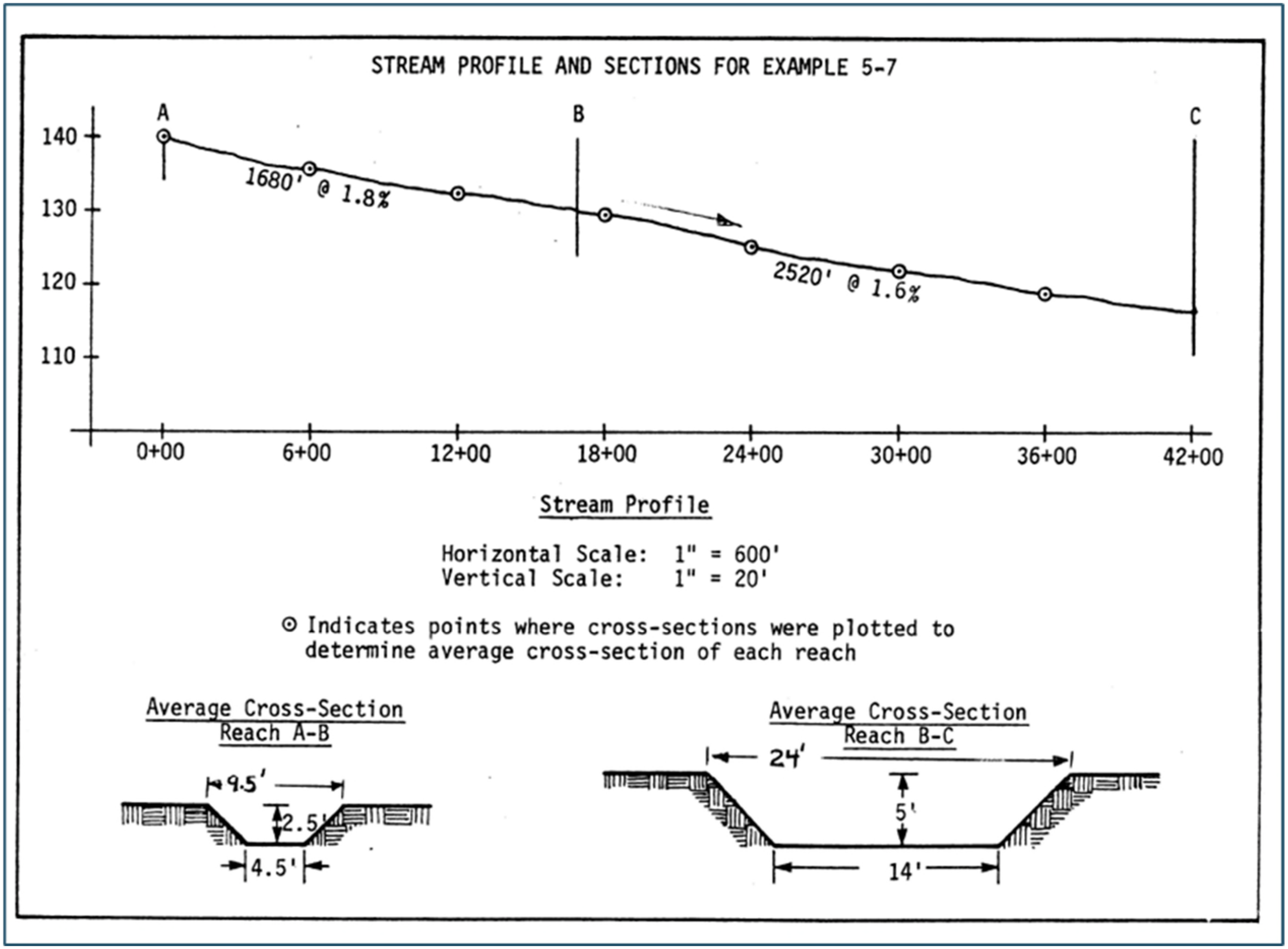
Soil Types	Permissible Velocity (ft./sec.)
Fine Sand (noncolloidal)	2.5
Sandy Loam (noncolloidal)	2.5
Silt Loam (noncolloidal)	3.0
Ordinary Firm Loam	3.5
Fine Gravel	5.0
Stiff Clay (very colloidal)	5.0
Graded, Loam to Cobbles (noncolloidal)	5.0
Graded, Silt to Cobbles (noncolloidal)	5.5
Alluvial Silts (noncolloidal)	3.5
Alluvial Silts (colloidal)	5.0
Coarse Gravel (noncolloidal)	6.0
Cobbles and Shingles	5.5
Shales and Hard Pans	6.0

Verifying Permissible Velocities

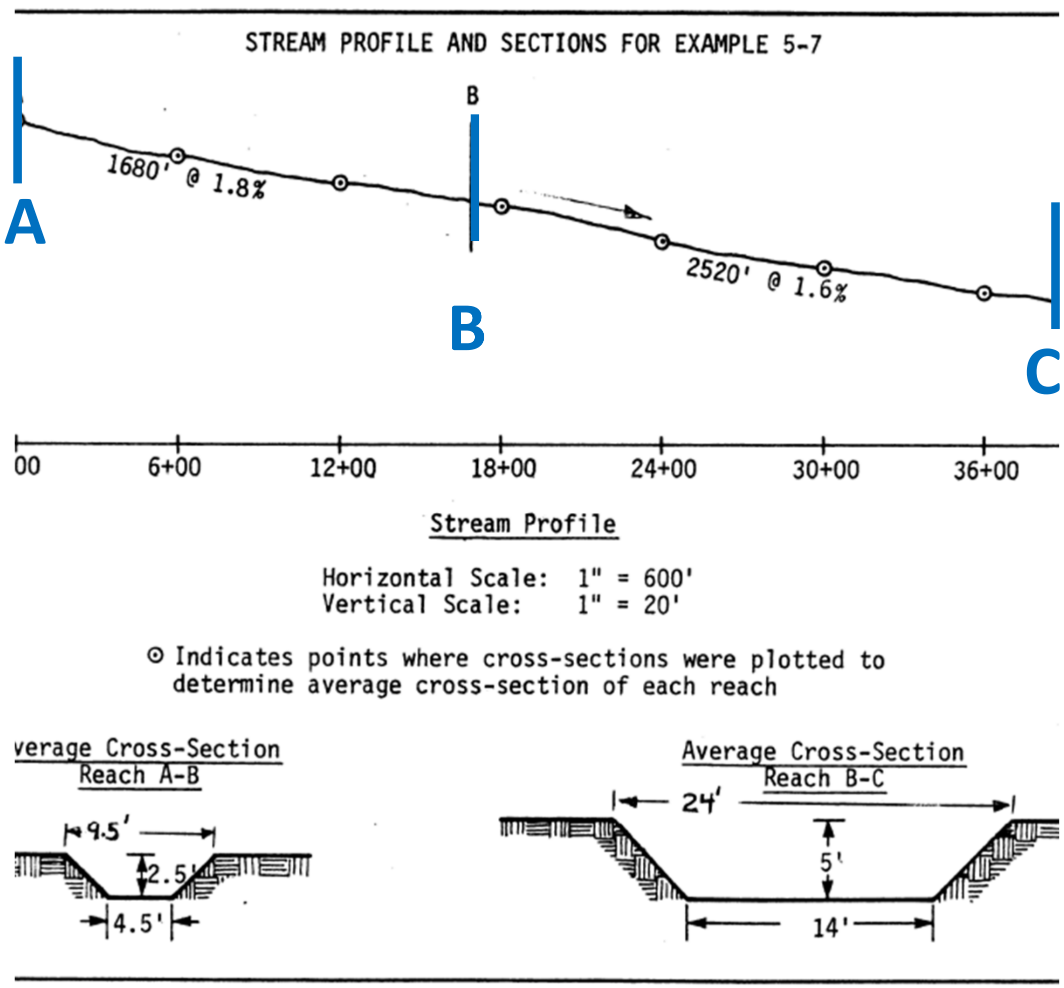
$$V = \frac{1.49}{n} \times R^{(2/3)} \times \sqrt{s}$$

Manning's Velocity Equation

Channel Sinuosity


STREAM PROFILE AND SECTIONS FOR EXAMPLE 5-7
A
B
C
140
130
120
110
1680' @ 1.8%
2520' @ 1.6%
0+00
6+00
12+00
18+00
24+00
30+00
36+00
42+00
Stream Profile
Horizontal Scale: 1" = 600'
Vertical Scale: 1" = 20'
⊙ Indicates points where cross-sections were plotted to determine average cross-section of each reach
Average Cross-Section Reach A-B
9.5'
2.5'
4.5'
Average Cross-Section Reach B-C
24'
5'
14'

Exercise



- Entire reach of channel analyzed (A to C) is 4,200 feet long
- Between A and C, elevation decreases from 140 feet to 120 feet (20 foot drop in elevation)

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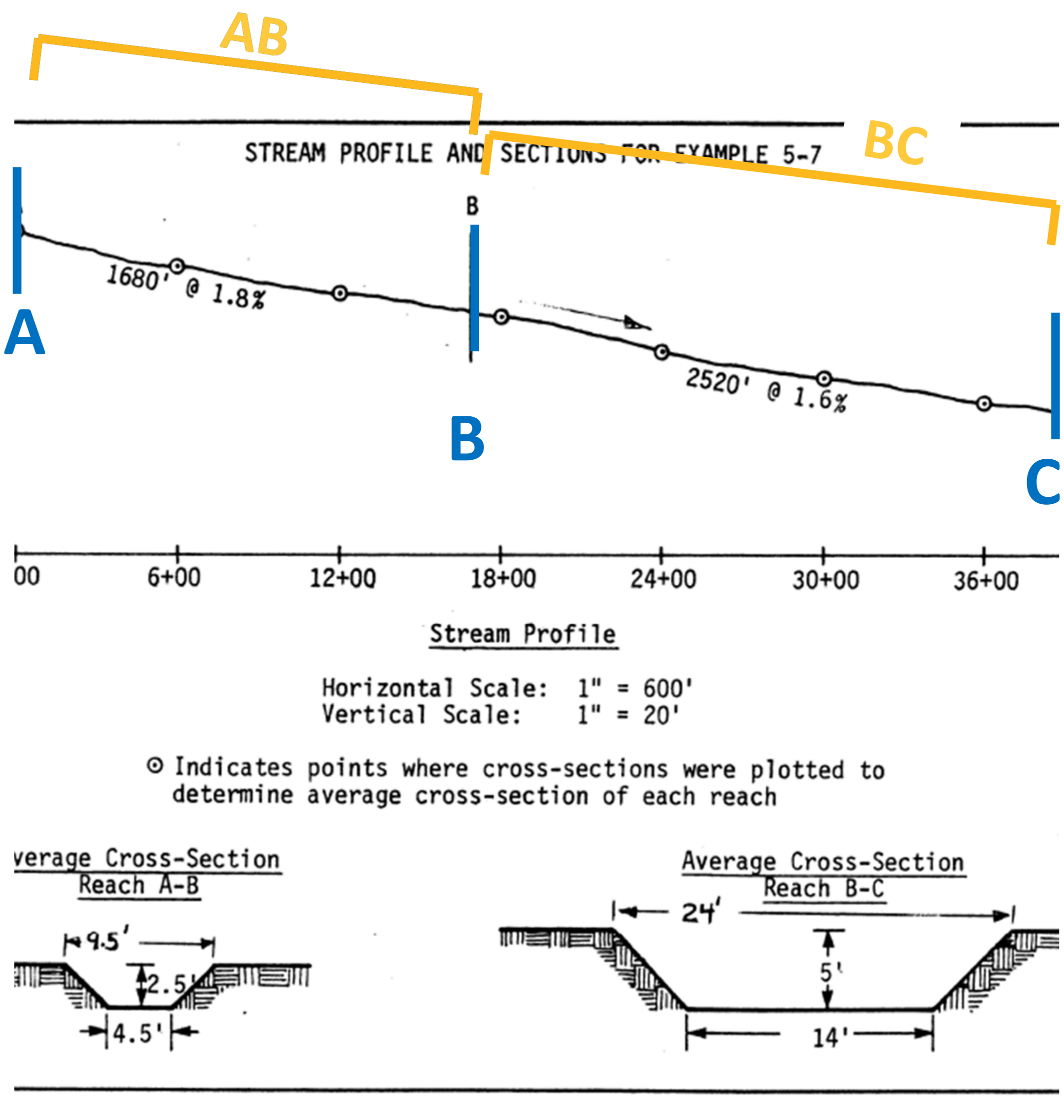
Exercise



- Channel has 2 reaches
- Reach AB analyzed at 3 cross-sections each 600 feet apart
  - Sta 0+00
  - Sta 6+00
  - Sta 12+00)
- Reach BC analyzed at 4 cross-sections each 600 feet apart

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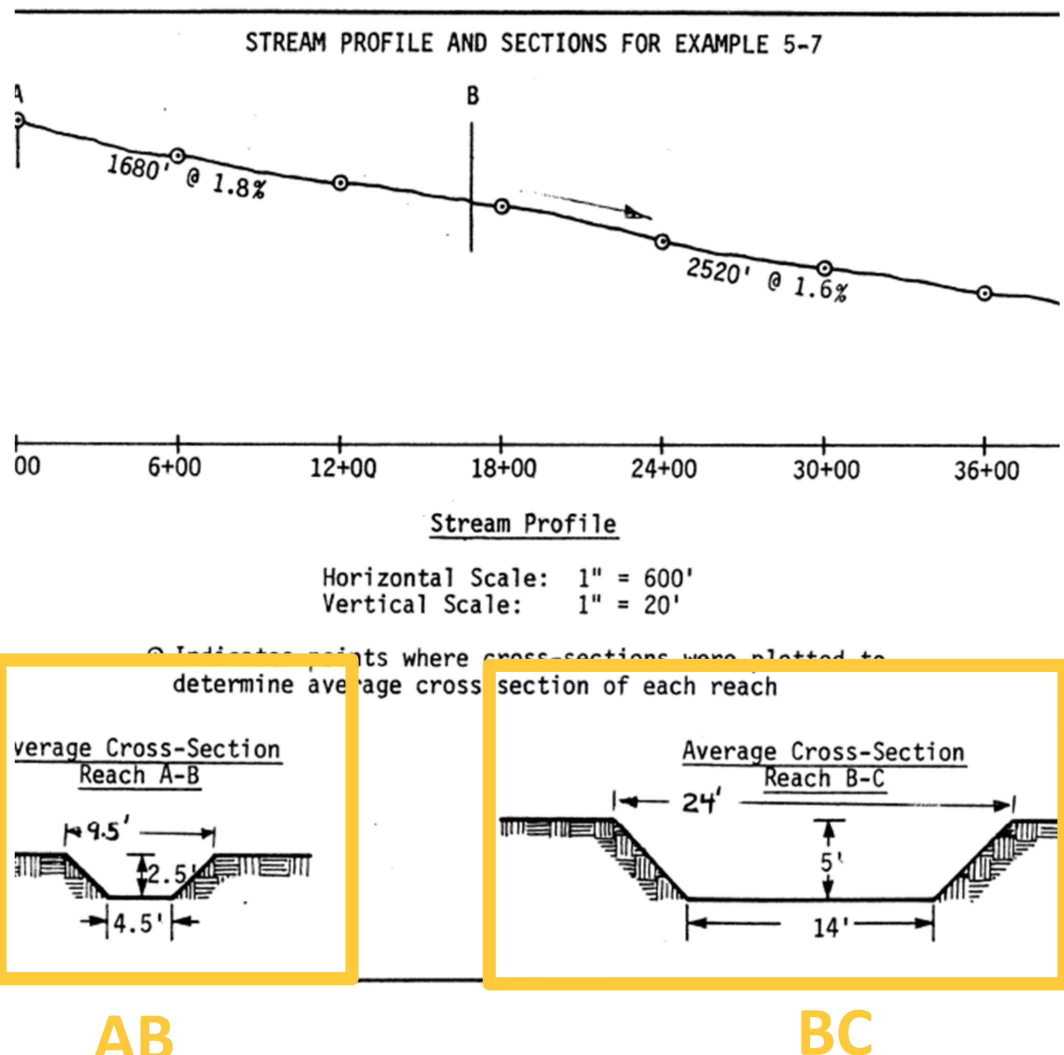
Exercise



- Average cross-section for each reach shown in cross-sectional diagrams.

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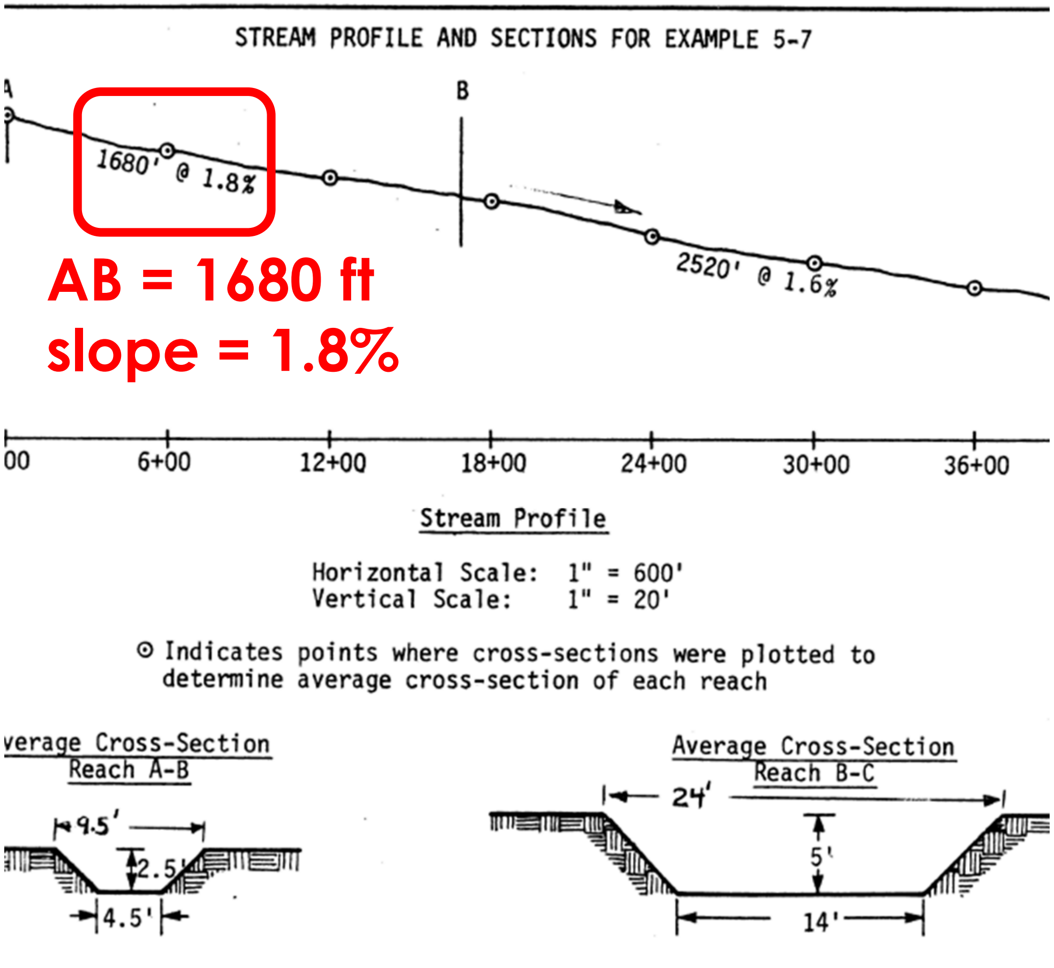
Exercise (1)



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

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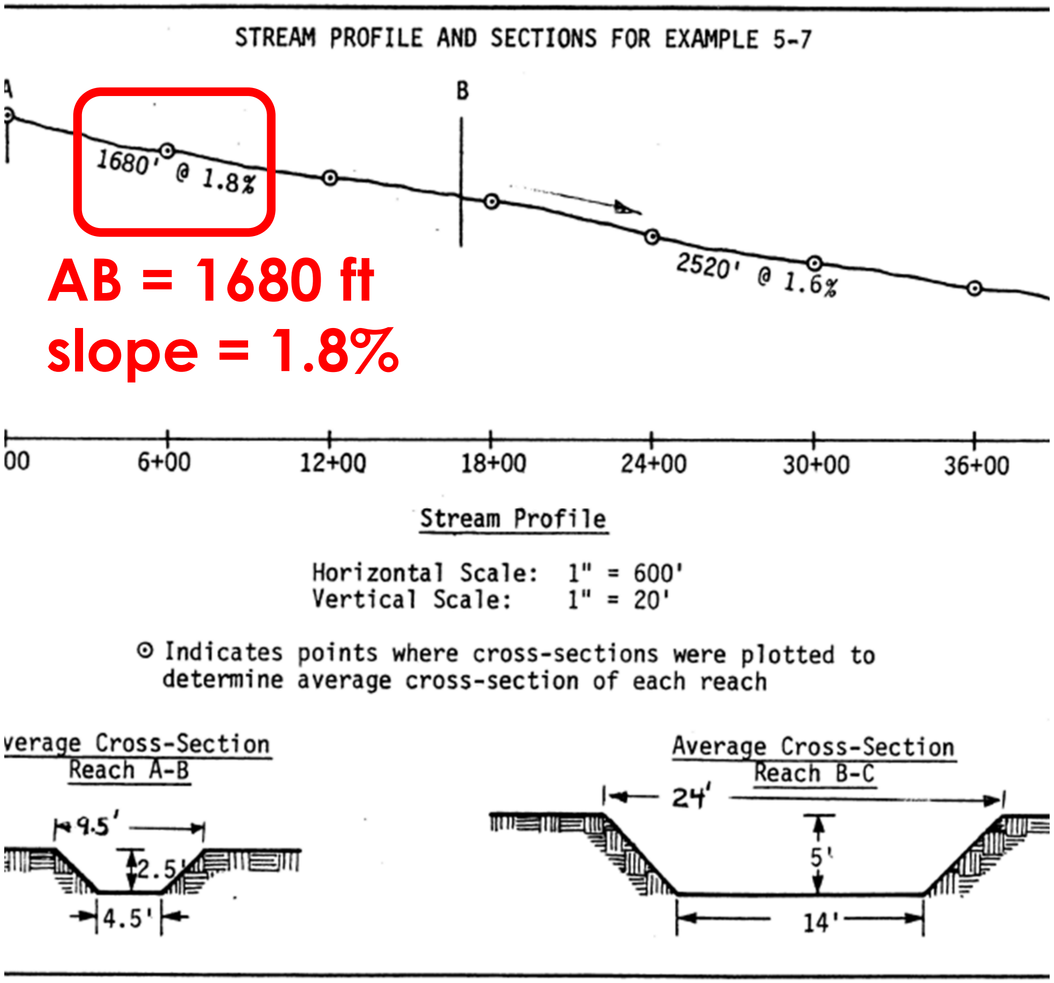
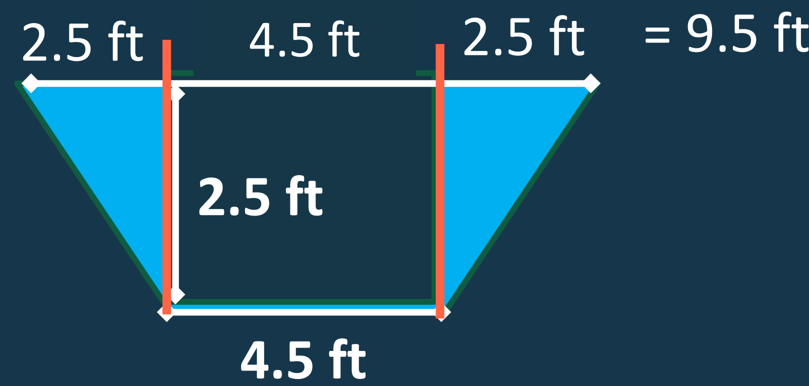
Exercise – AB Hydraulic Radius



For z:

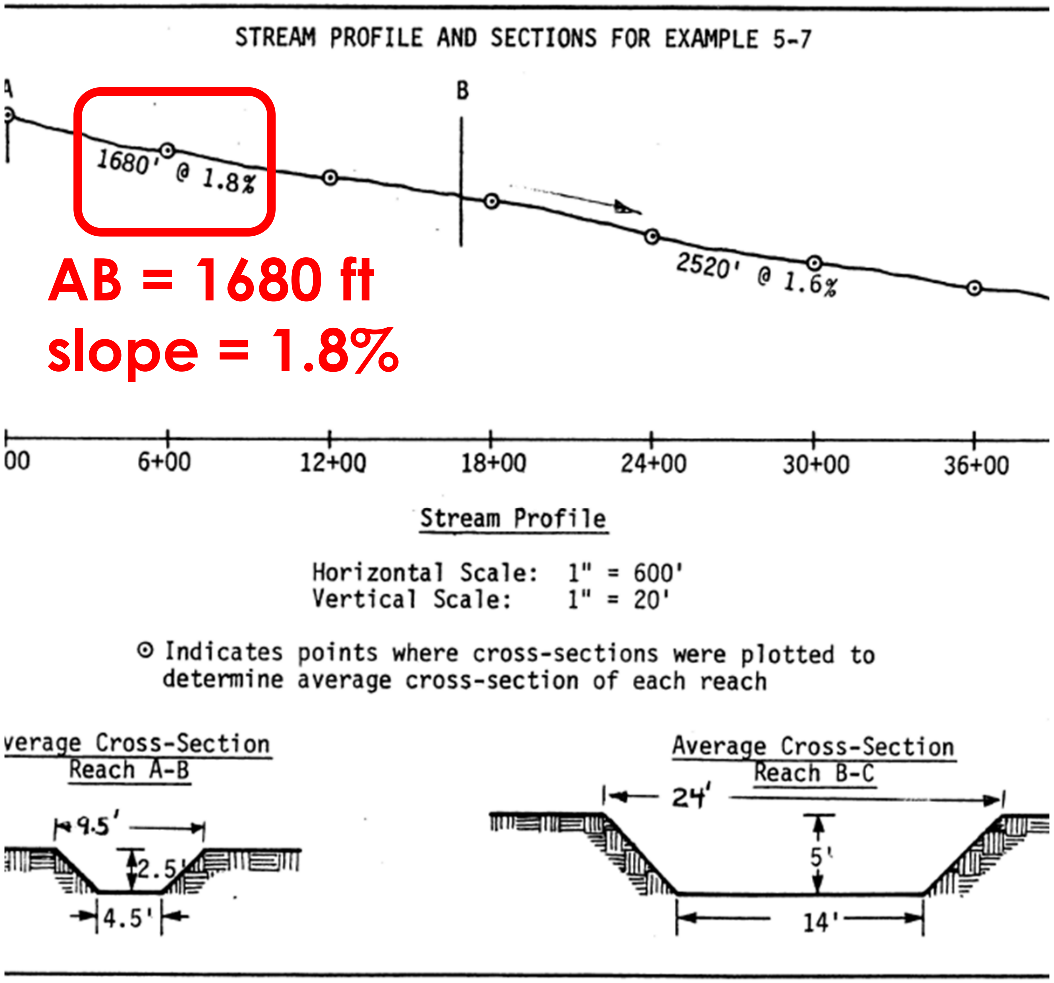
b=4.5 d=2.5



(9.5 ft – 4.5 ft)/2
= 2.5 ft

z = 2.5/2.5
= 1

Exercise – AB Hydraulic Radius



Use formula from Table 12-2, p. 8,
And b=4.5 d=2.5 z=1

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

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

$$R = \frac{17.5}{11.5} = 1.5$$

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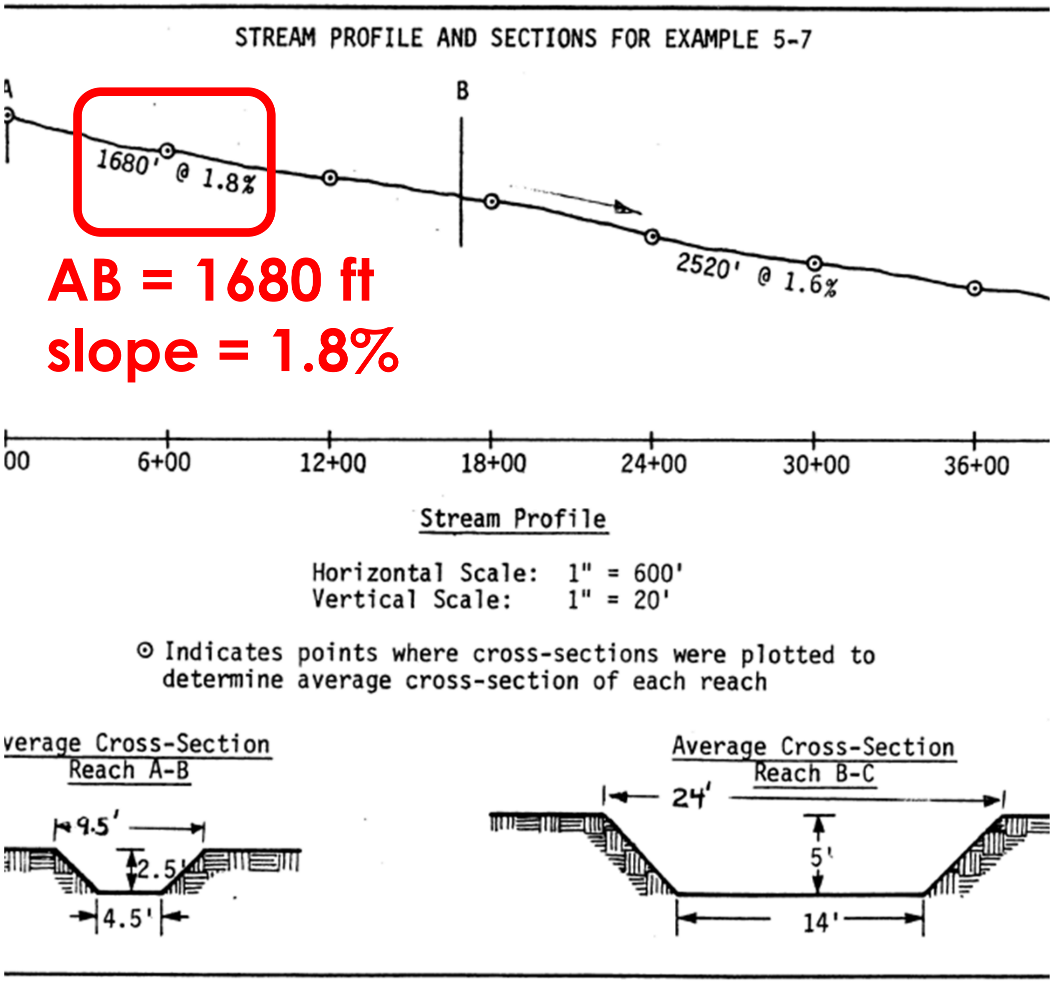
Exercise – AB velocity



Manning's Equation, p. 4,

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

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

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

$$V = 8.7\ ft/sec$$

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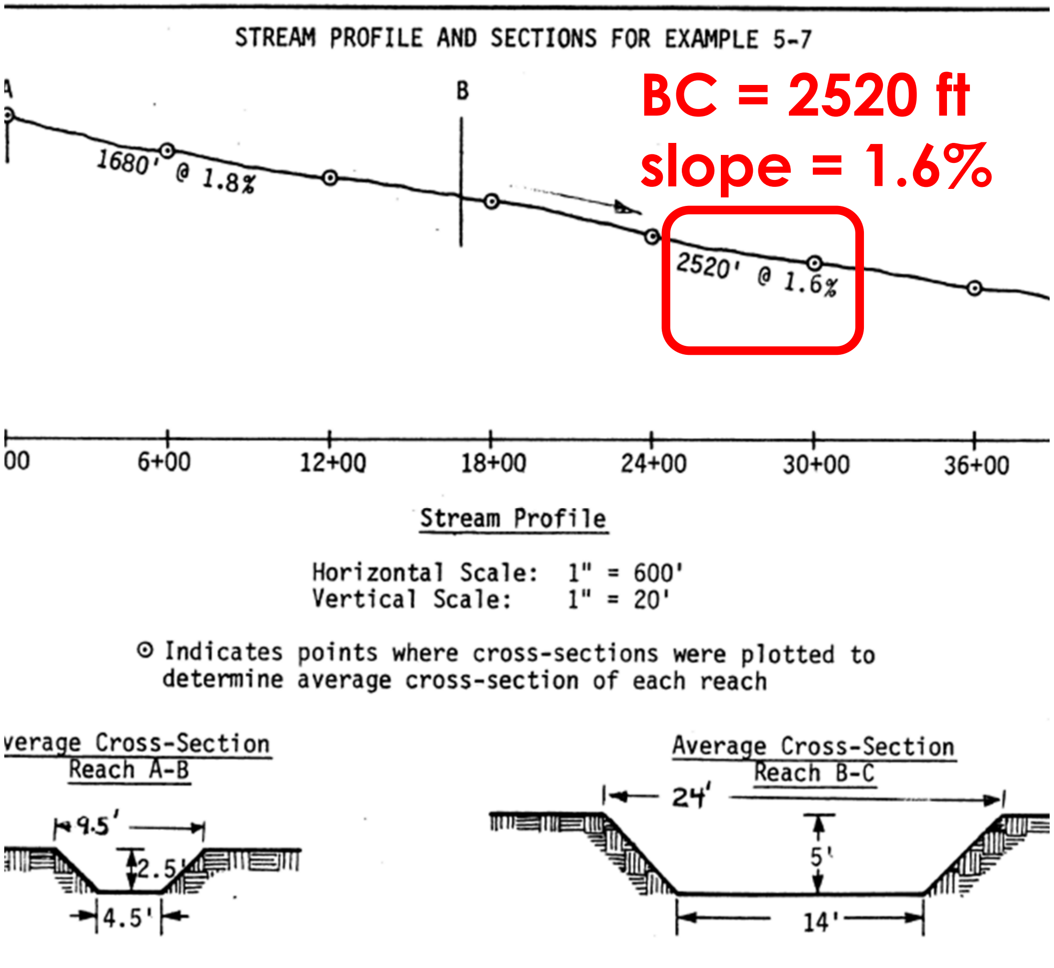
Exercise – BC Hydraulic Radius



Use formula from Table 12-2, p. 8,

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

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

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

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

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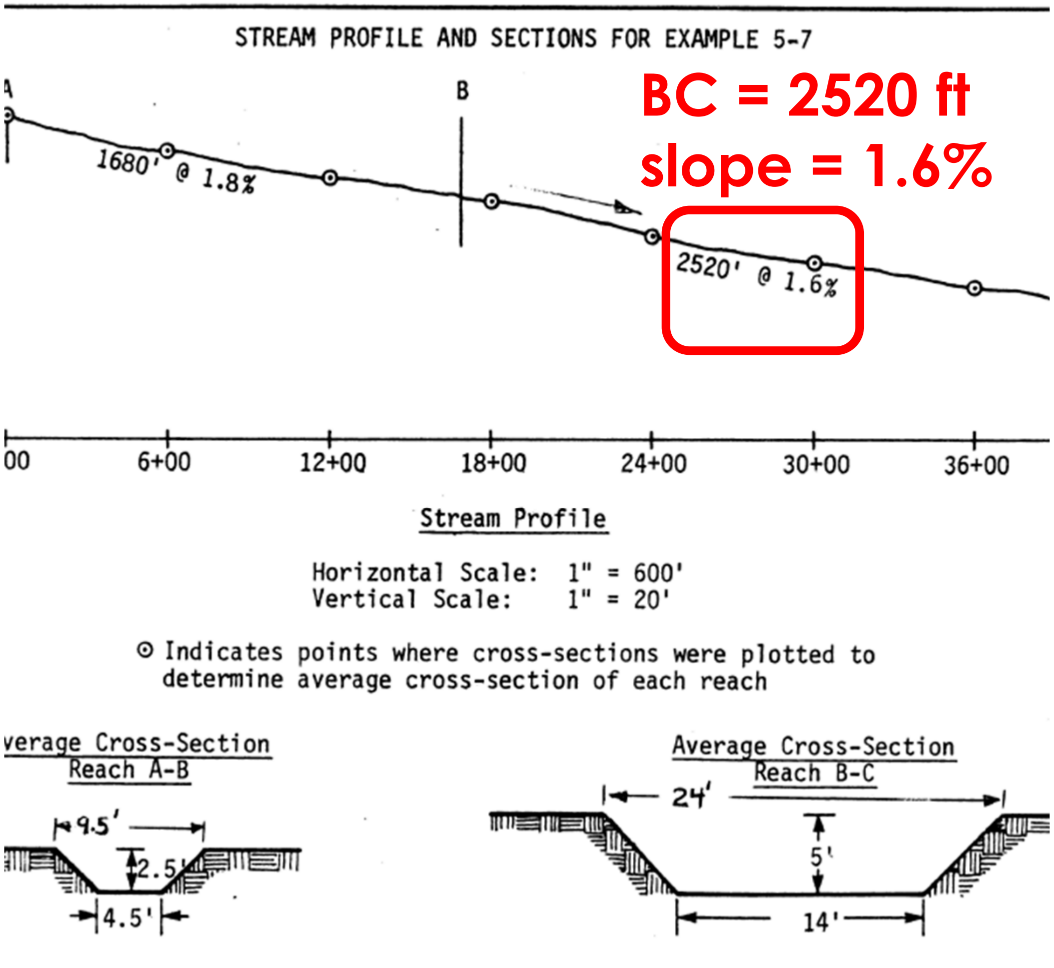
Exercise – BC velocity



Manning's Equation, p. 4,

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

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

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

$$V = 14.2\ ft/sec$$

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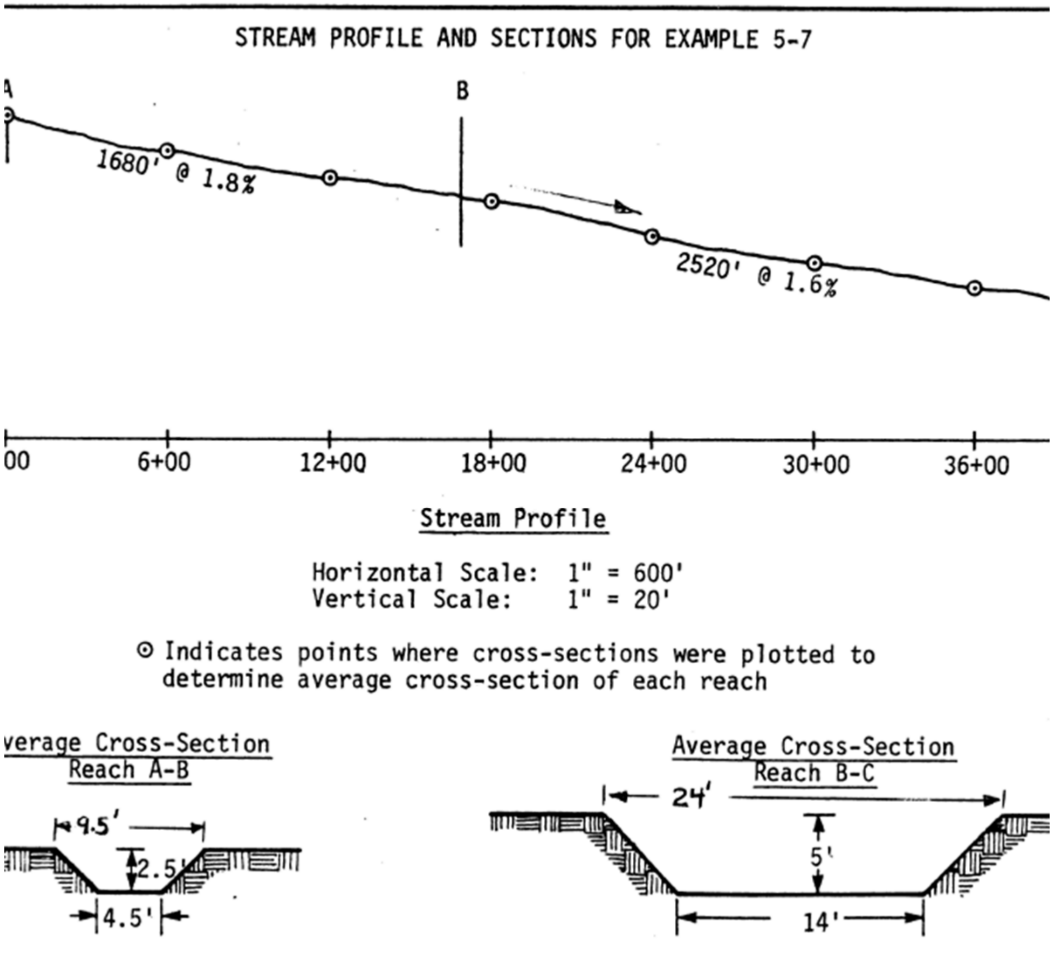
Exercise – (2) Permissible Velocity



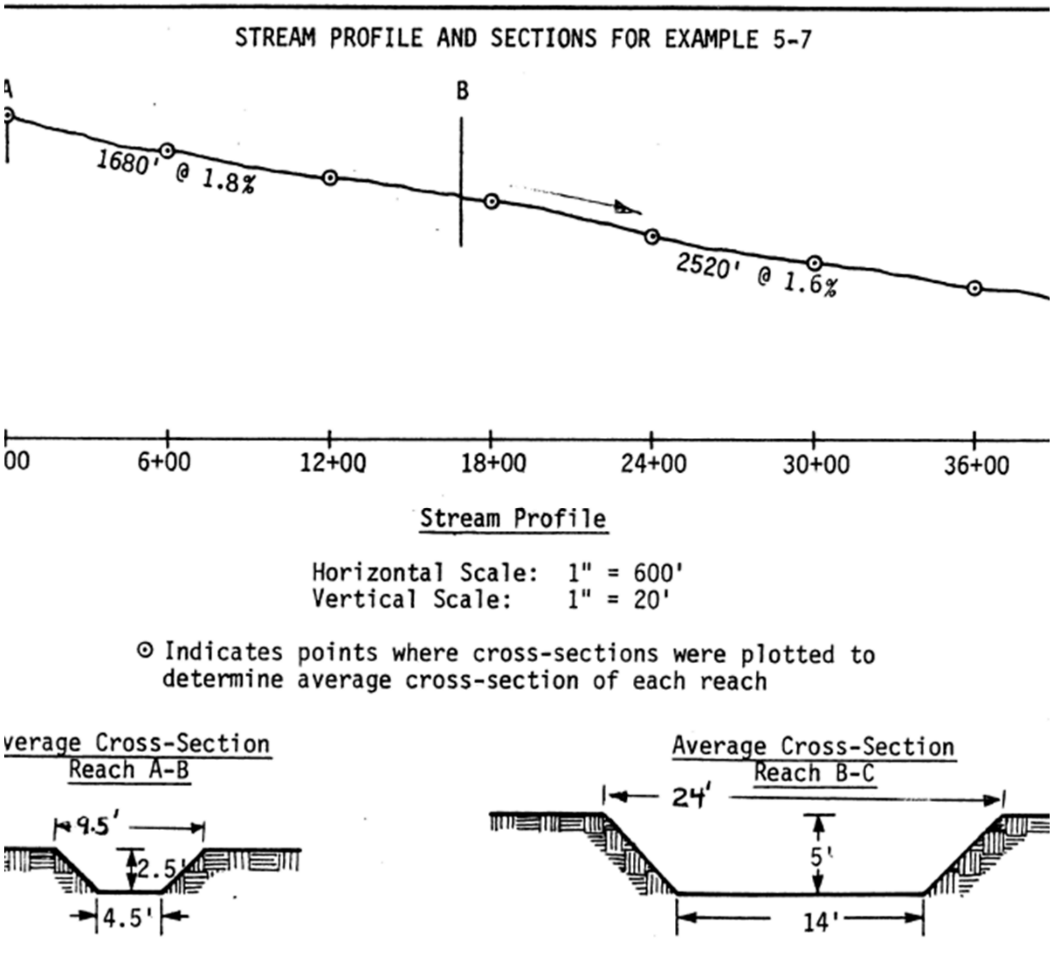
If channel lining equivalent to coarse gravel, what is permissible velocity?

6.0 ft/sec

Table 12-8, p. 18

Table C-ECM-15-3, VSWHB

Exercise – (3) Channel Stability



Would the channel erode under bankfull conditions?

AB velocity = 8.7 ft/sec

BC velocity = 14.2 ft/sec

6.0 ft/sec

Table 12-8, p. 168

Table C-ECM-15-3, VSWHB

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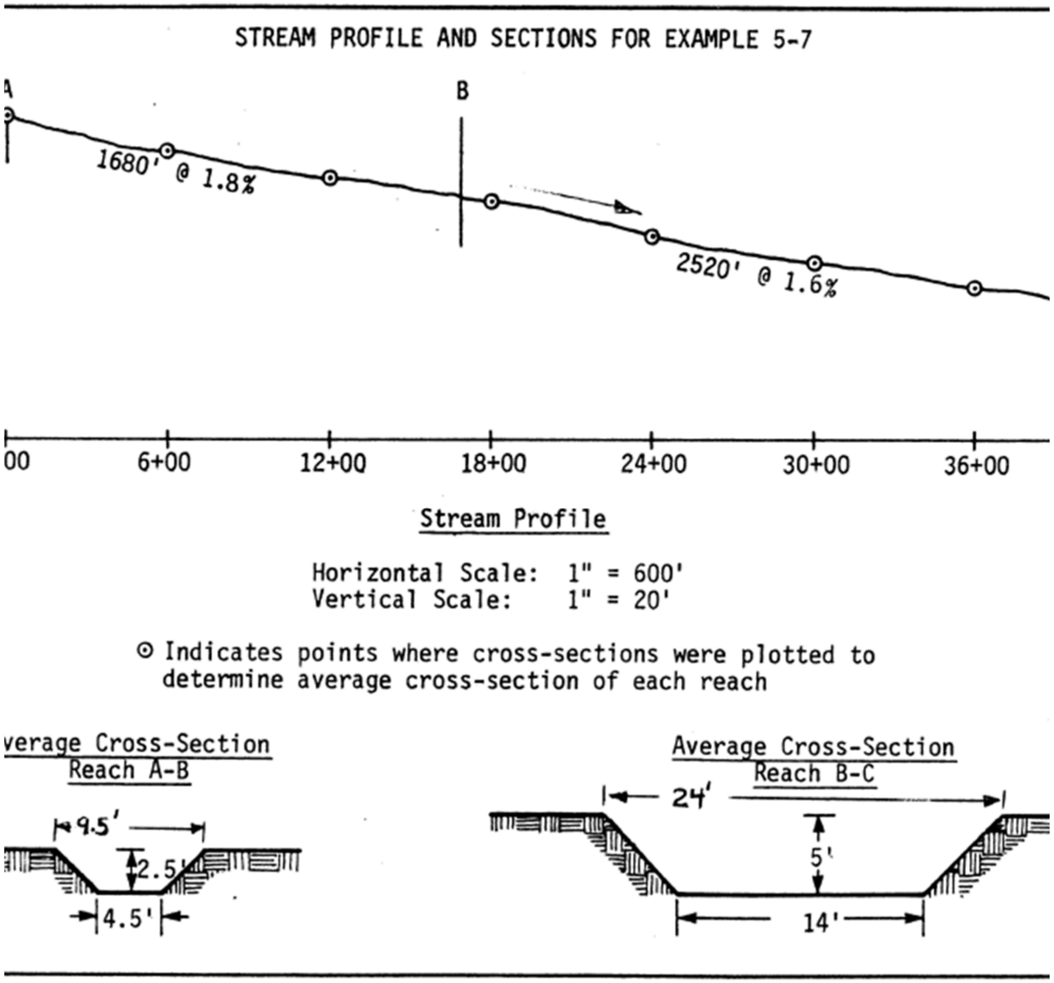
Exercise – (4) Adjust for 2-yr depth



2-year depth:

AB d=1.75 feet

BC d=3.5 feet

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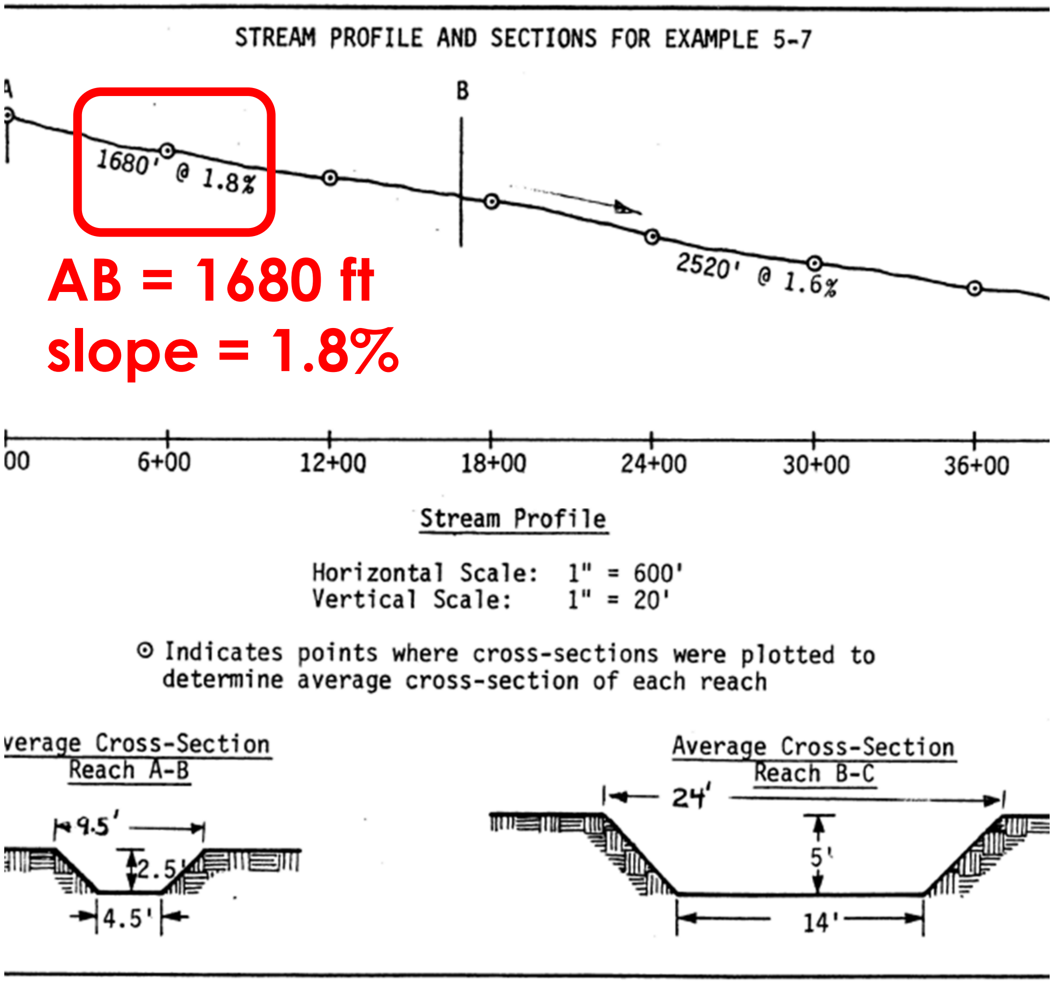
Exercise – (4) Adjusted AB Hydraulic Radius



Use formula from Table 12-2, p. 8,

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

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

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

$$R = \frac{10.9}{9.4} = 1.2$$

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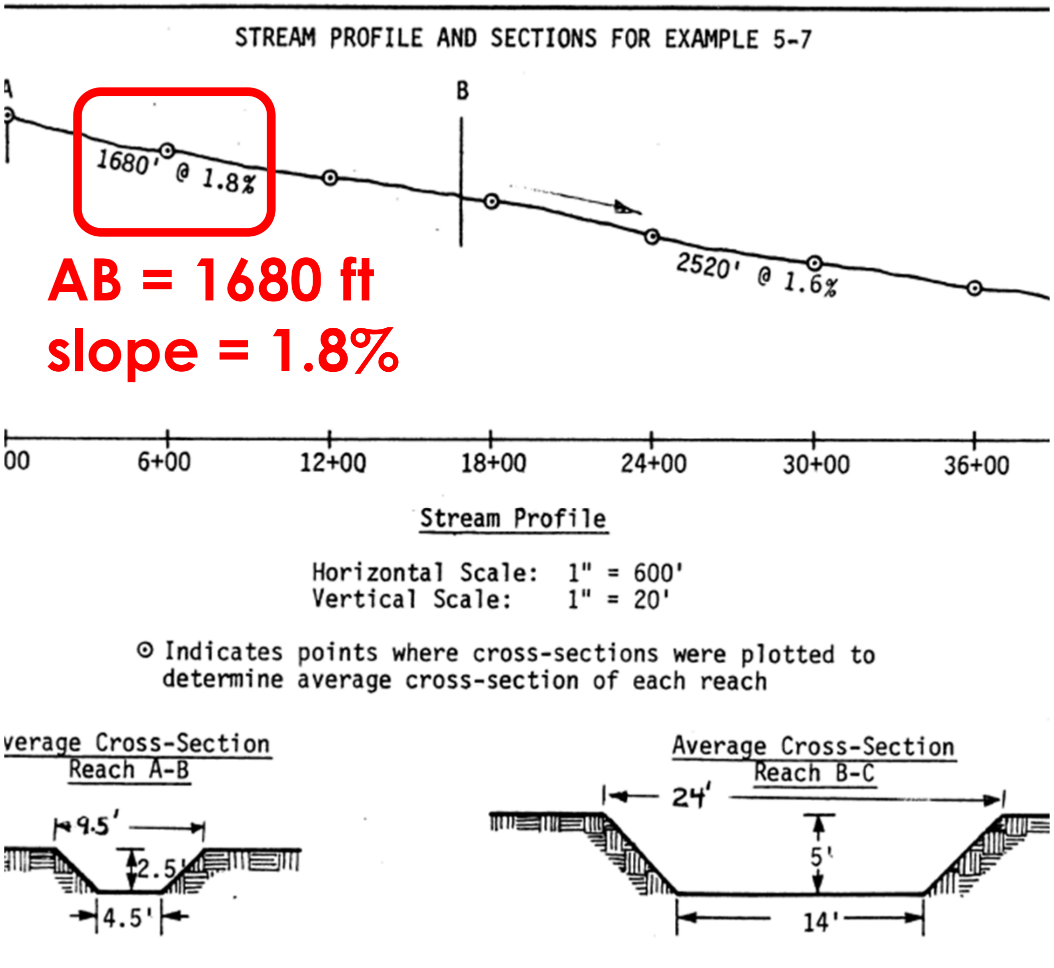
Exercise – (4) Adjusted AB velocity



Manning's Equation, p. 4,

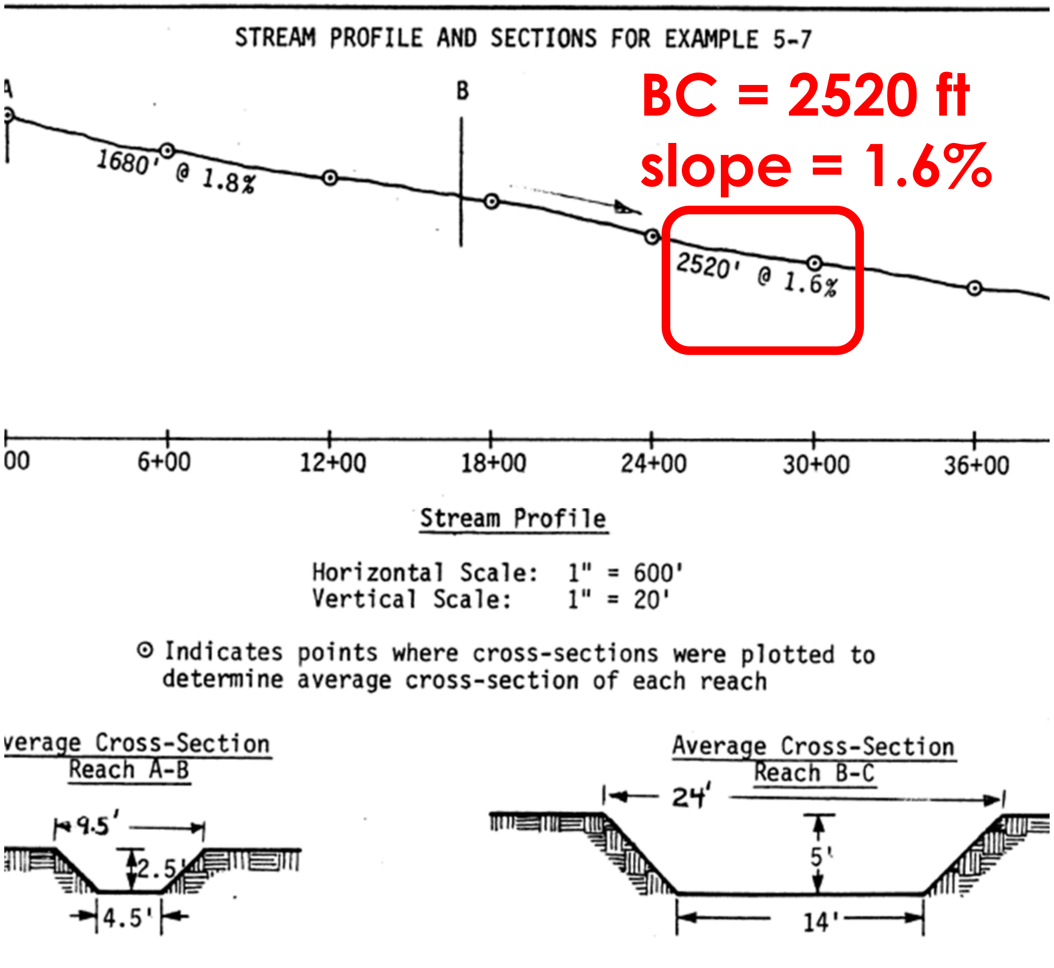
n=0.03 R=1.2 s=0.018 ft/ft

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

$$V = \frac{1.49}{0.03} \times 1.2^{2/3} \times \sqrt{0.018}$$

$$V = 7.5\ ft/sec$$ **>6.0 ft/sec**

Exercise – (4) Adjusted BC Hydraulic Radius



Use formula from Table 11-2, p. 8,

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

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

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

$$R = \frac{61}{24} = 2.5$$

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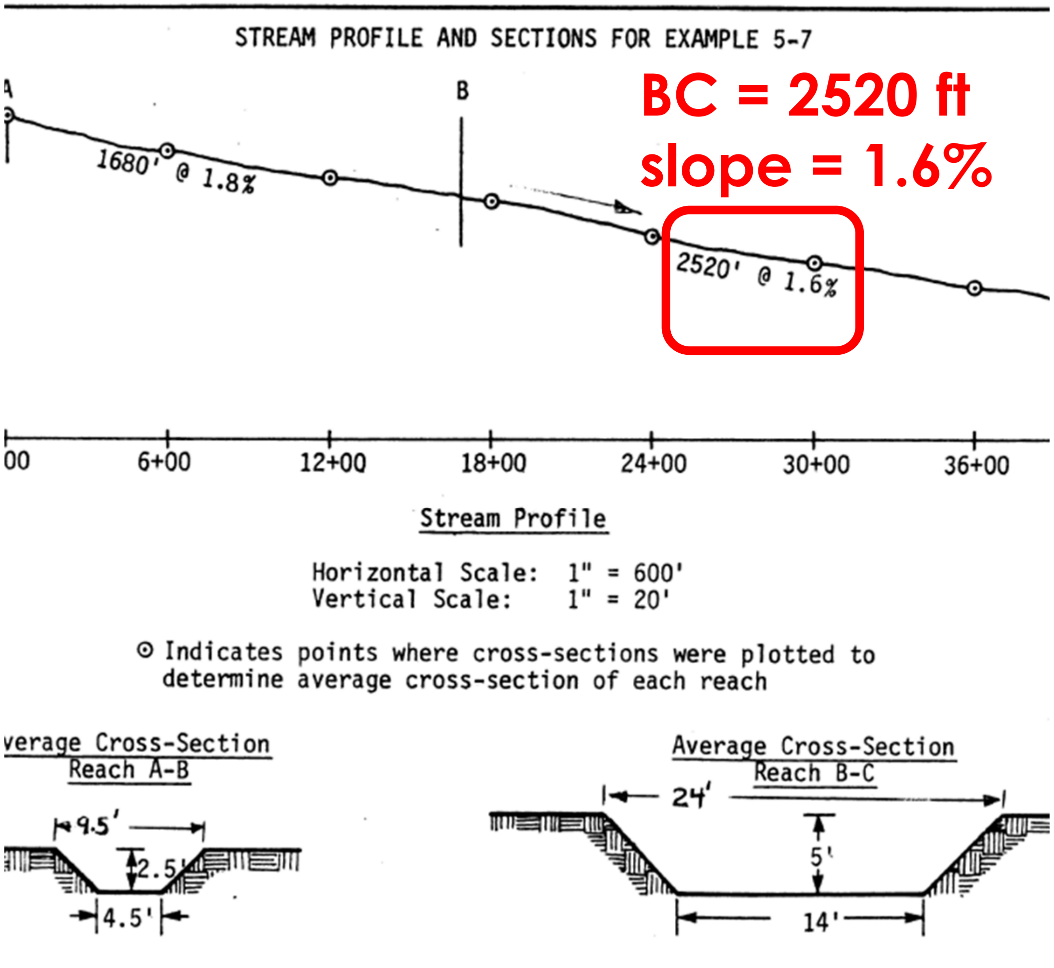
Exercise – (4) Adjusted BC velocity



Manning's Equation, p. 4,

n=0.03 R=2.5 s=0.016 ft/ft

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

$$V = \frac{1.49}{0.03} \times 2.5^{2/3} \times \sqrt{0.016}$$

$$V = 11.6\ ft/sec$$ **>6.0 ft/sec**

VIRGINIA DEPARTMENT OF ENVIRONMENTAL QUALITY

Continuity Equation
(Evaluating Capacity)

Continuity Equation used to evaluate channel capacity

Q = V x A

Q = flow rate (cfs)
V = velocity
(from Manning's, fps)
A = Cross-sectional area (ft^2)

cfs = fps * ft^2

Continuity Equation
(Evaluating Capacity)

Discharge Equation

$$Q = (1.49/n) * S^{1/2} * R^{2/3} * A$$

Q = flow rate (cfs)
V = velocity
(from Manning's, fps)
A = Cross-sectional area (ft^2)

cfs = fps * ft^2

Continuity Equation simplifies to Discharge Equation.

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Continuity Equation Exercise (5)

Q = V x A

Q = flow rate (cfs)
V = velocity
(from Manning's, fps)
A = Cross-sectional area (ft^2)

cfs = fps * ft^2

Using previous exercise, what flow rate can the channel accommodate?

Remember under bankfull conditions:

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

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Continuity Equation Exercise (5)

Q = V x A

Q = flow rate (cfs)
V = velocity
(from Manning's, fps)
A = Cross-sectional area (ft^2)

cfs = fps * ft^2

Using previous exercise, what flow rate can the channel accommodate?

Remember under bankfull conditions:

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

$$A = (bd + zd^2)$$
$$A_{AB} = 17.5, \quad A_{BC} = 95$$

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Continuity Equation Exercise (5)

$Q = V \times A$

Q_{AB} = 8.7 ft/sec x 17.5 sf
= 152 cfs

Q_{BC} = 14.2 ft/sec x 95 sf
= 1,349 cfs

Using previous exercise, what flow rate can the channel accommodate?

Remember under bankfull conditions:

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

$$A = (bd + zd^2)$$
$$A_{AB} = 17.5, \quad A_{BC} = 95$$

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Continuity Equation Exercise (5)

Is there a problem?

$Q = V \times A$

$Q_{AB} = 8.7 \text{ ft/sec} \times 17.5 \text{ sf}$
$= 152 \text{ cfs}$

$Q_{BC} = 14.2 \text{ ft/sec} \times 95 \text{ sf}$
$= 1{,}349 \text{ cfs}$

AB reach

Pre-dev. Q_{10} = 95 cfs

Post-dev. Q_{10} = 170 cfs

BC reach

Pre-dev. Q_{10} = 500 cfs

Post-dev. Q_{10} = 585 cfs

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Continuity Equation Exercise (5)

Is there a problem?

$Q = V \times A$

Q_{AB} = 8.7 ft/sec x 17.5 sf
Q_{AB} = 152 cfs

Q_{BC} = 14.2 ft/sec x 95 sf
Q_{BC} = 1349 cfs

<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

Continuity Equation Exercise (5)

YES!

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

$Q = V \times A$

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

Q_{AB} = 152 cfs

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

Q_{BC} = 1349 cfs

<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

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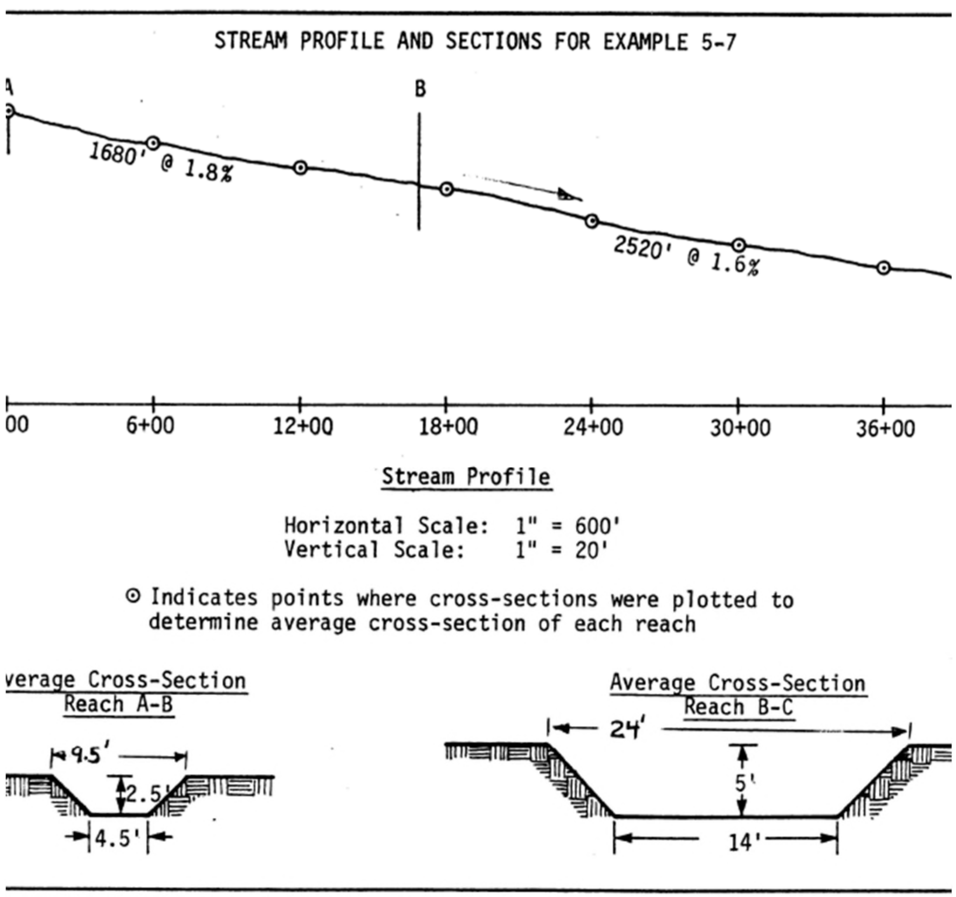
Q&A – Exercise (1) – (5)



Channel Stability

Channel Capacity

Module 12c.

Channel Computations Summary

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Channel Computations Summary

- Review pages 24-30

Channel Computations Summary

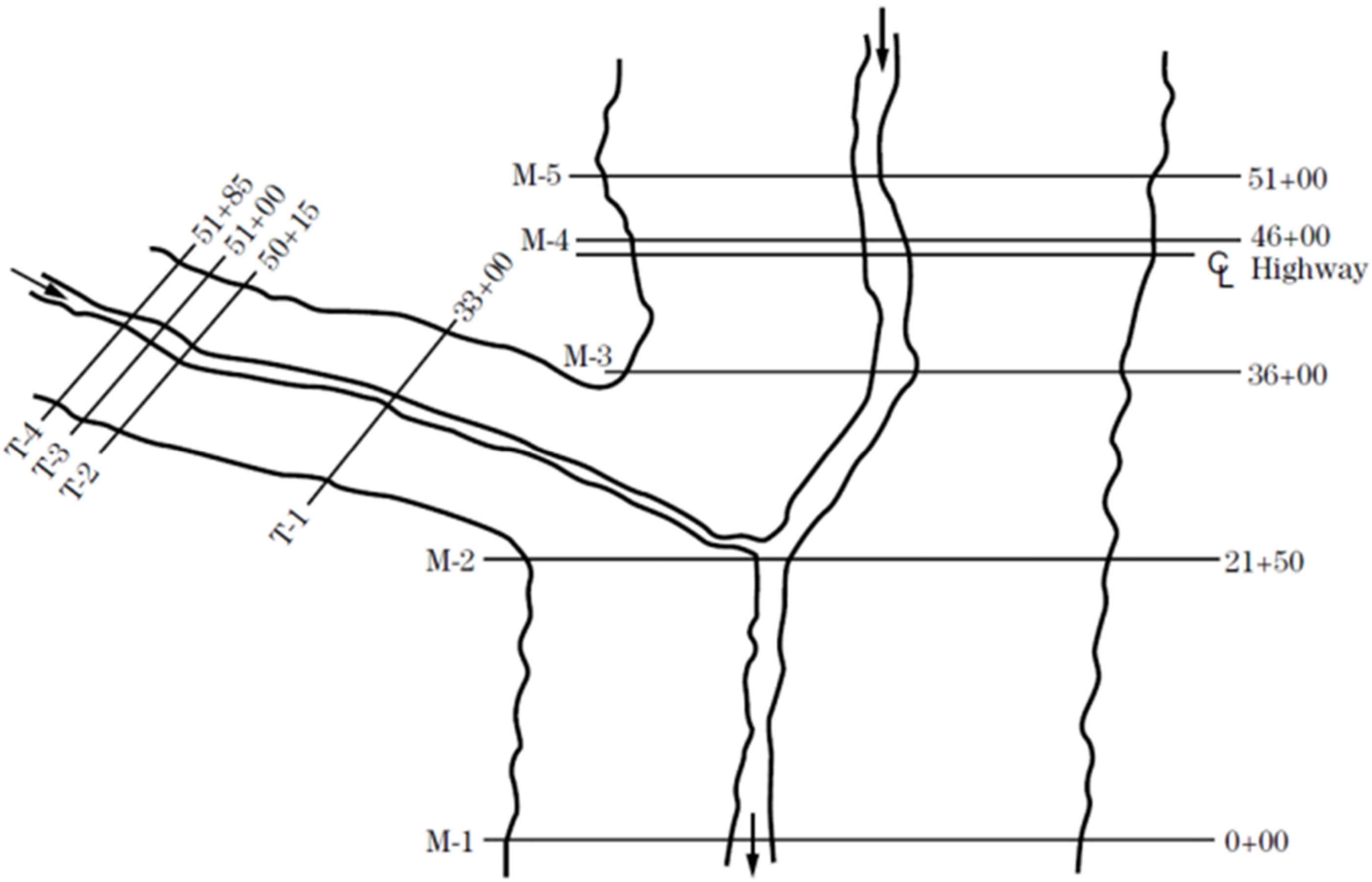
More information on how to perform and evaluate channel analyses can be found in these references:

DEQ Certification Course Participant Guide: Stormwater Management for Plan Reviewers

VSWHB

Construction BMP Specification C-ECM-09 (Stormwater Conveyance Channels)

Channel Computations Summary



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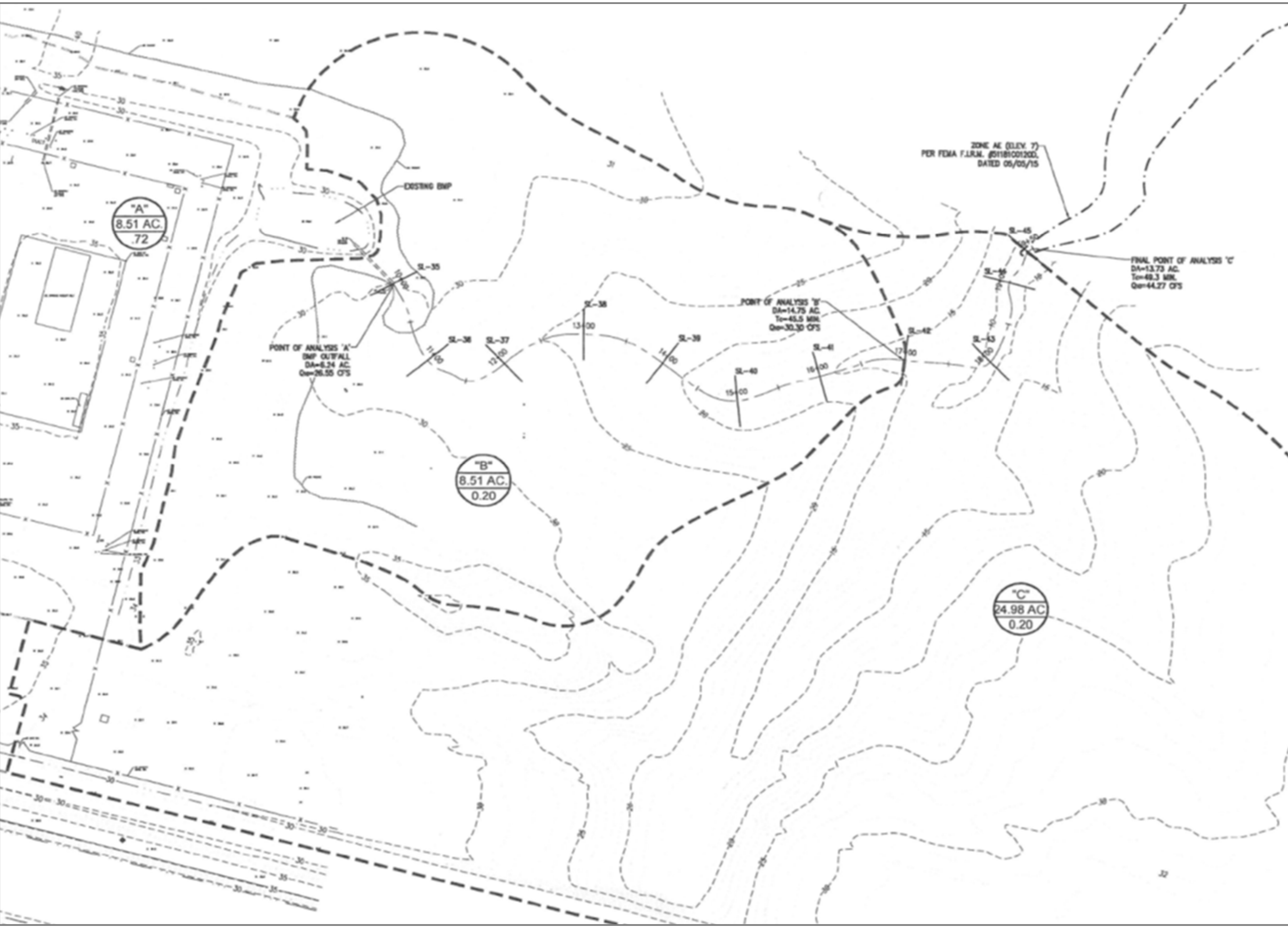
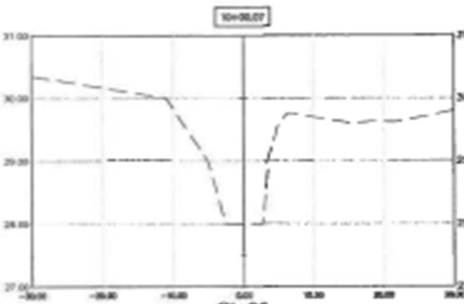
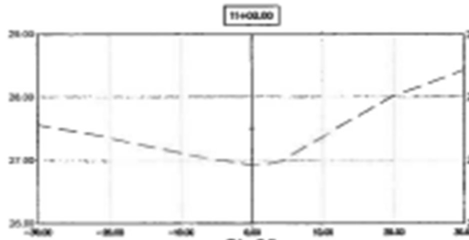
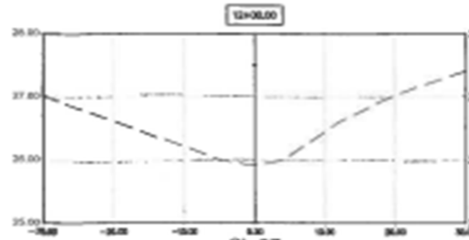
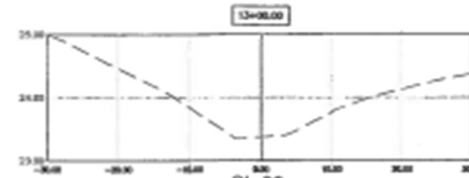
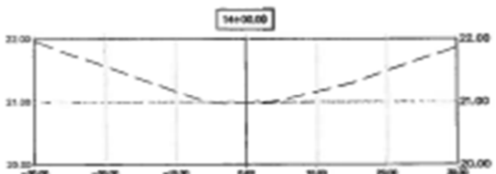

"A"
8.51 AC.
.72
EXISTING BMP
SL-35
POINT OF ANALYSIS 'A'
BMP OUTFALL
DA=6.24 AC.
Qo=26.55 CFS
SL-36
SL-37
SL-38
SL-39
SL-40
SL-41
SL-42
SL-43
SL-44
SL-45
"B"
8.51 AC.
0.20
POINT OF ANALYSIS 'B'
DA=14.75 AC.
Tc=45.5 MIN.
Qo=30.30 CFS
ZONE AE (ELEV. 7)
PER FEMA F.I.R.M. #01181C0120D,
DATED 05/05/15
FINAL POINT OF ANALYSIS 'C'
DA=13.73 AC.
Tc=49.3 MIN.
Qo=44.27 CFS
"C"
24.98 AC
0.20

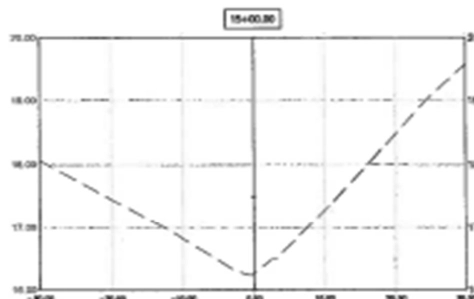

SL-35

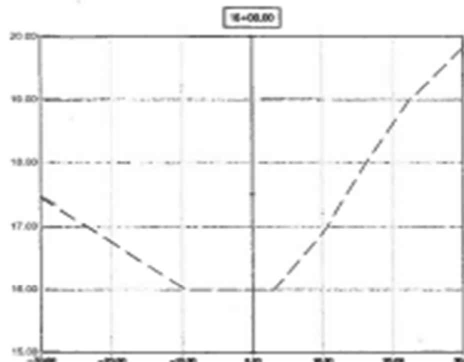

SL-36

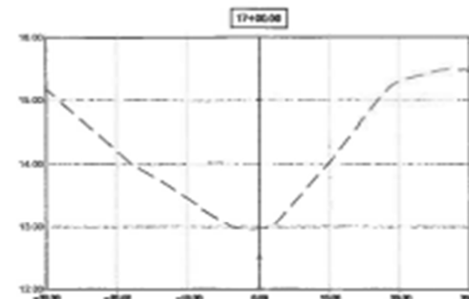

SL-37

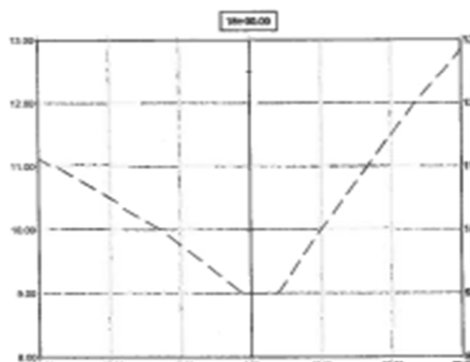

SL-38

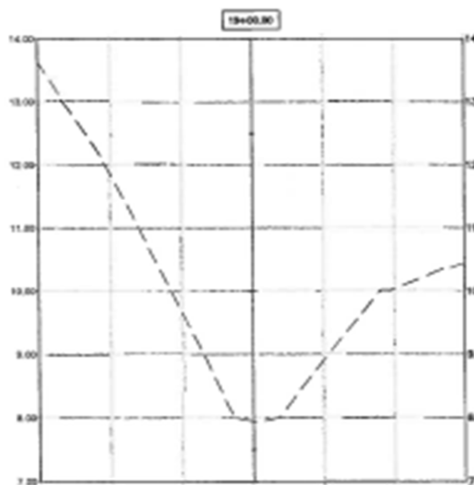

SL-39

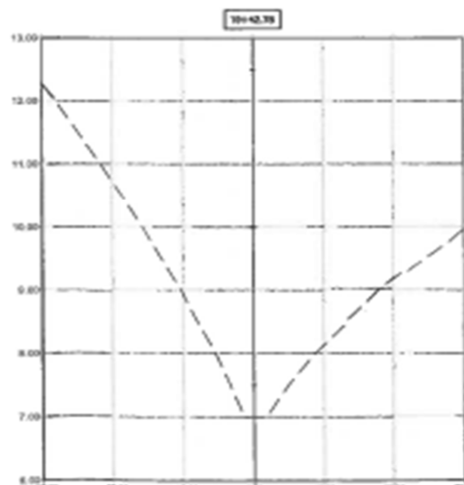

SL-40


SL-41


SL-42


SL-43


SL-44


SL-45

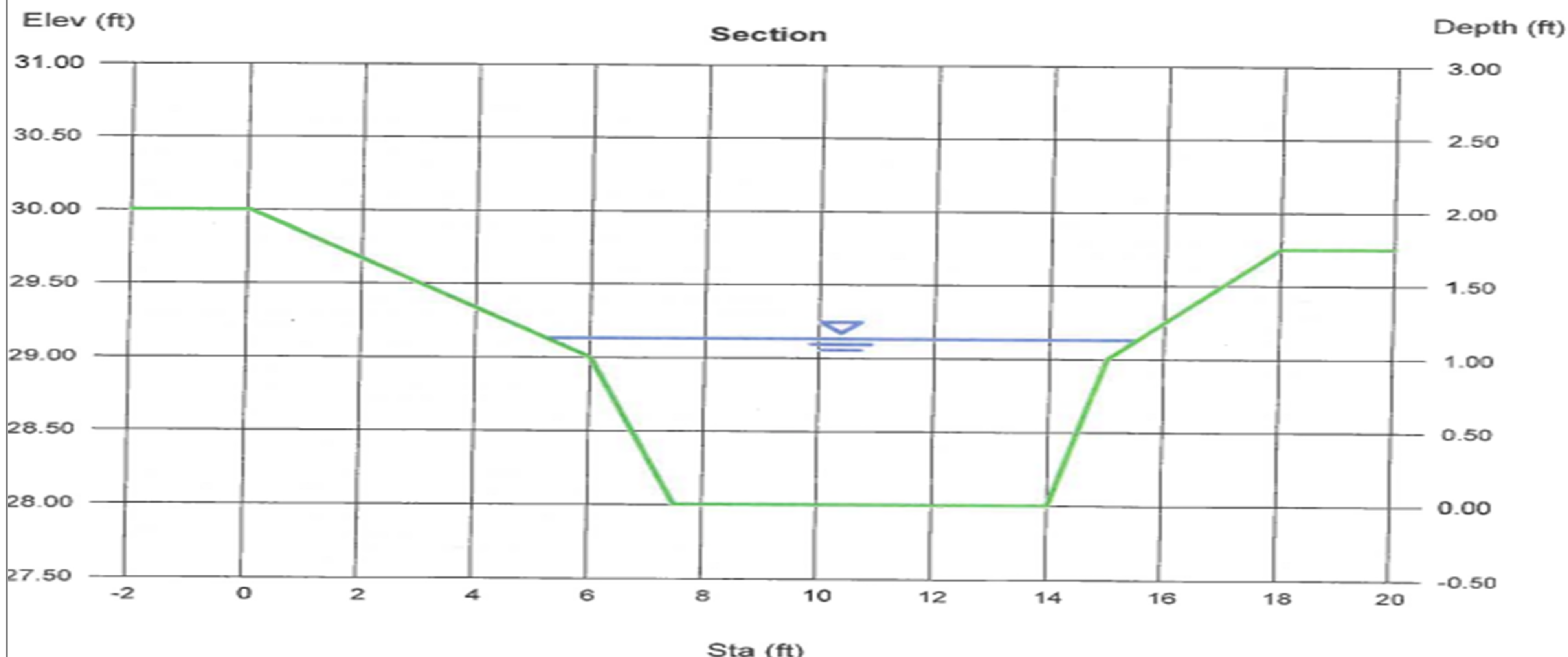
Channel Report

Hydraflow Express Extension for Autodesk® AutoCAD® Civil 3D® by Autodesk, Inc. Tuesday, Nov 28 2017

Channel Adequacy - Sta. 10+00 (10 Yr Storm)

User-defined		**Highlighted**	
Invert Elev (ft)	= 28.00	Depth (ft)	= 1.13
Slope (%)	= 0.25	Q (cfs)	= 26.55
N-Value	= 0.022	Area (sqft)	= 9.00
		Velocity (ft/s)	= 2.95
Calculations		Wetted Perim (ft)	= 11.04
Compute by:	Known Q	Crit Depth, Yc (ft)	= 0.77
Known Q (cfs)	= 26.55	Top Width (ft)	= 10.30
		EGL (ft)	= 1.27

(Sta, El, n)-(Sta, El, n)...
(0.00, 30.00)-(6.00, 29.00, 0.022)-(7.50, 28.00, 0.022)-(14.00, 28.00, 0.022)-(15.00, 29.00, 0.022)-(18.00, 29.75, 0.022)



Module 12d.

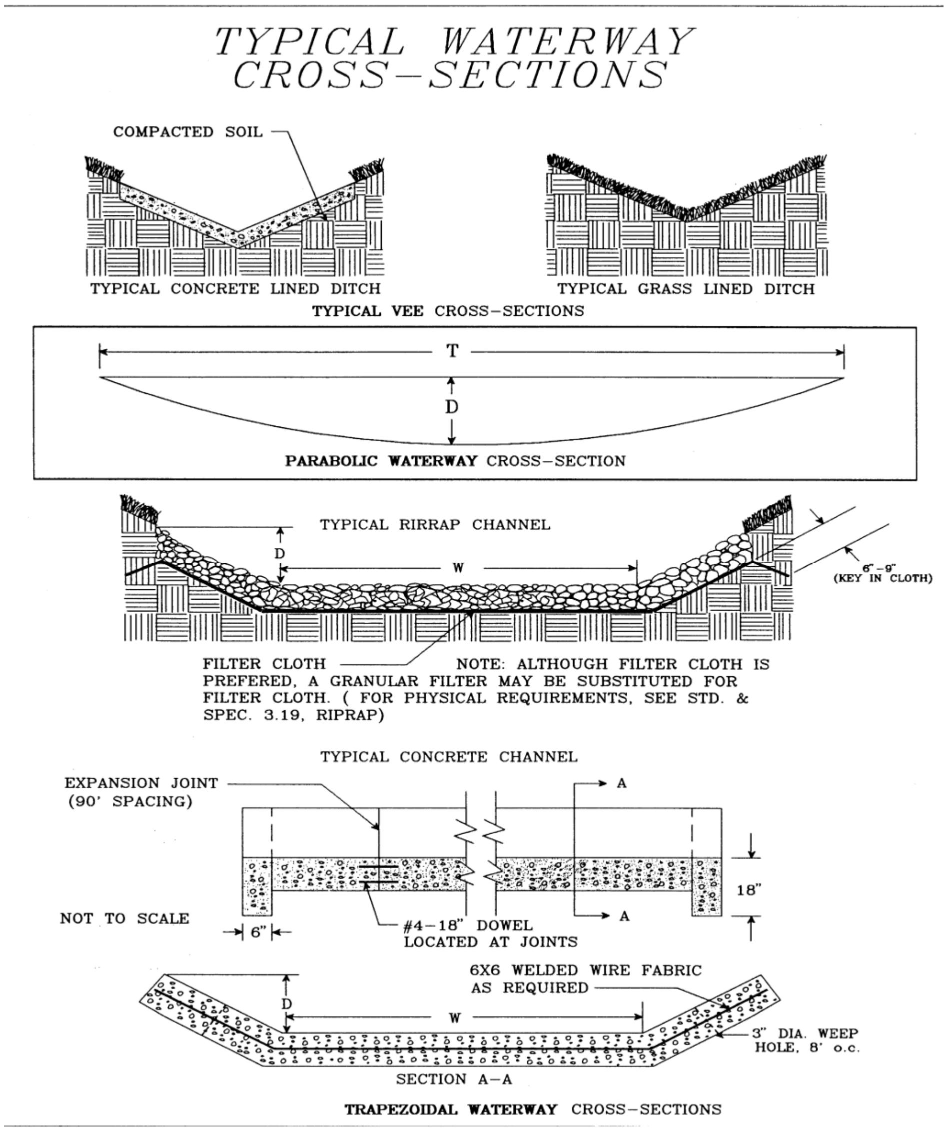
Reviewing Channel Design

VIRGINIA DEPARTMENT OF ENVIRONMENTAL QUALITY

Reviewing Channel Design

- VSWHB C-ECM-09/ Applicable P-BMP
- Most common: v-shaped, parabolic, trapezoidal
  - Top width of parabolic and v-shaped channels not to exceed 30’
  - Bottom width of trapezoid and grass lined not to exceed 15’
- Outlet protection (C-ECM-15)
- Appropriate channel lining (stable under runoff velocity)
- Grass-lined stabilized by perm. seeding and/or sod spec.
- Erosion netting
- Riprap use Std & Specs (C-ECM-13)

C-ECM-09 Stormwater Conveyance Channel



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Module 12 Problems

- Review problems on your own

DEQ
Virginia Department of Environmental Quality

Questions?