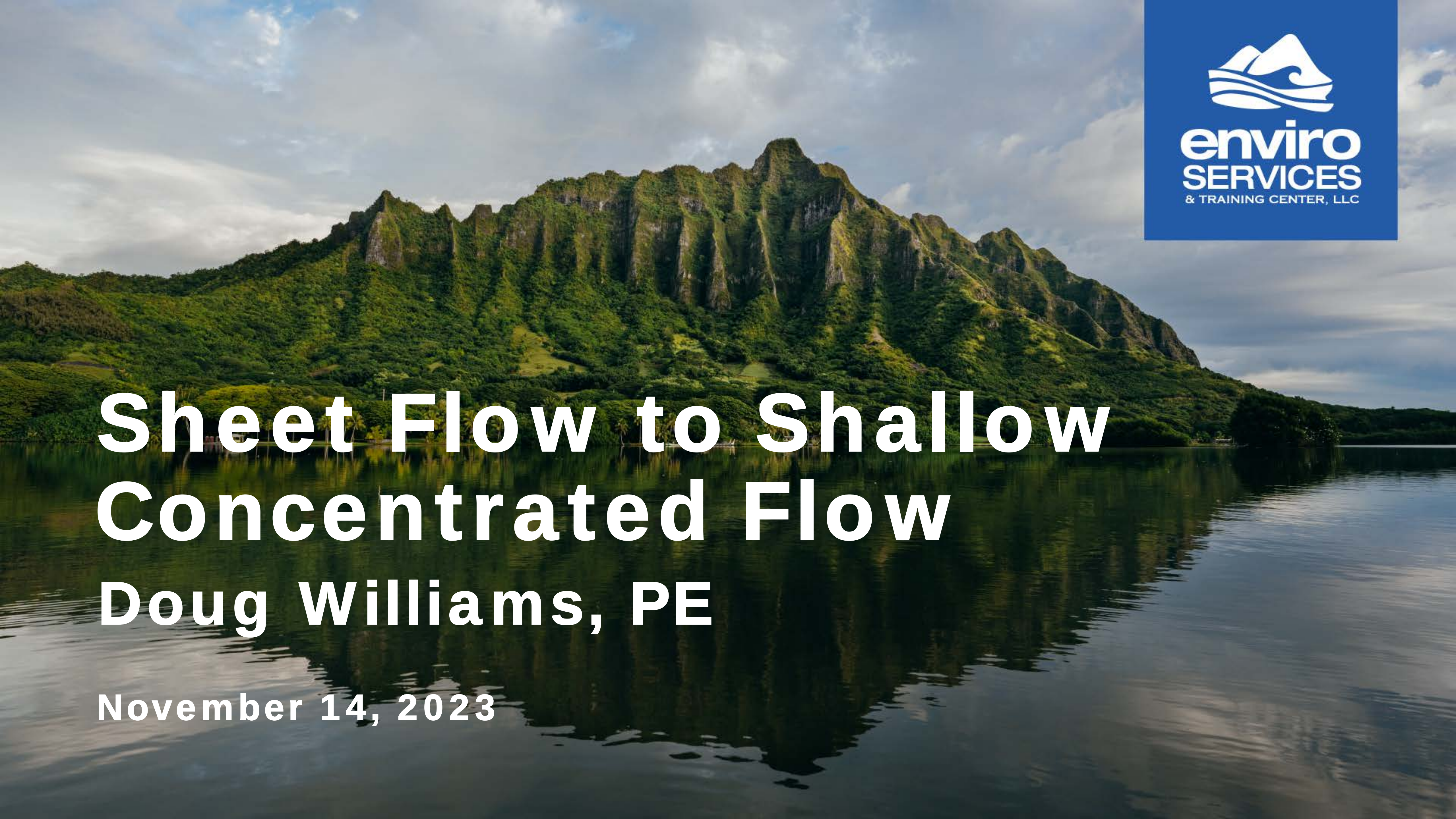

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Sheet Flow to Shallow Concentrated Flow

Doug Williams, PE

November 14, 2023

What’s the difference?

Sheet Flow

- Storm water in a thin layer, resembling thin film or “sheet”
- Slow Flow
- Not in distinct channels
- NRCS defines the transition point of sheet flow to shallow concentrated flow when depth reaches 1-inch

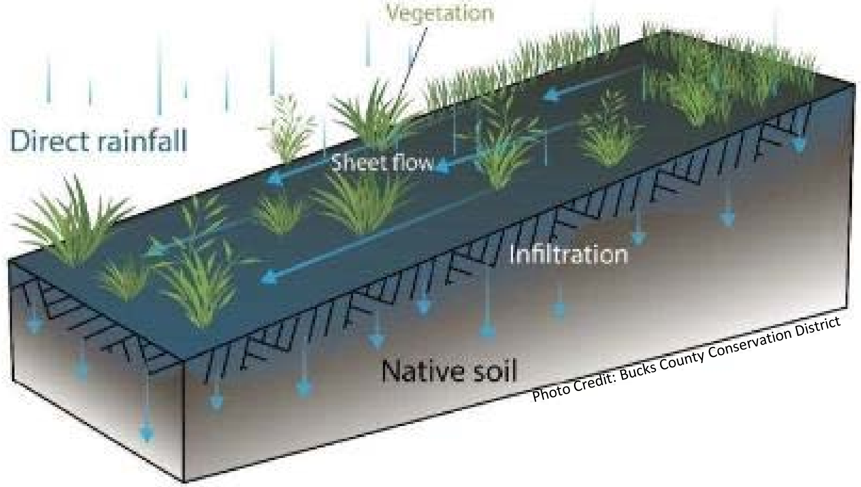


Photo Credit: Bucks County Conservation District

Shallow Concentrated Flow

- Concentrated storm water flow in a defined, yet shallow, path
- Flow is deeper and flows faster than sheet flow
- Flow depths of 0.1 to 0.5 feet
- Causes rill erosion

Flow Transition & Erosive Potential

- Sheet flow erosion is relatively low, transporting finer sediment from surface
- Shallow concentrated flow is more erosive due to increased depth and flow velocities
- Shallow concentrated flow transports coarser sediment

Estimating Sheet Flow Travel Length

Horton’s Average Overland Flow Length

(W.O. Ree. A Progress Report on Overland Flow Studies. 1963)

- Horton developed equation: L=1/(2Dd)
  - Where:
    - L is the sheet flow travel length
    - Dd is the sum of stream lengths for the watershed divided by the area of the watershed
- Measured stream lengths using aerial imagery.
- Σ Stream Lengths=48,900’, Area=206 acres, Avg Sheet Flow Length=92’

Manning n and the Overland Flow Equation

(Ree, et al. 1977)

- Average sheet flow length estimated by:
  - Length = Watershed Area / (2 * Σ Stream Lengths)
- Delineated and measured stream lengths using topographical contour maps
- Sheet flow lengths ranged from 197’ to 228’ (3 watersheds)

Roughness Coefficients for Routing Surface Runoff

(Emmett, W.)

- 1983:
  - Test plots varied from 10-20m, simulated precipitation from 5-10 cm/hr.
  - Roughness values developed for sheet flow, before concentrated flow
  - High Manning's n results in unreasonable depth for lengths extended to 300 ft
- 1986:
  - Excessive depths would not be encountered for slope lengths of 150-300 ft

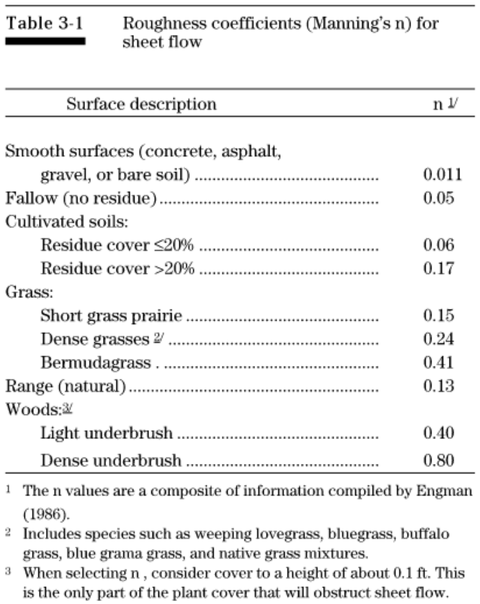


Table 3-1 Roughness coefficients (Manning's n) for sheet flow

Surface description	n [1]
Smooth surfaces (concrete, asphalt, gravel, or bare soil)	0.011
Fallow (no residue)	0.05
Cultivated soils:	
Residue cover ≤20%	0.06
Residue cover >20%	0.17
Grass:	
Short grass prairie	0.15
Dense grasses [2]	0.24
Bermudagrass	0.41
Range (natural)	0.13
Woods:[3]	
Light underbrush	0.40
Dense underbrush	0.80

[1] The n values are a composite of information compiled by Engman (1986).

[2] Includes species such as weeping lovegrass, bluegrass, buffalo grass, blue grama grass, and native grass mixtures.

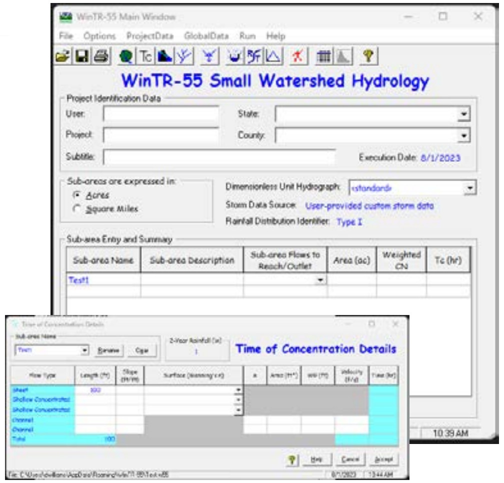
[3] When selecting n , consider cover to a height of about 0.1 ft. This is the only part of the plant cover that will obstruct sheet flow.

From TR-55, Chapter 3

USDA United States Department of Agriculture

NRCS Natural Resources Conservation Service

Conservation Engineering Division



Project Identification Data
User:
State:
Project:
County:
Subtitle:
Execution Date: 8/1/2023

Sub-areas are expressed in:
● Acres
○ Square Miles

Dimensionless Unit Hydrograph: <standard>
Storm Data Source: User-provided custom storm data
Rainfall Distribution Identifier: Type I

Sub-area Entry and Summary

Sub-area Name	Sub-area Description	Sub-area Flows to Reach/Outlet	Area (ac)	Weighted CN	Tc (hr)
Test1					

10:39 AM

WinTR-55 User Manual

(NRCS, 2009)

- Sheet flow originally limited to 300 ft or less
- "Sheet flow for 300 feet is very unusual because the surface and the corresponding flow would need to be extremely uniform."
- Sheet flow generally becomes concentrated after 100 ft, which became the new limit for WinTR-55

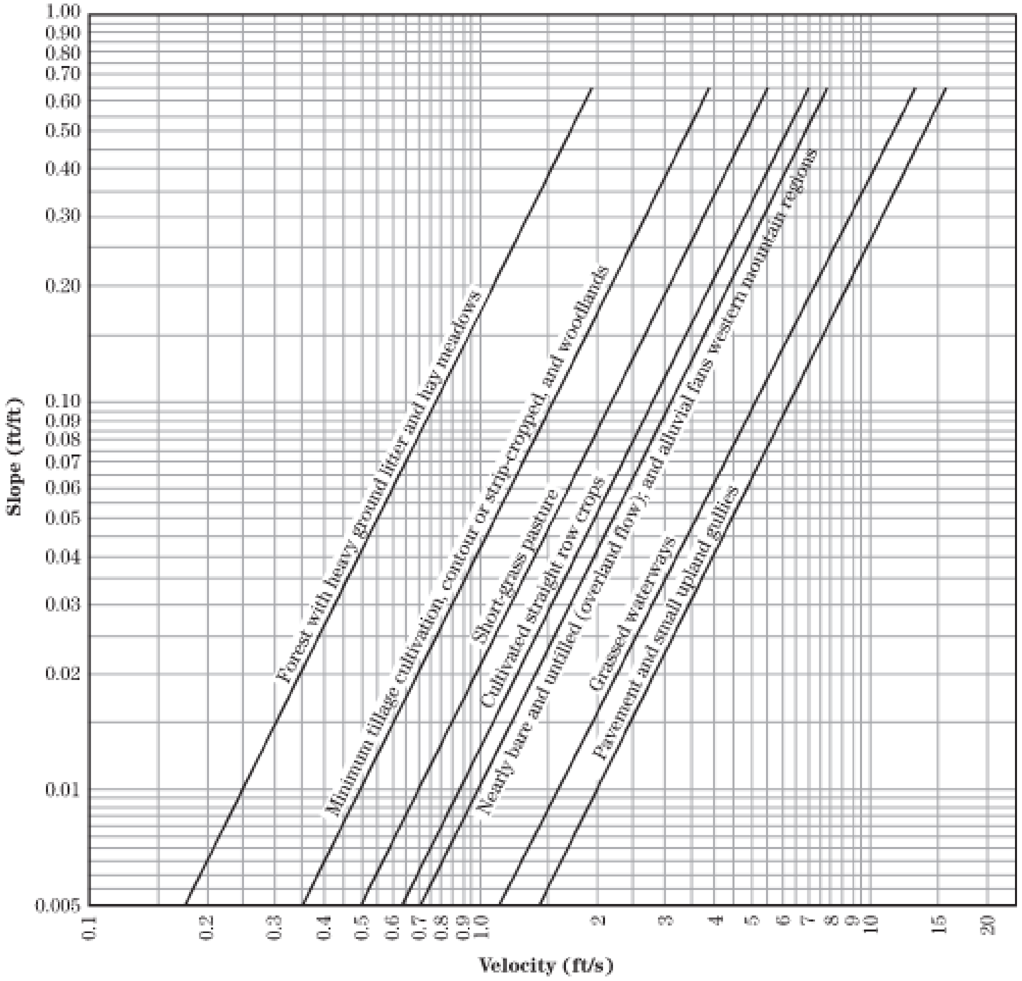
Assessment of Kinematic Wave Time of Concentration (McCuen & Spiess. 1995)

- Kinematic wave assumptions may no longer be valid if flow length alone is used as the limiting factor
- High roughness coefficient and/or flat slopes will generally result in overprediction of sheet flow length
- Factors should also include Manning’s n and slope
- $nL/\sqrt{s} \leq 100$

The Hydraulics of Overland Flow on Hillslopes (Emmett, W. 1970)

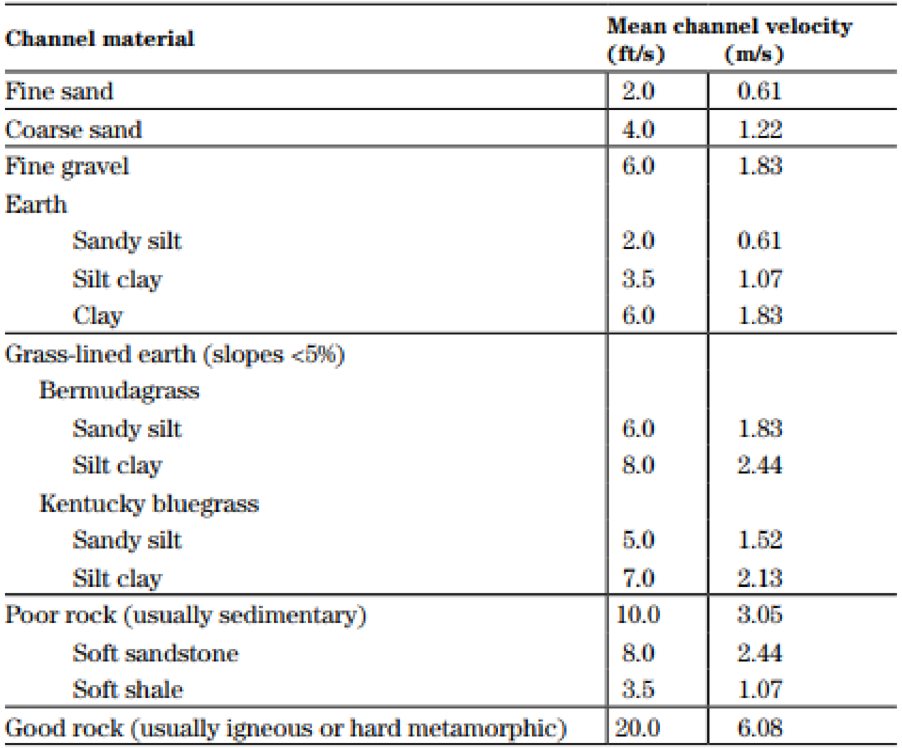
- 7 test plots, 7’ wide
- Varied slopes from 2.9 to 33%
- Shallow slopes micro-depressions dictated concentrate flow paths, but did not so much on steeper slopes
- Flow rarely occurred as uniform sheet flow for natural ground surface
- Sheet flow lengths limited to <50’

Figure 15–4 Velocity versus slope for shallow concentrated flow



NRCS National Engineering Handbook, Part 630, Chapter 15 (May 2010)

Table 8–4 Allowable velocities



Channel material	Mean channel velocity (ft/s)	(m/s)
Fine sand	2.0	0.61
Coarse sand	4.0	1.22
Fine gravel	6.0	1.83
Earth		
Sandy silt	2.0	0.61
Silt clay	3.5	1.07
Clay	6.0	1.83
Grass-lined earth (slopes <5%)		
Bermudagrass		
Sandy silt	6.0	1.83
Silt clay	8.0	2.44
Kentucky bluegrass		
Sandy silt	5.0	1.52
Silt clay	7.0	2.13
Poor rock (usually sedimentary)	10.0	3.05
Soft sandstone	8.0	2.44
Soft shale	3.5	1.07
Good rock (usually igneous or hard metamorphic)	20.0	6.08

NRCS National Engineering Handbook, Part 654, Chapter 8 (August 2007)

Design Equations

Time of Concentration
Kinematic Wave Equation

$$T_c = \frac{0.93}{i^{0.4}}\left(\frac{nL}{\sqrt{s}}\right)^{0.6}$$

Where:
T_c is the time of concentration
i is the rainfall intensity
n is the overland roughness coefficient
L is the flow length
S is the slope

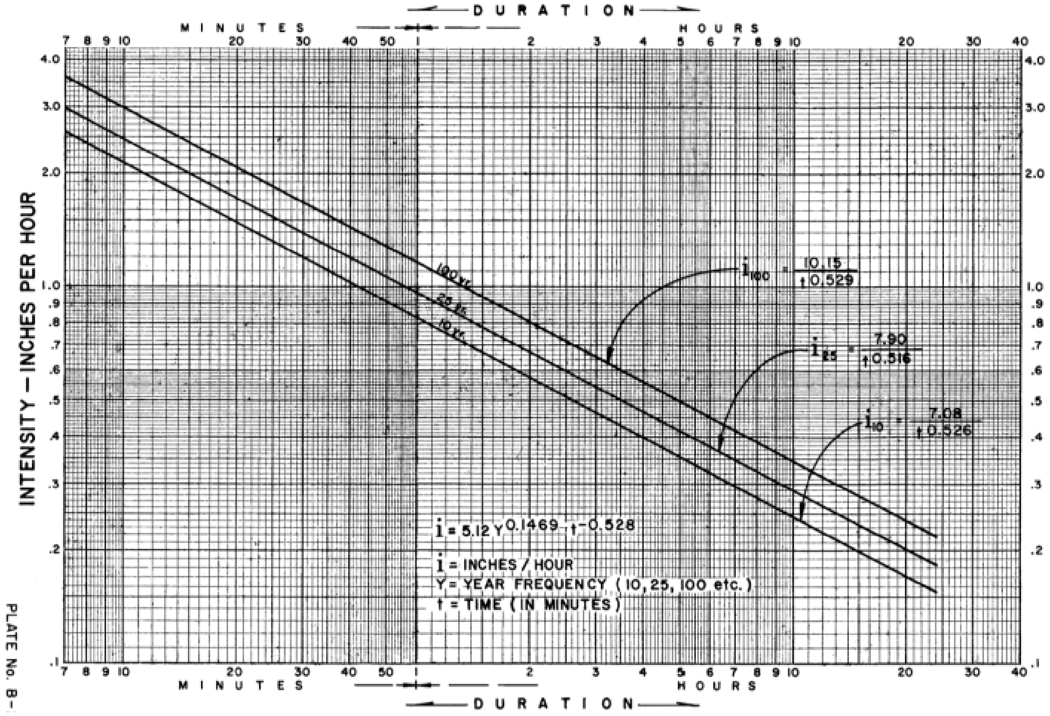


Chart 1: Sonoma County Water Agency IDF Curve (SCWA, 1983)

Estimate Sheet Flow Length

$$\frac{nL}{\sqrt{s}} \leq 100$$

$$L = \frac{100\sqrt{s}}{n}$$

Photo Credit: South Dakota NRCS

Example 1:

Should we design for sheet flow or shallow concentrated flow?

L = 300 feet, n = 0.41, s = 0.02 ft/ft

$$\frac{nL}{\sqrt{s}} \leq 100$$

$$\frac{nL}{\sqrt{s}} = \frac{0.41 * 300}{\sqrt{0.02}} = 869.74$$

Example 2:

At what interval should we space flow interception swales?

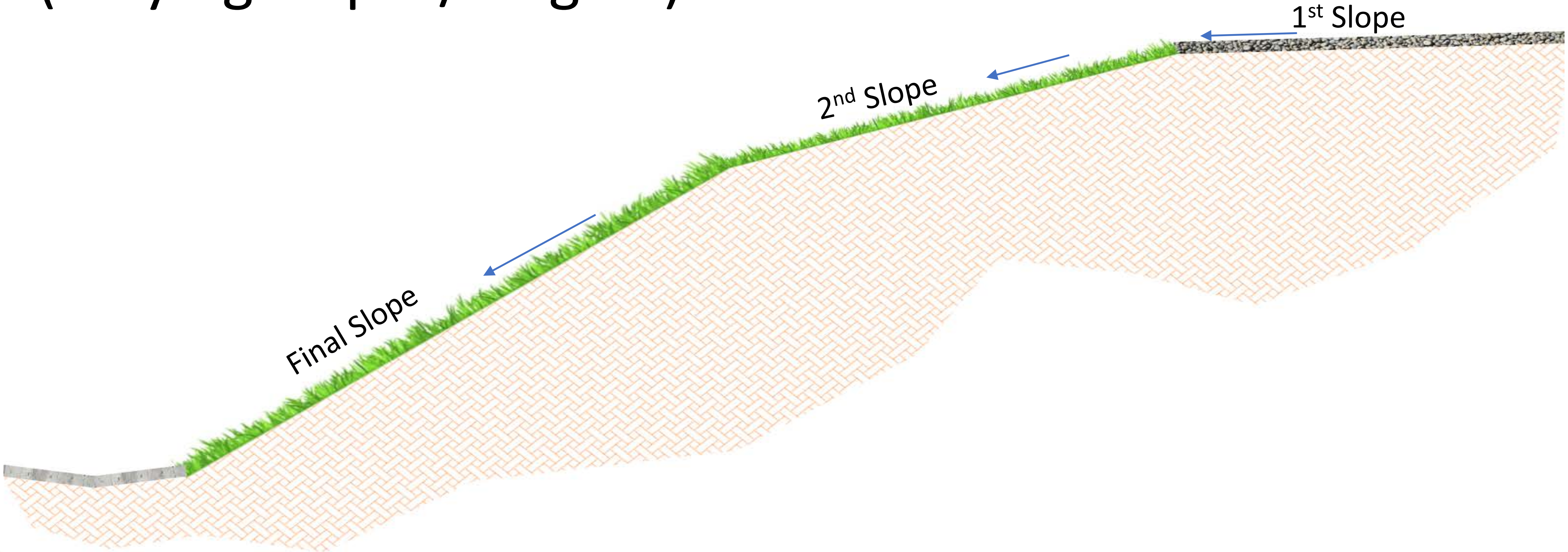
$n = 0.41$, $s = 0.10$ ft/ft

$$L = \frac{100\sqrt{s}}{n}$$

$$L = \frac{100\sqrt{s}}{n} = \frac{100\sqrt{0.10}}{0.41} = 77.13\ feet$$

But….

What if we have a compound slope (varying slopes/lengths)?



Compound Slopes

$$\frac{nL}{\sqrt{s}} = 100$$

$$\frac{n_f L_f}{\sqrt{s_f}} + \frac{n_1 L_1}{\sqrt{s_1}} + \cdots + \frac{n_n L_n}{\sqrt{s_n}} = 100$$

$$L_f = \left(100 - \frac{n_1 L_1}{\sqrt{s_1}} - \cdots - \frac{n_n L_n}{\sqrt{s_n}}\right)\frac{\sqrt{s_f}}{n_f}$$

Where:

L_f is the final slope length
L_1 is the first slope length
L_n is the nth slope length
n_f is the final roughnes coefficient
n_1 is the first roughness coefficient
n_n is the nth roughness coefficient
s_f is the final slope
s_1 is the first slope
s_n is the nth slope

Example 3:

We have 3 slope sections with varying slope parameters:

- *Slope 1: L=10 ft, n=0.15, s=0.02 ft/ft*
- *Slope 2: L=10 ft, n=0.41, s=0.06 ft/ft*
- *Slope 3: n=0.41, s=0.10 ft/ft*

$$L_f = \left(100 - \frac{L_1 n_1}{\sqrt{s_1}} - \frac{L_2 n_2}{\sqrt{s_2}}\right)\frac{\sqrt{s_f}}{n_f} = \left(100 - \frac{10*0.15}{\sqrt{0.02}} - \frac{10*0.41}{\sqrt{0.06}}\right)\frac{\sqrt{0.10}}{0.41}$$

$$L_f = 56\ ft$$

Mahalo Nui Loa

Questions?

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