Chapter 10

CHANNEL DESIGN

MONTANA
Department of Transportation

HYDRAULICS MANUAL

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CHANNEL DESIGN

10.1 INTRODUCTION

10.1.1 Overview

This Chapter presents typical MDT hydraulic design guidelines for constructed channels/ditches. The alignment, cross section, and grade of channels/ditches are usually determined by the geometric and roadside safety design applicable to the project. See the *MDT Road Design Manual*. MDT does not typically perform a hydraulic design for standard roadside ditches except for erosion protection; however, the following features do require a hydraulic design:

- Roadside ditches that collect significant drainage,
- Storm drain outlet channels (for riprap design and drainage),
- Relocated/realigned stream channels, and
- Lined ditches and chutes.

Irrigation channels are addressed in Chapter 12, "Irrigation Structures," and standard roadside ditches are discussed in the *MDT Road Design Manual*.

The *MDT Permanent Erosion and Sediment Control Design Guidelines* (PESC) contain information on maintaining existing drainage patterns and strategies for erosion control including channel linings. Further information on channel linings can be found in HEC 15 (1) (2).

This chapter provides the following:

- MDT design practices (Section 10.2),
- Design criteria (Section 10.3),
- Hydraulics of open channel flow (Section 10.4), and
- Documentation (Section 10.5).

10.1.2 Symbols

To provide consistency within this chapter, the symbols provided in Figure 10.1-1 will be used. These symbols are commonly used in open channel hydraulics.

Figure 10.1-1— SYMBOLS AND DEFINITIONS

Symbol	Definition	Units
A	Cross sectional area	ft^2
B	Bottom width	ft
d	Hydraulic depth (A/T)	ft
Δd	Change in depth due to superelevation of flow in a bend	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_L	Head loss	ft
K	Conveyance capacity	ft^3/s
k_s	Roughness height	ft
L	Channel reach length	ft
n	Manning’s roughness coefficient	—
P	Wetted perimeter	ft
Q	Discharge (flow rate)	ft^3/s
q	Discharge per unit width	$ft^3/s/ft$
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	ft/s
V_c	Critical velocity	ft/s
y	Depth of flow	ft
y_c	Critical depth	ft
z	Elevation of streambed	ft
γ	Unit weight of water	lb/ft^3
τ_d	Shear stress (tractive force)	lb/ft^2
τ_p	Permissible shear stress	lb/ft^2
α	Velocity distribution coefficient	—
θ	Channel slope angle	degrees

10.2 MDT DESIGN PRACTICES

This section includes the standard practices that MDT uses to design the following channels:

- Roadside Ditches, Section 10.2.1,
- Storm Drain Outlet Channels, Section 10.2.2,
- Relocated/Realigned Stream Channels, Section 10.2.3, and
- Lined Ditches and Chutes, Section 10.2.4.

Section 10.2.5 describes the hydraulic analysis methods MDT uses to evaluate channels.

10.2.1 Roadside Ditches

The alignment, cross section, and grade of channels/ditches are usually determined by the geometric and roadside safety design applicable to the project. See the *MDT Road Design Manual*. MDT does not typically perform a hydraulic design for standard roadside ditches except for erosion protection.

However, when roadside ditches collect significant offsite drainage, use the design flood frequency from Section 9.3.2.1 to complete a hydraulic analysis to evaluate the ditch for capacity, freeboard, and erosion.

10.2.2 Storm Drain Outlet Channels

The following will apply to the hydraulic design of storm drain outlet channels:

- Prior to initiating design, determine if there is an appropriate outfall.
- Design the capacity of the channel to match the design flood frequency for the culvert/storm drain.
- Provide a minimum of 1 foot of freeboard in the channel at the design flood discharge.
- Check to determine if erosion protection is needed and add protection if warranted.

See Chapter 14, “Storm Drain Systems”, for additional information on storm drain outfalls.

10.2.3 Relocated/Realigned Stream Channels

In general, avoid channel impacts and channel changes; however, in some cases, it may be necessary to realign or adjust a stream in the immediate vicinity of a bridge or culvert crossing. When channel impacts cannot be avoided, design the channel change to minimize the impact. Assuming that the channel is stable, design channel changes to:

- Replicate the natural channel cross section and slope upstream and downstream of the channel change;

- Match existing stream length;

- Provide a low flow channel when one is present;

- Align with upstream and downstream channels;

- Provide alignment, profile or elevations, cross-sections, and bank details; and

- Match the natural channel velocity upstream and downstream of the channel change.

When addressing channel modifications, the preferred procedure is to:

- Coordinate with the Environmental Services Bureau to determine if there are any resource agency concerns;
- Use upstream or downstream reference reaches to determine the existing channel characteristics (e.g., slope, section, meander pattern, and stage-discharge relationship);
- Consider the stream stability (see Chapter 16, "Stream Stability Assessment" and HEC 20 (3)); and
- Duplicate the existing channel characteristics as much as possible.

For major channel changes, refer to HEC 20 (3), HDS 6 (4) and the NRCS Part 653 (5).

10.2.4 Lined Ditches and Chutes

MDT has adopted the *MDT Permanent Erosion and Sediment Control Design Guidelines* (PESC) as its standard practice for the selection of the appropriate PESC measures to be included in the plans package. The following information, which is from and references the PESC, summarizes the Department's practices that relate to channels.

Lined ditches may be used in the following areas/situations:

- Areas that are susceptible to erosion where vegetation is difficult to establish,
- Steep grades/high flow velocities,
- Below steep grades where runoff begins to concentrate, or
- At the top of slopes to divert run-on from adjacent or undisturbed slopes.

Drainage chutes/embankment protectors may be required when:

- Intercepting a drainage in a backslope,
- Designing cut to fill transitions, or
- Designing bridge ends.

See the following PESC appendices for channel lining applications:

- Appendix A1.0, "Ditch Blocks"
- Appendix A2.0, "Check Dams"
- Appendix A3.0, "Lined Ditches"
- Appendix A4.0, "Interceptor Ditches"
- Appendix A7.0, "Drainage Chutes"

Lining ditches with riprap and rolled erosion control products (REC) is preferred over using concrete and asphalt as liners. Riprap and REC decrease flow velocities and allow infiltration, thus decreasing the erosion potential. In addition, rolled erosion control products (REC) promote vegetative growth. Concrete- and asphalt-lined ditches may be appropriate for ditches located within the clear zone and on heavily sanded mountain passes. Vegetated Concrete Mats (VCMs) are a newer product that may also be considered for ditch-lining applications if the velocities fall within the product specifications.

Use the FHWA Hydraulic Toolbox (see Chapter 8, “Hydraulic Software”) and the procedures in HEC 15 (1) (2) to design liners and to confirm the performance of the specified lining.

The decision matrix in Figure 10.2-1 provides assistance when selecting appropriate measures for permanent erosion control.

Figure 10.2-1 — GUIDELINES FOR SELECTION OF PERMANENT EROSION CONTROL

	Application	**PESC Reference**	**Comments**
Intercepting Drainages in Back Slope	Embankment Protector	Section A6.0	
	Drainage Chute	Section A7.0	
	Interceptor Ditch	Section A4.0	
Steep Embankment Slopes Behind Guardrail	Embankment Protector or Drainage Chute w/Channelizing Curb	Sections A6.0, A7.0, and A5.0.	
Long or Steep Ditch Grades	Check Dams	Section A2.0	
	Lined Ditch	Section A3.0	
	Ditch Block and Culvert to Divert Flows	Section A1.0	Use to maintain existing drainage patterns
Bridge Ends	Divert Flows Before the Bridge End		Route diverted flows through a vegetation strip before entering a stream
	Embankment Protector or Drainage Chute w/Channelizing Curb	Sections A6.0, A7.0, and A5.0.	Provide outlet protection and vegetation strip before flows enter a stream

Use Figures 10.2-2 and 10.2-3 to determine permissible velocities for earthen and vegetated channels.

Figure 10.2-2 — PERMISSIBLE VELOCITIES FOR EARTHEN CHANNELS

Soil Type or Lining (Earth with No Vegetation)	Maximum Permissible Velocities		
	Clear Water (ft/s)	Water Carrying Fine Silts (ft/s)	Water Carrying Sand and Gravel (ft/s)
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

Source: HDS 3, 1973 (6)

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

Figure 10.2-3 — PERMISSIBLE VELOCITIES FOR VEGETATED CHANNELS

Cover	Slope Range (%)	Permissible Velocity[1,2]	
		Erosion Resistant Soils (ft/s)	**Easily Eroded Soils (ft/s)**
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

Source: HDS 3, 1973 (6)

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

[2] *Use velocities over 5 ft/s only where good cover 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.*

10.2.5 Channel Hydraulic Analysis Methods

The hydraulic design 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 hydraulic analysis of open channels:

- The single-section method (Section 10.2.5.1), and
- Hydraulic model analysis (Section 10.2.5.2).

10.2.5.1 Single-Section Analysis

The single-section method is a simple application of Manning's equation to determine tailwater rating curves or situations in which uniform or nearly uniform flow conditions can be assumed. The single-section method is usually sufficient for standard roadside ditches and median channels.

The FHWA Hydraulic Toolbox program may be used for channel and channel lining design using a single-section analysis. In addition, the FHWA Hydraulic Toolbox User's Manual has useful information on channel and channel lining design. Chapter 8, "Hydraulics Software" includes additional options for channel analysis.

10.2.5.2 Hydraulic Model Analysis

Hydraulic models are recommended for more complex channel analysis and design including water surface profiles and gradually varied flow problems. Use hydraulic models for:

- Most irrigation ditches/canals (see Chapter 12, "Irrigation Facilities"),
- Storm drain outlet channels,
- Relocated/realigned stream channels,
- Channels that have flat or steep slopes,
- Channels that include drop or diversion structures,
- Channels that have flood risk to adjacent properties, or
- Channels that include roadway crossings.

Use software such as HEC-RAS or SRH-2D (see Chapter 8, "Hydraulics Software") to complete these calculations.

10.3 DESIGN CRITERIA

The following criteria apply to the design of channels:

- Use the design flood when sizing hydraulically designed roadside ditches, channels, and outfalls.

- Use the design flood to size and provide erosion protection for drainage chutes.

- Ensure that hydraulically designed channels cause no increase in depth or frequency of flooding to buildings on adjacent properties outside the right-of-way.

- Where channels are within the clear zone, check that side slopes adhere to appropriate roadside safety standards.

- Avoid flat or nearly flat longitudinal slopes. The minimum channel slope is 0.5%. If the 0.5% slope cannot be attained, verify the ditch function with a hydraulic model analysis (see Section 10.2.5) and consider a range of Manning's n values.

- At a minimum, at the design flood, provide 1 ft of freeboard in the channel.

- When alongside a roadway, design the channel such that the design flood water surface in the channel is below the roadway base course.
- Do not exceed 3H:1V sides slopes for unlined channels and 2H:1V side slopes for lined channels.
- Do not exceed a 4H:1V longitudinal slope for riprap-lined channels.
- When permanent ditch linings are needed to protect against erosion, design flexible channel linings:
    - Use the methods in HEC-15 (1), and
    - Use the design flood (check that the ditch remains stable during the passage of the design flood).
- Extend lining materials to the top of the freeboard elevation.
- Provide sufficient outlet erosion protection for drainage chutes and embankment protectors.

10.4 HYDRAULICS OF OPEN CHANNEL FLOW

10.4.1 General

This section contains a simplified discussion of open channel flow terms and concepts. For a more detailed explanation, refer to references (7) and (8). In addition, the terms below are explained in the NHI Basic Hydraulic Principles Review, Course number FHWA-NHI-135091, video, which is available free of charge on the NHI website (www.nhi.fhwa.gov).

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 uniform channels.

10.4.2 Definitions

10.4.2.1 Uniform Channels

A uniform channel has a constant slope and maintains its cross-section throughout its length.

10.4.2.2 Energy Grade Line

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 grade line or the energy line.

10.4.2.3 Steady and Unsteady Flow

A steady flow is one in which the discharge, depth, and velocity passing a given cross section is constant with respect to time. 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.

10.4.2.4 Uniform Flow and Non-Uniform Flow

A uniform flow is one in which the cross section and velocity remain constant through a reach of channel at a given time. Both the energy slope and the water slope are equal to the bed slope under conditions of uniform flow. Discharge passing a given cross section is constant with respect to time. A non-uniform flow is one in which the cross section or velocity changes through a reach of channel at a given time. Uniform flow can only occur in a uniform 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 uniform channel or in a natural channel with variable properties.

10.4.2.5 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.

10.4.2.6 Flow Classification

Below is a short summary of open channel flow classification.

<u>Steady Flow may consist of any of the following:</u>

- Steady uniform flow
- Steady non-uniform flow
- Gradually varied steady flow
- Rapidly varied steady flow

<u>Unsteady Flow may consist of any of the following:</u>

- Unsteady non-uniform flow
- Gradually varied unsteady flow
- Rapidly varied unsteady flow

When designing constructed channels, typically either steady uniform or steady non-uniform flow classification is assumed.

10.4.2.7 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:

$$Fr = \frac{V}{(gd)^{0.5}}$$ Equation 10.4-1

Where:

V = mean velocity = Q/A, ft/s
g = acceleration of gravity, 32.2 ft/s^2
d = hydraulic depth = A/T, ft
A = cross sectional area of flow, ft^2
T = channel top width at the water surface, ft
Q = total discharge, ft^3/s

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

10.4.2.8 Critical Flow

Critical flow occurs when the specific energy is a minimum (E_c) 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 (see Section 10.4.3.4, Specific Energy). During critical flow, the velocity head is equal to half the critical depth. The general expression for flow at critical depth is:

$$\frac{Q^2}{g} = \frac{A^3}{T}$$ Equation 10.4-2

Where:

Q = total discharge, ft^3/s
g = gravitational acceleration, 32.2 ft/s^2
A = cross sectional area of flow, ft^2
T = channel top width at the water surface, ft

When flow is at critical depth, Equation 10.4-2 applies, regardless of the channel shape.

10.4.2.9 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.

10.4.2.10 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.

10.4.2.11 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 the outlets of 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 (7) and (8)). Sills can also be used to control a hydraulic jump if the tailwater depth is less than the sequent depth.

10.4.3 Equations

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

10.4.3.1 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:

$$Q = A_1V_1 = A_2V_2 \qquad \text{Equation 10.4-3}$$

Where:

Q = discharge, ft^3/s
A = cross sectional area of flow, ft^2
V = mean cross sectional velocity, ft/s (which is perpendicular to the cross section)

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

10.4.3.1.1 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:

$$V = \left(\frac{1.486}{n}\right) R^{2/3} S^{1/2}$$ Equation 10.4-4

Where:

V = velocity, ft/s
n = Manning's roughness coefficient
R = hydraulic radius = A/P, ft
A = cross sectional area of flow, ft^2
P = wetted perimeter, ft
S = slope of the energy grade line, 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 Appendix 10A for a Manning's n guide.

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

$$Q = VA = \left(\frac{1.486}{n}\right) AR^{2/3} S^{1/2}$$ Equation 10.4-5

For steady uniform flow normal depth (y) occurs at a given channel geometry, slope, Manning's roughness, and a specified value of discharge Q. Equation 10.4-5 may be used to calculate normal depth using a trial-and-error solution or by using software such as the FHWA Hydraulics Toolbox (see Chapter 8, "Hydraulics 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.

10.4.3.2 Channel Conveyance

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

$$K = \left(\frac{1.486}{n}\right) AR^{2/3}$$ Equation 10.4-6

and then the discharge equation can be written as:

$$Q = KS^{1/2}$$ Equation 10.4-7

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.

10.4.3.3 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 a change in form.

Figure 10.4-1 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., $h_1 = z_1 + y_1$.

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 10.4-1), the energy equation is:

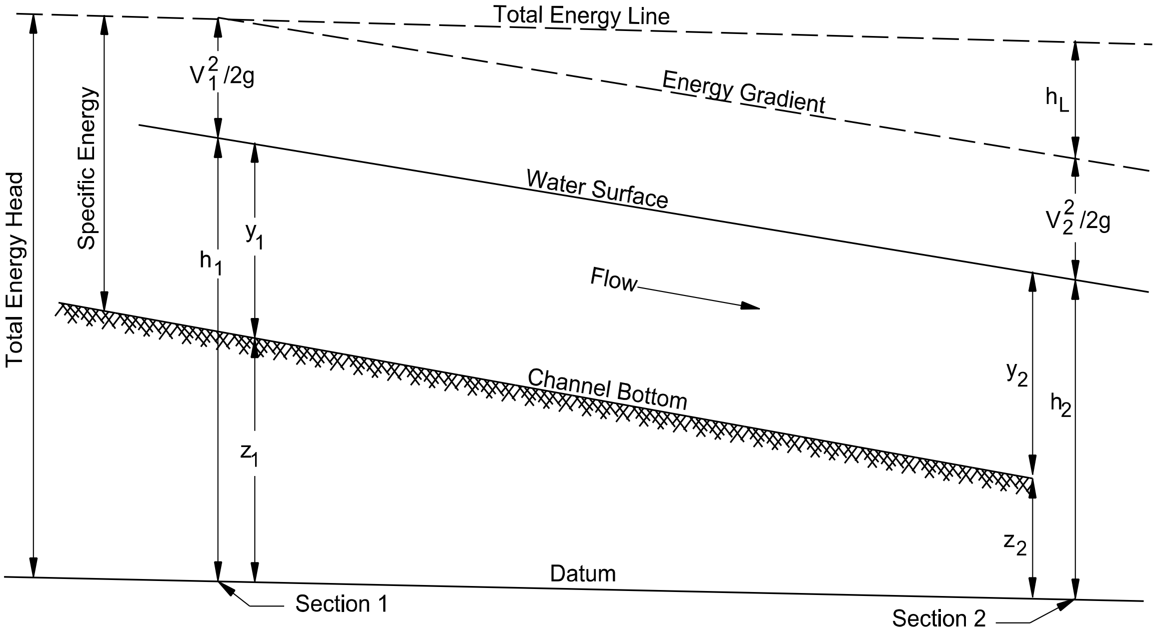
$$h_1 + \left(\frac{V_1^2}{2g}\right) = h_2 + \left(\frac{V_2^2}{2g}\right) + h_L \qquad \text{Equation 10.4-8}$$

Where:

h_1, h_2 = the upstream and downstream stages, respectively, ft
V = mean velocity, ft/s
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 10.4-1. 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.

Figure 10.4-1 — TERMS IN THE ENERGY EQUATION



Source: Adopted from HDS 4 (8)

10.4.3.4 Specific Energy

Specific energy, E, is defined as the energy head relative to the channel bottom (see Figure 10.4-1). Figure 10.4-2 is a plot of the 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:

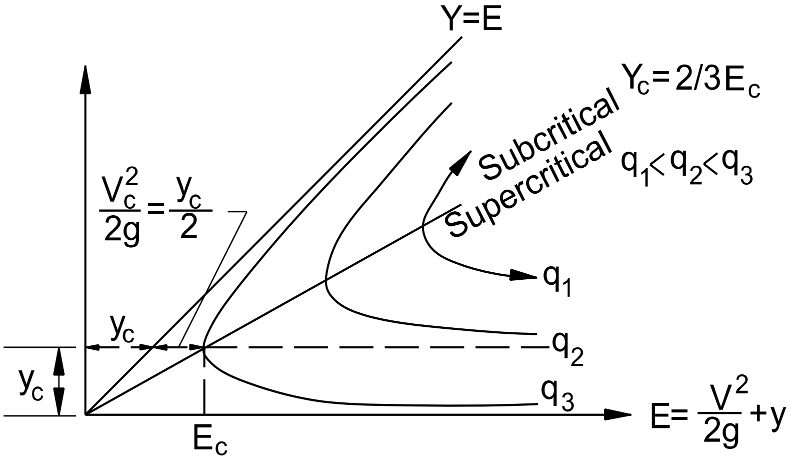
$$E = y + \left(\frac{V^2}{2g}\right) \qquad \text{Equation 10.4-9}$$

Where:

y = depth, ft
V = mean velocity, ft/s
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.

Figure 10.4-2 — SPECIFIC ENERGY DIAGRAM



Source: Adopted from HDS 4 (8)

10.5 DOCUMENTATION

In the design documentation, include all information required to justify the design. At a minimum, describe the design assumptions, the calculations that were used, any alternatives considered, and the final recommendation. This document serves as a resource for future hydraulic engineers when roadways require updates, changes, or rehabilitation.

10.6 REFERENCES

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Appendix 10A — MANNING'S n SELECTION

Manning's n, the roughness coefficient, is affected by many factors, and its selection in 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 (7), (9), and (10)) for estimating n values for various types of channels. The selected n values should be verified by reproducing historical high water marks, aerial flood photo extents, or gaged streamflow data, if available.

Use Figures 10.A-1, 10A-2 and 10A-3 as a guide in selecting the Manning's n value for ditches and channels.

Figure 10.A-1 — VALUES OF MANNING'S ROUGHNESS COEFFICIENT n (Uniform Flow)

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			
b. Clean bottom, brush on sides	0.050	0.080	0.120
c. Same, highest stage of flow	0.040	0.050	0.080
d. Dense brush, high stage	0.045	0.070	0.110
	0.080	0.100	0.140

Source: AASHTO MDM 2005 (11)

Figure 10.A-1 — VALUES OF MANNING'S ROUGHNESS COEFFICIENT n (Uniform Flow)

(*Continued*)

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

Source: AASHTO MDM 2005 (11)

Figure 10.A-1 — VALUES OF MANNING'S ROUGHNESS COEFFICIENT n (Uniform Flow)

(*Continued*)

Type of Channel and Description	Minimum	Normal	Maximum
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 (11)

Figure 10.A-2 — VALUES OF MANNING'S ROUGHNESS COEFFICIENT n (Selected Linings)

		Manning's n[1]		
Lining Category	**Lining Type**	**Maximum**	**Typical**	**Minimum**
Rigid	Concrete	0.015	0.013	0.011
	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[2]	0.025	0.020	0.016
	Rock cut (smooth, uniform)	0.045	0.035	0.025
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

Source: HEC 15 (2)

[1] *Based on data from Kouwen, et al. (1980), Cox, et al. (1970), McWhorter, et al. (1968) and Thibodeaux (1968).*

[2] *Minimum value accounts for grain roughness. Typical and maximum values incorporate varying degrees of form roughness.*

Figure 10.A-3 — VALUES OF MANNING'S ROUGHNESS COEFFICIENT n (Riprap, Cobble, Gravel Linings)

		Manning's n for Selected Flow Depths[1]		
Lining Category	**Lining Type**	**0.15 m (0.5 ft)**	**0.50 m (1.6 ft)**	**1.0 m (3.3 ft)**
Gravel Mulch	D_{50} = 25 mm (1 in.)	0.040	0.033	0.031
	D_{50} = 50 mm (2 in)	0.056	0.042	0.038
Cobbles	D_{50} = 0.10 m (0.33 ft)	—[2]	0.055	0.047
Rock Riprap	D_{50} = 0.15 m (0.5 ft)	—[2]	0.069	0.056
	D_{50} = 0.30 m (1.0 ft)	—[2]	—[2]	0.080

Source: HEC 15 (2)

[1] *Based on Equation 6.1 (Blodgett and McConaughy, 1985). Manning's n estimated assuming a trapezoidal channel with 1:3 side slopes and 0.6 m (2 ft) bottom width.*

[2] *Shallow relative depth (average depth to D_{50} ratio less than 1.5) requires use of Equation 6.2 (Bathurst, et al., 1981) and is slope dependent. See Section 6.1.*