

## **5.0 OPEN CHANNEL**

Open channel is frequently an integral component of an urban drainage system design. The drainage system may include the following types of channels or their combination:

- Natural Channel
- Constructed Channel
- Ditch
- Swale

These types of channel are ruled by common open channel design procedure. A stable open channel brings several advantageous features to the design:

- Relatively low construction cost,
- Potential flood control (instream storage attenuating downstream peak),
- Potential groundwater recharge,
- A habitat for native vegetation and wildlife,
- Areas for recreation, and
- An aesthetically pleasing environment adding social benefits.

The implementation of an open channel into the design requires careful planning and accounting for potential right-of-way constraints, utility conflicts, maintenance cost, and safety issues.

This section provides the necessary criteria and methodology for selection and design of open channels.

## **5.1 GENERAL DESIGN CRITERIA**

### **5.1.1 Design Storm Frequency**

Open channels shall be designed to convey the 10-year event below its freeboard height and the 25-year event below its bankfull elevation. The 100-year design storm shall be routed through the channel system to determine that no finished floor of residential dwellings, public, commercial, and industrial buildings will be inundated by the 100-year flood water surface elevation.

### **5.1.2 Geometry**

The channel geometry design depends on site conditions and conveyance needs. The channel cross section may be trapezoidal, parabolic, V-shaped, or combination of those geometric shapes. Most desirable and commonly used is trapezoidal channel cross section.

- Channel side slopes shall be stable throughout the entire length. The channel side slopes shall be a maximum 2:1 (H:V).
- Channels with bottom widths greater than 10 feet shall be designed with a minimum bottom cross-slope of 12:1 (H:V).

- If relocation of a stream channel is unavoidable, the geometry, meander pattern, roughness, and slope should conform to the existing conditions, as practicable. Some means of energy dissipation may be necessary when existing conditions cannot be duplicated.

### 5.1.3 Freeboard

Freeboard is extra height of channel lining above the design storm depth where overflow is expected to occur and potentially cause damage. This additional range of inundation creates a safety factor should unexpected obstructions or additional runoff create a rise in the design water surface elevation.

- For channels three feet or less in depth, one half of foot of freeboard shall be provided.
- For channels deeper than three feet and up to five feet in depth, one foot of freeboard shall be provided.
- For channels deeper than five feet in depth, freeboard that is at least equal to 20 percent of the total channel depth shall be provided.

### 5.1.4 Velocity Limitations

The final design of an open channel should be consistent with the velocity limitations for the selected channel lining to satisfy the condition of non-erosive velocity in the channel.

Maximum velocity values for selected lining categories are presented in Table 5-1. Velocity limitations for vegetative linings are reported in Table 5-2. The manufactured channel lining velocity limitations will be established by manufacturer.

### 5.1.5 Channel Lining

Channel linings include vegetative and engineered materials, further divided into flexible materials (as grass, riprap, articulated concrete, and gabions), and rigid materials (paving blocks and concrete). The channel lining design criteria require that two primary conditions are satisfied:

- The channel system with the lining in place must have capacity for the peak flow expected from the design storm, and
- The channel lining must be resistant to erosion for the design velocity.

### 5.1.6 Maintenance Easement

A maintenance corridor shall be provided with all drainage channels. This corridor shall provide a minimum access width of 20 feet from the channel bank on each side unless otherwise approved by the County. For small channels with cross sectional widths less than ten feet measured from top of bank to top of bank, this corridor may be provided only on one side. These dedicated maintenance corridors shall be sufficiently cleared and graded to allow easy access for maintenance equipment. If the channel is to be maintained by the County, the corridor will be within a dedicated easement.

**TABLE 5-1**  
**MAXIMUM VELOCITIES FOR COMPARING LINING MATERIALS**

Material	Maximum Velocity (ft/s)
Sand	2.0
Silt	3.5
Silty Clay	3.5
Firm Loam	3.5
Fine Gravel	5.0
Stiff Clay	5.0
Graded Loam or Silt to Cobbles	5.0
Coarse Gravel	6.0
Shales and Hard Pans	6.0

**TABLE 5-2**  
**MAXIMUM VELOCITIES FOR VEGETATIVE CHANNEL LININGS**

Vegetation Type	Slope Range (%) <sup>1</sup>	Maximum Velocity <sup>2</sup> (ft/s)
Bermuda Grass	0 - 5	6
	5 - 10	5
Bahia	All	4
Tall Fescue Grass	0 - 10	4
Mixtures <sup>3</sup>		
Kentucky Bluegrass	0 - 5	5
Buffalo Grass	5 - 10	4
	>10	3
Grass Mixture	0 - 5 <sup>1</sup>	4
	5 - 10	3
Sericea Lespedeza,	0 - 5 <sup>4</sup>	2.5
Weeping Lovegrass, Alfalfa	All	
Annuals <sup>5</sup>	0 - 5	2.5
Sod	All	4
Lapped Sod	All	5.5

<sup>1</sup> Do not use on slopes steeper than 10 percent except for side-slope in combination channels.  
<sup>2</sup> Use velocities exceeding 5 feet per second only where good stands can be established and maintained.  
<sup>3</sup> Mixtures of Tall Fescue, Bahia, and/or Bermuda.  
<sup>4</sup> Do not use on slopes steeper than 5 percent except for side-slope in combination channels.  
<sup>5</sup> Annuals - used on mild slopes or as temporary protection until permanent covers are established.

**5.2 CHANNEL DISCHARGE**

Designing a stable channel under dynamic channel conditions requires an understanding of sediment transport, stream channel response, and erosive forces which are at work. Unlined channels must be designed to minimize excessive scour while lined channels must be designed to prevent deposition of sediments. Details of methodology specific to protection from erosive forces can be found in the Federal Highway Administration, Hydraulic Design of Energy Dissipators for Culverts and Channels, Hydraulic Engineering Circular No. 14 (HEC-14), 1983.

All variables used in fluid mechanics and hydraulics fall into one of three classes: those describing the boundary geometry, those describing the flow, and those describing the fluid. Various combinations of these variables define parameters that describe the state of flow in open channels.

**5.2.1 Manning's "n" Values**

The Manning's "n" value is an important variable describing material roughness in open channel flow computations. Changes in this variable can significantly affect flow discharge, depth, and velocity estimates. Since Manning's "n" values depend on many physical characteristics of channel surface, care and good engineering judgment must be exercised in the selection process. The composite "n" value should be calculated where the lining material, and subsequently the Manning's "n" value, changes within a cross section.

Recommended Manning's "n" values for artificial channels with rigid, unlined, temporary, and riprap linings are given in Table 5-3.

Lining Category	Lining Type	"n" at various flow depths		
		0 - 0.5 ft	0.5 - 2.0 ft	>2.0 ft
Rigid	Concrete	0.015	0.013	0.013
	Grouted Riprap	0.040	0.030	0.028
	Stone Masonry	0.042	0.032	0.030
	Soil Cement	0.025	0.022	0.020
	Asphalt	0.018	0.016	0.016
Unlined	Bare Soil	0.023	0.020	0.020
	Rock Cut	0.045	0.035	0.025
Temporary <sup>1</sup>	Woven Paper Net	0.016	0.015	0.015
	Jute Net	0.028	0.022	0.019
	Fiberglass Roving	0.028	0.022	0.019
	Straw with Net	0.065	0.033	0.025
	Curled Wood Mat	0.066	0.035	0.028
	Synthetic Mat	0.036	0.025	0.021
Gravel	1-inch D <sub>50</sub>	0.044	0.033	0.030
	2-inch D <sub>50</sub>	0.066	0.041	0.034
Rock Riprap	6-inch D <sub>50</sub>	0.104	0.069	0.035
	12-inch D <sub>50</sub>	---	0.078	0.040

Source: Federal Highway Administration, Design of Roadside Channels with Flexible Linings, HEC-15, 1988.  
 Note: Values listed are representative values for the respective depth ranges. Manning's "n" varies with the flow depth.  
<sup>1</sup>Some "temporary" linings become permanent when buried.

Recommended Manning's values for natural channels which are either excavated or dredged and natural are given in Table 5-4. For natural channels, Manning's "n" values should be estimated using the procedures presented in the publication Guide For Selecting Manning's Roughness Coefficients For Natural Channels And Flood Plains, (FHWA-TS-84-204, 1984).

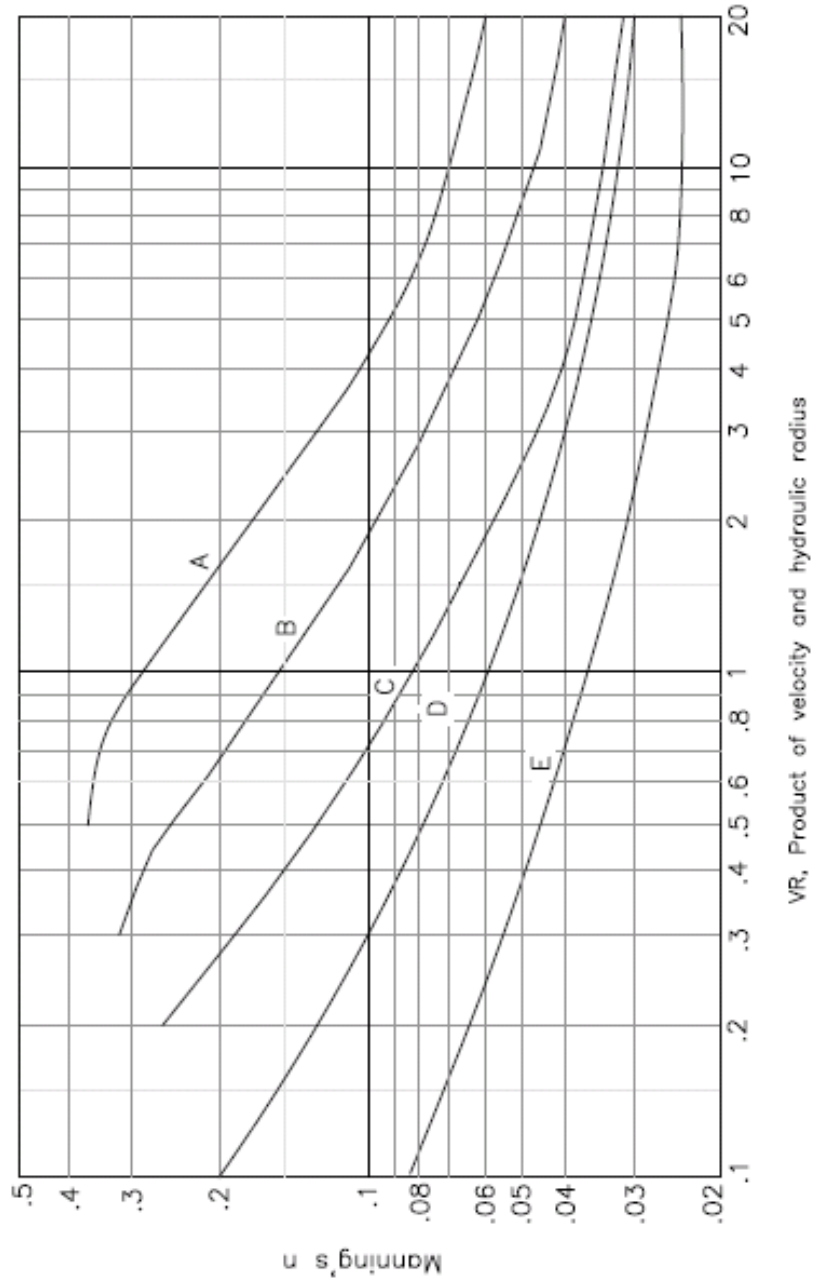
<b>TABLE 5-4</b>			
<b>UNIFORM FLOW VALUES OF ROUGHNESS COEFFICIENT "n"</b>			
<b>Type of Channel And Description</b>	<b>Minimum</b>	<b>Normal</b>	<b>Maximum</b>
<b>EXCAVATED OR DREDGED</b>			
Earth, straight and uniform	0.016	0.018	0.020
1. Clean, recently completed	0.018	0.022	0.025
2. Clean, after weathering	0.022	0.025	0.030
3. Gravel, uniform section, clean	0.022	0.027	0.033
Earth, winding and sluggish			
1. No vegetation	0.023	0.025	0.030
2. Grass, some weeds	0.025	0.030	0.033
3. Dense weeds/plants in deep channels	0.030	0.035	0.040
4. Earth bottom and rubble sides	0.025	0.030	0.035
5. Stony bottom and weedy sides	0.025	0.035	0.045
6. Cobble bottom and clean sides	0.030	0.040	0.050
Dragline-excavated or dredged			
1. No vegetation	0.025	0.028	0.033
2. Light brush on banks	0.035	0.050	0.060
Rock cuts			
1. Smooth and uniform	0.025	0.035	0.040
2. Jagged and irregular	0.035	0.040	0.050
Channels not maintained, weeds and brush uncut			
1. Dense weeds, high as flow depth	0.050	0.080	0.120
2. Clean bottom, brush on sides	0.040	0.050	0.080
3. Clean bottom, brush on sides, highest stage of flow	0.045	0.070	0.110
4. Dense brush, high stage	0.080	0.100	0.140
<b>NATURAL STREAMS</b>			
<i>Minor streams</i> (top width at flood stage < 100 ft)			
Streams on Plain			
1. Clean, straight, full stage, no rifts or deep pools	0.025	0.030	0.033
2. Same as above, but more stones and weeds	0.030	0.035	0.040
3. Clean, winding, some pools and shoals	0.033	0.040	0.045
4. Same as above, but some weeds and some stones	0.035	0.045	0.050
5. Same as above, lower stages, more ineffective slopes and sections	0.040	0.048	0.055
6. Same as 4, but more stones	0.045	0.050	0.060
7. Sluggish reaches, weedy, deep pools	0.050	0.070	0.080
8. Very weedy reaches, deep pools, or floodways with heavy stand of timber and underbrush	0.075	0.100	0.150
Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stages.			
1. Bottom: gravels, cobbles, few boulders	0.030	0.040	0.050
2. Bottom: cobbles with large boulders	0.040	0.050	0.070

<b>TABLE 5-4 - continued</b>			
<b>UNIFORM FLOW VALUES OF ROUGHNESS COEFFICIENT "n"</b>			
<b>Type of Channel And Description</b>	<b>Minimum</b>	<b>Normal</b>	<b>Maximum</b>
<b><i>Floodplains</i></b>			
Pasture, no brush			
1. Short grass	0.025	0.030	0.035
2. High grass	0.030	0.035	0.050
Cultivated area			
1. No crop	0.020	0.030	0.040
2. Mature row crops	0.025	0.035	0.045
3. Mature field crops	0.030	0.040	0.050
Brush			
1. Scattered brush, heavy weeds	0.035	0.050	0.070
2. Light brush and trees in winter	0.035	0.050	0.060
3. Light brush and trees, in summer	0.040	0.060	0.080
4. Medium to dense brush, in winter	0.045	0.070	0.110
5. Medium to dense brush, in summer	0.070	0.100	0.160
Trees			
1. Dense willows, summer, straight	0.110	0.150	0.200
2. Cleared land, tree stumps, no sprouts	0.030	0.040	0.050
3. Same as above, but with heavy growth of spouts	0.050	0.060	0.080
4. Heavy stand of timber, a few down trees, little undergrowth, flood stage below branches	0.080	0.100	0.120
5. Same as above, but with flood stage reaching branches	0.100	0.120	0.160
<b><i>Major Streams</i></b> (top width at flood stage > 100 ft).			
The "n" value is less than that for minor streams of similar description, because banks offer less effective resistance.			
Regular section with no boulders or brush	0.025	.....	0.060
Irregular and rough section	0.035	.....	0.100

**5.1.6 Maintenance Easement**

A maintenance corridor shall be provided with all drainage channels. This corridor shall provide a minimum access width of 20 feet from the channel bank on each side unless otherwise approved by the County. For small channels with cross sectional widths less than ten feet measured from top of bank to top of bank, this corridor may be provided only on one side. These dedicated maintenance corridors shall be sufficiently cleared and graded to allow easy access for maintenance equipment. If the channel is to be maintained by the County, the corridor will be within a dedicated easement.

n-vR For Various Retardance Classes.



Source: Design Hydrology and Sedimentology for Small Catchments. Haan et. al, 1994.

Figure 5-1 Manning's "n" Values for Vegetated Channels

Retardance	Cover	Condition
A	Weeping Lovegrass	Excellent stand, tall (average 30")
	Yellow Bluestem Ischaemum	Excellent stand, tall (average 36")
B	Kudzu	Very dense growth, uncut
	Bermuda grass	Good stand, tall (average 12")
	Native grass mixture: little bluestem, bluestem, blue gamma other short and long stem midwest lovegrass	Good stand, unmowed
	Weeping lovegrass	Good stand, tall (average 24")
	Laspedeza sericea	Good stand, not woody, tall (average 19")
	Alfalfa	Good stand, uncut (average 11")
	Kudzu	Dense growth, uncut
	Weeping lovegrass	Good stand, unmowed (average 13")
	Blue gamma	Good stand, uncut (average 13")
	C	Crabgrass
Bermuda grass		Good stand, mowed (average 6")
Common lespedeza		Good stand, uncut (average 11")
Grass-legume mixture: summer (orchard grass, redtop, Italian ryegrass, and common lespedeza)		Good stand, uncut (6 - 8")
Centipede grass		Very dense cover (average 6")
Kentucky bluegrass		Good stand, headed (6 - 12")
D		Bermuda grass
	Common lespedeza	Excellent stand, uncut (average 4.5")
	Buffalo grass	Good stand, uncut (3 - 6")
	Grass-legume mixture: fall, spring (orchard grass, redtop, Italian ryegrass, and common lespedeza)	Good stand, uncut (4 - 5")
	Lspedeza sericea	After cutting to 2" (very good before cutting)
	E	Bermuda grass
Bermuda grass		Burned stubble
Note: Covers classified above have been tested in experimental channels. Covers were green and generally uniform.		

**5.2.2 Channel Design**

The drainage channel design has to provide adequate capacity for flow resulting from the design storm. The hydraulic characteristics of open channels shall be determined by using Manning's and continuity equations. Manning's Equation is commonly expressed as:

$$V = 1.49/n R^{2/3} S^{1/2} \quad (5-1)$$

Where:

V	=	average flow velocity, in feet per second
n	=	Manning roughness coefficient
S	=	channel slope, in feet per foot
R	=	hydraulic radius, in feet, calculated as

$$R = A/P \quad (5-2)$$

Where:

A	=	flow cross sectional area, in square feet
P	=	wetted perimeter, in feet (length of boundary between water and channel)

Note: For prismatic channels, in the absence of backwater conditions, the slope of the energy grade line, water surface and channel bottom are equal.

The continuity equation is commonly expressed as:

$$Q = V A \quad (5-3)$$

Where:

Q	=	average flow through a cross section, in cubic feet per second
V	=	average flow velocity over a cross section, in feet per second
A	=	area of cross section, in square feet

The continuity and Manning's Equations together may be solved for channel flow:

$$Q = 1.49/n A R^{2/3} S^{1/2} \quad (5-4)$$

Area, wetted perimeter, hydraulic radius, and channel top width for standard channel cross-sections can be calculated from geometric dimensions. Irregular channel cross sections (i.e., those with a narrow deep main channel and a wide, shallow overbank flow area) must be subdivided into segments so that the flow can be computed separately for the main channel and overbank portions. This same process of subdivision may be used when different parts of the channel cross section have different roughness coefficients as previously mentioned. When computing the hydraulic radius of the subsections, the water depth common to the two adjacent subsections is not counted as wetted perimeter.

**Permissible Velocity**

Permissible nonerosive velocity of a channel is dependent upon stability of lining materials and channel vegetation. In stable channels, the flow velocities generated by the design storm event shall not exceed the permissible velocity of the channel liner.

To satisfy this condition it is necessary to calculate the velocity in the design channel for the design storm event and compare it with the permissible velocity for the selected channel lining shown in Tables 5-1 and 5-2. The Manning's "n" roughness coefficients for structural lining are in Table 5-3 and for vegetative linings in Table 5-4. For vegetative lining, the lower retardance (generally C or D) from Table 5-5 is recommended, because this condition is defined when vegetation is cut low or lies down, producing a lower Manning's "n" value, lower flow depths, and higher flow velocities.

Note: A temporary lining may be required to stabilize the channel until the vegetation is established. If a channel requires temporary lining, the designer should analyze shear stress in the channel to select an appropriate liner that provides protection and promotes vegetation establishment. For the design of temporary lining, the tractive force method is recommended.

The channel outfall has to be evaluated for stability and the receiving channel for carrying capacity. If discharge velocities exceed allowable velocities for the receiving stream, an outlet protection design will be required. This is further discussed in more depth in Chapter 3.4 Outlet Protection.

**Tractive Force**

The design of riprap lined channels and temporary linings is based on shear stress/tractive force analysis. This method assumes that the design flow is uniform and does not vary with time. Since actual flow conditions change through the length of the channel, it is necessary to subdivide the channel into design reaches with uniform flow and work within the tractive force method limitations.

**Shear Stress,  $\tau$** 

The critical shear stress or critical tractive force determines a soil's resistance to the shearing forces of concentrated flows. When the shearing forces of the flow exceed the critical tractive force of the soil, erosion takes place.

The slope, flow depth (normal depth,  $d_n$ ) calculated for the design flow generated by 25-year, storm, and other channel design characteristics are important variables in shear stress calculation.

The governing equation for channel shear stress is:

$$\tau = g d_n S \quad (5-5)$$

Where :

- $\tau$  = maximum shear stress, in pounds per square foot
- $g$  = unit weight of water = 62.4 pounds per cubic foot
- $d_n$  = maximum normal channel flow depth, in feet
- $S$  = channel bed slope, in feet per foot

**Permissible Shear Stress,  $\tau_d$**

Permissible shear stress is the force required to initiate movement of the lining material and is not related to the erodibility of the underlying soil. However, if the lining is eroded or broken, the bed material will be exposed to the erosive force of the flow.

If the permissible shear stress for the lining material in Table 5-6 is greater than the computed shear stress, the proposed riprap or temporary lining is considered acceptable. If the lining is unacceptable, lining with a higher permissible shear stress is necessary. In some cases it may be necessary to alter channel dimensions to reduce the shear stress to the level below the permissible value.

<b>TABLE 5-6</b>		
<b>PERMISSIBLE SHEAR STRESSES FOR RIPRAP AND TEMPORARY LINING</b>		
<b>Lining Category</b>	<b>Lypeining T</b>	<b>Permissible Unit Shear Stress, <math>\tau_d</math> [lb/ft<sup>2</sup>]</b>
Temporary	Woven Paper Net	0.15
	Jute Net	0.45
	Fiberglass Roving	0.60
	Straw with Net	1.45
	Curled Wood Mat	1.55
	Synthetic Mat	2.00
	<b>D<sub>50</sub> Stone Size [inch]</b>	
Gravel Riprap	1	0.33
	2	0.67
Rock Riprap	6	2.00
	9	3.00
	12	4.00
	15	5.00
	18	6.00
	21	7.80
	24	8.00

Source: Federal Highway Administration, Design of Roadside Channels with Flexible Linings, HEC-15, 1988.

**Normal Depth,  $d_n$**

Normal depth is unique for each channel with a particular slope and discharge and can be calculated using Manning's Equation 5-1. This generally requires a trial-and-error solution. Values of the Manning's roughness coefficient for different ranges of depth are provided in

Table 5-3 for temporary linings and for riprap. The trial-and-error method for normal depth calculation is described in the section below.

It is recommended that normal depth should be calculated for the following conditions:

- Bare matting with no vegetation,
- Matting with maintained vegetation, and
- Matting with un-maintained vegetation.

**Iterative Method for Normal Depth Calculation**

The use of Manning's procedure includes iterative calculations to calculate the normal depth of flow in a uniform channel when the channel shape, slope, roughness and design discharge are known.

Using Manning's Equation 5-1 and the continuity Equation 5-3, and solving for flow, Q, Equation 5-4 can be rearranged to the following ratio:

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

To calculate the normal depth of flow ( $d_n$ ) by the trial and error process, trial values of depth ( $d_n$ ) are selected to calculate a corresponding flow area (A), wetted perimeter (P), and hydraulic radius (R). For each trial depth selected, a corresponding  $AR^{2/3}$  value is calculated. Trial values of the depth are selected until the  $AR^{2/3}$  value equals the known ratio calculated by using the known roughness, design discharge, and channel slope.

**Computing Shear Stress around a Channel Bend,  $\tau_b$**

Computing shear stress around a channel bend requires special considerations because the change in flow direction imposes higher shear stress on the channel bottom and banks. The maximum shear stress in a bend is given by the following equation:

$$\tau_b = K_b \tau \tag{5-6}$$

Where :

- $\tau_b$  = bend shear stress, in pounds per square foot
- $K_b$  = bend factor
- $\tau$  = computed shear stress for straight channel, in pounds per square foot

The  $\tau_b$  value is related to the radius of curvature of the channel at its center line,  $R_c$ , and the bottom width of the channel, B, Figure 5-2. The length of channel requiring protection downstream from a bend,  $L_p$ , is a function of the roughness of the lining material and the hydraulic radius, R, as shown in Figure 5-3.

The design channels usually exhibit high stress around bends and therefore these areas should be carefully evaluated. The channel may be protected by change in cross sectional area that would decrease the shear stress, or upgrade the protective channel lining so it withholds the shear forces.

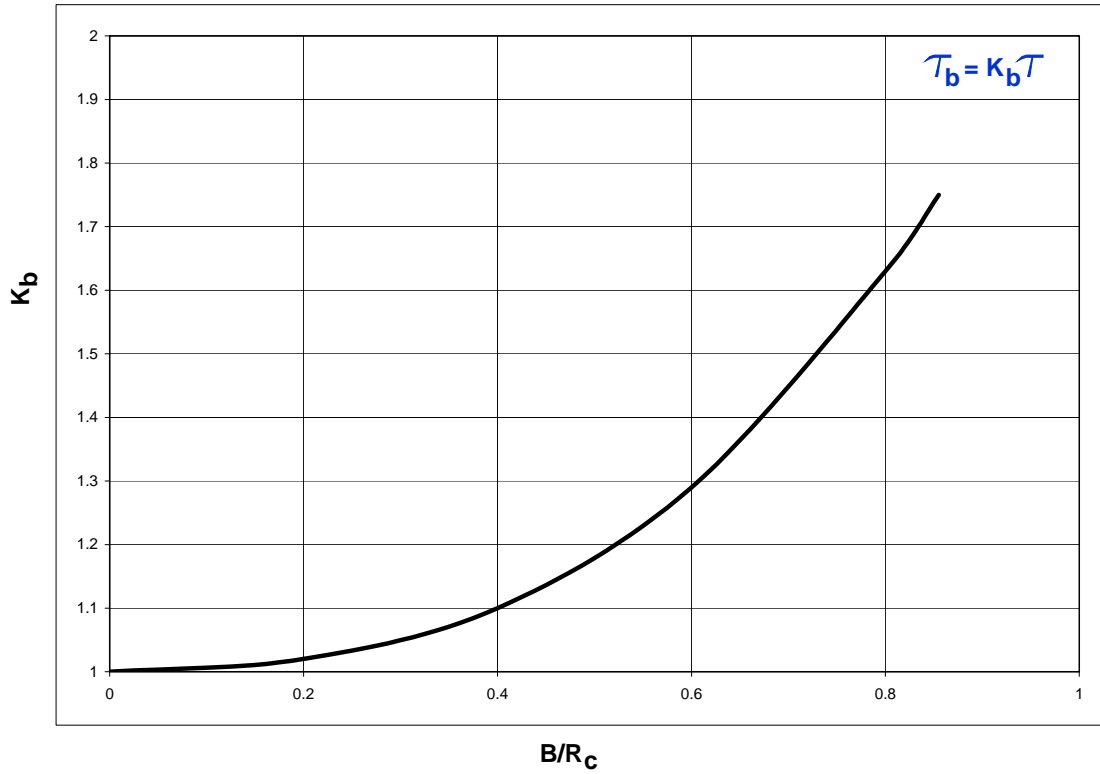


Figure 5-2  $K_b$  Factor for Maximum Shear Stress on Channel Bends  
Source: FHWA, HEC-15, April 1988

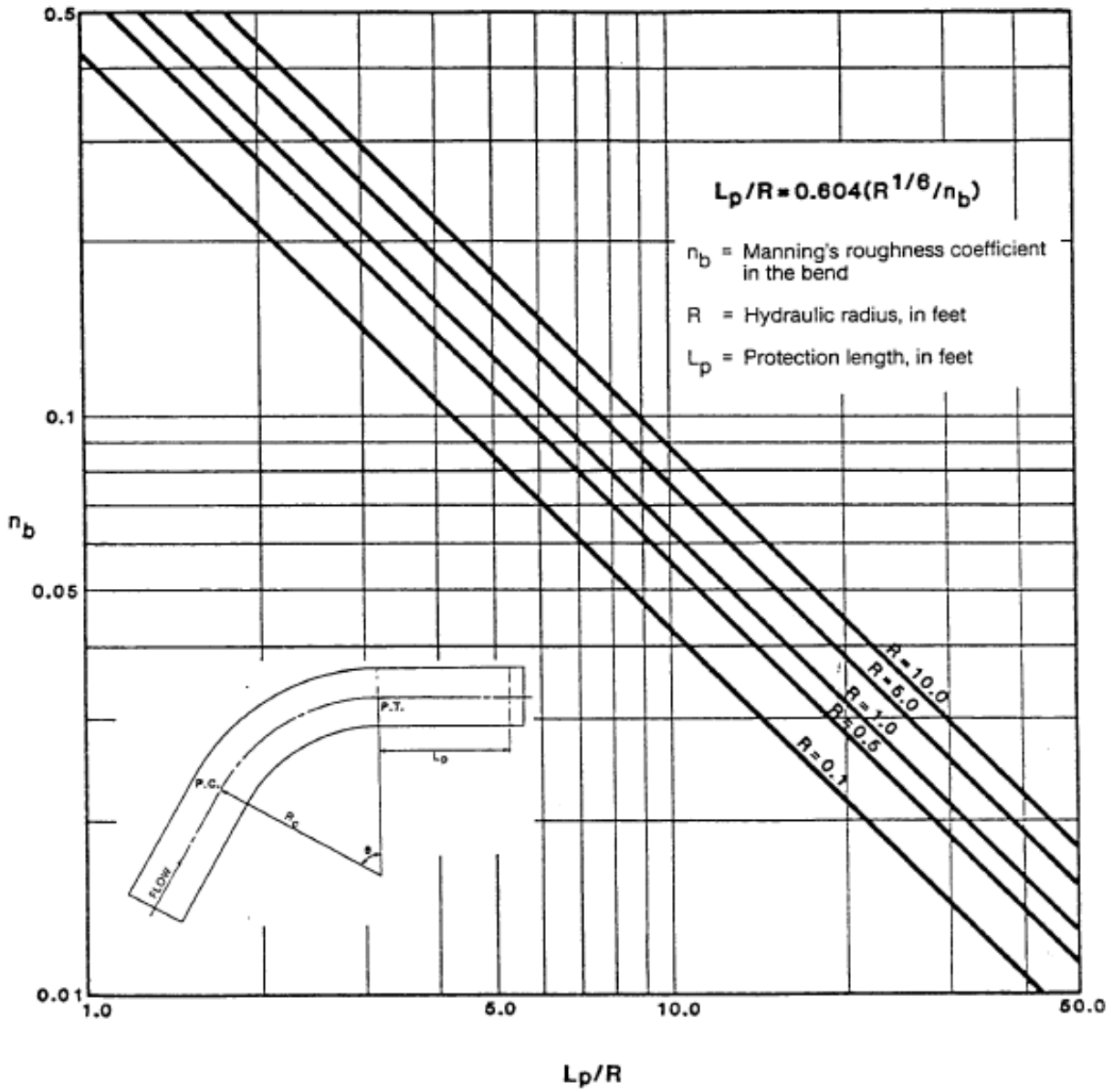


Figure 5-3 Protection Length,  $L_p$ , Downstream of Channel Bend  
Source: FHWA, HEC-15, April 1988