Channel Stabilization with Basic Flow Calculations

Description

The selection of a channel lining will greatly influence how a drainage channel performs, the amount of erosion and scour, the frequency and cost of maintenance, appearance, aesthetics, and even safety. In addition, the amount of sediment and nutrients conveyed can be influenced greatly by the type of channel lining selected. This BMP examines different factors and some basic design parameters for channels and channel linings.

Suitable applications are any areas which regularly receive and convey concentrated stormwater runoff, such as drainage channels, ditches, or swales. Channel linings can also be used in areas which occasionally convey stormwater runoff, such as overland relief swales or emergency spillways.

Selection Criteria

Every drainage channel, ditch, or swale must have some type of channel lining. By default and if not specified, then the existing channel lining is native soil or rock. The least expensive and most beneficial lining is usually a grass channel if design parameters do not indicate excessive velocities, regular submergence, inadequate flow capacity, or potential maintenance problems. Grass channels are easy to maintain, flexible and self-healing, attractive in appearance, remove pollutants (see 9.5 Filter Strips and Swales), and decrease the amount of runoff by allowing stormwater infiltration and evapotranspiration.

Grass channels are an example of a flexible lining (may also be called a “soft” or “green” lining) which include vegetation as the principal means of preventing erosion. A variety of temporary and permanent geosynthetic products can help to establish a soft lining; common examples are erosion control matting, excelsior blankets, geogrids filled with soil, or turf reinforcement mats. Soft linings are aesthetically pleasing, flexible, and easy to install and maintain. Some drawbacks to soft linings are the potential for damage by heavy traffic, excessive drought or pollution.

Riprap and concrete and some geosynthetic channel linings are examples of rigid or “hard” linings. These channel linings are used when design velocities exceed permissible values for soft linings, or to improve flow capacity by reducing roughness and flow losses.

Hard linings must be installed in a controlled manner with proper materials, compaction, bedding, and anchoring in order to prevent scour, undercutting or settlement.

By law, anyone who works within or along a stream must obtain an Aquatic Resource Alteration Permit (ARAP) from the TDEC Division of Water Pollution Control. The ARAP is required for activities such as: dredging, widening a stream channel, straightening a stream channel, building a dock or boat ramp, altering a wetland, utility line crossings or streambank stabilization. Visit the TDEC permitting website for more information at http://www.state.tn.us/environment/permits/

Related BMPS which impact the selection of channel linings include:

- Matting (MA)
- Geotextile (GE)
- Diversion Ditch (DI)
- Riprap (RR)
- Slope Drain (SD)

Basic Flow Calculations

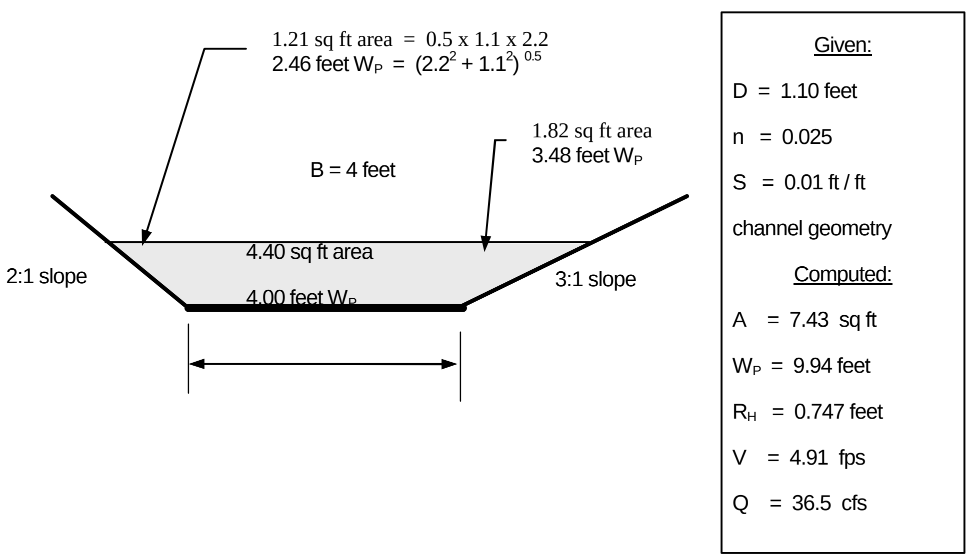
This section contains a description of basic flow computations for use in designing an open channel, ditch or swale. Drainage channels and ditches should generally be designed by a professional engineer to ensure that adequate drainage capacity and allowable flow velocities are provided. Open-channel computations are usually in the form of Manning's equation:

$$V = (1.49 / n)\ R_H^{2/3}\ S^{1/2}$$, where

V = average velocity in channel (feet per second)
n = Manning's roughness coefficient (dimensionless)
R_H = hydraulic radius of channel = A / W_P (expressed in feet)
S = energy grade line = channel slope for uniform flow (dimensionless)
A = cross-sectional flow area (square feet)
W_P = wetted perimeter of flow (feet)

The total flow through the channel (Q, expressed in cubic feet per second) is equal to the velocity times the cross-sectional flow area: $Q = V\ A$

Figure 1
Basic Flow Computation – Manning's Equation



Manning's equation is for open-channel flow and assumes a constant uniform flow rate at a specified slope. There are many factors which can affect this assumption, such as varying channel widths and slopes, downstream flow restrictions, backwater from dams or other berms, culvert entrance and exit losses, headwater at culverts or bridges, channel bends, varying lining materials, etc. Any of these factors will generally require that an experienced professional engineer be responsible for design and analysis. In addition, channels with unusual shapes, composite materials or uneven sections will generally require that a professional engineer with knowledge and experience should be responsible for the design and analysis. In addition, channels with unusual shapes, composite materials or uneven sections will generally require that a professional engineer with knowledge and experience should be responsible for the design and analysis. The major difficulty in estimating velocity and flow is usually the selection of Manning's roughness coefficient "n". Typical values are listed in Table 1 and Table 2. See Table 3 for n values of grass channels, based upon type and height of vegetation, and product of velocity (V) and hydraulic radius (R_H).

Subcritical and Supercritical Flow

It is useful to know whether a flow is subcritical (also called tranquil flow, backwater flow or downstream control) or supercritical (also called rapid flow or upstream control). This is determined by computing the Froude number; a value of F_R less than 1 is subcritical and a value greater than 1 is supercritical. Subcritical flow is greatly preferred because it has a lower velocity than supercritical flow. A value of F_R between 0.8 and 1.2 indicates that the channel is close to critical flow, and that small changes in channel cross section, flows, slopes, etc., may cause the water surface to change radically or even create a hydraulic jump or standing wave. Open channels should not be designed at or near critical flow conditions.

$$F_R = ((Q^2 * T) / (g * A^3))^{1/2}$$, where

F_R = Froude number (dimensionless)
Q = discharge or flow (cubic feet per second)
T = top width of water surface (feet)
g = gravitational constant = 32.2 feet/ second^2
A = cross-sectional flow area (square feet)

(for Figure 1) $F_R = ((36.5^2 * 9.5) / (32.2 * 7.43^3))^{0.5} = 0.98$

The example channel in Figure 1 is approximately at critical flow and should be changed. Since subcritical flow is the preferred flow regime, this can be accomplished by widening the channel, flattening the side slopes, increasing the Manning's roughness coefficient n, or decreasing the channel slope.

Critical depth (D_C) indicates the flow depth for which the specific energy (E) is at a minimum value for a given discharge. Specific energy is computed by the equation:

$E = D + V2 / (2g)$ For the example in Figure 1, the specific energy is 1.474 feet.

Using the example in Figure 1, a roughness coefficient value of 0.025 corresponds to any of several channel linings in Table 1 such as:

- Bare earth, straight and uniform, short grass
- Erosion control matting (excelsior mat)
- Rocky channel, smooth and very uniform

Using same geometry as shown in Figure 1 with a grass channel lining instead will yield the following two sets of answers for the same given flow of 36.5 cfs. In general, a conservative design will use unmowed grass to check conveyance and mowed grass to check for velocities. So the design depth would be 2.06 feet and the design velocity would be 3.56 fps.

Table 1
Manning's Roughness Coefficient – Channels

Closed Conduits	**n**
Brick	0.016
Cast-iron pipe	0.013
Cemented rubble	0.021
Concrete pipe	0.013
Corrugated metal pipe, plain, regular corrugations	0.024
Corrugated metal pipe, asphalt-paved invert, flowing full	0.020
Closed Conduits	**n**
Corrugated metal pipe, asphalt-paved, 50% flow depth	0.015
Corrugate metal pipe, large corrugations (1" or 2" deep)	0.030
Plastic pipe, smooth/corrugated (consult manufacturer)	------
PVC pipe	0.011
Steel pipe	0.010
Vitrified clay	0.013
Open Channels	**n**
Asphalt pavement	0.016
Bare earth, straight and uniform, no vegetation	0.020
Bare earth, straight and uniform, with some short grass	0.025
Bare earth, winding and sluggish	0.025
Bare earth, winding and sluggish, with some short grass	0.030
Brick	0.015
Cemented rubble	0.020
Concrete channel, unfinished	0.015
Concrete channel, troweled	0.013
Concrete channel, troweled with exposed gravel finish	0.017
Concrete channel with mortared or riprap sides	0.015 - 0.030
Concrete gutter, finished and troweled	0.013
Erosion control matting (excelsior mat or straw netting)	0.025 - 0.035
Erosion control matting (jute net)	0.022
Grass	Table 3
Gravel or aggregate, compacted	0.030 - 0.050
Gravel bottom, with weeds on banks	0.035
Riprap, dumped (n chosen from D50 size)	See 5.8 Riprap
Riprap, grouted and placed as a smooth uniform channel	0.030 - 0.040
Rocky channel, smooth and uniform	0.025 - 0.035
Rocky channel, irregular and winding	0.040 - 0.050
Weeds and brush, uncut, only on banks	0.040 - 0.080
Weeds and brush, uncut, across entire channel	0.080 - 0.120

Grass channels are frequently grouped into categories based upon the "retardance" that reflects the height and type of vegetation, flow characteristics of channel, etc. The retardance classification taken from Table 3 is then used in Figure 2 to select a Manning's roughness coeffficient based upon the product of velocity, V, and the hydraulic radius, R_H. Solving Manning's equation for a grass surface, due to the variable roughness coefficient, is an iterative process for which a spreadsheet may be helpful.

Table 2
Manning's Roughness Coefficient – Natural Channels **Closed Conduits**

Natural Stream (less than 100 feet wide at flood stage)	**n**
Clean, straight, no rifts or deep pools, grass banks*	0.025 - 0.035
Clean, straight, grass with some stones and weeds*	0.030 - 0.040
Clean, winding, pools and shoals*	0.033 - 0.045
Clean, winding, pools and shoals, some stones and weeds*	0.035 - 0.050
* Values may be increased by the largest of the 4 possible adjustments below:	
1. Adjust upward by 0.005 for lower stages or ineffective flow areas	
2. Adjust upward by 0.005 for larger stone and weeds	
3. Adjust upward by 0.010 to 0.020 for partially submerged trees / branches	
4. Adjust upward by 0.030 to 0.050 for entire submerged trees in channel	
Sluggish reaches, deep pools, many weeds	0.050 - 0.080
Sluggish, many deep pools, full of weeds, heavy timber	0.075 - 0.150
Mountain stream, gravel and cobbles, with steep banks	0.030 - 0.050
Mountain stream, cobbles and boulders, with steep banks	0.040 - 0.070
• In general, n values are lower for larger streams because the banks offer less resistance. Usually larger streams have been modeled by government agencies such as TVA, FEMA, or the City of Chattanooga so that some guidance is available on roughness coefficients used. • Manning's n values can be substantially different during summer when vegetation may be overgrown and trees contain branches full of leaves. Adjust values upward if stream flow submerges trees and tree branches.	
Floodplains (adjacent to natural streams)	**n**
Cleared land with tree stumps	0.040 - 0.050
Pasture, no brush, short grass	0.030 - 0.035
Pasture, no brush, high grass	0.035 - 0.050
Farmland, no crops	0.030 - 0.040
Farmland, mature crops	0.040 - 0.050
Heavy weeds, scattered brush	0.050 - 0.070
Light brush and trees	0.050 - 0.080
Medium to dense brush	0.070 - 0.110
Dense brush, thick trees, undergrowth, fallen logs	0.100 - 0.160

Natural streams have constantly varying cross sections and slopes, so that the Manning's equation should be used carefully with the understanding that other factors may affect flow depth. Therefore, the use of Manning's equation for natural streams should only be for rough estimating purposes.

Water surface profile programs (such as HEC-2 and HEC-RAS developed by the US Army Corps of Engineers Hydraulic Engineering Center and WSPRO) can handle multiple roughness coefficients, complex geometry, bridges, culverts, flow obstructions, and varied flow values into consideration. Water surface profiles must be prepared by a professional engineer using the best available data.

Table 3

Retardance Classifications for Grass Channels

Class	Type of Vegetation	Condition
A	Yellow bluestem ischaemum	Excellent stand, tall, 36" average
	Weeping lovegrass	Excellent stand, tall, 30" average
B	Alfalfa	Good stand, uncut, 11"
	Bermudagrass	Good stand, tall, 12"
	Blue gamma	Good stand, uncut, 13"
	Kudzu	Very dense growth, uncut
	Reed canarygrass	Good stand, cut, 12" to 15"
	Sericea lespedeza	Good stand, not woody, tall, 19"
	Tall fescue	Good stand, uncut, 18"
	Weeping lovegrass	Good stand, uncut, 13"
	Grass mixture #1	Good stand, uncut
	Grass mixture #2	Good stand, uncut, 20"
C	Bahiagrass	Good stand, uncut, 6" to 8"
	Bermudagrass	Good stand, cut, 6" to 8"
	Centipedegrass	Very dense cover, 6" to 8"
	Crabgrass	Fair stand, uncut, 10" and longer
	Kentucky bluegrass	Good stand, headed, 8" to 10"
	Redtop	Good stand, uncut, 15" to 20"
	Tall fescue	Good stand, cut or uncut, 6" to 8"
	Grass mixture #3	Good stand, uncut, 6" to 8"
D	Bahiagrass	Good stand, cut, 3" to 4"
	Bermudagrass	Good stand, cut, 2.5"
	Buffalograss	Good stand, uncut, 3" to 6"
	Centipedegrass	Good stand, cut, 3" to 4"
	Kentucky bluegrass	Good stand, cut, 3" to 4"
	Red fescue	Good stand, uncut, 12"
	Sericea lespedeza	Good stand, cut, 2"
	Tall fescue	Good stand, cut, 3" to 4"
	Grass mixture #4	Good stand, uncut, 4" to 5"
E	Bermudagrass	Good stand, cut, 1.5"
	Any type of grass	Burned or trampled, any length
Native grass mixture #1 - prairie grasses, bluestem, blue gamma		
Summer grass mixture #2 - tall fescue, red fescue, sericea lespedeza		
Summer grass mixture #3 - timothygrass, smooth bromegrass or orchardgrass		
Spring/autumn grass mixture #4 - orchardgrass, redtop, annual lespedeza		

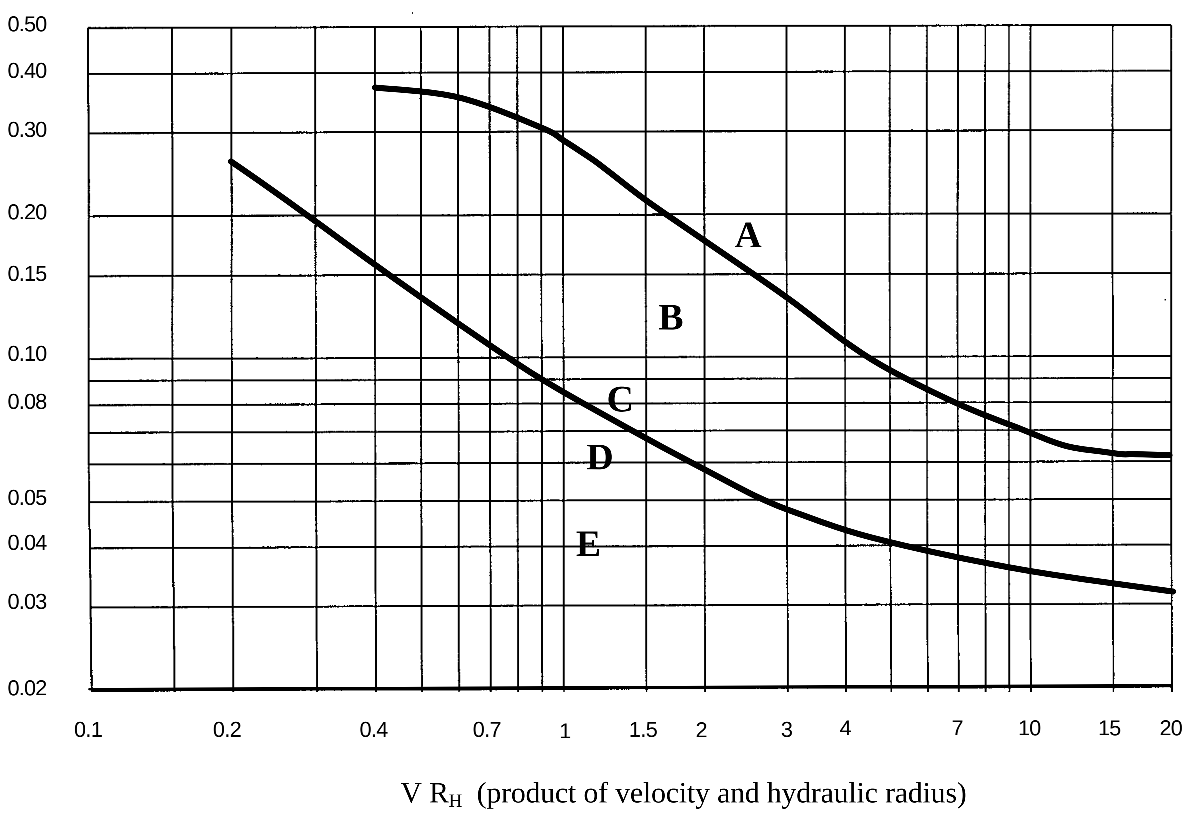
Grass channels are often designed as a parabolic shape without any corners or slope breaks. The following formulas for cross-sectional flow area (A) and hydraulic radius (R_H) are based on the top width of flow (T) and maximum flow depth at the center of channel (D):

$$A = 2/3\,(T\,D)$$

$$R_H = (T^2 D) / (1.5\,T^2 + 4\,D^2)$$

UNMOWED Retardance B:	*MOWED* Retardance D:
Q = 36.5 cfs	Q = 36.5 cfs
n = 0.089	n = 0.039
D = 2.06 feet	D = 1.38 feet
A = 18.85 sq ft	A = 10.28 sq ft
W_P = 15.12 feet	W_P = 11.45 feet
R_H = 1.247 feet	R_H = 0.898 feet
V = 1.94 fps	V = 3.56 fps

Figure 2
Manning's Roughness Coefficient – Grass Channels



A channel lining may be judged adequate or permissible based on two possible criteria, either permissible shear stress or permissible velocity. Permissible shear stress is based on the force necessary to displace or move the soil, aggregate, or other type of channel lining. The formula for normal shear stress (T) at the bottom of a uniform channel is shown below. This value is adjusted for several factors such as side slope, bend angles, shape of channel, etc., before being compared to published values of permissible shear stress.

$$T = \gamma D S$$

T = shear stress (pounds per square foot)
γ = unit weight of water (62.4 pounds per cubic foot)
D = flow depth of water (feet)
S = channel slope (feet per foot)

The simpler design method is to specify a permissible velocity for each type of channel lining. Typical permissible velocities are listed in Table 4. In general, a temporary channel lining should be considered if the design flow velocity for bare soil is greater than 2 feet per second. For preliminary design, a soil may be considered erodible if it has a published K value of 0.35 or greater in the Hamilton County soils map.

Table 4
Permissible Velocities

Channel Lining Material	Permissible Velocity (fps)		
Silt or very fine-grained materials	1.5		
Fine sand, sandy loam, silty loam	2.0		
Undisturbed alluvial sediments	3.5		
Stiff clay	3.5		
Coarse sand or fine gravel (no silt)	4.0		
Coarse gravel	5.0		
Cobbles, hard pan, shale	5.5		
	0- 5%	*5 -10%*	*≥10%*
Erodible Soil (silt, loam, sand)			
Bermuda grass	5.5	4.5	3.5
Bahia grass, Blue Gamma, Kentucky bluegrass Reed canary grass, Tall fescue	4.5	3.5	2.5
Mixture (fescue, lespedeza., legumes)	3.5	3.0	----
Alfalfa, Crabgrass, Kudzu, Sericea lespedeza Weeping love grass, Yellow bluestem	3.0	2.5	----
Resistant Soil (gravel, clay, cohesive)			
Bermuda grass	6.5	5.5	4.5
Bahia grass, Blue Gamma, Kentucky bluegrass Reed canarygrass, Tall fescue	5.5	4.5	3.5
Mixture (fescue, lespedeza., legumes)	4.5	3.5	----
Alfalfa, Crabgrass, Kudzu, Sericea lespedeza Weeping love grass, Yellow bluestem	3.5	3.0	----

Maintenance

Channel linings should be inspected at least weekly during the construction phases to ensure proper functioning and necessary control of erosion and sediment. Inspect channels monthly during the first year after construction to verify that drainage channels work properly as designed and constructed.

After the first year, channel linings should be inspected at least quarterly on a permanent basis. Look for erosion, siltation, undercutting or settlement throughout the length of channel. Verify that upstream and downstream portions of channel are not adversely affected.

Limitations

Flexible channel linings need frequent maintenance and inspections to ensure adequate function and erosion control. Soft channel linings can be damaged or stressed due to many factors.

Rigid permanent channel linings often result in prevention of habitat establishment. Hard linings may be damaged due to settlement, scour or undercutting despite the best efforts and care taken during installation.

Inadequate coverage or depth of channel linings will result in erosion, washout, and poor plant establishment. If the channel grade and liner are not appropriate for the amount of runoff, channel bottom erosion may result.

Riprap must be sized correctly and installed according to correct procedures. If the channel slope is too steep or riprap is too small, displacement may occur. Displaced riprap may obstruct channel or cause additional damage (see Section 5.8 Riprap).

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Photos 1 - 2

An Application of 'Soft' or 'Green' Channel Lining