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Chapter 7 Grassed Waterways

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Chapter 7 Grassed Waterways

650.0700 Introduction

Grassed waterways are natural or constructed channels shaped to required dimensions and lined with suitable vegetation for stable conveyance of runoff.

Grass-lined water conveyance channels are widely used to convey excess runoff water where flows are of a sufficiently short duration to allow the grass to withstand the inundation period and operation is sufficiently infrequent to allow healthy grass cover to be maintained. This type of channel may be used for diversions, spillways, and floodways, as well as for waterways to convey local runoff.

Research conducted during the 1930s and 1940s documented the benefit of grass as a water conveyance channel liner and provided the basis for engineering design of a stable section based on permissible velocity. This approach was documented in Soil Conservation Service (SCS) Technical Paper (TP)–61 published in 1947, revised in 1954 (SCS 1954), and was used for the design of grassed waterways 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 digital computer has allowed more extensive calculations to be easily carried out when needed. These advances led to the documentation of an effective stress approach to grass-lined channel design documented in USDA Agriculture Handbook #667 (Temple et al. 1987). This approach, which also incorporates more general stable channel design concepts and data, has been successfully integrated into the Waterway Design Tool (WDT) software used by the Natural Resources Conservation Service (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.

650.0701 Assessment of suitability

(a) General considerations

A constructed waterway is designed to carry the estimated flow without damage to the waterway or its lining. Waterways should be planned and designed to fit the conditions of a particular site, and the following factors dealing with construction and management should be determined before designing the waterway:

- slope of the proposed waterway (note that this may need to be modified to get a satisfactory design)
- vegetation suitable for site conditions
- expected height at which vegetative cover will be maintained, both in growing and dormant seasons
- allowance for area of field occupied by the waterway
- allowance for freeboard, if required by local standards and specifications

Design of a satisfactory vegetated waterway requires assessment of several site-specific factors: soil properties, management requirements of the vegetation, and climate. The soil properties define the allowable effective stress and are also a factor in the site hydrology and determination of the design discharge. Proper management of the vegetation is critical to its ability to provide the expected level of protection for the channel. The level of management at the site that is feasible, economical, and logistical should be determined and vegetation that will thrive under that degree of management selected. Since height of vegetation is an important factor in flow resistance, realistic estimates of the frequency of mowing and maximum height to be achieved between mowings should be made. In addition to its impact on site hydrology and design discharge, climate is an important factor in vegetation selection and the intensity of management required. In selecting the vegetation and maintenance program for a site, the goal should be to maximize the quality and uniformity of the resulting cover.

A successful grassed waterway also depends on good conservation treatment of the contributing watershed and a regular maintenance program. The better the erosion control in the watershed, the less silting there will be in the waterway. Good conservation practices also reduce the peak rate of runoff and volume of water to be carried by the waterway. When good conservation treatment of the drainage area is not obtained, greater maintenance is usually required.

Waterways subject to constant or prolonged flows require special supplemental treatment, such as stone centers or subsurface drains capable of carrying a portion of such flows. Typically, a grass lining is not suitable if continuous flows for more than 72 hours are expected. A grassed waterway is susceptible to considerable erosion damage until permanent vegetative cover is established. Flows experienced by the waterway during the establishment period may result in maintenance or repair being required.

If an existing natural waterway is to be used, it may need to be selectively cleared, shaped, or enlarged to accommodate the design flow. It also must be checked to ensure stability. Natural waterways that are providing important woody wildlife cover and are not seriously eroding should not normally be disturbed.

Avoid placing waterways where there are sharp, unnatural changes in flow direction. Land management systems should be planned to conform to natural land features. The location of the alignment should not pose a threat to important landscape elements such as unique trees, geologic formations, or scenic features. The slope of the waterway should not interfere with adjacent land uses. Shallower and broader designs usually blend in better and are less disruptive.

(b) Legal/regulatory considerations

If buried utilities cross the proposed alignment, contact the utility companies to determine the exact location of underground services, and analyze compatibility.

The use of public road ditches for the disposal of water should be in conformance with the policy of the local transportation authority and the NRCS. Where a road crosses a waterway, consideration should be given to providing a culvert, bridge, or lining to protect the waterway from resulting damage.

Any other applicable state laws and local ordinances and regulations must be observed in locating waterways and outlets.

650.0702 Planning and preliminary design considerations

(a) Location

If possible, consider more than one location, and select the most practical and economical alternative, considering aesthetics and the nature of local land use. Consider outlet conditions, topography, vegetation, land values, cultural activities, visual quality, soil type, length of slope, and natural features. Waterways should be located such that they will not experience vehicle traffic or other activity sufficient to damage the vegetal cover.

The location of waterways is important to a good program of erosion and sediment control. Wherever possible, the natural drainage system should be preserved and used. Waterways should generally be located in natural drainageways where water can drain in from all sides. Moisture conditions and soil fertility are usually best in such areas for establishment of vegetation. Other advantages of natural waterways include:

- flattest grade in the immediate area
- most stable waterway conditions
- adequate capacity
- sufficient depth for outletting diversions, terraces, and rows with minimum earthwork

Waterways can also be located along development boundaries, road rights-of-way, property lines, or along storm sewer center lines. Special precautions should be taken when waterways start or end near property lines. Care must be taken to prevent sediment from damaging lower or downstream properties. If the upper or upstream end is near a property line, the transition must be stable to prevent erosion or degradation of neighboring land.

In lieu of a constructed or natural channel, an adjoining pasture or meadow strip may be used. The surface of such areas should be checked, however, to ensure that uniform surface and adequate width are available to spread the flow and that the type and density of vegetation are adequate to protect the soil from erosion.

An area of land parallel to a field boundary should be used for the waterway, if suitable. One advantage of this location is that the waterway is less likely to be damaged by farm equipment. Such a location often requires the construction of a channel to:

- provide an outlet for terraces or diversions that cannot be extended to a natural draw
- provide an outlet away from buildings or other critical areas
- avoid the use of a gullied natural draw that would be impractical to stabilize, especially those with large watersheds

(b) Slope

The design bed slope will generally reflect the slope along the chosen channel alignment. If the slope at the site changes significantly and the bed slope will need to change, the channel can be broken up into reaches for analysis. While it is generally most convenient to follow the lay of the land in selecting a slope, there are occasions where modifications to the slope may be necessary such as:

- If it is not possible to find an appropriately sized stable section, it may be necessary to build the channel 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.

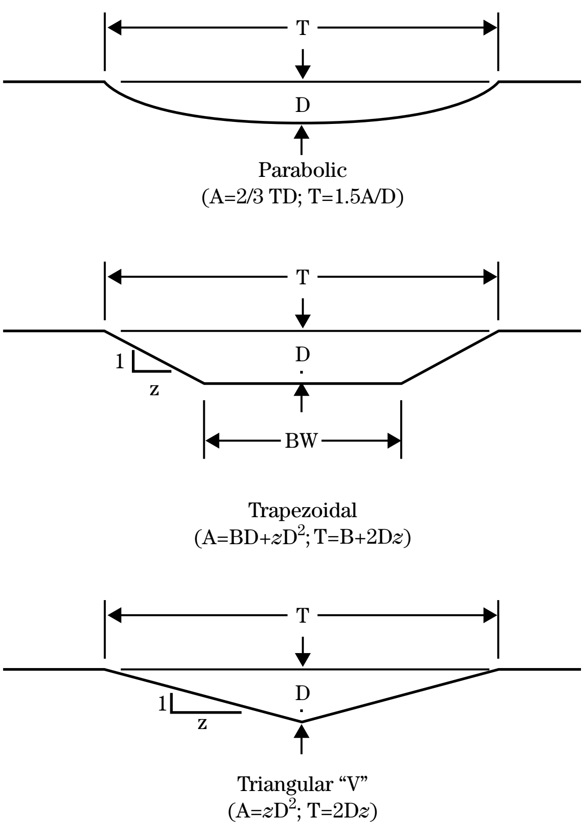
Final grades should be selected to meet capacity and stability requirements. When permanently vegetated waterways are used in residential or commercial developments to manage or convey storm water, the grade of the channel should be such as to minimize standing water or wetness problems. The slope should be steep enough to minimize sediment deposition in the waterway and flat enough to minimize erosion during large flow events.

(c) Cross section shape

The channel section is chosen to accommodate site conditions, limitations imposed by availability of excavating equipment, and allow for maintenance, grazing, or traffic.

Vegetated waterways may be built in a parabolic, trapezoidal, or V shape. Parabolic waterways are the most common and generally are the most satisfactory. This shape is ordinarily found in nature. Small flows are less likely to meander. Waterways constructed with a trapezoidal section often tend to revert to a parabolic cross section. A modified trapezoidal cross section with the bottom center constructed 0.3 to 0.5 feet lower than the edges is sometimes used on wide waterways. The cross section should be designed to permit easy crossing by equipment where necessary. Typical waterway cross sections are shown in figure 7–1.

Figure 7–1 Typical waterway cross sections



Where: A=cross section
D=design depth
T=design top width
B=design bottom width
z=side slope ratio

(d) Vegetation

Consider the possible future conditions of the vegetative lining based upon natural succession and maintenance. In some cases, the expected stand of vegetation may not be attained or will deteriorate under normal maintenance. Therefore, it is necessary to check the waterway design for stability under any eventual conditions of deterioration that may be anticipated. Select vegetation that will provide long-term uniform cover with the anticipated level of maintenance.

(e) Outlets

All waterways shall have stable outlets with adequate capacity for the design flow. The outlet may be another grassed waterway, earth ditch, structure, or other suitable outlet. In all cases, the outlet must discharge in a manner that prevents erosion. Outlets should be constructed and stabilized before the waterway is used.

(f) Sediment control

Permanent waterway channels should be protected from sediment. If sediment is not controlled before it reaches the waterway, several methods may be used:

- install a vegetated filter strip on each side of the waterway where surface water enters
- increase the channel depth to store trapped sediment and/or design areas of increased width or decreased slope to trap and store sediment
- provide for cleaning out the channel when its design capacity deteriorates

(g) Data collection

(1) Engineering surveys

A preliminary site investigation is recommended to determine the feasibility of using a natural watercourse or constructing a waterway. Such a survey includes a study of resource information such as soil maps, aerial photography, and contour maps; visual examination of potential alignment; topographic surveys; and estimating required capacity. A preliminary investigation should provide enough information to select a final alignment.

Surveys for waterways normally consist of field notes for waterway design, layout, and construction as shown by the example in Technical Release (TR)–62 (USDA 1979). These notes are satisfactory when drainage areas are small, topography is relatively uniform, and elevations with respect to other structures are not significant. Standard forms or data sheets approved for field offices may be used to record field notes. A profile and cross section of the original ground surface should be exhibited in enough detail to permit dividing the waterway into reaches of approximately uniform slope and shape.

Design information should include documentation of outlet conditions, topography, vegetation, land use and cultural patterns, soil type, length of slope, and other built or natural features. Typical design conditions will require general identification of the relative erodibility of the soil. Projects with larger drainage areas and more extensive design requirements may require more detailed information such as the unified classification of the soils that will be encountered along the alignment of the waterway, along with the plasticity index (I_w) and void ratio (e), or, for noncohesive soils, the representative particle diameter, d_{75}.

(2) Hydrologic investigations
Information on the watershed area, design storm frequency and duration, and runoff estimates are important in correctly sizing the waterway. The drainage area divides can be determined by field inspection or from topographic mapping. Drainage areas determined from mapping should be field-checked.

Determine the watershed area at the outlet of the waterway and at other points where it may be desirable to change the grade or cross section. Calculate the runoff in cubic feet per second at each design point for the frequency and duration of storm selected. Refer to EFH 650.02 (SCS 1989) or reference methods in National Engineering Handbook (NEH), Part 630 for the procedure.

650.0703 Design process

(a) Steps in the design of a waterway

Step 1 Plan the optimum location of the waterway centerline.

Step 2 Select design points along the waterway where grades, drainage areas, and/or type of lining change significantly.

Step 3 Determine the watershed area for the points in step 2 and for the outlet.

Step 4 Compute the peak runoff produced by the design storm.

Step 5 Determine the slope of each reach of the channel from the topographic map, profiles, or cross sections.

Step 6 Select the appropriate channel cross section and the type of channel lining(s) to be used.

Step 7 Design the channel for stability, typically based on the sparsest and shortest vegetation expected.

Step 8 Adjust the depth to obtain adequate capacity based on the densest and longest vegetation expected.

Step 9 Add appurtenant structures as needed to allow for prolonged flows.

(b) Initial design parameters: slope, discharge, section, and lining

If there are significant changes in slope or discharge along the waterway, it may be necessary to design the waterway in reaches. A reach (or segment) is generally a portion of the waterway having a near-uniform slope, discharge, soil type, and vegetal cover. A point of significant break in slope is a point of division between two reaches. The point of entrance of a diversion or other tributary where the discharge is significantly increased may also be a point of division between two reaches. Large changes in soil properties may also require cross section modification. Where there is a significant difference in cross section or slope between adjoining reaches, it may be necessary to install a transition section between them.

When the limits of two or more reaches have been determined, each reach is designed separately by procedures given in subsequent paragraphs.

Waterways are constructed to discharge the peak flow expected from at least a 10-year frequency, 24-hour duration storm. Out-of-bank flow may be permitted on land slopes parallel to the channel where the slope is not greater than one percent and where it is evident that no erosion or property damage will result. In every case, it is necessary to provide adequate capacity and limit velocities so there will be no danger to humans or animals, in accordance with site conditions.

The shape selected should be compatible with surrounding landform and landscape characteristics. Side slopes may be varied to better balance cut and fill and to improve aesthetics.

On sites where it is impossible to establish suitable permanent vegetation or it is desired to determine the stability of the channel in an as-constructed condition, the design can be based on bare ground conditions. Site conditions may warrant designing the waterway with a rigid or paved lining.

Perforated concrete blocks are a common form of structural lining in residential, commercial, or recreation areas where aesthetics, safety, maintenance, and rodent populations are primary design factors. First introduced as cellular concrete blocks by SCS in the 1950s, the improved versions are now referred to generally as grid pavers. Designed to carry heavy loads and allow turf to grow within the cells, their use is becoming more widespread as an alternative to conventional pavement surfaces or rock riprap (fig. 7–2).

The dimensions computed for waterway discharge capacity are the minimal measurements required to carry the actual flow and do not include a factor for extra depth required for space occupied by sedimentation or freeboard. Where local standards require such factors, they should be added to the computed dimensions. It is important that the depth be adequate to permit unimpeded discharge from terraces, diversions, and crop rows.

If the waterway must be crossed by farm equipment and other forms of traffic, consideration should be given to the need for increased width (fig. 7–3). Large combines, pickers, sprayers, and similar equipment may require a significant increase in width over that needed for hydraulic capacity and freeboard. This scenario deserves consideration so that the proper modifications are made in waterway width and side slopes to meet the needs of equipment common to the locality. Vegetated crossing areas that are not otherwise reinforced may require additional maintenance and/or repair following flow events. Where paved channels are to be crossed, the lining must be designed to carry the expected loads. Culverts or bridges with adequate capacity may also be used.

(c) Conditions for stability

The purpose of the grass lining is to prevent damage to the channel by protecting the soil from eroding. To accomplish this 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.

Once vegetation becomes weak or damaged in a local area, there is a strong potential for rapid unraveling of the channel lining. This fact, along with high variability within the vegetative cover, makes it advisable for design criteria to be conservative. A very dense and uniform cover may be able to withstand larger stresses than those recommended here for stability design. Increasing the allowable stress is not recommended, however, unless the designer can be certain that the quality of the vegetative cover will *always* be maintained. In addition, the design should be adjusted to account for instances where highly variable cover conditions or low levels of maintenance are expected.

Design based on the erosionally effective stress considers the drag forces that can move individual soil particles, along with the influence of the vegetation on the distribution of stress. The approach is based on separating the stresses on the channel into components. Erosionally effective stress (τ_e) hereafter referred to as effective stress, is computed as:

$$\tau_e = \gamma DS(1 - C_F)\left(\frac{n_s}{n}\right)^2 \qquad \text{(eq. 7–1)}$$

where:

γ = unit weight of water, 62.4 lb/ft³
D = maximum flow depth in the cross section
C_F = a vegetal cover factor
n_s = roughness associated with soil grain size
n = Manning's roughness coefficient
S = channel bed slope, ft/ft

The vegetal cover factor was developed based on experimental data and accounts for the cover density and uniformity (Temple 1980). It takes on values between 0 and 1, with 0 indicating no vegetal protection and 1 indicating the channel is completely protected from stress. The vegetal cover factor is a function of vegetation type and condition.

Figure 7–2 Cross section showing perforated grid pavers

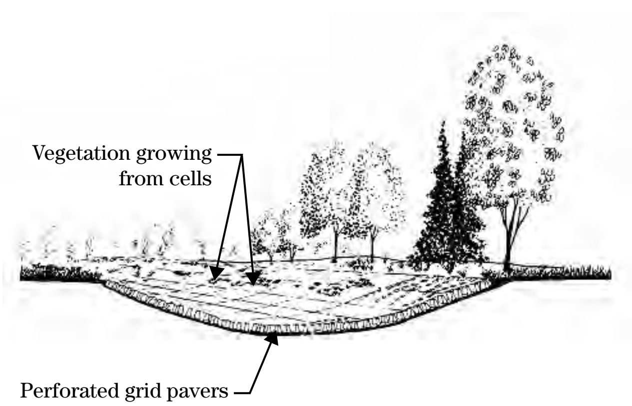
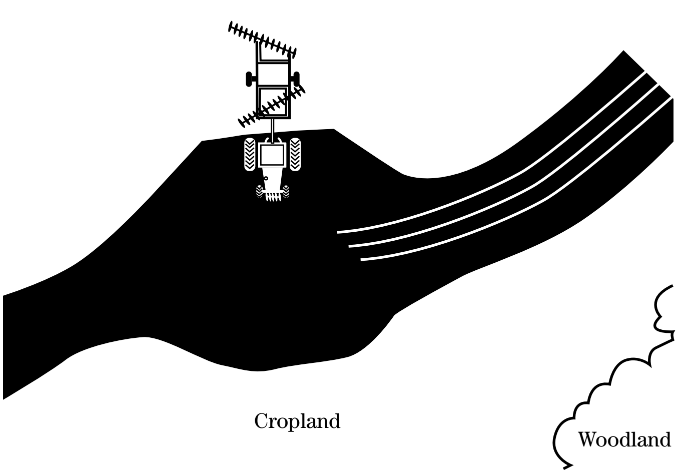


Figure 7–3 Provision for vehicle crossing



Flow depth rather than hydraulic radius is used in this calculation because it is the maximum stress in the cross section that governs the stability. The interaction of the vegetation and flow distorts the stress distribution in the cross section, and the vegetative lining tends to unravel rapidly once damage occurs.

Grain size roughness (n_s) for noncohesive soils is determined as:

$$n_s = \frac{d_{75}^{\frac{1}{6}}}{39} \qquad \text{(eq. 7–2)}$$

where the value of d_{75} is in inches. For fine-grained, cohesive soils, the value of n_s is taken as 0.0156. Figure 7–4 can be used to determine n_s based on d_{75}.

Steps in waterway design are as follows:

Step 1 Determine allowable effective stress based on an evaluation of the soil material.

Step 2 Determine the flow retardance and the allowable stress on the vegetation based on the sparsest and shortest vegetation expected (typically winter vegetation) and the flow retardance offered by the densest and longest vegetation (typically summer vegetation).

Step 3 Determine the vegetal cover factor associated with sparsest vegetation expected.

Step 4 Determine the bed slope.

Step 5 Choose a cross section shape.

Step 6 Use design aids or equations to size channel for sparsest and shortest vegetation.

Step 7 Use design aids or equations to determine depth required to contain the flow for densest and longest vegetation.

Step 8 Add freeboard as appropriate.

(1) Determination of allowable effective stress

The erodibility of the soil may be estimated to fall into one of these categories:

- easily eroded (sand textural soil classification)
- erodible (silt textural soil classification)
- erosion resistant (clay textural soil classification)
- very erosion resistant (based on local information or experience) (gravel textural soil classification)

Allowable effective stress is implied from this classification as indicated in table 7–1. Soil allowable effective stress may also be determined directly from soil properties. The allowable effective stress is the maximum hydraulic stress that may be applied directly to the soil without the occurrence of unacceptable erosion.

Figure 7–4 Calculation for grain roughness for noncohesive soils

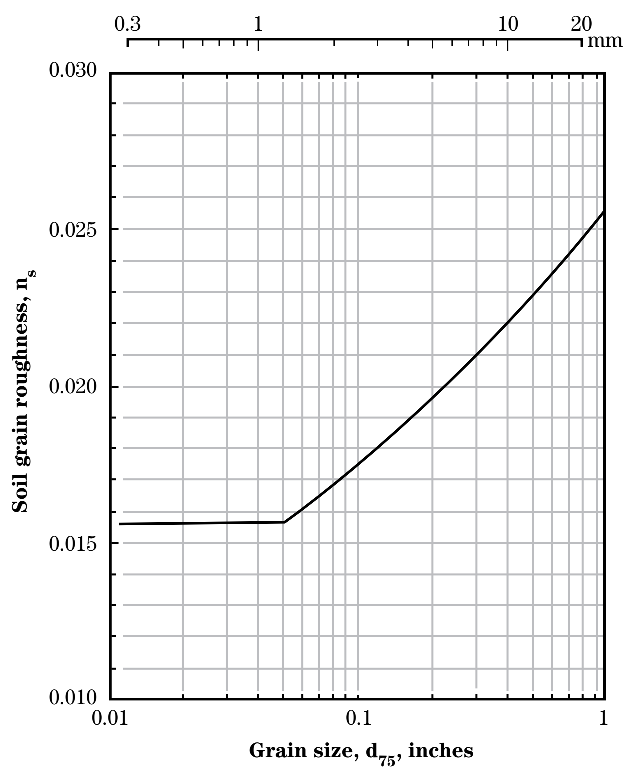


Table 7–1 Allowable effective stress for categories of soil erodibility

Category	Allowable stress, τ_a, lb/ft²
Easily eroded	0.02
Erodible	0.03
Erosion resistant	0.05
Very erosion resistant	0.07

The first step in defining allowable stress from soil properties is to determine the unified soil classification of the soil from which the channel is to be constructed. This information may be available from the county soil survey (NCSS Web Soil Survey: *http://websoilsurvey.nrcs.usda.gov*). 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, τ_a. The grain size may be estimated from data, found in the soil survey. Once the d_{75} is found, the allowable effective stress can be determined from figure 7–5 or from the equations in appendix B.

For cohesive soils, the plasticity and void ratio are needed. The plasticity index describes the range of water content over which a soil is in a plastic state, described as soft butter to stiff putty; deforms but will not crack (Sowers 1979). More specifically, it is the difference between the liquid limit and the plastic limit, where the liquid limit is the maximum water content at which the soil will hold a specific shape when vibrated and the plastic limit is the minimum water content at which the soil will not break and crumble. In general, an estimate of the plasticity index can be obtained from the county soil survey. Laboratory procedures for determination of liquid limit, plastic limit, and plasticity index are in ASTM D–4318–00 (ASTM 2000).

The void ratio is the ratio of the volume of voids (water and air) to the volume of solid particles. It is expressed as a decimal and may exceed 1. Void ratios may be estimated based on soil type as shown in table 7–2 (Das 1994) or by using standard laboratory procedures.

Determination of allowable stress for a cohesive soil is a two-step process. The first step is to use the plasticity index to determine the basic allowable stress, τ_{ab}. This can be estimated from figure 7–6 or by using the equations in appendix A.

A correction is then applied based on the void ratio. The correction, C_e, is determined from figure 7–7 or from the equations in appendix A. For the organic soils OH and OL, C_e is equal to 1.0. If the void ratio is not known, then the maximum value of C_e from figure 7–7 for the soil type can be used. This will result in a conservative design. The final allowable effective stress (τ_a) is then computed as

$$\tau_a = \tau_{ab} C_e^2 \qquad \text{(eq. 7–3)}$$

Figure 7–5 Allowable stress for noncohesive soils

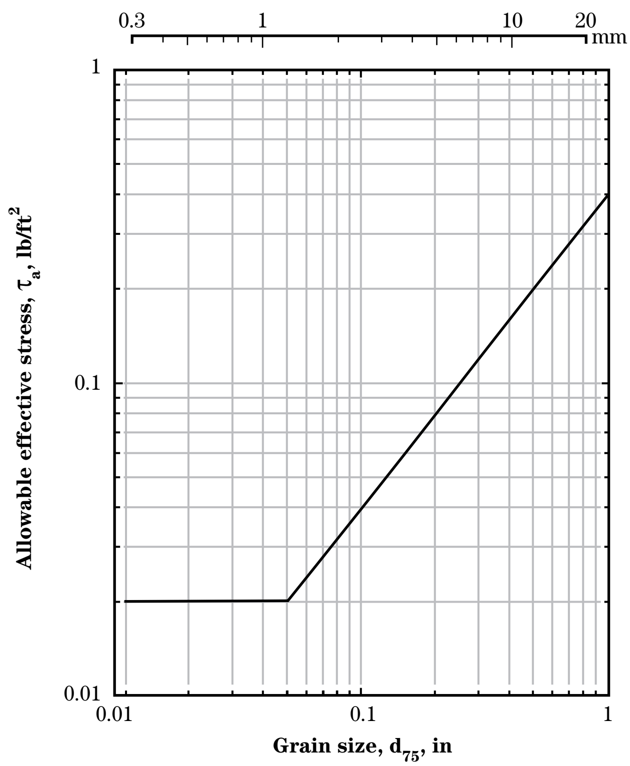


Table 7–2 Void ratios for selected soils

Soil Type	Void ratio, e
Loose angular-grained silty sand	0.65
Dense angular-grained slty sand	0.4
Stiff clay	0.6
Soft clay	0.9–1.4
Loess	0.9
Soft organic clay	2.5–3.2
Glacial till	0.3

Figure 7–6 Basic allowable stress for cohesive soils

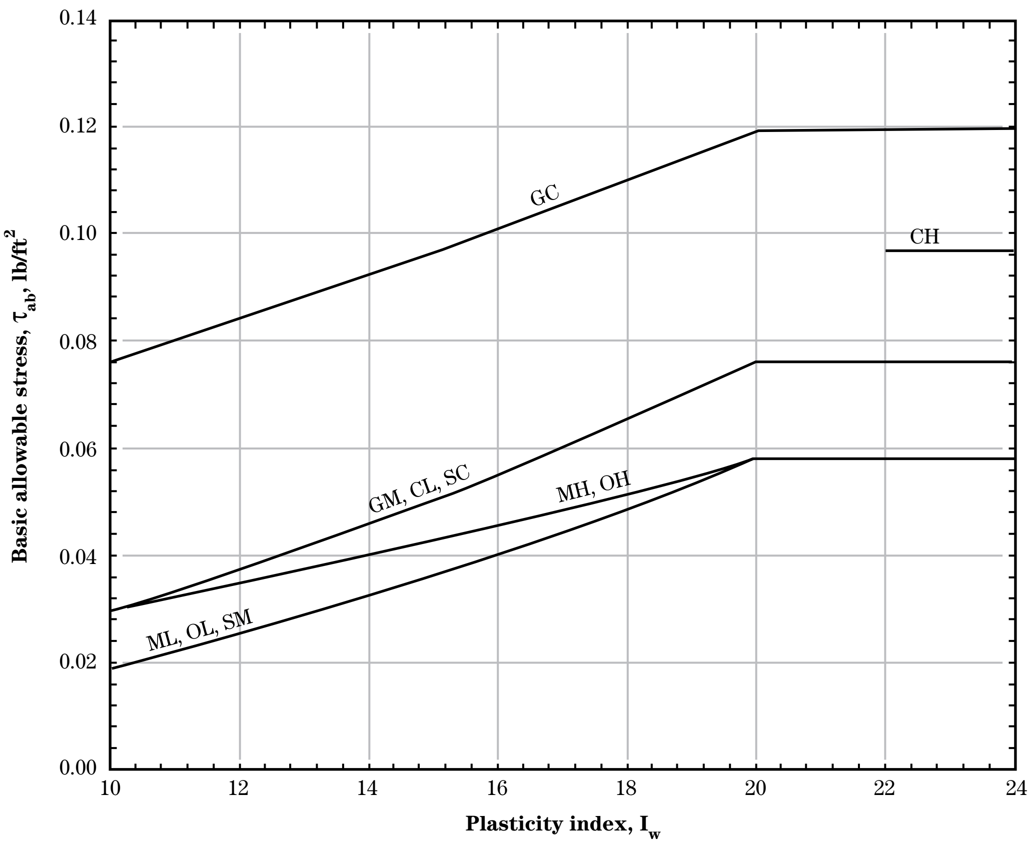
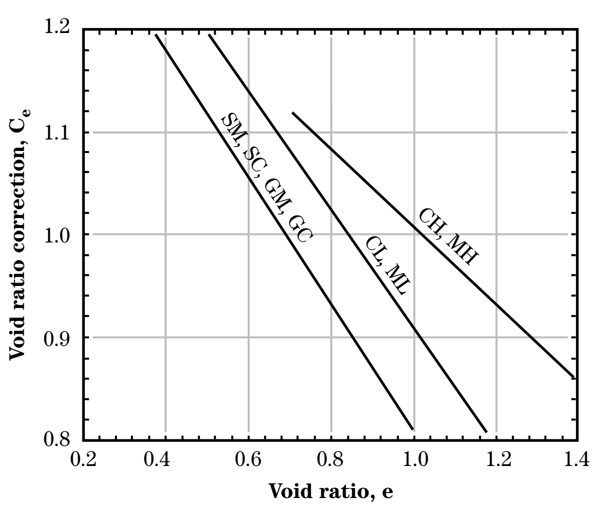


Figure 7–7 Correction for void ratio



(2) Determination of allowable vegetal stress

The allowable vegetal stress is the maximum total shear stress that may be withstood by the vegetal cover without unacceptable damage. It is directly related to the drag experienced by the stems and therefore to the level of flow retardance offered by the vegetal cover. The allowable vegetal stress (τ_{va}) is related to the retardance curve index as:

$$\tau_{va} = 0.75C_I \qquad \text{(eq. 7–4)}$$

Retardance curve index (C_I) is in turn related to the stem length and density of the cover as:

$$C_I = 2.5\left(h\sqrt{M}\right)^{\frac{1}{3}} \qquad \text{(eq. 7–5)}$$

where:

h = the representative height of the vegetation in feet

M = the stem density in stems per square foot

Table 7–3 lists stem density for several grasses. Since the density and height of vegetation is likely to be seasonal, upper and lower boundary values of C_I are typically established. The lower boundary value is used in determining if stability requirements are met (steps 5 and 6), and the upper boundary value is used to determine the additional capacity needed for summer vegetation, which generally provides more resistance to flow (step 7).

The value of C_I can also be determined using the retardance classes. The retardance class for various example ground covers is given in table 7–4, and the relation of retardance curve index to retardance class is shown in table 7–5.

(3) Determination of vegetal cover factor

The vegetal cover factor describes the ability of the vegetal cover to reduce the maximum hydraulic stress on the soil. It is related to the type and quality of the vegetal cover. Table 7–3 lists typical values of the vegetal cover factor. The value of the cover factor may be estimated by comparison of the sparsest expected cover with the covers described in the table.

(4) Determination of effective and vegetal stress

Design of a stable waterway requires that the hydraulic stress applied to the soil and vegetation by the flowing water be less than or equal to the computed allowable values. The design tables provided in this chapter were developed to provide a minimum cross sectional area satisfying this requirement. Otherwise, effective stress must be computed using equation 7–1 and compared with the allowable stress.

Calculation of effective stress will require the additional parameter of soil grain roughness and calculation of flow resistance in the form of Manning's *n* and of flow depth. For fine grained materials, including cohesive soils, the soil grain roughness n_s is equal to 0.0156. For coarse grained soils, n_s is a function of d_{75} and can be determined from figure 7–4 or equation 7–2. These computations may be carried out using the additional equations provided in appendix B. Because of the interaction of the flow with the vegetal cover, iterative solution of the equations is required and the computations are normally carried out using computer software.

The final step in designing a channel section is to compare the stress on the vegetation with the allowable vegetal stress, τ_{va}. When the allowable stress on the vegetation is the governing parameter, the stress on the soil will be only a small part of the total stress. Therefore, the computed allowable stress is compared to the total hydraulic stress, τ, where

$$\tau = \gamma DS \qquad \text{(eq. 7–6)}$$

Table 7–3 Properties of grass channel linings; values apply to good uniform stands of each cover[1/]

Cover factor, C_F	Covers tested	Reference stem density (stem/ft^2)
0.90	Bermudagrass	500
	Centipedegrass	500
0.87	Buffalograss	400
	Kentucky bluegrass	350
	Blue grama	350
0.75	Grass mixture	200
0.5	Weeping lovegrass	350
	Yellow bluestem	250
	Alfalfa[2/]	500
	Lespedeza sericea[2/]	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 7–4 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 bromegrass	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 bromegrass, or orchardgrass	Good stand, uncut (average 20 in)
	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)
C	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	Good stand, cut to 2.5-in height
	Red fescue	Good stand, headed (12 to 18 in)
	Buffalograss	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

Table 7–5 Retardance curve index by retardance class

SCS retardance class	Retardance curve index C_I
A	10.0
B	7.64
C	5.60
D	4.44
E	2.88

650.0704 Sizing channel sections

The channel cross section is normally sized for the minimum cross-sectional area satisfying the stability and capacity requirements for the geometry selected. The channel geometry is selected and the controlling parameters are computed to satisfy stability and capacity design requirements. Table 7–6 shows the typical parameters for design. The parameters specified as optional in table 7–6 influence the design only when the stability requirements would result in an unsuitably narrow cross section. The complete governing equations are given in appendix A, and all notation used throughout this and other sections of this chapter is described in appendix B.

(a) Techniques presented

Design tables are provided covering typical conditions for trapezoidal and parabolic cross sections. For other section shapes, and for use in checking calculations, the full equations are given in appendix A.

For conditions outside the range of parameters covered by the tables and when conditions warrant refinement of the design to better reflect details of the soil and/or vegetal conditions, the equations of appendix A may be solved directly. Because design generally requires iterative solution of the equation set, a programmed solution is generally appropriate. Waterway Design Tool (WDT) software has been developed to provide these solutions.

Finally, a set of examples demonstrating use of the techniques and also including examples of determining allowable effective stress, curve index, and vegetal stress is provided.

The design tables are intended for use with parabolic or trapezoidal channels and include a range of slopes, discharges, and dimensions and should not be used for situations outside the ranges given. They were developed for curve index numbers corresponding to the traditionally used retardance classes, as shown in table 7–4, and for allowable effective stress values representing a typical range of conditions. At times, it may be advantageous to use the tables to obtain preliminary dimensions and then refine the design using the equations. When using the equations for design, it will be necessary to verify that allowable effective stress is the appropriate design parameter by considering the optional limiting parameters of table 7–6 and the maximum total stress on the vegetation as described in previous sections.

Table 7–6 Cross section properties

Section shape	Required design criteria	Optional criteria	Parameters in design table	Parameters computed from tabular data
Trapezoid	Side slope	Minimum bottom width	Bottom width Depth	Top width
Parabolic	None	Steepest side slope at water's edge	Top width Depth	Parabolic coefficient, a_p Side slope at water's edge
Triangular	None	Minimum side slope	Not available	Use equations to design

(b) Use of the design tables for parabolic and trapezoidal channels

In the absence of precise field data regarding the height and stem density vegetation, it is still considered acceptable to design based on retardance classes. In this case, retardance class D is generally used for stability (shortest and sparsest cover) and B or C are used for capacity (longest and densest cover). Tables for B/D (capacity/stability) and C/D design are presented in appendices C and D.

Use of the tables requires the design discharge, bed slope, type of cover (vegetal cover factor), and soil erodibility (allowable effective stress) to be identified. The numbers in the table are for fine-grained cohesive soils. For other conditions, the design should be checked using the equations.

The table is then selected based on capacity retardance (B or C), soil erodibility, cover factor, and side slope (trapezoidal) and is entered using the bed slope and discharge. The trapezoidal channel design table gives the bottom width and depth (B and D), and the parabolic design table gives the top width and depth (T and D).

For a trapezoid, the top width is computed as:

$$T = B + 2zD \qquad \text{(eq. 7–7)}$$

For a parabolic channel, the parabolic channel coefficient (a_p) is computed as:

$$a_p = \frac{4D}{T^2} \qquad \text{(eq. 7–8)}$$

and side slope at the water's edge, that is, point where the water surface meets the channel bank, is computed as:

$$z = \frac{1}{a_p T} \qquad \text{(eq. 7–9)}$$

If this side slope is steeper than 4:1, modification to the design may be needed, depending on mowing and maintenance requirements.

If the exact slope is not included in the table, there are two approaches possible. The design for the slopes bracketing the exact slope can be computed and the final results found by interpolation. Alternatively, the next higher slope can be used to determine the minimum width (specific value of a_p) which will ensure stability criteria are met. To ensure adequate capacity, the depth should be increased to that associated with the next flatter slope or determined using the equations in appendix A and the curve index number for capacity. The final top width will increase accordingly. This computation is illustrated for a trapezoidal section in example 3.

If the exact discharge is not found in the table, the next higher discharge should be used. This will result in a slightly over designed channel, but stability and capacity criteria will be met.

(c) Design examples

Example 1
This example illustrates design of a trapezoidal channel and finding the soil effective stress. Find the channel depth, bottom width, and top width for the following design data. Check that the vegetal stress is within the allowable.

Channel parameters:	Trapezoidal section 6:1 side slopes bed slope = 0.75% Q = 300 ft^3/s
Soil parameters:	Easily eroded soil (SM with plasticity index of 12 and void ratio of 0.7)
Vegetation parameters:	Bermudagrass (C_F = 0.9) B retardance (maximum length approximately 14 in) D retardance (minimum length approximately 4 in)

Solution: The tables may be entered directly with the information given. A portion of the table for B/D design of a channel with bermudagrass or equivalent cover (C_F=0.9) over an easily eroded soil (τ_a=0.02 lb/ft^2) is shown in figure 7–8. A slope of 0.75 percent and a discharge of 300 cubic feet per second yields a bed width of 24 feet and a flow depth of 2.4 feet as shown in figure 7–8. The top width for the channel is computed as:

$$\begin{aligned} T &= B + 2zD \\ &= 24 + 2(6)(2.4) \qquad \text{(eq. 7–7)} \\ &= 53 \text{ ft} \end{aligned}$$

Using the more detailed information given, the design may be refined if considered warranted. To do this, first, find allowable effective stress and the void ratio correction using figures 7–6 and 7–7. Using τ_{ab} = 0.025 and C_e = 0.99, the allowable effective stress is:

$$\begin{aligned}\tau_a &= \tau_{ab} C_e^2 \\ &= 0.025(0.99) \\ &= 0.025 \text{ lb/ft}^2\end{aligned} \qquad \text{(eq. 7–3)}$$

Using the reference stem density for bermudagrass from table 7–3 of 500 stems per square foot with the stem lengths given yield retardance curve index values of 7.48 and 4.87, respectively, from equation 7–5. Solving the governing equations for stability and capacity with these values results in a channel section with a bed width of 10 feet and a flow depth of 3 feet with the difference dependent primarily on the larger value of τ_a used in the refined calculations.

$$\begin{aligned}C_I &= 2.5\left(h\sqrt{M}\right)^{\frac{1}{3}} \\ &= 2.5\left(14 \text{ in } \sqrt{500}\right)^{\frac{1}{3}} \\ &= 2.5\left(1.2 \text{ ft } \sqrt{500}\right)^{\frac{1}{3}} \\ &= 7.48\end{aligned} \qquad \text{(eq. 7–5)}$$

or

$$\begin{aligned}C_I &= 2.5\left(h\sqrt{M}\right)^{\frac{1}{3}} \\ &= 2.5\left(4 \text{ in } \sqrt{500}\right)^{\frac{1}{3}} \\ &= 2.5\left(0.33 \text{ ft } \sqrt{500}\right)^{\frac{1}{3}} \\ &= 4.87\end{aligned}$$

Finally, for the refined computations, the vegetal stress should be checked. The allowable vegetal stress is computed as:

$$\begin{aligned}\tau_{va} &= 0.75 C_{I\,(4 \text{ in length})} \\ &= 0.75(4.87) \\ &= 3.65 \text{ lb/ft}^2\end{aligned} \qquad \text{(eq. 7–4)}$$

Using the quick check for shear stress:

$$\begin{aligned}\tau &= \gamma DS \\ &= 1.12 \text{ lb/ft}^2\end{aligned} \qquad \text{(eq. 7–6)}$$

Since the total average shear stress is less than the allowable stress on the vegetation, this section can be used for the final design. This check will normally have been programmed into design software and will not require separate checking.

Figure 7–8 Design table for example 1

Input parameters:
Channel type=trapezoidal
Cover factor=0.9
Allowable soil stress=0.02
B-D design
Side slope=6

Q	S=0.1% D(ft)	S=0.1% B(ft)	S=0.25% D(ft)	S=0.25% B(ft)	S=0.5% D(ft)	S=0.5% B(ft)	S=0.75% D(ft)	S=0.75% B(ft)	S=1% D(ft)	S=1% B(ft)
10										
20										
30										
40										
50										
60										
70										
80										
90										
100										
110										
120										
130									2.2	10
140									2.1	11
150									2.1	13
160									2.1	15
170									2.0	16
180									2.0	18
190							2.6	11	2.0	19
200							2.5	12	2.0	21
210							2.5	14	2.0	22
220							2.5	15	2.0	24
230							2.5	16	2.0	25
240							2.4	17	2.0	26
250							2.4	19	1.9	28
260							2.4	20	1.9	29
270							2.4	21	1.9	31
280							2.4	22	1.9	32
290							2.4	23	1.9	33
300					3.4	10	2.4	24	1.9	35
310					3.4	11	2.4	26	1.9	36
320					3.3	12	2.3	27	1.9	38

Example 2

This example illustrates design of a parabolic channel and the addition of 0.5 feet of freeboard. Find the channel depth and top width for the following design data.

Channel parameters:	Q = 100 ft^3/s Bed slope S = 2 percent
Soil parameters:	Erosion resistant soil (τ_a=0.05 lb/ft^2)
Vegetation:	C retardance for capacity (C_I=5.60) D retardance for stability (C_I=4.44) Grass mixture (C_F = 0.75)

Solution: Using the appropriate C/D table (fig. 7–9) and entering the table with Q = 100 ft^3/s and S = 2%, the design depth and top width are D = 1.2 ft and T = 37 ft. The channel parabolic coefficient (which is needed for finding the new top width once the 0.5 ft of freeboard are added) is found using equation 7–8:

$$a_p = \frac{4D}{T^2} = \frac{4(1.2)}{(37)^2} = 0.0035 \qquad \text{(eq. 7–8)}$$

The side slope at the water's edge can now be found using equation 7–9:

$$Z = \frac{1}{a_p T} = \frac{1}{(0.0035)(37)} = 7.7 \qquad \text{(eq. 7–9)}$$

With the 0.5 feet of freeboard, the total section depth, D_T, will be equal to 1.7 feet. The final top width of the excavated section is computed as:

$$D_T = 1.2 + 0.5 = 1.7 \text{ ft}$$

$$T = \sqrt{\frac{4D_T}{a_p}} = \sqrt{\frac{4(1.7)}{0.0035}} = 44.1 \text{ ft} \qquad \text{(eq. 7–8)}$$

A final check of the side slope is computed using T = 44.1 feet.

$$z_f = \frac{1}{a_p T_f} = \frac{1}{(0.0035)(44.1)} = 6.5$$

Figure 7–9 Design table for example 2

Input parameters:
Channel type=parabolic
Cover factor=0.75
Allowable soil stress=0.05
C-D design

Q	S=0.1% D(ft)	S=0.1% T(ft)	S=0.25% D(ft)	S=0.25% T(ft)	S=0.5% D(ft)	S=0.5% T(ft)	S=0.75% D(ft)	S=0.75% T(ft)	S=1% D(ft)	S=1% T(ft)	S=1.25% D(ft)	S=1.25% T(ft)	S=1.5% D(ft)	S=1.5% T(ft)	S=1.75% D(ft)	S=1.75% T(ft)	S=2% D(ft)	S=2% T(ft)	S=3% D(ft)	S=3% T(ft)
10	1.1	95	1.6	10	1.5	8														
20	1.5	110	2	11													1.2	7	1	10
30	1.6	116	2.3	12									1.4	9	1.3	10	1.2	11	1	15
40	1.6	121	2.5	13							1.6	11	1.4	12	1.3	13	1.2	15	0.9	19
50	1.7	124							1.8	11	1.6	13	1.4	15	1.3	17	1.2	18	0.9	24
60	1.7	128							1.8	13	1.6	16	1.4	18	1.3	20	1.2	22	0.9	29
70	1.8	125					2.2	13	1.8	16	1.6	18	1.4	21	1.3	23	1.2	26	0.9	34
80	1.9	127					2.2	14	1.8	18	1.6	21	1.4	24	1.3	17	1.2	29	0.9	39
90	1.9	130					2.2	16	1.8	20	1.6	24	1.4	27	1.3	30	1.2	33	0.9	44
100	1.9	132					2.2	18	1.8	22	1.6	26	1.4	30	1.3	34	1.2	37	0.9	49
110	2	134					2.2	20	1.8	24	1.6	29	1.4	33	1.3	37	1.2	41	0.9	54
120	3.3	33			2.9	16	2.2	21	1.8	27	1.6	32	1.4	36	1.3	40	1.2	44	0.9	58

Example 3

This example illustrates using the tables to do stability and capacity design for a slope that is not listed. A similar approach may be used to interpolate for other parameters as appropriate.

Channel parameters:	Trapezoidal channel 4:1 side slopes Bed slope = 0.85 percent Q = 160 ft^3/s
Soil parameters:	Erodible soil (τ_a = 0.03 lb/ft^2)
Vegetal parameters:	C retardance for capacity (C_I=5.60) D retardance for stability (C_I=4.44) Grass mixture (C_F = 0.75)

Solution: To get the bottom width, the C/D table is entered using S = 1 percent. Figure 7–10 shows that the bottom width B should be 35 feet. Also from figure 7–10, for a slope equal to 0.75 percent, we get a trial capacity depth of 1.5 feet.

To find a more accurate capacity depth, start with the trial depth D = 1.5, B = 35, and S = 0.0085 ft/ft, and compute area (A), hydraulic radius (R), trial velocity (V_T), and n. Then use Manning's formula to check velocity. If the velocity computed with Manning's (V_M)is higher, deduct 0.1 foot from the depth and repeat. Keep deducting 0.1 foot until the Manning's velocity is less than the trial velocity. The exact depth will be between the values obtained in the last two steps, and the higher value should be used in the design. The computations are:

$$A = BD + zD^2 = 35(1.5) + 4(1.5)^2 = 61.5\ ft^2 \quad \text{(table 7B–3)}$$

$$R = \frac{A}{B + 2D\sqrt{z^2+1}} = \frac{61.5}{35 + 2(1.5)\sqrt{4^2+1}} = 1.298$$

$$V_T = \frac{Q}{A} = \frac{160}{61.5} = 2.60\ ft/s$$

$$n = \exp\left\{C_I\left(0.0133\left[\ln(VR)\right]^2 - 0.0954\left[\ln(VR)\right] + 0.297\right) - 4.16\right\} = 0.0479$$

(table 7B–2)

where:
C_I = 5.60
V = 2.60 ft/s
R = 1.298

$$V_m = \frac{1.49}{n} R^{\frac{2}{3}} S^{\frac{1}{2}} = \frac{1.49}{0.0479}(1.298)^{\frac{2}{3}}(0.0085)^{\frac{1}{2}} = 3.40 \quad \text{(table 7B–2)}$$

Table 7–7 lists the results of the remainder of the computations.

Since the difference changes from positive to negative between D=1.3 and D=1.2 feet, a depth of 1.3 feet should be used in the final design. As a final step, vegetal stress is checked, and the stress, τ, is found to be less than the allowable vegetal stress, τ_{va}.

$$\tau_{va} = 0.75C_I = 0.75(5.60) = 4.2 \quad \text{(eq. 7–4)}$$

$$\tau = \gamma DS = 62.4(1.3)(0.0085) = 0.69 \quad \text{(eq. 7–6)}$$

Figure 7–10 Design table for example 3

Input Parameters:
Channel Type = Trapezoidal
Cover factor = 0.75
Allowable Soil Stress = 0.03
C-D Design
Side Slope = 4

Q	S = 0.1%		S = 0.25%		S = 0.5%		S = 0.75%		S = 1%		S = 1.25%		S = 1.5%		S = 1.75%		S = 2%		S = 3%		S = 4%		S = 5%		S = 6%		S = 8%		S = 10%	
	D(ft)	B(ft)	D(ft)	B(ft)	D(ft)	B(ft)	D(ft)	B(ft)	D(ft)	B(ft)	D(ft)	B(ft)	D(ft)	B(ft)	D(ft)	B(ft)	D(ft)	B(ft)	D(ft)	B(ft)	D(ft)	B(ft)	D(ft)	B(ft)	D(ft)	B(ft)	D(ft)	B(ft)	D(ft)	B(ft)
10																														
20																					0.6	10	0.5	12						
30																			0.7	13	0.6	16	0.5	19						
40															0.9	11	0.9	13	0.7	18	0.6	23								
50											1.2	10	1	13	0.9	15	0.8	17	0.7	23	0.6	29								
60									1.3	10	1.1	13	1	16	0.9	18	0.8	21	0.6	28	0.6	35								
70									1.3	13	1.1	16	1	19	0.9	22	0.8	25	0.6	33	0.6	41								
80							1.6	10	1.3	15	1.1	19	1	22	0.9	26	0.8	29	0.6	38	0.5	47								
90							1.6	12	1.3	18	1.1	22	1	26	0.9	29	0.8	32	0.6	43	0.5	53								
100							1.5	14	1.2	20	1.1	25	1	29	0.9	33	0.8	36	0.6	48	0.5	59								
110							1.5	17	1.2	22	1.1	28	0.9	32	0.9	36	0.8	40	0.6	53	0.5	65								
120					2.1	10	1.5	19	1.2	25	1.1	30	0.9	35	0.9	40	0.8	44	0.6	59	0.5	71								
130					2.1	12	1.5	21	1.2	27	1.1	33	0.9	38	0.9	43	0.8	48	0.6	64	0.5	77								
140					2	13	1.5	23	1.2	30	1.1	36	0.9	42	0.9	47	0.8	52	0.6	69	0.5	83								
150					2	15	1.5	24	1.2	32	1	39	0.9	45	0.9	50	0.8	56	0.6	74	0.5	89								
160					2	16	1.5	26	1.2	35	1	42	0.9	48	0.9	54	0.8	59	0.6	79	0.5	95								
170					2	18	1.5	28	1.2	37	1	44	0.9	51	0.9	57	0.8	63	0.6	84										
180					2	19	1.5	30	1.2	39	1	47	0.9	54	0.9	61	0.8	67	0.6	89										
190					2	21	1.4	32	1.2	42	1	50	0.9	57	0.9	64	0.8	71	0.6	94										
200					1.9	22	1.4	34	1.2	44	1	53	0.9	61	0.9	68	0.8	75	0.6	99										
210					1.9	24	1.4	36	1.2	46	1	55	0.9	64	0.8	71	0.8	79												
220					1.9	25	1.4	38	1.2	49	1	58	0.9	67	0.8	75	0.8	82												
230					1.9	27	1.4	40	1.2	51	1	61	0.9	70	0.8	78	0.8	86												
240					1.9	28	1.4	42	1.2	54	1	64	0.9	73	0.8	82	0.8	90												
250					1.9	30	1.4	44	1.2	56	1	67	0.9	76	0.8	85	0.8	94												
260			3.5	10	1.9	31	1.4	46	1.2	58	1	69	0.9	79	0.8	89	0.8	98												
270			3.4	11	1.9	33	1.4	48	1.2	61	1	72	0.9	83	0.8	92														
280			3.4	11	1.9	34	1.4	50	1.2	63	1	75	0.9	86	0.8	96														
290			3.4	12	1.9	35	1.4	52	1.2	65	1	78	0.9	89	0.8	99														
300			3.4	13	1.9	37	1.4	54	1.2	68	1	80	0.9	92																
310			3.3	14	1.9	38	1.4	55	1.2	70	1	83	0.9	95																
320			3.3	15	1.9	40	1.4	57	1.2	72	1	86	0.9	99																
330			3.3	16	1.9	41	1.4	59	1.2	75	1	89																		
340			3.3	17	1.9	42	1.4	61	1.2	77	1	91																		
350			3.3	18	1.9	44	1.4	63	1.2	80	1	94																		
360			3.3	19	1.9	45	1.4	65	1.2	82	1	97																		
370			3.2	20	1.9	47	1.4	67	1.2	84	1	100																		
380			3.2	20	1.9	48	1.4	69	1.2	87																				
390			3.2	21	1.9	49	1.4	71	1.2	89																				
400			3.2	22	1.9	51	1.4	73	1.2	91																				
410			3.2	23	1.9	52	1.4	75	1.2	94																				
420			3.2	24	1.8	54	1.4	77	1.2	96																				
430			3.2	25	1.8	55	1.4	78	1.2	98																				
440			3.2	26	1.8	56	1.4	80																						
450			3.2	26	1.8	58	1.4	82																						
460			3.2	27	1.8	59	1.4	84																						
470			3.2	28	1.8	61	1.4	86																						
480			3.1	29	1.8	62	1.4	88																						
490			3.1	30	1.8	63	1.4	90																						
500			3.1	31	1.8	65	1.4	92																						

Table 7–7 Trial and error solution for example 3

Discharge, Q	160	160	160	160
Slope, S	0.0085	0.0085	0.0085	0.0085
Depth, D	1.5	1.4	1.3	1.2
Bottom width, B	35	35	35	35
Side slope, *z*	4	4	4	4
Area, A	61.5	56.84	52.26	47.76
Hydraulic radius, R	1.298	1.221	1.143	1.064
V_T, Q/A	2.602	2.815	3.062	3.350
C_I	5.6	5.6	5.6	5.6
n	0.048	0.048	0.047	0.047
V_M, Manning's	3.401	2.286	3.166	3.038
Difference: $V_M - V_T$	0.799	0.471	0.104	–0.312

650.0705 Layout and construction

(a) Layout

The layout of the waterway should begin at a key point. Usually, this is the outlet, but it may be a point determined by a building, property boundary, gully, or other landscape feature.

(b) Adjustment and marking

After the centerline has been staked, check and move some stakes, if necessary, to avoid landscape features or to improve alignment. The waterway should then be staked for construction. Mark all existing vegetation (trees, shrubs) and other landscape features to be protected during construction.

(c) Site preparation

A good time to build waterways is when the site has a good cover so that runoff and sedimentation will be at a minimum. All debris and vegetation not marked for retention should be removed from the site and disposed of in such a manner that does not adversely affect the environment or proper function of the waterway. For typical design and construction survey notes, see EFH 650.01. Soil may also be used as berms along the sides of the waterway.

(d) Excavation

The soil removed from the waterway should be deposited where it will not interfere with the flow of water into the waterway. Normally, the soil can be shaped and graded to fill low spots in the nearby fields or mounded to create visual interest and screening or to reduce noise and control wind.

The topsoil may be saved and spread in the constructed waterway if necessary for obtaining a good vegetative cover. Where this is done, the waterway should be overexcavated to allow for replacement of the topsoil without encroaching on the design cross section.

(e) Equipment

Many kinds of farming and construction equipment are adapted to the construction of waterways. However, it may be necessary to use equipment that will load and transport the excavated material to locations where it is needed, such as low spots in the surrounding field or washes in the waterway. Although scrapers that can be pulled by farm tractors are satisfactory for waterway construction, large self-propelled scrapers, bulldozers, and motor graders are the preferred equipment.

(f) Appurtenant structures

Effective vegetated waterways are not subjected to low flows of long duration nor kept wet for long periods. Subsurface drains, underground outlets, stone center drains, or other means of providing drainage and protecting the center of the waterway should be considered where low flows or wet conditions are prolonged.

(1) Subsurface drains
Subsurface drains should parallel the center of the vegetated waterway but be offset from the centerline at least a fourth of the top width of the waterway. Two drains may be required in some cases, one on each side of the center. The principles outlined in EFH 650.14 should be followed in designing and installing the subsurface drains. The subsurface drains may be outletted through a drop structure at the end of the waterway or through a standard pipe outlet.

(2) Underground outlets
Underground outlets can be used to carry prolonged low flows. Buried conduits with surface inlets are frequently used downstream of highway culverts or other locations where low flows are concentrated. Blind inlets are sometimes used, but they frequently become a maintenance problem.

(3) Stone center drains
In areas where field stones or other sources of rock are plentiful, a stone center drain may be the best solution to problems of prolonged flow and wetness, A gravel bedding or filter fabric (nonwoven geotextile) is commonly used under the rock to prevent erosion of the underlying soil. These drains are installed as shown in figure 7–11. An alternate cross section would have a stone center that could carry the flow from a

1-year, 24-hour event. Required stone size can be computed using techniques for sizing riprap found in EFH 650.16 or Hydraulic Engineering Circular 11 (FHWA 1989).

(4) Filter fabric barriers

The stability of grassed waterways is based on the establishment of vegetation within the constructed channel's boundaries. Until grass can be established, the waterway is subject to failure from rainfall events significantly less than the design storm. Installing filter fabric in the waterway immediately after the waterway has been constructed is one approach used to minimize the erosive damage caused by untimely rainfall events before the vegetation is established. The barriers are a light weight nonwoven filter fabric (geotextile) plowed into the waterway perpendicular to the direction of flow at intervals ranging from 50 to 100 feet (fig. 7–12).

(g) Postconstruction protection of channel lining

If vegetation is to be used for erosion protection, it should be established as soon after construction as weather conditions permit. (Check 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 an 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 on channel back slopes to improve screening, wildlife habitat, space definition, and climate control (fig. 7–13). 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 competition to permanent seeding. All seeding, planting, sodding, and mulching should conform to standards as given in the local Field Office Technical Guide.

Figure 7–11 Installation of stone center drain

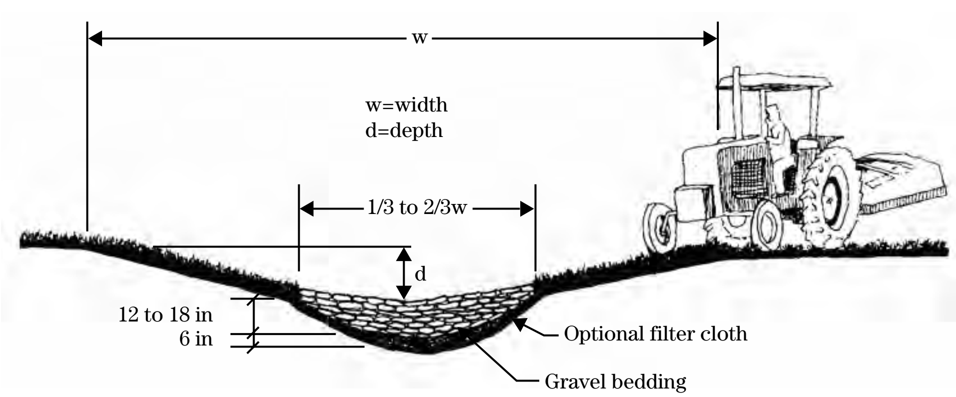
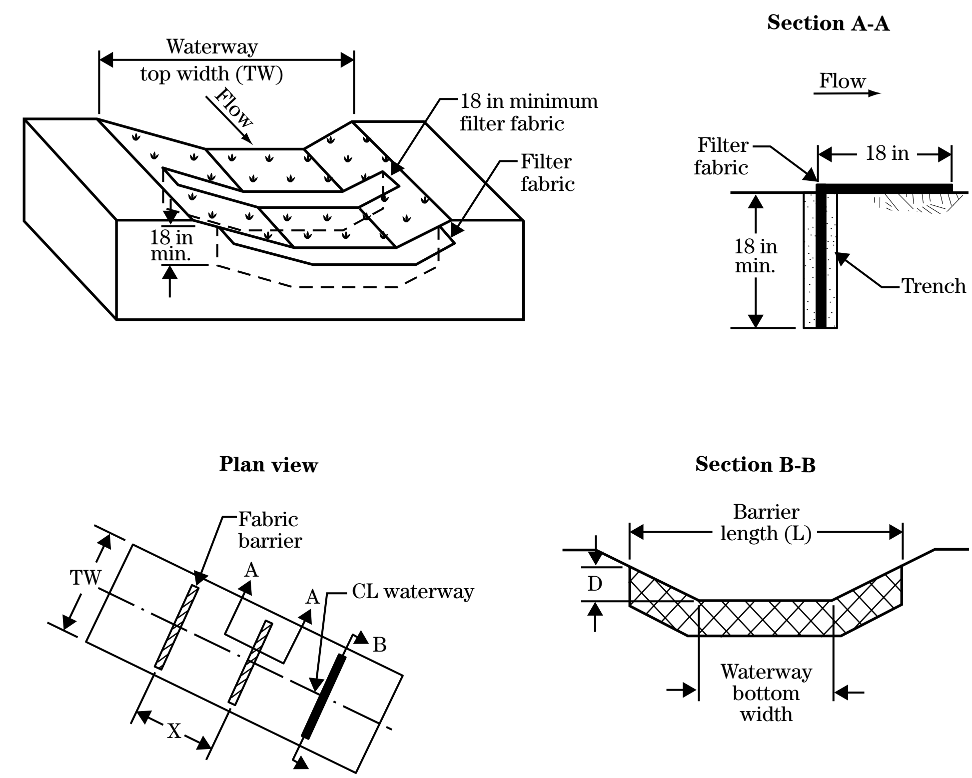


Figure 7–12 Fabric barrier



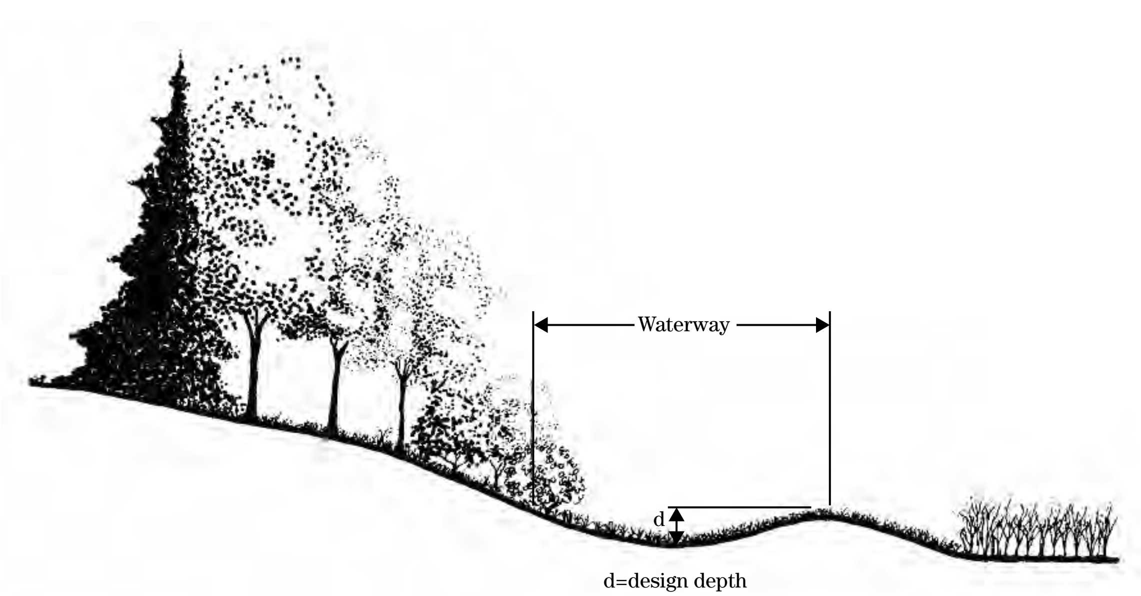
Barrier depth (D)
Barrier spacing (X)
Barrier length (L)

Notes
Fabric barriers are 36 inches wide with 18 inches of the fabric buried and anchored with compacted soil; lay the remaining 18 inches of fabric down the watercourse in the direction of the waterflow. After installation, compact the trench with rear tractor tire; the geotextile shall meet the requirements of NRCS Material Specification 592—Geotextile (ms592), class III nonwoven geotextile. Barriers need to be completed within 14 days after construction check-out. It is recommended that installation be done after seeding.

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

- Reduce the required capacity by dividing the runoff between two or more waterways.
- Construct and vegetate the waterway before any other channels or structures are allowed to discharge into it.
- Carry prolonged low flows in a subsurface drainage system or in a surface-protected section such as a stone center.
- When possible, divert major flows from the waterway during establishment period.
- Maintain vegetative cover by mowing, spraying, fertilizing, and performing other maintenance as needed.

Figure 7–13 Use of woody plantings



650.0706 Maintenance

(a) General

Timely maintenance is important for keeping a waterway in good working condition. Recommended maintenance generally includes mowing of waterways and removing vegetation so as not to retard water flow and cause excessive sedimentation in the channel. Timely mowing is critical for wildlife. The cool-season grasses typically should be fertilized for hay production, while the native grasses may not need fertilizer. Very often herbicides in field runoff can kill introduced grass species, while native grasses may not be affected as much by this problem. Grazing, if permitted, should be rigidly controlled. Livestock should be excluded during wet periods. Vehicular traffic should be excluded except at designated crossings.

(b) Removal of sediment

The waterway channel may require maintenance to remove small sediment deposits. However, if the deposit extends over long reaches or for the full length of the waterway, the channel should be reconstructed by use of appropriate construction equipment. Sediment should be used onsite or disposed of properly.

(c) Repair work

Eroded areas or damage to lining materials should be repaired promptly. This will prevent or reduce further degradation of the waterway system.

The transition section of waterway outlets is the most susceptible to erosion damage. Repairs should be made promptly to prevent gullying from advancing up the waterway 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.

Where underground outlets are used, it is important to keep the outlet free of trash that may plug it and cause failure.

650.0707 References

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Appendix A Notations

Table 7A–1 Description of symbols

Symbol	Description
A	Cross section area, ft^2
a_p	Parabolic coefficient (determines shape of parabola)
B	Bottom width of trapezoidal channel, ft
C_e	Correction for void ratio
C_F	Vegetal cover factor
C_I	Retardance curve index
D	Maximum depth of flow in cross section, ft
d_{75}	75th percentile particle diameter, in
D_T	Section depth after addition of freeboard, ft
e	Void ratio
h	Representative height of vegetation, ft
I_w	Plasticity index
M	Stem density, stems/ft^2
n	Manning's roughness coefficient
n_s	Roughness associated with soil grain size
Q	Discharge in channel, ft^3/s (cfs)
R	Hydraulic radius, ft
S	Channel bed slope, ft/ft
T	Top width of trapezoidal or parabolic channel, ft
V_M	Velocity computed with Manning's equation
V_T	Average section velocity, Q/A (trial value in iterative solution)
z	Side slope
γ	Unit weight of water, 62.4 lb/ft^3
τ	Maximum hydraulic stress, lb/ft^2
τ_a	Allowable effective stress on soil, lb/ft^2
τ_{ab}	Basic allowable stress on soil, before correction for void ratio, lb/ft^2
τ_e	Erosionally effective stress on soil, lb/ft^2
τ_{va}	Allowable stress on vegetation, lb/ft^2

Appendix B Equations

Table 7B–1 Equations for deternining allowable effective stress

Soil classification	Applicable range	Equation
Noncohesive soils	$I_w < 10$	
GW, GP, SW, SP	$d_{75} < 0.05$	$n_s = 0.0156$ $\tau_a = 0.02$
	$d_{75} \geq 0.05$	$n_s = 0.0256 d_{75}^{\frac{1}{6}}$ $\tau_a = 0.4 d_{75}$
Cohesive soils	$I_w > 10$	$n_s = 0.0156$ $\tau_a = \tau_{ab} C_e^2$
GM, SC		$C_e = 1.42 - 0.61e$
	$10 < I_w < 20$	$\tau_{ab} = \left(1.07 I_w^2 + 14.3 I_w + 47.7\right) \times 10^{-4}$
	$I_w > 20$	$\tau_{ab} = 0.076$
GC		$C_e = 1.42 - 0.61e$
	$10 < I_w < 20$	$\tau_{ab} = \left(1.0477 I_w^2 + 2.86 I_w + 42.9\right) \times 10^{-3}$
	$I_w > 20$	$\tau_{ab} = 0.119$
SM		$C_e = 1.42 - 0.61e$
	$10 < I_w < 20$	$\tau_{ab} = \left(1.07 I_w^2 + 7.15 I_w + 11.9\right) \times 10^{-4}$
	$I_w > 20$	$\tau_{ab} = 0.058$
CH		$C_e = 1.38 - 0.373e$
		$\tau_{ab} = 0.0966$

Table 7B–1 Equations for deternining allowable effective stress—Continued

Soil classification	Applicable range	Equation
CL		$C_e = 1.48 - 0.57e$
	$10 < I_w < 20$	$\tau_{ab} = \left(1.07I_w^2 + 14.3I_w + 47.7\right) \times 10^{-4}$
	$I_w > 20$	$\tau_{ab} = 0.076$
MH		$C_e = 1.38 - 0.373e$
	$10 < I_w < 20$	$\tau_{ab} = \left(1.0477I_w^2 + 1.43I_w + 10.7\right) \times 10^{-3}$
	$I_w > 20$	$\tau_{ab} = 0.058$
ML		$C_e = 1.48 - 0.57e$
	$10 < I_w < 20$	$\tau_{ab} = \left(1.07I_w^2 + 7.15I_w + 11.9\right) \times 10^{-4}$
	$I_w > 20$	$\tau_{ab} = 0.058$
OH		$C_e = 1.0$
	$10 < I_w < 20$	$\tau_{ab} = \left(1.0477I_w^2 + 1.43I_w + 10.7\right) \times 10^{-3}$
	$I_w > 20$	$\tau_{ab} = 0.058$
OL		$C_e = 1.0$
	$10 < I_w < 20$	$\tau_{ab} = \left(1.07I_w^2 + 7.15I_w + 11.9\right) \times 10^{-4}$
	$I_w > 20$	$\tau_{ab} = 0.058$

Table 7B–2 Governing hydraulic equations

Basic hydraulic equations	
Manning's *n*	$n = \exp\left\{C_I\left(0.0133\left[\ln(VR)\right]^2 - 0.0954\left[\ln(VR)\right] + 0.297\right) - 4.16\right\}$
Velocity (Manning's formula)	$V = \frac{1.49}{n} R^{\frac{2}{3}} S^{\frac{1}{2}}$
Unit discharge, or discharge per unit width	$q = \frac{Q}{T} = VD$

Stable unit discharge equations

Condition(s)	Equation	Parameters
$0.0025C_I^{2.5} \le q \le 36$ and $\gamma DS \le \tau_{va} + \tau_e$	$q = \exp\left\{\frac{-b - \sqrt{b^2 - 4ac}}{2a}\right.$	$a = 0.0133C_I$ $b = -(0.0954C_I + 0.429)$ $c = 0.297C_I - 0.5\ln(S) + 0.714\ln\left\{\frac{\tau_a}{(1 - C_F)n_s^{2}}\right\} - 6.94$
$q < 0.0025C_I^{2.5}$ or $q > 36$ and $\gamma DS \le \tau_{va} + \tau_e$	$q = \frac{0.0015\tau_a^{\frac{5}{3}} n^{\frac{7}{3}}}{(1 - C_F)^{\frac{5}{3}} n_s^{\frac{10}{3}} S^{\frac{7}{6}}}$	n computed with eq.: for $q < 0.0025C_I^{2.5}$ then $VR = 0.0025C_I^{2.5}$; for $q > 36$ then $VR = 36$
$0.0025C_I^{2.5} \le q \le 36$ and $\gamma DS \ge \tau_{va} + \tau_e$ (stess on vegetation controls)	$q = \exp\left\{\frac{-b - \sqrt{b^2 - 4ac}}{2a}\right.$	$a = 0.0133C_I$ $b = -(0.0954C_I + 0.429)$ $c = 0.297C_I - 1.67\ln(\tau_{va}) + 1.17\ln(S) + 2.33$
neither $0.0025C_I^{2.5} \le q \le 36$ or $\gamma DS \le \tau_{va} + \tau_e$ is satisfied	$q = \frac{0.0015\tau_{va}^{\frac{5}{3}}}{nS^{\frac{7}{6}}}$	$n = \exp(0.126C_I - 4.16)$

Table 7B–3 Cross section geometry equations

Area—trapezoidal channel	$A = BD + zD^2$
Area—parabolic channel	$A = \frac{D^{\frac{3}{2}}}{.75\sqrt{a_p}}$
Depth— trapezoidal channel	$D = \frac{-B\sqrt{B^2 + 4Az}}{2z}$
Depth—parabolic channel	$D = \left(0.75A\sqrt{a_p}\right)^{\frac{2}{3}}$
Hydraulic radius—trapezoidal channel	$R = \frac{A}{B + 2D\sqrt{z^2 + 1}}$
Hydraulic radius—parabolic channel	$R = \frac{A}{\sqrt{4D^2 + \frac{D}{a_p} + \frac{1}{2a_p}\ln\left(\sqrt{4a_pD} + \sqrt{4a_pD + 1}\right)}}$