**North Carolina Department of Transportation**

**Level III**

**Design of Erosion & Sediment Control Plans**

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**CONVERSION FACTORS**

1 acre = 43,560 ft2

1 mi2 = 640 acres

1 ft3 of water = 7.48 gallons = 62.4 pounds

1 ft3/sec = 1 cfs = 1 ac-in/hr = 448.9 gallons per minute (gpm)

1,000,000 gallons per day (1 MGD) = 695 gpm = 1.56 cfs

1 m = 100 cm = 1000 mm

**SYMBOLS**

**MODULE 1. Hydrology**

a watershed drainage area in acres (ac)

AJ Jarrett Maximum Area in acres (ac)

C Rational Method runoff coefficient (decimal ranging from 0 to 1)

H elevation change from most remote point to point of interest (ft)

i rainfall intensity in inches per hour (in/hr)

Lflow flow length from most remote point to point of interest (ft)

P probability of a hydrologic event being exceeded in any year (decimal)

Q peak runoff rate in cubic feet per second (cfs)

S slope equal to elevation change over length (ft/ft)

T return period for a specific hydrologic event (years)

tc time of concentration in minutes (min)

**MODULE 2. Erosion**

A soil erosion rate in (tons/ac-yr or month),

Cditch regression constant for secondary roads dependent on ditch side slopes

CP conservation practices factor (dimensionless)

K soil erodibility factor (dimensionless)

LS slope-length factor (dimensionless)

R rainfall factor (dimensionless)

Sditch slope of secondary road ditch (ft/ft)

Vditch secondary road sediment volume rate expected in (ft3 or yd3/ac)

**MODULE 4. Open Channel Design**

 average tractive force acting on the channel lining (lbs/ft2),

 unit weight of water, assumed to be 62.4 lbs/ft3,

dchan depth of flow in the channel (ft),

Schan slope of the channel (ft/ft).

**MODULE 5. Sediment Retention BMPs**

SA surface area of a sediment retention basin in square feet (ft2)

Dorifice diameter of the skimmer orifice in inches (in)

Hskim driving head at the skimmer orifice from Table 5.1 in feet (ft)

Qskim basin outflow rate in cubic feet per day (ft3/day)

tdewater dewatering time for a BMP (days)

Vbasin volume of a sediment retention basin in cubic feet (ft3)

Vskim basin volume to be dewatered in cubic feet (ft3)

**MODULE 6. Below Water Table Borrow Pits**

Vstill volume of stilling basin in cubic feet (ft3)

Qstill pumping rate entering the stilling basin in gallons per minute (gpm)



\*Contributing land slope must be <2%

<2%\*

**MODULE 1. Hydrology**

Hydrology is the study of water movement through the water cycle. The peak runoff/discharge rate in response to rainfall is required to design erosion and sediment control best management practices (BMPs). The rainfall-runoff relationship for a watershed is shown in Figure 1.1. During a rainfall event, the runoff rate increases as more land produces runoff. As rainfall continues, more remote land areas contribute runoff, and eventually the entire watershed produces runoff at the time of concentration, tc, producing the peak runoff rate, Q.



**Figure 1.1. Conceptualization of hydrologic processes.**

**Rational Method for Estimating Peak Runoff Rate**

The Rational Method (Water Pollution Control Federation, 1969) for predicting peak runoff rate is appropriate for designing small structures and channels in small watersheds:

 Q = (C) (i) (A) (Equation 1.1)

where:

 Q = peak runoff rate for a given return period in cubic feet per second (cfs),

 C = Rational Method runoff coefficient (decimal ranging from 0 to 1),

 i = rainfall intensity for a given return period in inches per hour (in/hr), and

 A = watershed drainage area in acres (ac).

Long-term records of rainfall and runoff at a specific location can be used to estimate the probability of a certain hydrologic event being exceeded in any year and the return period for a specific hydrologic event:

 T = 1 / P (Equation 1.2)

where:

 P = probability of a hydrologic event being exceeded in any year (decimal), and

 T = return period for a specific hydrologic event (years).

**Time of Concentration**

The time of concentration, tc, is defined by USDA‑NRCS (1986), as the time required for runoff water to travel from the watershed's most remote point to the point‑of‑interest. Many methods can be used to estimate tc (Kirpich, 1940; USDA-SCS, 1972b; USDA-SCS, 1986). The most conservative design approach is to use the lowest predicted tc in sizing a basin since it will result in the highest design rainfall intensity and largest basin size.

**Jarrett Method for Small Drainage Areas**

Jarrett (2005) determined that time of concentration, tc, is approximated as 5 minutes for watersheds smaller than the Jarrett Maximum Area:

 where:

 S = average watershed slope (ft/ft),

 AJarrett = 460 (S) (Equation 1.4)

where:

 AJarrett = Jarrett Maximum Area in acres (ac), and

 S = average watershed slope (ft/ft).

**NRCS Segmental Method**

For watersheds larger than the Jarrett Maximum Area, an appropriate method for estimating tc is the NRCS Segmental Method (USDA-SCS, 1986). This method is based on the premise that runoff from the most remote point will travel as sheet flow, then become shallow concentrated flow, and finally enter a channel. Since most of a small watershed’s flow path is shallow flow, the following equations for estimating tc are:

 Unpaved Areas: tc = 0.001 (Lflow ) / S0.53 (Equation 1.5)

 Paved Areas: tc = 0.0008 (Lflow ) / S0.53 (Equation 1.6)

where:

 tc = time of concentration in minutes (min),

 Lflow = flow length from most remote point to point of interest (ft),

 S = average watershed slope (ft/ft).

**Precipitation Data**

The rainfall intensity data required to predict runoff rates using the Rational Method are available on the National Weather Service web site and summarized in Table 1.1:

**Table 1.1. Rainfall Intensity Data for North Carolina for the Rational Method.**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **T (Yrs)** | **5 min** | **10 min** | **15 min** | **30 min** | **60 min** |
| Murphy |
| 10 | 6.40 | 5.12 | 4.32 | 3.13 | 2.04 |
| 25 | 7.41 | 5.90 | 4.99 | 3.69 | 2.46 |
| Asheville |
| 10 | 6.96 | 5.57 | 4.70 | 3.40 | 2.22 |
| 25 | 8.03 | 6.40 | 5.41 | 4.00 | 2.67 |
| Boone |
| 10 | 7.34 | 5.87 | 4.95 | 3.59 | 2.34 |
| 25 | 8.43 | 6.72 | 5.68 | 4.20 | 2.80 |
| Charlotte |
| 10 | 7.19 | 5.74 | 4.85 | 3.51 | 2.29 |
| 25 | 8.00 | 6.37 | 5.38 | 3.99 | 2.65 |
| Greensboro |
| 10 | 6.80 | 5.44 | 4.59 | 3.32 | 2.16 |
| 25 | 7.46 | 5.94 | 5.02 | 3.72 | 2.48 |
| Raleigh |
| 10 | 6.97 | 5.58 | 4.70 | 3.41 | 2.22 |
| 25 | 7.72 | 6.16 | 5.20 | 3.85 | 2.56 |
| Fayetteville |
| 10 | 7.84 | 6.27 | 5.29 | 3.83 | 2.49 |
| 25 | 8.86 | 7.05 | 5.96 | 4.41 | 2.94 |
| Wilmington |
| 10 | 9.60 | 7.68 | 6.48 | 4.69 | 3.05 |
| 25 | 10.91 | 8.70 | 7.35 | 5.44 | 3.62 |
| Washington |
| 10 | 8.04 | 6.43 | 5.43 | 3.93 | 2.56 |
| 25 | 9.13 | 7.28 | 6.15 | 4.56 | 3.03 |
| Manteo |
| 10 | 8.23 | 6.59 | 5.55 | 4.02 | 2.62 |
| 25 | 9.35 | 7.45 | 6.29 | 4.66 | 3.10 |

**Rational Method Runoff Coefficient, C**

The watershed characteristics affecting peak runoff rate are summarized in the runoff coefficient, C, a dimensionless parameter between 0.0 and 1.0. The value of C depends on soil infiltration rate, land use, and land slope. Sandy soils with rapid infiltration have low C values, while clay soils with slow infiltration have higher C values. Vegetation increases water infiltration, resulting in lower C values. For construction sites, land conditions are similar to disturbed agricultural watersheds. Table 1.4 summarizes typical C values based on soil texture, land use, and slope.

**Table 1.2. Rational Method C for Agricultural Areas (Schwab et al, 1971).**

|  |  |
| --- | --- |
| **Vegetation** | **Runoff Coefficient, C** |
|  **Slope** | **Sandy Loam1** | **Clay & Silt Loam2** | **Tight Clay3** |
| **Forest** |  |  |  |
|  0-5% slope | 0.10 | 0.30 | 0.40 |
|  5-10% slope | 0.25 | 0.35 | 0.50 |
|  10-30% slope | 0.30 | 0.50 | 0.60 |
| **Pasture/Grass** |  |  |  |
|  0-5% slope | 0.10 | 0.30 | 0.40 |
|  5-10% slope | 0.16 | 0.36 | 0.55 |
|  10-30% slope | 0.22 | 0.42 | 0.60 |
| **Cultivated/bare** |  |  |  |
|  0-5% slope | 0.30 | 0.50 | 0.60 |
|  5-10% slope | 0.40 | 0.60 | 0.70 |
|  10-30% slope | 0.52 | 0.72 | 0.82 |

*Example*: Determine the 10-year peak runoff rate, Q10, for a 5-acre construction site watershed near Asheville with a flow length = 600 ft and elevation drop = 36 ft. The land uses are shown below:

|  |  |  |  |
| --- | --- | --- | --- |
| Land Use, soil/ (slope) | A | C | (A) (C) |
| Forest, clay/ (11%) | 1 | 0.60 | 0.60 |
| Bare soil, clay/ (7%) | 3 | 0.70 | 2.10 |
| Grass, clay/ (3%) | 1 | 0.40 | 0.40 |
|  |  sum = 5 ac |  |  sum = 3.10 |

Weighted Runoff Coefficient: C = 3.10 / 5 = 0.62

Average watershed slope, S = 36 / 600 = 0.06 ft/ft

Jarrett Max Area = 460 (0.06) = 27.6 acres. Since 5 < 27.6, use tc = 5 min

Rainfall intensity for 10-year storm, i10, is determined from Table 1.1 for a 5-minute rainfall in Asheville: i10 = 6.96 in/hr

Peak runoff rate, Q10 = (0.62) (6.96) (5) = 21.6 cfs

**MODULE 2. Soil Erosion**

Erosion is defined as the process by which soil particles are detached and transported to a new location. Detachment is the dislodging of soil particles, caused by:

* Raindrops hitting the soil surface,
* Flow of water over the soil surface that can lift and detach particles,
* Movement of wind over the soil surface,
* Breaking of rock and soil aggregates caused by freezing and thawing,
* Disruption of soil caused by construction equipment, or
* Tillage practices to prepare a seed bed for crop production.

After soil particles have been detached, they may be transported by:

* Water flowing over the area where detached soil particles exist,
* Wind blowing over the area where detached particles exist,
* Raindrops impacting the surface and splashing detached soil to a new location, or
* Shoveling or trucking detached soil.

**Interrill Erosion** is the erosion that occurs as a result of raindrop energy and a thin sheet flow of runoff. As soon as the rainfall rate exceeds the soil’s infiltration rate, runoff begins flowing downslope as a thin sheet and carrying with it soil particles that have been dislodged.

**Rill Erosion** occurs when the runoff water from interrill areas enters small channels called rills. Rills are usually linear and are oriented in a direction perpendicular to the contour (straight down the hill). As the flow moves down slope, rills tend to grow deeper and wider until small channels are visible. Typically, rills are small enough to be removed by tillage operations. The process referred to as rill erosion, is the detachment, usually by shear forces, and transport of soil particles from within rills.

 **Factors Influencing Erosion**

The primary driving force of erosion on upland land areas is precipitation. Rainfall amount and intensity, both of which contribute to the energy of detachment, varies by location and time of year. Soil characteristics affect soil erodibility. Clay particles are cohesive and difficult to detach, but are easily transported long distances. Silty soils are generally well-aggregated, but large aggregates often fall apart when wetted resulting in small aggregates and individual soil particles, which are more easily transported. Sand-sized soil particles are difficult to transport even though they are easily detached, while silt- and clay-sized particles are more easily transported, but often are harder to detach from soil material. Land shape affects erosion potential as typically the steeper the land slope and the longer the length-of-slope the greater is the erosion potential. Land use and conservation practices affect the potential for erosion. Land use that maintains vegetation, which provides cover and root mass to bind soil together, generally results in less erosion than comparable land with little or no vegetation.

**Predicting Soil Erosion**

USDA-ARS developed the Revised Universal Soil Loss Equation (RUSLE) to estimate the long-term annual erosion potential on agricultural land. The equation is based on four factors affecting soil erosion potential:

 Aerosion = (R) (K) (LS) (CP) (Equation 2.1)

where:

 Aerosion = annual soil interrill + rill erosion in tons per acre per year (tons/ac-yr),

 R = rainfall factor (dimensionless),

 K = soil erodibility factor (dimensionless),

 LS = slope-length factor (dimensionless),

 CP = conservation practices factor (dimensionless).

**Rainfall Factor, R** is a measure of the erosive forces of rainfall for an area. It is based on a combination of rainfall intensity and accumulation. Annual R values for North Carolina are shown in Figure 2.1. However, because construction projects often do not last a year, it is necessary to compute partial-year R values. Partial-year R values area shown in Table 2.1 for the erosion region shown in Figure 2.2. The partial-year R factor can be computed by summing the monthly values in Table 2.1 for the appropriate region and then multiplying the sum by the annual R factor value.

**Table 2.1. Partial-Year Cumulative R Distributions (Renard et al, 1993).**

|  |  |
| --- | --- |
|  | **Geographic Region, Figure 2.2** |
| **Month** | **110 & 116** | **117** |
| Jan | 0.03 | 0.02 |
| Feb | 0.04 | 0.02 |
| Mar | 0.05 | 0.03 |
| Apr | 0.06 | 0.04 |
| May | 0.07 | 0.06 |
| Jun | 0.11 | 0.14 |
| Jul | 0.20 | 0.23 |
| Aug | 0.21 | 0.20 |
| Sep | 0.11 | 0.15 |
| Oct | 0.05 | 0.06 |
| Nov | 0.04 | 0.03 |
| Dec | 0.03 | 0.02 |



**Figure 2.1. Annual Rainfall Factor, R, for North Carolina.**



**Figure 2.2. Regions for Determining Partial-Year R Values.**

**Soil Erodibility Factor, K** is related to soil properties (Wischmeier et al, 1971):

* Percent silt (MS; 0.002 to 0.05 mm) and very fine sand (VFS; 0.05 to 0.1 mm),
* Percent sand (SA; 0.1 to 2 mm),
* Percent organic matter (OM),
* Soil structure (S1), and
* Soil permeability (P1).

These soil parameters have been used to determine K values for most soils as listed in Table 2.2 and in other references such as Table 8.01d (NCDENR, 2006).

**Length-Slope Factor, LS** is a single factor based on average land slope and the length of the uninterrupted slope over which water flows. The LS value is determined from Figure 2.3 for a known slope length and slope in %. For example, a slope length of 300 ft with slope of 0.05 ft/ft (5%) produces an LS value of 1.3.

****

**Figure 2.3. LS factors for construction and mining site land uses that have a high ratio of rill to interrill erosion. (Adapted from Renard et al., 1997).**

**Table 2-2. Hydrologic Soil Group (HSG), Permeability, K and T values.**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  |  | **B-Horizon** |  |  |  |  |
| **Soil** |  | **Permeability** | **RUSLE** | **RUSLE** | **RUSLE** | **RUSLE** |
| **Series** | **HSG** | **in/hr** | **T** | **K(A)** | **K(B)** | **K(C)** |
| Ailey | B | 0.6 to 2.0 | 2 | 0.15 | 0.24 | 0.24 |
| Appling | B | 0.6 to 2.0 | 4 | 0.24 | 0.28 | 0.28 |
| Autryville | A | 2.0 to 6.0 | 5 | 0.10 | 0.10 | 0.10 |
| Badin | B | 0.6 to 2.0 | 3 | 0.15 | 0.24 | 0.15 |
| Belhaven | D | 0.2 to 6.0 |  -- |  -- | 0.24 | 0.24 |
| Cecil | B | 0.6 to 2.0 | 4 | 0.24 | 0.28 | --  |
| Centenary | A | 6.0 to 20.0 | 5 | 0.10 | 0.10 | 0.10 |
| Chastain | D | 0.06 to 0.2 | 4 | 0.28 | 0.37 | --  |
| Chewacla | C | 0.15 to 0.24 | 5 | 0.28 | 0.32 | 0.28 |
| Cowee | B | 0.6 to 2.0 | 3 | 0.28 | 0.28 | 0.28 |
| Creedmoor | C | 0.2 to 0.6 | 3 | 0.28 | 0.32 | 0.32 |
| Emporia | C | 3.0 to 6.0 | 5 | 0.28 | 0.17 | 0.28 |
| Evard | B | 0.6 to 2.0 | 5 | 0.24 | 0.24 | 0.24 |
| Fannin | B | 0.6 to 2.0 | 3 | 0.32 | 0.32 | 0.32 |
| Goldsboro | B | 0.6 to 2.0 | 3 | 0.20 | 0.24 | 0.24 |
| Goldston | C | 2.0 to 6.0 | 2 | 0.15 | 0.05 | --  |
| Gritney | C | 0.06 to 0.2 | 3 | 0.32 | 0.32 | 0.20 |
| Helena | C | 0.06 to 0.2 | 4 | 0.24 | 0.28 |   |
| Hiwassee | B | 0.6 to 2.0 | 5 | 0.28 | 0.28 | 0.28 |
| Hyde | B/D | 0.2 to 0.6 | 5 | 0.17 | 0.43 | --  |
| Johnston | D | 1.25 to 1.45 | 5 | 0.17 | 0.17 | --  |
| Lynn Haven | B/D | 1.35 to 1.6 | 5 | 0.10 | 0.15 | --  |
| Madison | B | 0.6 to 2.0 | 3 | 0.28 | 0.32 | 0.32 |
| Mayodan | B | 0.6 to 2.0 | 4 | 0.24 | 0.32 | 0.28 |
| Norfolk | B | 1.30 to 1.75 | 5 | 0.17 | 0.24 | --  |
| Pacolet | B | 0.12 to 0.16 | 3 | 0.15 | 0.28 | 0.28 |
| Polkton | D | 1.15 to 1.60 | 2 | 0.37 | 0.37 | 0.37 |
| Portsmouth | B/D | 0.6 to 2.0 | 5 | 0.24 | 0.28 | 0.17 |
| Rains | B/D | 1.30 to 1.60 | 5 | 0.20 | 0.24 | --  |
| Rion | B | 0.6 to 2.0 | 3 | 0.24 | 0.24 | 0.24 |
| Roanoke | D | < 0.02 | 4 | 0.37 | 0.24 | 0.24 |
| Roper | B/D | 0.16 to 0.46 | -- | -- | 0.43 | 0.43 |
| State | B | 0.6 to 2.0 | 5 | 0.28 | 0.28 | 0.17 |
| Tatum | B | 1.10 to 1.60 | 4 | 0.37 | 0.28 | --  |
| Tomotley | A | 0.6 to 2.0 | 5 | 0.20 | 0.20 | 0.20 |
| Torhunta | C | 1.35 to 1.60 | 5 | 0.10 | 0.15 | 0.10 |
| Vance | C | 0.06 to 0.2 | 3 | 0.24 | 0.28 |  -- |
| Wakulla | B/D | 0.4 to 1.6 | 5 | 0.10 | 0.10 | 0.10 |
| Wedowee | B | 0.6 to 2.0 | 3 | 0.24 | 0.28 | 0.28 |
| Weeksville | B/D | 0.6 to 2.0 | 5 | 0.43 | 0.32 | -- |
| White Store | D | 0.06 to 0.6 | 3 | 0.37 | 0.37 | 0.32 |
| Woodington | A | 0.6 to 2.0 | 5 | 0.10 | 0.20 | 0.10 |

**Conservation Practice Factor, CP** accounts for the influences of protective vegetation and plant roots on erosion processes. The variations in earth-moving activities and their influence on erosion potential are shown in Table 2.3. To reduce erosion from construction sites, the practices with low CP factors should be implemented as soon as possible during the construction period.

 **Table 2.3 CP Values for Earth Disturbance Sites.**

|  |  |
| --- | --- |
| **Bare soil condition** | **CP** |
|  **Fill** |  |
|  Packed, smooth | 1.00 a |
|  Fresh disked | 0.95 a |
|  Rough (offset disk) | 0.85 a |
|  **Cut** |  |
|  Loose to 12 inches, smooth | 0.90 b |
|  Loose to 12 inches, rough | 0.80 b |
|  Compacted by bulldozer | 1.00 b |
|  Compacted by bulldozer and tracked parallel to the contour | 0.50 c |
|  Rough, irregular tracked all directions | 0.90 b |
|  **Surface Condition with No Cover** |  |
| Compact and smooth, scraped w/ bulldozer or scraper up / down hill | 1.3 d |
|  Compact and smooth, raked w/ bulldozer root rake up and down hill | 1.2 d |
|  Compact and smooth, scraped w/bulldozer or scraper across slope | 1.2 d |
|  Compact and smooth, raked w/bulldozer root rake across slope | 0.9 d |
|  Loose as a disked plow layer | 1.0 d |
|  Ryegrass (perennial type) | 0.05 d |
|  Small Grain | 0.05 d |
|  Sod (freshly placed) | 0.08 b |
|  Hay (1.0 tons/acre) | 0.13 d |
|  Hay (2.0 tons/acre) | 0.02 d |
|  Straw, 1 ton/acre, 69% cover when placed, 50% cover at 3 months | 0.24 a |
|  Straw, 2 tons/acre, 91% cover when placed, 84% cover at 3 months | 0.10 a |
|  Wood chips (2.0 tons/acre) | 0.70 e |
|  Wood chips (4.0 tons/acre) | 0.42 e |
|  Wood chips (6.0 tons/acre) | 0.22 e |
|  Bark mulch (10 tons/acre of 2.5-in chips) | 0.27 c |
|  Bark mulch (25 tons/acre of 2.5-in chips) | 0.06 c |
|  Stone (100 tons/acre) | 0.37 b |
|  Stone (200 tons/acre) | 0.21 b |
|  Stone (400 tons/acre) | 0.10 b |

a. Adapted from Toy and Foster, 1998.

b. Adapted from Israelson et al. (1980).

c. Adapted from Jarrett et al. (1984).

d. Adapted from USDA-NRCS, Connecticut Technical Guide

e. Transportation Research Board (1980)

**Erosion Volume Estimates from Secondary Roads**

Based on the RUSLE2 analysis results, following is a shortcut equation that estimates the eroded sediment volume expected from secondary roads based on a 30-foot roadway including the road ditch:

 Vditch = (Cditch) (R) (K) (Sditch) (Equation 2.2)

where:

 Vditch = secondary road sediment volume expected in cubic feet per acre (ft3/ac),

Cditch = regression constant for secondary roads dependent on ditch side slopes,

R = Rainfall Factor for the duration of construction,

K = Soil Erodibility Factor (B or C horizon, whichever his higher),

Sditch = slope of secondary road ditch (ft/ft).

The values of CS are determined using Table 2.4 depending on road ditch side slope.

**Table 2.4. Regression Constant, Cditch to be used in Equation 2.2.**

|  |  |
| --- | --- |
| **Ditch Side Slope** | **Constant Cditch** |
| 4:1 | 291 |
| 3.5:1 | 341 |
| 3:1 | 399 |
| 2.5:1 | 467 |
| 2:1 | 549 |
| 1.5:1 | 659 |
| 1:1 | 808 |
| 0.75:1 | 916 |
| 0.5:1 | 1067 |

*Example:* Estimate erosion volume from a 2-acre secondary roadway construction during June-July in Carteret County with Goldsboro soil. The road ditch has a slope of 0.05 ft/ft and 2:1 side slopes.

 Figures 2.1 and 2.2: Annual R = 340, and Carteret County is in Region 117.

 Table 2.1: During June-July, partial-year R = (0.14 + 0.23) (340) = 126

 Table 2.2: K value is 0.24 (assume B Horizon – subsoil)

 Table 2.4: Cditch is 549 for 2:1 ditch side slopes

 Vditch = (549) (126) (0.24) (0.05) = 830 cubic ft per acre (Jun-Jul)

 Total erosion for 2 acres = (830) (2) = 1,660 cubic ft (Jun-Jul)

 To convert to cubic yards: Erosion = 1,660 / 27 = 61 cubic yards

**MODULE 3. Regulatory Issues**

The North Carolina Department of Transportation is regulated by many different environmental laws and regulations. The current NC DENR Division of Water Quality General Permit NCG010000 to discharge stormwater under the NPDES for Construction Activities includes a requirement for ground cover stabilization as outlined in the table below.

|  |  |  |
| --- | --- | --- |
| **Site Area Description** | **Time Frame** | **Stabilization Time Frame Exceptions** |
| Perimeter dikes, swales, ditches and slopes | 7 days | None |
| High Quality Water (HQW) Zones | 7 days | None |
| Slopes steeper than 3:1 | 7 days | If slopes are 10 ft or less in height and are not steeper than 2:1, then 14 days are allowed |
| Slopes 3:1 or flatter | 14 days | 7-days for slopes greater than 50 feet in length |
| All other areas with slopes flatter than 4:1 | 14 days | None (except for perimeters and HQW Zones) |

* Basins with drainage area >1 acre must have surface dewatering device in basins that discharge from the project

**NC Turbidity Standards**

|  |  |
| --- | --- |
| **SW Classification** | **Turbidity not to Exceed (NTUs)** |
| Streams | 50 |
| Lakes and Reservoirs | 25 |
| Trout Waters | 10 |

**MODULE 4. Open Channel Design**

Open channel flow occurs due to gravity in natural water courses, channels, diversions, and culverts. Two limiting criteria for designing stable open channels are velocity and tractive force (sometimes termed shear stress). Both parameters increase with channel slope and depth of water. The basic design approach is to calculate the maximum allowable velocity and/or tractive force and then establish a liner that can withstand that force and not erode.

Tractive force, , is a measure of the frictional resistance to flow in a channel and is calculated using:

 = ( (dchan) (Schan) (Equation 4.1)

where:

  = average tractive force acting on the channel lining (lbs/ft2),

  = unit weight of water, assumed to be 62.4 lbs/ft3,

 dchan = depth of flow in the channel (ft),

Schan = slope of the channel (ft/ft).

The maximum tractive force in a channel occurs where the depth of flow is greatest. By comparing the maximum tractive force from Equation 4.1 with the maximum allowable tractive forces from the tables below, the appropriate channel lining can be selected to resist erosion. The NCDOT guidelines for selecting road ditch linings are listed in Table 4.1. Rock rip rap size gradations are listed in Table 4.2. Allowable tractive forces for various channel liners are listed in Tables 4.3 and 4.4. Table 4.4 also lists allowable hill slopes for liner applications.

**Table 4.1. NCDOT guidelines for selecting channel linings.**

|  |  |
| --- | --- |
| **Channel Slope (%)** | **Recommended Channel Lining** |
| < 1.5 | Seed and Mulch |
| 1.5 to 4.0 | Temporary Liners |
| > 4.0 | Turf Reinforced Mats (TRM) or Hard |

**Table 4.2. Rock Rip Rap Size Gradation.**

|  |  |
| --- | --- |
|  | **Graded Rock Size (inches)** |
| **Class or #** | **Maximum** | **D50** | **Minimum** |
| #57 | 1 | ½ | No. 8 |
| #5 | 1 | 3/4 | 3/8 |
| A | 6 | 4 | 2 |
| B | 12 | 8 | 5 |
| 1 | 17 | 10 | 5 |
| 2 | 23 | 14 | 9 |

**Table 4.3. Allowable Tractive Forces for Channel Linings (PADEP, 2000).1**

|  |  |  |
| --- | --- | --- |
| **Channel Lining Category** | **Lining Type** | **Allowable Tractive Force,  (lbs/ft2)** |
| **Unlined – Erodible Soils (K > 0.37)** | Silts, Fine – Medium Sands | 0.03 |
|  | Coarse Sands | 0.04 |
|  | Very Coarse Sands | 0.05 |
|  | Fine Gravel | 0.10 |
| **Erosion Resistant Soils (K < 0.37)** | Sandy loam | 0.02 |
|  | Gravely, Stony, Channery loam | 0.05 |
|  | Stony or Channery silt loam | 0.07 |
|  | Loam | 0.07 |
|  | Sandy clay loam | 0.10 |
|  | Silt loam | 0.12 |
|  | Silty clay loam | 0.18 |
|  | Clay loam | 0.25 |
|  | Shale & Hardpan | 1.00 |
|  | Durable Bedrock | 2.00 |
| **RECP** | Jute Netting | 0.45 |
|  | Geocoir/Dekowe; Straw; RS-1 | 0.83 |
|  | Profile; Futerra | 1.00 |
|  | Am. Excelsior Co.; Curlex Net Free | 1.00 |
|  | Am. Excelsior Co.; Straw; 1 net | 1.25 |
|  | Geocoir/Dekowe; Straw; RS-2 | 1.25 |
|  | E. Coast Ero. Blank.; Straw/Coir, 2 Jute nets | 1.35 |
|  | Am. Excelsior Co.; Straw; 2 nets | 1.50 |
|  | Am. Excelsior Co.; Curlex I.73; 1 net | 1.55 |
|  | E. Coast Ero. Blank.; Straw, 1 net | 1.55 |
|  | E. Coast Ero. Blank.; Coir, 2 Jute nets | 1.63 |
|  | Am. Excelsior Co.; Curlex I.98; 1 net | 1.65 |
|  | Am. Excelsior Co.; Curlex II.73; 2 nets | 1.75 |
|  | N. Am. Green; Straw; double net | 1.75 |
|  | E. Coast Ero. Blank.; Excelsior, 1 net | 1.80 |
|  | NAG; 70% straw: 30% Coconut; double net | 2.00 |
|  | NAG; Polypropylene; double net; Bare soil | 2.00 |
|  | Am. Excelsior Co.; Curlex II.98; 2 nets | 2.00 |
|  | Geocoir/Dekowe; Coconut, RSC-4 | 2.00 |
|  | E. Coast Ero. Blank.; Excelsior, 2 nets | 2.00 |
|  | E. Coast Ero. Blank.; Straw, Jute net | 2.10 |
|  | E. Coast Ero. Blank.; Straw, 2 nets | 2.10 |
|  | N. Am. Green; Coconut; double net | 2.25 |
|  | Am. Excelsior Co.; Curlex III; 2 nets | 2.30 |
|  | Am. Excelsior Co.; Curlex Enforcer; 2 nets | 2.30 |
|  | E. Coast Ero. Blank.; Straw/Coir, 2 nets | 2.60 |
|  | Am. Excelsior Co.; Curlex High Velocity; 2 nets | 3.00 |
|  | Geocoir/Dekowe; 400 | 3.10 |
|  | E. Coast Ero. Blank.; Coir, 2 nets | 3.20 |
|  | E. Coast Ero. Blank.; Polypropylene, 2 nets | 3.21 |
|  | Geocoir/Dekowe; 700 | 4.46 |
|  | Geocoir/Dekowe; 900 | 4.63 |
|  | NAG; Polypropylene; double net; Vegetated | 8.00 |
| **Turf Reinforced Mats (TRM)** | North Am. Green SC250; Bare soil | 2.50 |
|  | North Am. Green C350; Bare soil | 3.00 |
|  | North Am. Green P550; Bare soil | 3.25 |
|  | E. Coast Ero. Blank.; Coir, 3 nets | 3.50 |
|  | Profile/Enkamat; 7003 (BFM) | 5.00 |
|  | Profile/Enkamat; 7010, seed and hydromulch | 6.00 |
|  | Profile/Enkamat; 7010 – 7220, seed, BFM; Veg | 6.0-8.0 |
|  | Profile/Enkamat; 7010 - 7220, seed, BFM; Bare  | 6.7-11.2 |
|  | Profile/Enkamat; 7018, seed and hydromulch | 7.00 |
|  | North Am. Green SC250; Vegetated | 8.00 |
|  | Profile/Enkamat; 7020, seed and hydromulch | 8.00 |
|  | Profile/Enkamat II; seed and BFM; Vege. | 8.00 |
|  | Profile/Enkamat; 7920, seed and BFM; Vege. | 8.00 |
|  | North Am. Green C350; Vegetated | 10.0 |
|  | Profile/Enkamat II; seed and BFM; Bare  | 10.0 |
|  | Am. Excelsior Co.; Recyclex | 10.0+ |
|  | North Am. Green P550; Vegetated | 12.5 |
| **Grass Liners** | Class D | 0.60 |
|  | Class C | 1.00 |
|  | Class B | 2.10 |
| **Aggregate & Riprap**  | #57 | 0.25 |
|  | #5 | 0.50 |
|  | Class A | 1.00 |
|  | Class B | 2.00 |

**Table 4.4. Allowable Tractive Force of RECPs. (Table 6.17a NCDENR (2006))1**

|  |  |  |  |
| --- | --- | --- | --- |
| **Category** | **Product Type** | **Max. Permissible Shear Stress (lbs/ft2)** | **Slopes****Up to** |
| **RECP** | N. Am. Green; Straw; 1 net | 1.55 | 3:1 |
|  | Am. Excelsior Co.; Curlex Net Free | 1.00 | 3:1 |
|  | Am. Excelsior Co.; Straw; 1 net | 1.25 | 3:1 |
|  | Geocoir/Dekowe; Straw; RS-1 | 0.83 | 3:1 |
|  | N. Am. Green; Straw; 2 nets | 1.75 | 2:1 |
|  | Am. Excelsior Co.; Curlex I.73; 1 net | 1.55 | 2:1 |
|  | Am. Excelsior Co.; Curlex I.98; 1 net | 1.65 | 2:1 |
|  | Am. Excelsior Co.; Straw; 2 nets | 1.50 | 2:1 |
|  | Geocoir/Dekowe; Straw; RS-2 | 1.25 | 2:1 |
|  | Geocoir/Dekowe; 70% Straw 30% Coconut; RSS/C-3 | 1.85 | 2:1 |
|  | Geocoir/Dekowe; Poly/Fiber; RSP-5 | 2.00 | 2:1 |
|  | Geocoir/Dekowe; Coconut, RSC-4 | 2.00 | 2:1 |
|  | Am. Excelsior Co.; Curlex II.73; 2 nets | 1.75 | 1.5:1 |
|  | Am. Excelsior Co.; Curlex II.98; 2 nets | 2.0 | 1.5:1 |
|  | Am. Excelsior Co.; Straw/Coconut; 2 nets |  | 1.5:1 |
|  | NAG; 70% straw: 30% Coir; 2 nets | 2.00 | 1:1 |
|  | N. Am. Green; Coconut; 2 nets | 2.25 | 1:1 |
|  | Am. Excelsior Co.; Curlex III; 2 nets | 2.3 | 1:1 |
|  | NAG; Polypropylene; 2 nets; Bare soil | 2.0 | 1:1 |
|  | NAG; Polypropylene; 2 nets; Vegetated | 8.0 | 1:1 |
|  | Am. Excelsior Co.; Coconut; 2 nets |  | 1:1 |
|  | Am. Excelsior Co.; Curlex Enforcer; 2 nets |  | 0.75:1 |
|  | Am. Excelsior Co.; Curlex High Velocity; 2 nets | 3.0 | 0.75:1 |
| **TRM** | Profile/Enka; 7003, Vege. | 5.0 | 3.5:1 |
|  | Profile/Enka; 7010, 7210, 7910, Vege. | 6.0 | 2:1 |
|  | Profile/Enka; 7220, 7020, Vege. | 8.0 | 1.5:1 |
|  | Profile/Enkamat II | 8.0 | 1:1 |
|  | Profile/Enka; 7520, Vege. | 8.0 | 0.5:1 |
|  | Am. Excelsior Co.; Recyclex | 10.0+ | 0.5:1 |
| Degradable RECP’s | Nets and Mulch | 0.1 – 0.2 | 20:1 |
| (Unvegetated) | Coir Mesh | 0.4 – 3.0 | 3:1 |
|  | Blanket – Single Net | 1.55 – 2.0 | 2:1 |
|  | Blanket – Double net | 1.65 – 3.0 | 1:1 |
| Nondegradable | Unvegetated | 2 – 4 | 1:1 |
| Turf Reinforce Mats | Partially Vegetated | 4 – 6 | >1:1 |
|  | Fully Vegetated | 5 - 10 | >1:1 |

*Example:* Select a suitable channel liner for a triangular road ditch with maximum depth of 1 ft and slope of 1%.

 Table 4.1: NCDOT guidelines for 1% slope allow seed and mulch or RECP

 Equation 4.1:  = (62.4 lbs/ft3) (1 ft) (0.01 ft/ft) = 0.6 lbs/ft2

 Table 4.3: Apply seed and mulch or select a RECP channel lining with a maximum allowable tractive force greater than 0.6 lbs/ft2.

**Sizing Pipes for Flow**

Though circular channels obey the Manning’s equation, their geometry is more complex. Therefore, it is suggested that Figure 4.1 be used for sizing pipes that have relatively smooth linings such as clay or concrete pipe. 

**Figure 4.1. Pipe sizing chart for pipe with a smooth inner liner.**

**MODULE 5. Sediment Retention BMPs**

Sediment retention best management practices (BMPs) are treatment systems designed to remove suspended sediment from runoff water. BMPs are designed to maximize sediment retention based on (1) impoundment volume; (2) detention time; and (3) length of flow path within the structure. BMP characteristics that improve effectiveness include:

* Stable interior sideslopes no steeper than 1.5:1,
* Plastic liner and/or vegetation established within the structure,
* Stable inlet(s) for water entering the structure to settle sediment,
* Baffles of porous jute or coir to divide the structure into 3 or more chambers,
* Surface dewatering device to remove cleaner water first, and

In North Carolina, sediment retention BMPs (basins or similar retention structures) are sized based on two criteria:

1. **Volume**, Vbasin, in cubic feet (ft3):

 Vbasin ≥ 3,600 ft3 per acre of disturbed land

 Vbasin ≥ 1,800 ft3 per acre of disturbed land (with a surface dewatering device)

1. **Surface Area**, Abasin, in square feet (ft2):

 Abasin ≥ 435 Q10

 Abasin ≥ 325 Q10 (with a surface dewatering device)

 For **environmentally sensitive areas**, use the 25-year peak runoff rate, Q25.

*Example:* Calculate minimum volume and surface area for a skimmer basin serving a 6-acre construction site (all disturbed) with Q10 = 20 cfs.

 **Volume:** Vbasin ≥ 1,800 ft3 per acre of disturbed land

 Vbasin ≥ 1,800 ft3/ac (6 ac) = 10,800 ft3

 **Surface Area:**  Abasin ≥ 325 Q10 (with a surface dewatering device)

 Abasin ≥ 325 (20) = 6,500 ft2

**Dewatering Sediment Retention BMPs**

Sediment retention BMPs may have one or two spillways. The principal spillway is designed to pass all flows up to extreme conditions. The geometry and position of the principal spillway determine the discharge of water and the retention time for settling of suspended sediment. The design dewatering time ranges from less than a day up to several days to maximize settling while providing room for the next storm event. The most common dewatering devices are a rock section in the wall of the structure, a perforated riser, skimmer, or a flashboard riser.

**Rock Spillway.** This structure consists of a trapezoidal shaped stack of Class B structural rock with a 12-inch layer of #57 “sediment control stone” placed over the inside face. The water leaving the basin is expected to pass through the finer stone and be filtered leaving a substantial portion of the sediment inside the basin.

**Skimmer Surface Dewatering Device.** This device is designed to remove water from the surface of the water column to discharge the cleanest water. An orifice located just below the water surface controls the flow rate of discharge water. Table 5.1 lists design dewatering rates for several sizes of Faircloth Skimmers.

**Table 5.1. Faircloth Skimmer Dewatering Rates.**

|  |  |  |
| --- | --- | --- |
| Skimmer Diameter(inches) | QskimMax Outflow Rate(ft3/day) | HskimDriving Head(ft) |
| 1.5 | 1,728 | 0.125 |
| 2.0 | 3,283 | 0.167 |
| 2.5 | 6,234 | 0.208 |
| 3.0 | 9,774 | 0.250 |
| 4.0 | 20,109 | 0.333 |
| 5.0 | 32,832 | 0.333 |
| 6.0 | 51,840 | 0.417 |
| 8.0 | 97,978 | 0.500 |

Table 5.1 is used to size the skimmer orifice located at the top of the water entry point. This orifice controls the basin outflow rate and must be sized carefully. The skimmer size refers to the diameter of the float and arm. The Faircloth Skimmer is sized by determining the required basin outflow rate as the water volume divided by the dewatering time:

Qskim = Vskim / tdewater (Equation 5.1)

where:

 Qskim = basin outflow rate in cubic feet per day (ft3/day),

 Vskim = basin volume to be dewatered in cubic feet (ft3),

 tdewater = dewatering time (days).

For NCDOT skimmer basins, the current design standard calls for dewatering the top 2 feet of volume in 3 days. For the design Qskim, select a skimmer and orifice from Table 5.1 which meets or exceeds this rate. The Faircloth Skimmer comes with a plastic plug that can be drilled to provide an orifice with a diameter calculated using the discharge rate and the driving head:

  (Equation 5.2)

where:

 Dorifice = diameter of the skimmer orifice in inches (in),

 Qskim = basin outflow rate in cubic feet per day (ft3/day),

 Hskim = driving head at the skimmer orifice from Table 5.1 in feet (ft).

**Infiltration Basin.**  If soil conditions are conducive to high infiltration rates, most or all of the water entering a basin can be discharged through infiltration. For a conservative design, choose the permeability of the soil horizon with the slowest permeability. For NCDOT projects, the soil permeability must be at least 0.5 in/hr to meet the design criteria of dewatering 3 ft of water in 3 days or less.

**Baffles**. Baffles required in Silt Basins at drainage turnouts, Type A and B Temporary Rock Sediment Dams, Skimmer Basins, Stilling Basins:

3 baffles evenly-spaced if basin length > 20 ft

2 baffles evenly-spaced if basin length 10 - 20 ft

1 baffle if basin length ≤ 10 ft (State Forces)

**Emergency Spillway Weir**. Capable of passing runoff from large storms.

Skimmers and Infiltration Basins:

Weir Length = Qpeak /0.4

Temporary Sediment Dam - Type B:

Minimum 4ft for 1 acre or less

**Checkdams and Wattle Spacing o*n NCDOT projects****:*

Coastal Plain: Spacing = 600 / slope (%)

Piedmont and West: Spacing = 300 / slope (%)

*Example:* For 3% slope, space checks 100 ft apart

**MODULE 6. Below Water Table Borrow Pits**

Borrow pits are areas of suitable soil material excavated to provide necessary road building material. Between active borrow pit excavations, ground water may seep into the pit, and rainfall may produce runoff into the borrow pit, creating an impoundment that must be dewatered before additional borrow material can be removed. Because all or part of the whole borrow pit will fill with water at least to the depth of the regional water table, it is common practice for contractors to dewater borrow pits by placing a pump in the deepest location. If the pumped water has high turbidity, the pumped borrow pit water must be treated.

**Stilling basin for Pumped Borrow Pit Water**

A common practice is to discharge the water pumped from the pit into a stilling basin with a volume that provides sufficient time for settling. The required stilling basin volume can be calculated by multiplying the desired detention time by the pumping rate of water entering the basin. For NCDOT applications, the current design standard requires a detention time of at least 2 hours and a maximum pumping rate of 1,000 gpm. For a 2-hr detention time, the minimum stilling basin volume is:

 Vstill = 16 (Qstill) (Equation 6.1)

where:

Vstill = volume of stilling basin in cubic feet (ft3), and

Qstill = pumping rate entering the stilling basin in gallons per minute (gpm).

At the maximum NCDOT pumping rate of 1,000 gpm, the required stilling basin volume is 16,000 ft3.

If water pumped from the borrow pit has high turbidity, the water is most commonly discharged into a stilling basin located at the land surface. The stilling basin for pumped effluent is a rectangular-shaped basin with at least a 2:1 L:W shape, constructed from natural soil. The basin should receive sediment-laden water from a borrow pit excavation site where the water is pumped to the stilling basin for treatment. The maximum depth is 3 feet, and the embankment should have 1.5:1 interior and exterior side slopes. The basin is dewatered with a surface outlet device, most appropriately a 12-inch vertical riser pipe (with no perforations) set at the 3-ft water level. A flashboard riser system may also be used with the top flashboard set at 3 ft for normal operation.

**Polyacrylamide (PAM)**For high-turbidity water, a polyacrylamide (PAM) may be added to the pumped water as a flocculant to help settle sediment in the stilling basin system. When PAM is properly injected into the pumped water, the stilling basin can be designed to detain the water for as little as 2 hours. PAM is available in powder form and can be mixed with water to form a liquid suspension of PAM. Normal mixing rates are one pound of PAM added to 100 gallons of water. This liquid PAM solution can be injected into the positive side of the pump using an injection pump unit to produce a PAM concentration of about 1 mg/L. The liquid PAM application or injection rates needed to create a 1 mg/L PAM concentration in the sediment-laden water are show in Figure 6.1.

**Figure 6.1. PAM injection rate related to pump rate to create 1 mg/L of PAM.**

**Determining Wetland Setbacks From Borrow Pits**

Type 1: Flow from wetland to pit

Type 2: Flow from pit to wetland

Does not require Skaggs Method calculations

Minimum 25 ft buffer (setback) from wetland

Minimum 50 ft buffer from stream

Type 3: Flow-through pits: wetland to pit on one side, pit to wetland on other side

\*Type 1 and 3 Uncertain flow direction so: use 400ft or Skaggs Method determination

Where borrow pits are located near wetlands, it is critical that excavation be managed so that wetland hydrology is not altered. A site has wetland hydrology if, during the growing season, the water table is normally within 1 ft of the soil surface for a continuous critical duration, defined as 5 to 12.5% of the growing season (USACE, 1987). The lower limit of 5% of the growing season was used in the Skaggs Method.

The Skaggs Method was developed from simulating 50 years (1951-2000) of each county’s meteorological data on the flow cross-section shown in Figure 6.2 using a local hydric soil to determine the setback distance or “Lateral Effect” from the borrow pit (Figure 6.2). During simulations, a critical water table depth of 0.83 ft was used as a conservative approximation of the USACE (1987) 1-ft criterion. As boundary conditions for the simulations, two additional parameters were used; (a) depth of water stored on the soil surface, either 1 or 2 inches; and (b) depth below surface where the borrow pit has ponded water, ranging from 1 to 6 ft. Other parameters for each county included depth from surface to impermeable layer, ho, soil drainable porosity, f, and soil effective hydraulic conductivity, Ke.

**Lateral Effect EffEffect**

**Wetland**

**Borrow Pit**

**Water Table**

**h**

**do=ho-d**

**d**

**0.83 ft @ T25**

**hooooo0**

**o**

**Figure 6.2. Borrow Pit with Lateral Effect on Wetland Hydrology.**

The effective hydraulic conductivity is the depth-weighted average of conductivities of each soil layer above the impermeable layer.

For NCDOT applications, the current design standard is to set the following parameters as constants:

**Drainable porosity** (f) = 0.035 and Depth to pit water surface (**do**) = 2 ft