NATURAL RESOURCES CONSERVATION SERVICE

DOCUMENTATION REQUIREMENTS FOR

LINED WATERWAY OR OUTLET

CODE 468

Design Criteria

Design according to the guidelines in Chapter 7 of National Engineering Handbook Part 650 (NEH 650), *Engineering Field Handbook*, and the criteria in Conservation Practice Standard (CPS) 468, Lined Waterway or Outlet.

Surveys

The amount of survey information necessary to design the lined waterway or outlet will depend on the specific site conditions. In most cases, it will require a profile and cross section survey or a detailed topographic survey.

A profile and cross section survey should be run as follows:

- Profile the proposed centerline of the waterway or outlet taking shots on 100-foot stations and at significant breaks in grade. Cross section data should be taken at locations not to exceed 500 feet apart and more often as needed to accurately describe the topography of the area needed for construction. On longer waterways with more than one instrument set-up, rod readings should be converted to elevations using a common benchmark.
- Record survey data on Form NRCS-ENG-28 and Form NRCS-ENG-29, Loose Leaf Field Sheet, or Forms KS-ENG-37 and KS-ENG-37a, Field Notes (or equivalent). Record and plot the survey data according to the guidance in Chapter 1 in NEH 650 or Appendix D in National Engineering Handbook Part 645, *Construction Inspection*. Individual differences in note keeping are allowed, but the information shown in the references shall be the minimum requirements needed for adequate note keeping. Information collected and recorded electronically shall be plotted as needed to provide the basis for quantity calculations or other design documentation. A copy of the electronic data should be kept in the electronic design folders or as part of the project case file—whichever is more applicable to the project.
- Take additional shots or cross sections as needed at the outlet and at least 100 feet downstream if needed to determine tailwater elevations. Survey information of downstream road, bridges, or culverts will include elevations and dimensions.

A detailed topographic survey can be accomplished using a total station and data collector or a global positioning system (GPS) and data collector. Information collected and recorded electronically shall be plotted as needed to provide the basis for quantity calculations or other design documentation. A copy of the electronic data should be kept in the electronic design folders or as part of the project case file—whichever is more applicable to the project.

At least one benchmark shall be established on the site and recorded in the field notes or electronic data. All surveys shall meet the accuracy standards for rough surveys in Table 1-1 in NEH 650.

Design Procedures and Documentation

Hydrology. Use Form KS-ENG-137a, Hydrologic Summary Sheet, or Form KS-ENG-137b, Hydrologic Summary Sheet, or output from hydrology computer programs to

record the hydrologic data for the waterway drainage area and to compute the peak discharge in cubic feet per second (cfs) for the waterway or outlet. Runoff from a 10-year, 24-hour frequency rainfall will normally be used for design velocity and capacity, except when the waterway or outlet is constructed as part of an animal waste system or as part of a system to reduce flooding. The runoff from a 25-year, 24-hour frequency storm will be used for designs involving an animal waste system or flood reduction. Designs using turf reinforcement mats (TRM) as the lining material will also use the 2-year or 5-year frequency storms in the design procedure. The design storm criteria for stability are contained in Table 1 in CPS 468 and are shown below for convenience.

Hydraulic design. Determine the permissible velocity for the type of lining material being used based on the design guidance in the standard or manufacturers' recommendations. Determine the design cross section using an iterative process based on the peak discharge, slope, and type of lining material used. Design worksheets may be available for rock-riprap-lined outlets. Suppliers or manufacturers may have design programs available for articulated concrete blocks (ACBs), grid pavers, or TRM that can be used to determine the most desirable cross section.

Lined outlets are typically designed with an upstream apron, sloping section, and downstream apron. They should be designed to develop a hydraulic jump at or upstream of the change in grade at the bottom of the slope. A 10-foot level section should be designed as the downstream apron to help develop the jump. This section can be below the outlet grade (if desired) to help develop tailwater in locations where the downstream area is unconfined, and a minimum amount of tailwater is present during the design storm. The hydraulic jump increases the stress and erosion potential at the location of the jump. A minimum safety factor of 1.2 should be used for all lined outlets to account for the increased stress due to hydraulic jump. An upstream apron is recommended for lined outlets as a transition section from the grassed waterway. It should be at least $3d_c$ in length, where d_c is the critical depth of flow in the lined outlet—but not less than 4 feet.

Designs using TRM. Designs using TRM will be based on the permissible shear stress (allowable stress) of the TRM product, existing soils, and vegetation and the calculated shear stress (hydraulic stress) of the design. The terms hydraulic stress and allowable stress are used in NEH 650, Section 650.0703 and are referenced here to match terms used in product literature and design documentation. The permissible shear stress will be determined by the design software

Table 1–Design storms for stability of TRM-lined channels

Design Objective	Design Storm Frequency	Retardance Class	Vegetation Density	Limiting Condition or Phase
Erosion control	2-year	E	Poor	Unvegetated and underlying substrate
Flooding or animal waste	5-year	E	Poor	Unvegetated and underlying substrate
Erosion control	10-year	B[1/]	Fair to good	Fully vegetated
Flooding or animal waste	25-year	B[1/]	Fair to good	Fully vegetated

[1/] Retardance Class C can be used in counties where adjusted curve numbers ARC I + 0.4 (II-I) and ARC I + 0.2 (II-I) are allowed.

for the TRM product or provided as part of the product literature. The calculated shear stress may be determined by the design software for the product, Equation (eq.) 7-6 in NEH 650, Section 650.0703, or other means including Hydrologic Engineering Center-River Analysis System (HEC-RAS) or similar models. The allowable stress for different products is dependent on the type of materials used and the manufacturing process, so product design software will provide the best alternatives for each design. The design procedure and required safety factor is slightly different based on how the permissible and calculated shear stresses are determined, and each method will be further explained and illustrated with an example.

TRM design using hydraulic stress. This procedure uses the short-term maximum shear stress values for TRM products and is limited to designs for drainage areas with a time of concentration of 4.5 hours or less. The short-term stress is based on the TRM product testing procedure, and drainage areas with a time of concentration less than 4.5 hours will result in peak flow durations meeting the short-term requirements. Designs for drainage areas with a time of concentration greater than 4.5 hours will need to use the product design software procedure.

Use eq. 7-6 in NEH 650, Section 650.0703 and the grassed waterway spreadsheet to determine the hydraulic (calculated) shear stress of a proposed design. For ease of reference, eq. 7-6 in NEH 650, Section 650.0703 is shown here:

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

Where: τ = Hydraulic stress, lbs/ft^2
λ = Unit weight of water, 62.4 lbs/ft^3
D = Flow depth in cross section, ft
S = Channel slope, ft/ft

Use the Grassed Waterway (412) Spreadsheet to determine the flow depth based on a desired channel slope to fit the field conditions. The flow depth will be the design depth shown on the "Design" tab sheet using B retardance for capacity. Typical design velocities for TRM products should be in the range of 7 feet/second to 12 feet/second using D retardance for velocity. The bottom width can be adjusted to match the desired number of roll widths including overlap. Calculate the hydraulic stress using eq. 7-6 in NEH 650, Section 650.0703 and a safety factor of 2.2 to determine the minimum short-term permissible shear stress of the TRM product in the fully vegetated phase. TRM product sheets can be used to document the permissible shear stress and velocity of the product in the vegetated condition.

Example 1. A vegetated chute is designed for a peak discharge of 159 cfs from the 10-year storm. The chute slope is 0.125 foot/foot (8 horizontal to 1 vertical [8:1]) with a 50-foot bottom and 4:1 slopes. Using the Grassed Waterway (412) Spreadsheet, the velocity is 7.33 feet/second (f/s) and the design depth is 0.6 foot. The calculated shear stress from eq. 7-6 in NEH 650, Section 650.0703 is 4.68 pounds/square foot (lbs/ft^2). Using a factor of safety of 2.2, the allowable shear stress of the product must be greater than 10.3 lbs/ft^2. The product data sheet for XYZ TRM indicates a permissible shear stress of 11.0 lbs/ft^2, so it will meet the stress requirements of the design. This product comes in rolls that are 6.5 feet wide and should be installed with a minimum overlap of 3 inches. The required number of rolls is determined by the total width of the required installation by the product width minus the overlap. The product should be installed on the side slopes to at least the design depth and an additional foot should be added for the trench installation. For this example, the slope length is as follows:

4 x 0.7 = 2.8 feet + 1 = 3.8 feet (round up to 4 feet)
Total required width is 50 + 4 + 4 (or 58 feet)
58 ÷ 6.25 = 9.28 rolls

Since this will require at least 10 rolls wide, the design bottom width could be adjusted to fit the roll width better. Adjusting the bottom width to 54 feet does not change the stress parameters, and the required width adjusts to 62 feet:

62 ÷ 6.25 = 9.9 rolls

Use the adjusted bottom width of 54 feet.

If the product data sheets also have permissible shear for the unvegetated condition, that condition can be checked using the flow depth from the 2-year storm discharge. The flow depth will be the depth at design velocity using

the E retardance value for velocity. For this example the 2-year discharge is 59 cfs, and flow depth is 0.3 foot with a bottom width of 54 feet and a velocity of 5.11 feet/second (ft/s). The calculated shear stress from eq. 7-6 in NEH 650, Section 650.0703 is 2.34 lbs/ft^2. Using a factor of safety of 2.2, the allowable shear stress of the product must be greater than 5.15 lbs/ft^2. The product data sheet for XYZ TRM indicates a permissible shear stress of 5.5 lbs/ft^2 so it will meet the stress requirements of the design.

The stress requirements using the 2.2 safety factor may eliminate some potential products. NEH 650, Section 650.0703 does not provide an equation to determine allowable stress of vegetated waterways lined with TRM, so the safety factor is set high enough to provide a conservative design. If the proposed TRM product does not meet the minimum requirements from the design procedure using eq. 7-6 in NEH 650, Section 650.0703, it may still be used if design software for the product is available from the supplier and the analysis using the software indicates the product is adequate for the site conditions.

TRM design using product software. Suppliers of erosion control blankets and TRM may have software available to use as a design tool. The designer will need to supply the design discharge, flow duration, cross section information, channel slope, channel soil information, and vegetation information. Based on this information, the software will allow the designer to look at various types of materials and determine if the products are stable for each phase of vegetation growth or condition. The lined channel and underlying substrate must be stable in the fully vegetated phase for the design discharge determined from the hydrology section. This will be the peak runoff from a 10-year frequency storm—except when the waterway or outlet is constructed as part of an animal waste system or as part of a system to reduce flooding. If the runoff from the drainage area cannot be diverted away from the lined channel during establishment of vegetation, additional analysis should be done to check the stability of both the product and the underlying substrate during the establishment period. This analysis will use the peak runoff from a 2-year frequency storm—except when the waterway or outlet is constructed as part of an animal waste system or as part of a system to reduce flooding. Refer to Table 1 for design frequency requirements.

The permissible shear stress of a TRM product is based on laminar flow in a channel; therefore, designs using product design software will require a safety factor of at least 1.2 for all phases including unvegetated, vegetated, and underlying substrate. This safety factor will account for the additional stresses due to the hydraulic jump on the lined outlet. The design procedure using product software is sensitive to the flow duration, defined as the time period where the flow is at least 90% of the design discharge. The break between short-term and long-term flow duration is 2 hours. Drainage areas with a time of concentration less than 4.5 hours should use 2 hours as the peak flow durations. Larger drainage areas should use a flow duration greater than 2 hours or be analyzed with the SITES model to determine the time period where the inflow hydrograph is at least 90% of the peak discharge. Flow durations over 2 hours significantly reduce the permissible shear stress values of TRM products.

Example 2. Using the information from Example 1 and the design software, Products X, Y, and Z are all stable (factor of safety greater than 1.2) for flow conditions in the fully vegetated state for the 10-year peak discharge of 159 cfs. The underlying substrate is also stable for all 3 products with the same flow conditions. The proposed design used a 30-foot bottom width, B retardance with good vegetation density, a peak flow period of 2 hours, and silt loam soils. The TRM products are then checked using the 2-year peak discharge of 59 cfs, retardance class E, and poor vegetation density to check the underlying substrate and product prior to being fully vegetated. The other design parameters did not change. Products X, Y, and Z are stable in the unvegetated state with safety factors greater than 1.2, but the underlying substrate is not stable for product Y with a safety factor of 0.62. The bottom width must be increased to 60 feet to obtain a safety factor of

1.2 for this particular product. Recommend the use of product X or Z for the installation or provide an economic analysis to show that Product Y is the least cost alternative even with the greater installed area.

The bottom width should be checked for adjustment just like in Example 1. The total required width is as follows:

30 + 4 + 4 or 38

38 ÷ 6.25 = 6.08 rolls

Check a new bottom width of 28 feet to see if it is stable so that the installed width will be 6 rolls wide or less. Both products are stable with adequate safety factors using a bottom width of 28 feet. Use this for the design bottom width if both products are also stable with adequate safety factors in the fully vegetated state using peak discharge from the 10-year storm. The products must be installed to the depth shown in the fully vegetated state. An additional 0.25 foot for freeboard is recommended for all installations.

This same procedure should be used when the waterway or outlet is constructed as part of an animal waste system or as part of a system to reduce flooding—except that the peak design discharge for the fully vegetated state will be the 25-year storm or greater. The check for stability of the product in the unvegetated state and the underlying strata will use the peak discharge from the 5-year storm as indicated in Table 1.

TRM design using other models. Other methods may be used to calculate the shear stress on the TRM such as the HEC-RAS model or similar channel models. These models will provide a total stress due to flow in the channel and also indicate the location of the hydraulic jump. They do not indicate how the stress is applied to the TRM product and underlying substrate. Designs using shear stress from HEC-RAS should use the same procedures and safety factors as designs using the hydraulic stress from eq. 7-6 in NEH 650, Section 650.0703.

Include all hydrology calculations and design worksheets or design program outputs in the case file documentation. In some cases, the manufacturer may supply design documentation for grid pavers or other materials, and this should be reviewed for adequacy prior to including in the case file.

Construction Plan

The construction plan and specifications should be developed in accordance with CPS 468. The number of sheets required will be based on the complexity of the waterway or outlet. At a minimum, the construction plan should include a plan sheet showing the location of the waterway or outlet and other features, profiles of the waterway or outlet, cross sections showing the required excavation and lining materials, and adequate information on the lining materials and installation. The following items should also be included as part of the design and construction plan:

- A table with quantities for excavation, earthfill, lining materials, and seeding areas.
- Location of any buried or overhead utility lines which may affect the design or construction of the waterway or outlet. Safety procedures listed in National Engineering Manual (NEM) Part 503 and NEM Part KS503 should be strictly followed.

Layout

The distance between staked cross sections should not exceed 100 feet for straight centerlines. On curved centerlines, this distance may need to be reduced to 25 or 50 feet depending on the radius of curvature.

Offset hubs or stakes may be needed at full stations depending on the amount of cut or fill in the cross section. They are recommended when cuts or fills exceed 5 feet from original ground or when the finished elevations are critical to maintain specific grades in the waterway or outlet. They may also be placed on intermediate stations if required by the complexity of the design.

Additional temporary benchmarks shall be set as needed to provide accurate elevation information for construction. Offset hubs or stakes may be

used as temporary benchmarks if convenient. Surveys and elevations for temporary benchmarks shall meet the requirements for ordinary surveys as defined in Table 1-1 in NEH 650.

Quantities

Determine the quantities of excavation and earthfill from the layout notes using the average end area method or computer drafting software. End areas can be calculated using a variety of methods including calculating by hand, plotting and measuring using a planimeter, or using a computer spreadsheet. Form KS-ENG-4c, Earthwork Computation Sheet - Cut, and the Earthwork Volume spreadsheet can be used to determine excavated quantities from the design or construction surveys.

The quantity of installed rock can be computed using the average end area method, computer drafting software, or computer software similar to the Earthwork Volume spreadsheet. The measurement for payment will be based on the unit for payment. The conversion from cubic yards of rock to tons is typically in the range of 1.5 to 1.6 tons/cubic yard depending on the specific gravity of the rock.

Quantities for concrete will be based on the design depth, cross section, and installed length of the concrete lining.

The quantity of TRM will be based on the installed width and length of the mat disregarding anchor trenches and overlaps. The measurement unit of TRM is typically square yards which is square feet divided by 9.

The quantity of grid pavers or cellular blocks is typically the total number of blocks installed. The measurement unit for payment is typically square feet of area installed and is based on the unit area of a single block multiplied by the total number of blocks installed.

Checkout

Checkout tolerances are dependent on the item being checked. The overall finished appearance of the lined waterway or outlet should be taken into account as well as the recommended tolerances to the design elevations or slopes.

The finished surface of excavations shall be the design elevation plus or minus 0.2 foot—except for the subgrade surface for concrete lining. The subgrade for concrete shall be the design elevation minus 0.2 foot. The excavated surface should be checked and approved prior to installation of the lining. A profile along the centerline shall be completed, and adequate cross sections shall be taken along the profile to indicate that the completed excavation meets the design intent.

A centerline profile survey with adequate cross section information shall also be completed after installation of the lining—except for TRM lining. The centerline profile surveys should include centerline shots at all full stations and any significant break in grade. Cross sections should extend to natural ground on both the left and right. Left and right will be oriented looking at increasing stations.

Survey notes shall be kept as indicated in the "Surveys" section of this document or recorded on the as-built plan if space is provided. Final elevations from survey notes shall be transferred to the as-built plan along with final quantities. The as-built plan shall be signed and dated as complete by the preparer of the plan or the Natural Resources Conservation Service employee who has appropriate engineering job approval authority as delegated on Form KS-CPA-1, Kansas Practice Approval Certification. This will certify that the completed job conforms to the original design and is within allowable tolerances