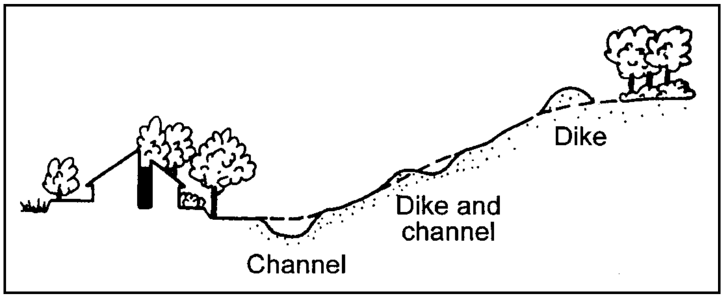
Structural Methods



General Description

There are several structural methods that can be used to provide permanent and temporary erosion protection on small construction sites. Three such methods are riprap and permanent or temporary diversion structures. This section presents the following structural methods:

- Inlet and outlet riprap
- Permanent diversion
- Temporary diversion, including diversion dikes, right-of-way diversion, water bars.

Advantages

- Relatively inexpensive to construct.
- Effective at reducing erosion and sediment transport off site.

Limitations

- Removal of temporary diversion structures can be difficult.

Riprap at Inlets and Outlets

Description

Riprap is heavy stone placed around inlets and outlets of pipes or paved channels to provide protection against erosion. Riprap is a permanent, erosion-resistant protective layer intended to prevent soil erosion in areas of concentrated flow, turbulence or wave energy.

To prevent erosion, velocities must be reduced to allowable levels before the flow enters an unprotected area. Outlet protection usually consists of a structural apron lining. In some cases, flow velocities may be too high for economical use of an apron. In those cases, a stilling basin or impact basin may be more appropriate. The stilling

Purpose

Water Quantity	
Flow attenuation	N/A
Runoff volume reduction	N/A

Water Quality	
Pollution prevention	
Soil erosion	■ Primary design benefit
Sediment control	■ Primary design benefit
Nutrient loading	◧ Secondary design benefit
Pollutant removal	
Total suspended sediment (TSS)	□ Little or no design benefit
Total phosphorus (P)	□ Little or no design benefit
Nitrogen (N)	□ Little or no design benefit
Heavy metals	□ Little or no design benefit
Floatables	□ Little or no design benefit
Oil and grease	□ Little or no design benefit
Other	
Fecal coliform	□ Little or no design benefit
Biochemical oxygen demand (BOD)	□ Little or no design benefit

■ Primary design benefit
◧ Secondary design benefit
□ Little or no design benefit

Riprap at Inlets and Outlets (continued)

basin is an excavated pool of water that is lined with riprap and used to dissipate energy from high-velocity flow. An impact basin is a reinforced concrete structure that slows water velocities to an acceptable level before discharging the water to an outlet channel.

The need for a riprap lined-channel on a small site of five acres or less is unlikely and therefore further discussion is not included. Many other overland conveyance systems are included in this manual and would typically be more appropriate. Channel riprap applies where design flow velocity exceeds 4 feet per second (ft/sec) and conditions are unsuitable for grass-lined channels.

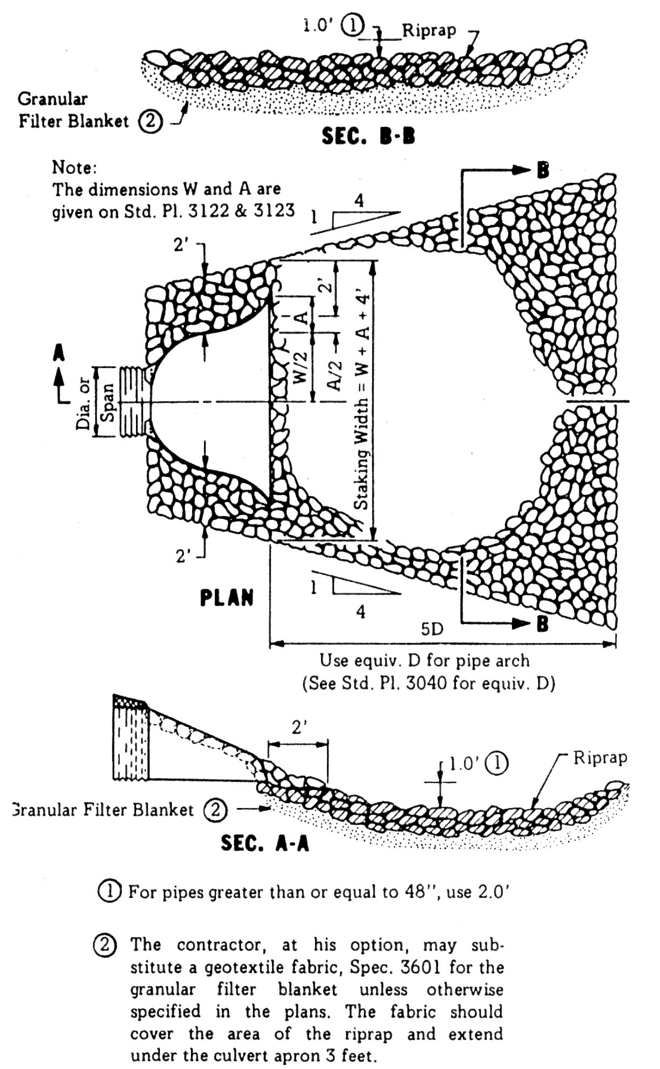


Figure 1: Riprap Outlet Protection
Source: MPCA, 2000.

Design Guidelines

Refer to MnDOT *Standard Specifications for Construction*, Section 3601 for MnDOT requirements.

Inlet and outlet protection may or may not require a detailed design, depending upon the scope and complexity of the job. For inlets and outlets with very high velocities or very low tailwater conditions, protection should be designed only by a qualified engineer. The following criteria are recommended for the design of structurally lined aprons below pipe outlets (see Figure 1 and Table 1).

Tailwater Depth

Determine the depth of tailwater immediately below the pipe outlet based on the design discharge plus other contributing flows. If the tailwater depth is less than half the diameter of the outlet pipe and the receiving stream is wide enough to accept the divergence of flow, it is classed as a minimum tailwater condition. If the tailwater depth is greater than half the pipe diameter, it is classed as a maximum tailwater condition. Pipes that discharge onto broad, flat areas with no defined channel may be assumed to have a minimum tailwater condition unless site conditions indicate otherwise.

Apron Size

The apron length and width can be determined according to the tailwater condition. If the water-conveyance structure discharges directly into a well-defined channel, extend the apron across the channel bottom and up the channel banks to an elevation of six inches above the maximum tailwater depth or to

TABLE OF QUANTITIES

RIPRAP AT CMP OUTLETS

	Class II d_{50} = 6"		Class III d_{50} = 9"		Class IV d_{50} = 12"		Class V d_{50} = 15"	
Dia. Round Pipe (In.)	9" Depth Riprap (Cu.Yd.)	4.5" Depth Granular Filter (Cu.Yd).	15" Depth Riprap (Cu.Yd.)	7.5" Depth Granular Filter (Cu.Yd.)	18" Depth Riprap (Cu.Yd.)	9" Depth Granular Filter (Cu.Yd.)	24" Depth Riprap (Cu.Yd.)	12" Depth Granular Filter (Cu.Yd.)
12	1.3	0.6	2.1	1.1	2.6	1.3	3.4	1.7
15	1.7	0.9	2.9	1.4	3.5	1.7	4.6	2.3
18	2.3	1.1	3.8	1.9	4.5	2.3	6.0	3.0
21	2.9	1.4	4.8	2.4	5.7	2.9	7.6	3.8
24	3.5	1.8	5.9	2.9	7.1	3.5	9.4	4.7
30	5.0	2.5	8.4	4.2	10.1	5.0	13.4	6.7
36	6.8	3.4	11.3	5.6	13.5	6.8	18.0	9.0
42	8.8	4.4	14.6	7.3	17.6	8.8	23.4	11.7
48	10.7	5.4	17.9	8.9	21.5	10.7	28.6	14.3
54	13.1	6.5	21.8	10.9	26.1	13.1	34.8	17.4
60	15.6	7.8	26.0	13.0	31.2	15.6	41.6	20.8
66	17.9	9.0	29.9	14.9	35.9	17.9	47.8	23.9
72	20.4	10.2	34.0	17.0	40.8	20.4	54.4	27.2
78	23.0	11.5	38.4	19.2	46.1	23.0	61.4	30.7
84	25.9	12.9	43.1	21.6	51.8	25.9	69.0	34.5

RIPRAP AT CMP-A OUTLETS

	Class II d_{50} = 6"		Class III d_{50} = 9"		Class IV d_{50} = 12"		Class V d_{50} = 15"	
Span Pipe-Arch (In.)	9" Depth Riprap (Cu.Yd.)	4.5" Depth Granular Filter (Cu.Yd).	15" Depth Riprap (Cu.Yd.)	7.5" Depth Granular Filter (Cu.Yd.)	18" Depth Riprap (Cu.Yd.)	9" Depth Granular Filter (Cu.Yd.)	24" Depth Riprap (Cu.Yd.)	12" Depth Granular Filter (Cu.Yd.)
17	1.7	0.8	2.8	1.4	3.3	1.7	4.4	2.2
21	2.2	1.1	3.6	1.8	4.4	2.2	5.8	2.9
24	2.8	1.4	4.6	2.3	5.6	2.8	7.4	3.7
28	3.5	1.7	5.8	2.9	6.9	3.5	9.2	4.6
35	4.9	2.4	8.1	4.1	9.8	4.9	13.0	6.5
42	6.7	3.3	11.1	5.6	13.4	6.7	17.8	8.9
49	8.6	4.3	14.3	7.1	17.1	8.6	22.8	11.4
57	10.6	5.3	17.6	8.8	21.2	10.6	28.2	14.1
64	12.9	6.5	21.5	10.8	25.8	12.9	34.4	17.2
71	15.5	7.7	25.8	12.9	30.9	15.5	41.2	20.6
77	18.2	9.1	30.4	15.2	36.5	18.2	48.6	24.3
83	21.2	10.6	35.3	17.6	42.3	21.2	56.4	28.2

Note: Requirements for riprap size and thickness and filter blanket will be designated in the plans.

Table 1: Riprap at CMP Outlets
Source: MPCA, 2000.

Riprap at Inlets and Outlets (continued)

the top of the bank, whichever is less. Determine the maximum allowable velocity for the receiving stream, and design the riprap apron to reduce flow to this velocity before flow leaves the apron. Calculate the apron length for velocity control or use the length required to meet stable conditions downstream, whichever is greater.

Grade

Ensure that the apron has zero grade. There should be no overfall at the end of the apron; that is, the elevation of the top of the riprap at the downstream end should be the same as the elevation of the bottom of the receiving channel or the adjacent ground if there is no channel.

Alignment

The apron should be straight throughout its entire length. If a curve is necessary to align the apron with the receiving stream, locate the curve in the upstream section of riprap.

Gradation

Ensure that riprap consists of a well-graded mixture of stone. Larger stone should predominate, with sufficient smaller sizes to fill the voids between the stones. The diameter of the largest stone size should be no greater than one and one-half times the D50 size.

- A well-graded mixture (a mixture composed of a variety of rock sizes rather than one, uniform size) of rock should be used for riprap. Riprap sizes are generally specified in both weight and average diameter. The standard MnDOT riprap gradations are listed in Table 2.
- When a rock gradation is specified other than a standard gradation, it must allow a range in sizes. Based upon the median size (D50), Table 3 can be used as a guide to determine the gradation.

Thickness

All stones used should lie within the riprap blanket to provide the maximum resistance against erosion. Protruding stones can alter the flow across the riprap mat. Oversize stones, even in isolated spots, may cause riprap failure by precluding mutual support between individual stones, providing large voids that expose filter and bedding materials and creating excessive local turbulence that removes smaller stones. Small amounts of oversize stone should be removed individually and replaced with proper-size stones. The following criteria apply to the riprap layer thickness:

- The thickness should not be less than 1.5 times the diameter of the upper limit D100 (W100) stone. However, for practical placement, the thickness should not be less than 12 inches.
- The thickness determined by either 1 or 2 above should be increased by 50 percent in all sections when the riprap is placed underwater in water deeper than 3 feet to provide for uncertainties associated with this type of placement.

Stone Quality

Select stone for riprap from field stone or quarry stone. The stone should be hard, angular and highly weather resistant. It should be resistant to weathering, free from overburden, spoil, shale and organic material. Rock or

		Riprap Class (percent of total weight smaller than given weight)					
Size (inches)	Weight (lb)	I	II	III	IV	V	
30	2,000					100	
24	1,000				100		
21	650					75	
18	400			100			
15	250				75	50	
12	120		100	75	50		
9	50		75	50			
6	15	100	50			10	
4	5				10		
3	2	50		10			
2			10				
1		10					

Table 2: MnDOT Standard Riprap Gradations
Source: MnDOT, 2000

Size of stone	Percent of total weight smaller than the given size
2.0 to 2.5 x d_{50}	100
1.6 to 2.1 x d_{50}	85
1.0 x 1.5 x d_{50}	50
0.3 x 0.5 x d_{50}	15

Table 3: Riprap Gradation Ranges
Source: MPCA, 2000

rubble that is laminated, fractured, porous or otherwise physically weak is unacceptable. The material specification for riprap should be referenced in construction documents. The specific gravity of the individual stones should be at least 2.5.

Filter

Install a filter to prevent soil movement through the openings in the riprap. The filter should consist of a graded gravel (granular) layer or a synthetic filter cloth.

Proper design and placement of granular filter material is often difficult. A granular filter is not cost effective for small areas of riprap typically used on small sites. Filter fabric is recommended for most sites due to better quality control of the materials, ease of construction and typically lower cost.

For the purpose of riprap application, filter fabric means nonwoven geotextile filter fabric. Filter fabric should meet the requirements for MnDOT Type III or IV geotextile per MnDOT Standard Specification 3733. Nonwoven

Riprap at Inlets and Outlets (continued)

geotextiles consist of polypropylene fibers that are needle-punched into a high-tensile-strength fabric that shows excellent physical and hydraulic properties for applications such as soil separation, filtration and protection. Synthetic fabric filters have found considerable use as alternatives to granular filters. The primary justification for fabric filter over a granular filter is economic. Geotextiles may be less costly, especially where a source of gravel is not convenient.

Many manufacturers offer an extensive line of geotextiles. Care should be taken to select the appropriate one for the site. The function of fabric filters is to provide both drainage and filtration. In other words, the fabric must allow water to pass (drainage) while retaining soil properties (filtration).

Allowable Slopes

- The riprap stability is related to the side slope, rock size, angularity of the rock and the angle of repose. The more angular the rock, the higher the angle of repose.
- The maximum (steepest) slope for riprap is recommended to be 2:1 (that is, 2 feet horizontally for every foot of vertical height. They prevent erosion by diverting runoff away from unprotected slopes to a stable outlet. They can also be used to direct sediment-laden runoff to a sediment-trapping structure. of vertical height). For small areas, such as around existing culverts or transitions where slopes steeper than 2:1 cannot be avoided, slopes up to 1:1 can be tolerated, provided that the riprap thickness and size are increased.
- Very angular rock must be used and carefully installed. The minimum D50 that can be used on slopes steeper than 2:1 is 4 inches. This must be angular rock, not rounded.

Construction

- Heavy riprap may stretch the nonwoven filter fabric as it settles, eventually causing bursting of the fabric. A 4- to 6-inch layer of gravel bedding should be placed on the fabric for riprap dropped more than 2 feet.
- Adequate overlaps of 18 to 36 inches must be provided between individual nonwoven filter fabric sheets. For lightweight revetments, this can be as little as 18 inches, and may increase to as much as 3 feet for large, underwater revetments.
- The nonwoven filter fabric should be overlapped during placement to eliminate tension and stretching under settlement.
- Securing pins with washers are recommended at 2- to 5-foot intervals along the midpoint of the overlaps.
- Proper stone placement on the nonwoven filter fabric requires beginning at the toe and processing up the slope. Dropping stone from heights greater than 2 feet can rupture fabrics (greater drop heights are allowable under water). A 6-inch layer of sand/gravel will cushion the impact and protect the fabric as the rock is dropped.
- The surface on which the nonwoven filter fabric is placed should be compacted and stable, reasonably smooth and free of holes, depressions, projections, mud and running water.
- The length of the nonwoven filter fabric should be placed parallel to the direction of flow.

Maintenance

- Riprap should be inspected annually and after major storms. If riprap has been damaged, repairs should be made promptly to prevent a progressive failure. Placement of additional riprap may be required.
- If repairs are needed repeatedly at one location, the site should be evaluated to see whether original design conditions have changed.

Permanent Slope Diversion

Description

A permanent slope diversion structure is typically a channel and dike constructed across a slope. Diversions are used to intercept runoff and divert it to stabilized outlets at nonerosive velocities. Diversion structures increase the flow length and reduce the slope for erosion control or divert runoff from downslope areas. See Figure 2 for various types of diversions.

Diversions can be very effective for erosion control on steep or long slopes. Diverting runoff will reduce the effective flow lengths or eliminate concentrated flow that would make establishment and maintenance of vegetation difficult. The erosion-control benefit from a diversion will depend upon the length of slope and type of soils in the area being protected.

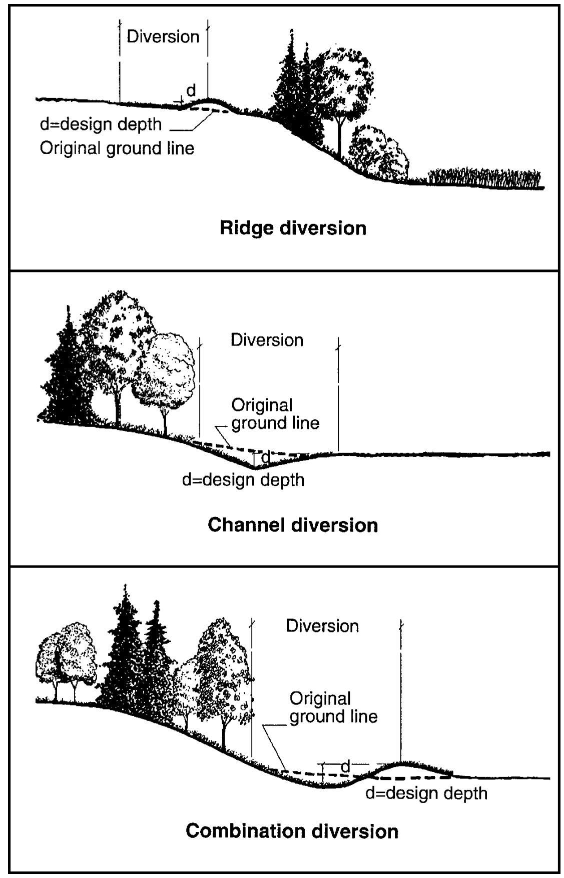


Figure 2: Permanent Diversions
Source: MPCA, 2000.

Design

- The capacity of a diversion should be suitable for the area that is being protected. Freeboard is the extra depth above the design depth that is added as a safety margin.
- The cross section may be parabolic, V-shaped or trapezoidal. The side slopes should be no steeper than the stable slope for the soil that is used.
- Where the diversion will need to be mowed, the slopes should be 3:1 or flatter.

Temporary Slope Diversion

Description

A temporary slope diversion may consist of a ridge of compacted soil; a channel; a flexible conduit such as a polyethylene pipe; or any combination of these located across a slope above a disturbed area. They prevent erosion by diverting runoff away from unprotected slopes to a stable outlet. They can also be used to direct sediment-laden runoff to a sediment-trapping structure. Temporary diversions can sometimes be used instead of a silt fence, often more effectively and with less routine maintenance.

Temporary Slope Diversion (continued)

Although temporary diversions will not control the detachment of soil particles from raindrop impact, they will reduce the amount of runoff flowing over a disturbed area. This will limit the potential transport of these particles by runoff. Temporary diversions can also be effective for controlling rill and gully erosion by preventing concentrated runoff from flowing over erosion-prone areas.

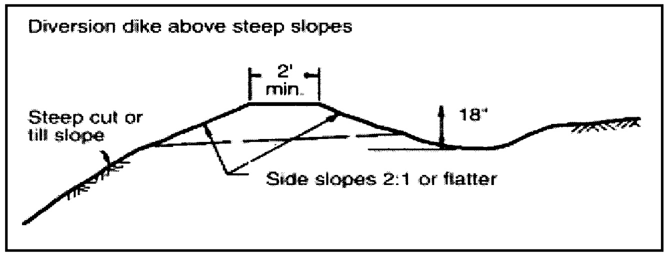


Figure 3: Temporary Diversion Earthen Dike Cross Section
Source: MPCA, 2000.

Design

- Capacity is based upon maximum drainage area rather than storm frequency.
- The maximum drainage area should be five acres.
- Channel grades of less than 2 percent should be stabilized with erosion control blankets. Grades greater than 2 percent should be stabilized with erosion-control blankets or turf-reinforcement mats. If flow velocities could exceed 9 feet per second (fps), rock riprap or turf reinforcement mats should be considered.
- The temporary diversion should be at least 1.5 feet high when measured from the channel. The side slopes should be at least 2:1 or flatter. See Figure 3 for a typical cross section.
- If the diverted runoff is sediment-free, it should be released through a stable outlet or channel. If the runoff is sediment-laden, it should be diverted to a sediment-trapping structure.

Maintenance

- Vegetation should be regularly inspected, especially during establishment, and repaired as needed. Excessive amounts of deposited sediment that would reduce capacity or damage vegetation should be removed.
- Inspect diversion dikes once a week and after every rainfall. Immediately remove sediment from the flow area and repair the dike.
- Check outlets and make timely repairs as needed to avoid gully formation. When the area above the temporary diversion dike is permanently stabilized, remove the dike and fill and stabilize the channel to blend with the natural surface.
- Diversions should be inspected regularly and repaired as needed for scour, bank failure, breaching, obstructions and other damage.
- Periodically inspect right-of-way diversions for wear and after every heavy rainfall for erosion damage. Immediately remove sediment from the flow area and repair the dike.
- Check outlet areas and make timely repairs as needed. When permanent road drainage is established and the area above the temporary right-of-way diversion is permanently stabilized, remove the dike and fill the channel to blend with the natural topography, and appropriately stabilize the disturbed area.
- The diversion should be inspected after all significant runoff events. Any damage should be repaired promptly.

Perimeter Diversion Dike

Description

- A perimeter diversion dike is a dike or dike and channel constructed along the perimeter of a disturbed construction area. Diversion dikes are used to prevent storm runoff from entering the work area or to prevent sediment-laden runoff from leaving the construction site (see Figure 4).
- Diversion dikes may be located at the upslope side of a construction site to prevent surface runoff from entering the disturbed area or at the downslope side of the work area to divert sediment-laden runoff to on-site sediment traps or basins.
- Diversion dikes do not usually encircle the entire area. The upslope dike can improve working conditions at the construction site and prevent erosion. The downslope dike assures that sediment-laden runoff will not leave the site without treatment.

Design

- *Drainage area*. Use diversion dikes to protect areas of five acres or less.
- *Capacity.* The capacity of a diversion dike should be consistent with the hazard involved and design life and with a 10-year peak runoff minimum.
- *Dike Design*. Side slope: 2:1 or flatter; 3:1 or flatter where vehicles must cross; Width: 2.0 feet minimum top width. Height: 1.5 feet minimum. Freeboard: 0.5 feet minimum. Settlement: 10 percent of fill height minimum.
- *Channel Design.* Shape: parabolic, trapezoidal, or V-shaped. Side slope: 2:1 or flatter; 3:1 or flatter where vehicles must cross. Stabilization: based on velocity by reaches.
- *Grade*. Dependent on site topography. Channel should have positive grade of 1 to 2 percent. Flatter grades may not drain properly. Steeper grades have higher velocities and need adequate protection to prevent erosion.
- *Outlet.* Divert sediment-laden water into a temporary sediment trap or sediment basin. Runoff from undisturbed areas should empty into an outlet-protection device, such as a level spreader or riprap outlet structure, unless well-stabilized natural outlets exist.

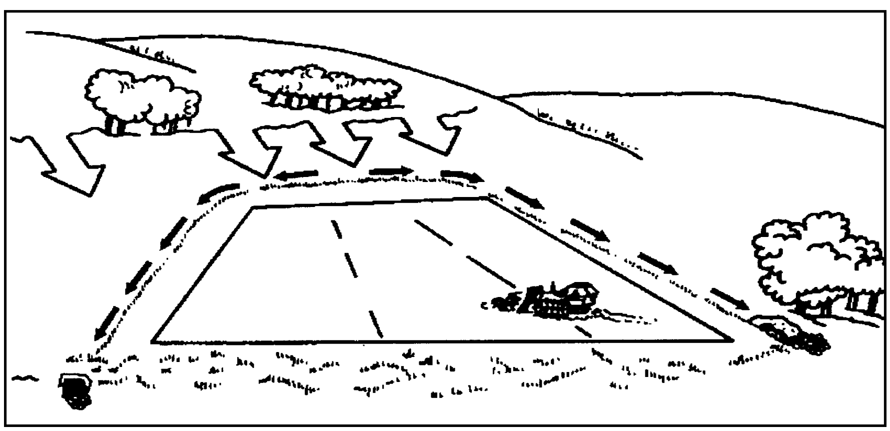


Figure 4: Perimeter Dike
Source: North Carolina, 1994.

Perimeter Diversion Dike (continued)

Construction

- Remove and properly dispose of all trees, brush, stumps and other objectionable material. Fill and compact, to natural ground level or above, all ditches and gullies that will be crossed by machinery.
- Disk the base of the dike before placing fill.
- Ensure that the constructed cross section meets all design requirements.
- Compact the dike by tracking with compaction equipment.
- Ensure that the top of the dike is not lower at any point than the design elevation plus the specified settlement after it has been compacted.
- Leave sufficient area along the dike to permit machine regrading and cleanout.
- Immediately stabilize and vegetate the dike after its construction and stabilize the flow portion in accordance with design requirements.

Temporary Right-of-Way Diversion

Description

- A temporary right-of-way (roadway) diversion is a ridge of compacted soil, loose rock or gravel placed perpendicular to roads, disturbed right-of-ways or similar long sloping areas that are disturbed.
- This ridge is used to divert water onto stabilized areas and to shorten the distance that runoff will flow down a long slope. This reduces the erosion potential of the runoff.
- This practice is normally used where there will be little or no construction traffic using the right-of-way until it is stabilized. Gravel diversions are more applicable where some traffic must use the right-of-way before it is stabilized.
- The effectiveness of temporary right-of-way diversions for controlling erosion depends upon the land slope and erodibility of the soil. In most cases, use of this practice will provide good control of rill and gully erosion in the disturbed right-of-way area.

Land Slope (percent)	Diversion Spacing (feet)
1	300
2	200
3-5	150
5 or greater	100 (or less)

Table 4: Land Slope/Diversion Spacing
Source: MPCA 2000.

Design

- Temporary right-of-way diversions should be spaced according to the land slopes as shown in Table 4.
- The maximum drainage area above the diversions should be three acres. With increase in slope, the watershed should be smaller.

- The width of a diversion base should be at least 6 feet. When vehicles will cross the diversion, the base should be 16 feet with a top width of 4 feet. This is to prevent vehicles from becoming hung up on the ridge.

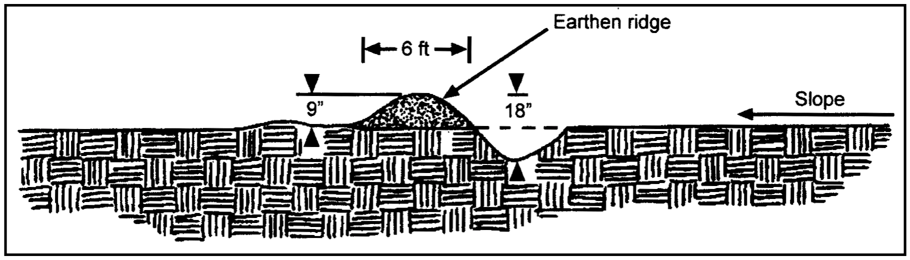


Figure 5: Water Bar Cross Section
Source: North Carolina 1994

- The diversion should be at least 18 inches high. The slope of the diversion channel should be less than 2%.
- Before the diversion is constructed, the base should be scarified to provide a bond between the existing soil and the fill material.
- *Height.* A water bar should have a 18-inch minimum, measured from the channel bottom to the ridge top (see Figure 5).
- *Side slope.* The side slope should be 2:1 or flatter; 3:1 or flatter where vehicles cross.

Slope (%)	Spacing (ft)
< 5	125
5 to 10	100
10 to 20	75
20 to 35	50
> 35	25

Table 5: Water Bar Spacing
Source: MPCA, 2000.

- *Base width of ridge.* The base width of a water bar should have a 6 foot minimum (see Table 4).
- *Grade and angle.* A crossing angle should be selected to provide a positive grade not to exceed 2 percent.
- *Outlet.* Diversions should have stable outlets, either natural or constructed. Site spacing may need to be adjusted for field conditions to use the most suitable areas for water disposal.

Construction

- Install the diversion as soon as the right-of-way has been cleared and graded.
- Disk the base for the constructed ridge before placing fill.
- Track and compact the ridge to the design cross section.
- Locate the outlet on an undisturbed area. Adjust field spacing of the diversion to use the most stable outlet areas. When natural areas are not deemed satisfactory, provide outlet protection.
- Immediately stabilize and vegetate the portions of the diversions not subject to construction traffic. Stabilize with gravel areas to be crossed by vehicles.
- Construction of access roads, power lines, pipelines and similar installations often requires clearing long, narrow rights-of-way over sloping terrain.

- Disturbance and compaction promotes gully formation in these cleared strips by increasing the volume and velocity of runoff.
- Gully formation may be especially severe in tire tracks and ruts. To prevent gullying, runoff can often be diverted across the width of the right-of-way to undisturbed areas by using small, predesigned diversions.
- Give special consideration to each outlet area as well as to the cumulative effect of added diversions. Use gravel to stabilize the diversion where significant vehicular traffic is anticipated.

Water Bars

Description

- A water bar is a permanent ridge or ridge and channel constructed diagonally across a sloping road, utility right-of-way, or path that is subject to erosion (see Figure 5 and Table 5).
- Water bars are used to limit the accumulation of erosive volumes of water by diverting surface runoff at predesigned intervals. Use a water bar where protection is needed to prevent erosion from runoff on sloping access rights-of-way or other long, narrow, sloping areas generally less than 100 feet in width.

Construction

See Right-of-Way Diversion, above.

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