5. ROADSIDE AND MEDIAN CHANNELS

Roadside and median channels are open-channel systems which collect and convey stormwater from the pavement surface, roadside, and median areas. These channels may outlet to a storm drain piping system via a drop inlet, to a detention or retention basin or other storage component, or to an outfall channel. Roadside and median channels are normally trapezoidal in cross section and are lined with grass or other protective lining.

This chapter presents design concepts and relationships for the design of roadside and median channels.

5.1 Open Channel Flow Concepts

The design and/or analysis of roadside and median channels follows the basic principles of open channel flow. Summaries of several important open channel flow concepts and relationships are presented in the following sections. A more complete coverage of open channel flow concepts can be found in References 7, 31 and 32.

5.1.1 Energy

Conservation of energy is a basic principal in open channel flow. As shown in Figure 5-1, the total energy at a given location in an open channel is expressed as the sum of the potential energy head (elevation), pressure head, and kinetic energy head (velocity head). The total energy at given channel cross section can be represented as:

$$E_t = Z + y + (V^2 / 2g) \qquad (5\text{-}1)$$

where:

E_t = Total energy, m (ft)
Z = Elevation above a given datum, m (ft)
y = Flow depth, m (ft)
V = Mean velocity, m/s (ft/s)
g = Gravitational acceleration, 9.81 m/s^2 (32.2 ft/s^2)

Written between an upstream cross section designated 1 and a downstream cross section designated 2, the energy equation becomes

$$Z_1 + y_1 + \frac{V_1^2}{2g} = Z_2 + y_2 + \frac{V_2^2}{2g} + h_L \qquad (5\text{-}2)$$

where:

h_L = Head or energy loss between section 1 and 2, m (ft)

The terms in the energy equation are illustrated in Figure 5-1. The energy equation states that the total energy head at an upstream cross section is equal to the total energy head at a downstream section plus the energy head loss between the two sections.

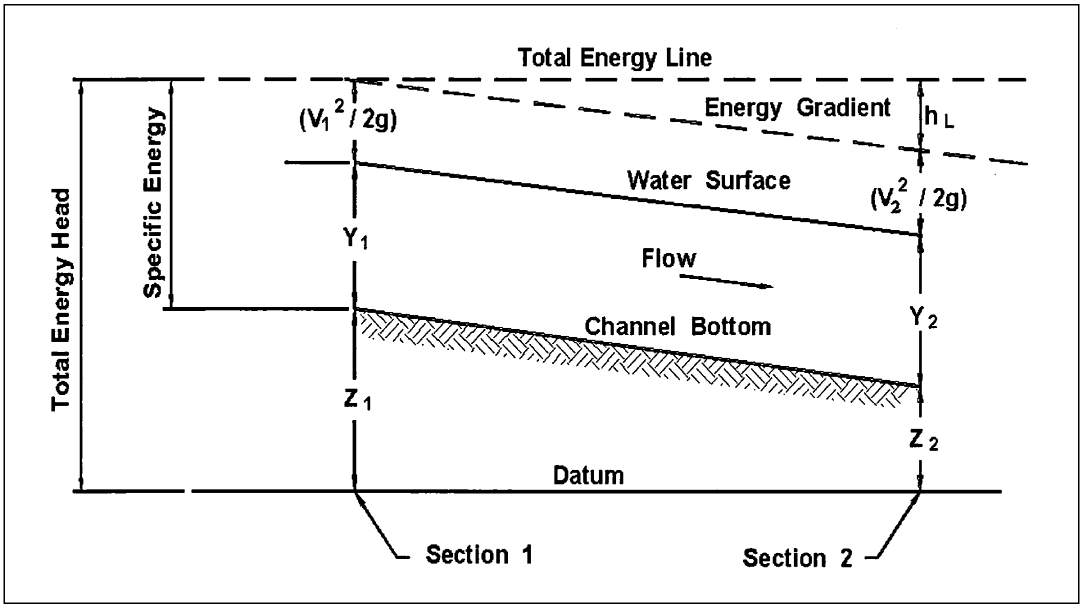

Figure 5-1. Total energy in open channels.

5.1.2 Specific Energy

Specific Energy, E, is defined as the energy head relative to the channel bottom. It is the sum of the depth and velocity head:

$$E = y + (V^2 / 2g) \qquad (5\text{-}3)$$

5.1.3 Flow Classification

Open channel flow is generally classified using the following characteristics:

- Steady or unsteady
- Uniform or varied
- Subcritical or supercritical

A **steady flow** is one in which the discharge passing a given cross-section remains constant in time. When the discharge varies in time, the flow is **unsteady**. A **uniform flow** is one in which the flow rate and depth remain constant along the length of the channel. When the flow rate and depth vary along the channel, the flow is considered **varied**. Gradually-varied flows are nonuniform flows in which the depth and velocity change gradually enough in the flow direction that vertical accelerations can be neglected. A typical example of a gradually varied flow is the stream channel condition upstream of a culvert with ponded flow. In rapidly varied flow the changes occur in a very short reach and the vertical accelerations cannot be neglected. A typical example of a rapidly varied flow is the flow profile through a constricted bridge opening. Most natural flow conditions are neither steady nor uniform. However, in roadside and median channels the flow can often be assumed to be steady and uniform for short periods and distances which simplifies hydraulic analysis and design.

Subcritical flow is distinguished from **supercritical flow** by a dimensionless number called the Froude number (F_r), which represents the ratio of inertial forces to gravitational forces and is defined for rectangular channels by the following equation:

$$Fr = \frac{V}{\sqrt{gy}} \tag{5-4}$$

where:

V = Mean velocity, m/s (ft/s)
g = Acceleration of gravity, 9.81 m/s^2 (32.2 ft/s^2)
y = Flow depth, m (ft)

Critical flow occurs when the Froude number has a value of one (1.0). The flow depth at critical flow is referred to as critical depth. This flow depth represents the minimum specific energy for a given discharge. Critical depth is also the depth of maximum discharge when the specific energy is held constant. These relationships are illustrated in Figure 5-2.

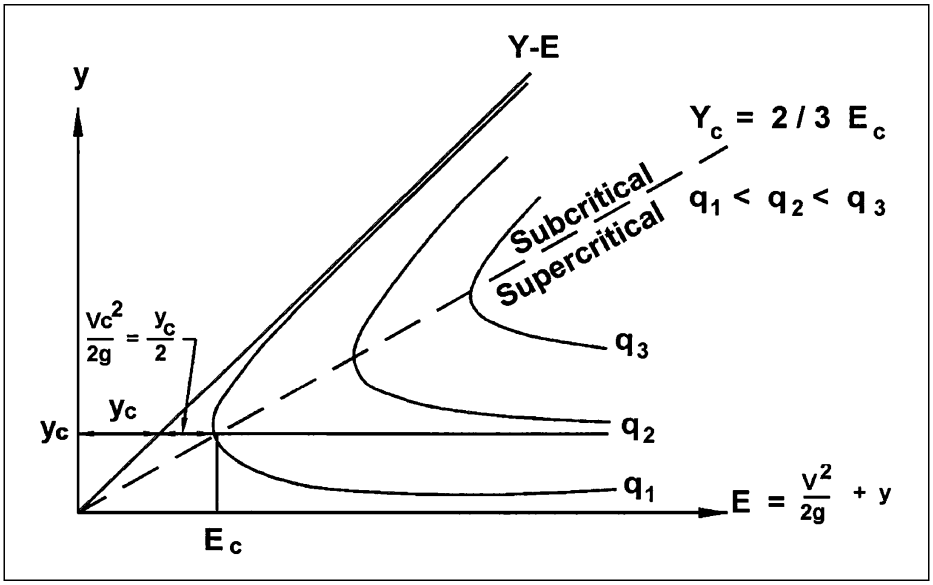

Figure 5-2. Specific energy diagram.

Subcritical flow occurs when the Froude number is less than one ($F_r < 1$). In this state of flow, depths greater than critical depth occur (refer to Figure 5-2), small water surface disturbances travel both upstream and downstream, and the control for the flow depth is always located downstream. The control is a structure or obstruction in the channel which affects the depth of flow. Subcritical flow can be characterized by slower velocities, deeper depths and mild slopes while supercritical flow is represented by faster velocities, shallower depths and steeper slopes. **Supercritical flow** occurs when the Froude number is greater than one ($F_r > 1$). In this state of flow, depths less than critical depth occur (refer to Figure 5-2), small water surface disturbances are always swept downstream, and the location of the flow control is always upstream. Most natural open channel flows are subcritical or near critical in nature. However, supercritical flows are not uncommon for smooth-lined ditches on steep grades.

It is important that the Froude number be evaluated in open channel flows to determine how close a particular flow is to the critical condition. As illustrated in Figure 5-2 and discussed in the next section, significant changes in depth and velocity can occur as flow passes from subcritical to supercritical. When the Froude number is close to one (1.0) small flow disturbances can initiate a change in the flow state. These possible changes and any resulting impacts on flow depth or channel stability must be considered during design.

5.1.4 Hydraulic Jump

A hydraulic jump occurs as an abrupt transition from supercritical to subcritical flow. There are significant changes in depth and velocity in the jump and energy is dissipated. Figure 5-3 illustrates a hydraulic jump.

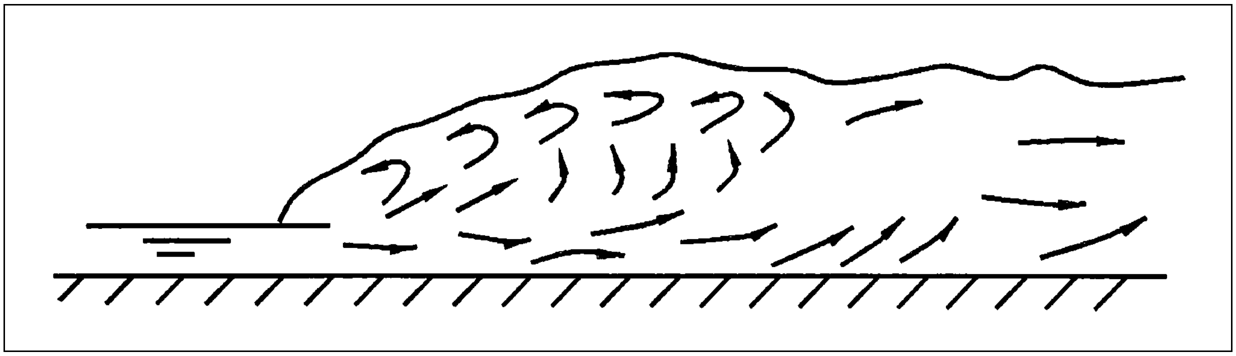

Figure 5-3. Hydraulic jump.

As discussed above, the potential for a hydraulic jump to occur should be considered in all cases where the Froude number is close to one (1.0) and/or where the slope of the channel bottom changes abruptly from steep to mild. The characteristics and analysis of hydraulic jumps are covered in detail in References 31 and 35.

5.1.5 Manning's Equation

Water flows in an open channel due to the force of gravity. Flow is resisted by the friction between the water and the channel boundary. In steady, uniform flow there are no accelerations, streamlines are straight and parallel, and the pressure distribution is hydrostatic. This is the simplest flow condition to analyze, but one that rarely occurs in the real world. However, for many applications the flow is essentially steady and changes in width, depth or direction (resulting in nonuniform flow) are so small that the flow can be considered uniform.

The depth of flow in steady, uniform flow is called the normal depth. The most commonly used equation for solving steady, uniform flow problems is the Manning's equation (expressed in the discharge form):

$$Q = (K_u/n)\ A\ R^{0.67}\ S^{0.5} \tag{5-5}$$

where:

K_u = 1.0 (1.486)
Q = Discharge rate, m^3/s (ft^3s)
A = Cross sectional flow area, m^2 (ft^2)
R = Hydraulic radius, A/P, m (ft)
P = Wetted perimeter, m (ft)
S_o = Energy Grade line slope, m/m (ft/ft)
n = Manning's roughness coefficient

It is important to repeat that Manning's equation is a steady, uniform flow equation. Using this equation for anything else, such as gradually varied or rapidly varied flow, will result in errors. Given steady, uniform flow, or a reasonable approximation of that condition, calculating the discharge capacity of a given channel section using Manning's equation is straightforward. However, given the discharge (i.e. from a hydrologic analysis) and sizing the channel needed to carry that discharge is more complicated and typically involves a trial and error solution. Various computer programs and/or nomographs are available to assist in such calculations, For reference, nomograph solutions to Manning's equation for triangular and trapezoidal channels are presented in Charts 1 and 14, respectively.

A critical parameter in solving Manning's equation is the Manning's roughness coefficient, n. The selection of an appropriate Manning's n value for design purposes is often based on observation and experience. For rigid boundary channels (e.g. concrete lined) the n-value is fairly constant, while in grass-lined channels the value can vary quite dramatically based on the type of vegetation and its height relative to flow depth. The effect of relative submergence for various lining types is illustrated by Chart 16. Roughness conditions on a floodplain are further complicated by dense vegetation, typically shallow flow depths, buildings, undefined flow direction, varying slopes and other complexities. In general, the resistance to flow is quite large on a floodplain. The presence of ice affects channel roughness and resistance to flow in various ways, but generally increases resistance and Manning's n values.

Over many decades, typical Manning's n values have been compiled for a wide range of channel conditions. Table 5-1 provides a tabulation of typical Manning's n values for various channel linings that might be used in a roadside channel.

Table 5-1. Typical Channel Lining Manning's Roughness Coefficients(34)

Lining Category	Lining Type	Manning's n		
		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 Element	0.025	0.022	0.020
	Asphalt	0.018	0.016	0.016
Unlined	Bare Soil	0.025	0.020	0.016
	Rock Cut	0.045	0.035	0.025
RECP	Open-weave textile	0.028	0.025	0.022
	Erosion control blanket	0.045	0.035	0.028
	Turf reinforcement mat	0.036	0.030	0.024

Example 5-1

Given: A trapezoidal channel (as shown in Figure 5-6) with the following characteristics:

S_o = 0.01
B = 0.8 m (2.62 ft)
z = 3
d = 0.5 m (1.64 ft)

Find: *The channel capacity and flow velocity if the channel is lined with a turf reinforcement mat with an n-value of 0.030.*

<u>SI Units</u>

Step 1. Determine the channel parameters

$$\begin{aligned} A &= Bd + 2(1/2)(d)(zd) \\ &= Bd + zd^2 \\ &= (0.8)(0.5) + (3)(0.5)^2 \\ &= 1.15\ m^2 \end{aligned}$$

$$\begin{aligned} P &= B + 2[(zd)^2 + d^2)]^{1/2} \\ &= B + 2d(z^2+1)^{0.5} \\ &= (0.8) + (2)(0.5)(3^2+1)^{0.5} \\ &= 3.96\ m \end{aligned}$$

$$\begin{aligned} R &= A/P \\ &= 1.15/3.96 \\ &= 0.29\ m \end{aligned}$$

Step 2. Compute the flow capacity using Equation 5-5.

$$\begin{aligned} Qn &= K_u\ A\ R^{0.67}\ S_o^{0.5} \\ &= (1.0)(1.15)(0.29)^{0.67}(0.01)^{0.5} \\ &= 0.05\ m^3/s \end{aligned}$$

$$\begin{aligned} Q &= Qn\ /\ n \\ &= 0.05/0.030 \\ &= 1.67\ m^3/s \end{aligned}$$

Step 3. Compute the flow velocity

$$\begin{aligned} V &= Q/A \\ &= 1.67/1.15 \\ &= 1.45\ m/s \end{aligned}$$

<u>English Units</u>

Step 1. Determine the channel parameters

$$\begin{aligned} A &= Bd + 2(1/2)(d)(zd) \\ &= Bd + zd^2 \\ &= (2.62)(1.64) + (3)(1.64)^2 \\ &= 12.4\ ft^2 \end{aligned}$$

$$\begin{aligned} P &= B + 2[(zd)^2 + d^2)]^{1/2} \\ &= B + 2d(z^2+1)^{0.5} \\ &= (2.62) + (2)(1.64)(3^2+1)^{0.5} \\ &= 13.0\ ft \end{aligned}$$

$$\begin{aligned} R &= A/P \\ &= 12.4/13.0 \\ &= 0.95\ ft \end{aligned}$$

Step 2. Compute the flow capacity using Equation 5-5.

$$\begin{aligned} Qn &= K_u\ A\ R^{0.67}\ S_o^{0.5} \\ &= (1.49)(12.4)(0.95)^{0.67}(0.01)^{0.5} \\ &= 1.79\ ft^3/s \end{aligned}$$

$$\begin{aligned} Q &= Qn\ /\ n \\ &= 1.79/0.030 \\ &= 59.7\ ft^3/s \end{aligned}$$

Step 3. Compute the flow velocity

$$\begin{aligned} V &= Q/A \\ &= 59.7/12.4 \\ &= 4.8\ ft/s \end{aligned}$$

Solution 1a: *Alternately use Chart 14A with*

$$\begin{aligned} d/B &= 0.5/0.8 \\ &= 0.63 \\ Qn &= 0.05\ m^3/s \text{ - Chart 14A} \\ Q &= Qn/n \\ &= 0.05/0.030 \\ &= 1.67\ m^3/s \end{aligned}$$

$$\begin{aligned} V &= Q/A \\ &= 1.67/1.15 \\ &= 1.46\ m/s \end{aligned}$$

Solution 1a: *Alternately use Chart 14B with*

$$\begin{aligned} d/B &= 1.64/2.62 \\ &= 0.63 \\ Qn &= 1.8\ ft^3/s \text{ - Chart 14B} \\ Q &= Qn/n \\ &= 1.8/0.030 \\ &= 59.7\ ft^3/s \end{aligned}$$

$$\begin{aligned} V &= Q/A \\ &= 59.7/12.4 \\ &= 4.8\ ft/s \end{aligned}$$

5.1.6 Flow in Bends

Flow around a bend in an open channel induces centrifugal forces because of the change in flow direction.(31) This results in a superelevation of the water surface at the outside of bends and can cause the flow to splash over the side of the channel if adequate freeboard is not provided. This superelevation can be estimated by the following equation.

$$\Delta d = (V^2\ T) / (g\ R_c) \tag{5-11}$$

where:

Δd = Difference in water surface elevation between the inner and outer banks of the channel in the bend, m (ft)
V = Average velocity, m/s (ft/s)
T = Surface width of the channel, m (ft)
g = Gravitational acceleration, 9.81 m/s^2 (32.2 ft/s^2)
R_c = Radius to the centerline of the channel m (ft)

Equation 5-11 is valid for subcritical flow conditions. The elevation of the water surface at the outer channel bank will be $\Delta d/2$ higher than the centerline water surface elevation (the average water surface elevation immediately before the bend) and the elevation of the water surface at the inner channel bank will be $\Delta d/2$ lower than the centerline water surface elevation. Flow around a channel bend also imposes higher shear stress on the channel bottom and banks and may impact channel stability.

5.1.7 Shear Stress

The hydrodynamic force created by water flowing in a channel causes a shear stress on the channel bottom. The bed material, in turn, resists this shear stress by developing a tractive force. Tractive force theory states that the flow-induced shear stress should not produce a force greater than the tractive resisting force of the bed material. This tractive resisting force of the bed material creates the permissible or critical shear stress of the bed material. In a uniform flow, the shear stress is equal to the effective component of the gravitational force acting on the body of water parallel to the channel bottom. The average shear stress is equal to:

$$\tau = \gamma R S \qquad (5\text{-}12)$$

where:

τ = Average shear stress, Pa (lb/ft^2)
γ = Unit weight of water, 9810 N/m^3 (62.4 lb/ft^3) (at 15.6°C (60°F))
R = Hydraulic radius, m (ft)
S = Average bed slope or energy slope, m/m (ft/ft)

The maximum shear stress for a straight channel occurs on the channel bed(31) and is less than or equal to the shear stress at maximum depth. The maximum shear stress is computed as follows:

$$\tau_d = \gamma d S \qquad (5\text{-}13)$$

where:

τ_d = Maximum shear stress, Pa (lb/ft^2)
d = Maximum depth of flow, m (ft)

Shear stress in channels is not uniformly distributed along the wetted perimeter of a channel. A typical distribution of shear stress is illustrated in Figure 5-4.

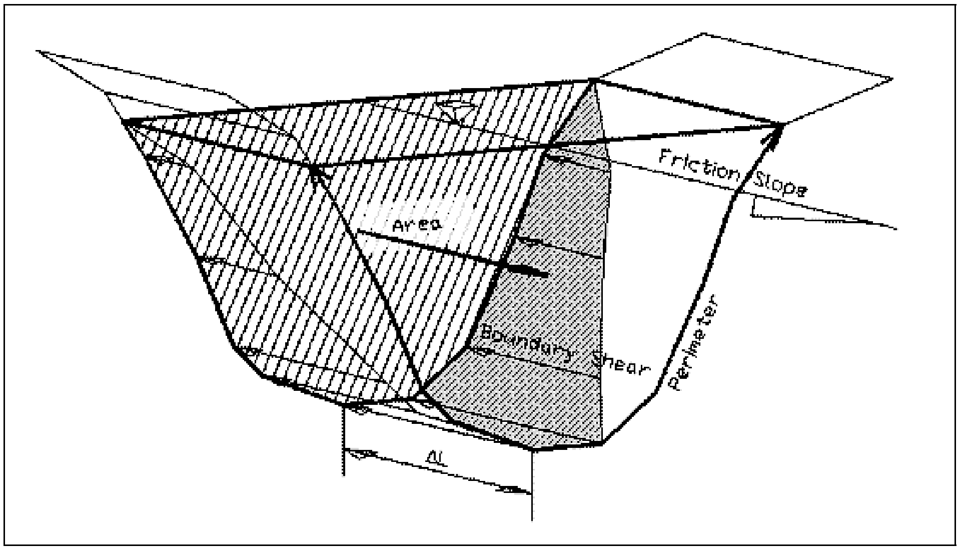

Figure 5-4. Distribution of shear stress.

The ratio of shear stresses on the sides and bottom of a trapezoidal channel, K_1, is given in Chart 17 and the tractive force ratio, K_2, is given in Chart 18. While the reduced shear stress on the channel sides might suggest increased stability in that region of the channel, this may be diminished by the steepness of side slope. For example, when designing a trapezoidal channel lined with gravel or riprap having side slopes steeper than 3:1, the side slope stability based on the angle of repose must be considered (Chart 19). In this situation, considering both shear stress and angle of repose concepts, the required rock size for the side slopes would be:

$$(D_{50})_{sides} = (K_1 / K_2)\ (D_{50})_{bottom} \tag{5-14}$$

where:

D_{50} = Mean riprap size, ft
K_1 = Ratio of shear stresses on the sides and bottom of a trapezoidal channel (see Chart 17)
K_2 = Ratio of tractive force on the sides and bottom of a trapezoidal channel (see Chart 18)

Flow around bends also creates secondary currents which impose higher shear stresses on the channel sides and bottom compared to straight reaches. Areas of high shear stress in bends are illustrated in Figure 5-5.

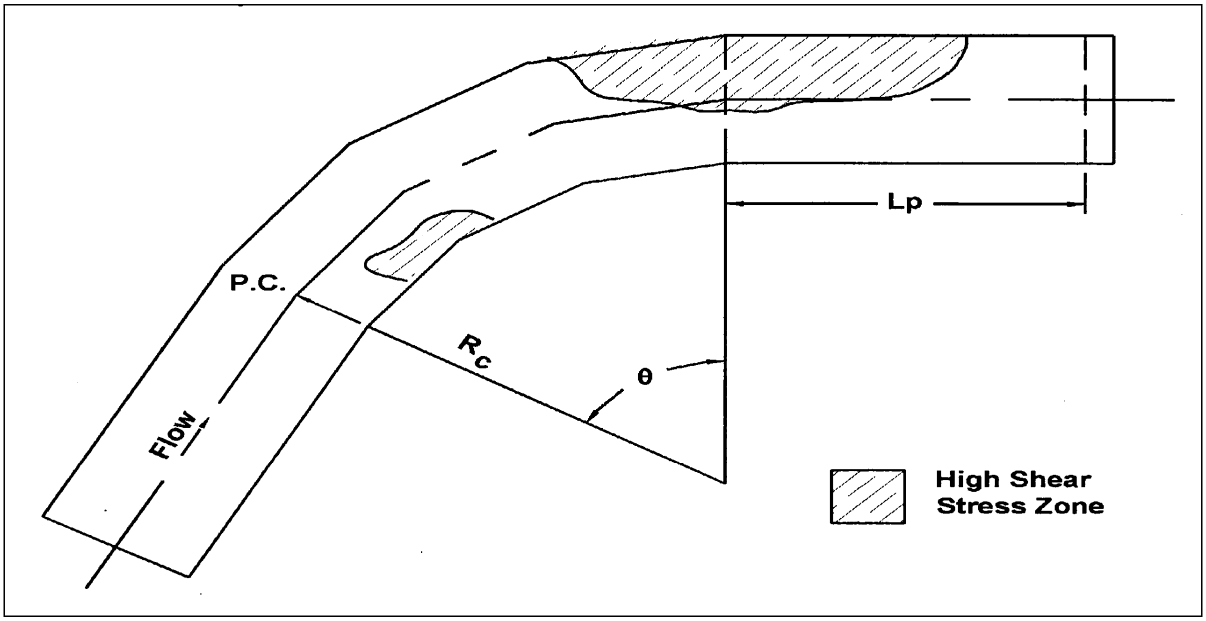

Figure 5-5. Shear stress distribution in channel bends.

The maximum shear stress in a bend is a function of the ratio of channel curvature to bottom width. This ratio increases as the bend becomes sharper and the maximum shear stress in the bend increases. The bend shear stress can be computed using the following relationship:

$$\tau_b = K_b\ \tau_d \tag{5-15}$$

where:

τ_b = Bend shear stress, Pa (lb/ft^2)
K_b = Function of R_c/B (see Chart 21)
R_c = Radius to the centerline of the channel, m (ft)
B = Bottom width of channel, m (ft)
τ_d = Maximum channel shear stress, Pa (lb/ft^2)

The increased shear stress produced by the bend persists downstream of the bend a distance L_p, as shown in Figure 5-5. This distance can be computed from Chart 20 or by using the following relationship:

$$L_p = (K_u R^{7/6}) / n_b \tag{5-16}$$

where:

L_p = Length of protection (length of increased shear stress due to the bend) downstream of the point of tangency, m (ft)
n_b = Manning's roughness in the channel bend
R = Hydraulic radius, m (ft)
K_u = 0.736 (0.604 in English Units)

Example 5-2

Given: *A trapezoidal channel with the following characteristics:*

S_o = 0.01 m/m (ft/ft) B = 0.90 m (3.0 ft)
z = 3
Lining = *turf reinforcement mat as described in Example 5-1with n = 0.030.*

The channel reach consists of a straight section and a 90 degree bend with a centerline radius of 4.5 m (14.8 ft). The design discharge is 0.80 m^3*/s (28.2 ft*^{3}*/s).*

Find: *The maximum shear stress in the straight reach and in the bend.*

Solution:

SI Units	***English Units***
Step 1. Compute channel parameters.	*Step 1. Compute channel parameters.*
$Qn = (0.80)(0.030)$ $= 0.024\ m^3/s$	$Qn = (28.2)(0.030)$ $= 0.85\ ft^3/s$
From (Chart 14A) $d/B = 0.38$ $d = B\ d/B$ $= (0.9)(0.38)$ $= 0.34\ m$	*From (Chart 14B)* $d/B = 0.38$ $d = B\ d/B$ $= (3.0)(0.38)$ $= 1.1\ ft$
Step 2. Compute maximum shear stress in straight reach.	*Step 2. Compute maximum shear stress in straight reach.*
$\tau_d = \gamma dS$ $= (9810)(0.34)(0.01)$ $= 33.4\ Pa$	$\tau_d = \gamma dS$ $= (62.4)(1.1)(0.01)$ $= 0.69\ lb/ft^2$

Step 3. Compute shear stress in bend.

$R_c/B = (4.50)/(0.90)$
$= 5.0$

From Chart 21
$K_b = 1.6$

Using Equation 5-15
$\tau_b = K_b\, \tau_d$
$= (1.6)\,(33.4)$
$= 53.4\ Pa$

Step 3. Compute shear stress in bend.

$R_c/B = (14.8)/(3.0)$
$= 4.93$

From Chart 21
$K_b = 1.55$

Using Equation 5-15
$\tau_b = K_b\, \tau_d$
$= (1.55)\,(0.69)$
$= 1.07\ lb/ft^2$

5.2 Design Parameters

Parameters required for the design of roadside and median channels include discharge frequency, channel geometry, channel slope, vegetation type, freeboard, and shear stress. This section provides criteria relative to the selection or computation of these design elements.

5.2.1 Discharge Frequency

Roadside and median drainage channels are typically designed to carry 5- to 10-year design flows. However, when designing temporary channel linings a lower return period can be used; normally a 2-year return period is appropriate for the design of temporary linings.

5.2.2 Channel Geometry

Most highway drainage channels are trapezoidal in shape. Several typical shapes with equations for determining channel properties are illustrated in Figure 5-6. The channel depth, bottom width, and top width must be selected to provide the necessary flow area. Chart 22 provides a nomograph solution for determining channel properties for trapezoidal channels.

Channel side slopes for triangular or trapezoidal channels should not exceed the angle of repose of the soil and/or lining material, and should generally be 1V:3H or flatter.(34) In areas where traffic safety may be of concern, channel side slopes should be 1V:4H or flatter. Design of roadside and median channels should be integrated with the highway geometric and pavement design to insure proper consideration of safety and pavement drainage needs.

5.2.3 Channel Slope

Channel bottom slopes are generally dictated by the road profile or other constraints. However, if channel stability conditions warrant, it may be feasible to adjust the channel gradient slightly to achieve a more stable condition. Channel gradients greater than 2% may require the use of flexible linings to maintain stability. Most flexible lining materials are suitable for protecting channel gradients of up to 10%, with the exception of some grasses. Linings, such as riprap and wire-enclosed riprap are more suitable for protecting very steep channels with gradients in excess of 10%. Rigid linings, such as concrete paving, are susceptible to failure from structural instability due to such occurrences as overtopping, freeze thaw cycles, swelling, and excessive soil pore water pressure.

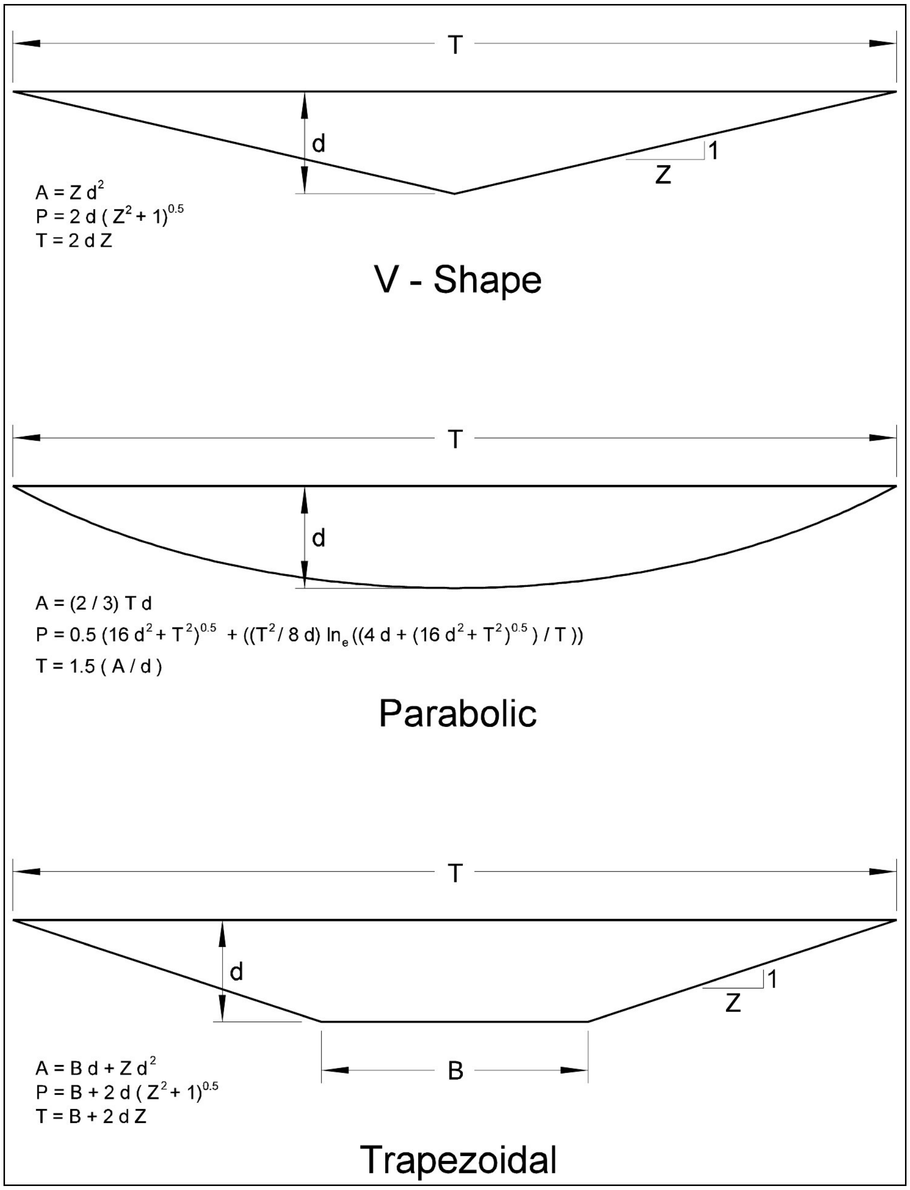

Figure 5-6. Channel geometries.

5.2.4 Freeboard

The freeboard of a channel is the vertical distance from the water surface to the top of the channel. 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, superelevation changes, or fluctuations in water surface from overflowing the sides. In a permanent roadside or median channel, about 150 mm (0.5 ft) of freeboard is generally considered adequate. For temporary channels no freeboard is necessary. However, a steep gradient channel should have a freeboard height equal to the flow depth to compensate for the large variations in flow caused by waves, splashing, and surging.

5.3 Stable Channel Design

Stable channel design concepts provide a means of evaluating and defining channel configurations that will perform within acceptable limits of stability. For most highway drainage channels, bank instability and lateral migration cannot be tolerated. Stability is achieved when the material or the channel lining forming the channel boundary effectively resists the erosive forces of the flow. Principles of rigid boundary hydraulics can be applied to evaluate this type of system.

HEC-15(34) provides a detailed presentation of stable channel design concepts related to the design of roadside and median channels. This section provides a brief summary of significant concepts.

5.3.1 Lining Materials

Lining materials may be classified as flexible or rigid. Flexible linings are able to conform to changes in channel shape and can sustain such changes while maintaining the overall integrity of the channel. In contrast, rigid linings cannot change shape and tend to fail when a portion of the channel lining is damaged. Channel shape may change due to frost-heave, slumping, piping, etc. Typical flexible lining materials include grass and riprap while a typical rigid lining material is concrete. Flexible linings are generally less expensive, have a more natural appearance, and are typically more environmentally acceptable. However, flexible linings are limited in the erosive forces they can sustain without damage to the channel and lining. A rigid lining can typically provide higher capacity and greater erosion resistance and in some cases may be the only feasible alternative.

Flexible linings can be either long-term, transitional or temporary. Long-term flexible linings are used where the channel requires protection against erosion for the life of the channel. Long-term lining materials include vegetation, cobbles, rock riprap, wire-enclosed riprap, and turf reinforcement. Transitional flexible linings are used to provide erosion protection until a long-term lining, such as grass, can be established. Temporary channel linings are used without vegetation to line channels that might be part of a construction site or some other short-term channel situation. Turf reinforcement can serve either a transitional or long-term function by providing additional structure to the soil/vegetation matrix. Typical turf reinforcement materials include gravel/soil mixes and turf reinforcement mats (TRM's). A TRM is a non-degradable rolled erosion control product (RECP) processed into a three-dimensional matrix. A TRM is stiffer, thicker and denser than an erosion control blanket (ECB), which is typically a degradable RECP composed of an even distribution of natural or polymer fibers bound together to form a continuous mat. Open-weave textiles (OWT) are a degradable RECP composed of natural or polymer yarns more loosely woven into a matrix. RECP's are laid in the channel and secured with staples or stakes.

Construction of rigid concrete linings requires specialized equipment and costly materials. As a result the cost of rigid linings is typically high. Prefabricated linings can be a less expensive alternative if shipping distances are not excessive. Interlocking concrete paving blocks are a typical prefabricated lining.

In general, when a lining is needed, the lowest cost lining that affords satisfactory protection should be used. In humid regions, this is often vegetation used alone or in combination with other types of linings. Thus, a channel might be grass-lined on the flatter slopes and lined with more resistant material on the steeper slopes. In cross section, the channel might be lined with a highly resistant material within the depth required to carry floods occurring frequently and lined with grass above that depth for protection from the rare floods.

5.3.2 Stable Channel Design Procedure

Two methods have been commonly used in stable channel design: the permissible velocity approach and the permissible tractive force (shear stress) approach. Under the permissible velocity approach the channel is assumed stable if the adopted mean velocity is lower than the maximum permissible velocity for the given channel boundary condition. Similarly, the tractive force approach requires that the shear stresses on the channel bed and banks do not exceed the allowable amounts for the given channel boundary. Permissible velocity procedures were first introduced around the 1920s and have been developed and widely used by the Soil Conservation Service, now the Natural Resource Conservation Service. Tractive force procedures based on shear stress concepts originated largely through research by the Bureau of Reclamation in the 1950s. Based on the actual physical processes involved in maintaining a stable channel, specifically the stresses developed at the interface between flowing water and materials forming the channel boundary, the tractive force procedure is a more realistic model and was adopted as the preferred design procedure for flexible linings in Hydraulic Engineering Circular Number 15(34).

The definition and equations for computing the average and maximum shear stress in a channel were provided above in Section 5.1.7. When the permissible shear stress is greater than or equal to the computed shear stress, the lining is considered acceptable.

$$\tau_p \geq SF\,\tau_d \tag{5-2}$$

where:

τ_p = Permissible shear stress for the channel lining, N/m^2 (lb/ft^2)
SF = Safety factor

The safety factor provides for a measure of uncertainty and failure tolerance, and typically ranges from 1.0 to 1.5.

Flexible linings act to reduce the shear stress on the underlying soil surface. Therefore, the erodibility of the underlying soil is a key factor in the performance of flexible linings. Erodibility of non-cohesive soils (plasticity index less than 10) is mainly due to particle size, while cohesive soils is a function of cohesive strength and soil density. Vegetative and RECP lining performance relates to how well they protect the underlying soil from shear stress, and so these lining types do not have permissible shear stresses independent of soil type. The basic procedure for designing a flexible lining consists of the following steps, which are summarized in Figure 5.7:

Step 1. Determine a design discharge, Q, and select the channel slope and channel shape.

Step 2. Select a trial lining type. Initially, the designer may need to determine if a long-term lining is needed and whether or not a temporary or transitional lining is required. For determining the latter, the trial lining type could be chosen as the native material (unlined), typically bare soil. For example, it may be determined that the bare soil is insufficient for a long-term solution, but vegetation is a good solution. For the transitional period between construction and vegetative establishment, analysis of the bare soil will determine if a temporary lining is prudent.

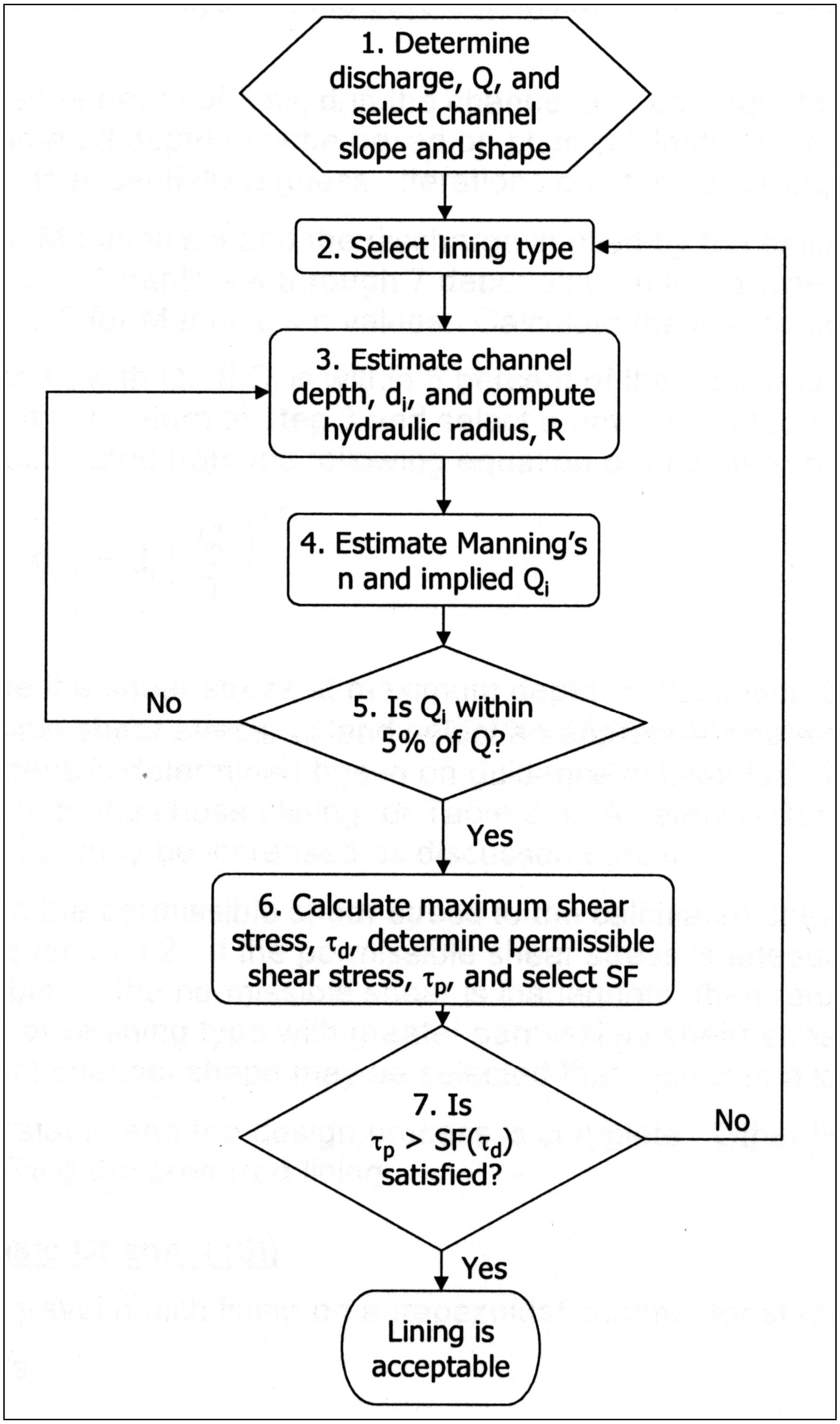

Figure 5-7. Flexible channel lining design flow chart (from HEC-15[34]).

Step 3. Estimate the depth of flow, d_i in the channel and compute the hydraulic radius, R. The estimated depth may be based on physical limits of the channel, but this first estimate is essentially a guess. Iterations on Steps 3 through 5 may be required.

Step 4. Estimate Manning's n and the discharge implied by the estimated n and flow depth values. Calculate the discharge (Q_i).

Step 5. Compare Q_i with Q. If Q_i is within 5 percent of the design, Q, then proceed on to Step 6. If not, return to Step 3 and select a new estimated flow depth, d_{i+1}. This can be estimated from the following equation or any other appropriate method.

$$d_{i+1} = d_i \left(Q/Q_i\right)^{0.4}$$

Step 6. Calculate the shear stress at maximum depth, τ_d (Equation 5.1), determine the permissible shear stress, τ_p, according to the methods described in HEC-15 and select an appropriate safety factor.

Step 7. Compare the permissible shear stress to the calculated shear stress from Step 6 using Equation 5.2. If the permissible shear stress is adequate then the lining is acceptable. If the permissible shear is inadequate, then return to Step 2 and select an alternative lining type with greater permissible shear stress. As an alternative, a different channel shape may be selected that results in a lower depth of flow.

The selected lining is stable and the design process is complete. Other linings may be tested, if desired, before specifying the preferred lining.

HEC-15 details the tractive force stable channel design procedure for vegetative linings, RECP's, riprap/cobble, and gabion linings. Information on special considerations for steep-slope riprap design and design of composite linings is also included.

5.4 Generalized Design Procedure for Roadside and Median Channels

This section presents a generalized procedure for the design of roadside and median channels. Although each project will be unique, the design steps outlined below will normally be applicable.

Step 1. Establish a Preliminary Drainage Plan

Development of a preliminary drainage concept plan is discussed in Section 2.6. For proposed median or roadside channels, the following preliminary action should be taken:

A. Prepare existing and proposed plan and profile of the proposed channels. Include any constraints on design such as highway and road locations, culverts, utilities, etc.

B. Determine and plot on the plan the locations of natural basin divides and channel outlet points.

C. Collect any available site data such as soil types and topographic information.

Step 2. Obtain or Establish Cross Section Data

Establish preliminary cross section geometric parameters and controlling physical features considering the following guides:

A. Adequate channel depth should be provided to drain the subbase and minimize freeze-thaw.

B. Channel side slopes based on geometric design criteria including safety, economics, soil, aesthetics, and access should be chosen.

Step 3. Determine Initial Channel Grades

Plot initial grades on the plan and profile. Note that slopes on roadside channels in cuts are usually controlled by highway grades. Use the following guides when establishing initial grades:

A. Provide a channel slope with sufficient grade to minimize ponding and sediment accumulation.

B. Where possible, avoid features which may influence or restrict grade, such as utility structures.

Step 4. Check flow Capacities and Adjust Sections as Necessary

A. Compute the design discharge at the downstream end of channel segments (see Chapter 3).

B. Set preliminary values for channel size, roughness, and slope, based on long term conditions and considering maintenance.

C. Determine the maximum allowable depth of channel including freeboard.

D. Check the flow capacity using Manning's equation (Equation 5-5; Chart 1 for V-shaped channels and Chart 14 for Trapezoidal Channels).

E. If the capacity is not adequate, possible considerations for increasing the capacity are provided below.

   - Increase bottom width
   - Make channel side slopes flatter
   - Make channel slope steeper
   - Provide smoother channel lining
   - Install drop inlets and a parallel storm drain pipe beneath the channel to supplement channel capacity

Step 5. Determine Channel Protection Needed

Follow the procedure outlined in Figure 5.7 to complete final design on any reaches requiring a lining for stability.

Step 6. Check Channel Transitions and End of Reach Conditions

Channel transition include locations where there are changes in cross section, slope, discharge, and/or roughness. At these locations, the gradually varying flow assumption may be violated, and a more detailed hydraulic evaluation may be required.

A. Identify transition locations.

B. Review hydraulic conditions upstream and downstream of the transition (flow area, depth, and velocity). If significant changes in these parameters are observed, perform additional hydraulic evaluations to determine flow conditions in the vicinity of the transition. Use the energy equation presented in Equation 5-2 or other information in References 7 and 31 through 35 to evaluate transition flow conditions.

C. Provide for gradual channel transitions to minimize the possibility for sudden changes in hydraulic conditions at channel transitions.

Step 7. Analyze Outlet Points and Downstream Effects

A. Identify any adverse impacts to downstream properties which may result from one of the following at the channel outlets:

- Increase or decrease in discharge
- Increase in flow velocity
- Confinement of sheet flow
- Change in outlet water quality
- Diversion of flow from another watershed

B. Mitigate any adverse impacts identified in 7A. Possibilities in order relative to above impacts include:

- Enlarge outlet channel and/or install control structures to provide detention of increased runoff in channel (see Chapter 8)
- Install velocity control or energy dissipation structure (see Reference 35)
- Increase capacity and/or improve lining of downstream channel
- Install sophisticated weirs or other outlet devices to redistribute concentrated channel flow
- Eliminate diversions which result in downstream damage and which cannot be mitigated in a less expensive fashion

To obtain the optimum roadside channel system design, it may be necessary to make several trials of the above procedure before a final design is achieved.