Part 650 – Engineering Field Handbook

Chapter 7 – Grassed Waterways

IL650.0703 (c) Velocity Design Method for Grassed Waterway

A. For Illinois soils and site conditions, the velocity method of determining grassed waterway stability has been shown to be equivalent to the tractive stress design method presented in Agricultural Research Service (ARS) Agriculture Handbook 667, *Stability Design of Grass-Lined Open Channels* and in the 2007 and later versions of the NRCS National Engineering Handbook, Part 650 – Engineering Field Handbook, Chapter 7.

B. Guidance for the velocity design method is contained within selected pages from the 1986 version of the Engineering Field Handbook, Chapter 7. These pages are retained as an Illinois supplement as follows:

7-6(2)	General design process
7-6(3)	Velocities
7-6(5)	Steps in design
7-6(6)	Example of parabolic waterway design
7-6(7)	Exhibit 7-1 Manning's "n" related to velocity, hydraulic radius and vegetal retardance
7-6(8)	Exhibit 7-2 Classification of vegetation cover as to degree of retardance
7-6(9)	Exhibit 7-3 Permissible velocities for channels lined with vegetation

Hydrologic Investigations

Information on the watershed area, design storm frequency and duration, and runoff estimates are important in determining the capacity of a waterway. The drainage area divides can be determined by field inspection, or by using a stereoscope on aerial photographs and then sketching the drainage area divides on the photographs for measurement.

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 meters per second (cubic feet per second), at each design point, for the frequency and duration of storm selected. Refer to Chapter 2 of this manual for the procedure.

General

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. Commonly needed for designing a waterway is information about the following:

1. Watershed area, in hectares (acres), together-with the soil characteristics, cover, and topography. This information is used to estimate runoff by the procedures set forth in Chapter 2 of this manual.
2. Grade of the proposed waterway in percent.
3. Proposed vegetative cover suitable for site conditions.
4. Erodibility of the soil in the waterway.
5. Expected height at which vegetative cover will be maintained.
6. The permissible velocity for the conditions encountered.
7. Allowance for space that will be occupied by the vegetative lining.
8. Allowance for freeboard, if required by local standards and specifications.
9. A stable starting and ending point.
10. Existing vehicular or pedestrian circulation patterns that may influence alignment or cross section.
11. Unique landscape features that will affect alignment or other components of design.

Waterways are frequently planned for areas where the slope is variable and where there is a wide difference in the watershed area at various points along the channel. In such cases, the waterway is designed in reaches. A reach is generally a portion of the watershed having a near-uniform slope and drainage area. 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 watershed area is significantly increased also may be a point of division between two reaches. Where there is a significant difference in velocity or capacity between adjoining reaches, it may be necessary to install a transition section between them.

Sometimes for ease of layout, construction, and maintenance, the width of the waterway is kept constant and the depth varied to provide required design capacities. However, equipment-crossing requirements must be considered.

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

Vegetative linings vary in their protective ability according to type, density, and height. Therefore, safe velocities under various conditions are a matter of careful consideration.

Velocities

Waterways should be planned and designed to fit the conditions of a particular site. The design of a grassed waterway is complicated because the value for "n" varies with different grass linings. Tests show that vegetation tends to bend and oscillate under the influence of velocity and depth of flow. Thus, the retardance to flow varies as these factors change.

Research has shown that in both large and small waterways, or those of different cross-sectional shape and bed slope, and with different vegetative covers, the retardance coefficient "n" (Manning's coefficient of roughness) varies with VR. See exhibit 7-1, page 7-17. VR is the product of velocity and the hydraulic radius. This relationship will be referred to as the "n-VR relationship," which is the recommended basis for grassed channel design.

The five general retardance curves, designated as A, B, C, D, and E in exhibit 7-1, page 7-17, have been developed for various cover conditions. The vegetal conditions under which the various retardances apply are shown in exhibit 7-2, page 7-18. These cover classifications are based on tests performed in experimental channels when the vegetation was green and generally uniform.

Most of the vegetation used in waterways does not exceed 45 cm (18 in) in height and may be much shorter at times during the year. Therefore, it is recommended that when designing the waterway for safe velocity, a retardance no greater than D be used. After the waterway is designed for safe velocity, it must be checked for capacity to accommodate the peak flow under conditions where vegetation gives the highest retardance. The retardance used in this instance is the curve corresponding to the expected vegetal cover and, in most cases, it will be retardance C, though curves B and A may be used where considered appropriate.

On urban and recreational developments, vegetation is generally maintained at a low height of 25 to 50 mm (1 to 2 in), such as for a lawn or turf. A retardance value of E should be used under these conditions.

All pertinent design data and computations shall be recorded.

In designing grassed waterways, care must be taken to ensure that the design velocity is within the limits of permissible velocities for the soil conditions given in exhibit 7-3, page 7-19. These values apply to average, uniform stands of each type of cover.

Erosion-resistant soils are cohesive (clayey) fine-grained and coarse-grained soils that have cohesive fines and a plasticity index of 10 to 40. Unified soil classifications include CL, CH, SC, and GC. Easily eroded soils do not meet the requirements for erosion-resistant soils. Easily eroded soils do not meet the requirements for erosion-resistant soils. Erosion resistance is also affected by soil density. Some soils such as dispersed clays and nonplastic fine silty sands may be so erosive that successful grassed waterways cannot be constructed.

The prevailing range of maximum permissible velocities used for design is from 0.8 to 2.4 m/s (2.5 to 8.0 ft/s). The maximum permissible velocity will be determined by individual site conditions:

1. A velocity of 0.9 m/s (3.0 ft/s) should be the maximum if, because of shade, soils, or climate, only a sparse cover can be established or maintained.
2. A velocity of 0.9 to 1.2 m/s (3.0 to 4.0 ft/s) should be used under normal conditions if the vegetation is to be established by seeding.
3. A velocity of 1.2 to 1.5 m/s (4.0 to 5.0 ft/s) should be used only in areas if a dense, vigorous sod is obtained quickly or if water can be diverted out of the waterway while the vegetation is being established.
4. A velocity of 1.5 to 1.8 m/s (5.0 to 6.0 ft/s) may be used on well-established, good-quality sod. Special maintenance may be required.
5. A velocity of 1.8 to 2.4 m/s (6.0 to 8.0 ft/s) may be used only on established, excellent quality sod, and only under special circumstances in which the flow cannot be handled at a lower velocity. Under these conditions, special maintenance and appurtenant structures will be required.

If the vegetative lining is supplemented by stone centers, or other erosion-resistant materials, the velocity given in exhibit 7-3 may be increased by

0.06 m/s (2.0 ft/s) or in accordance with local technical guides.

Channel Cross Section

Vegetated waterways may be built in a parabolic, trapezoidal, "V," or "W" 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. Most waterways constructed with a trapezoidal section tend to revert to a parabolic cross section. A modified trapezoidal cross section with the bottom center constructed 0.09 to 0.15 m (0.3 to 0.5 ft) 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 7-3. The "W" shape is sometimes used on flat land so spoil can be placed in the center section. Other uses of "W" shape are to divide flows and to provide a roadway in the center section.

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 add visual diversity.

Capacity

Waterways are constructed to discharge the peak flow expected from at least a 10-year frequency, 24-hour duration storm, as estimated in accordance with Chapter 2. 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 damage or serious property damage will result. In every case it is necessary to provide adequate capacity and safe velocities in accordance with site conditions.

Exhibits 7-4, pages 7-20 through 7-33, and 7-5, pages 7-34 through 7-47, have been prepared to simplify the determination of waterway size for given site conditions. The tables conform to the principles outlined in SCS-TP-61, "Handbook of Channel Design for Soil and Water Conservation." Programmable calculators can be used instead of exhibits 7-4 and 7-5 if appropriate software is available.

Grades

Grades should be selected to meet velocity, capacity, and lining requirements. When permanently vegetated waterways are used in developments to manage or convey storm water, the grade of the channel should be such as to minimize standing water or wetness problems.

Stability

Consider the possible future conditions of the vegetative lining based upon natural succession and maintenance. In some cases the expected stand of vegetation is not attained, or frequently it will deteriorate under normal maintenance. Therefore, it is necessary to check the waterway design for stability against erosion.

Channel Lining

Vegetative channel linings should be established as soon as possible after construction. Any of the following will help achieve this:

1. Establish vegetative cover by sodding part or all of the waterway channel.
2. Use mulch on all waterway seedings.
3. Irrigate sod or seedings as needed.

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 structural lining.

Linings should be designed for capacity and stability in accordance with the principles given in the Handbook for Channel Design (SCS-TP-61) by use of Manning's velocity equation given in Chapter 3 or by other approved procedures.

Perforated concrete blocks may be used as 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 1950's, 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 (See figure 7-4).

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.

Subsurface Drains

Subsurface drains should parallel the center of the vegetated waterway but be offset from the centerline at least one-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 Chapter 14 of this manual 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.

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.

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 is commonly used under the rock to prevent erosion of the underlying soil. These drains are installed as shown in figure 7-5. An alternate cross section would have a stone center that could carry the flow from a 1-year, 24-hour event. Required stone size in relation to grade of waterway and depth of flow can be determined from the nomograph, exhibit 7-6, page 7-48.

Steps in the Design of a Waterway

1. Plan the location of the waterway centerline that minimizes impacts.
2. Select design points along the waterway where grades change or drainage areas and type of lining change significantly.
3. Determine the watershed area for the points in step 2 and for the outlet.
4. Find the peak runoff produced by the design storm.
5. Determine the slope of the channel from the topographic map, profiles, or cross sections.
6. Select the appropriate channel cross section and the type of channel protection to be used—bare, vegetated, or lined.
7. Design the channel for stability by selecting the maximum permissible velocity (exhibit 7-1).

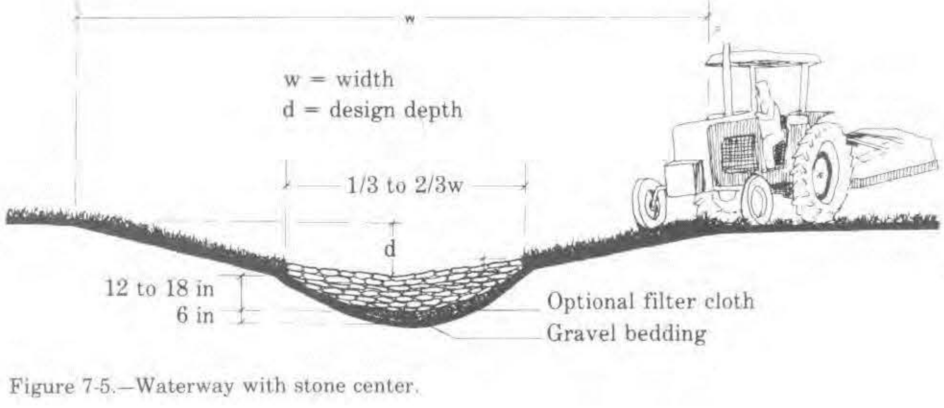

Figure 7-5.—Waterway with stone center.

8. Design the channel for adequate capacity using Manning's formula.
9. Design a system to adequately dispose of base flow and to keep the channel or lining well drained.
10. Select depth of waterway from exhibit 7-4 or 7-5.

The dimensions given by exhibits 7-4 and 7-5 are the minimums required to carry the actual flow. These tables 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 dimensions given in these tables. It is important that the depth be adequate to permit unimpeded discharge from terraces, diversions, and crop rows.

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

1. Installing a vegetation filter strip on each side of the waterway where surface water enters.
2. Increasing the depth and channel width to store trapped sediment.
3. Providing for clearing out the channel when its design capacity deteriorates.

Example of Parabolic Waterway Design

The following example demonstrates how to use the exhibits to design a parabolic channel.

Problem—

Determine the permissible velocity and dimensions for stability and capacity for a waterway with parabolic cross section.

Given—

Runoff: Q = 1.6 m^3/s (55 ft^3/s)
Grade: 5 percent
Vegetative Cover: Kentucky Bluegrass
Soil: Easily eroded.

Condition of Vegetation—

Good stand—After cutting to 50-mm (2-in) height: D curve retardance (from exhibit 7-2)
Good stand—Headed 150 mm to 300 mm (6 in to 12 in): C curve retardance (from exhibit 7-2)
Maximum Permissible Velocity—V_1: 1.2 m/s (4.0 ft/s) (from exhibit 7-3)

Horizontally opposite 1.6 m^3/s (55 ft^3/s) in exhibit 7-4 (5 percent slope) in the columns headed V_1 = 1.2 m/s (4.0 ft/s), find T = 10.4 m (34.1 ft), D = 0.2 m (0.7 ft), and V_2 = 1.0 m/s (3.3 ft/s). Therefore, a waterway with a parabolic cross section, a top width of 10.4 m (34.1 ft), and a depth of 0.2 m (0.7 ft) will carry 1.6 m^3/s (55 ft^3/s) at a maximum velocity of 1.2 m/s (4 ft/s) when the vegetative lining is short, 50 mm to 100 mm (2 in to 4 in) in height, and 1.0 m/s (3.3 ft/s) when vegetative lining is tall, 150 mm to 300 mm (6 in to 12 in). This complies with the requirements for safe velocity when vegetation is short (D retardance) and for capacity when vegetation is tall (C retardance).

If a stone center is used, the maximum permissible velocity can be increased to 1.8 m/s (6 ft/s). In time, stone center waterways usually become vegetated; so, for practical design purposes, the same retardance values in the preceding example can be used and dimensions changed to T = 4.8 m (15.9 ft) and d = 0.3 m (0.9 ft).

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. 7-6). Large combines, pickers, sprayers, and similar equipment may require a significant increase in width over that needed for hydraulic capacity and freeboard. This problem 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. Where paved channels are to be crossed, the lining must be designed to carry the expected loads. Culverts or bridges of adequate capacity may also be used.

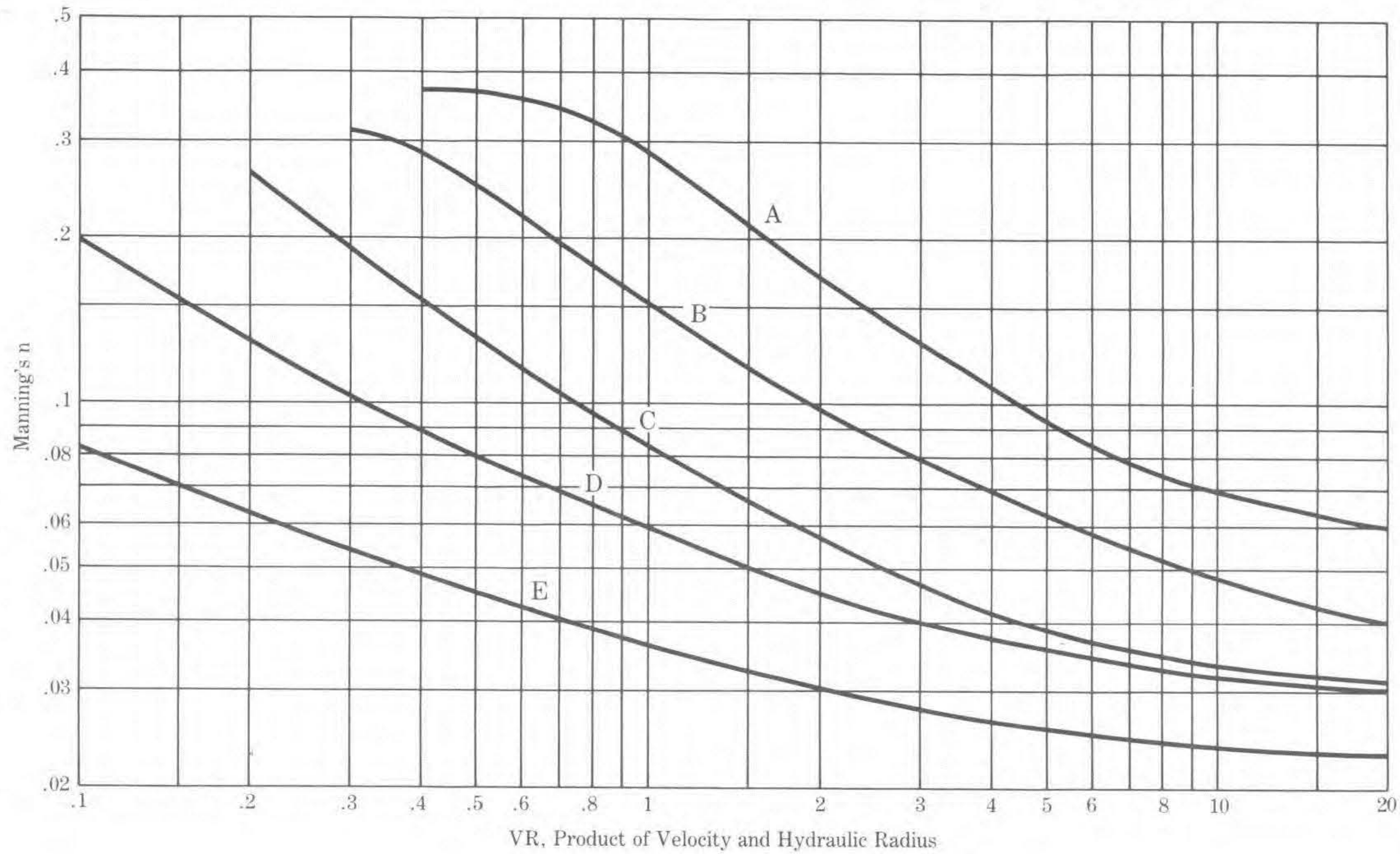

Exhibit 7-1.—Manning's "n" related to velocity, hydraulic radius, and vegetal retardance. (Ref: SCS-TP-61, Handbook of Channel Design for Soil and Water Conservation).

Retardance	Cover	Condition
A	Weeping lovegrass	Excellent stand, tall (average 30 inches)
	Reed canarygrass or Yellow bluestem ischaemum	Excellent stand, tall (average 36 inches)
B	Smooth bromegrass	Good stand, mowed (average 12 to 15 inches)
	Bermudagrass	Good stand, tall (average 12 inches)
	Native grass mixture (little bluestem, blue grama, and other long and short midwest grasses	Good stand, unmowed
	Tall fescue	Good stand, unmowed (average 18 inches)
	Sericea lespedeza	Good stand, not woody, tall (average 19 inches)
	Grass-legume mixture— Timothy, smooth bromegrass, or orchardgrass	Good stand, uncut (average 20 inches)
	Reed canarygrass	Good stand, uncut (average 12 to 15 inches)
	Tall fescue, with birdsfoot trefoil or ladino clover	Good stand, uncut (average 18 inches)
	Blue grama	Good stand, uncut (average 13 inches)
C	Bahiagrass	Good stand, uncut (6 to 8 inches)
	Bermudagrass	Good stand, mowed (average 6 inches)
	Redtop	Good stand, headed (15 to 20 inches)
	Grass-legume mixture—summer (orchardgrass, redtop, Italian ryegrass, and common lespedeza)	Good stand, uncut (6 to 8 inches)
	Centipedegrass	Very dense cover (average 6 inches)
	Kentucky bluegrass	Good stand, headed (6 to 12 inches)
D	Bermudagrass	Good stand, cut to 2.5-inch height
	Red fescue	Good stand, headed (12 to 18 inches)
	Buffalograss	Good stand, uncut (3 to 6 inches)
	Grass-legume mixture—fall, spring (orchardgrass, redtop, Italian ryegrass, and common lespedeza)	Good stand, uncut (4 to 5 inches)
	Sericea lespedeza or Kentucky bluegrass	Good stand, cut to 2-inch height. Very good stand before cutting
E	Bermudagrass	Good stand, cut to 1.5-inch height
	Bermudagrass	Burned stubble

Exhibit 7-2.—Classification of vegetation cover as to degree of retardance.

Cover	Slope range[2]	Permissible velocity[1] Erosion resistant soils[3]	Permissible velocity[1] Easily eroded soils[4]
	percent	*m/s (ft/s)*	*m/s (ft/s)*
Bermudagrass	<5	2.43 (8)	1.82 (6)
	5-10	2.13 (7)	1.22 (4)
	over 10	1.82 (6)	0.91 (3)
Bahiagrass Buffalograss Kentucky bluegrass Smooth brome Blue grama Tall fescue	<5 5-10 over 10	2.13 (7) 1.82 (6) 1.52 (5)	1.52 (5) 1.22 (4) 0.91 (3)
Grass mixture	[2]<	1.52 (5)	1.22 (4)
Reed canarygrass	5-10	1.22 (4)	0.91 (3)
Sericea lespedeza Weeping lovegrass Yellow bluestem Redtop Alfalfa Red fescue	[5]<5	1.06 (3.5)	0.76 (2.5)
Common lespedeza[6] Sudangrass[6]	[7]<5	1.06 (3.5)	0.76 (2.5)

1 Use velocities exceeding 1.52 m/s(5ft/s) only where good covers and proper maintenance can be obtained.
2 Do not use on slopes steeper than 10 percent except for vegetated side slopes in combination with a stone, concrete, or highly resistant vegetative center section.
3 Cohesive (clayey) fine-grain soils and coarse-grain soils with cohesive fines with a plasticity index of 10 to 40 (CL, CH, SC, and CG).
4 Soils that do not meet requirements for erosion-resistant soils.
5 Do not use on slopes steeper than 5 percent except for vegetated side slopes in combination with a stone, concrete, or highly resistant vegetative center section.
6 Annuals—use on mild slope or as temporary protection until permanent covers are established.
7 Use on slopes steeper than 5 percent is not recommended.

Exhibit 7-3.—Permissible velocities for channels lined with vegetation.