Chapter 8

ROADSIDE CHANNELS

ODOT ROADWAY DRAINAGE MANUAL

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Chapter 8
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8.1 INTRODUCTION

8.1.1 Description

Open channels are a natural or constructed conveyance for water in which:

- the water surface is exposed to the atmosphere, and
- the gravity force component in the direction of motion is the driving force.

There are various types of open channels that may be used in highway design. Artificial channels (also called "constructed" or "man-made" channels) include roadside ditches, depressed median ditches, culvert tailwater channels and irrigation channels that are:

- constructed channels with regular geometric cross sections, and
- unlined or lined with artificial or natural material to protect against erosion.

Stream channels are usually:

- natural channels with their size and shape determined by natural forces,
- compound in cross section with a main channel for conveying low flows and a floodplain to transport flood flows, and
- shaped in cross section and plan form by the long-term history of sediment load and water discharge that they experience.

8.1.2 Applications of Open Channel Flow

Chapter 8 applies to any regularly shaped, constructed channel where the flow is assumed to be uniform and the channel is assumed to be stable. The stability assumption can be tested by reviewing the reach with progressively more detailed study. This process is described in FHWA HEC 20 (1). Chapter 14 "Bank Protection" discusses potential remedial treatments if the stability assessment of a natural stream identifies a problem.

8.1.3 Symbols

To provide consistency within this Chapter, the symbols provided in Figure 8.1-A will be used. These symbols have been selected because of their wide use in channel hydraulics.

Symbol	Definition	Units
A	Cross sectional area	ft^2
B	Bottom width	ft
d	Hydraulics depth (A/T)	ft
d_c	Critical depth of flow	ft
D_{50}	Median diameter of riprap or median grain size	in
E	Specific energy	ft
Fr	Froude number	—
g	Acceleration due to gravity	ft/s^2
h	Stage (water surface height)	ft
h_D	Average hydraulics depth	ft
h_L	Head loss	ft
K	Conveyance capacity	cfs
k_s	Roughness height	ft
L	Channel reach length	ft
n	Manning’s roughness coefficient	—
P	Wetted perimeter	ft
Q	Discharge (flow rate)	cfs
q	Discharge per unit width	cfs
R	Hydraulic radius (A/P)	ft
R_c	Mean radius of the bend	ft
S	Energy gradeline slope or channel slope	ft/ft
T	Channel top width	ft
V	Velocity of flow	fps
V_c	Critical velocity	fps
y	Depth of flow	ft
y_c	Critical depth	ft
z	Elevation of streambed	ft
z	Slope factor	—
γ	Unit weight of water	pcf
τ_d	Shear stress (tractive force)	psf
τ_p	Permissible shear stress	psf
α	Velocity distribution coefficient	—
θ	Channel slope angle	degrees

Figure 8.1-A — SYMBOLS AND DEFINITIONS

8.2 OPEN CHANNEL FLOW

8.2.1 General

The design analysis for all channels proceeds according to the basic principles of open channel flow (see (2), (3), (4) and (5)). The basic principles of fluid mechanics — continuity, momentum and energy — can be applied to open channel flow with the additional complication that the position of the free surface is usually one of the unknown variables. The determination of this unknown is one of the primary objectives of open channel flow analysis. The following discussion is focused on the analysis of channels that are prismatic in shape. The regular shape can be an approximation so that a tailwater analysis can be simplified or an actual shape proposed for construction.

8.2.2 Definitions

8.2.2.1 Energy Gradeline

The total head is the specific energy head plus the elevation of the channel bottom with respect to some datum. The line joining the total head from one cross section to the next defines the energy gradeline or the energy line.

8.2.2.2 Steady and Unsteady Flow

A steady flow is one in which the discharge passing a given cross section is constant with respect to time. The maintenance of steady flow in any reach requires that the rates of inflow and outflow be constant and equal. When the discharge varies with time, the flow is unsteady.

8.2.2.3 Uniform Flow and Non-Uniform Flow

A uniform flow is one in which the discharge passing a given cross section is constant with respect to time. A non-uniform flow is one in which the velocity and depth vary in the direction of motion, while they remain constant in uniform flow. Uniform flow can only occur in a prismatic channel, which is a channel of constant cross section, roughness and slope in the flow direction; however, non-uniform flow can occur either in a prismatic channel or in a natural channel with variable properties.

8.2.2.4 Gradually Varied and Rapidly Varied Flow

A non-uniform flow in which the depth and velocity change gradually enough in the flow direction that vertical accelerations can be neglected is referred to as a gradually varied flow; otherwise, it is considered to be rapidly varied.

8.2.2.5 Froude Number

The Froude number, Fr, represents the ratio of inertial forces to gravitational forces, is an indicator of the type of flow, and is defined by:

$$Fr = \frac{V}{(gd \cos \theta)^{0.5}} \qquad \text{Equation 8.2(1)}$$

Where:

V = mean velocity = Q/A, fps
g = acceleration of gravity, 32.2 ft/s^2
d = hydraulics depth = A/T, ft
A = cross-sectional area of flow, ft^2
T = channel top width at the water surface, ft
Q = total discharge, cfs
θ = channel slope angle, degrees

This expression for the Froude number applies to any open channel or channel subsection with uniform or gradually varied flow. For rectangular channels, the hydraulics depth is equal to the flow depth.

8.2.2.6 Critical Flow

Critical flow occurs when the specific energy is a minimum for a given discharge in regular channel cross sections. The depth at which the specific energy is a minimum (E_c = 1.5y_c) is called critical depth (y_c). At critical depth, the Froude number has a value of one (Fr = 1). Critical depth is also the depth of maximum discharge when the specific energy is held constant. These relationships are illustrated in Figure 8.2-A. During critical flow, the velocity head is equal to half the critical depth. The general expression for flow at critical depth is:

$$Q^2/g = A^3/T \qquad \text{Equation 8.2(2)}$$

Where:

Q = total discharge, cfs
g = gravitational acceleration, 32.2 ft/s^2
A = cross-sectional area of flow, ft^2
T = channel topwidth at the water surface, ft

When flow is at critical depth, Equation 8.2(2) must be satisfied, no matter what the shape of the channel.

8.2.2.7 Subcritical Flow

The normal depth is greater than critical depth in subcritical flow, and the Froude number is less than one ($Fr < 1$). In this state of flow, small water surface disturbances can travel both upstream and downstream, and the control is always located downstream.

8.2.2.8 Supercritical Flow

The normal depth is less than critical depth in supercritical flow, and the Froude number is greater than one ($Fr > 1$). Small water surface disturbances are always swept downstream in supercritical flow, and the location of the flow control is always upstream.

8.2.2.9 Hydraulic Jump

A hydraulic jump occurs as an abrupt transition from supercritical to subcritical flow in the flow direction. There are significant changes in depth and velocity in the jump, and energy is dissipated. For this reason, the hydraulic jump is often employed to dissipate energy and control erosion at highway drainage structures.

A hydraulic jump will not occur until the ratio of the flow depth (y_1) in the approach channel to the flow depth (y_2) in the downstream channel reaches a specific value that depends on the channel geometry. The depth before the jump is called the initial depth (y_1), and the depth after the jump is the sequent depth (y_2). When a hydraulic jump is used as an energy dissipator, constructed controls are usually required to create sufficient tailwater depth, to control the location of the jump and to ensure that a jump will occur during the desired range of discharges. If the tailwater depth is lower than the sequent depth, a drop in the channel floor must be used to ensure a jump (see (4) and (5)). Sills can also be used to control a hydraulic jump if the tailwater depth is less than the sequent depth.

8.2.3 Flow Classification

The classification of open channel flow can be summarized as follows:

Steady Flow

- Uniform Flow
- Non-Uniform Flow
- Gradually Varied Flow
- Rapidly Varied Flow

Unsteady Flow

- Unsteady Uniform Flow (rare)
- Unsteady Non-Uniform Flow
- Gradually Varied Unsteady Flow
- Rapidly Varied Unsteady Flow

The steady, uniform flow case and the steady, non-uniform flow case are the most fundamental types of flow treated in highway engineering hydraulicss.

8.2.4 Equations

The following equations are those most commonly used to analyze open channel flow.

8.2.4.1 Continuity Equation

The continuity equation is the statement of conservation of mass in fluid mechanics. For the special case of one-dimensional, steady flow of an incompressible fluid, it assumes the simple form:

$$Q = A_1V_1 = A_2V_2 \qquad \text{Equation 8.2(3)}$$

Where:

Q = discharge, cfs
A = cross-sectional area of flow, ft^2
V = mean cross-sectional velocity, fps (which is perpendicular to the cross section)

The subscripts 1 and 2 refer to successive cross sections along the flow path.

8.2.4.2 Manning's Equation

For a given depth of flow in an open channel with a steady, uniform flow, the mean velocity, V, can be computed with Manning's equation:

$$V = (1.486/n)R^{2/3}S^{1/2} \qquad \text{Equation 8.2(4)}$$

Where:

V = velocity, fps

n = Manning's roughness coefficient

R = hydraulics radius = A/P, ft

A = cross-sectional area of flow, ft^2

P = wetted perimeter, ft

S = slope of the energy gradeline, ft/ft (Note: For steady uniform flow, S = channel slope, ft/ft)

The selection of Manning's n is generally based on observation; however, considerable experience is essential in selecting appropriate n values. See Section 8.3.3.

The continuity equation can be combined with Manning's equation to obtain the steady, uniform flow discharge as:

$$Q = VA = (1.486/n)AR^{2/3}S^{1/2} \qquad \text{Equation 8.2(5)}$$

For a given channel geometry, slope, Manning's roughness and a specified value of discharge Q, a unique value of depth occurs in steady, uniform flow. It is called normal depth (y) and is computed from Equation 8.2(5). The resulting equation may require a trial-and-error solution, which can easily be accomplished with the FHWA Hydraulics Toolbox (see Chapter 16 "Hydraulicss Software"). If the normal depth is greater than critical depth ($y > y_c$), the slope is classified as a mild slope. If the normal depth is less than critical depth ($y < y_c$), the slope is classified as a steep slope. Thus, uniform flow is subcritical on a mild slope and supercritical on a steep slope.

8.2.4.3 Channel Conveyance

In channel analysis, it is often convenient to group the channel properties in a single term called the channel conveyance, K:

$$K = AR^{2/3}/n \qquad \text{Equation 8.2(6)}$$

and then the discharge equation can be written as:

$$Q = KS^{1/2`} \qquad \text{Equation 8.2(7)}$$

The conveyance, K, represents the carrying capacity of a stream cross section based upon its geometry and roughness characteristics alone and is independent of the streambed slope.

The concept of channel conveyance is useful when computing the distribution of overbank flood flows in the stream cross section and the flow distribution through the opening in a proposed stream crossing.

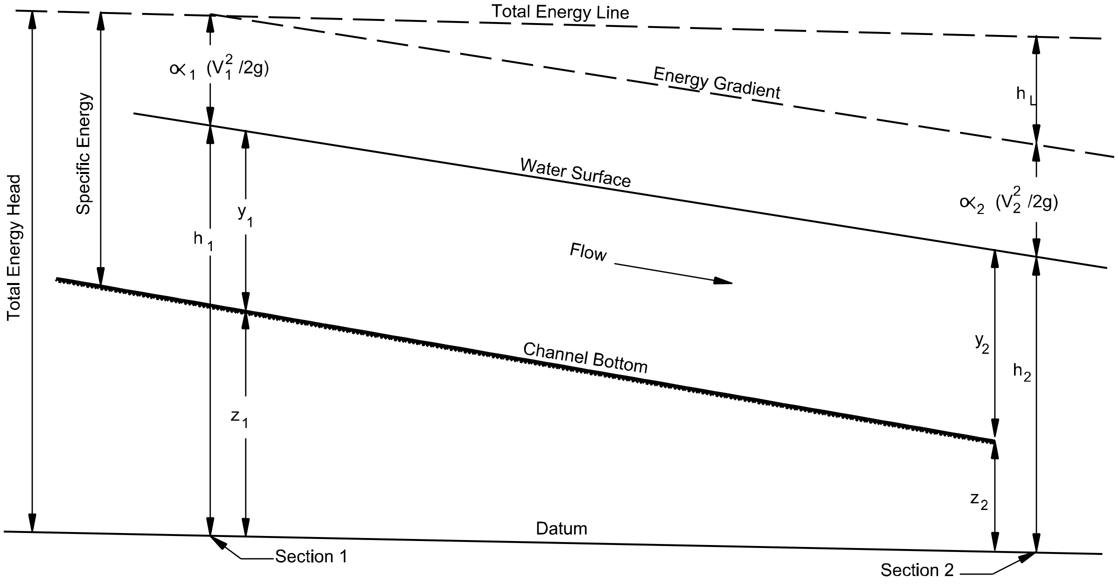
8.2.4.4 Energy Equation

This equation, also known as the Bernoulli Energy Equation, states that there is no loss of flow energy in any cross-section of the open channel, but only change in form.

Figure 8.2-A shows that the total energy head at cross section 1 is composed of potential energy head z_1, pressure head y_1 and kinetic energy head (velocity head) $V_1^2/2g$:

- Total energy head at cross section 1 = $z_1 + y_1 + (V_1^2/2g)$, or
- Total energy head at cross section 1 = $h_1 + (V_1^2/2g)$

Where h_1, called the stage, is the sum of the elevation head, z, at the channel bottom and the pressure head, which equals the depth of flow, y, for open channel flow; i.e., $h_1 = z_1 + y_1$.



Source: FHWA HDS 4, (5)

Figure 8.2-A — TERMS IN THE ENERGY EQUATION

The energy equation states that the total energy head at an upstream cross section is equal to the energy head at a downstream section plus the intervening energy head loss.

Written between an upstream open channel cross section designated “1” and a downstream cross section designated “2” (see Figure 8.2-A), the energy equation is:

$$h_1 + \left(V_1^2 / 2g\right) = h_2 + \left(V_2^2 / 2g\right) + h_L \qquad \text{Equation 8.2(8)}$$

Where:

h_1, h_2 = the upstream and downstream stages, respectively, ft

V = mean velocity, fps

h_L = head loss due to local cross-sectional changes (minor loss) and boundary resistance, ft

The terms in the energy equation are illustrated graphically in Figure 8.2-A. The energy equation can only be applied between two cross sections at which the streamlines are nearly straight and parallel so that vertical accelerations can be neglected.

8.2.4.5 Specific Energy

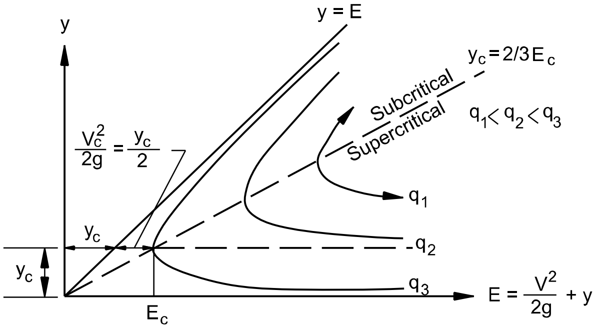
Specific energy, E, is defined as the energy head relative to the channel bottom. See Figure 8.2-A and Figure 8.2-B for a plot of the specific energy and specific energy diagram. If the channel is not too steep (slope less than 10%), the specific energy is expressed as the sum of the depth and velocity head:

$$E = y + (V^2/2g) \qquad \text{Equation 8.2(9)}$$

Where:

y = depth, ft
V = mean velocity, fps
g = gravitational acceleration, 32.2 ft/s^2

For uniform flow, the specific energy remains constant from section to section. For non-uniform and gradually/rapidly varied flow, the specific energy along the channel may increase or decrease.



Source: Adopted from FHWA HDS 4, (5)

Figure 8.2-B — SPECIFIC ENERGY DIAGRAM

8.3 HYDRAULICS ANALYSIS

8.3.1 General

The hydraulics analysis of a channel determines the depth and velocity at which a given discharge will flow in a channel of known geometry, roughness and slope. The depth and velocity of flow are necessary for the design or analysis of channel linings and highway drainage structures.

Two methods are commonly used in the hydraulics analysis of open channels:

- the single-section method (Section 8.3.4), or
- the step-backwater method (Section 8.3.5).

The single-section method is a simple application of Manning's equation to determine tailwater rating curves for culverts or to analyze other situations in which uniform or nearly uniform flow conditions can be assumed. The single-section method is usually sufficient for standard roadway ditches, culverts, storm drains or outfalls when the analysis of these structures does not require a water surface profile. More details about the single-section method can be found in the Section 8.3.4. Occasionally, the hydraulics designer may need to use a more detailed method of analysis than the single-section method or the computation of a water surface profile using the step-backwater method.

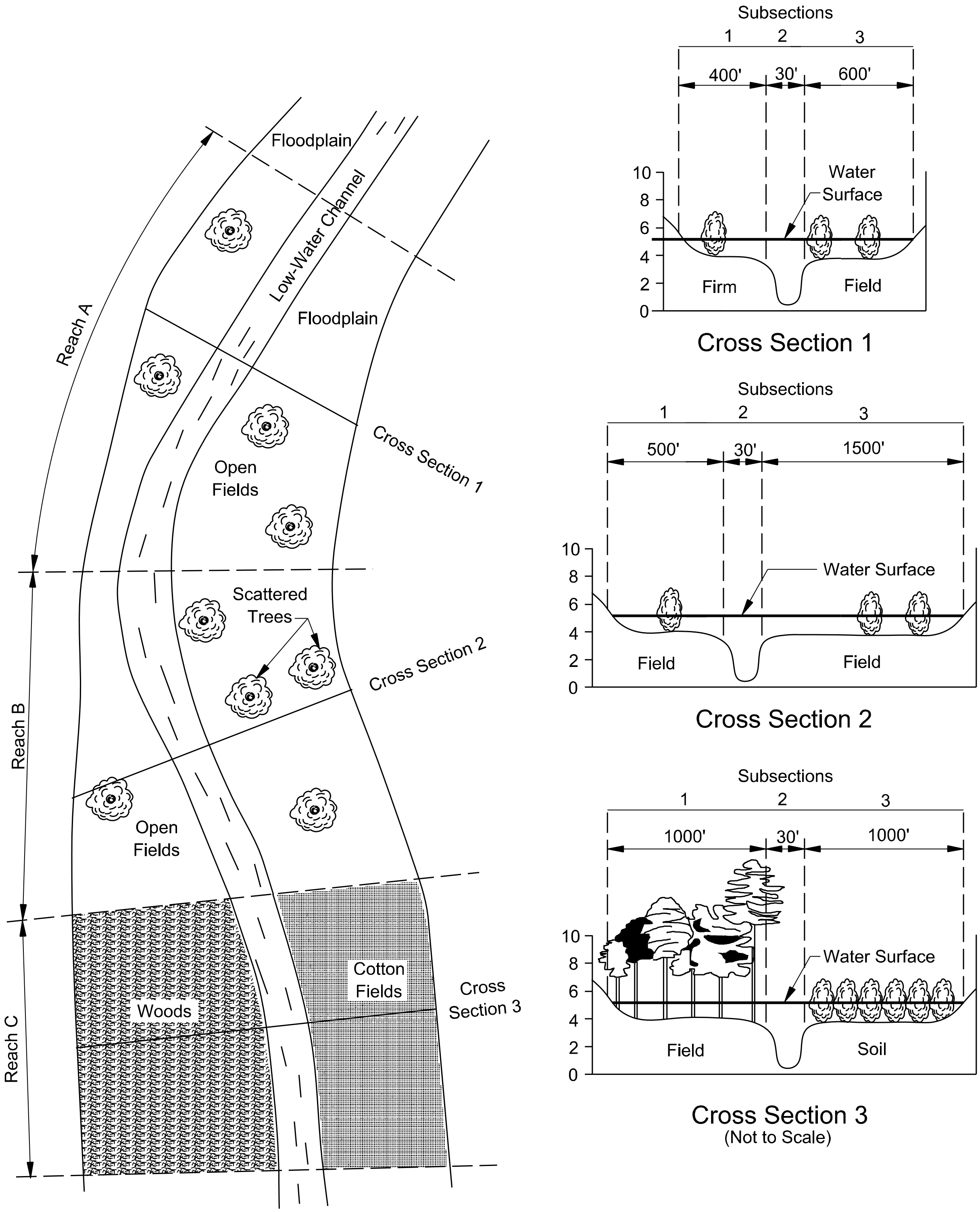
The step-backwater method is used to compute the complete water surface profile in a natural stream reach to evaluate the unrestricted water surface elevations for bridge hydraulic design (see Chapter 2 in *ODOT Bridge Manual*) or to analyze other gradually varied flow problems in streams (see Chapter 11 "Energy Dissipators").

8.3.2 Cross Sections

Cross-sectional geometry of channels can be defined by coordinates of lateral distance and ground elevation that locate individual ground points. The cross section is taken normal to the flow direction along a single, straight line where practical. Cross sections should be located to be representative of the subreach. Stream locations with major breaks in bed profile, abrupt changes in roughness or shape, control sections such as free overfalls, bends and contractions, or other abrupt changes in channel slope or conveyance will require cross sections taken at shorter intervals to better model the change in conveyance.

For roadside ditches, the cross section is usually determined by typical ODOT practices. Chapter 17 of the *ODOT Roadway Design Manual* presents the Department's typical cross sections for roadside ditches and depressed median ditches.

For natural streams, cross sections should be subdivided with vertical boundaries where there are abrupt lateral changes in geometry and/or roughness as in the case of overbank flows. The conveyance of each subsection is computed separately to determine the flow distribution and is then added to determine the total flow conveyance. The subsection divisions must be chosen carefully so that the distribution of flow or conveyance is nearly uniform in each subsection (see (6)). Figure 8.3-A presents the selection of cross sections and vertical subdivision of a cross section.



Source: USGS (6) *Revised*

Figure 8.3-A — HYPOTHETICAL CROSS SECTION SHOWING REACHES, SEGMENTS AND SUBSECTIONS USED IN ASSIGNING n VALUES

8.3.3 Manning's n Value Selection

Manning's n, the roughness coefficient, is affected by many factors, and its selection in natural channels depends heavily on engineering experience. Photographs of channels and floodplains for which the discharge has been measured and for which Manning's n has been calculated are very useful (see (4), (7) and (8)) for estimating n values for various types of channels. See Step 4 in Section 8.5 for n-values used for channel linings. The selected n values should be verified by reproducing historical high water marks or gaged streamflow data, if available.

Figure 8.2-B should be used as a guide in selecting the Manning's n value for roadside ditches and channels.

Type of Channel and Description	Minimum	Normal	Maximum
EXCAVATED OR DREDGED			
1. Earth, straight and uniform			
a. Clean, recently completed	0.016	0.018	0.020
b. Clean, after weathering	0.018	0.022	0.025
c. Gravel, uniform section, clean	0.022	0.025	0.030
d. With short grass, few weeds	0.022	0.027	0.033
2. Earth, winding and sluggish			
a. No vegetation	0.023	0.025	0.030
b. Grass, some weeds	0.025	0.030	0.033
c. Dense weeds or aquatic plans in deep channels	0.030	0.035	0.040
d. Earth bottom and rubble sides	0.025	0.030	0.035
e. Stony bottom and weedy sides	0.025	0.035	0.045
f. Cobble bottom and clean sides	0.030	0.040	0.050
3. Dragline-excavated or dredged			
a. No vegetation	0.025	0.028	0.033
b. Light brush on banks	0.035	0.050	0.060
4. Rock cuts			
a. Smooth and uniform	0.025	0.035	0.040
b. Jagged and irregular	0.035	0.040	0.050
5. Channels not maintained, weeds and brush uncut			
a. Dense weeds, high as flow depth	0.050	0.080	0.120
b. Clean bottom, brush on sides	0.040	0.050	0.080
c. Same, highest stage of flow	0.045	0.070	0.110
d. Dense brush, high stage	0.080	0.100	0.140

Figure 8.3-B — VALUES OF MANNING'S ROUGHNESS COEFFICIENT n (Uniform Flow)

Type of Channel and Description	Minimum	Normal	Maximum
NATURAL STREAMS			
1. Minor streams (top width at flood stage < 100 ft)			
a. 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/weeds	0.030	0.035	0.040
3) Clean, winding, some pools/shoals	0.033	0.040	0.045
4) Same as above, but some weeds/ 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
b. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stages			
1) Bottom: gravels, cobbles and few boulders	0.030	0.040	0.050
2) Bottom: cobbles with large boulders	0.040	0.050	0.070
2. Floodplains			
a. Pasture, no brush			
1) Short grass	0.025	0.030	0.035
2) High grass	0.030	0.035	0.050
b. 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
c. 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	0.050	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
d. Trees			
1) Dense willows, summer, straight	0.110	0.150	0.200
2) Cleared land with tree stumps, no sprouts	0.030	0.040	0.050
3) Same as above, but with heavy growth of sprouts	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
3. Major Streams (top width at flood stage > 100 ft)			
a. Regular section with no boulders or brush	0.025	—	0.060
b. Irregular and rough section	0.035	—	0.100

Source: AASHTO MDM 2005 (3)

Figure 8.3-B — VALUES OF MANNING'S ROUGHNESS COEFFICIENT n (Uniform Flow)
(Continued)

Lining Category	**Lining Type**	**k_s (ft)**	**n-value[1]**		
			Depth Ranges		
			0 – 0.5 ft	**0.5 – 2.0 ft**	**> 2.0 ft**
Rigid	Concrete Asphalt Grouted Riprap Soil Cement		0.015 0.018 0.040 0.025	0.013 0.016 0.030 0.022	0.013 0.016 0.028 0.020
Unlined	Bare Soil Rock Cut		0.023 0.045	0.020 0.035	0.020 0.025
Temporary[2]	Straw with Net Curled Wood Mat Synthetic Mat	0.121 0.112 0.066	0.065 0.066 0.036	0.033 0.035 0.025	0.025 0.028 0.021
Gravel[3]	1 in D_{50} 2 in D_{50}	0.082 0.164	0.044 0.066	0.033 0.041	0.030 0.034
Rock Riprap[3]	6 in D_{50} 12 in D_{50} (Class A)	0.5 1.0	0.104 —	0.069 0.078	0.035 0.040
Vegetation	Class A		0.500	0.219	0.219
Vegetation	Class B[4]		0.500	0.085	0.085
Vegetation	Class C		0.222	0.053	0.053
Vegetation	Class D		0.112	0.043	0.043
Vegetation	Class E		0.083	0.038	0.038

[1] n-values are representative of the depth ranges (i.e., n varies with the flow depth)

[2] Some “temporary” linings become permanent when buried.

[3] $k_s = D_{50}$ for gravel and rock riprap

[4] ODOT Practice is to use 0.035 for design

Source: 1988 version of FHWA HEC 15 (9)

Lining Category	**Lining Type**	**n-value[1]**		
		Maximum	**Typical**	**Minimum**
Rolled Erosion Control Products (RECP)	Open-Weave Textile	0.028	0.025	0.022
	Erosion Control Blankets	0.045	0.035	0.028
	Turf Reinforcement Mat	0.036	0.030	0.024

[1] Typical n-value should be used for design. Actual n-value is a function of shear stress on the lining and coefficients based on all three manufacturer-supplied values. See HEC 15 (2005), Chapter 5 for procedure.

Source: 2005 version of FHWA HEC 15 (10)

Figure 8.3-B — VALUES OF MANNING’S ROUGHNESS COEFFICIENT n (Uniform Flow)
(Continued)

8.3.4 Single-Section Analysis

The single-section analysis method (slope-area method) is a solution of Manning's equation for the normal depth of flow given the discharge and cross section properties including geometry, slope and roughness. It implicitly assumes the existence of steady, uniform flow; however, uniform flow rarely exists in either artificial or natural stream channels. Nevertheless, the single-section method is often used to design roadside channels assuming uniform flow and to develop a stage-discharge rating curve in a stream channel to be used for tailwater at a culvert or storm drain outlet.

A stage-discharge curve is a graphical relationship of streamflow depth or elevation to discharge at a specific point in a channel. This relationship should cover a range of discharges up to at least the base (100-year) flood. The stage-discharge curve can be determined as follows:

- Select the typical cross section at or near the location where the stage-discharge curve is needed.
- Subdivide the cross section and assign n values to subsections as discussed in Section 8.3.3 and Figure 8.3-A.
- Estimate water surface slope. Because uniform flow is assumed, the average slope of the channel can usually be used.
- Apply a range of incremental water surface elevations to the cross section.
- Calculate the discharge using Manning's equation for each incremental elevation. Total discharge at each elevation is the sum of the discharges from each subsection at that elevation. In determining hydraulics radius, the wetted perimeter should be measured only along the solid boundary of the cross section and not along the vertical water interface between subsections.
- After the discharge has been calculated at several incremental elevations, a plot of stage versus discharge should be made. This plot is the stage-discharge curve, and it can be used to determine the water surface elevation corresponding to the design discharge or other discharge of interest.

Although the above procedure can be accomplished manually, software (see Chapter 16 "Hydraulics Software") is normally used for trapezoidal and prismatic channels.

8.3.5 Step-Backwater Analysis

Step-backwater analysis is recommended for determining unrestricted water surface profiles for roadside channels that are long, large or costly. Because the calculations involved in this analysis are tedious and repetitive, the hydraulics designer will use software such as HEC-RAS (see Chapter 16 "Hydraulics Software"). This software can be used for calculating water surface profiles for steady, gradually varied flow in a natural or constructed channel. Both subcritical and supercritical flow profiles can be calculated.

1. Subcritical Flow. The water surface profile computation will start at the downstream cross-section and going upstream.
2. Super-critical Flow. The water surface profile computation will start at the upstream cross section and going downstream.

8.4 DESIGN POLICIES AND PRACTICES

This Section presents typical ODOT hydraulics design policies and practices for roadside channels/ditches. The alignment, cross section and grade of roadside channels/ditches is usually influenced by the geometric and roadside safety design applicable to the project.

The primary hydraulics function of roadside channels/ditches is to collect surface runoff from the highway and areas that drain to the right-of-way and convey the accumulated runoff to acceptable outlet points. A secondary function of a roadside channel/ditch is to drain subsurface water from the base of the roadway to prevent saturation and loss of support for the pavement or to provide a positive outlet for subsurface drainage systems such as pipe underdrains and edge drains.

8.4.1 Policy

Policy is a set of goals that establish a definite course or method of action and are selected to guide and determine decisions (see Chapter 2 "Legal Aspects"). The following Federal and ODOT policy (see Section 8.4.1.2) are implemented through ODOT practices (see Section 8.4.2).

8.4.1.1 Federal Policy

All ODOT channel/ditch designs will be consistent with the following Federal policies that relate to floodplains, if applicable:

- Channel/ditch designs and/or designs of highway facilities that impact channels/ditches should satisfy the policies of the Federal Highway Administration (FHWA) applicable to floodplain management if Federal funding is involved.
- Federal Emergency Management Agency (FEMA) floodway regulations and U.S. Army Corps of Engineers (USACE) wetland restrictions for permits should be satisfied.
- National Pollutant Discharge Elimination System (NPDES) requirements need to be satisfied. See Chapter 15 "Permits."

8.4.1.2 ODOT Policy

All ODOT channel/ditch designs will be consistent with the following:

- Coordination with other Federal, State and local agencies concerned with water resources planning should have high priority in the planning of highway facilities.
- The safety of the general public should be an important consideration in the selection of cross sectional geometry of artificial drainage channels.

- The design of artificial drainage channels or other facilities should consider the frequency and types of maintenance expected and make allowance for access of maintenance equipment.

- A stable channel is the goal for all channels that are located on highway right-of-way or that impact highway facilities.

- Vegetated swales (ditches) provide a water quality benefit and are preferred where feasible.

- Environmental impacts of channel modifications, including disturbance of fish habitat, wetlands and stream bank stability, should be assessed.

- The roadside channel should be designed at the same frequency with the cross drain structure frequency (see Chapter 9 "Culverts").

8.4.2 ODOT Practices

8.4.2.1 Design Methodology (Channel Linings)

ODOT uses both the 1988 version of HEC 15 (9) and the 2005 version of HEC 15 (10) as basic references to select and design linings for its roadside channels/ditches. See Chapter 16 "Hydraulics Software." The hydraulics designer should note that the riprap design procedures in HEC 15 are for constructed channels/ditches that have a uniform cross section. The flow in the channel/ditch should be either steady, uniform flow or gradually varied.

The HEC 15 design methodology for the evaluation of channel/ditch linings is based on shear stress. Shear stress is the tractive force caused by water flowing in the channel. A channel is unstable where the flow-induced shear stress exceeds the permissible shear stress of the channel liner material. Hydraulic conditions in a drainage channel can become erosive even at fairly mild highway grades. As a result, these channels often require stabilization against erosion.

Chapter 7 "Hydrology" presents the design frequencies for various conditions and ODOT hydrologic methods for calculating discharge. Typically, shear stress is analyzed for a 10-year flood event, and the discharges should be computed using the same hydrologic methods required for culvert design, which varies based on drainage area size.

8.4.2.2 Roadside Ditch and Channel Cross Sections

Chapter 17 "Cross Section Elements" of the *ODOT Roadway Design Manual* presents the Department's typical cross section for roadside ditches and depressed median ditches. In addition, the following will apply:

1. Roadside Ditches. Chapter 17 of the *ODOT Roadway Design Manual* presents the Department's typical cross section criteria for roadside ditches and depressed median ditches. These ditches tend to follow the roadway grade and alignment in addition, the following will apply:

- The typical ditch bottom width ranges from 2 ft minimum to 8 ft depending on Functional Classification and hydraulics design. See Chapter 17 "Cross Section Elements" for typical ditch cross sections.

- The typical ditch foreslopes and backslopes range from 1:3 to 1:6 depending on functional classification and clear zone criteria. See Chapter 17 "Cross Section Elements" and Chapter 19 "Roadside Safety" of the *ODOT Roadway Design Manual.*

- For median ditches, the fore slope and back slope should desirably be 1:6 or flatter to reduce the hazard to vehicles driving off the road.

2. Channels. For channels that convey runoff from off-site areas, to main water courses, rivers or appropriate outlets and may or may not follow the roadway grade and alignment the following will apply:

   - The channel bottom width should desirably be at least 8 ft with a 2% cross slope to one side. The cross slope is required for concentration of low flows and transportation of sediment.

   - For concrete-lined channels, the foreslope or backslope should not be steeper than 1:2.

   - For aggregate-lined, vegetative-cover and unlined channels, the foreslope or back slope should not be steeper than 1:3.

8.4.2.3 Channel/Ditch Slope

The channel/ditch bottom longitudinal slope is generally dictated by the adjacent roadway profile or by the natural ground and, therefore, is usually fixed. If channel stability conditions warrant and available linings are not sufficient, it may be feasible to reduce the channel gradient slightly relative to the roadway profile. Channel slope is one of the major parameters in determining shear stress (see Equation 8.5(1)). For a given design discharge, the shear stress in the channel with a subcritical slope is smaller than one with a supercritical slope.

Flat or nearly flat slopes should be avoided. Channels should have a minimum longitudinal slope of 0.3%. Channel slope may be reduced to 0.1% for concrete-lined channels. Where the natural ground terrain is flat, the channel longitudinal slope may be at the same gradient as that of the natural terrain.

8.4.2.4 Freeboard

The freeboard of a channel is the vertical distance from the water surface to the top of the channel at design condition. The importance of this factor depends on the consequence of overflow of the channel bank. At a minimum, the freeboard should be sufficient to prevent waves or fluctuations in water surface from overflowing sides. Lining materials should extend to the freeboard elevation. The following apply to freeboard:

- In temporary channels, freeboard is not necessary.
- In a permanent roadway channel, channel freeboard below the subgrade elevation should be the largest of the following:
    - 1 ft;
    - (Cy)0.5, where y = normal depth in ft at design discharge (C = 1.5 for 20 cfs and 2.5 for 3000 cfs); or
    - 0.20 $(y + V^2/2g)$, where y = normal depth in ft, V = flow velocity in fps and g = 32.2 ft/s^2.

  In no case should the design discharge headwater elevation come within 6 in of the subgrade intercept of the foreslope.
- Steep-gradient channels (> 10%) should have a freeboard height equal to the flow depth. This allows for large variations to occur in flow depth for steep channels caused by waves, splashing and surging.

8.4.2.5 Channel Bends

Flow around a bend in an open channel induces centrifugal forces because of the change in flow direction. This results in a superelevation of the water surface. The water surface is higher at the outside of the bend than at the inside of the bend. This superelevation can be estimated by the equation:

$$\Delta d = \frac{V^2 T}{g R_c} \quad = \quad \text{superelevation of the water surface} \qquad \text{Equation 8.4(1)}$$

Where:

V = mean velocity, fps
T = surface width of the channel, ft
g = gravitational acceleration, 32.2 ft/s^2
R_c = mean radius of the bend, ft

8.4.2.6 Channel Linings

Hydraulics designers should analyze drainage locations throughout the project with potential erosion problems to evaluate the suitability and stability of the channel lining. Examples of locations to consider are:

- flow velocity in the channel is greater than the permissible velocity (see Figure 8.4-A and Figure 8.4-B, Section 8.4.2.8),

- existing erosion areas,

- ditches with grades steeper than 3%,

- drainage areas greater than 10 acres,

- roadway embankments that transition from a ditch cut to a fill,

- toe of fills that result in a V-ditch, and

- narrow channel sections (steep-sided V-ditches).

In addition, the hydraulics designer should consider that occasionally even small concentrated flows in a channel may merit evaluation, depending on the channel grade and configuration.

The following identifies typical channel lining types used by ODOT:

1. Temporary Linings:

    - vegetative mulch (provides no value, just erosion control),
    - asphalt mulch,
    - excelsior mat,
    - excelsior mulch,
    - wood cellulose fiber, or
    - nylon erosion control mat.

2. Permanent Linings:

    Note: *The longitudinal channel slopes below provide a starting point for the selection of a trial lining. See Step 5 in Section 8.5.* Permanent linings may require environmental permits and other mitigation requirements if designed within the OHW.

    - vegetation (see Figure 8.5-B for Classes) for S < 3%,
    - turf reinforcement mats for 3% < S < 15%,
    - riprap for 3% < S < 10%,
    - concrete for S > 3%, or
    - gabions (see Chapter 11 “Energy Dissipators”) for S > 3%.

3. Special Linings. These include composite linings that have a low-flow channel with one type of lining and upper side slopes with a different lining.

8.4.2.7 Concrete Linings

Concrete linings for the proposed channel should be a continuously reinforced concrete design or reinforced using wire mesh. The following will apply:

1. Joints. Only construction joints will be used, except at channel lining/concrete structure junctions where expansion joints are required.

2. Weepholes. These will be provided where the channel exceeds 100 ft in length. On less than 100-ft long channels, granular backfill will vent the pressure.

3. Bottom Slab Thickness. Bottom slab thicknesses will be a minimum of 4 in.

   A minimum slab thickness of 6 in is required if the channel is intended to accommodate maintenance vehicles.

4. Side Slope Lining Thickness. Side slope lining thicknesses (for slopes 1:1½ or flatter) will be 4 in.

   For side slopes steeper than 1:1½, channel linings will be designed as retaining walls.

5. Cutoff Walls. Cutoff walls are not generally required to prevent progressive failure in reinforced concrete channels. However, there may be some concern for the stability of lining slope walls at transitions where the cross section shape changes or at locations where the channel slope changes. To prevent local buckling at these locations, cutoff walls rigidly attached to the paving should be installed to stiffen the linings. Cutoff walls will also be required at the start and end of channels where there is a change to other types of lining and at existing structures where the new linings cannot realistically be made continuous with the existing lining.

   ODOT *Standard Drawings* shows curtain walls at the beginning and end of the paved ditch and at a 100 ft maximum spacing along the ditch. For buried ends adjacent to drainage structures, the curtain walls at the beginning and end of the ditch are not necessary.

8.4.2.8 Minimum and Maximum Flow Velocity

The flow velocity in all channels should not be lower than 2.5 fps, desirably. The maximum velocity is obtained using the permissible shear stress for the lining material. A concrete-lined channel has no maximum flow velocity; however, if the velocity exceeds 40 fps, it should be checked. When the flow velocity is greater than 15 fps, see Chapter 11 “Energy Dissipators.”

For grass-lined, vegetative-covered and unlined channels, the permissible allowable velocity will be as shown in Figure 8.4-A and Figure 8.4-B.

8.4.2.9 Sediment Routing

If the channel is assessed as stable, the hydraulics designer should not be concerned with the quantity of sediment carried by the flow in the channel. If the sediment appears to be a problem, guidance for analysis can be found in FHWA HDS 6 (11), for computation in Chapter 13 “Erosion and Sediment Control” and for mitigation in Chapter 11 “Energy Dissipators.”

Soil Type or Lining (Earth; No Vegetation)	**Maximum Permissible Velocities**		
	Clear Water (fps)	**Water Carrying Fine Silts** (fps)	**Water Carrying Sand and Gravel** (fps)
Fine sand (noncolloidal)	1.5	2.5	1.5
Sandy loam (noncolloidal)	1.7	2.5	2.0
Silt loam (noncolloidal)	2.0	3.0	2.0
Ordinary firm loam	2.5	3.5	2.2
Volcanic ash	2.5	3.5	2.0
Fine gravel	2.5	5.0	3.7
Stiff clay (very colloidal)	3.7	5.0	3.0
Graded, loam to cobbles (noncolloidal)	3.7	5.0	5.0
Graded, silt to cobbles (colloidal)	4.0	5.5	5.0
Alluvial silts (noncolloidal)	2.0	3.5	2.0
Alluvial silts (colloidal)	3.7	5.0	3.0
Coarse gravel (noncolloidal)	4.0	6.0	6.5
Cobbles and shingles	5.0	5.5	6.5
Shales and hard pans	6.0	6.0	5.0

As recommended by Special Committee on Irrigation Research, American Society of Civil Engineers, 1926.

Source: FHWA, HDS 3, 1973 (12)

Figure 8.4-A — PERMISSIBLE VELOCITIES FOR CHANNELS WITH ERODIBLE LININGS, BASED ON UNIFORM FLOW IN CONTINUOUSLY WET, AGED CHANNELS

Cover	**Slope Range** (%)	**Permissible Velocity**[1,2]	
		Erosion Resistant Soils (fps)	**Easily Eroded Soils** (fps)
Bermudagrass	0-5 5-10 Over 10	8 7 6	6 5 4
Buffalograss Kentucky Bluegrass Smooth brome Blue grama	0-5 5-10 Over 10	7 6 5	5 4 3
Grass mixture	0-5 5-10	5 4	4 3
Lespedeza series Weeping lovegrass Yellow bluestem Kudzu Alfalfa Crabgrass	0-5	3.5	2.5
Common lespedeza[3] Sudangrass[3]	0-5[4]	3.5	2.5

1 *From Handbook of Channel Design for Soil and Water Conservation*

2 *Use velocities over 5 fps only where good covers and proper maintenance can be obtained.*

3 *Annuals, used on mild slopes or as temporary protection until permanent covers are established.*

4 *Use on slopes steeper than 5% is not recommended.*

Source: FHWA, HDS 3, 1973 (12)

Figure 8.4-B — PERMISSIBLE VELOCITIES FOR CHANNELS LINED WITH UNIFORM STANDS OF VARIOUS GRASS COVERS, WELL-MAINTAINED

8.5 DESIGN PROCEDURE (STEP-BY-STEP)

Each project is unique, but the following six basic design steps are normally applicable to the hydraulics design of roadside channels if the channel reach is assessed as stable. Section 8.6 presents an example to illustrate the hydraulics design procedure. To obtain the optimum roadside channel system design, it may be necessary to make several trials with various linings before a final design is achieved. Channel computations are facilitated by using the FHWA Hydraulics Toolbox (see Chapter 16 "Hydraulics Software") or by spread sheets.

<u>Step 1</u>. Establish a Roadside Plan

A. Collect available site data. See Chapter 5 "Data Collection."

B. Document the existing and proposed plan-profile layout including highway, culverts and bridges.

C. Plot the locations of natural basin divides and roadside channel outlets. Figure 8.5-A presents an example of a roadside channel plan/profile.

D. Lay out the proposed roadside channels to minimize diversion flow lengths.

<u>Step 2</u>. Establish Cross Section Data

A. Identify features that may restrict the cross section design:

- right-of-way limits,
- trees or environmentally sensitive areas,
- utilities, and/or
- existing drainage facilities.

B. Provide a channel depth adequate to drain the subbase and minimize freeze-thaw effects.

C. Choose channel side slopes and bottom width based on the ODOT design criteria, including the consideration of safety, economics, soils, aesthetics and access. See Section 8.4.2.2.

<u>Step 3</u>. Determine Channel Grade

A. Plot initial longitudinal grades on plan-profile layout, including inlet and outlet considerations. See Section 8.4.2.3 for ODOT practices.

B. Consider the influence of grade on type of lining. See Step 5.

C. Where practical, avoid features that may influence or restrict grade (e.g., utility locations).

D. Select final channel grade to minimize ponding and sediment accumulation.

<u>Step 4</u>. Check Flow Capacities and Adjust as Necessary

A. Compute the design discharge at the downstream end of a channel segment (see Chapter 7 “Hydrology”).

B. Set preliminary values of channel size, roughness coefficient and slope.

C. Determine maximum allowable depth of channel including freeboard. See Section 8.4.2.4 for ODOT practices.

D. Determine Manning’s Roughness Coefficient n from Figure 8.3-B.

E. If capacity is inadequate, possible adjustments are as follows:

- increase bottom width,
- make channel side slopes flatter,
- make channel slope steeper,
- provide smoother channel lining, and/or
- install drop inlets and a parallel storm drain pipe beneath the channel to supplement channel capacity.

F. Provide smooth transitions at changes in channel cross section.

G. Provide extra channel storage where needed to replace floodplain storage and/or to reduce peak discharge.

<u>Step 5</u>. Determine Channel Lining/Protection Needed

The hydraulics designer has two options for assessing the lining material:

- Option 1 - Considers only the shear stress on the lining or channel protection. This method was introduced in the mid-1970s, has substantial lining tests and has the advantage of being easy to use.

- Option 2 - Considers both the shear stress on the liner and the shear stress on the soil being protected. This method was introduced in 2005 and is best accomplished with the FHWA Hydraulics Toolbox since it requires trial and success procedures.

<u>Option 1</u>

The following procedure is based on HEC-15 (9) procedure, which considers the shear stress on the liner. The Hydraulics Toolbox can also be used (see Example 8.6-1 Single Section Example).

A. Select a trial lining and determine the permissible shear stress τ_p in psf from Figure 8.5-C. See Section 8.4.2.6 for typical ODOT practices on selecting channel linings.

B. Estimate the flow depth and choose an initial Manning's n from:

- Figure 8.3-B for rigid, unlined, temporary, gravel and rock riprap linings; or
- Figure 8.3-B for vegetative linings.

The hydraulics designer may select an alternative n value with proper documentation. For example, ODOT practice is to limit the n value for the permanent grass lining to 0.035 and to use 0.015 for concrete linings.

C. Calculate normal flow depth, y_n (ft), at design discharge using Manning's equation and compare with the estimated depth. If they do not agree, repeat Steps 5B and 5C.

D. Compute maximum shear stress at normal depth as:

τ_d (psf) = $62.4 y_n S$, where S = channel slope, ft/ft Equation 8.5(1)

E. If $\tau_d < \tau_p$, then lining is acceptable. Otherwise, consider the following options:

- choose a more resistant lining;
- decrease channel slope;
- decrease slope in combination with drop structures; and/or
- increase channel width and/or flatten side slopes.

Option 2

The following procedure is based on HEC-15 (2005) (10) procedure, which considers both the shear stress on the liner and the shear stress on the soil being protected. The Hydraulics Toolbox is used (see Example 8.6.2 Single Section Example).

A. Determine the permissible shear stress for TRM from Figure 8.5-C.

B. Determine n value from Figure 8.3-B.

C. Calculate y using Manning's equation (similar to Example 8.6-1) or use the FHWA Hydraulics Toolbox (Channel Calculator).

Step 6. Analyze Outlet Points and Downstream Effects

A. Identify any adverse impacts (e.g., increased flooding or erosion to downstream properties) that may result from one of the following at the channel outlet:

- increase or decrease in discharge,

- increase in velocity of flow,
- concentration of sheet flow,
- change in outlet water quality, or
- diversion of flow from another watershed.

B. Mitigate any adverse impacts identified in Step 6A. Possibilities include:

- increase capacity and/or improve lining of downstream channel;

- install velocity-control structures (see Chapter 11 “Energy Dissipators”);

- install sedimentation/infiltration basins or control structures to provide detention of increased runoff and/or sediment (see Chapter 12 “Storage Facilities”); and/or

- install weirs or other outlet devices to redistribute concentrated channel flow; see HEC 22 (13).

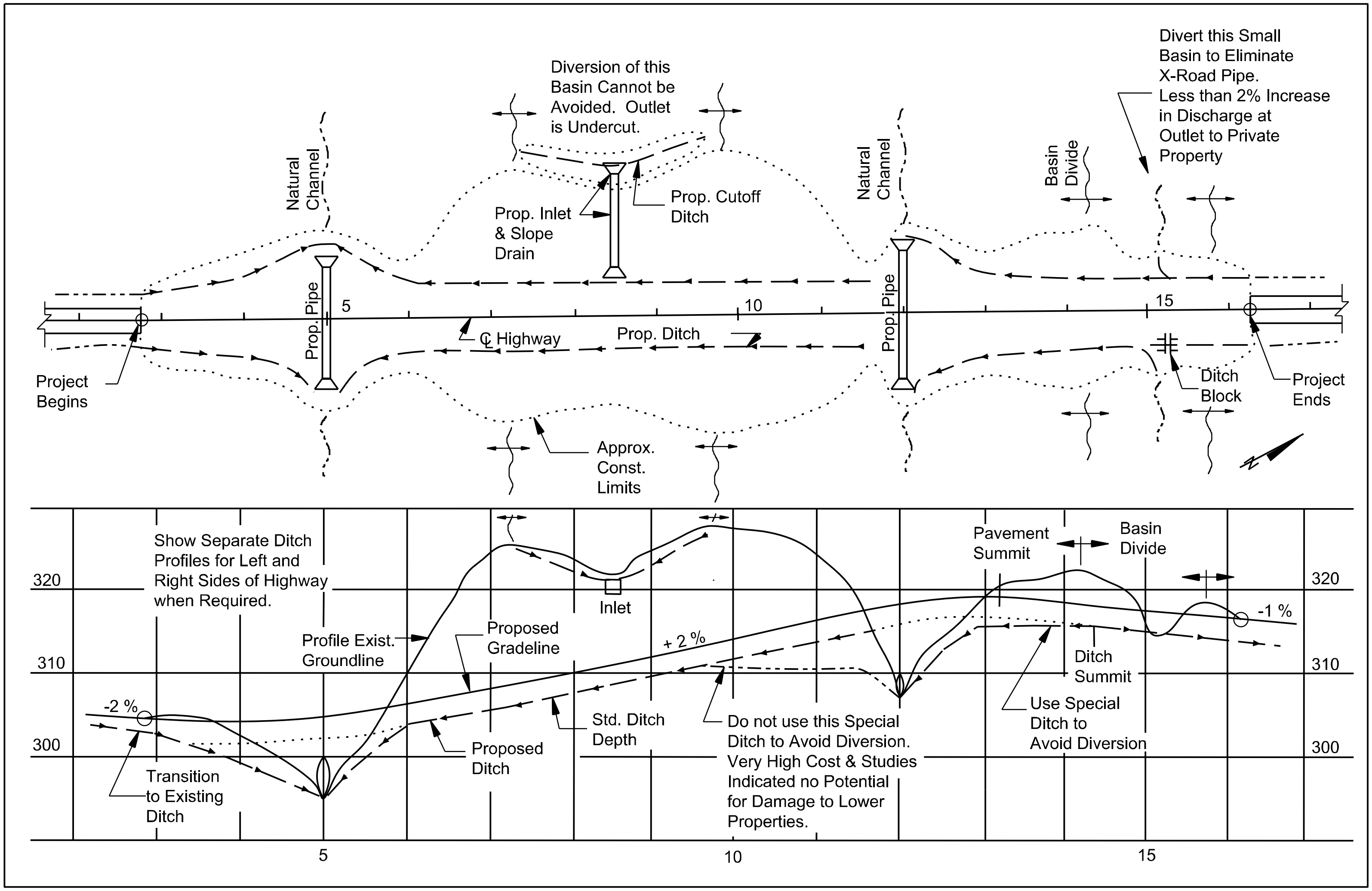


Figure 8.5-A — SAMPLE ROADSIDE CHANNEL

Retardance	Cover	Condition
A	Weeping lovegrass	Excellent stand, tall (average 30 in)
	Yellow bluestem Ischaemum	Excellent stand, tall (average 36 in)
B	Kudzu	Very dense growth, uncut
	Bermuda grass	Good stand, tall (average 12 in)
	Native grass mixture: little bluestem, bluestem, blue gamma, other short- and long-stem Midwest grasses	Good stand, unmowed
	Weeping lovegrass	Good stand, tall (average 24 in)
	Lasperdeza sericea	Good stand, not woody, tall (average 19 in)
	Alfalfa	Good stand, uncut (average 11 in)
	Weeping lovegrass	Good stand, unmowed (average 13 in)
	Kudzu	Dense growth, uncut
	Blue gamma	Good stand, uncut (average 13 in)
C	Crabgrass	Fair stand, uncut (10 in – 48 in)
	Bermuda grass	Good stand, mowed (average 6 in)
	Common lesperdeza	Good stand, uncut (average 11 in)
	Grass-legume mixture: summer (orchard grass redtop, Italian ryegrass and common lespedeza)	Good stand, uncut (6 in – 8 in)
	Centipedegrass	Very dense cover (average 6 in)
	Kentucky bluegrass	Good stand, headed (6 in –12 in)
D	Bermuda grass	Good stand, cut to 2½ in
	Common lespedeza	Excellent stand, uncut (average 4½ in)
	Buffalo grass	Good stand, uncut (3 in – 6 in)
	Grass-legume mixture: fall, spring (orchard grass redtop, Italian ryegrass and common lesperdeza)	Good stand, uncut (4 in – 5 in)
	Lespedeza sericea	After cutting to 2 in (very good before cutting)
E	Bermuda grass	Good stand, cut to 1½ in
	Bermuda grass	Burned stubble

Note: Cover classification has been tested in experimental channel. Covers were green and generally uniform. Source of table is FHWA HEC 15 (9)*.*

Figure 8.5-B — CLASSIFICATION OF VEGETATIVE COVERS WITH RESPECT TO DEGREES OF RETARDANCY

ODOT Typical Linings	τ_p **(psf)**
Class B Vegetation	2.10
Synthetic Mats (ODOT Nylon Erosion Control)	2.00
Turf Reinforcement Mat	4.00
Rock Riprap	
D_{50} = 6 in (50 lb Riprap)	2.50
D_{50} = 12 in (75 lb Riprap)	5.00
ODOT Special Linings	
Class A Vegetation	3.70
Class C Vegetation	1.00
Class D Vegetation	0.60
Class E Vegetation	0.35
4-to 8-in Gabions	0.35
3-to 5-in Revetment Mattresses	0.35
Jute Net	0.45
Straw with Net	1.45
Curved Wood Mat (ODOT Excelsior Mat)	1.55
Gravel	
D_{50} = 1 in	0.40
D_{50} = 2 in	0.80
4-in Geoweb	10.00
Concrete Construction Blocks (granular filter underlayer)	> 20.00
Wedge-Shaped Blocks (with drainage slot)	> 25.00
Soil Cement (8% cement)	> 45.00

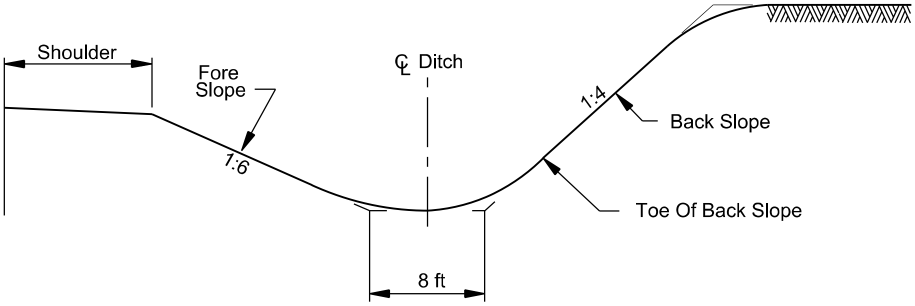
Source: (9), (10) and (14)

Figure 8.5-C — PERMISSIBLE SHEAR STRESSES (τ_p) FOR VARIOUS PROTECTION MEASURES

8.6 EXAMPLE PROBLEMS

Example 8.6-1

Given: The typical ODOT trapezoidal ditch section with 8 ft bottom shown below is lined with a good stand (unmowed) of native grass mixture. The ditch longitudinal slope (S) is 0.01 ft/ft. The side slope factor (z) on the roadway side (fore slope) is 6 and on the back slope side is 4.



Find: Using the step-by-step design procedure in Section 8.5, compute the maximum discharge for which this lining will be stable and the corresponding flow depth.

Solution: From Figure 8.5-B, Native Grass Mixture is a retardance class of B and, from Figure 8.5-C, the permissible shear stress is:

$$\tau_p = 2.1 \text{ psf}$$

$$n = 0.035 \text{ (ODOT Practice)}$$

The allowable depth can be determined by using Equation 5.5(1) and assuming $\tau_p = \tau_d$:

$$y = \tau_p/(62.4S) = 2.1/((62.4)(0.01)) = 3.36 \text{ ft}$$

Determine the flow area (A) and hydraulics radius (R) for $z_1 = 6$ and $z_2 = 4$:

$$A = y(b + z_1y/2 + z_2y/2) = 3.36\ (8 + 3(3.36) + 2(3.36)) = 83.3 \text{ ft}^2$$

$$P = b + y(1 + z_1^2)^{1/2} + y(1 + z_2^2)^{1/2}$$

$$P = 8 + 3.36\ (1 + 36)^{1/2} + 3.36\ (1 + 16)^{1/2} = 8 + 20.4 + 13.8 = 42.2 \text{ ft}$$

$$R = A/P = 83.3/42.2 = 1.97 \text{ ft}$$

Solving for Q from Manning's equation (Equation 8.2(5)) using n = 0.035:

$$Q = (1.486/0.035)(83.3)(1.97)^{2/3}\ (0.01)^{1/2} = 556 \text{ cfs}$$

$$V = Q/A = 556/83.3 = 6.67 \text{ fps}$$

Note: This method is called the maximum discharge method and is useful for determining the stable channel capacity for a variety of different linings for comparison.

The FHWA Hydraulics Toolbox (Channel Calculator) was used to produce the data in Figure 8.6-A.

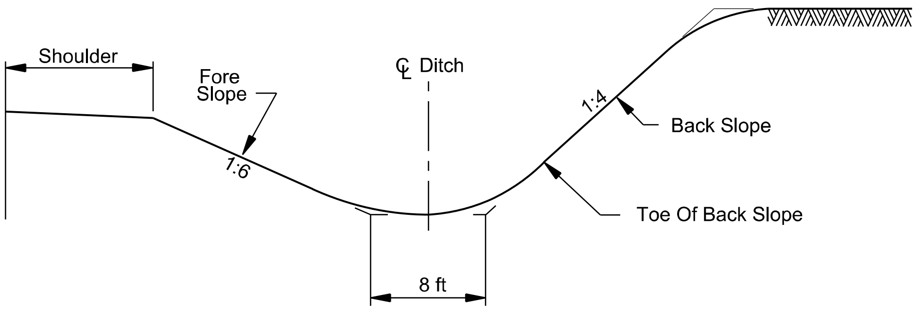
Slope (S) (ft/ft)	Maximum Depth (y) (2.1/62.4S) (ft)	Maximum Q (cfs)
0.01	3.36	556
0.02	1.68	176
0.04	0.84	63
0.06	0.56	36
0.08	0.42	25
0.10	0.34	19

Figure 8.6-A — MAXIMUM DEPTH AND DISCHARGE FOR CLASS B VEGETATION
(In ODOT Typical Channel used in Example 8.6-1 with n = 0.035)

Figure 8.4-B shows that the permissible velocity of Native Grass mixture covered channel with erosion resistant soils is 7.00 fps, which is greater than the computed flow velocity above (V = 6.67 fps). This confirms that the Native Grass mixture should be a sufficient channel lining.

Example 8.6-2

Given: The typical ODOT ditch section (shown below) will be used. The ditch longitudinal slope is 0.01 ft/ft. This is the same as Example 8.6-1, which established that Native Grass Mixture was acceptable for the permanent lining.



Find: Determine if the Turf Reinforcement Mat (TRM) is needed, either as a temporary or permanent lining.

Solution: The solution follows the procedure outlined in Section 8.5 (Step 5), which is based on the tractive force method:

(1) Determine the permissible shear stress for TRM:

$\tau_p = 4.0$ psf (Figure 8.5-C)

(2) Determine n = 0.03 from Figure 8.3-B.

(3) Calculate y using Manning's equation (similar to Example 8.6-1). The FHWA Hydraulics Toolbox (Channel Calculator) was used to produce Figure 8.6-B.

The TRM is not needed as a permanent lining on longitudinal slope less than 0.02 ft/ft if the design discharge is less than that shown in Figure 8.6-B. The TRM will provide temporary protection until grass is established and will provide for a stronger permanent lining. TRM substantially increases capacity of the channel as a permanent lining.

Slope (S) (ft/ft)	**Maximum Depth(y) (4/62.4S) (ft)**	**Maximum Q (cfs)**
0.01	6.41	2929
0.02	3.21	827
0.04	1.60	262
0.06	1.07	144
0.08	0.80	95
0.10	0.64	70

Figure 8.6-B — MAXIMUM DEPTH AND DISCHARGE FOR TRM
(In ODOT Typical Channel Used in Example 8.6-2 with n = 0.03)

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