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Using Weep Berms to Improve Water Quality

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Non-point source pollution (NPS) occurs when rainfall and snowmelt flows over the ground, picking up pollutants such as pathogens, sediments, and nutrients on its way to streams, rivers, lakes, and other bodies of water (Figure 1). More than 50 percent of the nation's rivers and streams and nearly 70 percent of the nation's lakes are impacted by NPS. Pathogens, sediments, and nutrients are the biggest contributors to impairment of rivers and streams while mercury, nutrients, and PCBs (polychlorinated biphenyls) are the biggest contributors to the impairment of lakes.

One method of managing NPS pollution is through the use of structural best management practices (BMPs). Structural BMPs are designed to decrease the volume of runoff that enters water bodies by increasing infiltration rates. Examples of structural BMPs include rain gardens, stormwater wetlands, and riparian buffers. A newer structural BMP is a weep berm.

Figure 1. Bare soils and livestock manure contribute to non-point source pollution.

Figure 2. Red arrows point to a contour weep berm installed on a horse farm.

Weep Berms

A weep berm is a structural BMP that is used in combination with a grassed or forested riparian buffer to manage runoff volumes and improve water quality (Figure 2). It is an earthen berm constructed perpendicular to the direction of runoff. The weep berm is designed to capture and infiltrate frequently occurring small storms. For larger storms, the weep berm stores runoff, allowing pollutants to settle out of suspension before the water is slowly released, passively, through multiple outlets to a grassed or forested riparian zone. The rate of water release is quite slow to maximize the treatment effectiveness of the riparian zone (Figure 3). The term "weep" describes the appearance of the water as it is slowly released through the pipes, earthen berm, and/or is infiltrated. It is this weeping or gradual seepage of water out of the berm that makes it such an effective BMP.

The two types of weep berms are contour weep berms and gradient weep berms. Contour weep berms typically are used in agricultural and construction operations. Gradient weep berms are typically most applicable to surface mining operations.

Contour weep berms are constructed along the contour which represents points of equal elevation. The ends of the contour weep berm turn up-gradient, perpendicular to the contour, to provide runoff storage. The shape of the contour weep berm resembles that of a horseshoe (Figure 4). If properly designed and constructed, contour weep berms blend into the landscape (Figure 5). For long contour weep berms, earthen dikes can be installed at regular intervals to create runoff storage cells. The advantage being that if one cell fails, then the entire stored volume of runoff is not discharged and the impact is minimized.

Gradient weep berms are constructed in conjunction with a diversion ditch or a sediment ditch. Gradient weep berms incorporate the use of check dams along the length of the weep berm for the purpose of providing runoff detention (Figure 6). During larger storm events, check dams slow runoff flow along the weep berms, thus increasing infiltration and settling rates.

Effectiveness of Weep Berms

Weep berms offer excellent results for small storms (one-year six-hour design storm) and good results for large storms (five-year 24-hour design storm). For design storms greater than the five-year 24-hour event, weep berms provide structural stability. Weep berms are quite effective at reducing the volume of runoff entering streams and rivers with measured reduction rates typically between 60-90 percent. Weep berms are most effective in reducing sediment and sediment-associated constituents in runoff. When properly designed and maintained, reductions in sediment concentrations of about 90 percent are possible with a weep berm, with additional treatment occurring through the use of a riparian buffer. Reductions in fecal coliforms, nitrogen, and phosphorus also have been measured.

Figure 3. Slow release of water from weep berm outlet to grassed riparian zone.

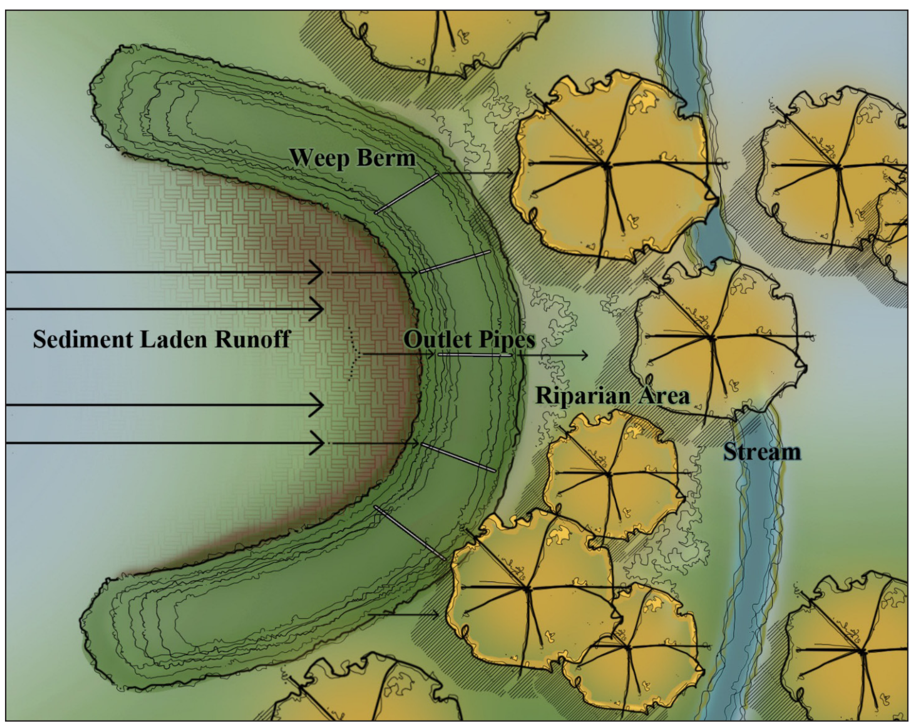

Figure 4. Contour weep berm and riparian buffer treatment system.

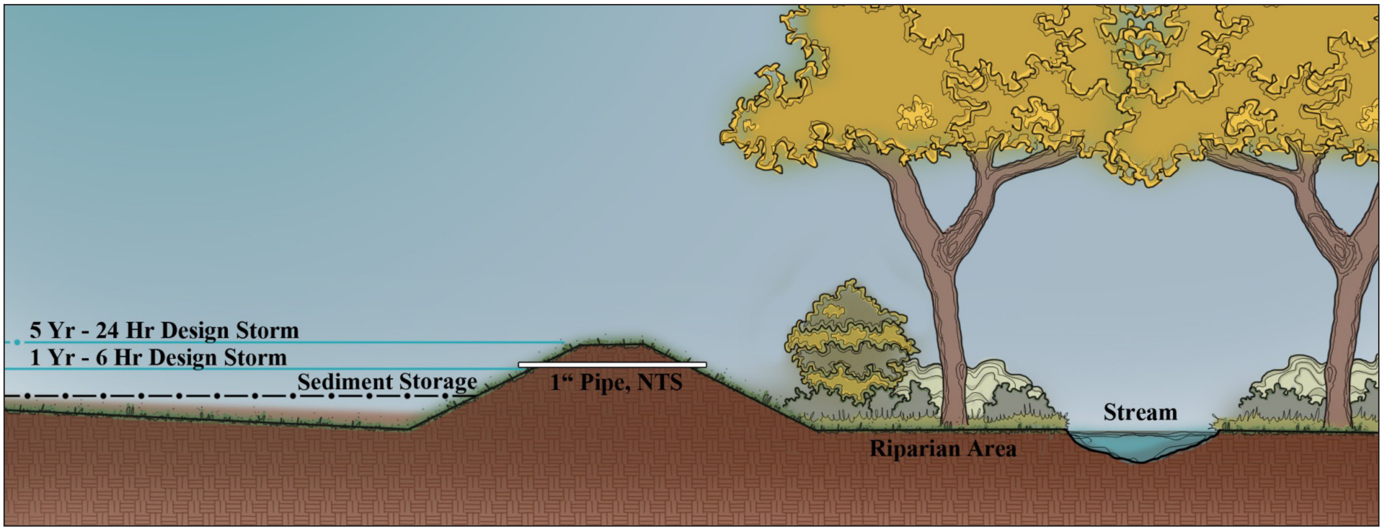

Figure 5. Cross-sectional view of a contour weep berm.

Advantages of Weep Berm

Weep berms offer a number of advantages. First, weep berms provide linear runoff control, meaning they require less land for construction. Often times weep berms are constructed along the perimeter of a land disturbance. Weep berms promote infiltration and sedimentation. With gradient weep berms, the spaces between the check dams allow for sediment storage, as do the spaces between the earthen dikes for contour weep berms. In many instances, weep berms allow for the down-sizing or even elimination of sediment ponds. Runoff from small storm events is completely captured and infiltrated while a sizeable portion of runoff from large events is stored and infiltrated. Additionally, weep berms are simple and cost effective to construct. For small areas (fewer than 10 acres), a skid steer, backhoe, or track hoe can be used.

Designing a Weep Berm

Siting Considerations

Weep berms are placed down-gradient of disturbed areas. Linear developments such as haul roads, pipe lines, and transmission lines are ideal. Other appropriate locations include those down-gradient of topsoil/spoil stockpile areas, cut or fill slopes, manure storage and/or composting facilities, high livestock use areas, fields receiving manure applications or injections, and dairy or hog waste lagoons.

For contour weep berms, the slope of the land up-gradient of the weep berm should not exceed 25 percent. With gradient weep berms, the slope of the diversion channel, which is parallel to the weep berm, should not exceed 10 percent. No restrictions are on the slope of the land up-gradient of gradient weep berms.

Consideration should also be given to the type of soil on which the weep berm is constructed. Sandy soils have high infiltration rates while clay soils have low infiltration rates (Table 1). The type of soil present will affect the size of the weep berm and dewatering rates. Larger weep berms will be needed for soils with low infiltration rates.

In addition to soil type, consideration should be given to the effect of pollutant loads on infiltration rates. Runoff high in organic matter, such as with runoff from areas with manure, can result in the formation of a thick biofilm or mat immediately up-gradient of the weep berm. Over time, infiltration rates will decrease. To prevent this decrease, the mat should be removed and the underlying soil loosened.

When siting the weep berm, be sure to consider accessibility for cleaning out sediments deposited behind the

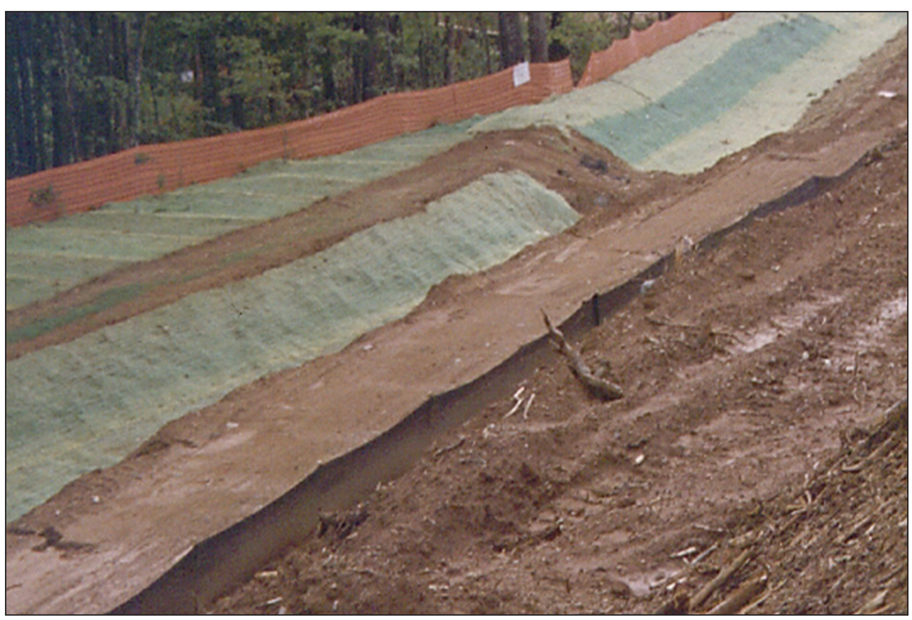

Figure 6. Gradient weep berm installed at a school construction site in Georgia.

Table 1. Typical Infiltration Rates for Soil Types.

HSG[1]	Soil Texture	Infiltration Rate (in./hr)
A	Sand, loamy sand, sandy loam	>0.30
B	Silt loam, loam	0.15-0.30
C	Sandy clay loam	0.05-0.15
D	Clay loam, silty clay loam, sandy clay, silty clay, clay	<0.05

[1] Hydrologic soil group (HSG) is a grouping of soils based on their minimum infiltration rate after prolonged wetting.
Source: Haan et al. (1994)

Table 2. Curve Numbers[1] for Agriculture and Disturbed Lands.

Land Use	Hydrologic Condition[2]	HSG[3]			
		A	B	C	D
Newly graded are as (pervious areas only, no vegetation)		77	86	91	94
Pasture or grassland—continuous forage for grazing[4]	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Row crops—straight rows[5]	Poor	72	81	88	91
	Good	67	78	85	89

[1] Average runoff condition and Ia=0.2S.
[2] Hydrologic condition refers to factors that affect infiltration and runoff such as canopy cover, vegetation density, and surface roughness.
[3] Hydrologic soil group (HSG) is a grouping of soils based on their minimum infiltration rate after prolonged wetting.
[4] Poor: less than 50% ground cover or heavily grazed; fair: 50%-75% ground cover and not heavily grazed; Good: Greater than 75% ground cover and lightly grazed.
[5] Poor: factors impair infiltration; good: factors promote average or better infiltration.
Source: National Engineering Handbook Part 630 Hydrology (2004); Iowa Stormwater Management Manual (2008)

weep berm. The required frequency of sediment cleanouts will depend on the quality of the incoming runoff and the size of the weep berm.

Design Storm

Typically, weep berms are designed to completely contain the one-year six-hour design storm plus any required sediment storage capacity, meaning the runoff volume is contained below the invert of the outlets. Captured runoff mainly will infiltrate, though some losses will occur through seepage through the weep berm with minimal occurring as evaporation. The five-year 24-hour storm normally is used to establish the crest elevation of the weep berm. Runoff from this storm exits the system in the same manner as the one-year six-hour storm as well as through the outlet structures. For storms larger than the five-year 24-hour event, the weep berm functions as a long broad-crested weir or emergency spillway. Water flows over the top of the weep berm as a thin sheet, so shear stresses along the crest of the weep berm remain low and the water has little erosive power.

Watershed

The amount of runoff or runoff volume is based on drainage area, land slope up-gradient of the weep berm, land use, and soil type. While various methods are used to estimate runoff, a commonly used method is the Natural Resource Conservation Service (NRCS) Curve Number (CN) method. With this method, the amount of rainfall that becomes runoff is expressed in the form of a CN. Higher CNs, up to 100, indicate that more rainfall becomes runoff while lower CN indicate more rainfall is intercepted, stored, and infiltrated. Table 2 contains typical CNs for agricultural and disturbed lands.

To calculate runoff depth, a CN is selected for the site based upon land use and soil type or hydrologic soil group (HSG). Based on their minimum infiltration rates after prolonged wetting, the NRCS classified soils into one of four HSGs. Tables of CN are widely available. Table 2 contains CN values commonly used in weep berm design. Once the CN is selected, runoff depth (in inches) is computed using equations 1 and 2.

$$\text{Runoff depth} = \frac{(P - 0.2S)^2}{(P + 0.8S)} \quad \text{(Equation 1)}$$

$$S = \frac{1000}{CN} - 10 \quad \text{(Equation 2)}$$

P = precipitation (in.)
S = maximum soil water retention parameter (in.)
CN = curve number

Once the runoff depth is known, it is multiplied by the drainage area to determine the runoff volume and then converted to units of acre-foot.

Design Specifics

The method for designing a weep berm varies depending on the type of weep berm selected. Contour weep berms involve fewer design steps than gradient weep berms. To accommodate the runoff volume from subsequent storm events, both types of weep berms should be designed to allow for 60 percent dewatering within 24 hours and complete dewatering in 72 hours. While the general methods for designing both types of weep berms will be discussed, a design example will be presented only for the contour weep berm.

Contour Weep Berm

The first step in designing a contour weep berm is to determine the height and length of the weep berm such that the appropriate amount of runoff volume is contained. The length of the weep berm is generally determined based on the extent of the land disturbance. Longer weep berms are typically shorter in height while short weep berms are typically taller. For larger areas of land disturbance, multiple weep berms in series may be required.

The weep berm height is set such that the runoff volume from the five-year 24-hour storm event is contained. For instances when the weep berm is used to control sediment-laden runoff, the weep berm height should also accommodate the necessary sediment storage capacity. A trade-off exists between sediment storage capacity, meaning a larger weep berm, and frequency of clean out. The inverts of the outlets are set such that the one-year six-hour storm is contained in addition to any sediment storage capacity requirements. Sufficient equipment access to the weep berm should be provided to allow for the removal of deposited sediments.

Gradient Weep Berms

The main design components of a gradient weep berm involve a trapezoidal channel, check dams within the trapezoidal channel, and outlets through the down-gradient side slope of the trapezoidal channel (Figure 6). The designer must determine the bottom width, side-slopes, and overall slope of the trapezoidal channel.

For the check dams, the top or crest determines amount of runoff that is stored. The heights of the check dams are set such that the runoff from the five-year 24-hour storm is contained while considering sediment storage requirements. The spacing of check dams affects the volume of runoff that is stored. Typically check dams are spaced such that the crest of the adjacent down-gradient check dam equates to 25-50 percent of the height of the immediate up-gradient check dam. As with the contour weep berm, the inverts of the outlets are set such that the one-year six-hour storm is contained in addition to any sediment storage capacity requirements.

Outlets

Though a number of outlet types have been used in the past, such as fixed siphons and perforated risers, only straight pipes and rock lenses are recommended at this time. While the invert of the outlet is set such that the one-year six-hour storm is contained, over any sediment capacity requirements, the designer must determine the type, size, shape, and spacing of the outlets. These characteristics will control the rate of water discharge from the weep berm.

For straight pipe outlets, schedule 40 PVC is often used. The designer must determine the pipe diameter and the pipe slope. For rock lenses, the designer must determine the width and height of the outlet along with the size of rock used. Figure 7 shows commonly used outlet configurations.

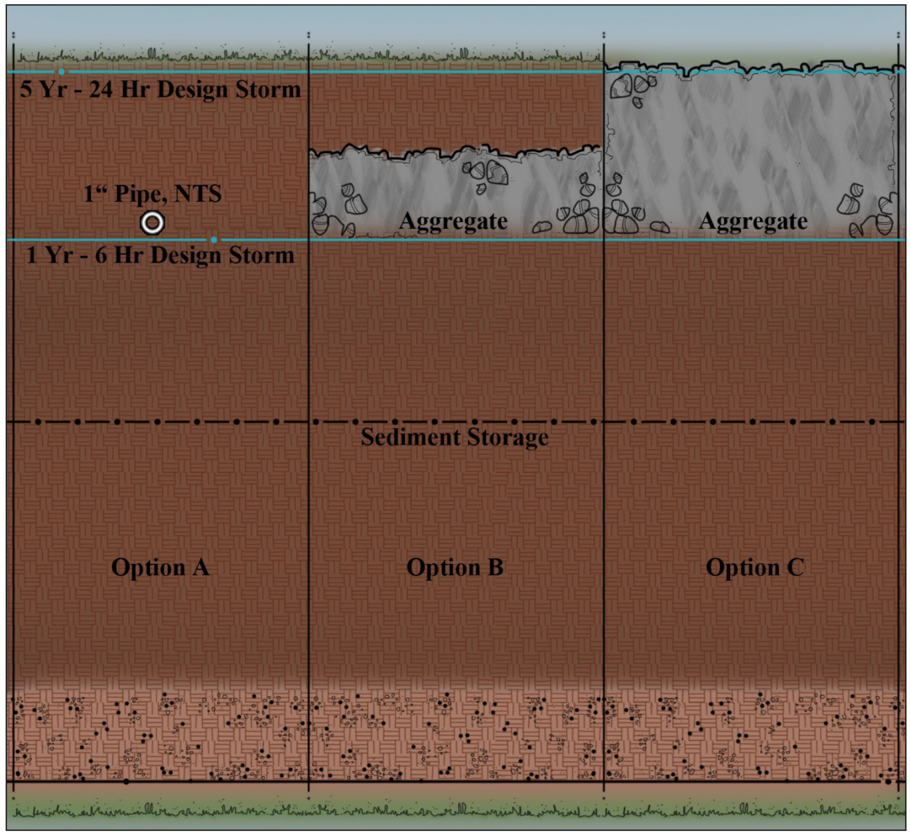

Figure 7. Outlet options for weep berms include pipes and rock lenses.

Riparian Buffer

A grassed or forested riparian buffer is an important part of the weep berm design. The required width of the riparian buffer is a function of slope, vegetation type, and soil types. A riparian buffer with sufficient width can infiltrate all runoff, from a five-year 24-hour storm, discharged from the weep berm. Such high efficiencies are achieved when runoff is slowly discharged. If space constraints limit the width of the riparian buffer, then smaller outlets will release water more slowly. However, the trade-off is that the weep berm will be bigger to contain the five-year 24-hour storm event.

Constructing a Weep Berm

Typical on-site construction or farm equipment such as a skid steer, backhoe, or track hoe are generally used to construct weep berms. The first step is to remove all vegetation from the footprint of the weep berm, taking care to minimize damage to any up-gradient or down-gradient vegetation. As the rate of infiltration is important to the efficiency of the weep berm, it is important to minimize soil compaction both up-gradient and down-gradient of the weep berm. If necessary, these soils may require loosening following construction of the weep berm.

It is important to compact the weep berm such that it is structurally stable but not to the point that runoff cannot seep through the earthen berm. Soils most suitable for constructing weep berms are those with greater than 10 percent clay content, greater than 20 percent silt and clay content, and the remaining percentage sand and gravel (e.g. gravelly clays, sandy clays, silty clays, poorly graded sand-clay, or gravel-sand-clay mixtures).

It is recommended that the weep berm be constructed in 6- to 9-inch lifts using the wheels or tracks of the equipment to compact the berm. It is important to survey the crest of the weep berm to ensure it is level within the allowable design tolerance (±0.25 feet is recommended). Alternatively, compaction with the bucket of a backhoe or track hoe is often adequate.

Placement of the outlets is done either during berm construction or immediately following berm construction. If the outlets are placed during berm construction, care must be taken not to crush the outlets when compacting soil, particularly when using PVC pipes. In such instances, larger soil lifts are recommended. For outlet placement post-berm construction, an excavator is needed to dig trenches for outlet placement. Depending on the outlet configuration, backfilling and careful compaction using the bucket on an excavator or similar piece of equipment may be required. Alternatively, a steel pipe with a conical end can be used to develop a hole for subsequently inserting the PVC pipes.

Lastly, erosion control measures are needed. Seed the weep berm and install an erosion-control blanket. Use products that are free of plastic netting. Plastic netting can trap and kill wildlife and is easily entangled in mowers. It is not a requirement to mow the weep berm, however some landowners prefer a mowed appearance. If mowing is desired, be sure to consider the steepness of the berm when selecting the method of mowing. Riding lawn mowers typically should not be operated on slopes steeper than 15 percent. Be sure to check all appropriate owner's manuals before operating mowing equipment.

Maintenance Requirements

Weep berms require little maintenance outside of periodic sediment removal and occasional mowing, if desired by the landowner. Clogging of outlets is rare as the outlets are above the sediment storage layer. A long piece of rebar is useful for unclogging a pipe. For rock lenses, any reduction in efficiency is most likely to occur at the lower portion of the lens closest to the sediment storage layer.

Contour Weep Berm Design Example

Alexa wants to design a contour weep berm to collect sediment-laden runoff from a 4 acre newly graded construction site in Fayette County, Kentucky. The land slope up-gradient of the planned location of the weep berm is 2 percent. The linear extent of disturbance is 500 feet. Soils at the project site are Bluegrass-Maury silt loam, which places them in HSG B. For sediment storage requirements, she needs 67 cubic yards per acre of disturbed land.

Using the Rainfall Frequency Values for Kentucky, Engineering Memorandum No. 2, Alexa determines that the one-year six-hour rainfall depth is 1.9 inches and the five-year 24-hour rainfall depth is 3.8 inches for Fayette County.

To design the contour weep berm, Alexa must complete the following steps:

1. Develop a berm height to storage volume relationship for a 2 percent slope and a 500-foot berm length.
2. Determine the sediment storage requirements for the weep berm.
3. Determine the runoff volume associated with the one-year six-hour design storm (Equations 1 and 2).
4. Determine the invert elevation of the outlet by adding the sediment storage requirements (Step 2) to the runoff volume of the one-year six-hour storm event (Step 3).
5. Determine the runoff volume associated with the five-year 24-hour design storm (Equations 1 and 2).
6. Determine the crest elevation of the weep berm by adding the sediment storage requirements (Step 2) to the runoff volume of the five-year 24-hour storm event (Step 5).
7. Select an outlet type and size.

Step 1: Stage-Storage Relationship

Assume the deposited sediment will form a triangular wedge, the watershed slope is constant, and the interior weep berm slope is 1.5:1 (height to volume). Calculate the volume of sediment that could be stored behind a 500 ft long weep berm of varying heights. Table 3 contains the weep berm height to storage relationship for a 500 ft length of weep berm with the aforementioned characteristics. Recall 1 ac=43,560 ft^2.

Step 2: Sediment Storage Requirements

The given sediment storage requirement is 67 yd^3 per acre of disturbed land. For 4 acres, 268 yd^3 or 0.166 ac-ft is required. Recall 1 yd^3=27ft^3. Use Table 3 to determine the associated weep berm height (0.71 ft) for a sediment storage volume of 0.166 ac-ft.

Table 3. Weep Berm Height-to-Storage-Volume Relationship (2% Watershed Slope; 500-ft Weep Berm Length).

Weep Berm Height (ft)	Storage Volume (ac-ft)
0.5	0.0739
1.0	0.2956
1.5	0.6650
2.0	1.1823
2.5	1.8473
3.0	2.6601
3.5	3.6207
4.0	4.7291

Step 3: Runoff Volume for One-year Six-hour Design Storm

The CN for a newly graded Bluegrass-Maury silt loam (HSG B) is 86 (Table 2). For a 1.9 inch rainfall depth over 4 acres, the associated runoff volume is 0.258 ac-ft.

Step 4: Outlet Invert Elevation

Add the sediment storage requirement (0.166 ac-ft) and the runoff volume from the one-year six-hour design storm (0.258 ac-ft). Use Table 3 to determine the elevation of the outlet invert (1.17 ft). This elevation corresponds to the point along the weep berm where the contour elevation is lowest.

Step 5: Runoff Volume for Five-year 24-hour Design Storm

For a 3.8 in. rainfall depth over 4 acres and a CN of 86, the associated runoff volume is 0.789 ac-ft.

Step 6: Crest Elevation

Add the sediment storage requirement (0.166 ac-ft) and the runoff volume from the five-year 24-hour design storm (0.789 ac-ft). Use Table 3 to determine the elevation of the crest of the weep berm (1.82 ft). This elevation corresponds to the point along the weep berm where the contour elevation is lowest.

Step 7: Outlet Type and Size

Select both the type and size of the outlets so that stored runoff is slowly released, preferably to a down-gradient riparian area. Discharge should be relatively uniform across the weep berm. For this example, 24 equally spaced 1-in. PVC pipes are used.

Useful Information

Technical Paper No. 40 (TP-40). Rainfall Frequency Atlas of the United States for Durations from 30 Minutes to 24 Hours and Return Periods from 1 to 100 Years. Available at: http://www.nws.noaa.gov/oh/hdsc/PF_documents/TechnicalPaper_No40.pdf.

Rainfall Frequency Values for Kentucky, Engineering Memorandum No. 2. Available at: http://water.ky.gov/permitting/Documents/WRRainfall_Frequency.pdf.

SEDCADTM 4 Design Manual and User's Guide.

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