Uniform Open Channel Flow

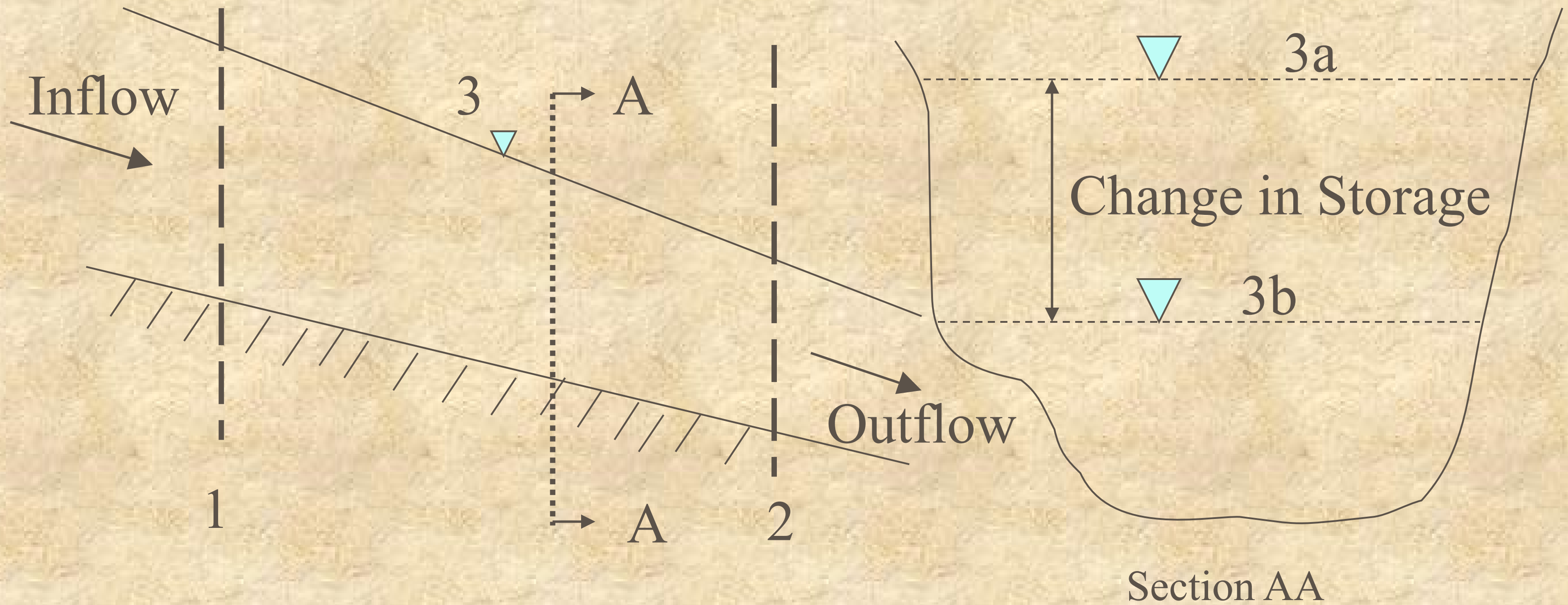
Basic relationships

Continuity equation
Energy equation
Momentum equation
Resistance equations

Flow in Streams

- Introduction
- Effective Discharge
- Shear Stresses
- Pattern & Profile
- ✓ **Open Channel Hydraulics**
- ✓ **Resistance Equations**
- ✓ **Compound Channel**
- Sediment Transport
- Bed Load Movement
- Land Use and Land Use Change

Continuity Equation



Inflow – Outflow = Change in Storage

General Flow Equation

$$Q = va$$

Equation 7.1

Q — Flow rate (cfs) or (m^3/s)

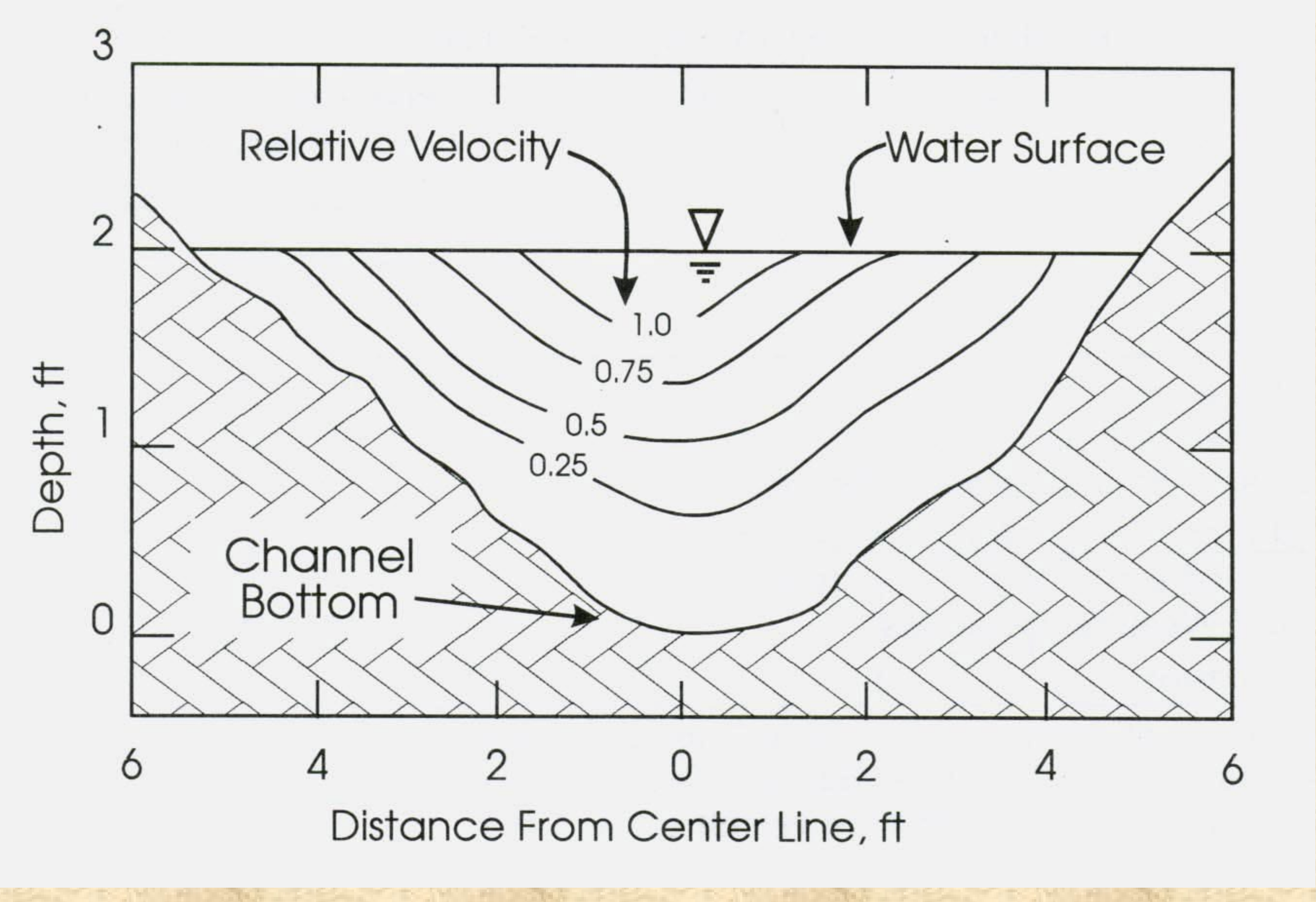
v — Avg. velocity of flow at a cross-section (ft/s) or (m/s)

a — Area of the cross-section (ft^2) or (m^2)

Resistance (velocity) Equations

- **Manning's Equation** Equation 7.2
- **Darcy-Weisbach Equation** Equation 7.6

Velocity Distribution In A Channel



Depth-averaged velocity is above the bed at about 0.4 times the depth

Manning's Equation

- **In 1889 Irish Engineer, Robert Manning presented the formula:**

$$v = \frac{1.49}{n} R^{2/3} S^{1/2}$$ **Equation 7.2**

✓ v is the flow velocity (ft/s)

✓ n is known as Manning's n and is a coefficient of roughness

✓R is the hydraulic radius (a/P) where P is the wetted perimeter (ft)

✓S is the channel bed slope as a fraction

✓1.49 is a unit conversion factor. Approximated as 1.5 in the book.

Use 1 if SI (metric) units are used.

Table 7.1 Manning's n Roughness Coefficient

Type of Channel and Description	Minimum	Normal	Maximum
Streams			
Streams on plain			
Clean, straight, full stage, no rifts or deep pools	0.025	0.03	0.033
Clean, winding, some pools, shoals, weeds & stones	0.033	0.045	0.05
Same as above, lower stages and more stones	0.045	0.05	0.06
Sluggish reaches, weedy, deep pools	0.05	0.07	0.07
Very weedy reaches, deep pools, or floodways	0.075	0.1	0.15
with heavy stand of timber and underbrush			
Mountain streams, no vegetation in channel, banks steep, trees & brush along banks submerged at high stages			
Bottom: gravels, cobbles, and few boulders	0.03	0.04	0.05
Bottom: cobbles with large boulders	0.04	0.05	0.07

	Coarse Gravel		0.027
Degree of irregularity	Smooth	*n1*	0.000
	Minor		0.005
	Moderate		0.010
	Severe		0.020
Variations of Channel Cross Section	Gradual	*n2*	0.000
	Alternating Occasionally		0.005
	Alternating Frequently		0.010-0.015
Relative Effect of Obstructions	Negligible	*n3*	0.000
	Minor		0.010-0.015
	Appreciable		0.020-0.030
	Severe		0.040-0.060
Vegetation	Low	*n4*	0.005-0.010
	Medium		0.010-0.025
	High		0.025-0.050

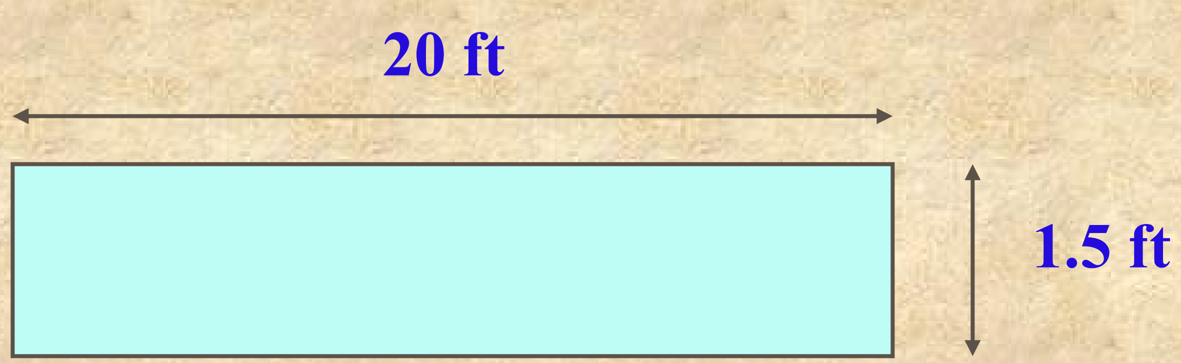
Table 7.2. Values for the computation of the roughness coefficient (Chow, 1959)

Channel Conditions		Values	
Material Involved	Earth	n0	0.025
	Rock Cut		0.025
	Fine Gravel		0.024
	Coarse Gravel		0.027
Degree of irregularity	Smooth	n1	0.000
	Minor		0.005
	Moderate		0.010
	Severe		0.020
Variations of Channel Cross Section	Gradual	n2	0.000
	Alternating Occasionally		0.005
	Alternating Frequently		0.010-0.015
Relative Effect of Obstructions	Negligible	n3	0.000
	Minor		0.010-0.015
	Appreciable		0.020-0.030
	Severe		0.040-0.060
Vegetation	Low	n4	0.005-0.010
	Medium		0.010-0.025
	High		0.025-0.050
	Very High		0.050-0.100
Degree of Meandering	Minor	m5	1.000
	Appreciable		1.150
	Severe		1.300

$$n = (n_0 + n_1 + n_2 + n_3 + n_4)\, m_5 \qquad \text{Equation 7.12}$$

Example Problem
Velocity & Discharge

- ✓ Channel geometry known
- ✓ Depth of flow known
- ✓ Determine the flow velocity and discharge



- ✓ Bed slope of 0.002 ft/ft
- ✓ Manning’s n of 0.04

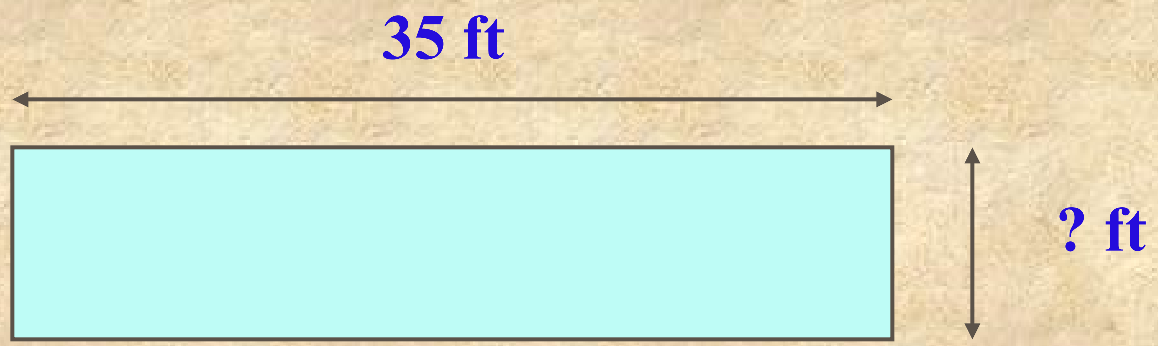
Solution

- $q = va$ equation 7.1
- $v = (1.5/n)\, R^{2/3} S^{1/2}$ (equation 7.2)
- $R = a/P$ (equation 7.3)
- a = width x depth = 20 x 1.5 ft = 30 ft^2
- $P = 20 + 1.5 + 1.5$ ft = 23 ft.
- $R = 30/23 = 1.3$ ft
- $S = 0.002$ ft/ft (given) and $n = 0.04$ (given)
- $v = (1.5/0.04)(1.3)^{2/3}(0.002)^{1/2} = 2$ ft/s
- $q = va = 2 \times 30 = 60$ ft^3/s or 60 cfs

Answer: the velocity is 2 ft/s and the discharge is 60 cfs

Example Problem
Velocity & Discharge

- ✓ Discharge known
- ✓ Channel geometry known
- ✓ Determine the depth of flow



- ✓ Discharge is 200 cfs
- ✓ Bed slope of 0.005 ft/ft
- ✓ Stream on a plain, clean, winding, some pools and stones

Table 7.1 Manning's n Roughness Coefficient

Type of Channel and Description	Minimum	Normal	Maximum
Streams			
Streams on plain			
Clean, straight, full stage, no rifts or deep pools	0.025	0.03	0.033
Clean, winding, some pools, shoals, weeds & stones	0.033	0.045	0.05
Same as above, lower stages and more stones	0.045	0.05	0.06
Sluggish reaches, weedy, deep pools	0.05	0.07	0.07
Very weedy reaches, deep pools, or floodways	0.075	0.1	0.15
with heavy stand of timber and underbrush			
Mountain streams, no vegetation in channel, banks steep, trees & brush along banks submerged at high stages			
Bottom: gravels, cobbles, and few boulders	0.03	0.04	0.05
Bottom: cobbles with large boulders	0.04	0.05	0.07

Solution

- q = va equation 7.1
- v =(1.5/n) $R^{2/3}$ $S^{1/2}$ (equation 7.2)
- R= a/P (equation 7.3)
- **Guess a depth! Lets try 2 ft**
- a = width x depth = 35 x 2 ft = 70 ft^2
- P= 35 + 2 + 2 ft = 39 ft.
- R= 70/39 = 1.8 ft
- S = 0.005 ft/ft (given)
- n = 0.033 to 0.05 (Table 7.1) Consider deepest depth
- v = $(1.5/0.05)(1.8)^{2/3}(0.005)^{1/2}$ = 3.1 ft/s
- q = va=3.1 x 70= 217 ft^3/s or 217 cfs
- If the answer is <10% different from the target stop!

Answer: The flow depth is about 2 ft for a discharge of 200 cfs

Darcy-Weisbach Equation

- **Hey's version of the equation:**

$$v^2 = \frac{8gRS}{f}$$

f is the Darcy-Weisbach resistance factor and all dimensions are in SI units.

Hey (1979) Estimate Of "f"

- Hey's version of the equation:

$$f^{-0.5} = 2.03\left(\frac{aR}{3.5D_{84}}\right)$$

a is a function of the cross-section and all dimensions are in SI units.

Bathurst (1982) Estimate Of "a"

$$a = 11.1\left[\frac{R}{d_m}\right]^{-0.314}$$

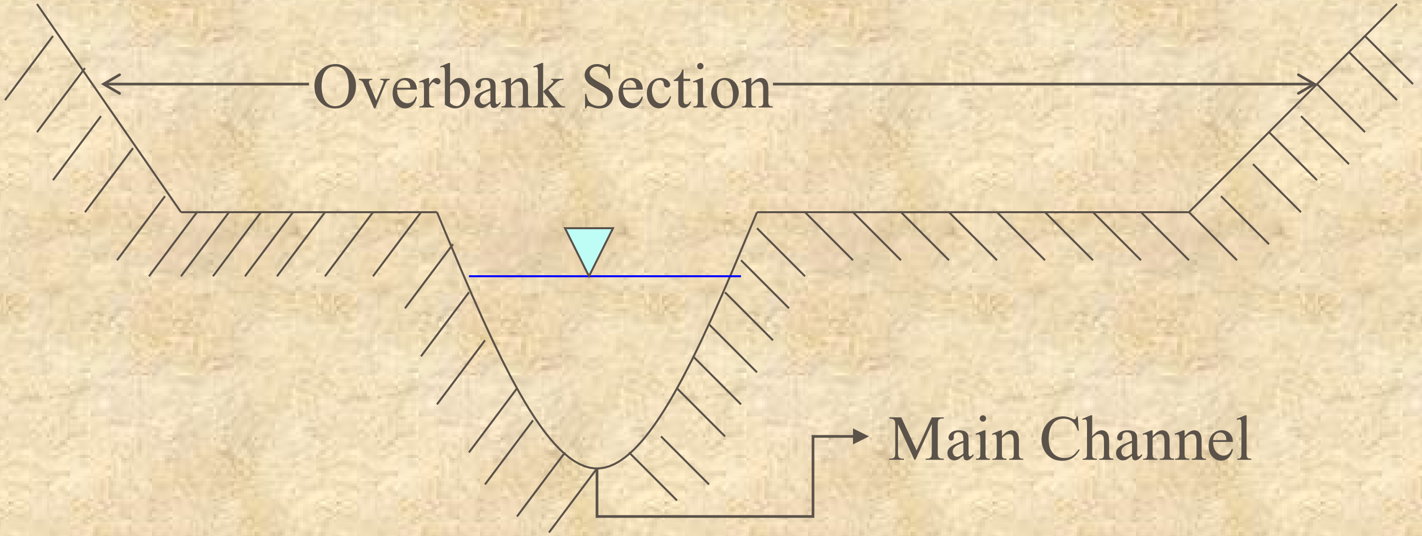
d_m is the maximum depth at the cross-section provided the width to depth ratio is greater than 2.

Flow in Compound Channels

- Most flow occurs in main channel; however during flood events overbank flows may occur.
- In this case the channel is broken into cross-sectional parts and the sum of the flow is calculated for the various parts.

Flow in Compound Channels

- **Natural channels often have a main channel and an overbank section.**



Flow in Compound Channels

$$V_i = \frac{1.49}{n_i} S^{1/2} \left(\frac{A_i}{P_i} \right)^{2/3}$$

$$Q = \sum_{i=1}^{n} V_i A_i$$

In determining R only that part of the wetted perimeter in contact with an actual channel boundary is used.

Channel and Floodplain Subdivision

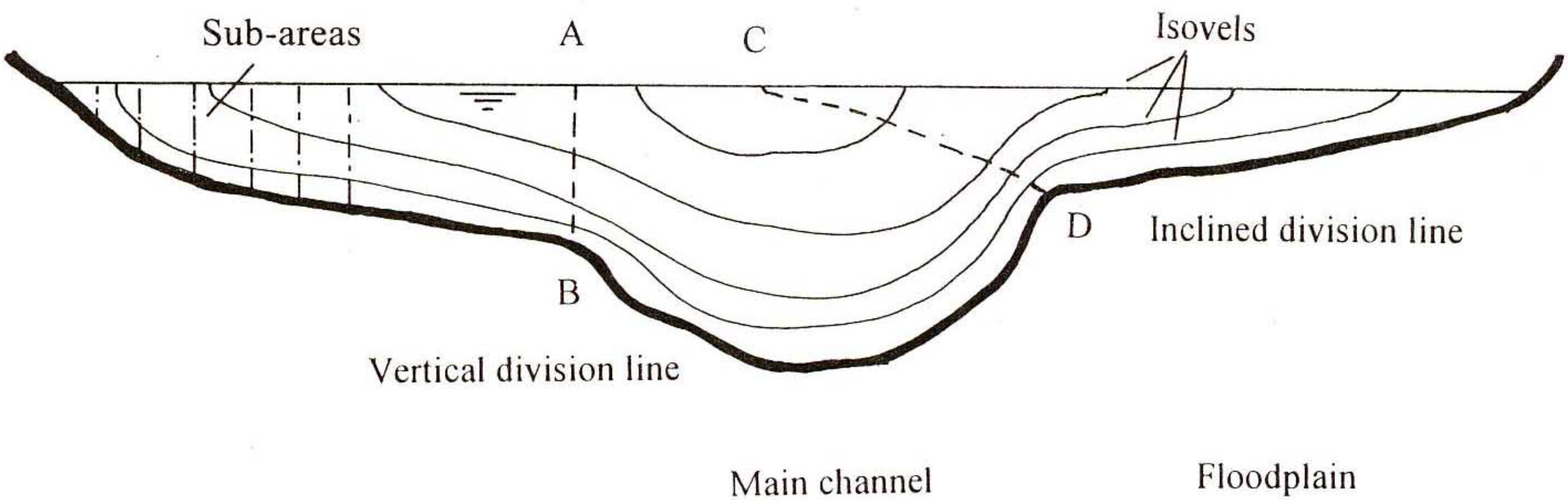


Figure 5.12 Channel subdivision methods for calculation of discharge

Variation in Manning's "n"

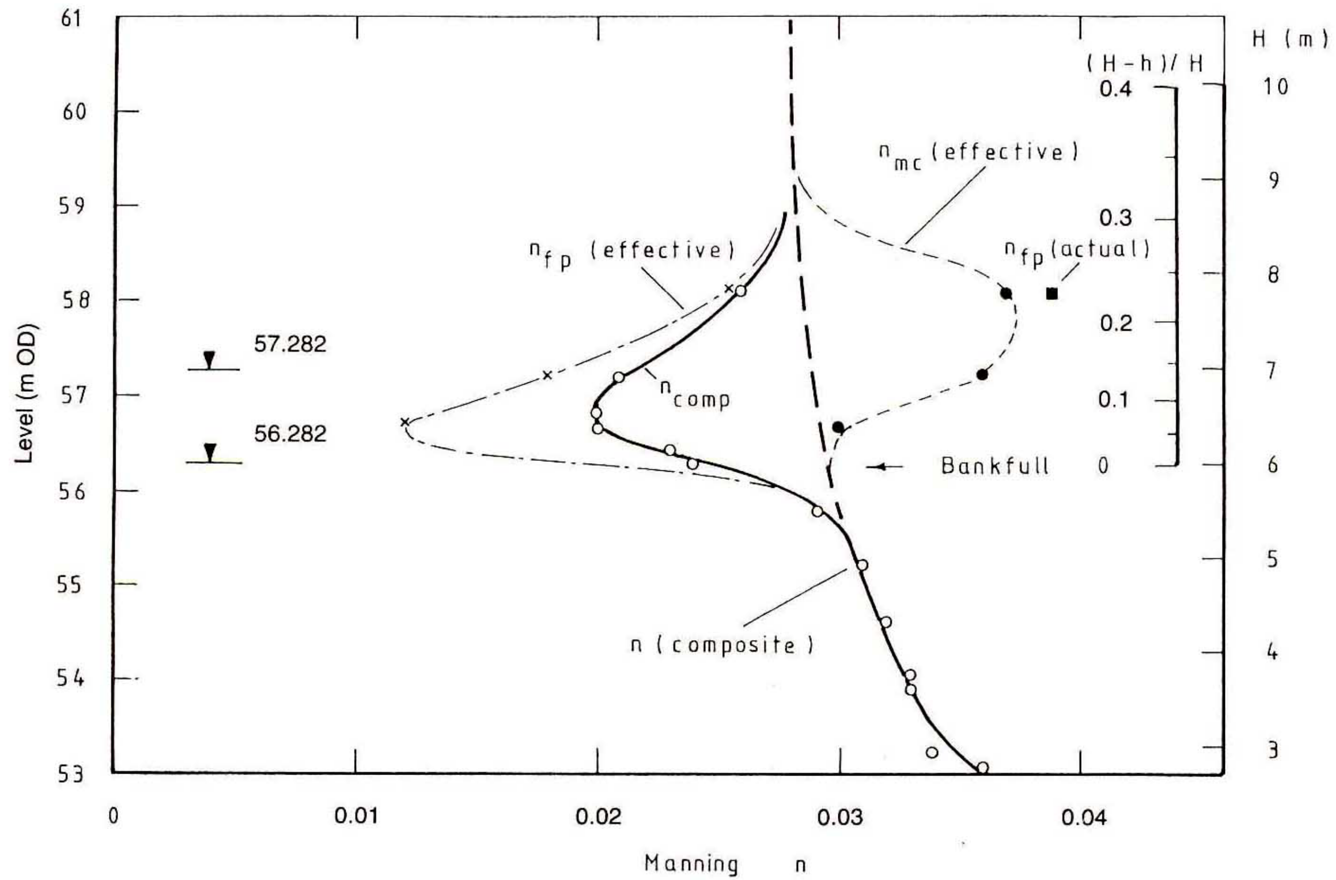
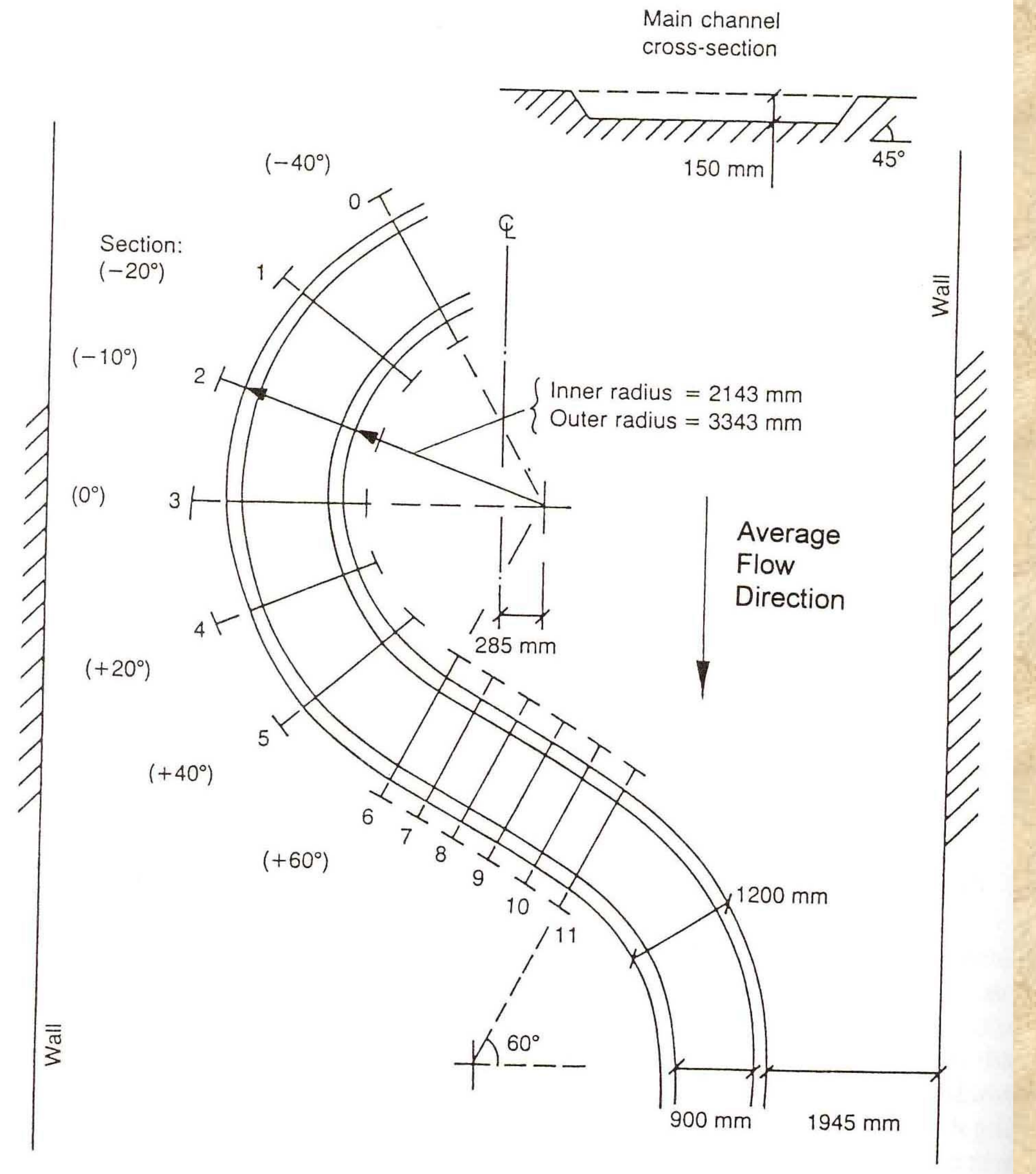
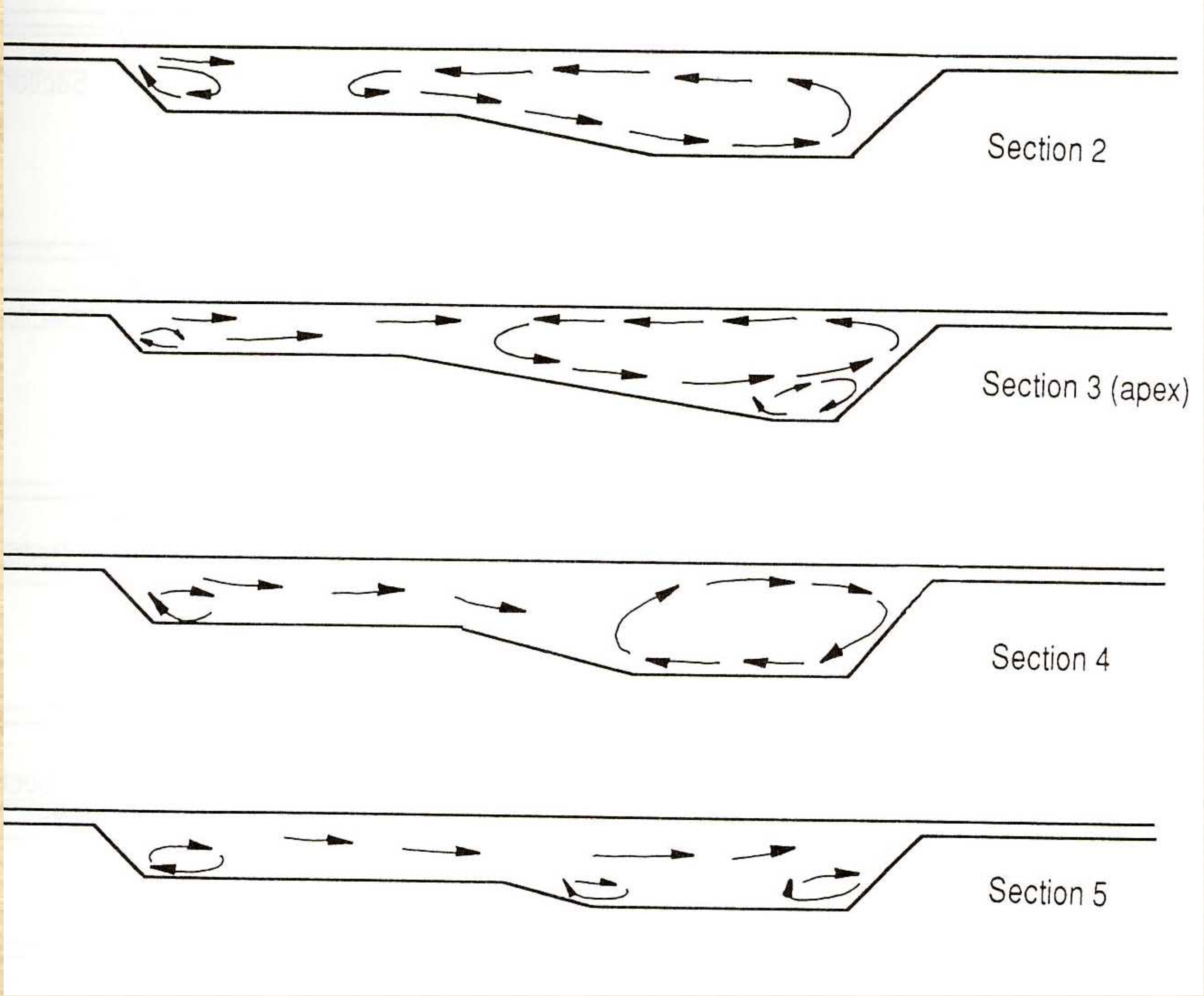


Figure 5.13 Variation of Manning "*n*" resistance coefficient for overbank flow at Montford, River Severn (after Knight *et al.*, 1989)

Section Plan



Shallow Overbank Flow



Deep Overbank Flow