DEPARTMENT OF TRANSPORTATION
STATE OF GEORGIA

INTEROFFICE CORRESPONDENCE

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SUBJECT: Channel Protection Explanation and Design Examples

Standard Specification Section 711 "Turf Reinforcement Matting" provides criteria for the proper selection of six TRM materials on the basis of six shear strength ranges. Under Section 711, contractors will be required to use the TRM that the designer specifies.

A computer program entitled ***Channel Lining Design*** has been developed to aid designers in the proper selection of all channel protection materials, which includes the higher shear strength protection materials Types 1 and 3 riprap and concrete. The program calculates the maximum hydraulic shear stress, which occurs on the channel bottom.

The document ***The Categorization of Erosion Control Matting*** explains the theory of channel protection design and the logic of the Channel Lining Design program. It is available indefinitely for designers to read, if they desire. A series of symbols "Trm-1" through "Trm-6", each corresponding to an applicable shear stress range, has been added to the ESPCP Legend. These symbols replaced the symbol "Ps" on July 1, 2013. The following are the six new pay item numbers and descriptions for TRM:

Pay Item	Description	Shear Stress Range	ESPCP Symbol
711-0100	Turf Reinforcing Mat, TP 1; (SY) (M2)	0-2 psf	Trm-1
711-0200	Turf Reinforcing Mat, TP 2; (SY) (M2)	0-4 psf	Trm-2
711-0300	Turf Reinforcing Mat, TP 3; (SY) (M2)	0-6 psf	Trm-3
711-0400	Turf Reinforcing Mat, TP 4; (SY) (M2)	0-8 psf	Trm-4
711-0500	Turf Reinforcing Mat, TP 5; (SY) (M2)	0-10 psf	Trm-5
711-0600	Turf Reinforcing Mat, TP 6; (SY) (M2)	0-12 psf	Trm-6

The Geotechnical Bureau of the Materials Office, under Glen Foster's supervision, has completed the revision of the soil survey report format to include the 75th percentile soil grain diameter (D_{75}), the plasticity index (PI), and the Unified Soil Classification System (USCS) soil symbols. Still, some projects underway do not have an updated soil survey. Below are some values that can be used as estimates for Blue Ridge and Piedmont soils for older projects:

- PI 10
- D_{75} 0.02 inches
- USCS e.g., usually silty sand(SM) sometimes clayey sand (SC) or sandy clay (CL)

Onsite soil sampling and analysis is the preferred method to determine the soil properties of all four of Georgia geological provinces, but sampling is especially necessary for determining the properties of the Ridge and Valley soils of Northwest Georgia and the Coastal Plain soils because they can be so unpredictable.

The NRCS website http://websoilsurvey.nrcs.usda.gov/ and other soil information sources are additional resources for estimating soil properties, both horizontally and vertically up to depths of 6 or 7 feet. Document all values used in the project's design data book.

We understand that assumptions on the characteristics of the established future vegetation must be made. These assumptions are often difficult to make because of the many variables: e.g., soil type, fertility, the time of year, and general setting. Good, conservative beginning estimates for the vegetative input are bunch grass, good cover density (75-95%), and 0.5-foot stem height.

For the past several months, our office has fielded comments from our inside designers and outside consultants about the program's limitations and problems, and we have addressed them and more. However, designers still must run each channel segment separately when using the Georgia Tech program.

Two appendices that explain the theoretical and practical aspects of channel protection design are attached below.

Should anyone need additional assistance, contact us at 404-631-1547 (Jon D. Griffith, P.G., P.E.) or 404-631-1630 (Brad McManus, P.E.).

cc: Daniel Pass, P.E.
Brad McManus, P.E.
Luis Vazquez, P.E.
File

Appendix 1

Theory:

Numerical Simulation

Two governing equations are included to establish the relationship between quantity of flow (Q), average velocity ($\bar{u}$) and flow depth (or cross-sectional area for given geometry):

(1) Continuity equation $Q = \bar{u} \cdot A$

(2) Backwater equation (Chow, 1959) $\frac{dy}{dx} = \frac{S_0 - S_f}{1 - F_r^2}$

Where $Fr = \frac{u}{\sqrt{gy}}$

The following examples present numerical simulations designed to mimic those conditions typically encountered for roadside channels in Georgia. Channel configurations were modeled according to the following parameters:

Flow rate: $Q = 15\,ft^3/\sec = 0.41 m^3/\sec$

Slope gradient: $\theta = 1^\circ, 2.5^\circ, 5^\circ, 10^\circ, 16.58^\circ \deg$

Manning's roughness coefficient: $n = 0.02, 0.03, 0.04 \sec/m^{1/3}$

Geometry of the channel: Trapezoidal with 2:1 sides lopes, and a 4 ft bottom width

Example

The depth of flow, flow velocity, and the influence of channel slope can be determined for a trapezoidal channel with the following initial conditions (Figure 1 and Figure 2):

Flow rate: $Q = 15\,ft^3/\sec = 0.41 m^3/\sec$

Initial head $h_0 = 0.1m$

Geometry $B = 1.2m$ 4:1 back slope and 4:1 foreslope $L = 20m$ L $\theta = 16.58^\circ$

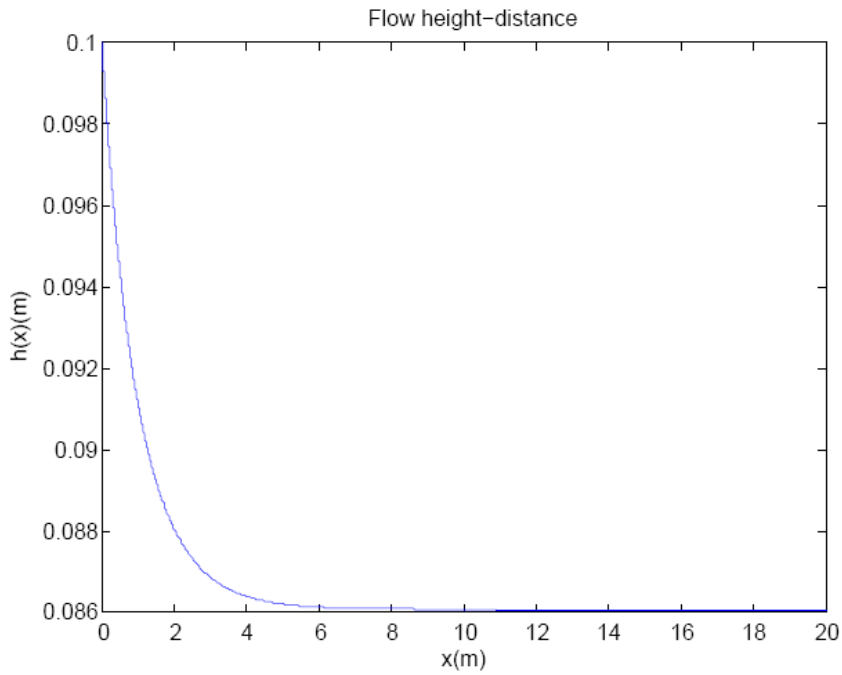

Figure 1. Flow depth-distance (along the slope).

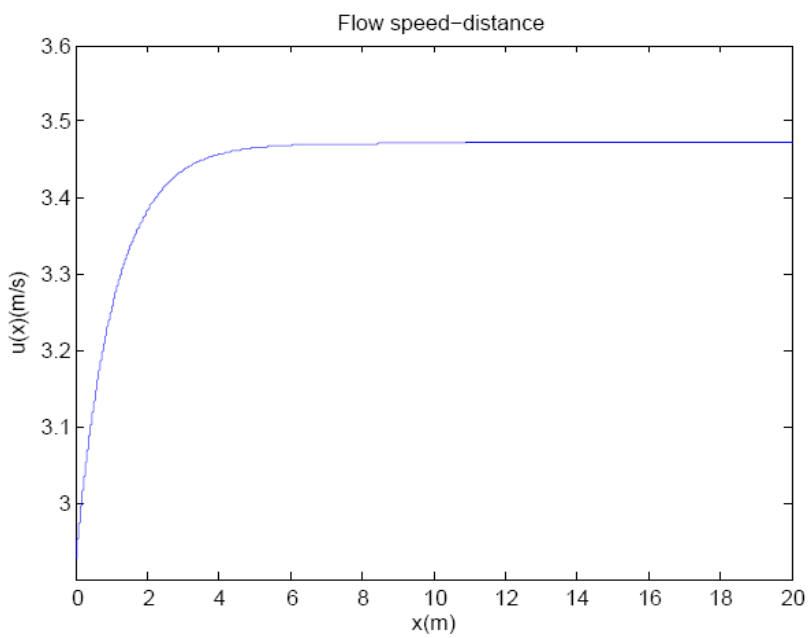

Figure 2. Flow speed-distance (along the slope).

As would be anticipated, increasing the slope resulted in more shallow flow depth and higher terminal velocity (Figure 3 and Figure 4).

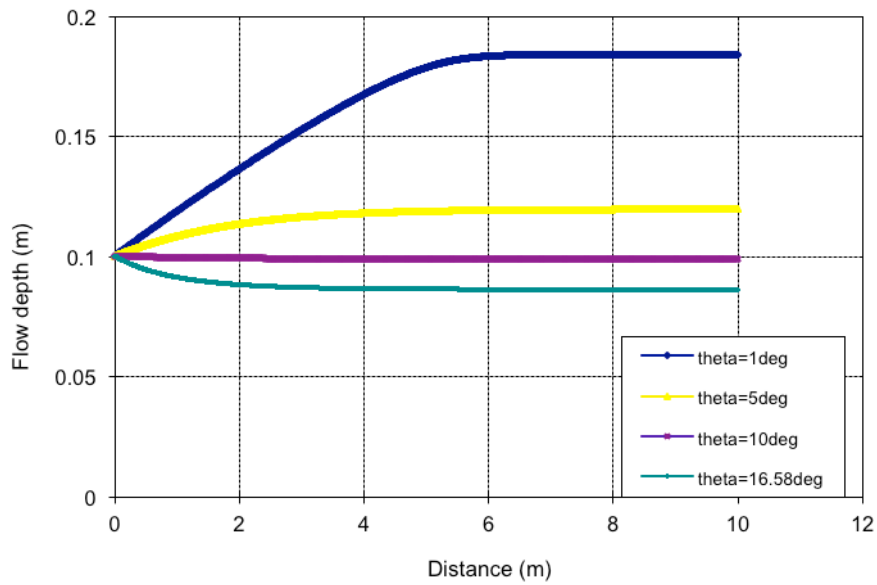

Figure 3. The influence of slope gradient on flow depth.

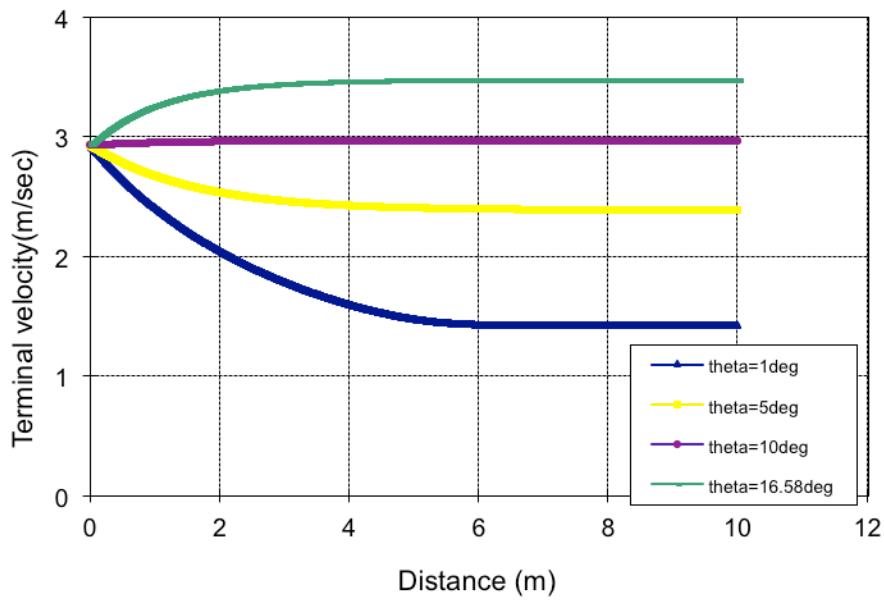

Figure 4. The influence of slope gradient on terminal velocity.

Comparison between Manning's equation and the Backwater equation resulted in relatively similar terminal velocity (Figure 5).

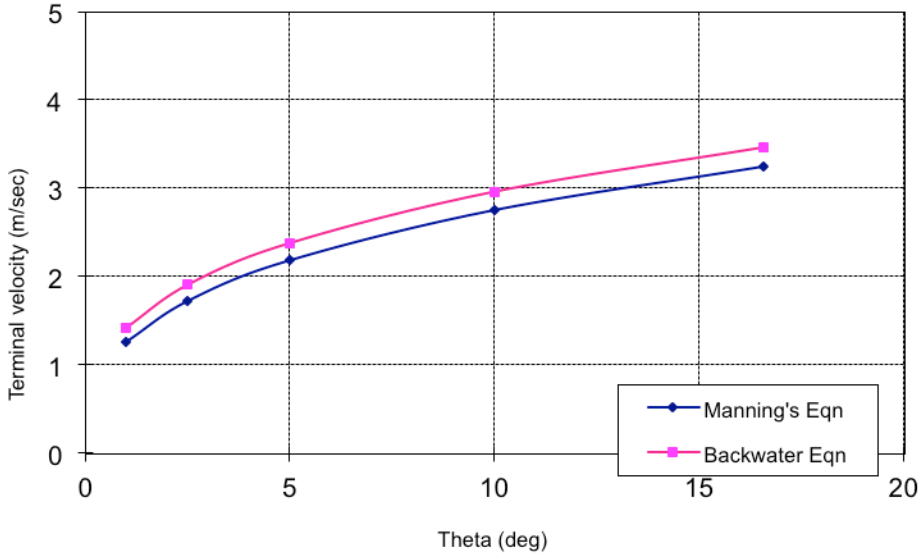

Figure 5. Comparison between Manning's equation and the backwater equation.

Manning's roughness coefficient

Manning's coefficient n is related to the roughness of the surface of the channel; as roughness of the bottom of the channel increases, head loss increases. However, for the case of side slopes, which are erodible, it is favorable to keep n large in order to reduce the flow speed. Manning's coefficient is especially important for steep slopes because it influences how much tractive force the channel can provide to slow the rapid flow against the slope gradient.

For linings, the value of Manning's coefficient can vary in a wide range. Simulations were performed in order to demonstrate the relationship between Manning's coefficient and terminal velocity of flow. Different values of *n* were simulated with the same fixed conditions as introduced before. Increasing the value of Manning's roughness resulted in a decrease in the terminal flow velocity (Figure 6).

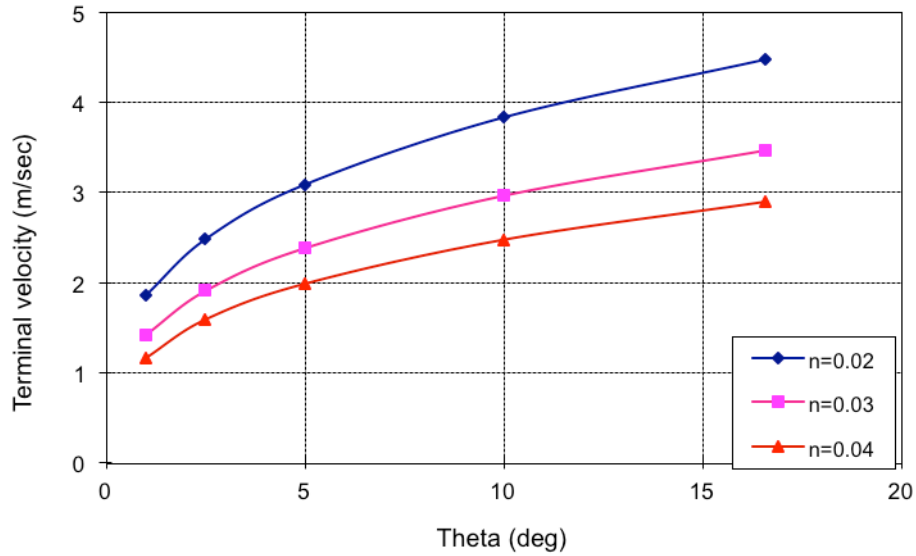

Figure 6. Terminal velocity as a function of slope and roughness.

Summary:

1. Manning's equation is applicable for the uniform open-channel flow condition, but it is important to note that before the fluid reaches a steady, uniform state, it can develop high velocity, with large shear stresses acting on the soil or lining.
2. Slope gradient is important for terminal velocity of flow.
3. Manning's roughness of the interface (or lining) is also important for flow velocity. For a given slope gradient, increasing the roughness of the interface can reduce the terminal velocity and raise the flow depth, reducing the applied shear stress on the interface (or lining).

Update to the Channel Protection Design Program

This section details the program logic required for update of the GDOT Ditch Protection Program. Design is based on the assumption of uniform and steady flow conditions, with stability in the banks and beds. HEC15 relies on the concept that the "flow induced tractive force should not exceed the permissible or critical shear stress of the lining materials" (HEC15, 2005).

As detailed in the previous section, the recommended design also assumes the maximum channel bottom shear stress is equivalent to:

$$\tau_d = \gamma d S_o$$

Channel lining types will be selected from one of the following:

- Types 1-6: TRM 1, 2, 3, 4, 5, or 6 (Alternatively, Type 1A, grass with a biodegradable RECP, may be specified for shear stresses of 0-3 psf when suitable site conditions exist.)
- Types 7 and 7A: Riprap
- Type 8: Concrete

Design logic as detailed in HEC15 is given in Figure 7.

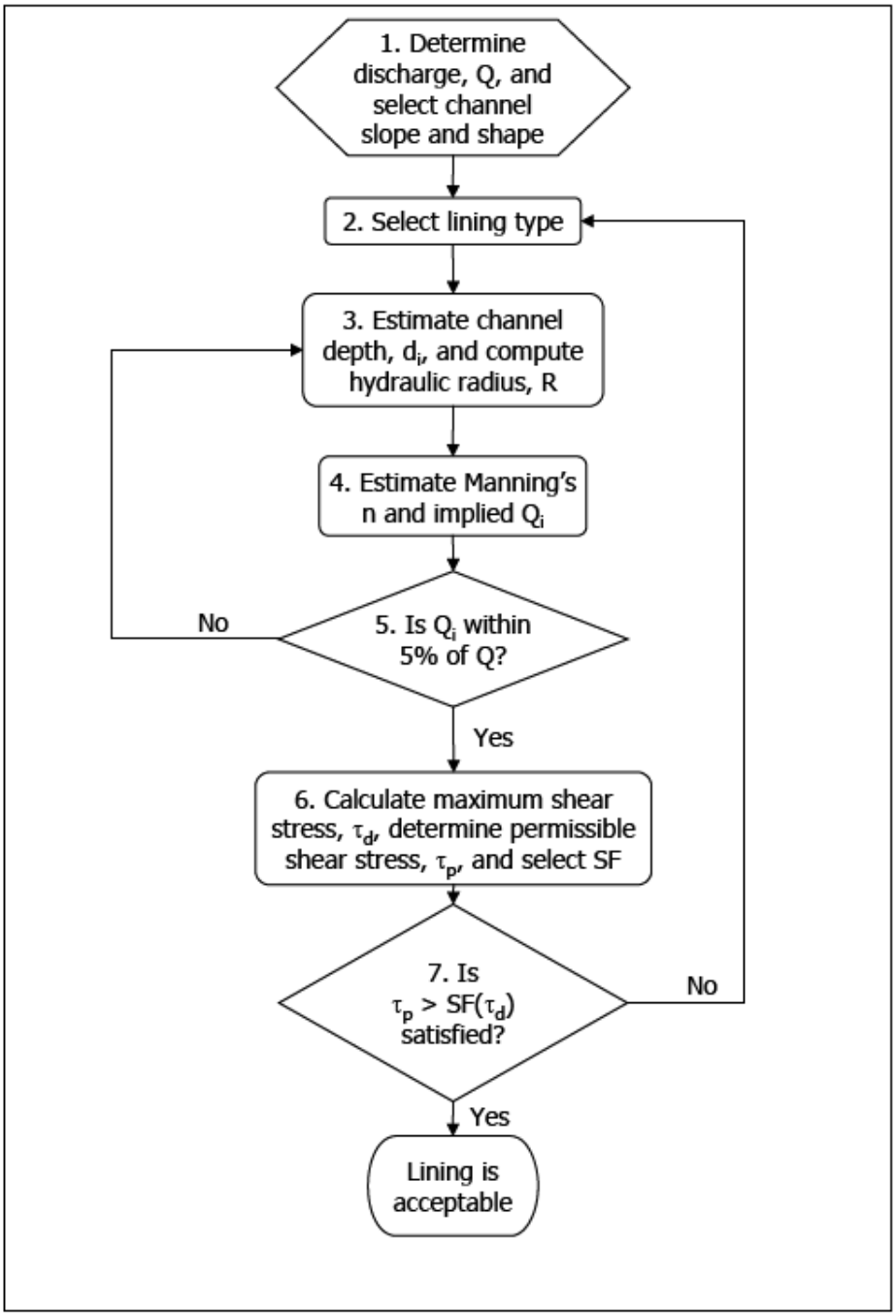

Figure 3.1. Flexible Channel Lining Design Flow Chart

Figure 7. Design logic from HEC15, 2005, Figure 3.1.

Program Input:

Project Number
Project Description:
County
Design Return Period (years)
Lower Station Limit
Upper Station Limit
Segment starting from XXX+XX and ending at XXX+XX
Discharge (cfs), Q
Longitudinal slope (ft/ft), S
Erosion Index (dimensionless)
Bottom Width (ft), B
Foreslope: S_1 (inverse = Z_1)
Backslope: S_2 (inverse = Z_2)
Channel Geometry (usually trapezoidal)
Channel Location (right, left, or median)

Determination of Manning's Roughness Coefficient

Manning's roughness coefficient is a critical parameter that will influence the depth and velocity of flow for a given channel slope. However, roughness is dependent on multiple factors, including grain size.

Calculation of Manning's Roughness for Grass linings

Determination of a roughness coefficient for grass is especially difficult because the roughness changes as flow depth and velocity increase. The change in roughness is attributable to the fact that stems bend as the shear stress is increased, and the bend results in a reduction in roughness. Manning's roughness coefficient for grass linings can be determined according to (HEC15, 2005):

$$n = \alpha C_n \tau_o^{-0.4}$$

Where n = Manning's roughness, $\tau_o = mean\ boundary\ shear\ stress\ (\frac{lb}{ft^2})$, α = unit

conversion = 1.0 (SI) 0.213 for (CU). The grass roughness coefficient, C_n is defined as (HEC15, 2005):

$$C_n = \alpha C_s^{0.10} h^{0.5}$$

Where C_n = grass roughness coefficient, C_s = density-stiffness coefficient, h = stem height, and α = unit conversion = 0.35 (SI) = 0.237 (CU).

Table 1. Density-Stiffness Coefficient, C_s (HEC 15, 2005)

Condition	Excellent	Very Good	Good	Fair	Poor
C_S (SI)	580	290	106	24	8.6
C_S (CU)	49	25	9.0	2.0	0.73

Calculation of Manning's Roughness for TRM Linings

Because the roughness of TRMs is also a function of applied shear stress, the *n* value must be determined from full-scale laboratory flume testing. TRM manufacturers supply three n values, measured as a function of applied shear stress. HEC15 specifies that the roughness should be measured at the values of applied shear stress, as given in Table 2, with the value of the upper shear stress equal to the strength of the liner.

Table 2. Standard n Value Versus Applied Shear (Manufacturer Supplied Data) (HEC15, 2005)

Applied shear stress (lb/ft2)	n value
$\tau_{lower} = \frac{\tau_{mid}}{2}$	n_{lower}
τ_{mid}	n_{mid}
$\tau_{uppwe} = 2\tau_{mid}$	n_{upper}

Using the manufacturer reported values for roughness as a function of shear stress, the *n* value can then be determined according to:

$$n = \alpha \tau_o^b$$

Where n = Manning's roughness for chosen TRM, $\tau_o = mean\ boundary\ shear\ stress\ (\frac{lb}{ft^2})$

,

and *a* and *b* are coefficients calculated according to:

$$a = \frac{n_{mid}}{\tau_{mid}^b}$$

$$b = -\frac{\sqrt{\ln\left(\frac{n_{mid}}{n_{lower}}\right)\ln\left(\frac{n_{upper}}{n_{mid}}\right)}}{0.693}$$

Calculation of Manning's Roughness for Riprap Linings

For the case where $1.5 \le {d_a}/{D_{50}} \le 185$ (where d_a = average flow depth in channel, and D_{50} = median riprap size), roughness can be calculated according to:

$$n = \frac{\alpha d_a^{1/6}}{2.25 + 5.23\log\left(\frac{d_a}{D_{50}}\right)}$$

Where α = unit conversion 0.319 (SI), and 0.262 (CU). In cases where the depth of flow is low relative to the size of the riprap $d_a / D_{50} \leq 1.5$, the semi-empirical Bathurst equation is recommended (HEC15, 2005).

Table 3. Manning's Roughness Coefficient (HEC15, 2005)

Boundary	**Manning's n**
Smooth concrete	0.011
Ordinary concrete	0.013
Rough concrete	0.015
Riprap	0.033
Grass	Function of shear stress
TRM	Function of shear stress

Determination of Permissible Shear Stress for Grass Linings

The permissible shear stress that can be tolerated by a lining represents the limit of applied shear stress to prevent the initiation of erosion. Permissible shear stresses for vegetative linings include contributions from both the underlying soil and the vegetative covering to produce a combined permissible shear stress.

Permissible shear stress for vegetation/soil lining can be determined according to (HEC15, 2005):

$$\tau_p = \frac{\tau_{p,soil}}{(1 - C_f)}\left(\frac{n}{n_s}\right)^2$$

Where τ_p = permissible shear stress on vegetative lining (lb/ft^2), $\tau_{p,soil}$ = permissible soil shear stress (lb/ft^2), C_f = grass cover factor (
Table 4), n_s = soil grain roughness, n = overall roughness:

n_s = 0.016, when D_{75}<1.3mm,

Otherwise: $n_s = \alpha(D_{75})^{1/6}$ $n_s = \alpha(D_{75})^{1/6}$

Where D_{75} = grain size at which 75% of soil is finer, mm (in), and n = Manning's roughness coefficient as determined for grass.

Table 4. Cover Factor Values for Uniform Stands of Grass (HEC 15, 2005)

Growth Form	Cover Factor, C_f				
	Excellent	Very Good	Good	Fair	Poor
Sod	0.98	0.95	0.90	0.84	0.75
Bunch	0.55	0.53	0.50	0.47	0.41
Mixed	0.82	0.79	0.75	0.70	0.62

Determination of Permissible Shear Stress for TRM Linings

Like grass linings, permissible shear stress for TRM linings also combine the properties of the underlying soil and vegetation, as well as the TRM. The presence of the TRM modifies the cover factor in the permissible shear stress relationship. Consequently, the permissible shear stress is determined according to:

$$\tau_p = \frac{\tau_{p,soil}}{(1 - C_{f,TRM})}\left(\frac{n}{n_s}\right)^2$$

And

$$C_{f,TRM} = 1 - \left(\frac{\tau_{p,VEG-test}}{\tau_{p,TRM-test}}\right)(1 - C_{f,VEG})$$

Where τ_p = permissible shear stress on vegetative/TRM lining (lb/ft^2), $\tau_{p,soil}$ = permissible soil shear stress (lb/ft^2)$C_{f,TRM}$ = TRM cover factor, $C_{f,VEG}$ = grass cover factor, $\tau_{p,VEG-test}$ = permissible shear stress on the vegetative lining, as reported by manufacturer's test data, and $\tau_{p,TRM-test}$ = permissible shear stress on the TRM reinforced lining, as reported by manufacturer's test data, n_s = soil grain roughness, n = overall roughness:

n_s = 0.016, when D_{75}<1.3mm,

Otherwise: $n_s = \alpha(D_{75})^{1/6}$

Where D_{75} = grain size at which 75% of soil is finer, mm (in), and n = Manning's roughness coefficient as determined for grass.

Determination of Permissible Shear Stress for Riprap Linings

Permissible shear stress for riprap linings is given in HEC15 (HEC15, 2005):

$$\tau_p = F * (\gamma_s - \gamma) D_{50}$$

Where F^* = Shields parameter, γ_s = specific weight of stone, γ = specific weight of water, and D_{50} = mean riprap size. Combining with shear stress relationships, allows sizing of riprap according to (HEC15, 2005):

$$D_{50} \geq \frac{SFdS_o}{F * (SG - 1)}$$

Where *SF* = safety factor, *d* = maximum channel depth, S_o = channel slope, and sg = specific gravity of rock.

Ranges of permissible shear stresses are given in Table 5.

Table 5. Permissible Shear Stresses

Lining Type	**Permissible Shear Stress (lb/ft^2)**
Type 1: TRM 1	0-2
Type 1A: Grass with temporary RECP	0-3
Type 2: TRM 2	0-4
Type 3: TRM 3	0-6
Type 4: TRM 4	0-8
Type 5: TRM 5	0-10
Type 6: TRM 6	0-12
Type 7: Riprap $D_{50} \leq 0.573$ ft (Type 3) [1]	$\tau_p = F_*(\gamma_s - \gamma)D_{50}$ (HEC 15)
Type 7A: Riprap $0.573 < D_{50} \leq 1.078$ ft (Type 1) [2]	$\tau_p = F_*(\gamma_s - \gamma)D_{50}$ (HEC 15)
Type 8: Concrete $D_{50} > 1.078$ ft	D_{50} sizing > Type 1

[1]GDOT Type 3 riprap average D_{50} = 0.67 ft.
[2]GDOT Type 1 riprap average D_{50} = 1.20 ft.

Historically, design for riprap and concrete channels has been performed not on the basis of a permissible shear stress but on a sizing criterion for riprap D_{50}. Riprap D_{50} is determined according to (HEC 15, 2005):

$$D_{50} \geq \frac{SFdS_o}{F_*(SG-1)}$$

where SF = safety factor, d = maximum channel depth, F_* = Shields parameter, and sg = specific gravity. Values for Shields parameter and safety factor are given as follows:

Table 6

Reynolds Number	**F_***	**SF**
$\leq 4\text{x}10^4$	0.047	1.0
$4\text{x}10^4 < Re < 2\text{x}10^5$	Linear interpolation	Linear interpolation
$\geq 2\text{x}10^5$	0.15	1.5

Program calculations

Estimate initial depth of flow derived from Manning's discharge equation assuming normal depth:

$$D_i = \left(\frac{0.033Q}{BS^{0.5}}\right)^{0.6}$$

Calculate the hydraulic radius, R:

$$A = BD + 0.5D^2(Z_1 + Z_2)$$

$$P = B + D[(Z_1^2 + 1)^{0.5} + (Z_2^2 + 1)^{0.5}]$$

$$R = A/P$$

Calculate new discharge Q_i using depth of flow determined previously.

$$Q = \frac{\alpha}{n} AR^{2/3}$$

If Qi > 1.05 Q or Qi < 0.95 Q, then, estimate new flow depth:

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

Recalculate hydraulic radius, and recheck flow condition.
If: 0.95 Q $\leq$ Qi $\leq$ 1.05 Q then calculate shear stress at maximum depth
Calculate the shear stress at maximum depth

$$\tau_d = \gamma d S_o$$

Compare to permissible shear stress.

If permissible shear stress is adequate, then the lining is acceptable.
If permissible shear stress is not adequate, then select another lining and redesign.
Determination of roughness is performed as previously discussed.

Categorization of Turf Reinforcement Mats and Recommended Guidelines

Turf reinforcement mats (TRMs) can be categorized according to two primary methods: testing of material properties (index testing) and large-scale performance testing in the field.

Index testing provides classification of TRMs based on properties of the materials that are easily quantified within a laboratory setting, e.g., mass per unit area. The ease and relative inexpense of index testing makes it appealing for testing a large number of samples; however, index testing does not provide quantitative data that can be used for design on the basis of conditions in the field.

Sample ASTM standards governing index tests performed on TRMs include:

D 4354 Practice for Sampling of Geosynthetics for Testing

D 5199 Test Method for Measuring the Nominal Thickness of Geosynthetics

D 6475 Test Method for Measuring Mass per Unit Area of Erosion Control Blankets

D 6525 Standard Test Method for Measuring Nominal Thickness of Permanent Rolled Erosion Control Products

D 6566 Test Method for Measuring Mass per Unit Area of Turf Reinforcement Mats

D 6567 Test Method for Measuring the Light Penetration of a Turf Reinforcement Mat (TRM)

D 6818 Test Method for Ultimate Tensile Properties of Turf Reinforcement Mats

In contrast, large-scale field testing does provide a performance measurement that can be used for design by subjecting the TRMs to actual flow conditions observed in the field. The disadvantage of field testing is the high cost and labor involved. Standards governing large scale tests include:

D 6459 – 07 Standard Test Method for Determination of Rolled Erosion Control Product (RECP) Performance in Protecting Hillslopes from Rainfall-Induced Erosion

D 6460 – 07 Standard Test Method for Determination of Rolled Erosion Control Product (RECP) Performance in Protecting Earthen Channels from Stormwater-Induced Erosion

Bench-scale testing does exist as an alternative to both the relatively simple index testing and the relatively expensive field testing. While bench-scale methods do not provide design numbers, they do result in semi-quantitative comparisons between different TRMs. Bench-scale ASTM standards include:

D 7101 – 08 Standard Index Test Method for Determination of Unvegetated Rolled Erosion Control Product (RECP) Ability to Protect Soil from Rain Splash and Associated Runoff under Bench-Scale Conditions

D 7207 – 05 Standard Test Method for Determination of Unvegetated Rolled Erosion Control Product (RECP) Ability to Protect Sand from Hydraulically-Induced Shear Stresses under Bench-Scale Conditions

D 7322 – 07 Standard Test Method for Determination of Rolled Erosion Control Product

(RECP) Ability to Encourage Seed Germination and Plant Growth under Bench-Scale Conditions

The Texas Transportation Institute (TTI) and Texas DOT (TxDOT) have conducted a series of large-scale channel tests to categorize TRMs for use as channel linings. On the basis of the test results, TTI grouped TRM performance into six categories of shear stress ranges. These six categories are shown below in Table 7 along with riprap and concrete channel linings. GDOT designates these nine channel linings as Types 1 through 9.

Table 7. Channel-Lining Material Classification by Allowable Shear Stress

Classification	Allowable Shear Stress
Type 1 TRM*	0-2 psf
Type 2 TRM	0-4 psf
Type 3 TRM	0-6 psf
Type 4 TRM	0-8 psf
Type 5 TRM	0-10 psf
Type 6 TRM	0-12 psf
Type 7: Type 3 Riprap average D_{50} = 0.67 ft	$\tau_p = F_* (\gamma_s - \gamma) D_{50}$ (HEC 15, 2005) 0-24 psf
Type 8: Type 1 Riprap average D_{50} = 1.2 ft	$\tau_p = F_* (\gamma_s - \gamma) D_{50}$ (HEC 15, 2005) 0-50 psf
Type 9: Concrete	For > 50 psf

* Alternatively, Type 0, grass with a biodegradable RECP, may be specified for shear stresses of 0-3 psf when suitable site conditions exist.

All products are classified into groups of acceptable performance, so the list of acceptable products is largest at 0-2 psf, and becomes smaller as the performance requirements increase (i.e., products drop off the list as the requirements become more stringent). If channel conditions exceed 12 psf of shear stress, then riprap, concrete, or other suitable channel lining is specified for application.

In addition to the Texas testing, rating, and approval process, the Erosion Control Technology Council (ECTC) manages a program for review and certification known as the Quality Data Oversight and Review (QDOR™) program. This program is an industry-derived certification procedure designed to review material performance data and index property test results, and to identify unique products. The program verifies TRM performance by issuing a QDOR™ certification for TRM meeting the QDOR™ testing protocol described in the QDOR™ Guidance Manual. For a TRM product to receive QDOR™ certification, the QDOR™ program requires that the TRM be tested under the guidance of the AASHTO-

NTPEP program for index testing and large-scale testing by the ASTM D 6459 and 6460 procedures. Currently approved GDOT products and their status in terms of TTI and TxDOT approval and QDOR™ certification are given in Table 8.

Manufacturers who wish to add new TRMs to the Georgia Department of Transportation Qualified Products List must submit their products to the AASHTO-NTPEP program and QDOR™ certification. Ideally, products would also the tested according to the Texas Transportation Institute guidelines as well. Backlogs in the testing system can make obtaining the TTI certification more difficult.

Table 8. Turf Reinforcement Mats on GDOT Qualified Product List (as of 11/9/2009)

Manufacturer	Product	Material Type	Texas Transportation Institute Results						QDOR Certified for Channel
			Type 1	Type 2	Type 3	Type 4	Type 5	Type 6	
			0-2 (psf)	0-4 (psf)	0-6 (psf)	0-8 (psf)	0-10 (psf)	0-12 (psf)	
American Excelsior Company	Recyclex TRM	Polyester Fibers Polypropylene Netting	x	x	x	x	x	x	Yes
Colbond Geosynthetics Incorporated	ENKAMAT 7020	Nylon	x						Yes
Contech Construction Products, Incorporated	Contech TRM C-45	Polypropylene	x	x	x	x			No (6/15/10)
East Coast Erosion Control Blankets	ECP-2	Polypropylene	Testing in Progress						To be submitted 2010
Erosion Tech	[1]ET-PM-10	Polypropylene	Not Tested						No (6/15/10)
Greenfix America	[2]CF 072 RP		No Longer Produced						
L and M Supply	EG-2P10	Polypropylene	Not Tested						
North America Green	[3]P300	Polypropylene	Not Tested						Yes
North America Green	C350	Polypropylene Coconut Fibers	x	x	x	x	x		Yes
North America Green	P550	Polypropylene	x	x	x	x	x	x	Yes
Propex	Landlok® 450	Polypropylene	x	x	x	x	x	x	
Propex	PYRAMAT® Tan/Green	Polypropylene	x	x	x	x			
Robex	Robexshield RSP5-10		Out of Production						No (3/15/10)
Rolanka	3DTRM-PP	Polypropylene	Not Tested						No (3/15/10)
Southern Environmental Conservation	SEC-P2	Polypropylene	x	x	x	x			No (3/15/10)
Tensar	[2,4]TB1000		No Longer Produced						
Tensar	[2,4]TB3000		No Longer Produced						
Webtec	Terra Guard 45P	Polypropylene	x	x	x	x			No (3/15/10)
Western Excelsior	PP5-10	Polypropylene	x	x	x	x	x		Yes

Manufacturer	Product	Material Type	Texas Transportation Institute Results						QDOR Certified for Channel
Western Excelsior	PP5-12	Polypropylene	x	x	x	x	x	x	Slope only

Working with the Channel Protection Design Computer Program

Before the designer uses the Georgia Tech program, the designer should note the two upper right options in the black horizontal on top of page 1: "Generate Report" and "Program Calculations". The first option allows the designer to generate a comprehensive report at any time by using the GDOT project identification number. The second option allows the designer to read the allowable plasticity index (PI) and the 75th percentile grain size in inches (D_{75}) ranges to use with respect to the USCS soil symbols.

Soils are broadly classified as either noncohesive (e.g., sand, gravel) or cohesive (e.g., clay, sandy clay). When working with the program, we use the unified soil classification system (USCS) symbols.

The symbols for noncohesive soils are:

SW for well-graded sands
SP for poorly graded sands
GW for well-graded gravels
GP for poorly graded gravels

The symbols for cohesive soils are:

GM for silty gravels
GC for clayey gravels
SM for silty sands
SC for clayey sands
ML for silts
CL for sandy clays
MH sandy silts
CH for inorganic clays of high plasticity

These soil symbols are important inputs to the program because they determine the acceptable ranges of the PI and the D_{75} for a particular soil cover; otherwise, the permissible soil and vegetative shear stresses are not calculated.

For example, if one enters a PI of 10 or greater for a noncohesive soil, the program shows "undefined" in the permissible soil shear stress output box and does not generate a combined permissible soil and vegetative shear stress. However, the program will generate a recommended channel lining. The PI of a noncohesive soil is less than 10, and entering a PI <10 for noncohesive soils is the same as entering PI = 0.

Similarly, if one enters D_{75} >/= 0.003 inches for a CL, CH, MH, or ML or >/= 0.2 inches for an SC or SM, the program shows "undefined" in the permissible soil shear stress output box, even if the measured soil properties are real values, and does not generate a combined permissible soil and vegetative shear stress. Again, the program will still generate a recommended channel lining, which should be manually checked against Table 7. In fact, knowing the actual maximum shear stress, one can select the proper channel lining by using Table 7 directly. Whether or not the soil properties are undefined, all other program outputs, such as flow velocity and the actual maximum shear stress on the channel bottom are correct.

On the following pages, we show two examples of a completed user interface. One that is defined for an

SC and one that is undefined for a CH because the D_{75} is too high for the soil symbol in this case.

Lining Design Application

- Home
- Channel Lining
- Generate Report
- Program Calculations

New Channel Lining Project

Grass, TRM and Riprap

Project & Channel

Project Data

Project Number
000346

Channel Dimensions

Channel geometery
Trapezoidal
Fore slope (horizontal ft per vertical foot)
4 ft/ft
Back slope (horizontal ft per vertical foot)
3 ft/ft
Channel bottom width
2 ft
Longitudinal slope
0.08 ft/ft
Initial water depth (enter 1 if unknown)
0.349 ft
Discharge (Q)
4.22 ft^3/s

Grass & TRM

Soil Inputs And Shear Stress

Soil Classification (USCS)
SC (Clayey sand)
Plasticity Index (PI)
15
Soil D_{75}
0.05 in
Permissible soil shear stress
0.0600 (lb/ft^2)

Good 75-95%

Stem height (ft)

0.75

Grass Roughness Coefficient

0.254

Calculate Channel Parameters & Lining Acceptability

Calculated Grass & TRM Parameters

Area of flow (A)

1.12 ft^2

Wetted perimeter (P)

4.54 ft

Hydraulic Radius (R)

0.25

Average Velocity

3.7 ft/s

Manning Roughness (n)

0.043 ft^2

Maximum shear stress on channel bottom

1.74 lb/ft^2

Compare to permissible shear stress

Grass only is acceptable

Final Depth

0.35 ft

Top width

4.44 ft

Final Discharge (Q)

Recommended TRM category
Use TRM Type 1 or Higher

[Calculate Riprap]

Calculated Riprap

Riprap Type 1

Riprap

Riprap Type 3

Riprap

Concrete

Concrete

top

[Submit] [Reset]

c :>Lining Design Application

- Home
- Channel Lining
- Generate Report
- Program Calculations

New Channel Lining Project

Grass, TRM and Riprap

Project & Channel

Project Data

Project Number
000346

Channel Dimensions

Channel geometery
Trapezoidal
Fore slope (horizontal ft per vertical foot)
3 ft/ft
Back slope (horizontal ft per vertical foot)
3 ft/ft
Channel bottom width
2 ft
Longitudinal slope
0.02 ft/ft
Initial water depth (enter 1 if unknown)
1.544 ft
Discharge (Q)
47.26 ft^3/s

Grass & TRM

Soil Inputs And Shear Stress

Soil Classification (USCS)
CH (High plasticity clay)
Plasticity Index (PI)
30
Soil D_{75}
0.004 in
Permissible soil shear stress
undefined (lb/ft^2)

Good 75-95%

Stem height (ft)

0.75

Grass Roughness Coefficient

0.254

Calculate Channel Parameters & Lining Acceptability

Calculated Grass & TRM Parameters

Area of flow (A)

10.25 ft^2

Wetted perimeter (P)

11.77 ft

Hydraulic Radius (R)

0.87

Average Velocity

4.6 ft/s

Manning Roughness (n)

0.042 ft^2

Maximum shear stress on channel bottom

1.93 lb/ft^2

Compare to permissible shear stress

Grass only is NOT acceptable

Final Depth

1.54 ft

Top width

11.27 ft

Final Discharge (Q)

Recommended TRM category
Use TRM Type 1 or Higher

[Calculate Riprap]

Calculated Riprap

Riprap Type 1

Riprap

Riprap Type 3

Riprap

Concrete

Concrete

top

[Submit] [Reset]

At this point, we must stress that the user should not skew the soil properties just to get defined results. The soil data is the soil data.

Next is Appendix 2 showing the protection design procedure of seven (7) actual ditch segments.

Appendix 2

Ditch Hydrology and Depth for EDS-0000-00(346)
PI NO. 0000346 Baldwin County

Seven Ditch Segments:

D1, D6, D11, D13, D14, D15, and D16

Location Left outside ditch from station 642+00 to 710+00

Given:

- Alignment (see plan and profile sheets)
- Cross sections with a predetermined ditch width (2 or 4 feet to start with, later check for capacity)
- Slope of ditch (from the cross sections)

Find:

- Flow in ditch for 25 year recurrence interval
- Depth of flow
- Depth of protection

Ditch 1 from station 642+00 to 643+50

Hydrology (finding Q):

We will be finding the drainage area (A) then the coefficient of runoff (C) and lastly the intensity in inches per hour of rainfall (I). The last step in hydrology will be calculating Q by multiplying the previous values together (Q=CIA).

The first step in performing ditch design with the information given above is to delineate your drainage area (also called a watershed or a drainage basin). A drainage area is the area that contributes rainwater to your section of ditch. Then determine your point of study (lowest point on you're the ditch section you are studying). Then using a map of the area with contours drawn begin to trace with micro station or by hand on a paper perpendicular to the contours going up in elevation until you reach a ridge or other feature that will prevent water from flowing into you ditch. Then run a line over the ridge and then once you reach a point where the path to the study point is perpendicular to the contours without going through the channel complete the drainage shape by

following a line perpendicular to the contours down to the study point. If you are not experienced with delineating drainage areas please have an experienced individual assist you. In any case it is good practice to have an experienced engineer review the drainage areas after you have finished.

In this case the drainage area is small so instead of using contours one can use the cross section sheets to identify the ridges and then transfer this information to the plan sheets. Once you have your drainage area delineated then measure the area in acres see the attached document, appendix A, for the first drainage area. In our case the ditch we are studying is D1 and the end of the ditch section or study point is at station 643+50. The measured area is 0.38 acres.

Now that we have our drainage area in order to calculate the peak flow or Q. Since the area is below 64 acres and we are finding peak flow we will be using the rational method for finding Q. With the drainage area (A) then finding the coefficient of runoff (C) and lastly finding the intensity in inches per hour of rainfall (I). The last step in hydrology will be calculating Q by multiplying the previous values together (Q=CIA).

When finding C we need to divide the area into sub areas. Each sub area will represent a rather homogenous surface type. You may subdivide your basin into forested land, open fields, pavement and further subdivide based on average slopes. It is helpful to review table 4.4 in our drainage manual to aid you in determining your subdivision categories based on a coefficient of runoff (C). In our case, we have grassed shoulders and slopes along with paved areas. Now delineate these sub areas and measure their areas in acres.

Area of total drainage area = 0.380

Sub area 1 (grassed) =0.263

Sub area 2 (paved) =0.117

Find the coefficient of run-off by using table 4.4 in the drainage manual for each sub basin

Sub area A1 (grassed side slopes) C = 0.30

Sub area A1 (paved) C = 0.95

To find the C to use in the rational equation simply determine the weighted value of C:

$$\frac{C1A1 + C2A2}{A}$$

$$\frac{0.30(0.263) + 0.95(0.117)}{0.38}$$

C=0.5001 use C=0.50

Lastly we need to find intensity or I. This is accomplished by first knowing the time of concentration (T_c) or the time when the entire drainage area is contributing to the point of study. To find this one needs to determine how the water flows to the study point. There are three main methods in which water flows to the study point. The first of these is sheet flow. The water flowing in sheet flow will either enter a shallow channel or a deep channel. Shallow channel flow uses one manning's n value in the equation and another for the deep channel. To determine which of these to model one must first make some judgment on how high the depth of flow is compared with the height of grass or other resistance in the channel. See chapter 4 of the Department's drainage manual.

In this case we have sheet flow for 60 feet (from site visits or other resources e.g. photos). Using the kinematic wave equation to find the travel time in minutes:

$$T = \frac{Kn^{0.6}L^{0.6}}{i^{0.4}S^{0.3}}$$

We have n as 0.24 see table 4.6 in GDOT's drainage manual, L as 60 feet, i as 7 (a preliminary reasonable starting value), S or slope as 0.00625 ft/ft (from the cross sections). K is a coefficient equal to 0.933.

$T = \frac{0.933(0.24^{0.6})60^{0.6}}{7^{0.4}(0.00625^{0.3})}$ T= 9.73 minutes.

Next we evaluate the time spent in shallow concentrated flow. For flow in shallow grassed channels or rills this the flow where the height of flow does not rise above the grass stems. Manning's n values for shallow concentrated flow are much higher than those for concentrated channel flow. One can use the Manning's equation below but for simplicity we are using figure 3.1 from NRCS TR-55. Enter the table with a slope of 0.014063 ft/ft and running horizontally until the unpaved line is reached. From this point drop down vertically we reach a velocity value of 1.9 ft/sec. Knowing the length of shallow concentrated flow as 128 feet this should give us a travel time T of 1.12 minutes.

Next we evaluate the time spent in concentrated flow.

To begin with we have started with a preliminary flow of using 10 as a preliminary intensity 0.38 acres as our area and 0.47 as our coefficient of runoff. The equation of Q=CIA yields$Q = CIA$

Next the water will enter the ditch and in this case we can assume a starting flow of 1 ft^3/s (using the rational method with a 10 inch per hour intensity). The velocity of the ditch is calculated using Manning's equation. Using a beginning depth of 0.5 feet and with the ditch geometry of 6:1 front slopes and 3:1 back slopes and 2' bottom, the flow area is 0.710 $ft^2$and the wetted perimeter is 4 ft.

The hydraulic radius is 0.175 ft (or the area divided by the wetted perimeter). Next the Manning's roughness coefficient n is 0.03 since the channel lining is grass (from Chow, 1959; other sources can be FHWA HEC-15). The slope of the ditch is 0.0056 ft/ft. Manning's equation is :

$$V = \frac{1.49}{n} R^{\frac{2}{3}} S^{\frac{1}{2}}$$

$$V = \frac{1.49}{0.03} 0.175^{.6667} 0.0056^{0.5}$$

V=1.16 feet/second

The ditch length is 83 feet. Simply divide the length by the velocity to find the number of seconds of travel. 93 seconds is 1.6 minutes of travel time.

The time of concentration is the addition of all forms of travel from the most hydrologic remote point the point of study. In this case it will be the sum of the sheet flow time, shallow concentrated channel flow time, and the concentrated channel flow time (9.73 +1.12+1.60) to give 12.45 or one can use 10 minutes for expediency since it will be slightly conservative). To find the intensity use NOAA Atlas 14 online at: http://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html?bkmrk=pa

In the upper section of the page in the Data Description fields simply set the data type to precipitation intensity and be sure the time series type is set to partial duration. Next type in the latitude and longitude in degree decimal form (remember western longitudes which Georgia is in are negative values). In this case it we have Latitude: 32.979 and Longitude: -83.214. You may then scroll down and view the table below. With a 25 year recurrence interval and a duration (time of concentration which we suggested using 10 minutes) you will find the intensity is 6.92.

Since the rational equation is Q=CIA, Q=0.5*6.92*0.38, flow in the ditch is **Flow Q= 1.32ft^3/s** (remember to use the frequency factor for the year storm modeled in this case it is 1.1 for the 25 year storm in the following ditches it was applied to the runoff coefficient C).

Plug this back into Manning's equation to check the depth of flow estimated earlier. This is a an iterative process. $Q = \frac{1.49}{n} AR^{0.667} S^{0.5}$ Solving for $AR^{0.667} = \frac{Qn}{1.49S^{0.5}}$; $AR^{0.667}$= 0.375858 And so after a few iterations one arrives at a depth of flow:

Depth of flow = 0.309 ft.

Conservatively use 6 inches or **0.5 ft** and add another 0.5 ft for the required free board.

Depth of Protection = 1.0 ft

Another way to simplify the process is to use the FHWA's Hydraulic Tool Box Channel Analysis.

Now that the depth and slope are known, the only other piece of information needed to determine the ditch lining is the soil information

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Ditch 6 from station 656+00 to 659+24.91 left

Note: The same methodologies applied above are applied to each subsequent ditch and so there is no need to detail the process again. For missing details please review the example for Ditch D1.

Hydrology:

Since the area is so small the cross sections were used to delineate the drainage area on the plan sheets.

A=0.46

Area of total drainage area = 0.460

Sub area 1 (grassed) =0.14 , C=0.30

Sub area 2 (paved) =0.32 C=0.95

Composite C = 0.76

Tc Calcution:

Sheet flow across pavement where n = 0.011 and slope = 0.08485 (see cross section and profile sheets). 9.47 inches/hour was chosen for intensity (I) since it is expected to be a very short time (less than 5 minutes).

$$T = \frac{Kn^{0.6}L^{0.6}}{i^{0.4}S^{0.3}}$$

$$T(sheet) = \frac{0.933(0.011^{0.6})60^{0.6}}{9.47^{0.4}(0.08485^{0.3})}$$ T= 0.606 minutes.

Concentrated flow is checked to see if the travel time plus the sheet flow travel time will be above 5 minutes. Otherwise 5 minutes is used for the Tc. Where L= 300 ft., Flow estimated as Q=CIA or 0.75*9.47*0.48 = 3.4092 ft^3/sec. Ditch parameters are placed into HEC where:

S= 0.023096 ft./ft.

Front Side Slopes 3:1

Back Side Slopes 8:1

Bottom width = 2 ft.

n= 0.030

Q= 3.4092

From Hydraulic Tool Box Velocity = 2.687

$T_{channel}$ = 280/2.687 = 104 sec. or 1.74 minutes

$T_c = T_{sheet} + T_{channel}$ =0.606 + 1.74 = 2.34 minutes since less than 5 minutes use 5 minutes so the earlier estimate of **3.41 ft^3/sec**. is good to use

From the Hydraulic Tool Box depth of flow = 0.327 ft. **Use 0.5 ft.**

With 0.5 ft. of free board depth of protection = 0.5 +0.5 = **1.0ft.**

Note that for the ditch lining a Q of 3.90 ft^3/sec. was used because the example project was first calculated using older IDF curves for I

Ditch 11 from station 663+50 to 673+50 left

Note: The same methodologies applied above are applied to each subsequent ditch and so there is no need to detail the process again. For missing details please review the example for Ditch D1.

Hydrology:

This area is large enough to use the contours generated from the project's survey. The cross sections were used to delineate the drainage area on the plan sheets.

A = Area of total drainage area = 7.63

Sub area 1 (forest) =6.89 , C=0.20

Sub area 2 (paved) =0.74 C=0.95

Composite C = 0.29 (rational method frequency factor , 1.1 multiplied here to keep in sync with designer's data)

Tc = Time of Concentration

Sheet flow across forested areas where n = 0.4 slope = 0.04375 (see cross section and profile sheets). 8.33 inches/hour was chosen for I since it is expected to be a very short time (<5 minutes).

$$T = \frac{Kn^{0.6}L^{0.6}}{i^{0.4}S^{0.3}}$$

$$T(sheet) = \frac{0.933(0.4^{0.6})80^{0.6}}{8.33^{0.4}(0.04375^{0.3})}$$ T= 8.172 minutes.

Now to find shallow concentrated flow time: simply use the TR55 figure 3-1 "average velocities for estimating travel time for sheet flow". Our slope is 0.11 measured from the contours. The surface is unpaved. From the figure we get a velocity of 5.4 ft./s. The length of shallow concentrated flow has been determined to be 192ft. taken from the drainage area map (which is the distance between the constructed ditch and the end of the sheet flow). This gives us a travel time of 35.5 seconds or 0.6 minutes.

Since the concentrated flow is usually fairly fast it is prudent to use the combination of the sheet flow travel time and shallow concentrated flow travel time as the T_c (8.77 minutes) to use to estimate the velocity in the concentrated flow. Interpolation is necessary to determine I. Even though the true path is curvilinear a straight interpolation can be used since the difference will be small. Interpolated I is 7.54484 inches per hour. Flow is estimated as Q=CIA or 0.29*7.54*7.63= **16.69 ft^3/sec**. Ditch parameters are placed into HEC where:

S= 0.041891 ft/ft

Front Side Slopes 3:1, Back Side Slopes 3:1

Bottom width = 2 ft

n= 0.030

Q= 16.69

From Hydraulic Tool Box Velocity = 5.89 ft./s

Channel Length = 603 $T_{channel}$ = 603/5.89 = 102 sec. or 1.70 minutes

$T_c = T_{sheet} + T_{shallow} + T_{channel}$ =8.172 + 0.6 + 1.70 = 10.472

Find new I using 10.472 as T_c (recommend using 10 since it's a little conservative and easy to calculate) then plug back into the rational equation to find a new Q

I from Atlas 14 is 6.92; Q=CIA or 0.29*6.92*7.63= **15.31 ft^3/sec**.

Note that for the ditch lining a Q of 18.47 ft^3/sec. was used because the example project was first calculated using older IDF curves for I

From the Hydraulic Tool Box depth of flow = .665 ft. **use 0.67 ft. (8 inches)**

Depth of protection = depth of flow + .5 or 1.16 ft. (14 inches) use 15 inches or **1.25 ft**

Ditch 13 from station 680+00 to 687+50 left

Note: The same methodologies applied above are applied to each subsequent ditch and so there is no need to detail the process again. For missing details please review the example for Ditch D1.

Hydrology:

This area is large enough to use the contours generated from the project's survey. the cross sections were used to delineate the drainage area on the plan sheets.

A = 1.75

Area of total drainage area = 1.75

Sub area 1 (forest) = 1.34 , C=0.20

Sub area 2 (paved) = 0.41 C=0.95

Composite C = 0.39 (rational method frequency factor , 1.1 multiplied here to keep in sync with designer's data)

Tc = Time of Concentration.

Sheet flow across forested areas where n = 0.4 slope = 0.02125 (see contours and cross section). 7.335 inches/hour was chosen for as a starting point for I

$$T = \frac{Kn^{0.6}L^{0.6}}{i^{0.4}S^{0.3}}$$

$$T(sheet) = \frac{0.933(0.4^{0.6})80^{0.6}}{7.335^{0.4}(0.02125^{0.3})}$$ T= 10.681 minutes.

Now to find shallow concentrated flow time: simply use the TR55 figure 3-1 "average velocities for estimating travel time for sheet flow". Our slope is 0.064634 measured from the contours. The surface is unpaved. From the figure we get a velocity of 4.1 ft./s. The length of shallow concentrated flow has been determined to be 82ft. taken from the drainage area map (which is the distance between the constructed ditch and the end of the sheet flow). This gives us a travel time of 20 seconds or 0.33 minutes

Since the concentrated flow is usually fairly fast it is prudent to use the combination of the sheet flow travel time and shallow concentrated flow travel time as the T_c (11 minutes) to use to estimate the velocity in the concentrated flow. In this case I would use 10 minutes rather than interpolate. I is 6.92 inches per hour. Flow is estimated as Q=CIA or 0.39*6.92*1.75= **4.72 ft^3/sec**. Ditch parameters are placed into HEC where:

S= 0.020587 ft/ft

Front Side Slopes 6:1, Back Side Slopes 3:1

Bottom width = 2 ft.

n= 0.030

Q= 4.72 ft^3/s

From Hydraulic Tool Box Velocity = 2.98 ft/s

Channel Length = 801 $T_{channel}$ = 801/2.98 = 102 sec. or 4.48 minutes

$T_c = T_{sheet} + T_{shallow} + T_{channel}$ =10.681 + 0.33 + 4.48 = 15.49

Find new I using 15.49 as T_c (recommend using 15 since it's a little conservative and easy to determine) then plug back into the rational equation to find a new Q

I from Atlas 14 is 6.92; Q=CIA or 0.39*5.63*1.75= **3.80 ft^3/sec**.

Note that for the ditch lining a Q of 5.00 ft^3/sec. was used because the example project was first calculated using older IDF curves for I

From the Hydraulic Tool Box depth of flow = 0.369 ft. **use 0.5 ft**

Depth of protection = depth of flow + 0.5 or **1.0 ft**

Ditch 14 from station 687+50 to 688+50 left

Note: For missing details, please review the example for Ditch D1.

Hydrology:

This area is large enough to use the contours generated from the project's survey. the cross sections were used to delineate the drainage area on the plan sheets.

A = Area of total drainage area = 0.82

Sub area 1 (forest) =0.75 , C=0.20

Sub area 2 (paved) =0.07 C=0.95

Composite C = 0.28 (rational method frequency factor, 1.1 multiplied here to keep in sync with designer's data)

Tc Calculation:

Sheet flow across forested areas where n = 0.4, slope = 0.00938 (see cross sections), I = 7.383 inches/hour was chosen for as a starting point for I.

$$T = \frac{Kn^{0.6}L^{0.6}}{i^{0.4}S^{0.3}}$$

$$T(sheet) = \frac{0.933(0.4^{0.6})80^{0.6}}{7.383^{0.4}(0.00938^{0.3})}$$ T= 13.62 minutes.

Now to find shallow concentrated flow time: simply use the TR55 figure 3-1 "average velocities for estimating travel time for sheet flow". Our slope is 0.034965 measured from the contours. The surface is unpaved. From the figure we get a velocity of 3.016 ft/s The length of shallow concentrated flow has been determined to be 286 ft taken from the drainage area map (which is the distance between the constructed ditch and the end of the sheet flow). This gives us a travel time of 95 seconds or 1.58 minutes.

Since the concentrated flow is usually fairly fast it is prudent to use the combination of the sheet flow travel time and shallow concentrated flow travel time as the T_c (15.2 minutes) to use to estimate the velocity in the concentrated flow. In this case I would use 15 minutes rather than interpolate. Intensity (I) is 5.63 inches per hour. Flow is estimated as Q=CIA or 0.28*5.63*0.82= **1.29 ft^3/sec**. Ditch parameters are placed into HEC where:

Note that for the ditch lining a Q of 1.71 ft^3/sec. was used because the example project was first calculated using older IDF curves for I

S= 0.007727 ft/ft

Front Side Slopes 6:1, Back Side Slopes 3:1

Bottom width = 2 ft

n= 0.030

Q= 1.29 ft^3/s

From Hydraulic Tool Box Velocity = 1.47 ft/s

Channel Length = 44 $T_{channel}$ = 44/1.47 =30 sec. or 0.5 minutes

$T_c = T_{sheet} + T_{shallow} + T_{channel}$ =13.62 + 1.58 + 0.50 = 15.7

Since 15.7 is very close to 15 recommend keeping with the information given in the last Hydraulic Tool Box

From the Hydraulic Tool Box depth of flow = 0.273 ft **use 0.5 ft**

Depth of protection = depth of flow + 0.5 or **1.0 ft**

Ditch 15 from station 688+50 to 704+00 left

Note: For missing details please review the example for Ditch D1.

Hydrology:

This area is large enough to use the contours generated from the project's survey. The cross sections were also used to help delineate the drainage area on the plan sheets.

A=3.34

Area of total drainage area = 3.34

Sub area 1 (forest) =1.82 , C=0.20

Sub area 2 (paved) =1.53 C=0.95

Composite C = 0.55 (rational method frequency factor, 1.1 multiplied here to keep in sync with designer's data)

Tc Calculation:

Sheet flow across forested areas where n = 0.011 slope = 0.07013 (see cross sections). I = 11.0 inches/hour was chosen for as a starting point for I

$$T = \frac{Kn^{0.6}L^{0.6}}{i^{0.4}S^{0.3}}$$

$$T(sheet) = \frac{0.933(0.011^{0.6})80^{0.6}}{11^{0.4}(0.07013^{0.3})}$$ T= 0.74 minutes.

Our shallow concentrated flow is only a couple of feet in this instance and so does not contribute in any significant amount to the time of concentration.

In this case we have only around ½ minute of sheet flow time before the concentrated flow. Since the concentrated flow is usually fairly fast and there is so little time from sheet flow it is a wise idea to use the 5 minute minimum as the starting point for the time of concentration. I for 5 minutes according to NOAA is 9.46 inches per hour. Flow is estimated as Q=CIA or 0.55*9.46*3.34= **17.37 ft^3/sec**. Ditch parameters are placed into HEC where:

Note that for the ditch lining a Q of 19.91 ft^3/sec. was used because the example project was first calculated using older IDF curves for I

S= 0.056986 ft/ft

Front Side Slopes 6:1, Back Side Slopes 3:1

Bottom width = 2 ft

n= 0.030

Q= 17.37 ft^3/s

From Hydraulic Tool Box Velocity = 6.14 ft/s

Channel Length = 813 $T_{channel}$ = 813/6.14 =2.2 minutes

$T_c = T_{sheet} + T_{shallow} + T_{channel}$ =0.74 + 0.0 + 2.2 = 2.94 minutes since 2.94 is less than 5 use 5

Therefore the last Q for 5 minutes is good use 17.37 ft^3/s

From the Hydraulic Tool Box depth of flow = 0.60 ft. **use 0.75 ft**

Depth of protection = depth of flow + 0.5 so for simplicity sake use **1.5 ft**

Ditch 16 from station 706+50 to 710+00 left

Note: For missing details please review the example for Ditch D1.

Hydrology:

This area too small to use contours so the cross sections were used to delineate the drainage area on the plan sheets.

A=0.63 acres

Area of total drainage area = 0.63

Sub area 1 (grassed) =0.36 , C=0.30

Sub area 2 (paved) =0.27 C=0.95

Composite C = 0.60 (rational method frequency factor = 1.1 multiplied here to keep in sync with designer's data)

Tc = Time of Concentration

Sheet flow across forested areas where n = 0.011 slope = 0.07806 (see cross sections). 11.0 inches/hour was chosen for as a starting point for I

$$T = \frac{Kn^{0.6}L^{0.6}}{i^{0.4}S^{0.3}}$$

$$T(sheet) = \frac{0.933(0.011^{0.6})80^{0.6}}{11^{0.4}(0.07806^{0.3})}$$ T= 0.54 minutes.

The shallow concentrated flow is only a couple of feet in this instance and so does not contribute in any significant amount to the time of concentration.

In this case, we have only around ½ minute of sheet flow time before the concentrated flow. Since the concentrated flow is usually fairly fast and there is so little time from sheet flow it is a wise idea to use the 5-minute minimum as the starting point for the time of concentration. Intensity (I) for 5 minutes according to NOAA is 9.46 inches per hour. Flow is estimated as Q=CIA or 0.60*9.46*0.63= **3.58 ft^3/sec**. Ditch parameters are placed into HEC where:

Note that for the ditch lining a Q of 4.22 ft^3/sec was used because the example project was first calculated using older IDF curves for I

S= 0.046796 ft/ft

Front Side Slopes 3:1, Back Side Slopes 4:1

Bottom width = 2 ft.

n= 0.030

Q= 3.58 ft^3/s

From Hydraulic Tool Box Velocity = 3.9 ft/s

Channel Length = 353 $T_{channel}$ = 353/3.9ft./s =1.51 minutes

$T_c = T_{sheet} + T_{shallow} + T_{channel}$ =0.54 + 0.0 + 1.51 = 2.03 minutes since 2.03 is less than 5 use 5

Therefore, the last Q for 5 minutes is good use 3.58 ft^3/s

From the Hydraulic Tool Box depth of flow = 0.30 ft, **use 0.5 ft**

Depth of protection = depth of flow + 0.5; so for simplicity use **1.0 ft**.