Section 5

Open Channel Flow

Open Channel Topics

- Manning's Equation & Normal Flow
- River Backwater Analysis
- Scour
- River Stabilization

Manning's Equation

Manning's Equation is an open channel flow equation that can be used to calculate the normal depth of flow that will occur in a sufficiently long conduit or channel. It is given by:

$$Q = \frac{1.486}{n} A R^{2/3} S^{1/2}$$

Where:

n = Manning's Roughness Coefficient (dimensionless)

The n value is an estimate of the resistance to flow in a given channel section. of The table shown below illustrates the n value of some common channels and conduits. See Appendix 4 of the Hydraulics Manual for a more detailed list.

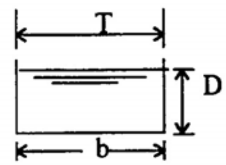
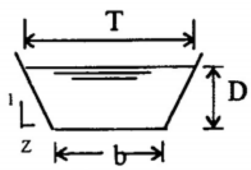
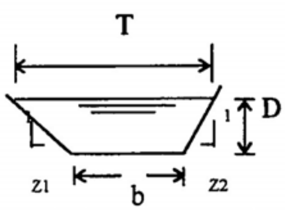
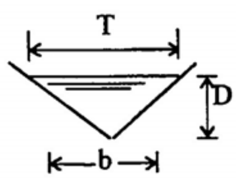
Material	Manning's n Value
Smooth Plastic Pipe	0.009
Concrete Pipe	0.012
Corrugated Metal Pipe	0.013 - 0.024
Concrete-Lined Channels	0.013 - 0.017
Gravel-Lined Excavated Channel	0.022 - 0.030
Quarry Spalls	0.030 - 0.035
Minor Stream	0.030 - 0.035
Light Loose Riprap	0.035 - 0.040
Heavy Loose Riprap	0.040 - 0.045
Mountain Streams, No Vegetation Bottom of Gravel, Cobbles, and Boulders	0.040 - 0.050

A = Cross-sectional area of flow (ft^2)

R = Hydraulic Radius

S = Slope of the channel

Cross Sectional Flow Area

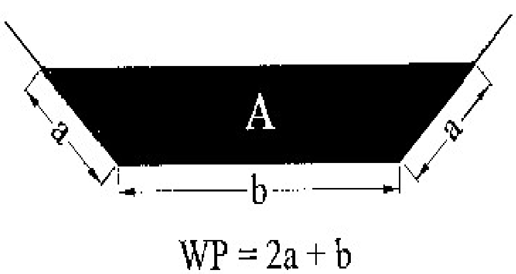
Cross Section	Area, A	Wetted Perimeter, WP
 Rectangle	bD	$b + 2D$
 Trapezoid (equal side slopes)	$(b + ZD)D$	$b + 2D\sqrt{1 + Z^2}$
 Trapezoid (unequal side slopes)	$\frac{D^2}{2}(Z_1 + Z_2) + Db$	$b + D(\sqrt{1 + Z_1^2} + \sqrt{1 + Z_2^2})$
 Triangle	ZD^2	$2D\sqrt{1 + Z^2}$

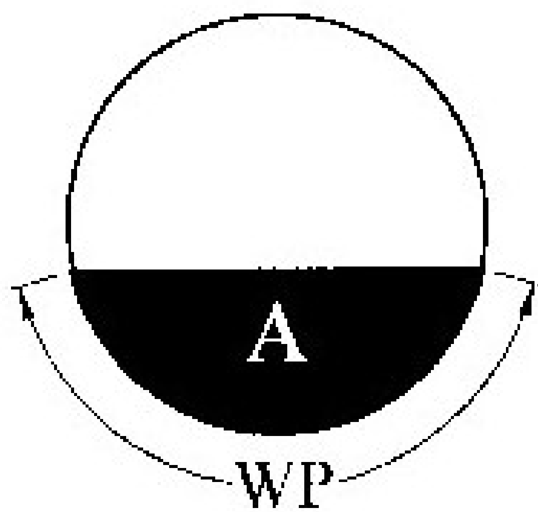
Reference: VT Chow "Open Channel Hydraulics" for a more complete table of geometric elements.

Figure 4-2.2.1
Geometric Elements of Channel Sections

Hydraulic Radius

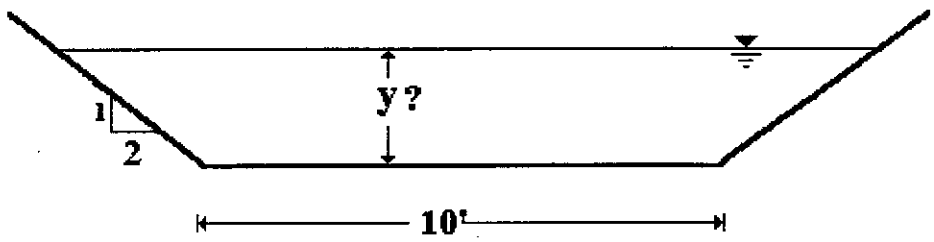
$$R = \frac{\text{Area (A)}}{\text{Wetted Perimeter (WP)}}$$





Example: It has been determined that the flow in a channel is 1200 cfs. Calculate the normal depth in the channel if a trapezoidal section with 2:1 side slopes and a 10' bottom width is used. Assume: $n = 0.035$

$S = 0.004$ ft/ft



Q = 1200 cfs

Solution: By trial and error, choose a depth y and solve Manning's equation, then compare the calculated flow with the actual flow.

y	A	P	Q

River Backwater Analysis

- Computation of a change in the water surface profile
- Suitable for channels irregular in shape
- Required Information
  - Contour map with 1 ft or 2 ft. intervals extending a minimum of 500 ft upstream and downstream of the bridge.
  - Photographs or descriptions of the channel and ground cover.

Scour Categories

- Bridge placement within the waterway must consider potential scour
- Four types of scour
  - ~General Scour
  - ~Lateral Channel Migration
  - ~Contraction Scour
  - ~Local Scour
- Required Information
  - ~Same for river backwater analysis

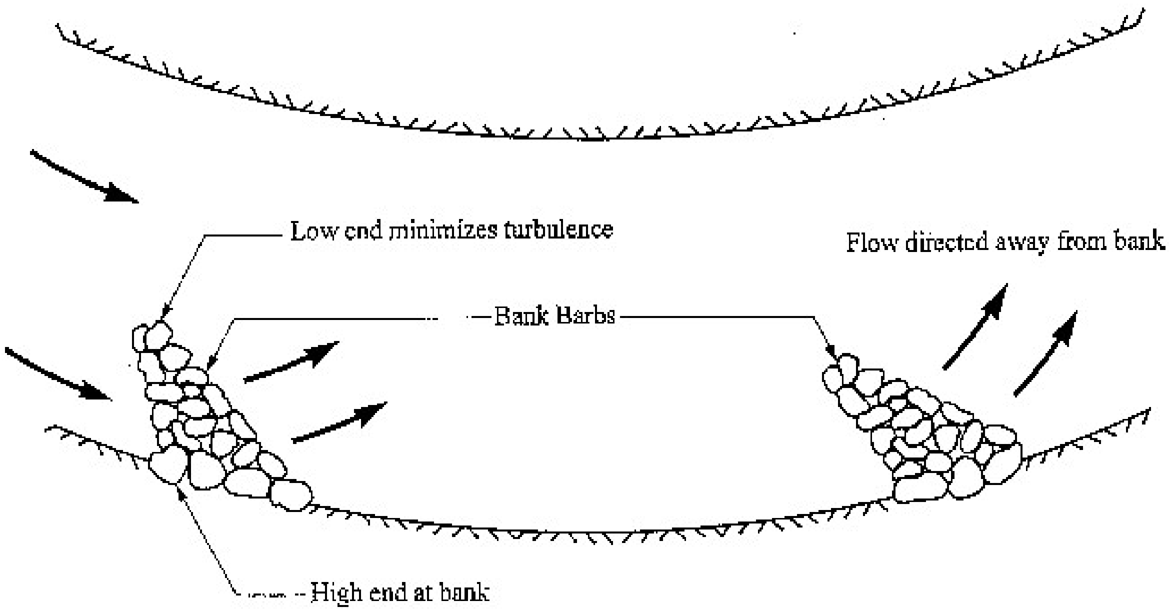
River Stabilization

- Barbs
- Riprap Bank Protection

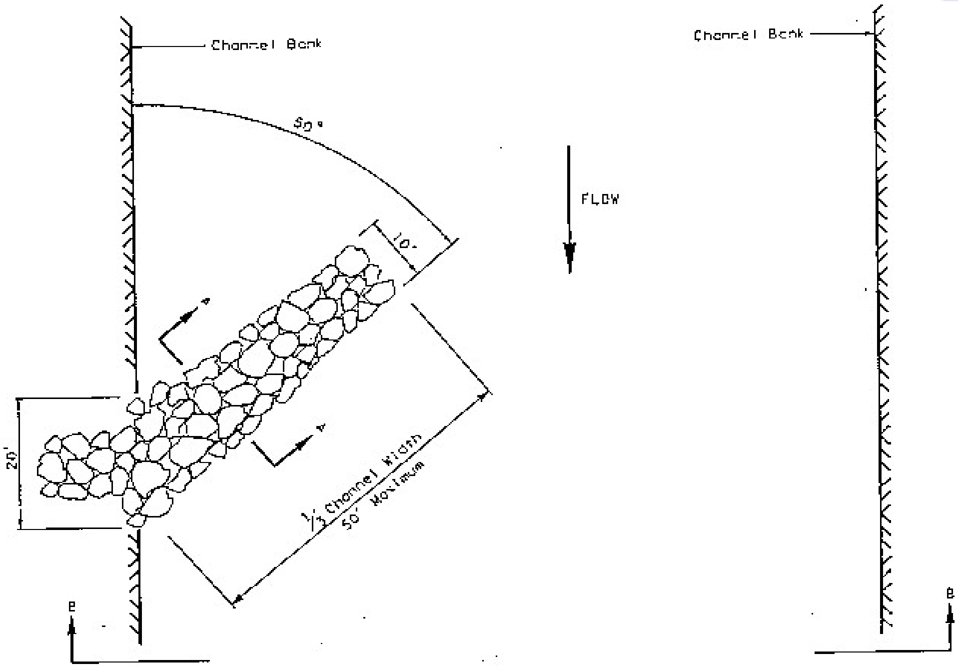
Stream Characteristics

- Channel width, configuration, material
- Sediment Transport
- Flow velocity, depth
- Floodplains
- Ice&Debris

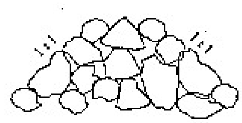
Barbs



Typical Barb Layout

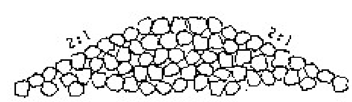


BANK BARB - PLAN VIEW



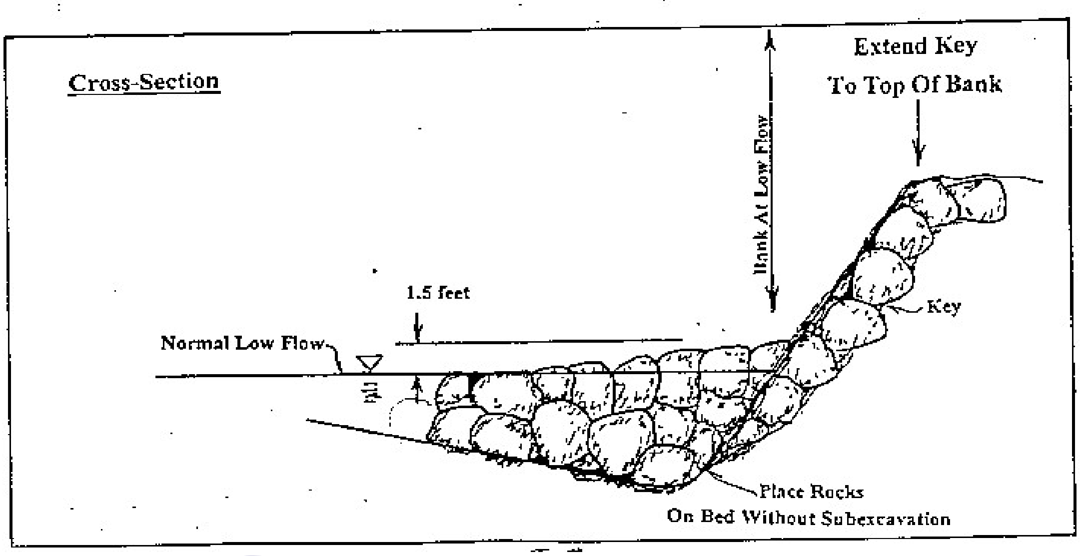
SECTION A-A

Use this cross section for rock sizes greater than 3' in diameter



SECTION A-A

Use this cross section for rock sizes equal to or less than 3' in diameter



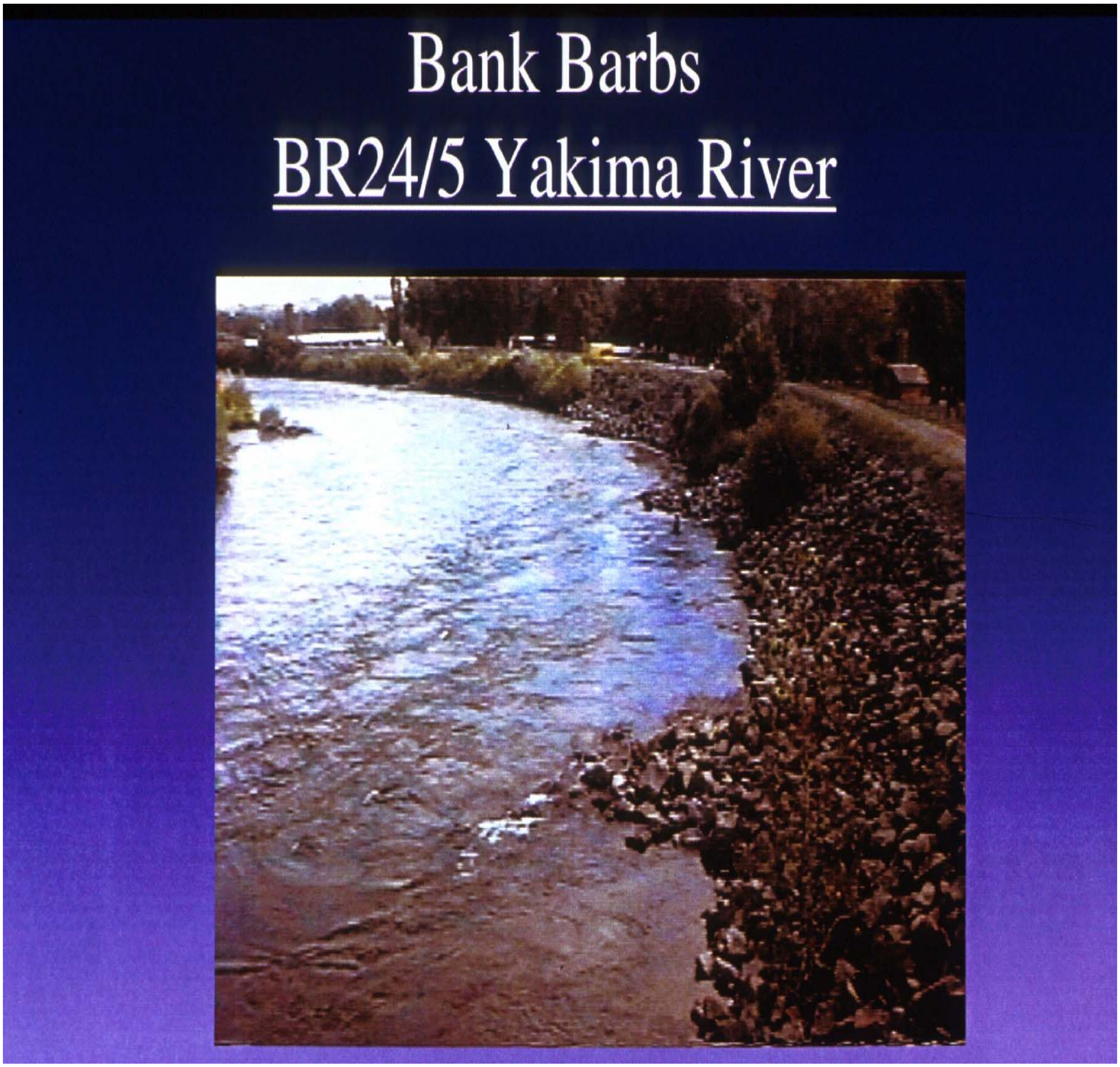
Barbs

<u>Advantages</u>

- Shift thalweg away from eroding embankment
- Encourages sediment deposition
- Provide channel roughness & energy dissipation
- Provides fish habitat
- Cost effective – less rock

<u>Disadvantages</u>

- Rivers with large sediment movement
- Rivers with high degree of sinuosity
- Rivers with very sharp bends
- Vertical height of the barb


Bank Barbs
BR24/5 Yakima River

Thalweg Shift

Riprap Bank Protection

Advantages

- Cost
- Availability
- Emergency Repairs
- Safer Roadsides
- Self-Healing
- Infil./Exfil.

Disadvantages

- Conveyance
- Volume
- Solve Problem?
- Downstream Impact
- Aesthetics

Riprap Bank Protection

Using measured data and Manning's Equation, the designer can determine the required minimum D_{50} riprap size by using the following equation:

$$D_{50} = (C_R)\,(d)\,(S_o)$$

where: D_{50} = particle size of gradation (ft) of which 50% by weight of the mixture is smaller

C_R = Riprap Coefficient (see table below)

d = Depth Of Flow In Channel (ft)

S_o = Longitudinal Slope Of Channel (ft/ft)

B = Bottom Width Of Trapezoidal Channel (ft)

Riprap Coefficients (C_R)						
Channel Side Slopes	Angular Rock			Rounded Rock		
	B/d = 1	B/d = 2	B/d = 4	B/d = 1	B/d = 2	B/d = 4
1.5:1	21	19	18	28	26	24
1.75:1	17	16	15	20	18	17
2:1	16	14	13	17	15	14
2.5:1	15	13	12	15	14	13
3:1	15	13	12	15	13	12
4:1	15	13	11.5	15	13	11.5
Flat Bottom	12.5	12.5	11.5	12.5	12.5	11.5

Once the required D_{50} has been determined, the appropriate type of rock lining is chosen from the table below:

Type of Rock Lining	D_{50}	Manning's "n"
Quarry Spalls	0.5 ft	0.030 - 0.035
Light Loose Riprap	1.1 ft	0.035 - 0.040
Heavy Loose Riprap	2.2 ft	0.040 - 0.045

Riprap Bank Protection Example

A channel has a trapezoidal shape with side slopes of 2:1 and a bottom width of 10 ft. It conveys a Q_{25} = 1,200 cfs and has a longitudinal slope of 0.004 ft/ft. Determine the type of riprap that is needed for channel bank protection.

From Manning's Equation: Depth of Flow = 7.14 ft

$$B/d = {}^{10}/_{7.14} = 1.40 \Rightarrow C_R = 15$$

$$D_{50} = (CR)(d)(So) = (15)(7.14)(0.004) = 0.43 \text{ ft}$$

The closest riprap D_{50} is that of Quarry Spalls. Quarry Spalls should be used to protect the stream bank unless the D_{50} of the streambed material at the location being analyzed is greater than or equal to 0.43 ft.

Riprap Bank Protection Class Problem

Using the same channel, determine the size of riprap needed for channel bank protection during the Q_{100} flow. The depth of flow is 10 ft during Q_{100}.

Typical Riprap Detail

Open Channel Flow

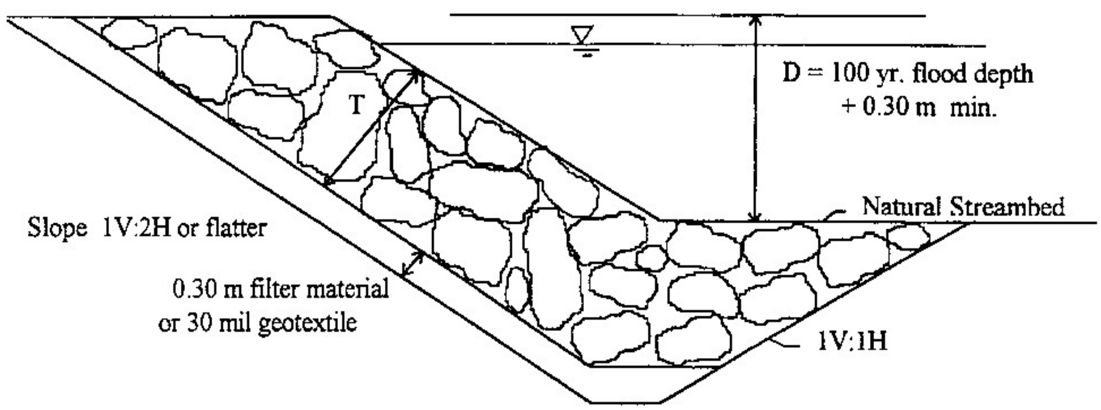


Figure 4-5.3.3
Typical Rock Riprap