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United States  
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# Part 650

## Engineering Field Handbook

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# Chapter 9

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# Diversions

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# Chapter 9

# Diversion

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**650.0900 Introduction**

A diversion is a channel with a supporting ridge on the lower side constructed across the slope (fig. 9–1). Diversions are used for one or more of the following purposes to:

- divert water away from active gullies or critically eroding areas.
- supplement water management on conservation cropping or strip cropping systems.
- break up concentrations of water on long, gentle slopes and on undulating or warped land surfaces that are generally considered too flat or irregular for terracing.
- divert water away from farmsteads, agricultural waste systems, and other improvements.
- collect or direct water for water-spreading or water-harvesting systems.
- increase or decrease the drainage area above ponds.
- protect terrace systems by diverting water from the top terrace where topography, land use, or landownership prevents terracing the land above.
- intercept surface and shallow subsurface flow.
- protect flat lands from upland runoff and overland flow from adjacent areas.
- control runoff and erosion on urban or developing areas, construction sites, and surface mine sites.
- act as a grass filter for reducing sediment in runoff waters when vegetated.

Diversions are frequently constructed with grass or other vegetation liners. The permissible velocity approach to diversion design presented in the previous version of this chapter was documented in SCS TP–61, published in 1947 and revised in 1954 (USDA SCS 1954) and used for the design of diversions throughout the remainder of the 20th century. Since the development of the permissible velocity approach and procedure, additional research has led to a more in-depth understanding of the interaction of the flow with the vegetated boundary of a grass-lined channel,

and the computer has allowed more extensive calculations to be easily carried out when needed. These advances led to the documentation of an erosionally effective stress approach to grass-lined channel design documented in USDA Agriculture Handbook #667 (AH–667) (Temple et al. 1987). This approach, which also incorporates more general stable channel design concepts and data, has been successfully integrated into the software used by NRCS for design of vegetated earth spillways and is being used for design of other grass-lined channels. Incorporation of the allowable effective stress approach into the NRCS Engineering Field Handbook (EFH) allows additional design flexibility through separation of the effects of soil and vegetal parameters and makes the procedures used for waterway and diversion design consistent with those used for other grass-lined and unlined channels. Procedures used in this chapter are the same as those used in the EFH650.07, Grassed Waterways.

**Figure 9-1** Typical diversion



## 650.0901 Assessment of suitability

### (a) General considerations

A preliminary site investigation is recommended to determine the feasibility of constructing a diversion. Such an investigation includes the study of resource information such as soil maps, aerial photography, contour maps, and visual examination of potential alignments. Sufficient information to determine the runoff characteristics related to soils, as described in EFH650.02 of this handbook, is needed. If the channel is not to have a rigid liner, then sufficient soils information to determine allowable effective stress is also needed. Aerial photography combined with visual examination of the proposed location will aid in determining if the terrain is suitable and in determining if there are any structures or other obstacles that would make the project not feasible. Topographic information that is sufficiently detailed to determine the slopes along the proposed alignments, lengths, and slopes required for design discharge determination and sufficient data to estimate the amount of cut or fill required for the type of diversion being proposed is also necessary.

The preliminary investigation should provide enough information to select a final alignment. If possible, consider more than one location and select an alternative which is the most practical, aesthetic, and causes the least disturbance to the existing landscape. Consider outlet conditions, topography, vegetation, land use, cultural activities, visual quality, soil type, length of slope, and natural features.

### (b) Legal/regulatory considerations

Applicable local, State, and Federal laws governing the diversion of water must be followed in planning, design, and installing a diversion. Permits are the responsibility of the owner/sponsor, when required. The landowner is required to contact the utility companies or one-call system to determine the exact location of underground services.

## 650.0902 Planning and preliminary design considerations

### (a) Type of diversion

There are three basic types of diversions: ridge diversions, channel diversions, and combination diversions. The ridge diversion (fig. 9–2) is located at the upper edge of a steeper slope to divert water from flowing down the slope. This type of diversion is constructed by placing fill to form a ridge, which creates a channel. The depth is measured from the bottom of the channel to the top of the ridge.

The channel diversion (fig. 9–3) is usually located at the base of a slope. It is constructed by excavating a channel. The spoil is spread or disposed of and is not used to form the channel. The depth is measured from the bottom of the channel to the low bank.

The combination type diversion (fig. 9–4) is constructed by pushing material from the channel to form a ridge. The depth is measured from the channel bottom to the top of the ridge.

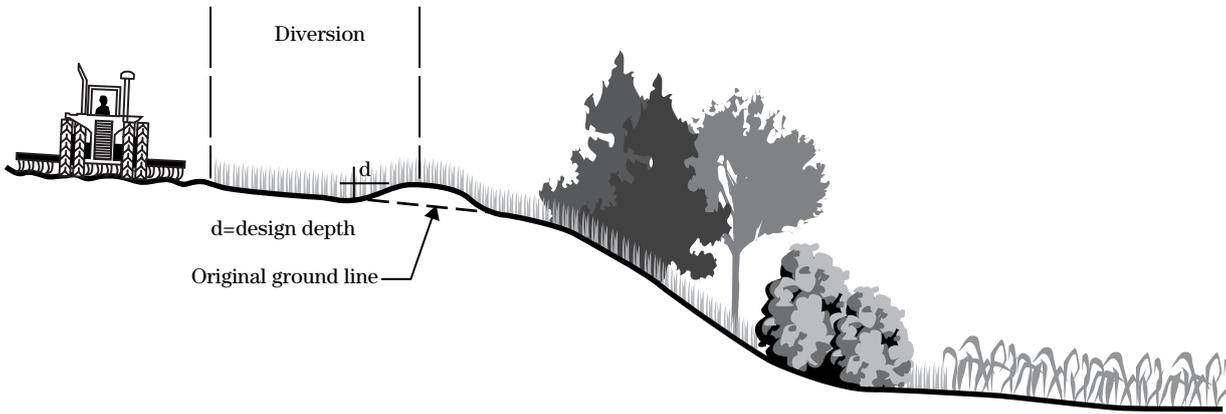
Diversions used to intercept shallow subsurface flows in addition to surface runoff have a location and depth of cut based on the location of the seepage. Exploratory soil borings usually are required to determine the location of interceptors. Refer to the local drainage guide or field office technical guide for additional information on the use of diversions for subsurface drainage. Subsurface drains may be needed in conjunction with this type of diversion.

### (b) Location

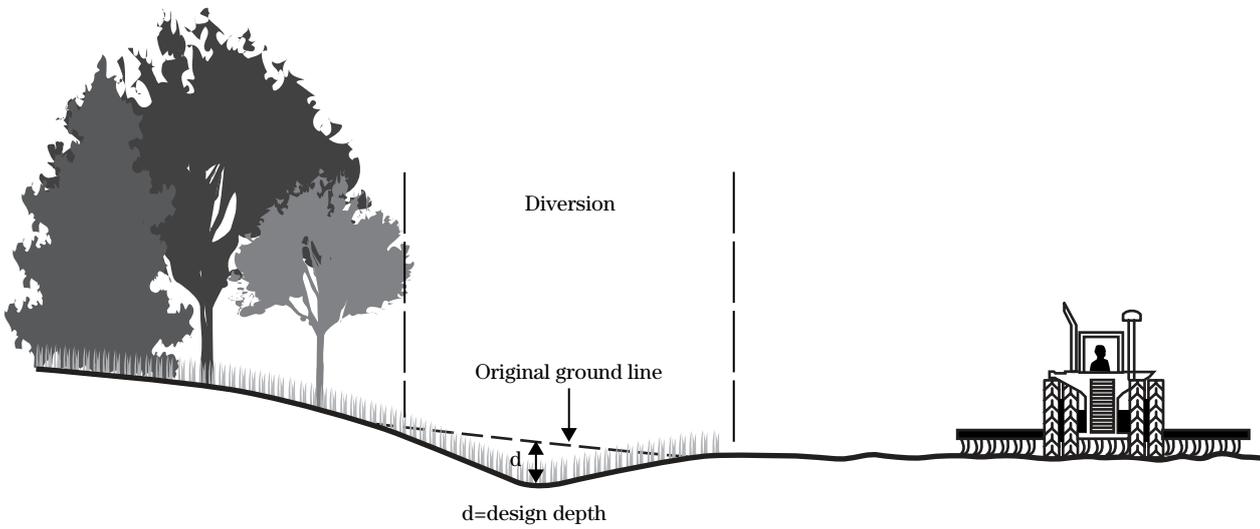
If a diversion is to be constructed to protect cropland from the runoff from grassland or forestland, it should be built close to the boundary between the land uses. This is especially applicable where a vegetated diversion is also to be used for hayland, pasture, or range.

If water is being diverted away from the head of a gully, it is important that the diversion be located a sufficient distance from the head of the gully overfall so

**Figure 9-2** Ridge diversion



**Figure 9-3** Channel diversion



that stable slopes will exist after bank sloping and expected sloughing has taken place.

Diversions should be located so that the outlet is stable and empties on established disposal areas, natural outlets, grassed waterways, underground outlets, or water detention facilities for water conservation.

If diversions are used to protect flatland from upland runoff, they should be located at or near the base of the upland slope to divert the water before it can spread over the flat bottomland and so that the constructed side slopes blend into existing slopes or topography.

Finally, the alignment should be located so as not to damage important landscape elements, such as unique trees, geologic formations, or scenic features. The slope of the diversion should not interfere with adjacent land uses. Shallower and broader designs usually blend in better and are less disruptive.

### (c) Slope

The bed slope of the diversion should be selected to meet velocity, capacity, and lining requirements for the site. Variable grades may be needed to obtain more uniform cross sections and improve alignment. Refer

to applicable local guides and standards for recommended diversion grades and conditions under which they are applicable.

Once a slope is selected, modifications may be necessary; for example:

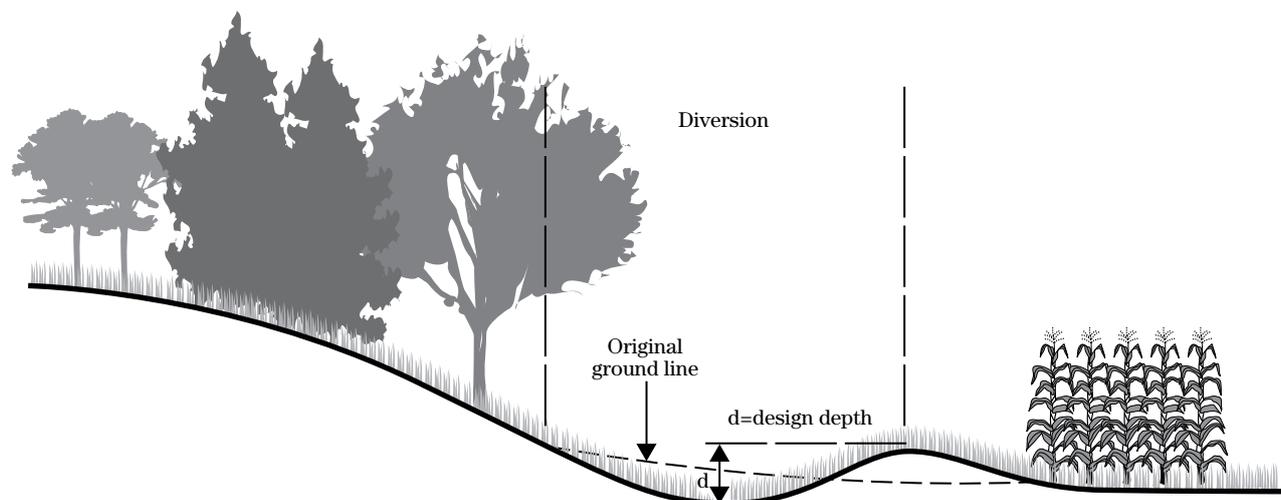
- If it is not possible to find an appropriately sized stable section, it may be necessary to construct the diversion on a flatter bed slope.
- If it is not possible to obtain adequate capacity under a depth and/or width limitation, then a steeper bed slope is needed.

Final grades should be selected that meet capacity and stability requirements. When permanently vegetated diversions are used to manage or convey storm water, the grade of the channel should be such as to minimize standing water or wetness problems.

### (d) Velocities

Diversions should be planned and designed to the conditions of a particular site. If the diversion is grass- or earth-lined, the velocities to be expected will be determined by the allowable soil effective stress and the properties of the vegetation.

**Figure 9-4** Combination diversion



If the diversion is to have a rigid liner, velocities should be limited so they do not represent a hazard to humans or animals. In all cases, the velocities in the diversion should not be a source of potential property damage downstream of the diversion.

### (e) Cross-section shape

The land slope where the diversion is to be constructed must be taken into consideration when choosing a channel cross section. On the steeper slopes, narrow and deep channels may be required to reduce earth-moving quantities. However, if the diversion is to be vegetated or unlined, there may be a limit to how steep and deep it can be and still meet allowable effective stress criteria for stability. Broad, shallow channels usually are applicable on the more gentle slopes. The wide, shallow section will be easier to cross with equipment. If placed through woodland, narrow channels will generally be less damaging to vegetation. The minimum stable channel width and depth will be determined by the bed slope, type of vegetal lining, and soil conditions. Locations with steeper slopes, poorer vegetal cover, and more erodible material will require greater widths for stability.

A typical diversion cross section consists of a channel and a supporting ridge. The channel may be parabolic, trapezoidal, or V shaped (fig. 9-5). Several factors are considered when selecting the type of channel cross section.

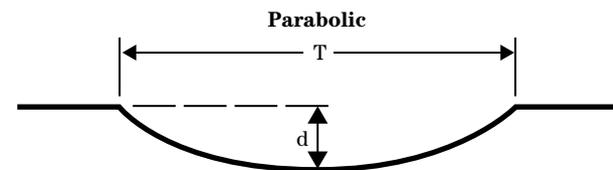
The type of land use is a factor in choosing cross section shape. In agricultural areas, the diversion dimensions should be adapted to farming equipment. Diversions which are easy to cross with equipment will be easier to maintain. Steep back diversions are not designed to be crossed by equipment and should be maintained in grass or woody vegetation. Diversions associated with residential developments or recreation areas should be designed to be safe and unintrusive.

The type of equipment available for construction should also be considered. For example, a tractor and blade or bulldozer is often used to shape a parabolic channel, and motor graders are more suitable for trapezoidal or V-type channels.

### (f) Vegetation

The possible future condition of the vegetative lining based on natural succession and maintenance should always be considered. In some cases, the expected stand of vegetation is not attained, and frequently the vegetative stand will deteriorate under normal maintenance. Therefore, it is necessary to check the diversion design for stability against erosion. For example, assume that a diversion is to be built in a clay soil.

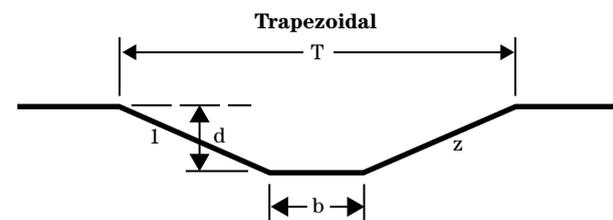
**Figure 9-5** Typical diversion cross sections



Cross-sectional area (A) =  $\frac{2}{3} TD$

Design top width (T) =  $\frac{1.5A}{d}$

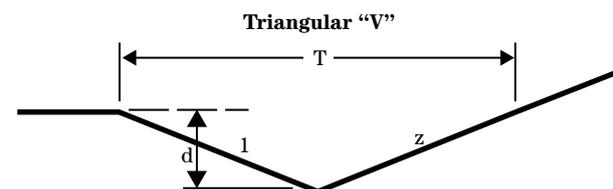
Hydraulic radius (R) =  $\frac{2dT^2}{3T^2 + 8d^2}$



Cross-sectional area (A) =  $bd + zd^2$

Design top width (T) =  $b + 2dz$

Hydraulic radius (R) =  $\frac{A}{b + 2d\sqrt{z^2 + 1}}$



Cross-sectional area (A) =  $zd^2$

Design top width (T) =  $2dz$

Hydraulic radius (R) =  $\frac{A}{2d\sqrt{z^2 + 1}}$

d = design depth  
T = design top width  
b = design bottom width  
z = side slope ratio

The vegetation to be established with a good stand will produce a relatively high value of retardance curve index, which is a measure of the resistance to flow produced by the vegetation. However, with the diversion located on a pasture or range site that may be heavily grazed at times, the stand can be reduced to “fair,” and the curve index will decrease. A vegetated channel should be evaluated for stability based on the curve index and vegetal cover factor that represents the poorest expected condition of the vegetation and evaluated for capacity with the maximum expected retardance curve index.

### (g) Sediment control

Any high sediment-producing area above a diversion should be controlled by good land use management or by structural measures to prevent accumulation of damaging sediment in the diversion channel. Where it is not possible or desirable to establish land treatment measures on the watershed area above the diversion, the channel depth must be increased to provide for sediment storage or provisions made for prompt and frequent maintenance. Designing the channel with velocity and erosionally effective stress near the allowable values will maximize sediment transport capability.

### (h) Outlets

All diversions must have stable outlets. If the diversion outlets at excessive velocities or on overfalls, erosion can proceed up the diversion channel. Suitable outlets for diversions include grassed areas, waterways, ponds, grade stabilization structures, and underground outlets.

### (i) Data collection

#### (1) Engineering surveys

Survey reports for diversions normally consist of field notes for diversion design, layout, and construction. Samples are shown in Soil Conservation Service

Technical Release Number 62, Engineering Layout, Notes, Staking, and Calculations. Such notes are satisfactory if drainage areas are small, topography is relatively uniform, and elevation differences with respect to other structures are not significant. Standard forms or data sheets approved for field offices may be used to record field notes for diversions.

#### (2) Hydrologic investigations

Information on watershed area, design storm frequency and duration, and runoff estimates are important in determining the capacity of a diversion. Typically, the minimum storm frequency and duration is defined by conservation practice standards.

The watershed area should be determined at the outlet of the diversion and at other points where it may be desirable to change the grade or cross section size. The peak runoff in units such as cubic feet per second should be computed at each design point for the frequency and duration storm selected. Refer to chapter 2 of the EFH for procedure.

#### (3) Soils investigations

Determine the types of soil textures that will be encountered along the diversion. Soil textures are needed to determine allowable soil effective stress for stability assessment of bare soil and vegetated channels. Sufficient soil information to set an appropriate Manning's  $n$  value is needed for capacity design of earth-lined diversions.

For stability design, the erodibility of the soil must be determined. If the relative erodibility class of the soil is not known, the allowable erosionally effective stress may be determined from soil properties. For cohesive soils, the unified soil classification, plasticity index, and void ratio are needed. With noncohesive soils, the unified classification and particle size,  $d_{75}$ , are required.

## 650.0203 Design of diversions

### (a) Capacity and stability

The minimum capacity should be that required to convey the peak runoff from the design storm plus required freeboard (table 9–1). The design storm and freeboard should comply with minimum criteria as defined in the applicable conservation practice standard. Note that application of the stability and capacity design methods in this chapter or in EFH650.07 yield the minimum depth that provides adequate capacity. The freeboard then represents additional depth above the minimum that is added to provide a factor of safety or to satisfy any applicable regulations. It should not be assumed that the diversion is still stable with the addition of additional depth in the form of freeboard. An analysis should be completed for all final cross sections.

The design of vegetative linings for capacity and stability should be in accordance with the principles given in EFH650.07 or the publication *Stability Design of Grass-Lined Open Channels* (AH-667).

Consider the type and growth habits of the vegetative lining and the expected quality of the stand to be obtained. This determines the retardance curve index to be used for designing for capacity. Tables 9–2 and 9–3 can be used as guides in determining vegetal parameters for design. If variations in the height and density of vegetation are expected throughout the year, stability should be assessed using the retardance curve index and vegetal cover factor representing the sparsest vegetation, and capacity should be assessed using the curve index for the densest, longest vegetation. If there is not sufficiently detailed information about the vegetation to compute the curve index, a satisfactory design can generally be obtained by assuming retardance class D for stability design and retardance class B for capacity design (table 9–3). If the stand is expected to be poor during all seasons or if the vegetation is to be well-maintained by mowing, retardance class C may be used for capacity design.

**Table 9–1** Recommended design frequency and freeboard requirement

Diversion type	Typical area of protection	24-hour design storm frequency (years)	Minimum freeboard required (ft)
Temporary	Construction areas (structures, roads, pipelines, etc.)	2	None
	Building sites	5	None
	Agricultural land	10	None
	Surface mine reclamation, playfields, recreation areas	10	0.3
Permanent	Agricultural buildings, pollution abatement systems, etc.	25	0.3
	Urban land area, schools, industrial buildings, etc.	50	0.5

**Table 9-2** Properties of grass channel linings; values apply to good uniform stands of each cover<sup>1/</sup>

Cover factor, $C_F$	Covers tested	Reference stem density, $M$ (stem/ft <sup>2</sup> )
0.90	bermudagrass	500
	centipedegrass	500
	buffalograss	400
0.87	kentucky bluegrass	350
	blue grama	350
	smooth bromegrass	210
0.75	grass mixture	200
	weeping lovegrass	350
	yellow bluestem	250
0.50	alfalfa <sup>2/</sup>	500
	lespedeza sericea <sup>2/</sup>	300
	common lespedeza	150
	sudangrass	50

1 Multiply the stem densities given by 1/3, 2/3, 1, 4/3, and 5/3, for poor, fair, good, very good, and excellent covers, respectively. The equivalent adjustment to  $C_F$  remains a matter of engineering judgment until more data are obtained or a more analytic model is developed. A reasonable, but arbitrary, approach is to reduce the cover factor by 20 percent for fair stands and 50 percent for poor stands.  $C_F$  values for untested covers may be estimated by recognizing that the cover factor is dominated by density and uniformity of cover near the soil surface. Thus, the sod-forming grasses near the top of the table exhibit higher  $C_F$  values than the bunch grasses and annuals near the bottom.

2 For the legumes tested, the effective stem count for resistance (given) is approximately five times the actual stem count very close to the bed. Similar adjustment may be needed for other unusually large-stemmed, branching, and/or woody vegetation.

**Table 9-3** Retardance curve index by SCS (1954) retardance class

SCS retardance class	Retardance curve index $C_1$
A	10.00
B	7.64
C	5.60
D	4.44
E	2.88

## (b) Alternative channel linings

On sites where it is impossible to establish suitable permanent vegetation or it is desired to determine the stability of the channel before establishment of vegetation or if the land is to be farmed, the design can be based on bare ground conditions. Site conditions may warrant designing the diversion with a protective lining such as riprap or concrete cellular blocks. Typically Manning's equation with an  $n$  value appropriate to the type of material is used. Flow resistance and stability of riprap can be evaluated using the methods given in EFH650.16 or the Federal Highway Administration Circular HEC-11, Design of Riprap Revetment. If concrete cellular blocks, also known as grid pavers, are used, the manufacturer typically provides  $n$  values and other design information.

Temporary geotextiles that degrade as vegetation becomes established or bank-stabilizing geotextiles intended for permanent installation may also be appropriate when establishing vegetation through conventional means is not practical. The manufacturers of these products will generally provide detailed design procedures or software that can be used to determine an appropriate channel section and bed slope to meet stability and capacity requirements.

## (c) Steps in designing a diversion

- Step 1* Plan the location and type of diversion that minimizes negative impacts.
- Step 2* Select design points along the diversion where grades change or drainage areas and type of lining change significantly.
- Step 3* Determine the watershed area for the points in step 2 and for the outlet.
- Step 4* Find the peak runoff produced by the design storm at each design point identified in step 2. Refer to EFH650.02 procedure.
- Step 5* Determine the slope of each reach of the diversion.

**Step 6** For the type of diversion to be constructed, select the appropriate channel cross section and the type of channel lining to be used; for example, bare soil, vegetation, rigid lining, or some combination.

**Step 7** Design the channel cross section for adequate capacity, typically based on the densest vegetation expected.

**Step 8** Check the design for stability by computing effective stress based on the sparsest vegetation expected. Repeating stability design computations may be necessary to complete the design if the stability check shows an inadequate design.

**Step 9** Add appurtenant structures, such as stone centers, as needed to allow for prolonged flows.

#### (d) Capacity design for diversions with concrete lining

If the diversion is to have a rigid lining, such as concrete, capacity design can be computed using Manning's formula:

$$Q = \frac{1.49}{n} AR^{\frac{2}{3}} S^{\frac{1}{2}} \quad (\text{eq. 9-1})$$

where

A = cross-sectional area

R = hydraulic radius

n = roughness coefficient

S = slope of the energy grade line (typically, the channel slope)

Table 9-4 and figure 9-5 give the formulas for A and R for trapezoidal, triangular, and parabolic sections. In table 9-4, B is bottom width, D is depth, A is area, z is side slope, and T is the width at the water surface. More details on use of Manning's formula and values for n are in EFH650.03.

If the channel is to be vegetated or unlined earth, capacity design is complicated by the fact that the cross section must be chosen that also satisfies stability criteria. Design of vegetated channels is further complicated by the fact that resistance, as represented by

Manning's n, varies with discharge and flow depth. Under most circumstances, the tabular design aids given in EFH650.07 may be used to establish appropriate dimensions.

#### (e) Stability and capacity design for diversions without rigid linings

If the diversion will not have a rigid lining, then designing a stable channel requires limiting the stress on the soil and vegetation such that soil particles will not be detached and the vegetation will not be damaged. For most soils that will be encountered in practice, soil particles will be detached before damage to the vegetation occurs. In this case, the effective stress on the soil controls channel stability. With highly erosion-resistant soils, however, the vegetation can become damaged before soil detachment occurs. The consequences of either mode of failure are similar.

##### (1) Design of stable vegetated diversions

The recommended procedure is to find the allowable stress based on the soil, then check the design based on the allowable stress on the vegetation. Allowable soil stress in pounds per square foot (lb/ft<sup>2</sup>) is a function of several soil properties. For broad categories of soils, allowable stress can be assigned using table 9-5. Alternatively, a site-specific determination of soil allowable stress can be made.

**Table 9-4** Area and hydraulic radius for typical cross sections

Shape	Area (A)	Hydraulic radius (R)
Parabolic	$\frac{2}{3}TD$	$\frac{2DT^2}{3T^2 + 8D^2}$
Trapezoid	$BD + zD^2$	$\frac{A}{B + 2D\sqrt{z^2 + 1}}$
Triangular	$zD^2$	$\frac{A}{2D\sqrt{z^2 + 1}}$

The first step in finding a site-specific allowable effective soil stress is to determine the unified soil classification of the soil in which the channel will be excavated. This information may be available from the Web Soil Survey or Soil Data Mart. Soils classified as GW, GP, SW, and SP are considered noncohesive soils. The remainder of the soils (GM, SC, GC, SM, CH, CL, MH, ML, OH, and OL) are considered cohesive soils.

For noncohesive soils, the grain size  $d_{75}$  in inches is needed to determine the allowable effective stress,  $\tau_a$ . If field testing is not available, the grain size may be estimated from data found in the Web Soil Survey or Soil Data Mart. Once the  $d_{75}$  is found, the allowable effective stress can be determined from figure 9-6 or from the equations in EFH650.07.

For cohesive soils, the following information is needed:

- plasticity index
- poid ratio

Determination of allowable stress for cohesive soils is a two-step process. The first step is to use the plasticity index to determine the basic allowable stress,  $\tau_{ab}$ . This can be estimated from figure 9-7 or by using the equations in appendix B of EFH650.07. Generally, the plasticity index can be obtained from the Web Soil Survey or the Soil Data Mart.

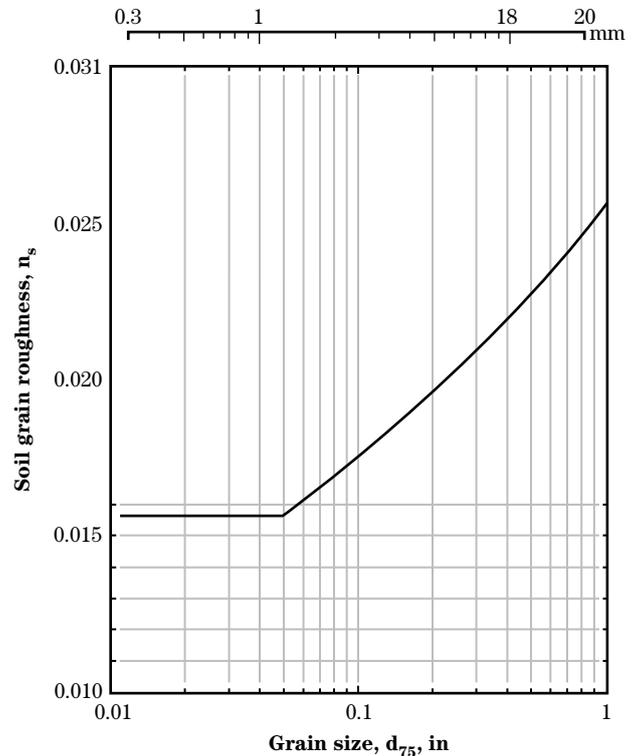
A correction is then applied based on the void ratio. The correction,  $C_e$ , is determined from figure 9-8 or from the equations in appendix B of EFH650.07. For the organic soils OH and OL,  $C_e$  is equal to 1.0. If the void ratio is not known, then table 9-6 can be used to estimate it. The final allowable effective stress is then computed as:

$$\tau_a = \tau_{ab} C_e^2 \quad (\text{eq. 9-2})$$

**Table 9-5** Allowable stress for categories of soil erodibility

Category	Allowable stress, $\tau_a$ , lb/ft <sup>2</sup>
Easily eroded	0.02
Erodible	0.03
Erosion resistant	0.05
Very erosion resistant	0.07

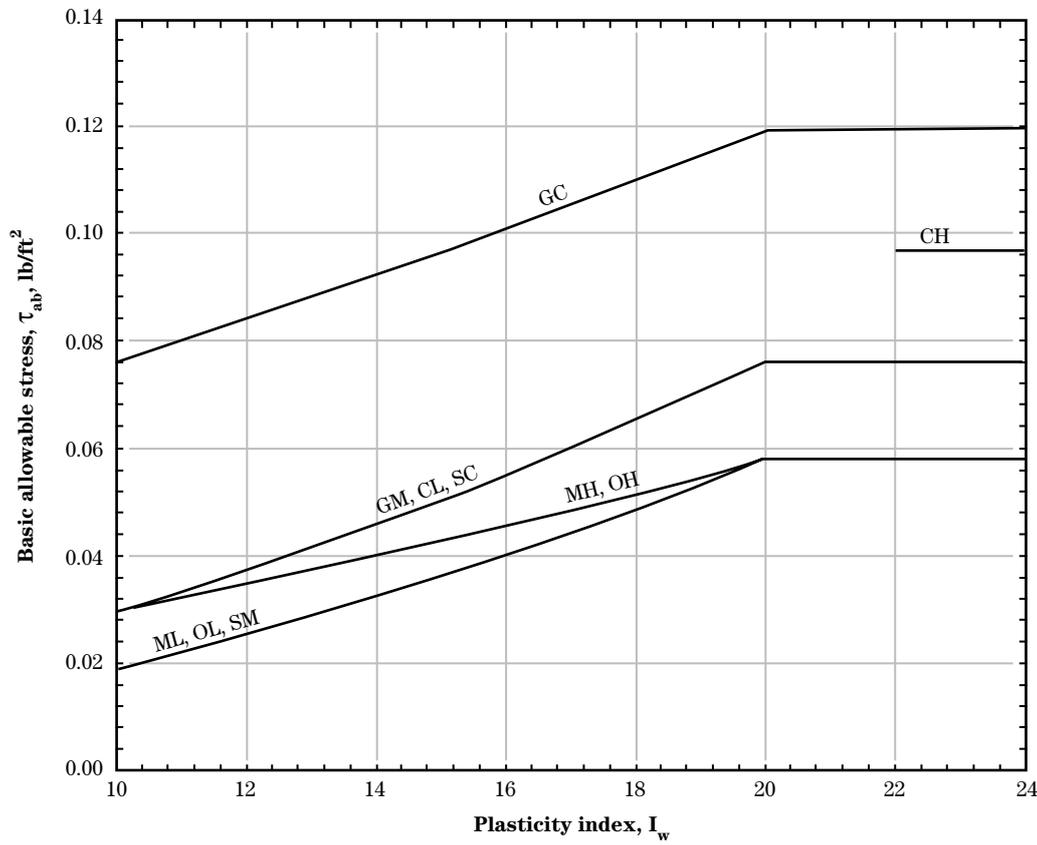
**Figure 9-6** Allowable effective stress—noncohesive soils



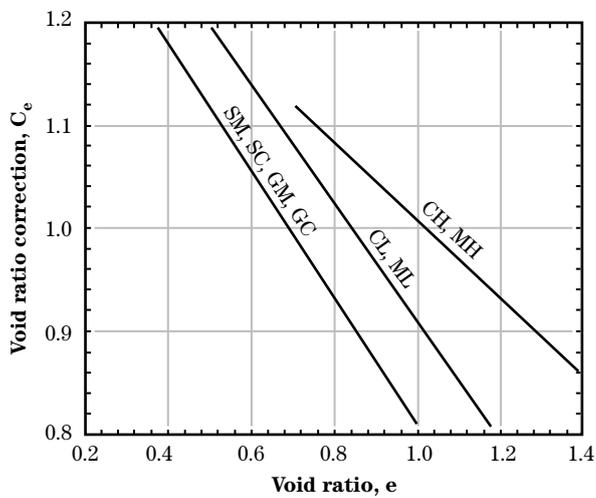
**Table 9-6** Void ratios for selected soils

Soil type (USCS)	Void ratio, e
Loose uniform sand (SW,SP)	0.80
Dense uniform sand (SW,SP)	0.45
Loose angular-grained silty sand (SM)	0.65
Dense angular-grained silty sand (SM)	0.40
Stiff clay (CL, CH)	0.60
Soft clay (CL, CH)	0.90 – 1.40
Loess (ML, CL)	0.90
Soft organic clay (CL, OL)	2.50 – 3.20
Glacial till (CL, CH)	0.30

**Figure 9-7** Basic allowable effective stress—cohesive soils



**Figure 9-8** Correction for void ratio



**Table 9-7** Classification of vegetation cover as to degree of retardance

Retardance	Cover	Condition
A	Weeping lovegrass	Excellent stand, tall (average 30 in)
	Reed canarygrass or Yellow bluestem ischaemum	Excellent stand, tall (average 36 in)
B	Smooth brome grass	Good stand, mowed (average 12 to 15 in)
	Bermudagrass	Good stand, tall (average 12 in)
	Native grass mixture (little bluestem, blue grama, and other long and short midwest grasses)	Good stand, unmowed
	Tall fescue	Good stand, unmowed (average 18 in)
	Sericea lespedeza	Good stand, not woody, tall (average 19 in)
	Grass-legume mixture Timothy, smooth brome grass, or orchardgrass	Good stand, uncut (average 20 in)
C	Reed canarygrass	Good stand, uncut (average 12 to 15 in)
	Tall fescue, with birdsfoot trefoil or ladino clover	Good stand, uncut (average 18 in)
	Blue grama	Good stand, uncut (average 13 in)
	Bahiagrass	Good stand, uncut (6 to 8 in)
	Bermudagrass	Good stand, mowed (average 6 in)
	Redtop	Good stand, headed (15 to 20 in)
	Grass-legume mixture-summer (orchardgrass, redtop, Italian ryegrass, and common lespedeza)	Good stand, uncut (6 to 8 in)
	Centipedegrass	Very dense cover (average 6 in)
	Kentucky bluegrass	Good stand, headed (6 to 12 in)
	D	Bermudagrass
Red fescue		Good stand, headed (12 to 18 in)
Buffalo grass		Good stand, uncut (3 to 6 in)
Grass-legume mixture-fall, spring (orchardgrass, redtop, Italian ryegrass, and common lespedeza)		Good stand, uncut (4 to 5 in)
Sericea lespedeza or Kentucky bluegrass		Good stand, cut to 2-in. height. Very good stand before cutting
E	Bermudagrass	Good stand, cut to 1.5-in height
	Bermudagrass	Burned stubble

Once the allowable stress is determined, the channel section can generally be designed for stability and capacity using the tables in appendices C and D of EFH650.07.

Design of a vegetated liner requires determination of the retardance class (retardance curve index) and cover factor ( $C_F$ ) of the vegetation. Tables 9-7 and 9-2 may be used to determine retardance class and cover factor. If a more detailed analysis of retardance based on specific vegetation properties (height and stem density) is needed, EFH650.07 should be consulted.

The following sections describe use of the tables for the trapezoidal and parabolic shapes typically seen in diversion design. For channel sections, slopes, discharges, or allowable stresses that are outside the ranges given in the tables, EFH650.07 should be used.

#### Example: Trapezoidal and triangular channels

Figure 9-5 shows the geometry parameters associated with a trapezoidal section. Use of the design tables in EFH650.07 requires the design discharge, bed slope, type of cover (vegetal cover factor), and soil erodibility (allowable effective stress) to be identified.

The appropriate table in appendix C or D of EFH650.07 is then selected based on capacity retardance (B or C), soil erodibility, cover factor, and side slope and is entered using the bed slope and discharge.

The trapezoidal channel design table gives the bottom width and depth (B and D), the top width of the channel is computed as:

$$T = B + 2zD \quad (\text{eq. 9-3})$$

where:

$z$  = the side slope as shown in figure 9-5

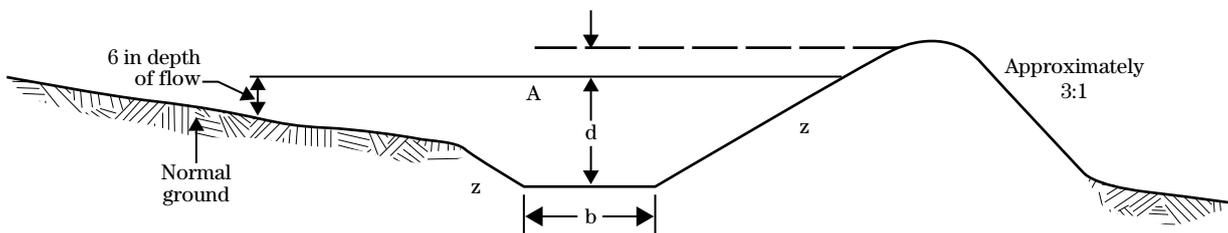
If the design is to have identical side slopes on both sides as shown in figure 9-5, then the bottom width and depth determined from the design tables can be used as is. The case wherein one side slope needs to follow the normal ground, as shown in figure 9-9, is described in 650.0903(e)(3).

#### Example: Parabolic Channels

Figure 9-5 shows the geometry parameters for a parabolic cross section. As with the trapezoid tables, the parabolic table in appendix D of EFH650.07 is also selected based on capacity retardance (B or C), soil erodibility, and cover factor and is entered using the bed slope and discharge. The parabolic design table gives the top width and depth (T and D). The parabolic channel coefficient  $a_p$  is calculated as:

$$a_p = \frac{4D}{T^2} \quad (\text{eq. 9-4})$$

**Figure 9-9** Diversion following normal hill slope



$d$  = depth of flow, ft

$b$  = bottom width of channel, ft

$A$  = channel capacity,  $\text{ft}^2$ , including area below 0.5-ft freeboard and excluding any area less than 0.5 ft depth of flow

$z$  = side slope of channel (horizontal to vertical)

Side slope at the water's edge; i.e., point where the water surface meets the channel bank, is computed as:

$$Z = \frac{T}{4D} \quad (9-5)$$

If this side slope is steeper than 6H:1V, modification to the design may be needed, depending on mowing and maintenance requirements.

If a detailed shape of the parabolic cross section is desired, the parabolic channel coefficient can be computed using equation 9-2. Distance – elevation data can then be computed as:

$$\text{Elev} = a_p (\text{distance})^2 \quad (\text{eq. 9-6})$$

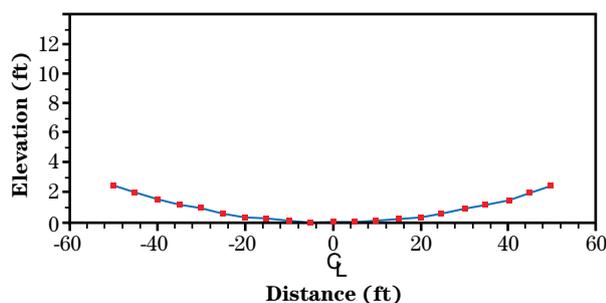
An example is shown in figure 9-10, where  $a_p$  is equal to 0.001. Distance zero represents the diversion centerline and lowest elevation. Note that the vertical scale is exaggerated.

### (1) Design of stable diversions with bare soil linings

Design of a stable diversion with a bare soil channel using erosionally effective stress as the criterion for stability is similar to designing a vegetated diversion without the allowances for the extra stability and resistance to flow offered by the vegetation. The following steps are recommended:

*Step 1* As with a vegetated channel, determine the soil allowable effective stress, either by using table 9-5, figures 9-6 through 9-8, or by following the more detailed methods given in AH-667.

**Figure 9-10** Parabolic cross section



*Step 2* Determine the appropriate  $n$  value. It is important that a realistic  $n$  value be chosen. It is recommended that the designer consult a reliable source, such as Open Channel Flow by V.T. Chow or the U.S. Army Corps of Engineers HEC-RAS Hydraulic Manual. A grain size roughness,  $n_s$ , also needs to be chosen. For cohesive soils, the value of  $n_s$  may be assumed to be 0.0156. For noncohesive soils, the value of  $n_s$  should be determined using figure 9-6.

*Step 3* Find the maximum allowable depth that will limit the maximum effective stress to less than the allowable. In the absence of the protection of vegetation, the computation of effective stress  $\tau_e$  reduces to:

$$\tau_e = 62.4dS \left( \frac{n_s}{n} \right)^2 \quad (\text{eq. 9-7})$$

where

$D$  = the maximum depth in the channel

$S$  = the bed slope in feet per foot

The maximum allowable depth can therefore be computed as:

$$d = \frac{\tau_a}{62.4S} \left( \frac{n}{n_s} \right)^2 \quad (\text{eq. 9-8})$$

where

$\tau_a$  = allowable stress computed from soil properties or obtained from table 9-5

The remainder of the section properties are then determined by finding the dimensions that will satisfy Manning's equation, or

$$AR^{\frac{2}{3}} = \frac{Qn}{1.49S^{\frac{1}{2}}} \quad (\text{eq. 9-9})$$

This requires a trial and error solution of equation 9-9 and the equations in table 9-4. Appendix C of EFH650.07 includes design charts which can be used to determine channel width and depth for known dis-

charge, slope, Manning's  $n$ , and soil conditions. The charts in the appendix only apply to bare soil conditions where the width to depth ratio is large enough for the bank slope to have minimal impact on channel dimensions. Normally, selection of a trapezoidal bed width and flow depth using these charts will be adequate. If a bare soil channel is to be designed with a small width to depth ratio or a slope and discharge combination outside those found in the appendix, a trial and error solution as shown in example 3 in EFH650.0903(f) is required.

### (3) Cross section adjustment for overbank area

Trapezoidal vegetated diversions designed using the criteria in EFH650.07 are sized so that the trapezoidal section will be stable and have adequate capacity. When the natural hillslope of the diversion is significantly flatter than the embankment slope, as suggested by figure 9-9, it may be possible to reduce the depth because of the extra overbank area. Figure 9-11 further illustrates this situation. The heavy dotted line shows the trapezoidal section specified in EFH650.07 tables for the soil, bed slope, and discharge. Since the

natural hillslope is flatter than the side of the trapezoidal section, there is additional conveyance for the discharge. To allow for irregularities in the natural ground and for the fact that the velocity of shallow flow over a vegetated surface is very low, the amount of extra conveyance available is restricted to that part of the overbank where the depth is 6 inches (0.5 foot) or greater, as shown in figure 9-11.

The greatest advantage to be gained is when the ratio of trapezoidal depth to depth on the natural hillslope side ( $d_T/d_n$  in fig. 9-11) is large and when the natural hillslope ( $z_n$ ) is significantly flatter than the trapezoid side slope ( $z_T$ ). Typically, the depth reduction obtainable is small. A large database of trapezoidal sections was evaluated, and the maximum depth adjustment was approximately 0.3 feet.

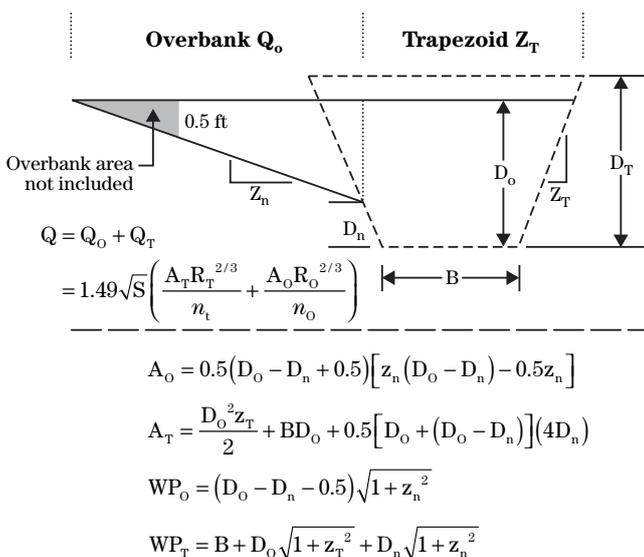
Finding the modified depth is a complicated procedure which requires an iterative solution of the equations found in figure 9-11 and the equations for  $n$  versus VR found in AH-667. Computer software is required to make these computations. As long as the normal hillslope ( $z_n$ ) is equal to or flatter than the trapezoid side slope ( $z_T$ ), using the depth and bottom width from the tables in appendices C and D of EFH650.07 will produce a section that meets stability and capacity criteria.

## (f) Examples

### Example 1

A trapezoidal ridge diversion is to be constructed with a bed slope of 0.75 percent and a design discharge of 160 cubic feet per second. The soil is a cohesive, erosion-resistant soil. Cover factor is 0.75. For mowing, the bottom width should be no less than 10 feet, and the side slopes no steeper than 4:1. The normal hill slope is 8:1. B/D retardance capacity, stability design should be used. The diversion is a permanent diversion in an urban area. Calculate the top width for the diversion.

Figure 9-11 Section following natural hillslope



**Given:**

Trapezoidal cross section

Side slope = 0.75

 $C_r = 0.75$  $Q = 160 \text{ ft}^3/\text{s}$  $\tau_a = 0.05 \text{ lb}/\text{ft}^2$  (table 9–5)

Freeboard = 0.5 ft (table 9–1)

**Calculations:**

Since the hillslope is flatter than the 4:1 slope for the trapezoid, an adequate design will be obtained from the tables. The EFH650.07 table for B/D design, allowable stress of 0.05 pounds per square foot, cover factor of 0.75, and 4:1 side slopes is entered with  $Q$  equals 160 cubic feet per second and slope equals 0.75 percent. From the table, a depth of 2.5 feet and bottom width of 11 feet are obtained. For final design, table 9–1 and any applicable ordinances should be consulted for freeboard requirements.

 $D = 2.5 \text{ ft}$  $B = 11 \text{ ft}$  $D_f = 2.5 \text{ ft} + 0.5 \text{ ft}$ 

freeboard = 3 ft

Final top width is computed using equation 9–3.

$$\begin{aligned} T &= B + 2zD \\ &= 11 + 2(4)(3) \\ &= 35 \text{ ft} \end{aligned}$$

The final trapezoid section properties are depth equals 3 feet, bottom width equals 11 feet, and top width equals 35 feet.

**Example 2**

A parabolic channel diversion is to convey 60 cubic feet per second on a 3 percent slope. The soil is a stiff clay, classification CL, plasticity index of 14, and cover factor is 0.9. B/D retardance design should be used for capacity/stability.

From table 9–6, the void ratio for stiff clay can be estimated as 0.6. From figure 9–7, the basic allowable stress is 0.046 pounds per square foot. From figure 9–8, the correction for void ratio is 1.104. Allowable stress is therefore computed as:

$$\tau_a = \tau_{ab} C_e^2 = 0.046(1.104)^2 = 0.056 \quad (\text{eq. 9-10})$$

A stable design will be obtained if the table value for allowable stress of 0.05 is used. Entering the B/D parabolic table in appendix 7D for  $C_r = 0.9$  yields a depth of 1.7 feet and a top width of 12 feet.

**Example 3**

Find a trapezoidal section for a bare soil channel in cohesive soil with allowable stress of 0.05 pounds per square foot,  $Q$  equals 60 cubic feet per second, bed slope of 0.75 percent, and a Manning's  $n$  value of 0.03. For cohesive soils,  $n_s$  is assumed to be 0.0156.

Maximum depth is found as:

$$\begin{aligned} d &= \frac{\tau_a}{62.4S} \left( \frac{n}{n_s} \right)^2 \\ &= \frac{0.05}{62.4(0.0075)} \left( \frac{.03}{0.0156} \right)^2 \\ &= 0.4 \end{aligned} \quad (\text{eq. 9-11})$$

and from equation 9–9 the minimum  $AR^{2/3}$  required is:

$$\begin{aligned} AR^{2/3} &= \frac{Qn}{1.49S^{1/2}} \\ &= \frac{60(.03)}{1.49(.0075)^{1/2}} \\ &= 13.9 \end{aligned} \quad (\text{eq. 9-12})$$

A trial and error solution is required, and the results are summarized in the following table. Area and  $R$  are computed using the equations in table 9–4 with  $d$  equal to 0.4 ft and  $z$  equals 4:1. The tabulation shows that, to the nearest foot, a bottom width of 64 feet is needed to have a stable channel.

B	Area	R	$AR^{2/3}$
60	24.64	0.389	13.1
61	25.04	0.389	13.4
62	25.44	0.390	13.6
63	25.84	0.390	13.8
64	26.24	0.390	14.0
65	26.64	0.390	14.2

Note that charts in appendix A may be used for wide channels with  $n$  values of 0.025, 0.030 or 0.035. This is done by entering the chart with slope, allowable stress, and  $n$  to obtain the unit discharge (discharge per unit of channel width). The total discharge is then divided by the unit discharge to obtain the channel width. Channel depth is also obtained from the chart.

## 650.0905 Layout and construction

### (a) Layout

The layout of the diversion should begin at a key point, usually the outlet, but it may be a point determined by a building, property boundary, or a gully. On smooth, uniform slopes the stakes may be set 100 feet apart; however, on abrupt changes in topography or on grades less than 1 percent, stakes are usually set on 50-foot stations. When the diversion outlets onto grassland or a broad, shallow waterway, allowance must be made for the depth of channel cut plus gradient in the last 50 to 100 feet in order to outlet the water at ground level. On erosive soils, the last 50 to 100 feet is sometimes constructed on zero grade to reduce erosion at the outlet section. Sample layout notes are shown in Soil Conservation Service Technical Release Number 62, Engineering Layout, Notes, Staking, and Calculations.

### (b) Adjustment and marking

After the centerline has been staked, it is recommended to check and move some stakes, if necessary, to improve alignment. The staked line then may be marked with a plow or other means to make a continuous reference line. Existing vegetation (trees, shrubs) and other landscape features to be protected during construction should also be marked.

### (c) Construction

#### (1) Preparation of site

A good time to build diversions is when the watershed has a good cover so that runoff and silting will be at a minimum. All ditches or gullies that are to be crossed should be filled and compacted before construction begins so as to prevent seepage through the ridge, prevent more than normal settlement, and facilitate construction. Any vegetation that would interfere with constructing a dense fill should be removed. Heavy sod should be thoroughly disked and removed with the topsoil to obtain a good bond between the ridge and natural ground. Topsoil from cross sections should be salvaged for later use in improving vegetation or crop production on the completed diversion.

**(2) Allowance for settlement**

Settlement should be allowed for at the time of design. The amount will depend on soils, moisture conditions, and type of construction equipment. Five percent of fill height is common when scrapers or rubber-tired tractors are used and 10 percent when crawler tractors with blades are used.

**(3) Checking construction**

The diversion should be checked for compliance with design and layout while the construction equipment is still onsite and available to make necessary changes. The finished grade and ridge height should be checked throughout the length of the diversion and the cross section of the channel should be checked at several locations, including the location least likely to meet the design.

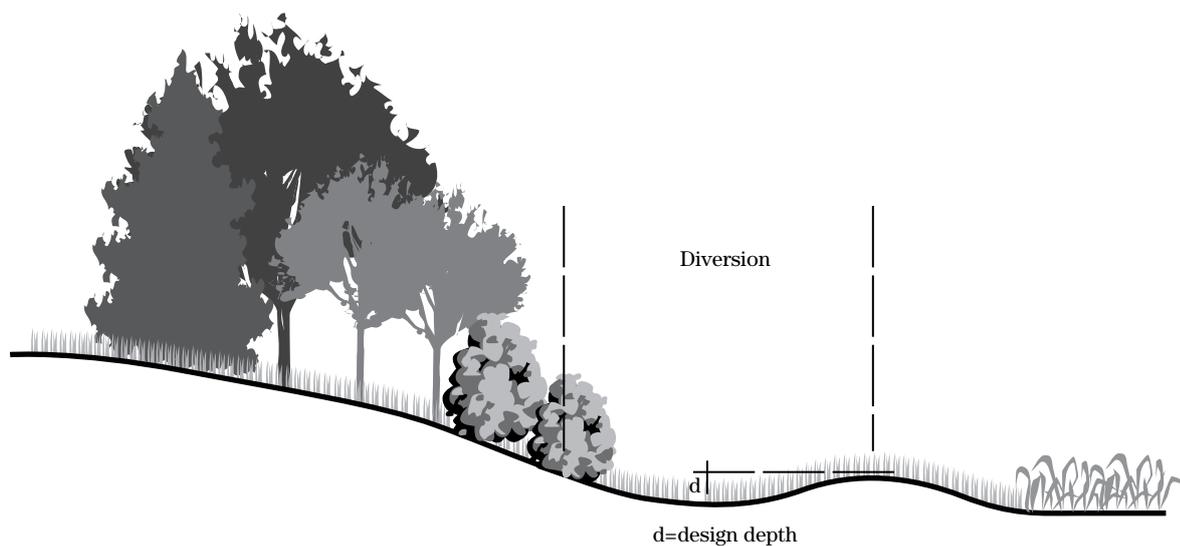
**(4) Establishment of vegetation**

If vegetation is to be used for erosion protection, it should be established as soon after construction as weather conditions permit. Check the field office technical guide for local planting dates. Prepare a seedbed

and seed with a mixture of grasses and legumes adapted to soil conditions and local climate. Most excavated areas will require fertilizers to establish good cover. If weather conditions are not favorable for permanent seeding, it may be necessary to use a temporary seeding, mulch, or lining. Irrigation may be needed to assure adequate germination and growth initially. If immediate turf cover is desired or if it is difficult to establish turf from seed, it may be necessary to use sod. Sodding by sprigging or broadcasting root stalks and stolons gives good results with bermudagrass and other grasses in favorable climates. In other areas, direct planting of sod in strips is practical. Woody plantings may be appropriate along the channel back slope to improve screening, wildlife habitat, space definition, and climate control (fig. 9-12). Check field office technical guides for tree planting dates.

Mulching materials such as straw, hay, jute, paper, or plastic mesh should be used to protect new seeding. At least the center-third portion of the cross section should be anchored. If temporary seedings or nurse crops are used, they should be mowed to reduce com-

**Figure 9-12** Planting of woody vegetation along back slope



petition to permanent seeding. All seeding, planting, sodding, and mulching should conform to standards as given in the field office technical guide.

The diversion may be protected by using a combination of the following steps that best fits the needs of the site:

- Step 1* Reduce the required capacity by dividing the runoff between two or more diversions.
- Step 2* Construct and establish vegetation on the diversion before any other channels or structures are allowed to discharge into it.
- Step 3* Carry prolonged low flows in a subsurface drainage system or in a surface-protected section such as a stone center.
- Step 4* Divert major flows, when possible, from the diversion during establishment period.
- Step 5* Maintain vegetative cover by mowing, spraying, fertilizing, and performing other maintenance as needed.

#### (d) Outlets

The runoff collected by a diversion must be conveyed to a point of safe disposal or usage. An adequate vegetated, riprapped, paved, or underground outlet should be included as part of the design. See EFH650.06 for structures, EFH650.07 for vegetated waterways, and EFH650.08 for underground outlets. It is important that vegetated waterways used as outlets be well established before diversions are constructed.

## 650.0905 Maintenance

### (a) General

The success of a properly designed and constructed diversion depends on a well-maintained channel and outlet. The vegetation in the diversion channel should be fertilized periodically. In arid areas, irrigation may be needed to ensure adequate plant growth. It is important that the channel of a diversion used for intercepting seepage flow be maintained in short vegetative growth to prevent retardation of flow and to reduce seepage through the ridge. On diversions collecting heavy flows of seepage water, it may be necessary to install a subsurface drain or a riprapped center to carry the prolonged flows.

### (b) Care of vegetation

Mowing, spraying, or prescribed grazing of vegetated diversion channels is essential to prevent weeds, briars, and brushy growth from obstructing flow. When woody growth gets too large, mowing becomes difficult and the diversion channel gradually becomes clogged. Diversions clogged with tall grass and brush encourage channel blockage and may cause seepage through the ridge or overtopping. Failure can result. Woody vegetation and tall grass may be left along the back slopes of diversions (fig. 9–12).

### (c) Removal of sediment

The channel may require maintenance to remove small sediment deposits. However, if the deposits extend over long reaches or for the full length of the diversion, the channel should be reconstructed by using appropriate construction equipment.

Sediment should be disposed of properly. The waste can be stacked, spread, or removed from the site. Waste material can also be designed to be functional. It can screen undesirable views, buffer noise and wind, or improve the site's suitability for recreation.

**(d) Repair of eroded areas, breaks, and rodent holes**

Diversions left in permanent vegetation some times attract rodents and other burrowing animals. The ridge should be examined several times a year. If any eroded areas, breaks, or holes are observed, they should be repaired. Rodent control measures should be considered in maintenance plans.

**(e) Reseeding**

Cultural operations should be parallel to the centerline of the channel when reseeding the diversion. Plowing should be performed by back-furrowing on the ridge with a dead furrow in the channel. This method of plowing will maintain the ridge height required in the original design. Reseeding can also be performed by conservation tillage methods.

**(f) Paving or riprap**

Displaced or damaged lining materials should be repaired promptly. This will reduce or prevent further degradation of the diversion lining.

**(g) Outlets**

When the diversion outlet is a grassed waterway, the transition section is the most susceptible to erosion damage. Repairs should be made promptly to prevent gully erosion from advancing up the diversion channel. If vegetation proves inadequate in the transition section, it may be necessary to line this section of channel or construct a grade stabilization structure.

An underground outlet used as a diversion outlet must be kept free of trash and rodents that may plug the outlet and cause failure.

**(h) Symbol description**

<b>A</b>	Cross section area, ft <sup>2</sup>
<b>a<sub>p</sub></b>	Parabolic coefficient (determines shape of parabola)
<b>B</b>	Bottom width of trapezoidal channel, ft
<b>C<sub>e</sub></b>	Correction for void ratio
<b>C<sub>F</sub></b>	Vegetal cover factor
<b>C<sub>I</sub></b>	Retardance curve index
<b>D</b>	Maximum depth of flow in cross section, ft
<b>d<sub>75</sub></b>	75th percentile particle diameter, in
<b>D<sub>T</sub></b>	Section depth after addition of freeboard, ft
<b>e</b>	Void ratio
<b>h</b>	Representative height of vegetation, ft
<b>I<sub>w</sub></b>	Plasticity index
<b>M</b>	Stem density, stems/ft <sup>2</sup>
<b>n</b>	Manning's roughness coefficient
<b>n<sub>s</sub></b>	Roughness associated with soil grain size
<b>Q</b>	Discharge in channel, ft <sup>3</sup> /s
<b>R</b>	Hydraulic radius, ft
<b>S</b>	Channel bed slope, ft/ft
<b>T</b>	Top width of trapezoidal or parabolic channel, ft
<b>V<sub>M</sub></b>	Velocity computed with Manning's equation
<b>z</b>	Side slope
<b>τ<sub>a</sub></b>	Allowable effective stress on soil, lb/ft <sup>2</sup>
<b>τ<sub>ab</sub></b>	Basic allowable stress on soil, before correction for void ratio, lb/ft <sup>2</sup>
<b>τ<sub>e</sub></b>	Erosionally effective stress on soil, lb/ft <sup>2</sup>

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