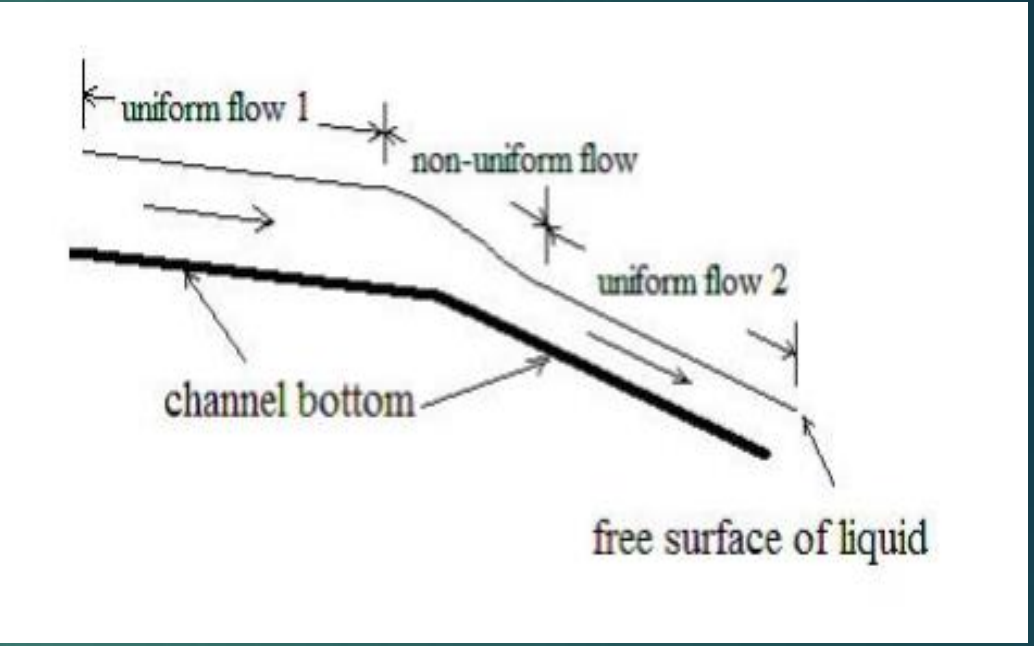
CHAPTER 3

Normal Flow

Normal Flow

- **Uniform** flow: there is a **constant** flow rate of liquid passing through it, average velocity, bottom slope, and cross-section shape & size.
- Such a channel is called prismatic channel.
- The depth in the channel with uniform flow is **normal depth** (y_n).



- For reaches of channel where the bottom slope, cross-section shape, and/or cross-section size change, **non-uniform** flow will occur.

Normal Flow

- Strictly speaking, normal flow is possible only in prismatic channels, and it rarely occurs naturally.
- However, the flow tends to become normal in very long channels in the absence of flow controls such as hydraulic structures.
- Please be noted that the concept of normal flow is central to the analysis and design procedures for open channels.

Chezy Equation

- To have uniform flow, the channel must be **straight** and without change in **slope** and **cross section** along the length of the channel.

- In a uniform flow we can show that:

$$V = C\sqrt{R_h S_0}$$

C is called the Chezy C

R_h the hydraulic radius

- The Chezy coefficient C are function of the roughness of the channel bottom and wall; and the depth of flow.

Description of Channel	Chezy Coefficient
Many grove heights of flood waters	7 - 12.5
Many weeds as high as water	12.5 - 20
Base of channel is clean with a little to moderate grove on the cliff wall channel	20 - 30
Channel with a bit of short grassy weeds	30 - 45
Channel is clean and not a new channel, it has been decaying	40 - 55

Manning equation

Manning equation

One the most commonly empirical equations governing Open Channel Flow

$$V = \frac{1}{n} R_h^{2/3} S_0^{1/2}$$

$$Q = \frac{1}{n} A R_h^{2/3} S_0^{1/2}$$

SI system

$$C = \frac{R_h^{1/6}}{n}$$

n is Manning roughness coefficient

S_0 is channel slope

$$Q = \frac{1.49}{n} A R_h^{2/3} S_0^{1/2}$$

English system

Channel type	Surface material and form	Manning's *n* range
River	earth, straight	0.02-0.025
	earth, meandering	0.03-0.05
	gravel (75-150mm), straight	0.03-0.04
	gravel (75-150mm), winding	0.04-0.08
unlined canal	earth, straight	0.018-0.025
	rock, straight	0.025-0.045
lined canal	concrete	0.012-0.017
lab. models	mortar	0.011-0.013
	Perspex	0.009

Continuity equation

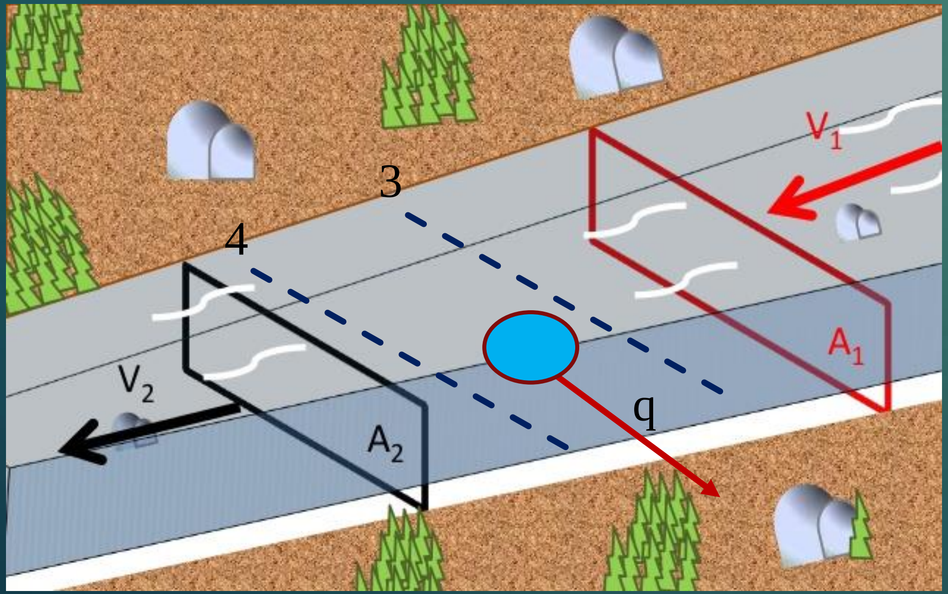
Continuity equation

$$Q = AV$$

Q is typically called the discharge

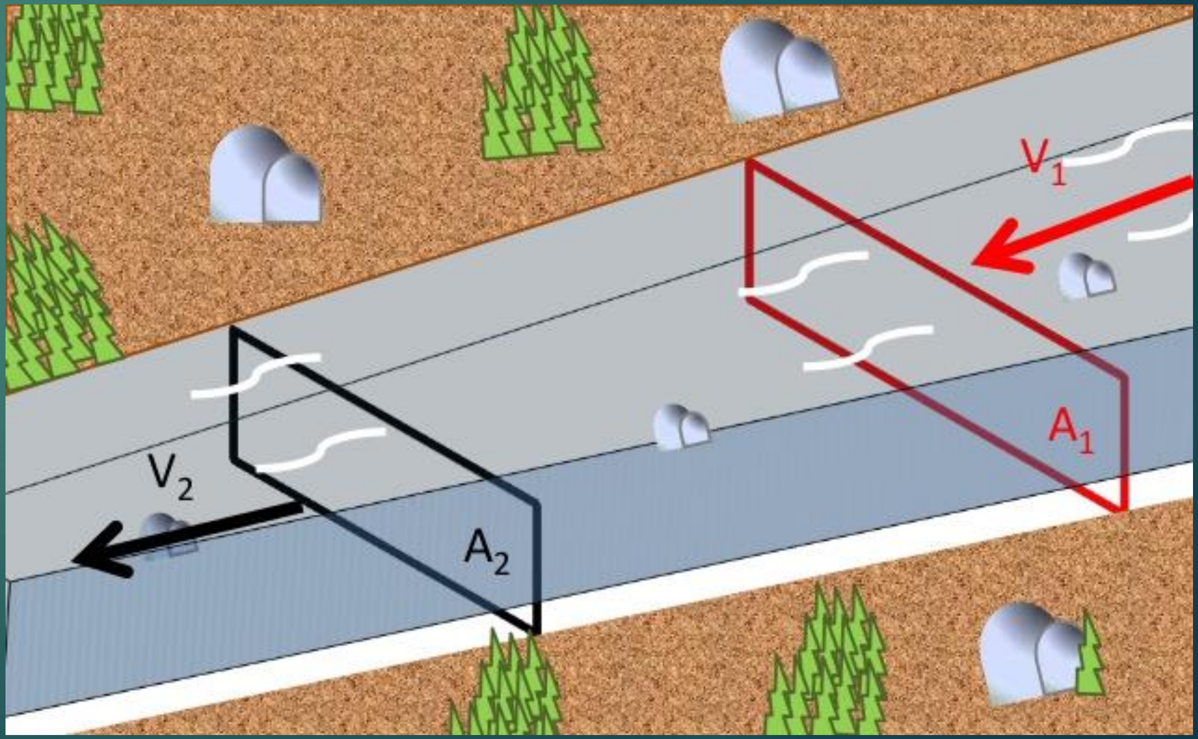
A The cross sectional area of flow

V The mean velocity



If the flow is steady, inflow is equal to the outflow.

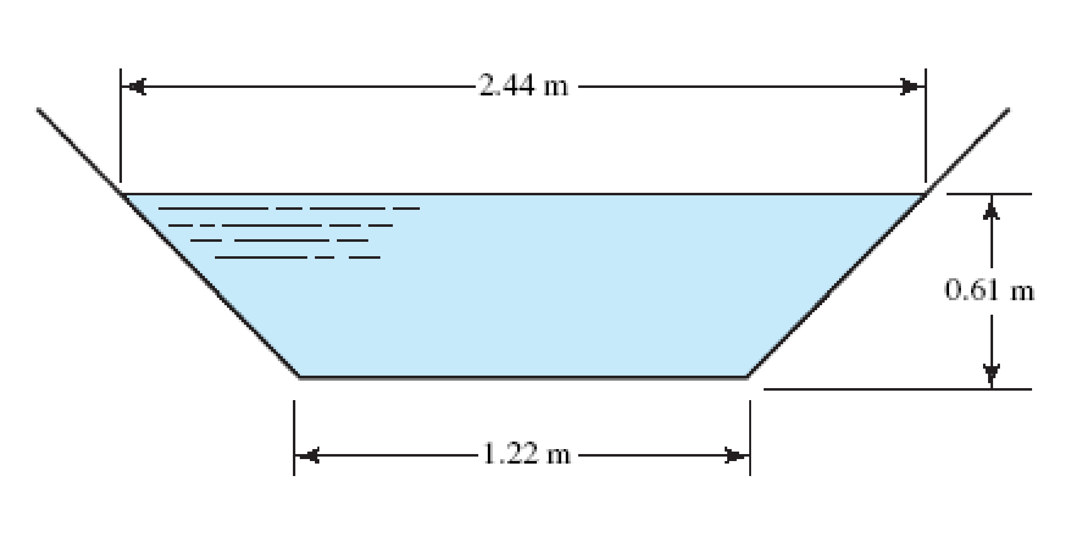
$$Q_{entering} = Q_{leaving} \rightarrow A_1V_1 = A_2V_2$$



Manning equation

Example 3-1

Calculate the slope on which the channel shown in the following figure must be laid if it is to carry 1.416 m3/s of water with a depth of 0.61 m. The sides and bottom of the channel are made of formed, unfinished concrete.

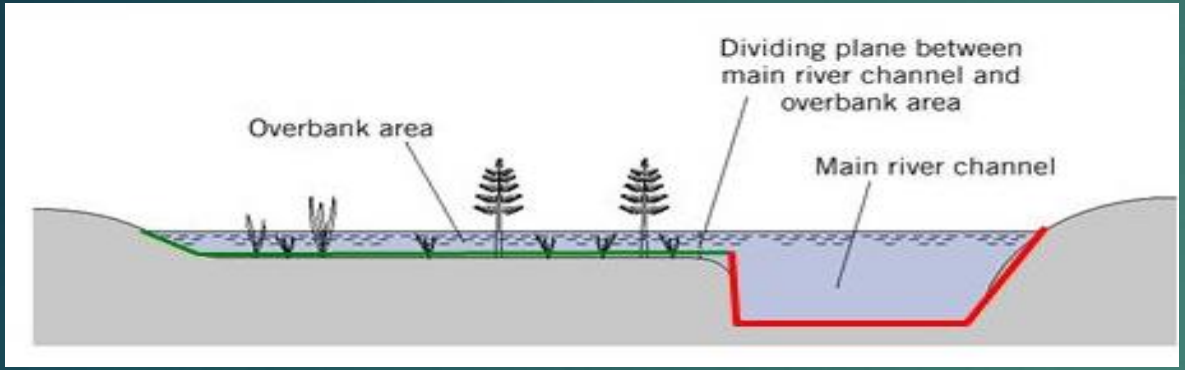


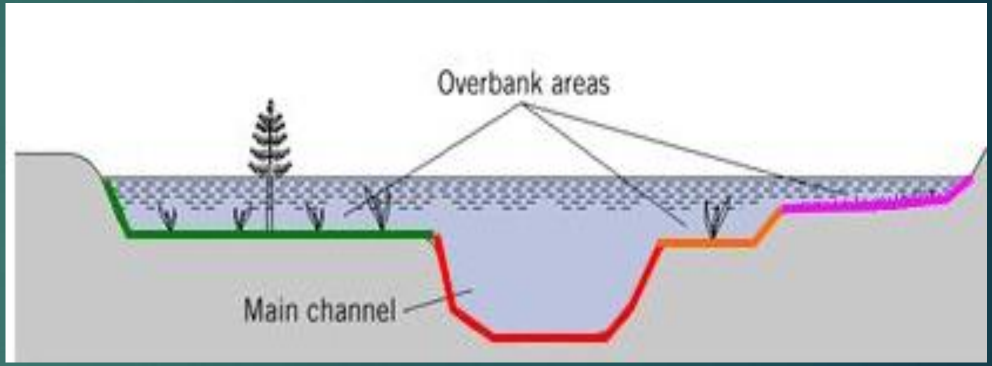
Manning equation

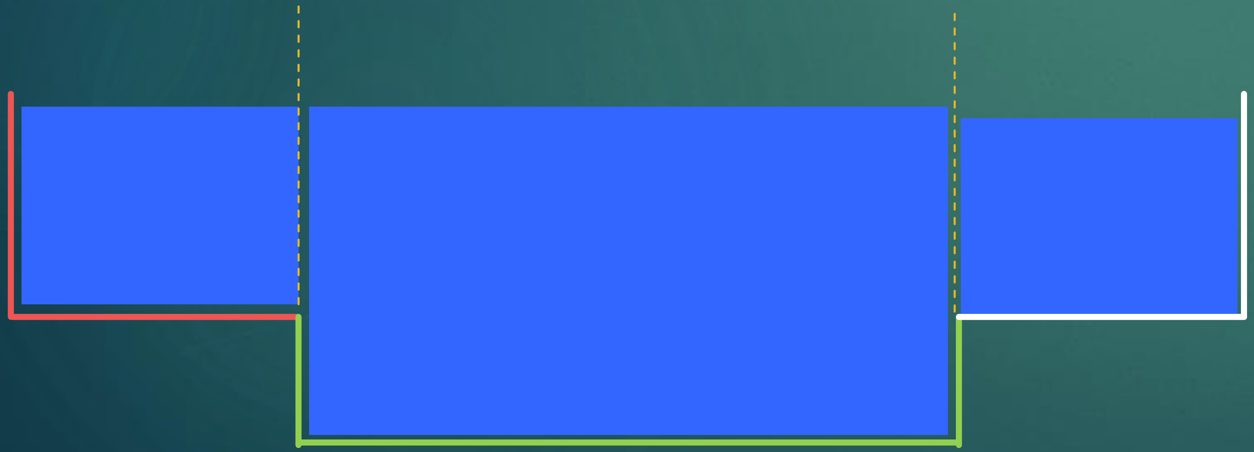
Example 3-2

Determine the depth of the water in a rectangular channel that is made of unfinished concrete with the width of 2 m to carry 12 m3/s of water when laid on a 1.2-percent slope.

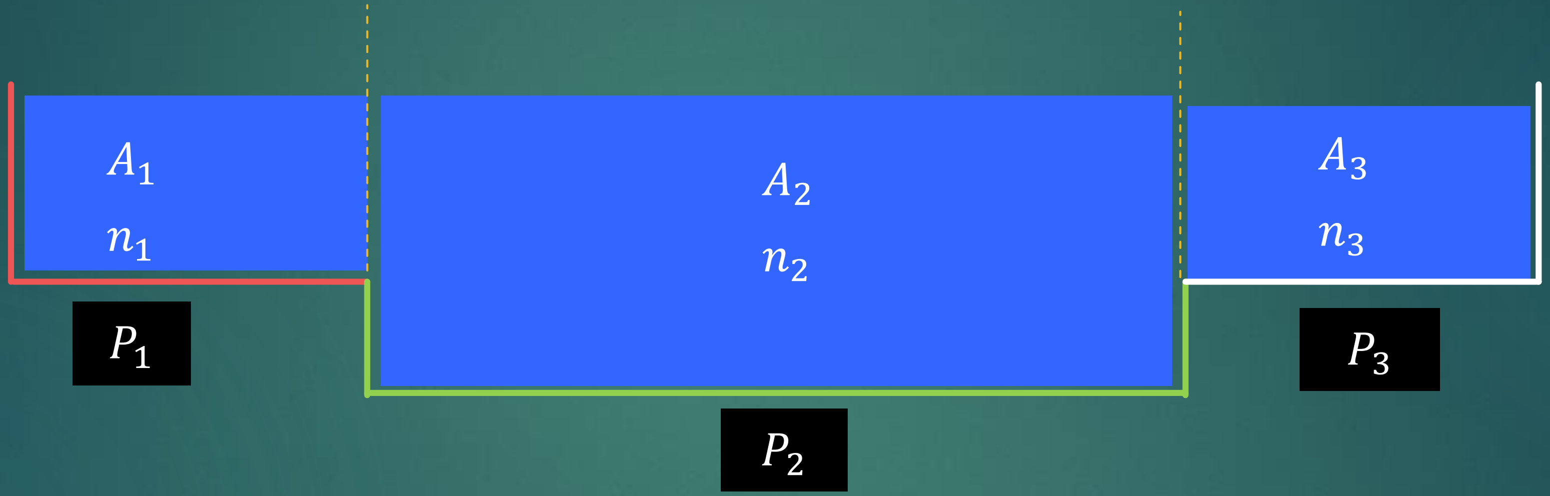
Compound Channels







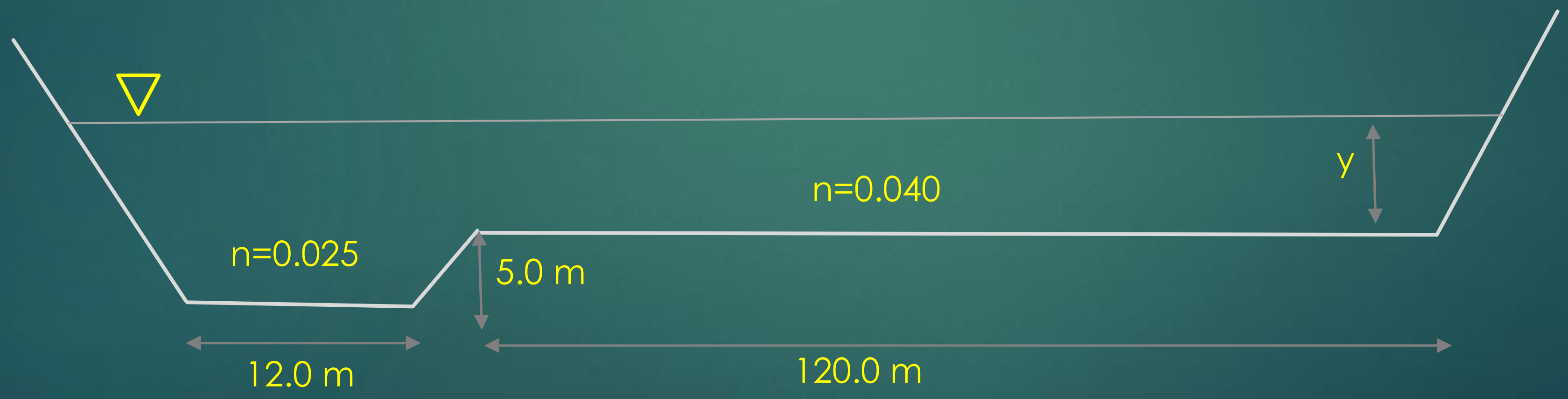
Compound Channels



$$Q = \left[\frac{1}{n_1} A_1 R_{h1}^{2/3} S_0^{1/2}\right] + \left[\frac{1}{n_2} A_2 R_{h2}^{2/3} S_0^{1/2}\right] + \left[\frac{1}{n_3} A_3 R_{h3}^{2/3} S_0^{1/2}\right]$$

Example 3-3

Determine the discharge in the following compound channel as bed slope is 0.0009, the depth is 8.0 ft, and side slope 1:1.



Design of unlined and lined channels

- In general, a natural channel system continually changes its position and shape as a result of hydraulic forces acting on its bed and banks.
- The design of open channels should be based on maximum permissible velocities.

Design of unlined and lined channels

In the unlined channels:

- The stability of channels is more dependent on the physical and chemical properties of the soil than hydraulic properties.
- Stable hydraulic section is the most important factor.
- If a higher velocity is desired, a geotechnical report should be provided to identify the soil material classification for the maximum permissible velocity determination.

Material	Side slopes (vert:hor)
Hard rock	Vertical
Weathered, cracked or soft rock	Vertical
Clay and hard gravel	1:0,5
Clay loam and gravel loam	1:1
Sandy loam	1:1,5
Sandy soil	1:2

Design of unlined and lined channels

In the lined channels:

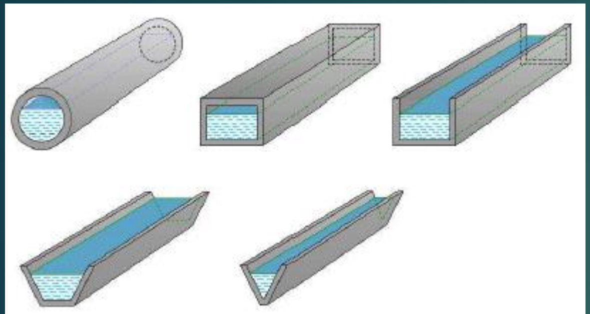
- These channels are lined with materials that do not erode easily, e.g. concrete, stone pitching, steel, wood, glass, plastic, etc.
- The choice of material depends on availability and cost of respective materials.
- The aspect that need to be taken into consideration is the quantity of lining material (or finding the best hydraulic cross section).
- Minimizing lining material costs is a factor.

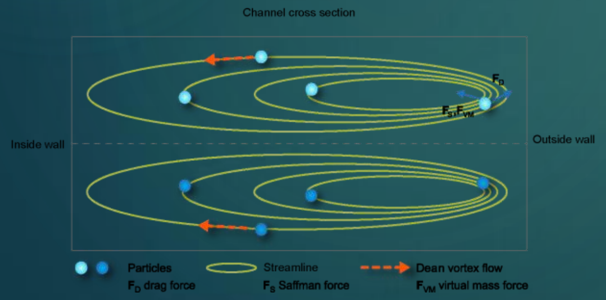
Design of erodible or unlined channels

Design procedure

- Estimate Manning Coefficient (n)
- Compute the value of the section factor ($AR_h^{2/3}$)
- Compute Normal Depth (y_n)
- Compute channel properties (y, Q, V)
- Check minimum permissible velocity

Design of erodible or unlined channels





Maximum Permissible Velocities

TABLE 7.5 Maximum permissible velocities as recommended by Fortier and Scobey (1926) for straight channels of small slope and after aging

		Clear water				Water transporting colloidal silts			
Material (1)	n (2)	$\bar{u}$, ft/s (3)	τ_o, lb/ft^2 (4)	$\bar{u}$, m/s (5)	τ_o, N/m^2 (6)	$\bar{u}$, ft/s (7)	τ_o, lb/ft^2 (8)	$\bar{u}$, m/s (9)	τ_o, N/m^2 (10)
Fine sand, noncolloidal	0.020	1.50	0.027	0.457	1.29	2.50	0.075	0.762	3.59
Sandy loam, noncolloidal	0.020	1.75	0.037	0.533	1.77	2.50	0.075	0.762	3.59
Silt loam, noncolloidal	0.020	2.00	0.048	0.610	2.30	3.00	0.11	0.914	5.27
Alluvial silts, noncolloidal	0.020	2.00	0.048	0.610	2.30	3.50	0.15	1.07	7.18
Ordinary firm loam	0.020	2.50	0.075	0.762	3.59	3.50	0.15	1.07	7.18
Volcanic ash	0.020	2.50	0.075	0.762	3.59	3.50	0.15	1.07	7.18
Stiff clay, very colloidal	0.025	3.75	0.26	1.14	12.4	5.00	0.46	1.52	22.0
Alluvial silts, colloidal	0.025	3.75	0.26	1.14	12.4	5.00	0.46	1.52	22.0
Shales and hardpans	0.025	6.00	0.67	1.83	32.1	6.00	0.67	1.83	32.1
Fine gravel	0.020	2.50	0.075	0.762	3.59	5.00	0.32	1.52	15.3
Graded loam to cobbles when noncolloidal	0.030	3.75	0.38	1.14	18.2	5.00	0.66	1.52	31.6
Graded silts to cobbles when colloidal	0.030	4.00	0.43	1.22	20.6	5.50	0.80	1.68	38.3
Coarse gravel noncolloidal	0.025	4.00	0.30	1.22	14.4	6.00	0.67	1.83	32.1
Cobbles and shingles	0.035	5.00	0.91	1.52	43.6	5.50	1.10	1.68	52.7

Small Slope Channels: having a bottom slope less than 1 in 10 (10%).

Large Slope Channels: having a bottom slope greater than 1 in 10 (10%).

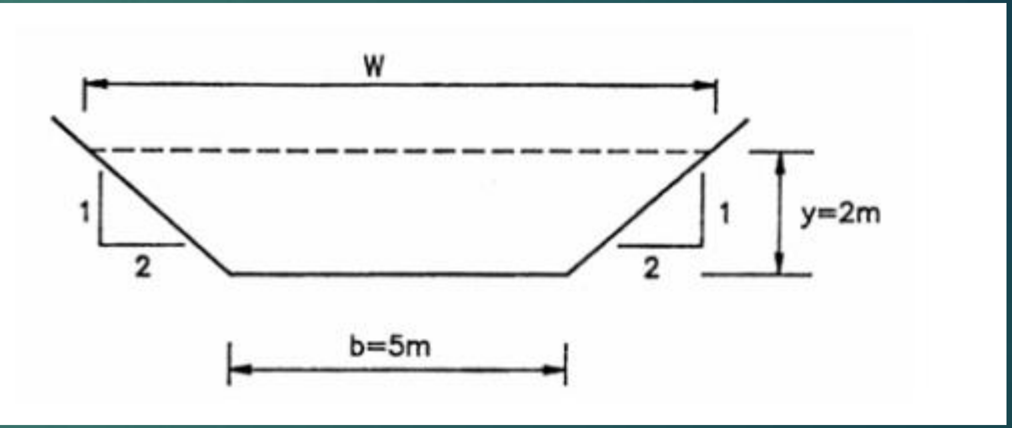
Design of erodible or unlined channels

Material	Average flow velocity [m/s]
Very light flowing sand	0,2 – 0,3
Very light loose sand	0,3 – 0,4
Coarse sand or light sandy soil	0,4 – 0,6
Normal sandy soil	0,6 – 0,7
Sandy loam soil	0,7 – 0,8
Loamy alluvial soil	0,8 – 1,0
Firm loam, clay loam	1,0 – 1,2
Stiff clay and gravely soil	1,2 – 1,5
Coarse and rocky gravel	2,0 – 2,5
Conglomerate, soft shale, soft rock formation	2,0 – 2,5
Hard rock	3,0 – 4,5
Concrete	4,5 – 6,0

Design of erodible or unlined channels

Example 3-4

The normal flow depth in a trapezoidal concrete channel is 2 m. The base width is 5 m with side slopes 1:2. The channel slope is 0.001 and Manning's n = 0,015. Determine the *flow rate,* and *average flow velocity*.



Design of erodible or unlined channels

Example 3-5

Determine the width (b) and safe flow depth (y) of a trapezoidal spillway with a slope of 0.0016, side slope 1:1.5, and a flow rate of 7750 m^3/h. The spillway is built in sandy loam soil.

Design of erodible or unlined channels

Example 3-6

A trapezoidal open channel (Stiff-Clay, n=0.035) with the side slope 1:3 (m=3) is to be constructed with the following conditions: Q100 = 191 cfs, Upstream elevation 4,918 ft, Downstream elevation 4,917 ft, Channel length 900 ft, Bottom width 10 ft. Calculate velocity.

* 100-year design flow or Q_{100} means a flow with the return period of 100 years. A return period, is an estimate of the likelihood of an event, such as an earthquake, flood or a river discharge flow to occur.

This does not mean that a 100-year flood will happen regularly every 100 years, or only once in 100 years. In any given 100-year period, a 100-year event may occur once, twice, more, or not at all, and each outcome has a probability that can be computed as below.

Best Hydraulic Cross Sections

- The quantity of $AR_h^{2/3}$ in the manning equation is called the section factor.
- In another words, the section factor relating to uniform flow is given by $A\left(\frac{A}{P}\right)^{2/3}$

$$Q = \left[\frac{1}{n} A R_h^{2/3} S_0^{1/2}\right] = \left[\frac{1}{n} A \left(\frac{A}{P}\right)^{2/3} S_0^{1/2}\right] = \left[\frac{1}{n} A^{5/3} \left(\frac{1}{P}\right)^{2/3} S_0^{1/2}\right]$$

- For a given roughness and slope, the **discharge** will increase with **increasing cross-sectional area** while decrease with **increasing wetted perimeter**.

Best Hydraulic Cross Sections

- The best hydraulic cross-section for a given A, n, and S_0 is the cross-section that conveys maximum discharge.

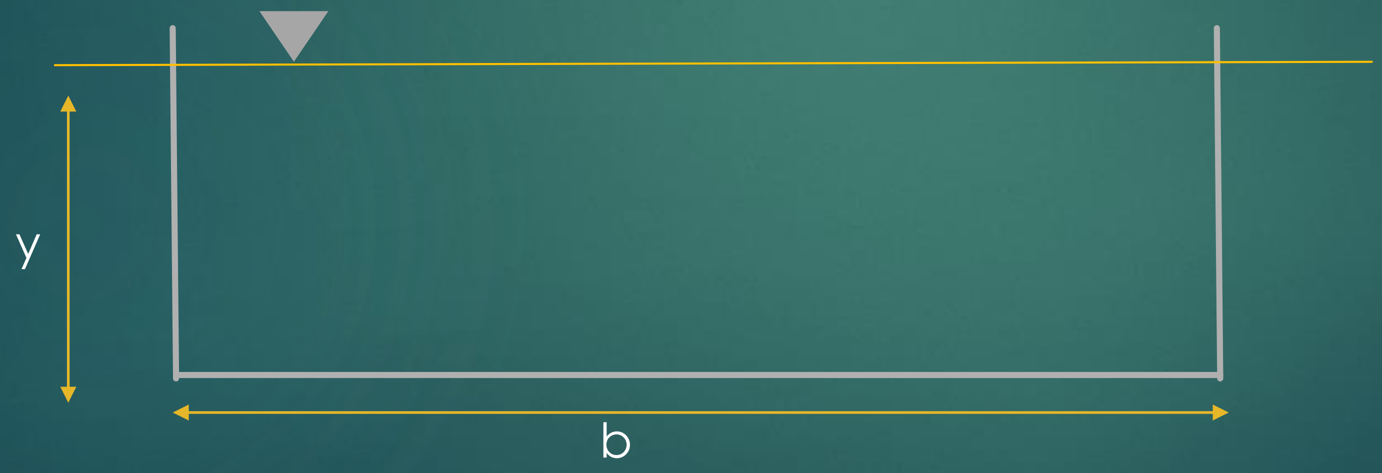
- The minimum lining area will reduce construction expenses and therefore that cross-section is economically the most efficient one.

$$\underbrace{Q}_{Q_{max}} = \underbrace{\left[\frac{1}{n} S_0^{1/2} A^{5/3}\right]}_{Constant} \left[\left(\frac{1}{\underbrace{P}_{P_{min}}}\right)^{2/3}\right]$$

Best Hydraulic Cross Sections

Example 3-7

Determine the best cross-sectional area for a rectangular channel with $Q=10\ m3/s$, $n=0.02$, and $S_0=0.0009$.



Best Hydraulic Cross Sections

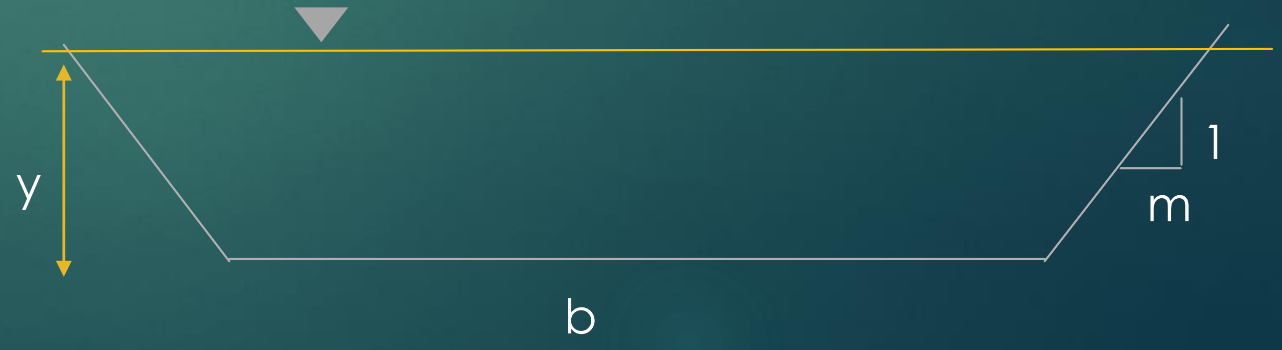
- To find the best cross-sectional area for a Trapezoidal channel, the following requirements should be met:

$$\begin{cases} P = 4y\sqrt{1+m^2} - 2my \\ m = \dfrac{1}{\sqrt{3}} \end{cases} \rightarrow \left| \begin{aligned} P &= 2\sqrt{3}y \\ b &= \frac{2\sqrt{3}}{3}y \\ A &= \sqrt{3}y^2 \end{aligned} \right.$$

$$\boldsymbol{R_h = \frac{y}{2}}$$

- Or, if there is a predetermined value for **m**, just the first requirement needs to be met.

$$P = 4y\sqrt{1+m^2} - 2my$$



Best Hydraulic Cross Sections

Example 3-8

Determine the best cross-sectional area for a trapezoidal channel with Q=200 m3/s, n=0.016, and S_0=0.0004.

Best Hydraulic Cross Sections

Example 3-9

Determine the best cross-sectional area for a trapezoidal channel with m=2, Q=20 m3/s, n=0.025, and S_0=0.0009.

Homework 3

Q1-3 Water flows in a rectangular channel which are made of concrete with the width of 12 m and depth of 2.5 m. The bottom slope is 0.0028 m/m. Find the velocity and flow rate.

Homework 3

Q2-3. Water flows in a circular channel which are made of unfinished concrete with the diameter of 500 mm and the bottom slope of 0.005 m/m. Find the velocity and flow rate if the channel is half full.

Homework 3

Q3-3. Water flows in a rectangular channel with the width of 18 m, flow rate of 35 m3/s, n = 0.011 and the bottom slope of 0.00078 m/m. Find the depth.

Homework 3

Q3-4 What is the flow rate in the following channel with S_0=0.0007 and n=0.025. Assume all side slopes are 45 degree.