



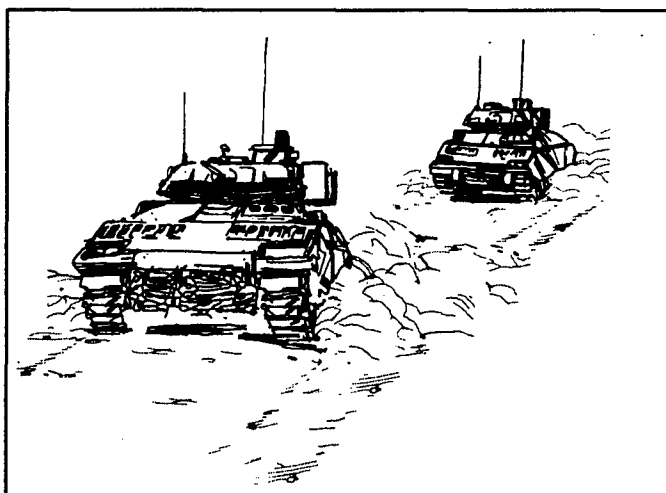
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Maintenance and Control of Erosion and Sediment Along Secondary Roads and Tertiary Trails

by
Sara J. White



Active secondary and tertiary roads are a significant source of nonpoint source sediment from disturbed military lands. Roadway surface degradation, roadside gully development, deposition of sediments in culverts and ditches, and roadway flooding due to reduced ditch capacity are common problems encountered by the military land manager. The form of roadway degradation may vary, but the cause most frequently can be attributed to the intensity of use; improper road location, design, or drainage; or inadequate maintenance. The ability to identify the geomorphic condition of a road section and its adjacent slopes, as well as to predict potentially unstable conditions, can significantly enhance the timeliness, placement, and effectiveness of maintenance or mitigation measures.

This report is intended to provide land managers and road maintenance personnel with supplementary information to promote a better understanding of the geomorphic condition of the roadway, thereby enhancing the ability to prevent and mitigate degradation. Use of this information should simplify selection, placement, and timing of the most appropriate maintenance measures typically applied to the secondary road or tertiary trail.

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Foreword

This study was conducted for Headquarters, Forces Command (FORSCOM) and Army Materiel Command (AMC) under Military Interdepartmental Purchase Request (MIPR) No. ENV 9595, work unit HT5, "Maintenance and Erosion Control on Secondary Roads and Tertiary Trails." The technical monitors were Stuart Cannon, FORSCOM, AFPI-ENE, and Rich Clewell, USAMC Installations and Services Activity, AMXEN-M.

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COL James A. Walter is Commander and Dr. Michael J. O'Connor is Director of USACERL.

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Background

Problem

Any unsurfaced road system used on military testing or training areas will display some degradation despite, or because of the physiographic region. The form of degradation may vary, but the cause most frequently can be attributed to the intensity of use; improper location, design, or drainage; or inadequate maintenance. Primary range roads usually are found along topographic high points. Uncontrolled drainage may lead to accelerated erosion and degradation of water bodies. Secondary roads and tertiary trails can be found within forests and across rangelands, often without regard to topography and drainage patterns. Too frequently, roads traverse slopes on a path that is perpendicular to the contour rather than one that is on a diagonal. This greatly exacerbates the potential for accelerated erosion, gullying, and sedimentation. Improperly designed road surfaces hinder effective drainage, lead to excessive surface maintenance efforts, and promote sedimentation of water bodies or sensitive areas. The lack or improper design of roadway drainage ditches may result in gully development and extension, roadbed damage, sediment pollution, and the flooding of road reaches. Ironically, some maintenance efforts may be causing additional harm. The inability to identify the geomorphic condition of a roadway section and to predict potentially unstable road sections significantly impairs the effective placement of mitigation measures and prevention of degradation in the first place. The lack of a geomorphic perspective to secondary roadway maintenance and drainage control can result in the development of hazardous road sections, costly and time-consuming mitigation efforts, loss of access to important training or testing areas, and even closure of some road sections because of the risk to personal safety and the high cost of rehabilitation.

Current Situation

Installations are currently spending more than \$1 million per year to repair just 5000 miles of the most degraded trails. This does not include the cost of restoration or repair of areas disturbed or damaged by erosion and sedimentation from degraded roads. Labor and equipment required to perform almost constant maintenance on frequently-used roads are additional costs that are not considered. In drawing upon varied resources to aid in determining the most effective use of limited funds and labor, the lack of roadway maintenance guidance becomes apparent. Apart from engineering-specific documents, little guidance is available to non-engineering personnel responsible for daily maintenance activities and the control of erosion and sedimentation along the secondary and tertiary roadways.

Objectives

The design, development, presentation, and evaluation of workshops regarding road and ditch rehabilitation and maintenance provided the background information necessary for developing this Special Report. This document is intended to provide land managers and roadway maintenance personnel with supplementary information to promote a better understanding of the geomorphic condition of the roadway and enhance the ability of individuals to predict erosion. Assimilation of this information should simplify selection, placement, and timing of the most appropriate preventive or mitigatory maintenance measures typically applied to aggregate roads, drainage ditches, culverts, low water crossings, and adjacent slopes.

Approach

This Special Report has been prepared following an exhaustive review of literature discussing current technology and methods of aggregate road maintenance and drainage control. Research focused on techniques and methods that have been tested and are in use by a variety of commands, including the Army Materiel Command (AMC), Forces Command (FORSCOM), and the Military District of Washington (MDW). This Special Report is based on materials from the road and ditch rehabilitation and maintenance workshops and has been significantly guided by comments, suggestions, and information from land managers, highway engineers, erosion control specialists, and road maintenance personnel attending those workshops.

Introduction

Active secondary and tertiary roads are a significant source of nonpoint source (NPS) sediment from military lands. The roadway (surface and ditches) can convey from 25 to 80 percent of the sediment produced by erosion on disturbed sites to adjacent properties or water bodies. The eroding roadway itself can often produce more sediment than adjacent disturbed areas. Roadway surface degradation, roadside gully development, deposition of sediments in culverts and ditches, and flooding are not uncommon. These problems occur more often because of extreme topography, failure to identify and work with the natural drainage patterns of the landform, uncontrolled runoff on and/or along the roadway, or ineffective hydraulic design of the roadway.

Concerns over damage by sediment (nonpoint source pollution) to wetlands, navigable waterways, and threatened and endangered species habitats has resulted in the development of NPS pollution regulations by Federal, state, and local agencies. "Boundary erosion" also has been targeted by legislation based on the Clean Water Act, as revised in 1987. This type of erosion describes the movement of sediment from one property (the installation) and eventually into a stream on another property (adjacent private or public property). Amelioration of these two types of regulated pollution, and the protection of water bodies and sensitive areas within the installation, falls upon the installation land manager and the professionals who provide support in land management issues. Fortunately, yields of sediment in drainage ditches and gullies can be prevented or reduced as much as 60 to 80 percent when appropriate land rehabilitation and maintenance efforts are combined with vegetative practices and structural erosion and sedimentation control measures.

On most installations, active roadway maintenance efforts include (1) increasing infiltration and decreasing overland flow adjacent to the roadway with vegetation, (2) spreading or diverting runoff adjacent to the roadway instead of concentrating it within the ditches, (3) regularly scheduling road surface maintenance to remove irregularities, and (4) maintenance of the road prism to direct runoff to well-designed drainage ditches/conveyances.

Teamwork and Cooperation

The development of effective roadway maintenance programs can benefit from input by personnel with technical expertise in diverse areas. An optimal cooperative effort would involve people well-versed in hydrology, soil sciences, geology, engineering, planning, geomorphology, forestry, biology, and ecology.

Effectiveness and efficiency of effort are additionally facilitated by open communications between installation personnel. This is particularly true in regard to those responsible for (1) planning, scheduling, and executing training activities requiring use of the road and trail networks, (2) ensuring that the roadways are in optimal condition for achievement of the training mission, (3) preparation of roadway designs or specifications, (4) construction of roads and ditches, and (5) land rehabilitation and maintenance operations. Road maintenance is a problem shared by land managers, trainers, planners, engineers, and maintenance personnel. Mitigation requires a cooperative effort.

In-house Expertise and Equipment

In curtailing the rising costs of road maintenance and rehabilitation, it may be practicable for installation or visiting engineer units to participate in these activities. Technical Manual (TM) 5-330, page 1-2, sec. 1-5, indicates that engineer construction units are responsible for both road and bridge maintenance, improvement, and construction in the theater of operations. Participating units may look upon an opportunity to participate in roadway

rehabilitation or maintenance as realistic training for mission preparedness.

Sources of Information

Among the military documents used in preparing this document and available for road maintenance guidance are the following:

TM 5-330, Planning and Design of Roads, Airbases, and Heliports in the Theater of Operations, August 1987.

TM 5-331A, Volume A-Earthmoving, Compaction, Grading, and Ditching Equipment, August 1967.

TM 5-337, Paving and Surfacing Operations, February 1966.

TM 5-530, Materials Testing, August 1987.

TM 5-545, Geology, July 1971.

TM 5-624, Maintenance and Repair of Surface Areas, March 1977.

TM 5-822-2, General Provisions for Geometric Design for Roads, Streets, Walks, and Open Storage Areas, July 1987.

TM 5-822-4, Soil Stabilization for Pavements, October 1980.

TM 5-822-5, Pavement Design for Roads, Streets, Walks, and Open Storage Areas, June 1992.

TM 5-830-3, Dust Control, September 1987.

FM 5-34, Engineer Field Data, September 1987.

FM 5-430-00-1 Planning and Design of Roads, Airfields, and Heliports in the Theater of Operations - Road Design, August 1994.

FM 5-430-00-2 Planning and Design of Roads, Airfields, and Heliports in the Theater of Operations - Airfield and Heliport Design, September 1994.

FM 5-541, Military Soils Engineering, May 1986.

In addition, information on aggregate-surfaced roads, prepared by the U.S. Department of Transportation, USDA Forest Service, USDI Office of Surface Mining, and USDI Bureau of Land Management can be obtained from the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, VA 22161.

Even more readily available are a variety of state-specific guidelines for erosion and sedimentation control in urban areas, on construction sites, and for agriculture and/or forestry purposes. Often, state agencies related to mining, forestry, natural resources, transportation, public roads, etc., offer relevant design and maintenance information for unpaved or secondary roads in specific physiographic areas.

Check with appropriate state or regional offices or NTIS for document availability. Almost daily, new information is placed on the Internet for quick and simple access and download. Useful files may contain construction standards, specifications, and computer-aided drawing (CAD) or computer-aided drawing and design (CADD)-based designs for various components of roadway design or construction.

The AASHTO standards referenced throughout this text are from *Standard Specifications for Transportation Materials and Methods of Sampling and Testing*, 15th edition, 1990, Vols I and II, American Association of State Highway and Transportation Officials, Washington, DC.

1 Soil Erosion

1.1 Erosion Processes

A better understanding of erosion and the geomorphic processes that regulate it may facilitate the development of more effective roadway maintenance and rehabilitation programs. Geomorphology is the study of changes in the land surface in response to natural or anthropogenic disturbances. Recognition of the dynamics of the soil-water interface within a given drainage basin can greatly enhance the management of land disturbances.

One of the benefits of better understanding erosion lies in the awareness of specific geomorphic precursors to degradation. Identification of these precursors can allow appropriate preventive maintenance measures to be taken before any significant problems arise. Fortunately, a variety of geomorphic and engineering principles and practices can be combined to ensure the most environmentally stable, effective, and low-maintenance roadway within a given drainage basin.

The Drainage Basin: A drainage basin (or watershed) is that area of the landscape that supplies water to a specified point on a given stream. For the purpose of understanding, a roadside ditch may be considered a first order (ephemeral) stream component of a drainage basin, similar to a gully. The discharge from the drainage ditch typically enters a second order (perennial) stream. A generally accurate estimate of the actual drainage area of any point along a ditch can be determined with a topographic map and a quick field survey. Often, the drainage basin of interest may simply be made up of the road surface, the ditch, and the adjacent slope(s) feeding runoff to that point.

Only those areas upslope or above the point on the ditch can supply runoff to that point. Recognizing that the ditches on each side of the road have

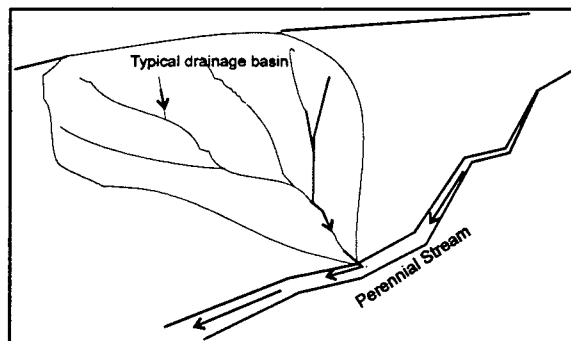


Figure 1-1. Drainage basin within a larger watershed.

independent drainage areas is important in design and rehabilitation work. Crossroad culverts and rolling dips sited mid-slope will increase the drainage area flowing into a ditch by conveying the runoff from one side of the road to the other. In this way, one drainage area is added to another, unless the water is directed to a level spreader on an adjacent stable slope.

Stability: From a geomorphic perspective, all slopes and channels within a drainage basin are either stable or unstable. When the surface environment is undisturbed, an approximate balance exists between the environmentally-controlled geomorphic processes and the surface form, which may be considered stable (resistance forces are greater than erosional forces). However, the surface of the landform may become unstable due to varied levels of human disturbance, including vehicular movement, maneuver activities, and munitions testing, thereby initiating a system-wide imbalance (erosional forces exceed resistance forces).

Human-induced erosional process rates are typically accelerated in comparison to those natural rates observed during predisturbance periods. This acceleration occurs because the prevailing forces and resistances seek to immediately reestablish a balance in the system. The ultimate goal in maintenance and mitigation efforts is for the surface features of the disturbed site to approximate those of the predisturbance period. When successful, this will reduce instability and allow process rates to approach baseline rates of adjacent or similar areas.

Considerable effort and money may be saved by applying geomorphic criteria for recognition of landform susceptibility to erosion control efforts. Project failure assumes a higher probability when the geomorphic character (or degree of stability) of the immediate landform is overlooked during construction, maintenance, or rehabilitation of roadway drainage systems. Both favorable and unfavorable conditions and locations for erosion control efforts appear within the roadway-based drainage basin. Failure to identify unstable areas or upslope causes of instability, may lead to placement of costly control measures in locations where they are inherently ineffective. Some erosion control measures are best installed after an eroding slope has evolved to a state of stability. Without effective preventive management and appropriate placement of mitigation measures, environmental impacts resulting from human disturbances can be extremely damaging both onsite and on adjacent lands.

1.2 Accelerated Erosion

Although erosional processes are natural and continuous, erosional rates may be significantly accelerated by some training or maintenance activities occurring along sections of the roadway. Depending on soil type and site conditions, disturbed lands may erode at a rate up to 1000 times greater than undisturbed lands. Included among the variety of human activities that exacerbate natural erosional processes along the roadway are:

Excavation: Excavation may involve roadway development, widening, or ditch construction by removal of adjacent slopes. Excavation exposes additional soil surface area to the erosive forces of water and loosens the soil structure, thereby making soil particles more susceptible to detachment.

Clearing of Vegetation: Clear-cutting woody growth on adjacent slopes, and vegetation damage or loss through vehicular movements, will expose additional soil surface area to the erosive forces of water and wind; loosen soil structure through loss of soil binding properties of root systems, again

making the soil more susceptible to detachment; and cause increases in runoff volume and velocity by reducing raindrop interception by leafy material (the plant canopy) and losses due to evapotranspiration.

Grade Changes in Adjacent Slopes or the Road Surface: Any abrupt change in the grade will disturb the natural drainage patterns of the hill-slope; increase the velocity of runoff flow; and concentrate flow volumes at undesirable locations such as road surfaces or ditches.

Soil Compaction: Compaction of either the road surface, ditches, or adjacent slopes (in comparison to the natural bulk density of the undisturbed hillslope) will increase runoff by reducing the infiltrative capacity of soil and will upset the natural pattern of drainage.

Drainage System: Ditch construction alongside the roadway can lead to an increase in runoff volume with a related increase in erosive velocities, and can loosen soils, making them more susceptible to erosion.

1.3 Water Erosion and Sediment Movement

Roadways are affected directly by three classifications of water-induced soil erosion.

Sheet Erosion: During a gentle rain on non-vegetated soil, much of the water may infiltrate into the ground. When the surface layer becomes saturated and no further infiltration can occur, overland flow begins. However, on sun-dried, clay-rich, surface crusts, runoff may begin when a thin surface layer is wetted by capillary absorption. Sheet erosion is the removal of thin layers of soil caused by sheet flow across generally uniform surfaces such as a freshly graded road surface, the road shoulders or a nonvegetated adjacent slope.

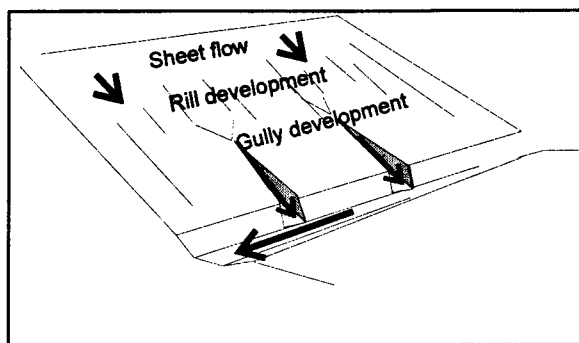


Figure 1-2. Development of water erosion on a hillside.

Sheet flow is common in arid and semi-arid lands or in humid areas where vegetation and soil structures have been destroyed. The two principal factors governing the erosive force in sheet flow are depth of flow and gradient. Therefore, to control sheet erosion, avoiding high concentrations of runoff flow on slopes is critical. Soil compaction by vehicular traffic and vegetation removal by grading, burning, or vehicular traffic can exacerbate the erosive tendencies of sheet flow by reducing infiltration and canopy cover. Unchecked sheet erosion rapidly becomes rill erosion.

Rill Erosion: Where overland flow is concentrated on disturbed sites, on road shoulders, in track or tread marks, or in topographic irregularities, the depth and velocity of flow increases to perhaps 50 times that of adjacent areas. As the increased erosive force of the concentrated flow exceeds the resistance of the soil particles, individual grains are detached and transported. Small channels or rills form due to the concentrated or repeated runoff. Rills often appear on road surfaces and shoulders as sets of well-defined parallel channels. Rills may be up to several centimeters in width and depth. These are easily removed by grading or other maintenance activities. Where a good vegetative cover can be maintained, rills will be much less common because the erosive velocities cannot be attained to initiate particle detachment. Uncontrolled sheet and rill erosion may result in a gully network developing.

Gully Erosion: As rills grow and coalesce, flow is further concentrated, producing greater tractive force and resultant stress on the cross section of the rill. Erosion enlarges the rill channel until it

surpasses the loose definition of size for a rill (can be graded out of existence), thereby forming a gully. The gully, if left unchecked, can grow to hundreds of feet in width, depth, and length. Gullies initiated by high velocity flows in ditches can quickly exceed the size of the ditch. They often expand branch-like into adjacent slopes or even into the roadbed.

Gully erosion occurs within drainage ditches because of (1) an increase in the runoff conveyed within the ditch, but the capacity of the ditch to convey the flow is reduced, or (3) the velocity of the runoff in the ditch is erosive in relation to the ditch lining. The most common causes of an increase in runoff or ditch degradation are changes in vegetation cover, increases in local land disturbance, and variations in rainfall periodicity and intensity.

Gully development provides an indicator of instability either above or below the location of the knickpoint or headcut. Immediate measures should be taken to divert runoff from the ditch to offset further headward migration of the gully. An examination of the source or cause of the instability should provide guidance as to the appropriate type of activity required to mitigate the gully development.

Damage Caused by Water Erosion: Water-induced erosion can quickly lead to costly, environmentally-damaging, and potentially unsafe situations.

Soil Loss: The removal of soil from eroding surfaces is the most apparent damage caused by water erosion. This material often contains the needed organic matter, nutrients, and moisture to sustain a good vegetative cover. Manipulation and amendment of exposed, less-productive, sub-surface soils with mulch and fertilizers are periodically required to support cover plants.

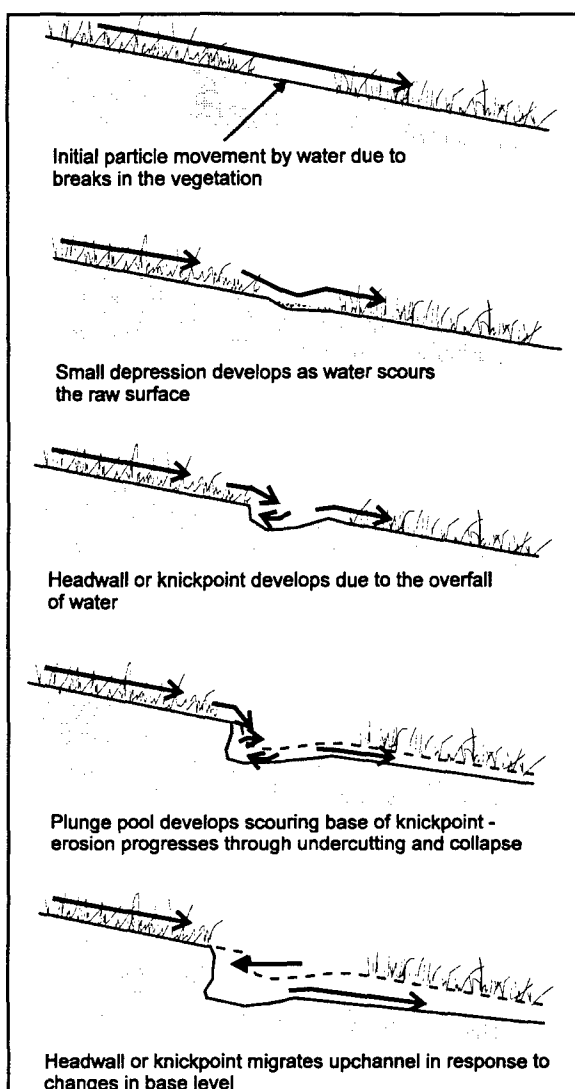


Figure 1-3. Development of a gully within a ditch.

Soil Structure Damage: Excessive water flowing over the soil surface can alter the soil structure in several ways. As erosion begins, the finer silt and clay-sized particles are transported away while the coarser sand-sized particles remain near their original location. This often causes sandy soils to become even more sandy and potentially less productive.

As the erosive force of raindrop impact acts to disintegrate surface aggregates, it also compacts a thin layer of material into a surface crust. As precipitation infiltrates into the soil, silt and clay-sized particles clog the remaining surface pores and increasing erosion rates.

Sedimentation: The single greatest pollutant of surface water on a volume basis is sediment. The higher the sediment load, the less suitable aquatic systems are for fish and wildlife habitats, recreational use, and home and industrial uses. The transport of soil-borne contaminants, such as fertilizers, pesticides, and the variety of toxic materials resulting from the use, testing, or demolition of munitions into water bodies, presents a significant threat to plants, animals, and people. Sedimentation of stream beds reduces the depth and capacity of the channel to convey peak or flood flows.

Damage to Structures: Water erosion can cause extensive and costly damage to roads, bridges, and other related structures. Foundations can be undermined and approaches to bridges, footings, pilings, or supports can be washed away, leading to structural weakening. Erosion in roadway ditches and at culvert discharge points frequently leads to gully development. Headward-extending gullies can cut through or under roadbeds, thereby resulting in roadway closure and costly repair.

Factors Influencing Water Erosion: For water erosion to occur, several elements must be in place. These include a certain amount of precipitation leading to surface runoff, a slope to provide gravitational forces, and a surface characterized by a certain degree of compaction, or lack of vegetation, or a combination of both.

Runoff. Runoff is separated into overland flow and channelized flow. While overland flow seldom exceeds 0.15 inches in depth, flow in rills and gullies can range from 0.20 inches to 6 feet deep. Flow in ditches can be considered channelized flow (similar to that of streams), although it would be hoped that the depth of flow in a ditch would never exceed 3 feet. The factors influencing the erosive ability of runoff include depth, velocity, turbulence, and transported sediment. The erosive force of runoff is related to the volume and velocity of flow. Velocity typically increases with the depth of water in ditches, but rarely exceeds 150 cm per second even in flashy gully flows. The slower the flow, the less erosive it will be. As the depth of flow increases in a ditch, the velocity also

typically increases resulting in even greater erosion. Runoff carrying coarse particles has an abrasive quality or a greater power to break up aggregates on the ditch bed and put them into motion. As runoff depth and velocity increase, random oscillations in direction occur, leading to varying changes in both horizontal and vertical velocity. This irregular motion is called turbulence. Both the kinetic energy and the erosive capacity of the flow are increased by turbulence.

Slope. Erosion, runoff velocity, and runoff volume are strongly influenced by the slope of the surface over which the water flows. Four features of any slope affect the velocity and amount of runoff: slope form, slope length, slope gradient, and slope aspect.

Slope Form. The form or shape of the slope is one factor that can be manipulated to reduce or prevent degradation. A uniform slope is less erodible than a convex slope, but more erodible than a concave slope. The convex slope is more erodible at the shoulder and toe of the slope where the slope is steeper and the runoff volume is greatest. A concave slope is less erodible because the sediments eroded from the upper portion of the slope may be deposited above or at the slope toe. A complex slope typically found in humid regions is convex at the top and concave near the toe. This form produces less sediment than the uniform slope. Overall, the less erodible slopes have short lengths, low gradients, and minimal convexity.

Slope Length and Gradient. The length of the slopes related to ditches can be determined by measuring the distance from the crest of the highest contributing slope to the point where runoff enters either the ditch or a natural channel. The steepness of a slope is measured in units of vertical fall per single horizontal unit (decimal) or per hundred horizontal units (percent). For disturbed slopes, overland flow typically increases in flow depth downslope. Increases in slope gradient and length can produce increases in flow velocity, tractive shear stress or force, and capacity for detachment, entrainment, and transport of grains.

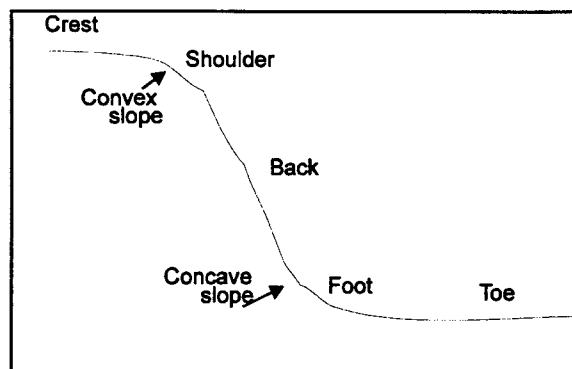


Figure 1-4 Slope components and shapes

Runoff from medium and fine-grained soils usually increases with the slope gradient. Runoff from sandy soils may not increase with increasing slope, however. Soils that are more permeable, and consequently less erodible, tend to be less affected by slope length. Some research indicates that under special conditions (desert environment or resistant materials) erosion rates may decline with increases in gradient. However, erosion increases more with hillslope length on steep rather than gentle slopes. The depth of erosion and amount of soil loss appear to increase with hillslope length.

The length of slope and gradient can be manipulated to some extent on adjacent slopes by terracing or benching the slope to provide shorter and lower slope sections. In ditches, ditch banks can be both vegetated and designed at 3:1 to 4:1 slopes to minimize erosive velocities. Ditch bottom gradients can be modified by installing channel lining materials, grade level structures, or check dams.

Slope Aspect. The rate of erosion on adjacent slopes and ditch banks is also influenced by aspect. South-facing slopes in the southwestern United States are subjected to greater surface erosion than those that face north. Solar conditions on south-facing slopes produce more xeric conditions making vegetative growth difficult. Drainage density is frequently greater for south-facing slopes, indicating the general lack of vegetation. In the eastern United States, slope and channel erosion processes are more apparent on northwest and southwest-facing slopes. Drainage density is typically higher for west-facing slopes. Because of this, seeded slopes must be provided with protec-

tive mulch or mulch blankets to offset aspect problems.

Slope Failure: Ditch banks and/or adjacent cut slopes are often prone to collapse or failure when the angle of repose or angle of stability is exceeded through erosion or improper design or grading. The angle of repose is the maximum slope or angle at which material such as soil or loose rock remains stable. When exceeded, mass movement by slipping or by water erosion can be expected. Theoretically, any slope greater than 55 percent (30 degrees) will tend toward instability and the probability of mass failure.

As water erosion cuts away the supporting toe of a slope or bank, particularly one that is oversteepened, gravitational forces overcome frictional resistance and the slope or bank will collapse into the ditch. Debris movement is likely to develop suddenly in bedded sediments or on shallow, relatively coarse-textured, cohesionless soils on steep shoulders or slopes adjacent to trails or roads. Soil creep, rotational slumps, or earthflows are likely to occur in deep, saturated, fine-textured soils on more moderate slopes and normally extend over a smaller area.

Signs indicative of imminent failure of adjacent slopes, cutbanks, or ditch banks often include:

- Sagging of cutbank, subgrade, or road or slope fill.
- Trees that tip or lean as supporting soils are eroded.
- Appearance of new or accelerated groundwater discharge from cutbanks or adjacent side slopes.
- Presence of standing water in ditches.

Surface Condition: The frictional resistance offered by different surfaces greatly influences the amount and velocity of runoff reaching or moving through a ditch. Smooth, bare surfaces offer the least frictional resistance to runoff, while soils protected by a dense vegetative cover present much greater resistance.

Infiltration and permeability are also affected by texture. While the large pore spaces between sand particles allow rapid water movement, the fine pores found in loam, clay loams, and clays tend to restrict water movement. Fine-textured soils have greater porosity than coarse-textured soils, but slower infiltration and permeability because the pores are so much smaller in fine-textured soils. More runoff and erosion will be produced on fine-textured soil than on sandy soils, given a moderate rain event.

Sedimentation: The deposition of eroded materials, called sedimentation, is a fundamental component of the erosion process. No matter how effective maintenance or rehabilitation efforts are on and along the roadway, some natural sedimentation will occur. Where sites have been disturbed by human activities, accelerated erosion tends to remove the more productive surface soil and deposit it lower in the drainage system. While this may benefit the depositional site at first, the eroded site will soon be transporting and depositing less productive subsoil materials that will bury the sediment deposited earlier.

Sedimentation damages trees and ground cover through burial, compaction, loss of oxygen, and severing of nutrient sources, within channels. It can also produce serious, long-term negative consequences. Because the water table of most alluvial soils is close to the surface, as the channel bed is elevated, the water table rises also. This may locally result in shallower well-aerated soil, until the soil is too wet for even native vegetation to survive. Roadbeds in depositional areas may require relocation or augmentation to compensate for the expanding hydric or wetland soils.

In a drainage basin, hillslope erosion processes and stream channel erosion will yield sediment that may eventually be transported out of the basin system. In the subbasin providing runoff to a roadway section, similar processes occur involving the adjacent slopes, the roadway surface and the adjoining ditch channel(s). These processes result in sediment that is typically first transported to and deposited within the ditch, and from there into an ephemeral gully or stream. Eventually storm

surges may lead to resuspension of the deposited material and relocation out of the subbasin system into a secondary or perennial stream.

Ditches convey runoff and sediment through the ephemeral drainage network similarly to conveyance within perennial stream channels. Because the ditch or gully flows only in response to rain events, sediment moves in surges. Depositional materials often remain within the ephemeral channel for a relatively long time before a significant storm event provides adequate runoff to flush the sediment into a second-order channel or water body. This can make the assessment of erosion or sedimentation from a disturbed site difficult.

Sediment Transport: Ditches convey erosional debris as suspended load, bedload, and dissolved load. Suspended load is composed of fine silts and clays that are light enough to be carried or float within the flow. Bedload is made up of coarser grains of sand and is transported along the bottom of the ditch by rolling or saltation (jumping). The dissolved load is not usually visible as it is made of chemical constituents derived from the weathering of rock.

Suspended sediment concentration is generally independent of flow conditions while a maximum bed load transport rate may be defined for given discharges and sediment sizes. Sediment sizes can be readily determined by sieve, while the discharge (Q) of a ditch at a given point or cross section is the product of the mean velocity (V) and the cross-sectional area of flow at that point.

$$Q = AV$$

where A is the channel width (w) times the depth of flow (d). The sediment discharge of a section of ditch, either as suspended load or bed load, will vary both spatially and temporally. Factors that determine the load include discharge, velocity, channel geometry, roughness, slope, and physical characteristics of the sediment particles in the load.

Sediment transported through ditches is another indicator of instability. With adequate maintenance or rehabilitation of disturbed sites, little

sediment would be available for transport to water bodies from ditches. By assessing sediment transport rates before disturbances or mitigation, one can determine the effectiveness of either maintenance or rehabilitation efforts. Monitoring programs to evaluate sedimentation should be part of the ongoing maintenance program. Ditches, particularly those that discharge into perennial or second order channels, provide easily monitored sampling sites for evaluation of sedimentation.

Mechanics of Erosion Within Drainage Ditches:

There are two components to the mechanics of erosion in ditches. Downcutting leads to gully or ditch bottom deepening. Widening and headcutting extends the incision upslope or into stable areas such as shoulders, road surfaces, and adjacent slopes. Changes in either erosional resistance or erosional forces are responsible for downcutting or headcutting. These changes may depend on controls acting at a given site, upstream or downstream changes in land use, or modifications to the road or ditch that may affect the site.

Ditch channels are subject to two natural external forces: gravity and the resistance forces of friction. Gravity tends to accelerate water downslope, while the frictional forces within the water and between the water and channel boundaries resist the downstream movement.

The shear stress or resisting force exerted by the bed and banks of the ditch, is a function of the specific weight of water, the hydraulic radius, and the slope of the ditch channel. The hydraulic radius is the ratio of the cross-sectional area of the ditch to the wetted perimeter. The wetted perimeter is that part of the channel below the water line of the flow of runoff.

Minimal ditch bed erosion occurs when the slope is low and the wetted perimeter is large compared to the ditch channel cross-sectional area. Therefore, the resisting force per unit area of a ditch channel perimeter is proportional to the product of the hydraulic radius and the channel slope. The relationship between the forces of flow and resistance is expressed in the Chezy and Manning equations.

The Chezy equation

$$V = C\sqrt{RS}$$

shows that the mean velocity (V) depends on the square root of the product of the hydraulic radius and the slope. The Chezy constant (C) is 1.49.

Manning's equation

$$V = 1.49/nR^{2/3}S^{1/2}$$

shows that the mean velocity depends on the hydraulic radius and slope of the ditch channel and inversely on a roughness factor (n). Manning's n factor is based on judgement of the roughness of the channel in the field.

Velocity and turbulence are related to erosion, transportation, and deposition occurring within the ditch. The processes discussed above constitute the geomorphic work that the flowing water in the ditch can perform. They represent the driving and resisting forces.

Forces: By better understanding the force responsible for the forms of degradation, developing maintenance and mitigation efforts to counter them is much easier. For example:

- Rills can be caused by decreased erosional resistance due to the removal or destruction of vegetational cover, surface disturbances, and/or by increased erosive force due to artificial steepening of the slope.
- Shoulder gullies or rills can be caused by decreased erosional resistance due to the removal or destruction of vegetation, surface disturbances, and/or by increased erosive forces caused by the concentration of runoff on and along roads, trails, and ditches, and by mass movement and piping.
- Gullies within the ditch can also be caused by decreased erosional resistance due to decreased vegetation, surface disturbances, and/or increased erosive force due to constriction of flow, steepening of the ditch gradient by sediment deposition, and by base-level lowering.

Incision and Deposition: Some ditches appear to be in a constant state of deposition. Runoff is often observed to seep into the depositional material or to transport silts only in a shallow flow. The source of the sediment filling the ditches is important. Runoff from road surfaces or adjacent slopes may transport loose surface sediments into the ditches or the sediment may be mechanically moved into the ditches by vehicles or grading activities. The road shoulder is occasionally subjected to grading to maintain a too-steep gradient in soils with a lower angle of repose. Sands, particularly when dry conditions prevail, require a lower slope to remain stable. Materials graded into ditches from road shoulders and surfaces will cause a significant sedimentation problem.

If the volume and velocity of runoff within the ditch cannot transport the excessive sediment to a secondary channel, the ditch will fill, be prone to flooding, and be subject to reduced culvert capacity. If the cause of the problem can be identified, appropriate maintenance and erosion control measures should be effected at the source to reduce both accelerated and natural sedimentation.

Some ditches display a narrow, deep, raw incision or gully paralleling the road. These ditches are often in more cohesive soils on steeper slopes and lack the appropriate hydraulically-designed shape or channel lining to withstand the volume or velocity of the runoff flowing through them. As slopes increase, velocities increase and bare soils begin to scour at relatively low velocities. Even grass-lined ditches cannot withstand velocities over 2 to 3 miles per hour before scouring begins. Where higher volumes of runoff cannot be diverted away from a ditch, scour will also begin. Gullies incising into unconsolidated materials may have a V-shaped cross-section where the subsoil is fine textured and resistant to rapid cutting, but may have an U-shape in material like loess where the soil and subsoil are equally susceptible to erosion.

Ditches will cycle through episodes of scour and fill as pulses of sediment move through the ditch. Incisions will be propagated upslope as the base level is lowered by scour. This can be seen in the presence of knickpoints (abrupt changes in eleva-

tion along the longitudinal profile of a ditch) which migrate up the ditch bottom, and also in the development of road surface and shoulder rills. Ditch scouring, shoulder erosion, and mechanical movement of surface materials produces large quantities of sediment that may be transported and deposited within another ditch section lower on the slope. As deposits are subjected to rain events, they will move in pulses to a secondary channel or lower-lying water body. It is common for incision to take place at one point in a ditch section while deposition is occurring in another part of the same section. Incision follows deposition as sediment loads decrease and cleaner water begins to cut into the newly deposited sediment.

1.4 Impacts of Roadway Degradation on Water Quality

Erosion and subsequent sediment movement into lakes, streams, reservoirs, ponds, or wetlands can have a significantly adverse effect on water quality, fish and wildlife habitat, downstream property, vehicle maintenance, roadway maintenance, and safety. Sediment-laden runoff transports many pollutants associated with road activities. These pollutants may include pesticides, herbicides and fungicides; petrochemical and heavy metals (oil, gas, diesel, asphalts, lead, cadmium, copper, etc.); construction chemicals (acids, soil additives), wastewater (aggregate washwater, pesticide rinsate), dust palliatives (calcium chloride, sodium chloride, lignin, asphalt emulsions, resins, polymers, etc.), and amendments (lime and fertilizer) from land rehabilitation or maintenance activities.

Sediments suspended and transported in runoff from nonpoint sources such as roads and ditches are a primary source of both pollutants and nutrients. Up to 80 percent of the total phosphates and 73 percent of the nitrogen compounds in streams today can be attributed to eroded sediments. As a result, fish-kills due to deoxygenation have become increasing more prevalent. Nitrogen and phosphorus compounds used in soil amendments and fertilizers stimulate aquatic plant growth causing algal blooms and noxious conditions. Certain

pesticides contain highly toxic chemicals that may persist for long periods in soil and water and can be passed along plant and animal food chains. Even small concentrations of many chemicals transported via detached soil particles are adequate to cause the death of aquatic organisms and poison public water supplies.

Sediment suspended in stream or pond water will disrupt aquatic ecosystems in a variety of ways. Reduced light penetration inhibits photosynthetic plant growth and the ability of sight-feeding organisms to locate food sources. Fish exposed to sudden and prolonged sediment increases may experience gill clogging and abrasion, eventually leading to fatal stress. Spawning gravels are destroyed as they are covered by deposited sediments. Further downstream, reservoirs and channels are affected by both lowered water conveyance and capacities because of bottom filling. Where severe erosion provides large quantities of sediment and debris, flood damage is a major concern because of the reduction in competence of drainageways.

2 Soils

Soils are made up of mineral and organic particles that occupy some 50 percent of the soils volume, with pore space occupying the remaining 50 percent. They provide a natural media for plant growth and development. Available pore space is critical to the development of healthy root development. Pores allow the movement of both air and water in the root zone. Clay-rich soils, or those soils that are impenetrable due to the nature of the subsoil or to the presence of water-saturated soil near the surface, tend to encourage shallow plant root development. Sandy soils, even those that tend toward drought and unfertile conditions, typically show marked improvement with the implementation of irrigation and under these conditions, plant roots can readily penetrate deeply into the surface and subsoils. Most plants, however, simply will not develop well in soil that is dry, very acid, very alkaline, or very wet.

Five macronutrients and eight micronutrients are extracted by plants from the soil. Elements required in large amounts by plants include nitrogen, phosphorus, potassium, calcium, and magnesium. Few soils can supply all of the nutrient needs of a healthy plant cover for any prolonged period. Fortunately, these can be obtained from amendments when the soil is found deficient.

Master Horizons: As soil layers form relatively parallel to the surface of the landscape, several layers may develop at the same time. Although the soil layers are related genetically, their chemical, physical, and biological properties will be different from each another.

The soil profile comprises the horizons or soil layers in a vertical exposure of the soil. Each horizon is unique because of the processes involved in soil formation: additions, losses, transformations, and translocations. For example,

organic matter is often added to the upper horizons from vegetation; soluble components are lost from upper horizons and added to lower ones by leaching; materials are transformed through the breakdown of organic matter; and suspended mineral and organic particles are translocated from upper horizons to lower ones. Six master horizons are readily identified in the soil profile by specific morphological characteristics.

The “O” or organic horizon is that soil layer dominated by organic material. This layer develops from organic litter from plants and animals. Among the soils formed entirely of organic matter are peat, muck, and the Histisols.

The mineral horizons and layers are typically found immediately below an O horizon or in the absence of an O horizon.

The “A” horizon is formed at the surface or below an O horizon. It may be made up of humified organic matter mixed with mineral material. It may have properties resulting from agricultural or other human activities, such as plowing or pasturing. While the structure is typically granular, it can sometimes be massive.

The “E” horizon features a distinctive loss of clay, iron, or aluminum, along with higher concentrations of sand and silt-sized quartz or similar materials, resulting in a pale or light color in relation to the horizon above or below. Structural development is present.

The “B” horizon has several potential identifying characteristics. The most obvious of these is an illuvial accumulation of clay, iron, aluminum, carbonates, gypsum, or humus; coatings of sesquioxides on grains resulting in darker, stronger, and/or redder color than the surrounding material; and evidence of carbonate removal.

The “C” horizon generally is not altered by the soil forming processes. It will often have a massive structure and lack the properties of the O, A, E, or B horizons.

The "R" horizon is the surface of the underlying bedrock material. In some areas, this may be exposed at the surface with little evidence of soil development.

Subordinate Characterizations: The specific features unique to a master horizon are noted by the placement of one or more lowercase letters after the identifying capital letter.

- a:** highly decomposed or sapric organic material; only used with the O horizon.
- b:** buried horizon; not used with the O horizon.
- c:** concretions or hard, cemented nodules of iron, with a high bulk density; no roots.
- e:** partially decomposed or hemic organic material.
- f:** frozen soils and is usually used with C horizons.
- g:** strong gleying as evidenced by low chroma color caused by reduction of iron in stagnant, saturated conditions.
- h:** illuvial accumulation of organic matter or the presence of humus.
- I:** slightly decomposed or fibric organic matter.
- k:** accumulation of carbonates.
- m:** cementation or induration.
- n:** accumulation of exchangeable sodium (Na).
- o:** the residual accumulation of sesquioxides following intensive weathering.
- p:** the presence of plowing or mechanical disturbance that mixes a surface layer.
- q:** accumulation of silica (quartz).
- r:** weathered or soft bedrock.
- s:** illuvial accumulation of sesquioxides and organic matter.
- t:** accumulation of clay as evidenced by clay coatings on ped faces.
- v:** plinthite or a very hard, iron rich layer with mottling of reds, yellows, and grey colors.
- w:** development weak color and structure.
- x:** fragipan or genetically developed firm, brittle, and/or high bulk density material in the B or C horizons. No cementing will be evident.
- y:** accumulation of gypsum.
- z:** an accumulation of soluble salts (those more soluble than gypsum).

2.1 Soil Characteristics

An awareness of certain characteristics of the soil to be used as foundation, subgrade, base, or surface material can aid in avoiding, preventing, or mitigating some roadway maintenance problems. Soil analysis provides the following information.

Particle Size: Particle size analysis provides a measurement of the percentages of the sand, silt, and clay separates in a soil.

Bulk Density: This is the ratio of the mass (weight) to the bulk volume of soil particles plus pore spaces. Bulk density information can establish the presence of fragipan layers or volcanic ash in a soil, the degree of weathering of a parent material, or provide an evaluation of root impedance.

Soil Moisture Parameters: A determination of the permanent wilting point for plants is provided by soil moisture tests. Complete moisture sorption data is useful for irrigation and moisture supply studies and in erosion monitoring.

Shrink-Swell Capacity or Linear Extensibility: The amount of montmorillinitic clay in a soil can affect the physical qualities of the soil in times of drought and rainfall. Shrinkage and swelling can produce large and deep cracks in the soil and subsoil during dry periods while swelling can produce undulating surfaces as clay-rich soils absorb moisture during the wet season. This presents a critical problem when selecting sites for road or trail routes. When the Coefficient of Linear Extensibility (COLE) exceeds 0.09, significant shrink-swell activity can be expected and roadway development will be difficult. Anytime the COLE exceeds 0.03, significant amounts of montmorillinitic clay exist. COLE values will often be available in the County Soil Survey.

pH Measurements: Measurements of soil pH provide many general inferences. Most vegetation thrives between 5 and 7.

pH <3.5. Typically associated with a pH drop after a cycle of wetting and drying. Acid sulfates are present and provide a problem. In a severely disturbed area, such as a mine or a spoil pile, the low pH may indicate sulfides present in a buried geologic formation that are being oxidized. In a marshy coastal area, the low pH suggests "cat clays" or acid sulfate soils with very serious agricultural problems.

pH <4.5. This indicates an abundance of exchangeable hydrogen and perhaps aluminum.

pH 4.5 to 5.8 in mineral soils. Indicates that there are adequate exchangeable aluminum and hydrogen ions present to affect plant growth and the base saturation is probably low.

pH 4 to 5.2 in organic-rich soils. May indicate too much exchangeable hydrogen and aluminum in the soil to promote plant growth.

pH 5.8 to 6.5. Acidic, probably due to the presence of exchangeable aluminum and hydrogen; the base saturation has increased to 70-90 percent. This soil will provide problems for acid-sensitive crops such as alfalfa.

pH 6.5 to 8. The base saturation is 100 percent and there is no exchangeable aluminum present. Neutral to slightly alkaline range.

pH 8 to 8.5. The base saturation is at 100 percent and there is free calcium carbonate (CaCO_3) present in the system. The exchangeable cation population is predominantly Calcium (Ca) and Magnesium (Mg). Fairly alkaline.

pH 8.5 to 10. The soil contains significant amounts of soluble salts and has a high conductivity. Exchangeable sodium is inadequate to qualify as a natric horizon. Very alkaline.

pH >10. Alkali soil, saturated with sodium.

Percentage Base Saturation (PBS): PBS data can provide information on the degree of leaching which is very diagnostic in soil classification, soil fertility, and mineral nutrition studies. Soils in

warmer, wetter, and older landscapes tend to have PBS values less than 35 in the B horizons, or decreasing from the B to the C horizon. Soils found in more humid temperate regions and on younger landscapes will have PBS values greater than 35. Mollisols, utisols, and Alfisols are differentiated by the PBS.

2.2 Soil Properties

Soil has four physical properties that can be used to predict erodibility: structure, texture, organic matter content, and permeability. Erodibility is dependent on the detachability and transportability of individual grains. Structure and texture strongly influence permeability and erodibility.

Soil Structure: Large stable aggregates (clusters of soil particles) tend to resist detachment and transportation. Clay generally acts as the cementing and aggregating agent. The higher the clay content, the larger the aggregate size, and the greater the stability. However, clay content in excess of 40 percent can lead to the development of smaller aggregates that are more readily eroded. Soil low in organic matter and high in silt tends to produce unstable aggregates. Silts and very fine sands are examples of this. As finer particles clog available pore space at the surface, water infiltration is slowed resulting in increased runoff and erosion.

The type of clay also influences the aggregation of soils. Soil in the tropical and subtropical regions, with high percentages of iron and aluminum oxides and kaolinite, are better aggregated than soils high in montmorillinite and illite. Some iron compounds tend to bind clays and other soil grains into very stable forms, particularly in strongly leached, temperate region soils and in tropical soils. Secondary lime can also act as a cementing agent to bind particles into aggregates.

Soil Texture: All soils are made of up varying amounts of sand, silt, and clay particles. The finer-grained particles, like clay, tend to stick to each other making them difficult to detach. However,

once detached, clay particles are readily transported great distances in runoff flow. Silts are typically well aggregated. However, the aggregate breaks down easily when wet. Wet silt particles detach and transport with as much ease as clays. Coarse-grained particles, like sand, are readily detached from the soil mass, but their size makes them difficult to transport.

Well-graded soils have an equal representation of all particle sizes from the largest in the category to the smallest. Well-graded soils have a designation of GW (well-graded gravel) and SW (well-graded sands).

Poorly-graded soils can be either uniformly-graded with particles all of a nearly uniform size or gap-graded with some particle sizes missing. Uniformly-graded or gap-graded soils have designations of GP (poorly-graded gravel) or SP (poorly-graded sand).

These designations are important in assessing the bearing capacity of the material. ***Well-graded, coarse materials are preferred for their high density and stability.*** By manipulating the percentages of various particle size groups in a material, it is possible to increase the strength and stability. This is accomplished by an interlocking of particles as smaller particles fill the voids between the larger particles, forming a strong bond. This binding property greatly decreases the tendency for displacement of individual particles.

Shape: The shape of individual particles is also important in determining stability. Angular shapes are best for construction purposes. Rounded shapes, such as well-washed river rock, particularly if uniformly-graded, will create soil stability problems.

2.3 Soil Classifications

Classifications used in the Unified Soil Classification System (USCS) are commonly used to describe the materials used in roadway rehabilitation and maintenance.

Coarse-grained soils: These are typically the sands and gravels or those mixtures in which one-half the material, by weight, does not pass the No. 200 sieve. Sands pass the No. 4 sieve while gravels do not. Sandy gravel indicates that more of the mixture was gravel than sand by weight.

Fine-grained soils: These are typically the silts and clays. They are soils in which more than half of the material passes a No. 200 sieve. Silts may include very fine sands, rock flours, silty or clayey fine sands or clayey silts, loess, and micaceous or diatomaceous soils. Clays may include gravelly clays, sand clays, silty clays, fat clays, gumbo clays, volcanic clays, glacial clays, and bentonite.

Highly organic soils: Highly organic soils (Pt) such as peat are easily identified by their color, odor, spongy feel, and fibrous texture. Grass, leaves, branches, etc., may be visible within the material. ***Rich, organic soils are highly undesirable for construction or foundation uses.***

Desirable Characteristics: When assessing soils for the construction, relocation, maintenance or rehabilitation of roadways, many critical factors require consideration.

- The soils for foundations under the road or trail and for base courses must exhibit adequate strength, suitable compaction characteristics, satisfactory drainage, resistance to frost action (where appropriate), and low compression and expansion characteristics. Where certain properties are lacking, supplementing them through good construction methods is possible.
- Materials having poor drainage characteristics can be aided by installing adequate subdrains and using geotextiles to promote drainage.
- Although the strength requirement for base course materials is very high, low strengths in subgrade materials can be supplemented by adding a base course or increasing the thickness of the base course.

Note: G = gravel
S = sand

W = well-graded
P = poorly-graded
M = silt
C = clay
O = organic soils
H = high liquid limits
L = low liquid limits

2.4 Subgrade or Subbase Materials

Coarse-grained materials usually make the best subgrade or subbase materials. The GW group is most suitable for subgrades, subbases, and base courses. In this instance, GW refers to high quality crushed stone.

The GP group and some silty gravels (GM) are adequate for subbase or subgrade materials and under some circumstances, for base materials. The problem with these materials is a poor gradation that can reduce the soil strength.

The GM, GC (clayey gravels), and SW groups are slightly less suitable as subgrade and subbase materials, but cannot be used for base courses.

The SP and SM (Silty sands) soils provide only fair to good subbase or subgrade materials, but are not suitable for base courses.

The fine-grained soils, both silts and clays, make very poor subgrade or subbase materials. Clays are the worst materials to use.

The qualities lacking in these soils can sometimes be compensated for by increasing the thickness of the overlying base material. However, the overlying base material must be appropriately selected.

The organic materials are very poor subgrade materials and should be removed wherever possible to avoid highly-specialized construction requirements.

2.5 Surfacing Materials

For aggregate-surfaced roads and trails, the GC group (sand-clay-gravel mixture) is considered the most suitable choice. Ensuring that this group does not contain a too high percentage of silts of clays is very important, and the plasticity index should range from 5 to 15. In addition, the roadbed must have either a suitably high crown or well-designed drainage structures to allow rapid drainage and runoff control.

In areas prone to frost action, avoid the use of fine silty sands and silts as they lose strength significantly in response to frost action. Fortunately, coarse-grained materials with little or no fines are minimally affected by frost action. Appropriate drainage is critical in frost prone areas. Where subgrade materials are adversely affected by frost, laying a protective course of granular material over the foundation soil to limit the depth of freezing in the subgrade may be necessary. Another method involves reducing the depth of the granular subbase material to allow freezing of the subgrade. This method requires design based on the reduced strength of the subgrade during the frost-thaw period.

2.6 Drainage Characteristics

The presence of moisture in subgrade, subbase, and base course materials, in all but the free-draining, coarse-grained materials, is directly linked to the development of pore water pressures and the loss of strength in the roadbed. The sources of the moisture may be rain or a locally high local water table.

Adequate drainage must be provided regardless of materials. Although the coarse-grained materials permit rapid draining, they also allow a rapid ingress of water. This may cause adjacent, less-pervious materials to be subject to saturation.

Well-drained Soils: The GW, SW, GP, and SP groups have excellent drainage characteristics. These are considered clean materials or free of

finer. They are readily drained by gravity systems. Open ditches are used to intercept and convey runoff along roads in these soils. For maximum effectiveness, the ditches are used in conjunction with road surface sealing to reduce infiltration into the base or subgrade.

Poorly-drained Soils: The ML, OL, MH, GM, GC, SC, and SM groups have fair to poor drainage characteristics. Groups include organic and inorganic fine sands and silts and organic clays of low compressibility along with coarse-grained soils with an excess of nonplastic fines. Drainage by gravity alone is very difficult in these soils. Filter fabrics and subsurface drains may be required if suitable roadbed materials cannot be made available.

Impervious Soils: The CL, CH, and OH groups are fine-grained, homogeneous soils and coarse-grained soils containing plastic fines. Subsurface drainage is extremely slow and any form of drainage control will be difficult and costly. Again, filter fabrics, subsurface drains, or replacement of poor materials with well-graded aggregates would be required.

2.7 Soil Assessments

While it is possible to conduct rehabilitation efforts without knowing the soil type, the pH, or how much potassium or phosphorus is present within that soil, it is not recommended. Efforts will be much more successful if soils information, and someone who understands how to use it, are available. Soil tests are an easy and quick way to gather this information. The results of soil tests guide efforts in mitigation through soil improvement and fertilization.

Soil Tests: Soil tests should be made on samples of the soils collected within the section of the roadway requiring rehabilitation or maintenance. Most soil samples are sent to either a local cooperative extension service or commercial soil testing laboratory for evaluation.

Besides soil texture, nitrogen, phosphorus, and potassium, soil samples can be tested for calcium, manganese, magnesium, iron, copper, and zinc. Occasionally, heavy metals such as lead, silver, mercury, chromium, nickel, and cadmium can also be detected in the soils sampled on and adjacent to older roadways.

Collecting a Soil Sample: Test results can be no better than the samples tested. To get an accurate picture of the soil at the site in question, the sample must be representative of the entire area. Use a clean trowel, shovel, spade, or soil auger to collect the soil sample. For gathering the samples, a large bucket that is free of contaminants is suitable. Any fertilizer residue can destroy the test results.

Soil samples are best taken when the soil is free of frost and is fairly dry. If the area is large, taking a series of samples from several spots will be necessary. Mix them together to provide an overall representation of the soil. **IF** there are two or more distinctly different areas, however, a combined sample would not suitably represent either one. In this instance, collecting a series of samples from each site and keeping them separate will be required.

To take a composite sample, start at one end of the site, and cut straight down about 6 to 8 inches with a sharp, narrow, and clean tool. Lift out a narrow slice, and lay it aside. Then take another thin slice, about ½-inch thick, from the same spot and put it in the collection container. Shovel the first slice back into the hole. Move about 6 to 10 feet in any direction and repeat the process. Continue until samples have been taken from all over the site.

After the samples are collected, mix the soil in the bucket thoroughly. Remove one pint of soil and spread this homogenized sample out on newspapers on a table where it can dry out. The sample must be well-dried because damp or wet soils will give false readings. Once the soil sample is dry, rub it through a screen or in some manner crush all clumps or clods.

At this point there are two options: (1) a Soil Testing Kit or a Turf Lab Kit can be used to

perform the required tests or (2) the sample can be placed in a sterilized container with a label identifying where and when it was taken and the type of vegetation growing on the site. Send this prepared sample to a commercial soil lab or a cooperative extension soil lab.

Soil Sampling for Profile Classification: Soil samples for soil classification (examination of horizons) should be taken to depths of not less than 4 feet. A soil punch or auger can be used to obtain the preliminary samples. Soil profiles can be made from the classified soil samples. Samples of representative soils from the profile are then subjected to testing. Soil pits provide onsite evaluation of the characteristics of subgrade materials. Soil moisture, density, and strength can each be evaluated onsite if the field test equipment is available. This subgrade information is used to determine the depth to which compaction must extend and to identify soft layers in the subsoil.

The soil profile shows the soil boundaries, elevation of bedrock, and water table. It should be used to locate the grade line, for excavation, and for grading and drainage plans. It is used to aid in planning drainage structures and also to indicate the need for special drainage installations needed with soils that are difficult to drain as in areas where the water table is close to the surface.

Preliminary Soil Evaluation in the Field Environment: Review of the local NRCS Soil Survey(s) can make preliminary field evaluations simpler by providing information on the primary soils types in any given area of the installation. The following paragraphs describe an assortment of techniques that are commonly used in field soil assessment.

pH Tests. pH stands for potential hydrogen and refers to the amount of free hydrogen in the soil. Soil pH influences the ability of plants to use nutrients in the soil. A pH reading of 7 is neutral, >7 is alkaline, and <7 is acid. Acid soils prevent the plants from obtaining the necessary nutrients for establishment and vigorous growth. Several quick methods for determining the pH of the soil are available.

A combination soil pH and moisture meter can provide fairly accurate spot soil pH and moisture percentages. An electrode in the small instrument can measure pH values from 3.5 to 8 and soil moisture from 0-100 percent.

An electronic pH meter uses electrodes, one of which is sensitive to hydrogen ions while the other is set to neutral. Soil pH causes the former to change. A comparison between the electrodes determines the pH.

Chemical pH tests provide pH values when soil is mixed with chemicals. The chemicals turn different shades that are compared with a chart to determine the pH. This method is not recommended for heavy clays.

Ribbon Test. The ribbon test provides an evaluation of the soil texture and only works on materials that will pass the No. 40 sieve. Place a golf ball size sample of soil that is slightly below the sticky limit in your hand (it may be necessary to add a drop or two of water). Roll the soil between your hands until it forms a cigar-shape about 3 to 5 inches long and one half inch in diameter. Place the soil in one hand, one end between the finger and thumb, the remainder in the palm. Flatten the roll, forming a ribbon 1/8 to 1/4 inch thick. The ribbon is formed by squeezing the cigar-shaped soil sample between the thumb and forefinger. Handle carefully until the longest ribbon possible has been created. If the ribbon holds together for eight to ten inches without breaking, the material can be considered highly plastic and compressive (very clayey). If the soil cannot be formed into a ribbon at all, it is non-plastic or clay-free. A shorter length of ribbon indicates a soil with some lower percent of clay. The more plastic the material, the less desirable it is for subgrade, subbase, or base material.

Odor Test. Fresh samples of organic materials typically yield a musty, dirty odor that, with experience, is unmistakable. Organic materials are very unsuitable as foundation or base course materials.

Grit Test. With this method, identifying sand, silt, and clay -sized particles is simple. Take a small pinch of the subject soil and gently grind the material between the upper and lower front teeth.

Sandy soils will grate very harshly and individual grains will be quite noticeable.

Silty soils are much, much smaller than sandy particles and feel much less gritty between the teeth although detecting the presence of the particles is still easy.

Clayey soils are not gritty at all. They tend to feel smooth and powdery like flour. Dry lumps of clayey soils will stick when lightly touched with the tongue.

Acid Test. A few drops of a weak solution (10 percent) of hydrochloric acid (pure vinegar or Coca-Cola will also work in some instances) will produce a fizzing reaction when placed on the fresh surface (broken or scratched with a knife) of some sedimentary rocks and soils containing calcium carbonate. The presence of some calcium carbonate in the soil is desirable because of the cementing action it provides to add to the stability.

Shine Test. A slightly moist sample of highly plastic clay will produce a shine when rubbed with a fingernail or knife blade or between the thumb and forefinger, whereas a lean clay sample will not.

Sedimentation Test. Place a small amount of the subject soil (less than 1/3 cup dry) into a quart jar. Break up all clumps. Cover with 5 inches of water. Agitate by shaking or stirring well. Leave the container on a stable surface to allow the particles to settle out.

This test allows a crude differentiation of the coarse (0.072 mm) fraction from the fine fraction of the soil sample. Since the coarse fraction will have settled out within the first 30 seconds, the fines are in suspension. By carefully pouring the water containing the suspended fines into a second container and allowing the water to evaporate, the relative amounts of fines and coarse particles can be determined.

Settling Time	Grain Diameter (in mm)	Particles Settling Out
2 seconds	0.4	Coarse to fine sand
30 seconds	0.072	Fine sands to fines
10 minutes	0.03	Coarse silt to fine silt
1 hour	0.01	Silt to Clay

Table 2-1. Settling time for soil particles.

Soil Texture Test. This test involves the use of an inexpensive, portable kit containing a set of calibrated tubes with a supporting frame, a dispersing agent, and a flocculating reagent. Once the particle fractions are separated out and the percentage of each determined from the calibrated tubes, the texture class is determined from a soil texture triangle chart that accompanies the kit.

Field Sieve Test. Portable and affordable field sieve sets provide reliable grain size analysis. One type consists of a frame containing nested sieves. Another type can be carried in a pocket. Mesh sizes run from No. 8 to 200. Soil samples are placed on the top of the nested sieves and shaken until the particle fractions have separated out.

Particle Size Test. A pocket-sized geotechnical gauge provides a guide to color, description, and particle size for sand, silt, and clay. Sand samples are fused to a card. The card provides shear strength ranges and unconfined compressive strength ranges for clay consistency. It also provides relative percent of density and describes field tests to determine sand types.

A sand gauge on a pocket-sized plastic card can be used in determining size classification, bed thickness, and angularity of sand grains. Sand grains are fused to the plastic card.

Soil Color Test. Soil color charts are available from a variety of sources to aid in determining the soil type.

Soil Nutrient Test. Soil nutrient levels can be loosely determined using field chemical test kits. Soils are placed into test tubes with chemicals and compared to color charts to determine the values for nitrogen, phosphorus, potassium, and pH.

Shear Testing. A portable device is available for a general measurement of the shear strength of cohesive soils to be used in foundations and embankments. This information is used to determine how great a load the soil can support before it will fail laterally. The device will measure a stress range of 0 to 2.5 kg/sp cm (tons/sq ft).

Compressive Strength Test. A pocket or field penetrometer can be used to determine the unconfined compressive strength of a soil. Compressive load in tons/sq ft and kg/sq cm is indicated on a scale on the piston barrel.

Compaction Testing. A portable compaction testing (penetrometer) device can be used to determine the compaction of a soil (in relation to an undisturbed site) down to 24 inches below the surface. Compaction levels in psi are read in 50 lb increments to 500 psi on a color-coded dial on the handle.

Soil Test Sources: Materials for soil pH and nutrient level testing are available from many mail-order scientific supply companies such as General Supply, Ben Meadows, or Forestry Suppliers.

Most cooperative extension service offices do soil tests for a fee. Look under the city or county government listings in the phone book. Many universities or agricultural colleges are also willing to provide lab services for a fee.

3 The Roadway

3.1 Rehabilitation or Maintenance Planning

For the purposes of brevity, the term roadway will be used to describe the joint components of road surface, roadbed, roadside drainage ditches, and adjacent slopes.

Roadway Location: Siting on geomorphically stable or less-degradable slopes can remedy most of the erosional problems associated with the roadway. On occasion, prudence suggests relocation of roadway sections that require constant maintenance. The origin of many problems lies in poor subgrade materials, steep slopes, or disruption of natural drainage patterns. In anticipation of these types of maintenance problems, several planning considerations should be evaluated before design and construction.

Topographic location and natural drainage patterns are the most important considerations in selecting a site for a new roadway or in rerouting a degraded section of roadway. Familiarity with the most detailed topographic maps, soil maps, and aerial photographs of the site of the degraded or proposed roadway is a good starting point.

Planning Considerations: Identify areas that should be avoided such as wetlands; sensitive areas; threatened and endangered species habitat; very steep, wet, or rocky slopes; areas with shallow or erosive soils; and areas where the water table is close to the surface.

To reduce the slope and length of the roadway section, select a starting point elevation on the existing road that is close to that of the destination elevation. Although the shortest length is optimal, roads and trails should NOT be aligned perpendicular to the contours of a steep slope. Erosion can

be reduced if roads and trails follow either the contour of the slope or a gentle diagonal to the contours when in steep terrain.

Locate the road or trail on a topographic map. Then find the points through which the road or trail section must pass. These may include high or low points, intersections with other roads or trails, or points of interest (training sites, bivouac areas, firing points, etc.). Determine the total elevation difference between consecutive control points. Multiply each elevation difference by 12.5 to determine the minimum road length required between the control points. This length assumes a trail constructed on an average grade of 8 percent.

Example: Starting point elevation = 1940 ft.
Ending point elevation = 2000 ft.
 $2000 - 1940 = 60$ foot change in grade.
 $60 \times 12.5 = 750$ ft.
Therefore, the minimum length of this road section should be 750 ft. at an 8 percent average grade.

The benefits of siting the roadway over less steep terrain include less difficult and time-consuming construction and maintenance efforts; simpler, less costly, and more effective erosion and sedimentation control methodology; safer roads; and an enhanced ability to support the mission

A foot survey will permit the identification of features that are not visible on aerial photos or topographic maps, yet may present a problem. To obtain the best overview of the site, work from the upper slopes to the lower. Identify potential buffer strips, ephemeral or perennial channels (gullies or creeks), springs, bogs, outcrops, or other features not visible on the topographic map or air photos.

Route roadway sections above wet areas where possible. Development through wetlands can only be accomplished with a permit. Where ephemeral or perennial channels must be crossed, make those crossings at right angles to the flow of the water. Use either culvert crossings, low-water crossings, or bridges to avoid disturbance to aquatic ecosystems.

Topography: The shape of the landscape influences runoff patterns and conditions. Slope length, gradient, and the size of the drainage area above the roadway section are very important in controlling runoff volumes and velocities. Move roadways away from erodible or environmentally sensitive areas such as steep slopes, bluff edges, river banks, natural drainageways, lakes, ponds, springs, windy areas, high water tables, floodplains, and wetlands.

The height of the roadway above a stable base-level affects runoff conditions. Midslope road sections are afforded better drainage than flat reaches or toeslope locations. While the rates and quantities of runoff will increase with slope steepness, gentler slopes may provide more difficulties in the development of adequate plans for surface and subsurface drainage.

In steep terrain, the costs of roadway rehabilitation, maintenance or construction may increase because of shallow soils, rocks outcropping on the surface and/or the need for more earthmoving in cut and fill sections. The width of the roadway on steeper slopes decreases with time, while the width on gentler slopes increases. Maintenance efforts must ensure that design widths are maintained.

Aspect: The aspect influences the exposure of soils and vegetation to weathering forces. South- and west-facing aspects are often more susceptible to erosion due to solar intensity (drier soil surfaces and potential for burning of newly established vegetation).

Climate: Climate influences soil infiltrative capacity, soil cohesion, and runoff conditions. Total annual rainfall, rainfall intensity and duration, storm/flood frequency, and seasonal temperature extremes should be available to use in the hydraulic design of drainage control structures (diversions and ditches) and implementation schedules.

While erosion and sedimentation on and along the roadway system are greatly influenced by topography, the intensity of rain events and the type and amount of surface covering are also critical factors.

Where precipitation exceeds soil infiltration rates, overland flow and erosion occur. Hydraulically-designed collection and dispersion systems for runoff must be integrated into the rehabilitation plan to prevent erosion of cutbanks, slope fill, roadway surfaces, adjacent slopes, or ditches.

The lack of rainfall in an area will typically have an adverse impact on the establishment of roadside vegetation. Obtain seed mixtures tested for critical sites or roadsides in the immediate region.

The relative humidity, wind characteristics, amount and intensity of solar radiation of the region, and the nature of the surface material will affect the degree of dust problems encountered.

The costs of winter rehabilitation or construction increase because it may take longer to perform required repairs or to build. Schedule implementation of these activities before spring or fall rains and fall freezes.

Subgrade strength can be adversely affected by freezing conditions and the frequency of freeze-thaw cycles, thereby increasing the importance of surface and subsurface moisture control.

Type of Military Activity: The type, length, durability, and longevity of the roads or trails are often determined by the nature of the training or testing activity. This knowledge also provides planning information for widening roads and trails and the strengths needed for the subgrade, subbase, base, and surface course of existing roads.

Characteristics of Foundation Materials: Specific properties are required for suitable foundations under the roadway, subgrades, and base courses. Among these properties are strength adequate to the weight of the vehicles; good compaction characteristics; adequate drainage; frost heave resistance (where appropriate); and limited expansion or compression characteristics.

Where some of these properties are lacking, supplementation with good construction methods may be possible. For example, where foundation materials exhibit poor drainage characteristics,

adequate subdrainage and surface design can solve most problems.

While strength in base course materials is critical, a lack of strength in subgrade materials may be compensated for by either installing a base course or making the base course thicker.

Consideration must be made of subsurface and surface drainage management. Soft or expansive subgrade materials, or materials susceptible to frost damage warrant consideration.

The thickness of the soil cover over bedrock and the type and thickness of the material used in the subgrade will determine the thickness of the road-bed courses.

The costs of locating or rehabilitating the roadway on rocky sites may increase because of the need to use explosives to break up large rocks and to move materials. Incorporating ordinance or demolition training activities with road construction or rehabilitation may be advantageous.

Soil samples should be collected and analyzed for mechanical and chemical properties. Soil type and texture influences compaction, infiltrative capacity, resistance to erosion by particle size, and vegetative suitability.

For example, well-graded, coarse materials are more conducive to high density and stability. The proportioning of particle sizes is critical in the development of an interlocking of particles. With smaller particles filling the voids between larger particles, the soil gains strength and can support heavier loads. The sands and gravels are considered coarse-grained materials. Typically the best subgrade and base materials are those free-draining, coarse-grained soils such as GW, GP, SW or SP because they exhibit almost no expansion or tendency toward high compressibility.

The county Soil Survey document can provide information on the soils prevalent on most installations.

Existing Vegetation: If woody vegetation or trees are to be cleared before relocation or rehabilitation activities, flag those trees slated for removal and check with installation foresters for necessary approval or assistance in harvesting the timber.

Impacts Caused by Roadway Development: A variety of adverse effects accompany the construction or rehabilitation of roads and each serves to accelerate natural and continuous processes. Where possible, prevent or minimize the following:

Excavation of Cut Slopes and Roadbeds: This practice exposes unprotected soil surfaces to the erosive forces of wind and water, loosens soil structure, and makes soil more susceptible to detachment.

Removal of Vegetation Along the Roadway: This activity exposes soil surface to erosive forces of wind and water, reduces infiltration through removal of root systems, and increases runoff volume and velocity by reducing interception.

Grade Changes Between Road Surfaces and Adjacent Slopes: This activity disturbs natural drainage patterns and increases flow velocities or concentrates flow at undesirable locations.

Grade Changes Along Roadway Surface: This practice exacerbates rill and gully development as runoff concentrates in channels left by vehicle treads laid perpendicular to the contour of the slope. It also causes road surface degradation like rutting and washboarding as vehicles attempt to navigate slopes that are unstable or too steep and leads to accelerated erosion in steeply sloping ditches.

Compaction of Road Surfaces: This activity increases runoff by reducing the infiltration capacity of the soil, thereby making stable water dips and hydraulically-designed surfaces and ditches mandatory.

Concentration of Runoff: This practice increases erosive velocities, resulting in increasing erosion and sedimentation on and along trails.

Sedimentation: Decreased vegetation and inadequate ditch design and drainage control increases road, ditch, and side-slope erosion and the transport of sediments to adjacent waterways.

Erosion and Sediment Control: Erosion and sedimentation control needs are determined during the process of selecting the optimal location for the roadway section and incorporated into the overall project plan to ensure timely application and proper construction.

The first step in assessing erosion and sediment control needs is to gather basic geomorphic data on the disturbed site or on the alternative sites selected for roadway relocation. These may include factors influencing soil erodibility or erosion potential. Comparisons of the data collected from each alternative site can be incorporated into soil loss prediction equations (i.e., Revised Universal Soil Loss Equation) allowing the most stable route for roadway relocation to be selected.

NOTE: When selecting a new site, consider the categories of erosion and sedimentation control required to prevent degradation and possible violation of state and/or Federal environmental regulations. These may include general control measures, surface stabilization, runoff collection and conveyance, runoff dispersion, and sediment collection.

Road Layout: The optimal route of the roadway can be laid out on any given slope using a simple 2- or 3-person survey technique. The process involves staking the centerline of the road; identifying locations for low-water crossings, rolling dips, and culverts; and staking out cut and fill slopes.

Start by placing a stake at the point of origin on the existing roadway surface. The person with the hand level should note their eye-level against either a measuring rod or the rover (typically the taller person). The rover then walks up the slope a short distance, turns and faces the instrument person who aligns the hand level with the previously noted eye-level on the rover or the rod. The hand level will provide the slope on the attached scale.

Should the slope exceed 10 percent, the rover would move up or down the slope to locate a more suitable gradient.

As each suitable reach is determined, mark them with the flags so they can be relocated. After the route is established, go back and carefully mark the centerline of the road, location of culverts and low-water crossings, curves, slope edges in steep areas, and planned turnouts, parking or staging areas. Ensure that the width of the roadway allows for drainage ditches of an adequate size.

The equipment for accomplishing this process may be available at the installation.

- *Abney Level or Clinometer:* An inexpensive hand-held tool for measurement of roadway grades.
- *50- to 100-Foot Measuring Tape or Measuring Wheel:* To measure road width, length, distance between culverts, cut/fill slopes, etc.
- *Survey Flags/Stakes/Tape:* To mark the proposed route and location of culverts, edges of trail bed or cut/fill slopes.
- *Bush Hook/Ax:* To clear dense underbrush and drive stakes.

3.2 Design Considerations

Aggregate surfaced roads are classified as "unsurfaced roads." They are commonly called gravel roads or earth roads. They are also classified by road category as "rural roads" or more commonly as secondary, tertiary, or local roads. In military terms, tank trail, access road, or simply trail may be used to describe this type of road.

Aggregate surfaces are those made of a mixture of coarse material (sand, gravel, or stone fragments) and fine materials (silt or clay). This combination forms a hard and lasting crust when the moist mixture is compacted and dried. Aggregate surfaces are frequently produced by adding coarse material to the natural soil in the roadbed.

Treated surfaces, in comparison, are the result of stabilization of the surface by another material or additive. These additives may include calcium chloride, petroleum resins, nonpetroleum resins, Portland cement, lignin, or asphalt emulsions. Treated surfaces include those produced by simply adding a stabilizer or palliative to the surface to control dust.

Road Structure Terms:

Roadbed: The roadbed consists of suitable native soil and supports the base and surface courses.

Subgrade: The subgrade consists of suitable native soil that may be either treated or untreated. It serves as the top of the roadbed. The subbase and/or base courses are constructed directly on it.

Subbase: The subbase consists of either a compacted granular material (treated or untreated) or a compacted layer of treated soil. It will protect the base and surface course from intrusion of fine-grained roadbed soils, frost damage, or accumulation of free water above or below the pavement structure. The pavement structure consists of the subbase, base course, and surface course.

Base Course: The base course is typically made of treated or untreated aggregate. It serves as the immediate support for the surface course. It may be built directly on the subgrade if no subbase is required. Base course construction criteria are more stringent than for the subbase.

Surface Course: The surface course consists of aggregate mixture with binder (either plastic fines or stabilizing products). The surface course must carry the traffic load, provide a smooth-riding surface, and resist skidding, traffic wear, and water penetration into the pavement structure.

Shoulder: Shoulders are parallel and contiguous to the roadway to which they provide lateral support. Shoulder cross slopes on unpaved roads are 0.04 to 0.06 ft per 1 ft on gravel or crushed stone shoulders and 0.08 ft on grassed shoulders. Shoulders are often made up of the same material as the road base or a surface that has been very well compacted.

Ditch: Ditches may be trapezoidal or parabolic in shape. They are typically constructed by excavation of the native material at the site of the roadway or may be constructed within the fill brought in to stabilize a slope. Ditches may require protective lining to prevent erosion by runoff. Linings include native soil, grass, riprap, erosion fabric or matting.

Adjacent slope: The areas adjacent to the ditches may consist of native materials in level rangeland or forests. In steeply sloping terrain they may be made up of native or fill materials.

Roadway Design: The geometry of the roadway can be used to an advantage in reducing soil erosion and potential sedimentation problems and control measures. Proper alignment and grade, the design cross-section, and number of low-water crossings are geometric features that each have a degree of flexibility that allow for adjustments to reduce erosion and sediment damage potential.

The slopes of the roadway in cross-section should be as flat as possible and consistent with soil stability, climatic exposure, geology, and proposed or existing rehabilitation and maintenance procedures. The cross-section is varied to minimize erosion and facilitate safety and drainage. Site landscaping and drainage control should be compatible with erosion control and vehicular safety.

Erosion of bare adjacent slopes is typically caused by runoff flowing down the slope. A crest cut or berm and swale could be constructed at the top of the slope to divert runoff to a stabilized outlet. Well-defined, lined ditches should be installed at the toe of all adjacent slopes. On long slopes, benches or terraces may be necessary to break up the flow of runoff.

Road Grade: The alignment and grade of the roadway are inherently adjustable, allowing the shift or relocation of the section to a less sensitive area. Adjustments to alignment and grade should blend smoothly with the surrounding landform, thereby reducing the need for cut and fill sections.

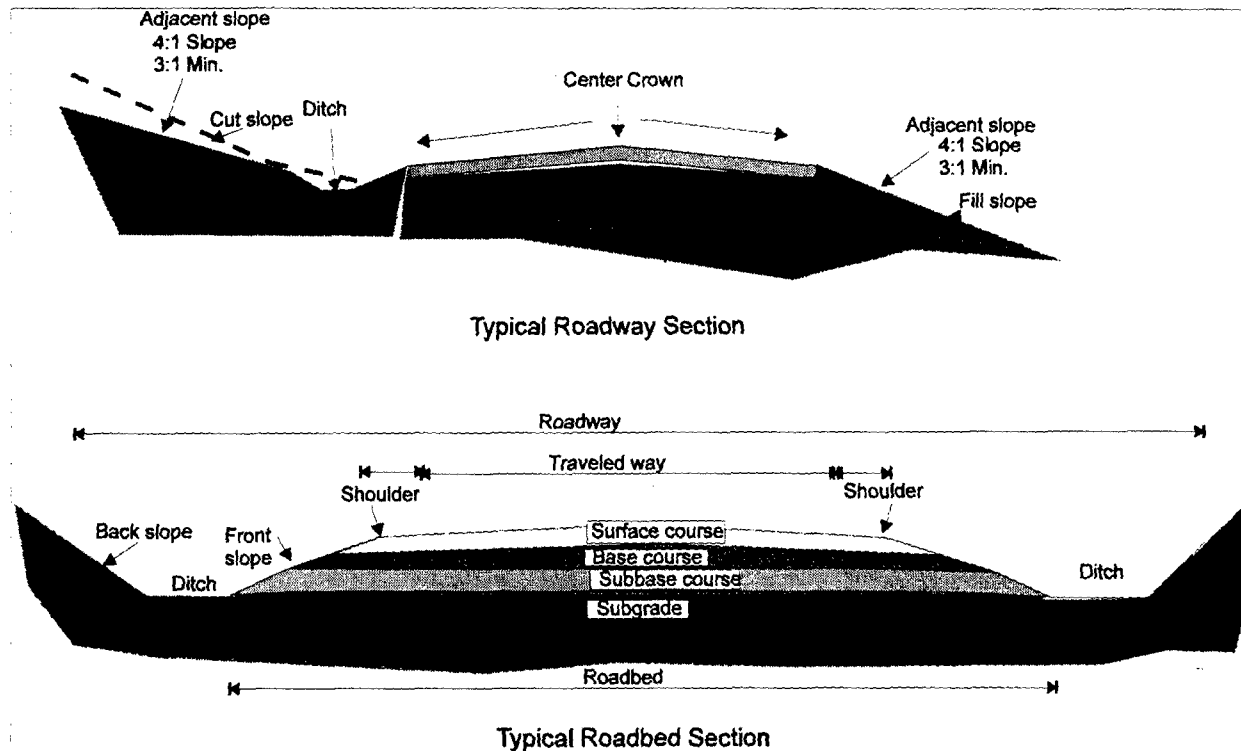


Figure 3-1. Typical roadway and roadbed in cross-section.

Both natural and constructed drainage must be taken into consideration. The grade of the roadway should be less than 10 percent (10 ft vertical to 100 ft horizontal) for minimal maintenance and repair requirements. Maximum grades should never exceed the following: 6 percent for natural loamy soil and grass surfaces; 10 percent for gravel or crushed rock surfaces; or 16 percent for paved surfaces. If crushed stone is used as a surface material, the grade may be increased to 15 percent for reaches of less than 200 ft where no other alternative exists. Avoid steep grades at curves or intersections.

Traveledway Width: The minimum width of a road surface should be 14 ft for one-way traffic and 20 ft for two-way traffic. Keep the width of the traveledway to the minimum safe width for traverse by the largest vehicle anticipated. This may be accomplished by reducing any disturbance to adjacent areas and more stringent maintenance requirements.

Side Slopes: All cuts and fills should have slopes that are stable for the particular soil and site conditions.

In stable materials, cut slopes less than 3 ft in height can be near vertical, however they should not be steeper than 1.5:1 where the slope is greater than 3 ft. Fill slopes should be no steeper than 2:1. When maintenance mowing is required, side slopes should be no steeper than 3:1.

Surface Drainage: No other aspect of roadway design is more critical to maintenance and rehabilitation efforts than surface drainage on and along the roadway surface. Surface runoff from ALL sources should be conveyed from the roadway to control soil erosion, maintain a stable surface, and reduce future maintenance and repair. Consider runoff from the road surface and adjacent slopes; overland flow from the drainage area above the roadway section; and springs, ephemeral channels, or perennial streams intercepted by the roadway. Shaping the roadway surface to drain by itself will reduce degradation and maintenance requirements.

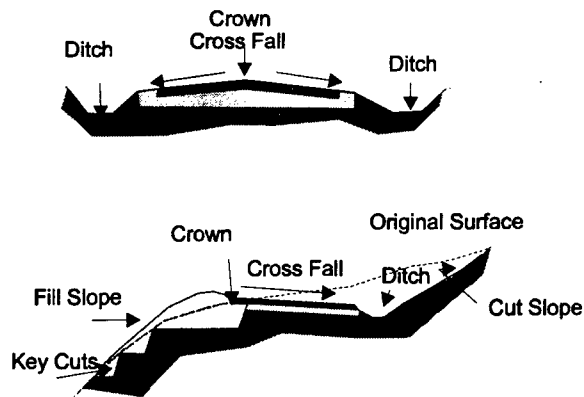


Figure 3-2. Placement of crown on aggregate road.

The road surface can be slightly elevated at the center, at either side, or left flat in some situations. Crowning involves sloping the roadbed to a slight peak at the center. Cross-sloping involves sloping the entire roadbed into or away from a cutslope. These design and grading methods permit runoff to flow across the roadway surface and into a prepared ditch rather than along the roadway. The grade should be less than $\frac{1}{2}$ in. in 1 ft on crowned sections or about 6 in. across the entire width of the roadway.

Construct ditches on the inside of all roads with overland flow from single adjacent slopes and on both sides of roads with slopes to either side. Flat-bottomed ditches with bottom widths of at least 2 ft and 3:1 side slopes are the most effective shape of ditch. These parabolic or trapezoidal shapes are much more resistant to runoff erosion, provide greater safety, and greatly reduce maintenance efforts. The steeper and deeper V-shaped ditches present more problems.

On roads left flat, drainage is accomplished by installing frequent rolling dips to convey water accumulated on the road surface to prepared discharge points or channels. Install rolling dips or crossroad culverts in all natural drainage channels (ephemeral or perennial) crossed by the road. Corrugated steel, aluminum, or plastic pipes are the most commonly used materials for drainage culverts because they are heavy-duty and can withstand substantial abuse.

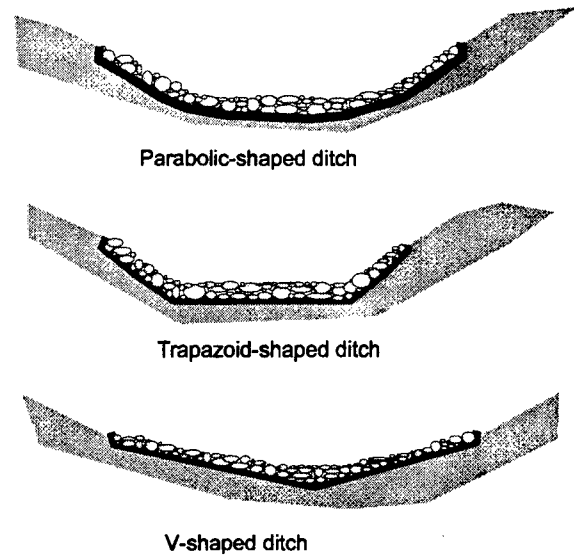


Figure 3-3. Common drainage ditch shapes.

Any culvert with only a shallow cover can readily be crushed by heavy vehicles. The exposed ends of culverts are particularly subject to damage by vehicles if not protected with either concrete, riprap, or sandbag headwalls.

Culverts should be spaced a minimum of 130 ft apart on all insloped trails. Install each culvert a minimum of 18 in. below surface grade and compact supporting materials firmly. To ensure adequate hydraulic capacity, design the culvert for the 25-yr, 24-hr storm event at a minimum (oversizing the culvert presents less of a problem than undersizing). Place riprap discharge aprons at the outlet of all culverts to reduce degradation.

Low-water crossings can be easily constructed across channels too large to be handled with culverts alone or where the elevation of the water fluctuates greatly throughout the year. Low-water crossings typically are designed with culverts to

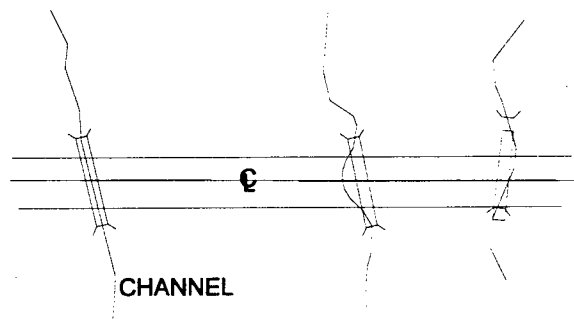


Figure 3-4. Culverts located on natural channels.

handle the base flow of the channel. They permit safe traverse by vehicles when waters are flowing higher than the culverts can handle and greatly reduce damage to aquatic ecosystems and the riparian zone by keeping vehicles out of the channel.

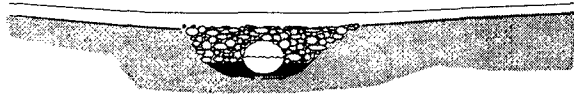


Figure 3-5. Typical low water crossing on low-weight aggregate-surfaced road.

Avoid siting any road section where the water table is less than 24 in. from the surface. Roadbed construction in wet areas often results in costly and labor intensive maintenance efforts.

Curves: The minimum radius of curvature of the centerline of the roadway should be 35 ft for vehicles less than 50 ft long. Bank curves inward to provide crossroad drainage to prepared drainage ditches and reduce the outward expansion of the curve by vehicles.

Materials:

- **Crushed Stone:** A product resulting from crushing bedrock and having fragments with fractured faces.
- **Gravel:** A naturally-occurring coarse granular product defined as that material retained on a No. 4 screen and that passes a No. 3 screen. Gravel is the product of natural weathering and the erosion of rock.
- **Crushed Gravel:** A product resulting from crushing ordinary gravel. The number of resulting faces will depend on the original gradation of the natural gravel. The coarser the gradation, the higher the percentage of fractured faces.
- **Sand:** A fine granular material resulting from the natural disintegration of rock. Sand is that material that passes a No. 4 sieve but is retained on the No. 200 sieve.

- **Slag:** A byproduct of the steel industry.

● **Filler and Binder Materials:** Those mineral materials added to improve the aggregate performance. Fillers are added to improve the gradation of the aggregate while binders are added to increase the cohesiveness or binding quality of the aggregate. Clay is the most commonly used binder. Sand-clay bases are often constructed in areas with abundant sand because the sand alone is too loose and plastic to form a well-compacted and stable material. Fillers or binders are added only when sufficient quantities are not naturally present in the aggregate. They must be uniformly blended with the aggregate. Fillers for pit-run or grid-rolled aggregates are added on the road. Fillers for crushed or screened aggregates are blended at the plant during processing.

● **Chemical Additives:** A variety of chemical additives may be added to aggregates to control dust (palliative), lower a high pH, or to act as a binding agent. Among these products are calcium chloride, magnesium chloride, sodium chloride, hydrated lime. See specifications from the American Association of State Highway and Transportation Officials (AASHTO) or the American Society for Testing and Materials (ASTM). Soil-cement and asphaltic emulsions are also used in base course stabilization. A newer line of products for stabilization and dust control include petroleum resins, nonpetroleum resins, byproducts of the paper industry, byproducts of the sugar beet industry and various polymers.

Aggregate Gradation: The gradation is a measure of suitability for use in base or surface construction. The term gradation refers to the sizes of aggregate particles and the relative distribution of those particle sizes in the aggregate material.

The relative distribution of the particles is expressed as the percentage (by weight) of particle sizes in the total material. For example, a material may consist of 30 percent 1- to 1.5-in. material, 30 percent 4-in. to No. 4 material, 15 percent No. 4 to No. 10 material, 10 percent No. 10 to No. 40 material, 10 percent No. 40 to No. 200 material, and 5 percent minus No. 200 material.

Material gradation is determined by sieving. A sample of the aggregate material is dried, weighed, and then passed through a series of sieves. The size of the sieve corresponds to the size of the openings in the mesh. The weight of the contents of each sieve is then measured.

The coarse sieves are classified by size of mesh in linear inches. Thus, the 1-inch sieve has an opening of 1 inch. In describing aggregates, a plus or minus indicates that particles coarser than, for example, the 1-inch sieve are identified as plus 1 inch, while those finer than the 1-inch sieve are identified as minus 1 inch.

The smallest sieve measured in inches is the 0.25-inch sieve. The No. 4 sieve, and those with finer openings, are classified according to the number of openings per linear inch. A No. 4 sieve is slightly finer than a 0.25-inch sieve.

A No. 10 sieve has 10 openings per linear inch. The No. 100 sieve is four times as fine as the No. 50 sieve. The No. 200 sieve is so fine that it looks like delicate fabric. The only particle that can pass the No. 200 sieve is the fine silt (dust) from the aggregate.

Typically, the gradation requirements are expressed as the percentage of aggregate passing specific sieves. The aggregate gradation requirements depend on the manner in which the aggregate is produced. For aggregate produced by crushing or screening, the requirements will be found on the drawings in the project specifications. For pit-run or grid-rolled aggregate, there are NO standard gradation requirements.

Aggregate Quality: Quality refers to determinations of aggregate physical and chemical properties other than the gradation. These determine the suitability of the aggregate material for specific uses in road construction.

The requirements for quality are based on the manner in which the aggregate is produced. Typically, aggregate furnished by pit-run or grid-rolling must be reasonably hard, durable, and free of organic or other objectionable materials.

AASHTO standards for durability of crushed or screened aggregate are typically referenced in the project specifications.

AASHTO M 147 lists the requirements for materials used in aggregate and soil-aggregate subbase, base, and surface courses. These requirements may be modified by the project engineer.

Crushed or screened aggregate should be tested for the following:

- **Liquid Limit (LL):** Refers to the moisture content at which an aggregate material passes from a plastic to a liquid state. High liquid limits indicate soils of high clay content and low load-carrying capacity. See AASHTO T 89.

- **Plasticity Limit (PL):** Refers to the moisture content at which a soil changes from a semisolid to plastic state. It is influenced by the clay content of the aggregate material and indicates the load-carrying capacity. A reduction in the moisture content below the PL leads to a rapid increase in load-carrying capacity. Increasing the moisture content above the PL leads to a rapid decrease in the load-carrying capacity. See AASHTO T 90.

- **Plasticity Index (PI):** Is the numerical difference between the LL and the PL, representing the moisture content range within which an aggregate material passing a No. 40 sieve is plastic. Specifications for aggregate surfacing typically require a PI value between 4 and 9 to ensure that there is adequate clay binder in the aggregate mixture. Aggregate base course specifications may have a maximum PI requirement of 6 to ensure a clean, free-draining material.

- **Amount of minus 200 material:** This affects the stability of the material. See AASHTO T 11.

- **Los Angeles Abrasion Test:** Provides a measure of the toughness of the aggregate or its ability to resist abrasion and degradation. It is expressed as the maximum allowable percentage of wear. See AASHTO T 96.

- **Sand Equivalent:** Represents the relative proportion of fine dust or clay particles in the aggregate material. See AASHTO T 176.

- **Percentage of Fractured Faces:** Provides the relative proportion of aggregate having one or more broken faces. At least 50 percent by weight of the particles retained on the No. 4 sieve must have at least one fractured face. The percentage of fractured faces is an indication of how well the aggregate particles will interlock and provide friction to form a stable base or surface course.

- **Durability Index:** Indicates the relative resistance of aggregate to degrading forces. See AASHTO T 210.

Road Surfacing: The design and specification of surfacing materials should be based on identified traffic needs, frequency of usage, the grade of the roadway section, the type of soil on natural roadbeds, available materials, costs of transport and materials, and aesthetics or realism.

Grass: A grass surface will work well on infrequently used roads/or trails. The soil must be well-drained and the grades less than 8 percent. Grass is the least expensive surface material and only requires periodic amendment, reseeding, mowing or burning. The roadbed must be stable and capable of supporting the weight of the vehicles expected to use the grassed trail.

Crushed Stone Only: Crushed 1- to 1.5-in. stone with some fines is suitable for use on medium to high traffic reaches. Crushed stone works very well on naturally sandy or gravelly roadbed soils. It is recommended for use on grades of 15 percent and less. Specify "roadbase or basecourse" when purchasing this size of material.

Crushed Stone Over Washed Gravel: Crushed 1- to 1.5-in. crushed stone over washed gravel is recommended for use on medium to high traffic reaches located on soft soils (silty or loamy). It should only be used on reaches of 15 percent or less. When ordering these materials, specify "base course over gravel." In poorly-drained areas, use

crushed stone with filter fabric to enhance drainage and stabilize the roadbed.

Crushed Stone Over 3" Diameter Rock: Specify 1- to 1.5-in. crushed stone over 3-in. or greater rock or rubble for use on for use on wet sections of trail with soft soils. This combination can be used for all for all traffic conditions and on grades less than 15 percent. Request "3-in. washed stone or ballast stone." Crushed stone over 3-in. rock requires periodic maintenance and grading. In poorly-drained areas, use crushed stone with filter fabric to enhance drainage and stabilize the roadbed.

Surfacing materials should be applied immediately after construction or repair to reduce soil erosion and insure a good bond between the disturbed soil and stone.

3.3 Construction Considerations

Erosion and Sediment Control: Provide early runoff and sediment control such as slope diversions or crest cuts and sediment traps to prevent sedimentation from becoming a problem.

Clearing Vegetation: Consider the design width of the roadbed and the drainage ditches when clearing vegetation for a right-of-way. Some trees or woody growth may have to be cleared from heavily forested areas, however, consult with the installation foresters and/or environmental staff BEFORE cutting any trees. Clear a slightly wider area around curves to improve visibility. In poorly drained areas, thinning or clearing extra vegetation from the right-of-way will reduce the canopy cover and permit solar drying of problem wet spots.

- Cut materials may be valuable as timber, pulpwood, or firewood. Smaller brush and cut wood may be chipped or shredded to create organic mulch and/or compost for revegetation projects.

- Where grubbing will be required, leave stumps 3 to 4 ft above ground to simplify removal by bulldozer. Avoid grubbing if possible, because grubbed areas are extremely erosion-prone.

- Ensure that NO organic matter (trees included) is incorporated into fill material. As organic matter decomposes, it may make the fill unstable.

Route: Be alert to stake placement throughout clearing activities. Note any new wet spots or seepage areas after grubbing as they may pose significant problems in the future. Where the water table is close to the surface, grubbing can cause surface seepage. Rough in NO MORE than 1000 ft of trail until the first 500 ft are completed and reseeded to reduce erosion and sedimentation.

Drainage Structures: Before surfacing the road or trail, inspect the drainage structures for proper installation (rolling dips, ditches, and culverts). This will ensure that adequate erosion and sediment control measures are maintained. Check to see that the crown and insloping or outslowing of the roadway surface is adequate to handle expected runoff. Make corrections at this time if the work is not to specifications and designs.

- The control of runoff volume, velocity, and concentration depends on hydraulically-designed and well-constructed road surfaces, ditches, and culverts.

- Where turnouts, level spreaders, and diversions are used for runoff dispersion, divert water to stable areas that have adequate vegetative cover and/or energy dissipation structures to prevent incision.

- Ditch work and culvert installation must be accomplished to avoid flow constriction and subsequent velocity increases that may accelerate ditch or channel bottom erosion.

Revegetation: Reestablish and maintain vegetative cover on road shoulders, ditches, and adjacent slopes to prohibit erosion and sediment transport. During regular maintenance, reseed disturbed sites as soon as possible to prevent sedimentation.

Compaction: Compaction is accomplished by pressing soil particles into closer contact, with air being squeezed out in the process. Compaction of soils used in foundations, embankments, sub-

grades, and road bases can prevent settlement, increase shearing resistance, reduce the movement of water, and reduce soil volume change (shrink-swell). Volume change is critical when soils are to be used for roads. Clay soils have the greatest potential for volume changes in response to moisture. A greater effort is required to increase the density of clay to 95 percent maximum density than is required to effect a similar change in sand. Increasing the weight of the roller and/or the number of passes will increase the compactive effort.

Soils that are very light, such as volcanic soils or diatomaceous earths may have maximum densities under a given compactive effort as low as 60 lb/cubic ft. Under the same effort, the maximum density of clay may be around 90 to 100 lb/cubic ft, while that of a well-graded, coarse-grained soil may be as high as 135 lb per cubic ft.

With cohesive soils, it has been found that drying the soil following compaction may increase the strength of the subgrade and base materials.

The protection that a subgrade soil receives after construction has a strong influence on the permanence of compaction. The use of good shoulders and adequate drainage will greatly increase the lifespan of the compacted subgrade and base.

Aggregate Base and Surface Construction:

Materials: The base and surface courses are composed of aggregate and water. The aggregate that forms the bulk of the base and surface courses is made of gravel, crushed stone particles, soil, or sand. To provide a dense, tight, yet flexible mass, the aggregate must be well-graded. This means that the different particle sizes will fit together snugly, with a minimum of void space.

Water is essential to hold the aggregate particles together. If absent, water must be added during the mixing and/or placing process. Without water, the mixture cannot be compacted thoroughly.

Construction Steps:

- **Hauling and Dumping Aggregate:** Aggregate produced by crushing, screening, or pit-run operations must be hauled to the job site and dumped on the prepared subgrade or base course. Grid-rolled material may be either native material or hauled in and placed on the road.

Typically, the aggregate is hauled in and dumped on the roadway. The aggregate is shaped into a windrow or long row paralleling the roadway centerline by a motor grader. Dumping is done within computed spread distances staked or marked on the road. Occasionally, the filled haul trucks are routed over the placed aggregate to aid in compaction.

- **Mixing and Spreading Aggregate:** After the dumped aggregate has been windrowed, it is mixed and spread. Water is added at this point to achieve a uniform blend of materials with a suitable moisture content for compaction. The prepared aggregate is next spread to the required line, width, and depth.

The motor grader first evens up the windrow, then cuts material from the windrow by inserting the end of the blade into the windrow's side and carrying the material across the road.

After several passes, the windrowed aggregate will have been spread across the road. Water may be added to the aggregate at this point. As the layer of aggregate is spread, apply water from a watering truck. Once should be adequate.

Continue to mix and spread until a uniform consistency has been achieved and a uniform moisture content exists. Once uniformity had been achieved the final spreading or "laydown" takes place.

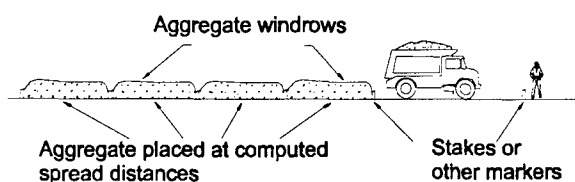


Figure 3-6. Placement of aggregate on road.

- **Compacting and Finishing the Course:** After the aggregate mixture is spread it must be promptly compacted and finished to obtain the required density (95 percent) and a smooth, even surface.

Equipment used for compacting and finishing the aggregate base and surface courses include rubber-tired rollers that are often used for the initial rolling; steel-wheeled rollers that are very effective for the finish rolling; vibratory rollers used where noncohesive materials in open areas are encountered; and sheepfoot rollers used for sand-clay base and surface courses.

3.4 Drainage

The drainage system of the unpaved roadway should optimally be designed by an engineer with a knowledge of open-channel hydraulics, roadway drainage practices, and erosion and sedimentation control measures. Considerations: the local topography, amount and rate of rainfall, area of runoff collection, natural drainage features, local water table depth, and nature and intensity of roadway use.

The function of drainage structure maintenance includes:

- Keeping the water course free of accumulations of sediment, debris, vegetation and other obstructions.
- Correcting malfunctioning parts of the system such as the erosion or sediment control structures, channel liners, culverts, and inlet and outlet protection structures.
- Anticipating problems and making repairs or modifications to prevent degradation.
- Maintenance of the roadway also includes practices such as slope protection, contour grading and ditching to divert runoff on hillsides to stabilized areas or channels to reduce slope degradation.

Damage caused by storms is an indicator of the inadequacy of the system. Plan the drainage

system to handle the maximum potential storm that monies allow. The 25-yr, 24-hr event should be considered in the absence of other determinations.

Subsurface drainage problems often present themselves in surface settling or lateral blowout of the shoulders.

Roadside Ditches: Roadside ditches are separate from the roadway and constructed parallel to it, with sufficient depth, cross section, and grade to handle the expected flow of runoff from the road surface, shoulder, adjacent slope, and the ditch itself. The ditch is typically open except where it crosses under a side road, access road, or a walkway.

- Ditches are often lined with paving material, loose or grouted rock, grass, or geotextiles where the native soil lacks the stability to withstand runoff velocities.
- Ditches should be maintained to line, grade, depth, and cross section to which they were built or subsequently improved.
- Periodically clean ditches by removing rocks, sediment, debris, tall weeds, brush, and leaves that may restrict the normal flow of water.
- Material left on the shoulder after cleaning should be removed daily and disposed of properly or reused to widen the roadway or shoulder at proper locations.
- Do not blade material cleaned from the ditches across the road surface.
- Avoid cutting ditches to a "V" section in erodible soils.
- Cut ditches only deep enough to provide under-drainage for the roadbed and design runoff.
- Avoid undercutting the back slopes of the ditches to prevent erosion.

● Water should never stand within roadside channels. Correct immediately through redesign or bringing the grade to the design shape.

- When ditch cleaning results in the loss of or damage to vegetation, prompt reseeding is critical to prevent erosion and sedimentation.
- To prohibit excessive erosion in natural soil or unlined ditches, pit-run gravel, talus, or quarry-run rock can be used to fill eroded areas and line the bottom of the ditch.
- A succession of check dams can be constructed across the channel to reduce velocity where erosion or incision is a problem. It is important that these structures be well designed and properly installed to prevent greater damage to the ditch.

Interceptor Ditches: Interceptor ditches include those diversion ditches or bench-cut slope channels serving to intercept surface runoff on adjacent slopes. They function to divert the water from reaching the roadway structure by channeling it into a dispersion system such as a roadside ditch, a natural channel, a stable field, or a retention pond. Runoff may be diverted into sediment traps if removing sediments from surface waters is necessary. Grass-lined interceptor ditches should be kept free of weeds and obstructing materials.

Culverts: Culverts serve to convey water from one side of an embankment to the other to continue to a natural channel. Larger culverts or those subject to vehicle damage will have headwalls and inlet and outlet aprons to improve their hydraulic characteristics and to reduce erosion by scour.

The most commonly used culverts are constructed of corrugated steel aluminum, or plastic. Keeping culverts clean and free of obstacles is critical. Both sediment and debris should be removed promptly. Patrol critical areas during significant rain events to remove debris and clear inlets. When sediment deposits cause realignment of inlet or outlet channels, it is essential that those areas be cleaned to correct the alignment.

- Inspect headwalls, wingwalls, and culvert ends for scour.

- Limit vegetation around culvert inlets to permit the free flow of water. Icing within culverts can be corrected with calcium chloride or a mixture of calcium chloride and sodium chloride.

- To prevent material from washing into the culvert, remove debris from the channel over a minimum distance of 100 ft above and below the culvert. Debris-collection devices may be required in some areas.

- Check culverts for excessive sediment buildup following prescribed or accidental range fires.

- Immediately repair or replace culverts that have settled, heaved, pushed out of line, or are broken, worn, or damaged.

- Where soils or waters are particularly acid or alkaline, some metal culverts may be subject to rapid deterioration. Special measures may be required to protect against corrosion. A combination of high-velocity flow and stone and rock passage may require securing railroad rails or steel plate longitudinally along the bottom to prevent scour.

Check Dams and Berms: Check dams are often constructed of riprap, rock, earth, baled hay, or similar materials, depending upon the longevity of the need for the dam. They are used to collect water, redirect the flow, provide settling basins for siltation control, reduce the velocity of the flow of runoff within the channel and protect slopes from erosion. Water intercepted by a check dam should be dispersed to a stable outlet. Repair check dams to their original shape when damaged. The properly designed ditch will require few, if any, check dams.

Natural Channels: Natural channels include those gullies or arroyos that drain into rivers or streams. Channels must be maintained free of debris to assure an adequate conveyance capacity. Bank scour is prevented by keeping the channel alignment natural and protecting the banks with

riprap or other approved methods. Discharge aprons are used to reduce the energy of flow where ditches drain into natural channels.

Erosion protection methods should maintain the location and natural roughness of the channel bank while making optimum use of local materials. For example, willow wattles along an overflow bank may help control erosion along the bank by reducing the velocity of the flow.

Materials for bank protection:

- **Stone Riprap:** Stone riprap placed over a filter material of sand (6 in. minimum thickness) or a geotextile fabric provides a flexible, easily repaired surface resistant to the impact of fast-moving water, debris, and drift. Riprap is placed to a thickness no less than 1.5 times the diameter of the median stone size. Amount, size, and weight of the stone to be used are determined by the velocity of the water, the depth of the flow, embankment slope, and buoyant forces of the water course. Where no filter material is used, stones should be well-graded to avoid leaching of bank material through the voids.

- **Sacked Concrete Riprap:** Sacked concrete riprap protection of embankments is easy to repair and is adaptable to any slope. It may be placed on 1:1 slopes when the embankment is stable and will not become saturated. Do not use sacked concrete on slopes steeper than 1.5 to 1 if the embankment is unstable, loosely compacted, or saturated. Class C concrete, at about 3.5 bags per yard, is generally used, with the sacks being filled to about 2/3 capacity. When placing, each succeeding row of sacks should overlap the joints of the previous row.

Safety Concerns and Drainage Structures: Drainage ditches should be maintained to present the least possible hazard to vehicles possible leaving the roadway.

Ditches and channels should not be dredged to a depth or cross section other than designed (a shallow parabolic or trapezoidal shape) or natural.

Drainage structures that present a hazard to out-of-control vehicles or vehicles operating partially off the roadway surface should be redesigned, adequately marked, and hardened against potential vehicular contact.

Maintenance Scheduling: The frequency of drainage structure inspections should be regulated by local conditions such as seasonal rains, winter weather, freeze-thaw conditions, and significant rain events. Inspections should be conducted to confirm that satisfactory conditions exist and to evaluate needs for cleanup and repair. Inspections also serve to identify structures requiring modification or redesign.

General clean-out of drainage systems is most effective when it precedes the rainy season or takes place in the early part of the season. Any material that can cause an obstruction should be removed promptly. Inspections of new drainage systems should be conducted during heavy rainfalls to determine high water levels and unanticipated developments. Minor erosion damage should be repaired promptly and measures taken to prevent a recurrence.

3.5 Roadbed Repair

To ensure a stable aggregate base and surface course, the roadway must have a properly constructed foundation. The foundation for the base course is either the subbase or subgrade. The foundation for the surface course is the base course. If the foundations are poorly constructed or absent, the surface course will not stand up to traffic or weathering. Density problems in the roadbed can lead to failure in the aggregate base or surfacing. Checking the roadbed can often be accomplished by a practiced eye. Where doubts exist, density tests should be run to determine the degree and extent of deficiencies.

Roadbed Inspection: For roads receiving aggregate bases or surface courses, only rocks that do not protrude above the subgrade more than 1/3

of the depth of the base or surface course or 3 in., whichever is less, may remain in place.

For unsurfaced roads, the uppermost 4 in. below the finished road surface should not contain rocks larger than 4 in. in diameter.

The subgrade should be visibly moist during shaping and dressing. Bring low sections, holes, cracks, or depressions to grade with suitable material. Final compaction should meet the 95 percent density requirements.

The finished roadbed must meet 95 percent density requirements to prevent failure of the base or surface course. Areas lacking in sufficient density will appear soft and spongy. Typically a probe of the soft area will detect a loose subgrade.

Where the roadbed displays problems such as potholes, pumping (corrugations), rutting, rill development, or wet, squishy areas, immediate repairs must be made before surface materials can be installed.

Roadbed Repair: Repair of base or subgrade failures under aggregate surfaces, or failures in earth surface roadbeds involves excavation of the damaged area, removal of unsatisfactory materials, and replacement with appropriate aggregate or other suitable materials.

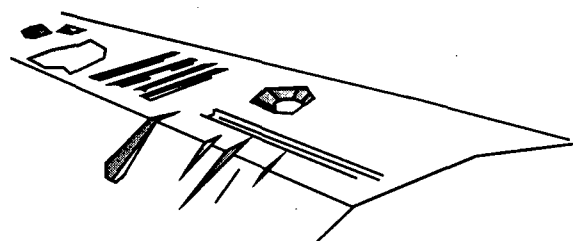


Figure 3-7. Typical road surface problems.

Steps involved in roadbed repair:

1. Excavate damaged surface areas with grade-all, back-hoe, end loader, dozer, or other suitable equipment.
2. Remove unsatisfactory material from base or subgrade with appropriate equipment.

3. Unsatisfactory materials should be properly removed and disposed of to prevent sedimentation or degradation of the environment.
4. Where seepage, a high water table, or a high soil moisture content in the subgrade are the causes of failures, install subsurface pipes or a French drain system to drain excess water out through the shoulder into a stabilized drainage ditch.
5. Filter fabric may be necessary to promote drainage and provide for future stability of wet sites.
6. New or more appropriate subgrade and base materials should be laid in 6-8 in. lifts in the prepared section.
7. New materials must be rolled, tamped, or in some way thoroughly compacted by lifts.
8. Apply water as necessary to achieve 95 percent density during compaction.
9. Ensure that the final base lift is compacted to an elevation equal to that of the top of the existing base.
10. Replace the aggregate surface in 6-8 in. lifts, wetting (as necessary) and compacting until the surface is at the same elevation as the adjacent existing surface.

3.6 Aggregate Surfaces

The most effective roadway surfaces can resist deformity and material loss and have achieved at least 95 percent of their compaction capability. They should also have good drainage qualities and to be subject to capillary action.

Structures constructed of large granular materials are usually not affected by water problems, whereas clays and fine sands require a certain amount of moisture to preserve their cohesive qualities. A soil analysis by a materials laboratory is the best method

to learn the optimal method of stabilizing a soil that is causing a recurrent maintenance problem.

Stabilized Roadways: Stabilized earth-aggregate roadways offer several advantages. They provide a firm load bearing surface that resists raveling and aggregate loss, are resistant to water and frost action, and can be maintained at a reasonable cost.

The materials used in soil stabilization include asphalt additives, calcium or sodium chloride, Portland cement, lime, lignin, and a group of proprietary resins and organic materials. Stabilizer application can be accomplished with scarifiers, mixers, sprayers, or spreaders with various capabilities.

When choosing a stabilizing material and method of application, consider the desired qualities of the stabilized roadway. To ensure success, obtain a laboratory determination of the engineering properties of the soil to be stabilized.

Methods of Stabilization: A variety of methods exist to accomplish stabilization of unpaved surfaces. The most used method involves pulverizing the soil to be stabilized and road-mix with a stabilizing material such as asphalt emulsion, Portland cement, calcium chloride, sodium chloride, lime, or a trade name resin or polymer product. The mix is then shaped and compacted with a rubber-tired roller. Another method is to plant-mix the stabilizing material with aggregate and apply the mixture with a spreader.

Surface Problems:

Corrugations: The progressive growth of lateral corrugations in earth-aggregate roadways is caused by traffic. These surface irregularities can cause inconvenience, damage to vehicles, and a safety hazard. Corrugations are repaired by scarifying to an appropriate depth, pulverizing the material, shaping, and compacting. By mixing suitable stabilizing materials into the pulverized soil, the ability of the roadway to resist corrugations can be substantially increased.

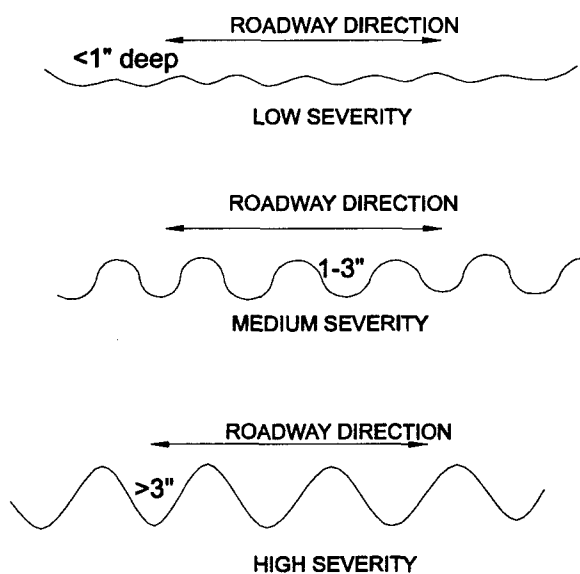


Figure 3-8. Corrugations - Degrees of severity (CRREL SP 92-26).

Ruts: Longitudinal depressions occurring in earth-aggregate surfaces and caused by traffic tend to direct the wheels of the vehicles and can be a safety hazard. Surface runoff collects within the ruts and subsequent erosion initiates gully development. Ruts are evidence of material being displaced or dislodged from the road surface. Inadequate compaction or materials lacking proper grading can also allow ruts to develop. Repairs are made by dragging or blading when the surface material is wet, followed by compaction. To preserve the crown section, blade from the outside of the roadway to the center.

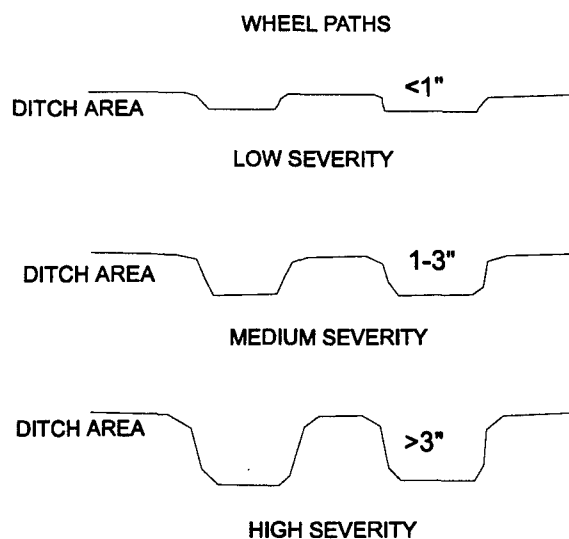


Figure 3-9. Road surface ruts - levels of severity (CRREL SP 92-26).

Soft spots: Settling of the earth-aggregate roadway is attributed to problems with either drainage or soil characteristics. When poor drainage is the problem, it must be corrected before any other repairs can be made. Drainage problems may be due to a high water table, hydrostatic head, capillary action, or ground water seepage. Saturated subgrade materials should be removed and replaced with a subgrade or coarse graded material. When traffic loads are greater than the design capacity of the subgrade or base courses, subsequent settling of subgrade materials can be repaired by filling, compacting, and regrading of the settled area.

Potholes: Materials for repair of potholes should be similar to that of the existing road surface. Each spring, the road surface should be bladed or scarified and mixed to correct potholing. The best indication of the need for upgrading the roadway is the condition it is in at the end of the dry season. The success of repairs to potholes can be directly related to the preparation of the hole and amount of compaction used. The most effective rolling equipment available should be used. The wheels of a fully loaded dump truck can be used if no other equipment is available.

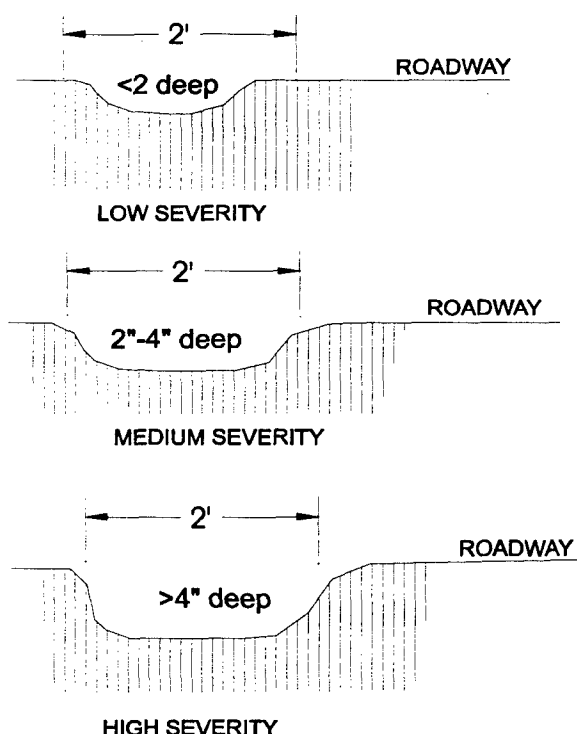


Figure 3-10. Road surface potholes - levels of severity (CRREL SP 92-26).

Dust Control: Dust can present a severe safety hazard, an inconvenience to motorists, a significant environmental pollution problem, and a cause of excessive wear to vehicles. The use of palliatives in the presence of such conditions is definitely suggested on roads having a substantial amount of traffic.

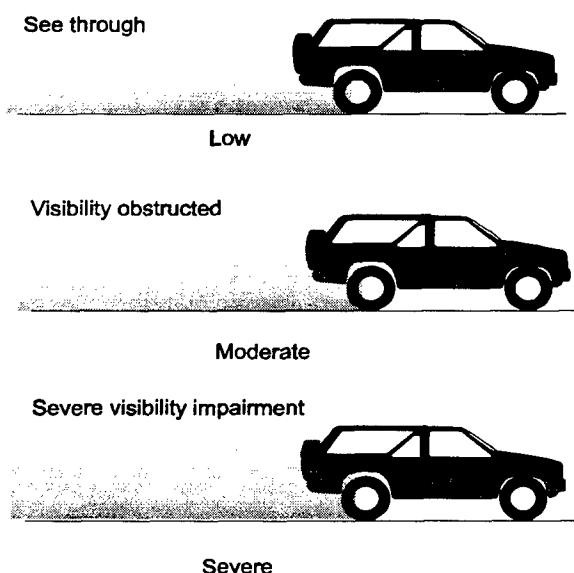


Figure 3-11. Road dustiness - levels of severity (CRREL SP 92-26).

Loose Aggregate: Excessive aggregate on the road surface can lead to rutting, accidents, ponding of water, and sediment graded into ditches and water bodies during maintenance activities.

Materials for Surface Maintenance:

Aggregates: Aggregates are simply a mixture of separable mineral particles. The quality of the roadway surface depends largely on the aggregate used. Aggregates may be classified as talus, pit-run, quarry rock, crushed rock, or slag. The following control factors aid in the determination of suitability of the aggregate.

- **Grading:** The grading is determined by representative samples passed through a range of sieves having various sized square openings. These openings measure from 3 in. down to 0.25 in. The 0.25-in. sieve is approximately equal to a No. 4 while the smallest sieve used for grading is a No. 200 used for sands.

Aggregate grading is used to limit the quantity of loose aggregate and control fines. Grading also improves drainage (where water or frost are problems), shear strength, stability, and surface texture. Grading assures that material of a smaller size is adequate to fill the voids between larger sizes.

Aggregate mixes are classified according to the amount of aggregate passing or retained by each sieve, by weight, in a declining series. For example, an aggregate may be classified as 100 percent of the material that passed the ½-in. sieve or as 80 percent of the material that passed the 0.375-in. sieve, etc.

- **Shape:** The preferred material is crushed stone made up of pieces having overall maximum dimensions that do not exceed their minimum dimensions by more than 3:1. Rounded aggregate tends to polish and may cause a slick surface. Shapes that are too elongated may make initial compaction difficult. Flakiness indices are used to determine the void characteristics of different flat shapes. Slotted sieves are used to determine the flakiness index.

- **Hardness:** The wearing quality is determined by testing for resistance to abrasion. A sample is carefully graded and weighed before and after being rotated in a cylindrical drum containing ball bearings. The difference in the weights of the sample before and after testing is expressed as a percentage and indicates the amount of wear. Polishing will occur if the aggregate is not sufficiently hard.

- **Fracture:** The fracture is determined by visual examination of a representative graded sample. Proper interlock cannot be achieved with worn polished surfaces. At least 50 percent of the gravel retained by a No. 4 sieve should have at least one fractured face.

Dust Palliatives: Palliatives are products that act to mitigate or alleviate the problem of dust on roadways.

Water. Water can be an efficient temporary dust palliative; however it has the disadvantage of drying out too quickly and allowing the particles to loose cohesion.

Chlorides. Sodium chloride and calcium chloride have a longer effect, although, not much. Calcium chloride is more effective than sodium chloride in holding together clusters of small particles because of its greater ability to absorb and retain moisture. Typically 1.5 pounds of calcium chloride is added to each square yard of pulverized soil. Chlorides can either be added singly or combined when the roadway surface is damp. They may also be sprayed on in solution.

Lignin. Lignin is an organic substance that, with cellulose, forms the main part of woody tissue. It is a waste or by-product of the paper industry that can be applied to the soil to provide moisture retention.

Asphalt. Cutback asphalt or 3:1 up to 10:1 diluted asphalt emulsions can be used to prevent dust under some conditions. When sprayed on dusty surfaces, the emulsion should penetrate the surface and coat the upper layers of fine dust-producing particles. However, a buildup of an asphalt surface

to form a crust should be avoided. The material and rate of application of asphaltic materials should be determined by a materials laboratory for best results.

Maintenance Methods:

Scarifying and Blading. Scarifying describes the breaking up of the surface course of a roadway by mechanical means. Often a tractor using from one to three ripper teeth or a blade with scarifier teeth is used to conduct the scarification. This activity is best conducted during a season when the surface course contains adequate moisture to ease mixing and prevent dust.

Scarifying can be used to correct minor grade irregularities. New materials for reconditioning can be added to the scarified materials and mixed in with harrows or plows. The surface is then shaped to a proper crown and thickness and the surface is compacted with pneumatic-tired rollers or a sheepsfoot. A new surface course is then applied.

Blading should be done in the spring after frost has left the ground and/or while the structure of the roadway is still moist. Gravel that has moved outward from the center of the road should be bladed back across the road surface. Large rocks that have worked their way up to the surface should be removed and the holes filled. After grading is complete, remove windrows from the shoulder or drainage systems can be adversely affected.

Compacting. The purpose of compacting is to achieve the maximum density of the earth-aggregate materials. Where maximum density is not achieved, settling or lateral movement of the material under traffic will produce more failures and need for repairs.

Moisture is required for compaction of earth-aggregate materials; however, too much moisture in the presence of excessive fines or clays can cause the material to become too loose or fluid.

Pneumatic or vibratory equipment is used to compact materials after scarifying and mixing

stabilizing materials into the earth-aggregate structures. Equipment may range from the rear tires on a loaded dump truck to an 8- to 10- ton pneumatic or steel-wheeled rollers. Six to eight passes of a heavy roller may be adequate in a given area to achieve maximum density if moisture levels are optimal. Experience with native (local) materials and/or compaction determinations made by a materials lab are the two best methods for maintenance personnel to use. Where problems frequently arise with a particular aggregate, both time and money can be saved by subjecting the material to lab analysis. The analysis will provide the most effective stabilizing measures and compaction effort.

Compaction is essential in preparing the subgrade and other granular subsurface structures. Many surface failures can be attributed to inadequate compaction during construction. Repair efforts should assure that failures do not recur for the same reason. For optimal effectiveness, compact materials in layers not to exceed 3 in. thick — less for materials containing aggregates under ½ in. in diameter.

Road Surface Cross-Section: Proper cross-section is initially a design and construction concern, although maintenance efforts are required to ensure the crown is restored following degradation by traffic use. Graders are typically used to reshape the roadway to its original form. Refer to the plans and drawings to decide the proper crown and grading of a roadway before extensive maintenance.

In the absence of plans and drawings, examine the natural drainage patterns. Water should run off the roadway into adequate drainage disposal facilities such as ditches or channels. Curves require super-elevation to avoid a cross slope that will cause vehicles to slide toward the outside edge of the curve. Usually, the slope for crowns and super-elevations is between ½ in. and 1 in. per foot of width. Round the crown sections such that water cannot collect. The roadway grade and transition areas between crowned and super-elevated sections should be checked to ensure that they do not cause

undesirable runoff patterns or cause water to be retained on the roadway.

Thickness of the Surface Course: The thickness of the gravel or crushed-stone surface course on the roadway plays a significant role in reducing degradation.

Logging roads in the western part of the country respond very well to surface application of 4 to 6 in. of 1.5-in. diameter crushed stone. Roads treated in this manner have up to a 90 percent reduction in sediment yield. Logging roads in the eastern part of the country have responded well to 6-in. lifts of 1.5- to 3-in. diameter washed gravel or crusher-run gravel. The reduction in sediment yield on these roads approaches 90 percent also.

Surface Drainage: Fill local depressions in the roadway with appropriate aggregate and provide hydraulically-designed outlets for water. Unpaved roads should be kept crowned to prevent water from remaining on the road where it will saturate and weather the surface. If roads are uncrowned by design, ensure adequate water bars or rolling dips exist to take water away from the road surface.

Avoid the creation of windrows or undesigned berms at the road edges. They concentrate drainage along the road surface and then divert that water to inappropriate locations. Insloping road surfaces to drainage ditches and providing more uniform spacing of crossroad drainage structures should significantly reduce sediment transport via the roadway.

Road-Mix Method of Surfacing: This method involves mixing the aggregate with water and any additives (fillers or binders) directly on the road-bed. Moisture is the key factor at this stage. The aggregate should be mixed and spread at or near the optimum moisture content for best compaction results. These moisture conditions can be determined by checking the results of the moisture-density relationship tests (AASHTO T 99) or by using expert judgement based on the observed behavior of previously placed and compacted aggregate.

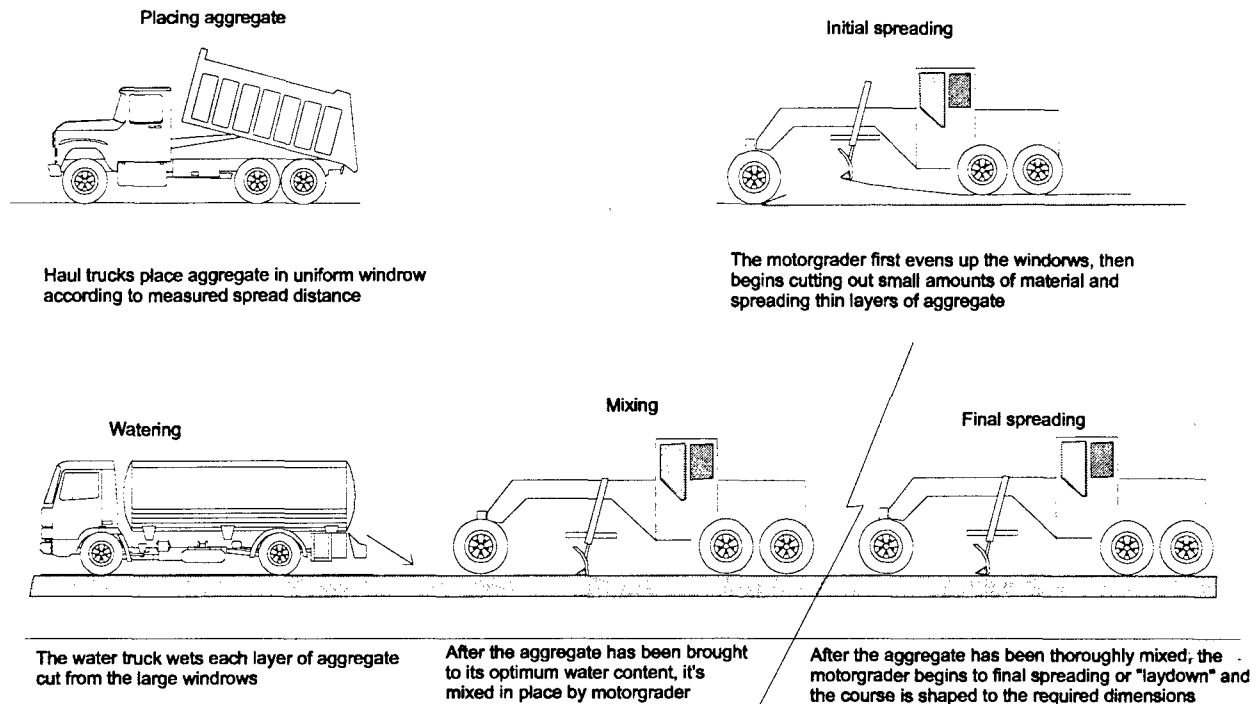


Figure 3-13. Road mix method.

Compaction and Finishing: Compaction follows immediately after completion of the final spreading and shaping of the aggregate. Compaction acts to force the aggregate particles together into a more dense mass without breaking down the particles (except the grid roller). As compaction occurs, the finer particles are forced into the voids between larger particles. Having the correct moisture content is critical at this stage.

The properly compacted aggregate base or surface course will be very hard, dense, and durable. Compaction is measured in terms of density.

Finishing involves the final blading or rolling needed to produce a smooth, uniform surface. The condition of the surface of both the aggregate base and surface course is very important.

The following provides an example of general specifications for compaction as used by the USDA Forest Service:

Compaction (A) The aggregate is compacted by driving equipment (spreading and hauling) over the full width of each layer of the aggregate.

Compaction (B). The aggregate is moistened or dried to a uniform moisture content suitable for compaction. Rollers are operated over the full width of each layer until visual displacement ceases, but not fewer than three complete passes.

Compaction (C). Each layer of aggregate is compacted to a density of at least 95 percent of the maximum density, as determined by AASHTO T 99, Method C or D.

Compaction (D). Each layer of aggregate is compacted to a density of at least 95 percent of the maximum density, as determined by AASHTO T 180, Method C or D.

Compaction (E). Each layer of aggregate is compacted to at least 95 percent of the target density as determined by a control strip.

Compaction (F). Materials produced by pit-run and grid-rolling must be visually moist and compacted by operating compaction equipment over the full width of each layer until visual displacement ceases.

When compacting, the surface of each layer is bladed during the compaction operation to remove irregularities and produce a smooth, even surface. Density requirements for each layer can be determined according to AASHTO [T 191, T 205], or [T 238, T 217, T 239], or [T 255, T 224].

Compacting plastic materials such as sandy clays is accomplished using the sheepsfoot roller. Non-plastic materials can be suitably compacted with either rubber-tired rollers or steel-wheeled vibratory rollers.

Although there are no specified rolling patterns or number of passes, covering the full width of the aggregate layer with adequate passes is important.

A motor grader is used to blade the surfaces of each layer to remove high spots, fill low spots, and produce a smooth, even surface. Finish rolling will further compact the course as it seals the surface.

Compaction and Finishing Requirements:

- Each layer of aggregate must be compacted separately.
- The rolling equipment must cover the full width of the base or surface course, including shoulders. Each layer must be compacted fully and evenly.
- Each layer must have a smooth and even surface. Moisture and density tests are used at this stage to decide if the effort is adequate. The USDA Forest Service Handbook 7109.17, Chapter 24, provides an example of performance of moisture and density tests.

Finished Surface Evaluation: The most important factors to examine following compaction and finishing of a repaired section of the roadway are the thickness of the layers and the finished surface conditions. A statistically random method of sampling provides the best valuation of the thickness. A uniform thickness provides a uniform load-carrying capacity.

Thickness can be determined by means of a soil probe, a graduated ruler or stick, or by excavating

a small sample pit through one layer into the next lower layer. Density can be determined visually, by walking over the suspect area, or by using a penetrometer. Soft areas should be dried out and rerolled to correct the problem.

The crown must be adequate to provide effective cross-drainage. A string line can be stretched across the roadway and the crown measured in relation to the outer edges of the traveledway. Another method involves using a hand level and rod to measure the cross slope. The finished surface should have an adequate crown, be smooth, even, and of uniform thickness.

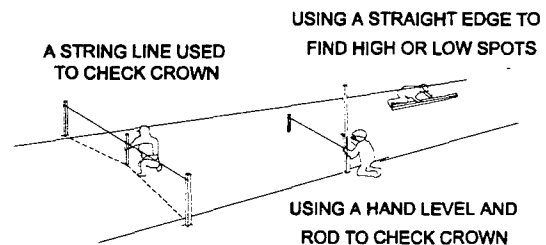


Figure 3-14. Methods of checking unpaved road surfaces for proper crown or high and low spots.

3.7 Dust Palliatives and Surface Stabilization

Hundreds of thousands of tons of dust are created each year by military vehicles. Dust control becomes an essential component of road maintenance when concealing military activities is necessary. Reduction of environmental impacts and the safety of human health or life are also critical. A variety of hazards to both operators and vehicles are attributed to road dust. Visibility reduction, damage to vehicles, increased vehicle maintenance, increased road maintenance, increased environmental degradation, sedimentation, air pollution, inconvenience, and respiratory difficulties to those subjected to the dust are among the most significant problems.

Use of Dust Palliatives: The term dust palliative refers to a material applied to a soil surface to prevent soil particles from becoming airborne. Over time, many other terms have been used to describe these materials, including: palliative, dustproofer, surface or soil stabilizer, soil water-proofer, dust control agent, or dust layer.

Many dust palliatives evaluated from the early 1900's through the mid-1970's were determined to be ineffective, cost-prohibitive, or provided only temporary mitigation. Road dust was recognized as a hazard to human health (particulate pollution) in the 1970's. Several studies were initiated to quantify dust sources and emissions created by traffic on unpaved roads and identify possible solutions for low cost dust control and surface improvement. Dust is produced when the forces acting on a soil particle exceed the force holding the particle in place. This may be caused through natural forces or by human activity.

The average dust generation from unpaved roads is around 1 ton/mile/year/vehicle of average daily traffic within a 1000-ft wide corridor centered on the roadway. Throughout the 1970's and 1980's, chlorides, Portland cement, lime, lignin, lime fly ash, organic and inorganic chemicals, and various formulations of bitumen were examined for effectiveness as palliatives. However, many of these products were ineffective, too costly, too labor-intensive to apply or maintain, or too hard to obtain.

Most of the products used for dust palliation today have been tested and approved by a range of Federal and state agencies (departments of transportation and environmental protection, primarily).

Stabilization of on-site materials has long been recognized as the most effective means of mitigating dust and improving road surfaces within reasonable cost constraints. This is accomplished through either surface spray or mixed-in-place applications.

Several nonpetroleum-based, resin-modified emulsions were recommended for use by the Army Environmental Center and were field tested in

Somalia and Saudi Arabia during recent military activity. One of these newer nonpetroleum-based products has been evaluated for effectiveness in stabilization of roads at Fort Leonard Wood, MO and Fort Carson, CO. The Corps of Engineers has also tested it to stabilize beach sands in Hawaii. USACERL has also been conducting palliative effectiveness tests on roads at Fort Campbell, KY, Fort McCoy, WI, and Fort Sill, OK. Unfortunately, no single product is effective in all areas. Some products require a critical percentage of fines in the surface aggregate, others do not work well in sands, while others do not work well in clays. Current, comparative information is essential to aid the land manager in selecting those products most appropriate for use on a given installation or on a specific soil.

The presence of dust or fine particles in the surface aggregate does not necessarily suggest a dust problem. Factors influencing the severity of a dust problem include soil texture and structure, soil moisture content, soil density, presence of salts or organic matter in the soil, smoothness of the surface, vegetative cover, wind velocity, and humidity.

Dust clouds can be generated by moving air from natural winds, aircraft engines, helicopter rotor, or ground vehicles. Vehicles not only produce drafts of moving air, but also abrade the surface of the road and dislodge fine particles.

Considerations for Use: Dust palliatives are primarily intended for low volume, low cost roads. The performance of the dust palliative is directly related to the performance of the unpaved road on which it is applied. Therefore, the first consideration in evaluating the cost-effective use of the palliative is to choose unpaved roads with properly designed and constructed subgrades. The properties of the road subgrade, base, and wearing surface greatly affect the effectiveness of any dust control program. Inspection and rehabilitation are required before treatment to provide surface stabilization.

Other factors to consider in ensuring the successful control of dust include the intensity of vehicular

traffic, type of vehicles, topography, soil type, soil characteristics, and climate.

Soil Types. Soils to be treated for dust control are classified according to the Unified Soil Classification System, MIL-STD-619B.

- Silts or clays (high liquid limit): The relatively impervious, plastic, fine-grained soils encompass USCS types CH, OH, and MH.
- Silts or clays (low liquid limit): The moderately permeable, low to medium plasticity, fine-grained soils encompass USCS types ML, CL, ML-CL, and OL.
- Sands (with fines): The moderately permeable, coarse-grained soils contain an appreciable amount of fines encompassing USCS types SM, SC, SM-SC, GM, GM-GC, and GW-GM.
- Sands (with little or no fines): The highly permeable sands or gravelly sands contain little or no fines encompassing USCS types GP and GW.
- Gravels (with little or no fines): The highly permeable gravels or sandy gravels contain little or no fines encompassing USCS types GP and GW.

Soil Characteristics. The degrees of compaction and saturation of the soil in the immediate area are important characteristics.

- Loose and dry or slightly damp: A 0.25- to 2-in. thick surface layer of uncompacted soil overlying a relatively firm subgrade and ranging in moisture content from dry to slightly damp.
- Loose and wet: A 0.25- to 2-in. thick surface layer of uncompacted soil overlying a soft to firm subgrade and of high moisture content. This soil must be dried before treatment.
- Firm and dry or slightly damp: A 0.25-in. thick surface layer of loose soil with a dry to slightly damp moisture content overlying a compacted soil subgrade.

- Firm and wet: Similar to the previous, but the surface must be dried before treatment.

Palliative Performance Criteria: Many products have been tried and evaluated as dust palliatives. Some proved ineffective, while others were disregarded due to adverse environmental effects. An acceptable dust palliative should satisfy the following basic requirements:

- It should be environmentally acceptable.
- It should be easily applied with common road maintenance equipment.
- It should be workable and respond to maintenance.
- It should provide reasonable retention and good dust control.
- It should provide surface stabilization.
- It should reduce maintenance efforts.
- It should be cost effective.

TM 5-830-3 (1987) identifies traffic areas requiring palliative treatment to include roadways and vehicle parking areas, walkways, and tank trails. Economic analysis of the cost to maintain an unsurfaced road versus the costs associated with a paved surface road suggested the break-even point occurred at a traffic level of approximately 100 vehicles per day.

Applicability of Dust Palliative Use: The commonly accepted cutoff for cost-effectiveness of dust palliatives is an average daily traffic (ADT) count of 500 vehicles. Where volumes are greater than 500 ADT, multiple treatments or more extreme surface treatments may be necessary. Roads with an ADT of less than 15 generally do not require dust control, however this may differ from site to site depending on the risk to human safety.

Roads with ADT between 15 and 500 are candidates for dust control, particularly at intersections, railway crossings, curves, and bridge approaches.

The life expectancy of the dust palliative decreases with more intensive traffic and particularly with truck traffic. This is very true of products that create a hard surface crust, which is subject to pothole development, such as ligno-sulfonates and most petroleum products.

Increased volumes of traffic require increased rates and/or frequency of palliative application to achieve the desired degree of dust control. To some extent, economics may dictate upgrading to a surface seal or some form of paving.

To obtain maximum benefits from the palliatives, the roads to which they are applied must be able to carry the expected traffic without failing. Before placing a dust palliative, unstable areas should be repaired and unsuitable subgrade materials removed and replaced with select materials compacted at optimum moisture content. Drainage improvements should be made to ensure that the subgrade does not become saturated and thereby weakened. Surface aggregate should be added if insufficient and a proper crown maintained to ensure good drainage.

Selection of Palliatives: Selecting the type of dust palliative that will best suit the existing surface material or the subgrade lacking surfacing structure is important. An analysis of the subgrade will provide information on the percentage of clay, silt, sand, and gravel. If a match cannot be made between the materials and products, modifying the surface material by adding fines or gravel may be necessary. As a rule, total fines should range from 10 to 20 percent of surface course materials to provide a dense compact surface free from loose aggregate. (Material that passes the 75 μm sieve is the fines portion and may also be called the minimum 200 sieve, 0.075 mm, 71 μm , or 80 μm sieve size.)

Local climatic conditions must also be considered before selecting a dust palliative. Chlorides and ligno-sulfonates leach out and wash away under heavy rains. They also may become slippery when wet, particularly when there is a high fines content in the surface material. Petroleum products can also be slippery in wet weather.

Calcium chloride loses its ability to absorb moisture as relative humidity decreases and should be used with caution if long droughty periods are anticipated or low humidity conditions prevail.

Ligno-sulfonates work better in dry climates because of the cementing action that binds particles together without relying on atmospheric water.

Magnesium chloride remains hygroscopic than calcium chloride at higher temperatures and lower relative humidity levels. It may, therefore, be more suitable to dry climates.

Application Rates and Frequency. Once the appropriate product has been selected, the application rates and frequency must be determined. The manufacturer-suggested rates may vary from site to site, soil to soil. Experience is a good means of determination. Variations depend on type of product, degree of dust control required, subgrade conditions, type of wearing surface, type of vehicles, climatic considerations, and frequency of maintenance.

A higher application rate or greater frequency of application is required under the following conditions: high traffic volumes, high speeds, high percentage of trucks, low humidity conditions, low fines content, poorly bladed surfaces, and loose wearing surfaces.

General Application. Before using surface-applied products, grade or scarify the surface to a depth sufficient to remove surface irregularities. This should be done immediately following rains so surface material is more workable. A water truck can provide the moisture required if rains are inadequate.

- Shape the correct crown and super-elevation and compact the surface thoroughly.
- When using ligno-sulfonates, blade any loose material to the shoulder before application.
- Dampen the surface thoroughly except when using nonemulsified petroleum products.

- Uniformly apply the dust palliative using a pressure distributor for good penetration.
- When using ligno-sulfonates or chlorides, lightly compact the surface with a rubber-tired roller.
- After applying chlorides, traffic can resume immediately; however, a curing time is required before allowing traffic to return to a road treated with other products. Follow the manufacturer's instructions.

Labor and Equipment: Labor and equipment requirements for a dust palliative treatment vary considerably based on road and surface conditions, traffic volume, treatment width, and compaction requirements. Most products currently in use can be applied with standard road maintenance equipment, except where a special nozzle through which a product is sprayed under pressure is needed.

Program Costs: The three components of dust control programs are upgrading the roadway, surface preparation, and product supply and application costs.

Road Upgrading. Upgrading a poor road to obtain the maximum benefit from the dust palliative treatment is essential. In most instances the roads would require attention whether or not they received treatment. Road improvement costs may include drainage improvements, geometric improvements, repair of failed or weak areas of the roadbed, and addition of surface materials.

Surface Preparation. Costs include labor and equipment directly attributable to surface preparation before and after application of dust palliatives. This preparation involves the addition of fine or coarse materials, scarification, water application, shaping, and compaction.

Product Supply and Application. Costs include material, transportation, and application costs.

Benefits of a Dust Control Program: The most tangible benefits are those related directly to cost

savings among those persons responsible for road management. These can be seen in the reduction of blading frequency and reapplication of surface materials. The following are included in the more intangible benefits:

- Reduced vehicle accidents
- Reduced vehicle damage
- Improved aesthetics
- Reduced maintenance (down time) for vehicles
- Reduced dust induced health hazards
- Reduced sedimentation of waterbodies
- Reduced impact on dust sensitive vegetation
- Reduced complaints

Dust Control Methods: Three types of treatment methods have proven most effective for dust control on unpaved roads: surface penetrant, admix (mix-in-place), and surface blanket.

Surface Penetration Method. The dust palliative in a liquid form is applied directly on the soil surface by spraying or sprinkling and is allowed to penetrate the surface under its own accord. A liquid pressure distributor, a gravity-flow water distributor, or a hand-held device may be used for application.

Effectiveness depends on the depth of penetration, which varies with viscosity and the permeability of the soil. Often penetration can be helped by pre-watering the road surface. Penetrating palliatives include bitumens, resins, emulsions, lignins, chlorides, and water.

- **Bituminous Materials:** These include cutback asphalts, emulsified asphalts, and road tars. Cutback asphalts consist of a blend of asphaltic-cements and petroleum solvents. They are classified as rapid curing (RC), medium curing (MC), and slow curing (SC) depending on the type of solvent used. The product is graded by its viscosity. RC and SC grades of 70 and 250, respectively, and MC grades of 30, 70, and 250 are the most commonly used. Soil surfaces should be moist when applying bituminous materials.

Emulsified asphalts are blends of asphalt, water, and an emulsifying agent. They are available as either ionic or cationic emulsions. The application of this product is extremely temperature-sensitive.

Road tars are viscous liquids obtained by distillation of crude tars obtained from coals. Curing time can take days or even weeks and tars are susceptible to temperature changes.

Asphaltic penetrative soil binder is a commercial product that composed of high penetration grade asphalt and a solvent blend of kerosene and naphtha. This product requires heat to facilitate application and the cured product is tacky at surface temperatures of 100 °F and above.

- **Resinous Materials:** These products may be used as either surface penetrants or surface blankets. Applicable only to occasional traffic areas where rutting will not occur, they are not recommended for use with silts and clays.
- Resin-petroleum-water emulsions are stable and resistant to weathering. Coherex and similar products are of this type. These products are primarily suited to dry, sandy soils and are unsuitable for use with silts and clays.
- Lignin is a by-product of the manufacture of wood pulp. It is soluble in water and therefore susceptible to leaching. Repeat applications are required. It is not recommended where durability is a factor.
- Chlorides used in palliation include liquid and solid forms of calcium chloride, sodium chloride, and magnesium chloride. Calcium chloride use is limited to occasional traffic areas. Sodium chloride applications can build up a thin and hard surface, however, it is corrosive to metals. **Magnesium chloride will control dust on gravel roads with tracked vehicle traffic, particularly in areas with occasional rainfall or where the humidity is above 30 percent.**

- Water is a commonly used palliative, but its effectiveness is very limited temporally. Application to clays can lead to slippery surfaces and puddles.

Mixed-in Place Method: The dust palliatives are blended with the soil to produce a uniform mixture with increased soil strength. Treatment to a depth of 4 in. (minimum) is required to dust-proof traffic areas. The two types of admix materials used as dust palliatives are powders such as Portland cement and liquids such as bituminous materials.

Portland cement is generally suited for all soil types. Hydrated lime is applicable only to soils containing a high percentage of clay. Bituminous materials are more versatile than cementing materials in providing adequate dust control and waterproofing on roads. Once soils and palliatives have been mixed, spread, and compacted, the soil surface must be kept moist for a minimum of seven days. Travel must be rerouted until the material has cured.

Surface Blanket Method. This method involves the use of aggregates, prefabricated membranes, bituminous surface treatments, polyvinyl acetates, and polypropylene-asphalt membranes to create a surface blanket for dust control.

Aggregate, and prefabricated (rolled) membrane treatments can be easily placed and will withstand considerable rutting.

The other surface blanket methods can only withstand minimal rutting. Once the blanket is torn or compromised, the soil is exposed. Subsequent traffic increases the damage while producing dust from the exposed surface.

The three types of materials used as surface blankets are minerals (aggregates), synthetic (membranes), and liquid (bituminous or polymer materials).

- Aggregates are acceptable for dust control in arid areas with occasional traffic. Traffic over aggregates pulverizes the surface. The aggre-

gate (1.5 to 2 in. diameter) should be laid in 2-in. thick courses over the traveledway.

- Prefabricated membrane used to surface an area can control dust and even provide a surface course for traffic that will not cause rutting. Detail on the use and installation of prefabricated membranes is found in TM 5-330 Volume II.
- Bituminous surface treatments, either single or double, can be used to control dust on most soils. Fine-grained soils are primed with MC-30 and coarse-grained soils with MC-70. After curing, a bituminous material is uniformly applied. Gravel, slag, or stone aggregate is then spread over the treated area. The rate of application is approximately 25 pounds of aggregate per square yard. This method of application is described in detail in TM 5-822-8, Chapter 9.
- Polyvinyl acetate (DCA 1295) has the appearance of latex paint. It forms a clear, flexible film on the treated surface. Fiberglass can be added to reinforce the product.
- Polypropylene-asphalt membrane can be used in all traffic areas. It is durable and withstands rutting up to 2 in. in depth. It is a combination of a polypropylene fabric sprayed with an asphalt emulsion. A layer of asphalt is first placed and then covered with a layer of polypropylene fabric. Asphalt is then placed on top of the fabric and a sand blotter course is applied over that.

Commercially Available Dust Palliatives: The following dust palliatives were in common use through the mid 1990's:

Hygroscopic and Deliquescent Chemicals: Present usage for dust palliation across the country is estimated at 75 to 80 percent. These chemicals absorb moisture from the atmosphere or the road surface and maintain a film of water that attracts dust particles. They include calcium chloride, magnesium chloride, and natural brines containing chloride salts.

Petroleum-based Products: Current usage is estimated at 10 to 15 percent. These products are derived from petroleum, are not water-soluble, and generally form coherent surface layers that seal the road surface and hold the soil particles. These include bunker oil, asphalt primers (MC 30, etc.) and asphalt emulsions (S-1, DL-10, RS-1, etc.).

- Organic Non-Bituminous Binders: Use presently is estimated at 5 to 10 percent. Products within this category physically bind the soil particles together or physically stick to individual soil particles weighing them down. Ligno-sulfonate products are the most common in this category and are composed of by-product wastes of the wood-pulping process. Variations include calcium ligno-sulfonate, sodium ligno-sulfonate, and ammonium ligno-sulfonate. Other products include a binder produced from the processing of sugar beets, and a resin modified emulsion produced as a by-product of the forest industry.
- Water-Soluble Resins and Emulsions: A newer category of products, still in the field-testing phase, includes a group with proprietary formulas. These include polymer or acrylic resins, biocatalysts, or blends of complex surfactants. These products are water-soluble, environmentally safe (EPA-approved), and effective. They may be costly initially, but are more effective over time.

3.8 General Roadway Maintenance

To paraphrase TM 5-330, **Maintenance** is the routine prevention and correction of normal damage and deterioration from use and the elements, as necessary to keep road surfaces and facilities in usable condition. **Repair** is that work necessary, other than maintenance, to maintain surfaces and facilities in usable condition. It is the repair of damage caused by abnormal use, accidents, hostile forces, and severe elemental forces, and includes the resurfacing of a road when maintenance can no longer accomplish its purpose. **Rehabilitation**, as used in this document, is the restoration of road

beds, surfaces, ditches, and adjacent slopes to a useable and environmentally stable condition following severe disturbing activities. Routine activities include inspections, maintenance, and repair of all road surfaces and drainage systems, stockpiling of materials for maintenance and repair work, dust and mud control, snow and ice removal, and other work necessary to keep roads in the required condition.

Principles: Any maintenance or rehabilitation job should begin by determining the cause of the particular damage or degradation.

Mitigation of the cause should be undertaken before repairs are made.

Ignoring the cause of the degradation will only exacerbate the problem.

Surface repairs made on a defective subgrade are a waste of time.

When rehabilitation or maintenance is carried out, the existing surfaces should conform to the original surfaces as designed.

The prioritization of roadway maintenance or rehabilitation depends on personnel safety, training requirements, traffic volume, and any hazards or inconvenience that would result from complete failure of the facility.

Objective: The objective of the maintenance program should be to maintain secondary roads and trails in such a manner as to:

- Reduce or prevent erosion and sedimentation on, along, and from the roads and trails.
- Provide a safe means of reaching training and testing areas and rangelands across the installation.
- Protect the military's investment in the system of roads and trails used on installations.
- Promote an efficient and cost-effective maintenance program.

- Provide aesthetically pleasing and durable roads and trails for training and testing activities.

Priorities: Obviously, all conditions that may present a hazard to the safety of personnel should be addressed before other work is undertaken.

The level of importance to place on a road or trail problem depends on several criteria, not the least of which is the intensity of use. Problems considered critical on a high-volume secondary road, may be tolerable on low-volume tertiary trails.

When deciding the order of priority of maintenance problems, it may be beneficial to examine the following criteria:

- Potential for sedimentation or damage to adjacent or nearby sensitive areas or waterbodies.
- Extent of future costs of rehabilitation or repair in terms of money, labor, and time if the problem is allowed to get worse.
- Potential for inconvenience based on present or anticipated intensity of road or trail use if the road or trail becomes impassible or hazardous.
- Effectiveness of repeated temporary repairs versus permanent rehabilitation.

Maintenance and Rehabilitation Considerations:

Seasonal Scheduling. Plan all major maintenance or rehabilitation of roadway sections to occur during the milder, drier seasons of the year. In most areas the preferred windows for roadway work are March-May and August-October because of good weather and optimal seeding conditions. Avoid the rainy season(s) and cold winter months when more damage than rehabilitation can be done.

Construction Schedule. Where repair, rehabilitation, or construction is extensive or covers a long section of the roadway, establish a work schedule that will allow no more than 500 ft of roadway to be worked on in succession. Aggregate surfacing and seeding are best completed while the soil is

still freshly disturbed. Do not delay surfacing or reseeding after repairs.

More than one section can be worked at the same time. As grading, grass seeding, and surfacing on one 500-ft reach is completed, the next reach can be excavated or filled. A much higher risk of extensive environmental damage is incurred by disturbing a very long section of road and/or trail.

Materials List. Prepare a list of required materials and check suppliers early regarding availability, shipping times, price, terms, etc. Be specific about the type and amount of materials needed. Fill material for roadbeds, culverts, headwalls, temporary silt fencing, mulch blankets, channel lining fabric, filter fabric, crushed stone, washed rock, riprap, straw mulch, seed, fertilizer, and lime are among the materials to be considered. Materials should all be on-site or available at a staging area *before* they are needed. Find out what materials may already be stockpiled on the installation or available for use.

Contract-For-Bid. Maintaining and rehabilitating the road system can usually be accomplished with installation personnel and equipment. This may involve the provision of active, reserve, or guard unit expertise, personnel, and equipment as roadway construction, maintenance, and rehabilitation falls within their training mission (TM 5-330). However, when the equipment cannot be borrowed, rented, or brought in by visiting engineer units, it must be contracted for and this can be very costly. Seeking out experienced and reputable road construction and/or maintenance firms would be prudent.

Having an engineer or road construction specialist available to supervise and keep track of the progress of road repairs or construction would be practical. If the installation lacks a civil engineer, arrange to contract one with experience from a local firm or university.

Regular Maintenance Activities. Routine inspection and maintenance of the road surface, ditches, culverts, and erosion and sediment control measures are especially important following periods of

high runoff to detect structural damage and inadequate hydraulic design.

Effective roadway construction and maintenance activities should provide proper final grading of the road surface and adjacent slopes, appropriate shaping of the ditches, feathered cuts, and blended shoulders and slopes to ditches.

Erosional problems can be reduced if natural drainage patterns can be maintained in an unaltered state. Ditches, sediment traps, and culverts must be cleaned regularly of accumulated debris and sediment to prevent plugging, flooding, or wash-outs.

Excessive sediments suggest geomorphic problems (instability) farther upslope or on the road way. Where excessive sediments are found, conduct a foot or windshield survey upslope to identify the source of the sediment and cause of the instability.

Maintenance Inspections. Two areas of concern in roadway maintenance inspections are the road surface and drainage structures.

- **Road Surface Inspection:** Regularly scheduled "windshield" inspections can facilitate early detection of surface defects before actual failures occur. Surfaces inspected on a more frequent basis are less likely to develop any major problems that are going to escape notice. Spot repairs or immediate follow up activities are critical to prevent minor problems from becoming major. Unless the source of the problem is identified and corrected, repairs to the surface will be a waste of effort and money.
- **Drainage Structures:** Inspections of drainage ditches and associated structures should take place both during and immediately following rain events to determine their effectiveness and identify problems. Culverts, inlets, outlets, and check dams should be inspected for erosion and debris accumulation. Ditch bottoms should be inspected for incision and/or deposition, knick-point migration, and gully development. The cause of ponded water or roadway flooding should be identified.

Schedule Inspections: For example, in humid climates, detailed inspections of the entire road and trail system are typically scheduled in early March and August (before the rainy season), and after each significant rain event. Where possible, get out of the vehicle and walk the entire length of suspect road sections examining ditches, culverts, energy dissipators, adjacent slopes, and the roadbed itself. Closely inspect cross-sloped and crowned reaches to ensure that adequate grades remain to promote road surface drainage. The roadbed should be free of ruts, ridges and edge berms where sidecast materials have been accumulating. Examine turnouts and outlet structures for signs of sedimentation and other degradation.

Schedule Regular Cleaning: Schedule cleaning of ditches, adjacent or receiving waterways, and sediment collection systems to remove debris and prevent degradation regularly or as required by local climatic conditions.

Roadside Maintenance	Priority-Due to Safety Hazard	Priority - Due to Cost of Repair or Potential for Degradation
Vegetation	2	1
Ditches	1	1
Culverts	1	1
Drains	2	2
Gutters	2	3
Debris Barriers	3	3
Slope Bench	1	1
Retaining Walls	1	1
Cattle Guard	1	2
Guard Rails or Guide Posts	1	2

Table 3-1. Prioritization of maintenance efforts.

Cleaning operations should also follow significant rain events where increased runoff and sediment movement may cause erosional damage to the roadway. An additional problem or decrease the capacity of ditches and culverts. Any blockage or damage to culverts or drainage ditches or other structures should be immediately repaired.

Repair Eroding Areas. Disturbed sites, bare slopes, or eroding areas should be reseeded or stabilized immediately upon completion of rehabilitation, maintenance, or construction. Reshape rills with hand tools or tractor and disk. Gullies are to be filled and thoroughly compacted after reducing the volume and velocity of runoff upslope. At culvert outlets, riprap should be underlain by filter fabric to protect against erosion and sedimentation. Where gullies exist, either reduce runoff flow or divert runoff away from the gully head or the gully will quickly reincise.

Maintain Vegetation. Maintain vigorous vegetative cover along trails to include trail shoulders, drainage ditches, adjacent slopes, and runoff outlet areas. Apply 2 tons of lime per acre or per soil test during late fall or winter every 2 to 4 years. Apply fertilizer annually or per soil test as follows: Grasses - 500 pounds of 10-10-10 per acre in the early fall; Legumes - 500 pounds of 0-10-20 per acre in early spring; Mixture - 500 pounds of 5-10-10 per acre in late winter or early spring.

Control Vegetation. Periodically mow or cut back vegetation that encroaches on the roadway, prevents surface water from flowing freely to drainage structures, or shades moist areas. Limit the use of herbicides as runoff may result in contamination of streams or ponds. Inspections of revegetation efforts should be conducted seasonally until soils are stabilized. This will allow a determination of the need for supplementary or modified seed, fertilizer, or mulch treatment.

Minimize Soil or Vegetation Disturbance. During routine road and ditch maintenance activities such as surface grading, recompaction, or rehabilitation, particular care should be taken to avoid disturbing roadside vegetation OR to allow surface materials or other sediments to enter ditches or water bodies.

Maintenance crews must avoid sidecasting materials into ditches, particularly above culverts, ditch outlets to turnouts, or waterways.

Instability within ditches or on cutbanks can be incurred by undercutting sideslopes or overcutting shoulders (cutting at an angle greater than the angle of stability of the soil). The angle of repose for most coarse-grained, unconsolidated materials is 33 to 35 percent. Cutting a steeper slope than this can lead to significant and rapid instability.

Drainage-Related Maintenance Problems: A variety of drainage-related problems occur on the roadway that can be remedied or prevented by appropriate and timely maintenance efforts.

- The elevation of the roadway is too low.
- The surface crown (either center or side) is inadequate to ensure proper drainage.
- The grade of the roadway is too steep.
- Drainage ditches are absent or inadequate to handle runoff.
- Outlet channels are inadequate to handle the discharge.
- Turnouts or water diversions are absent, inadequate or improperly spaced.
- The bottom gradient of the ditches is too steep or the ditches are too narrow.
- Drop structures installed in ditches are either the wrong type or they are improperly placed.
- Adjacent slopes are too steep and/or not vegetated.
- Discharge aprons are absent or inadequate at discharge outlets.
- The crossroad drains (culverts, open-box culverts, water bars, water dips) are too flat, too shallow, or too deep.

- The approach to inlets is inadequate to handle volume of water.
- Berms or diversions are improperly placed.

3.9 Roadway Erosion Control

Effective gully control within ditches must act to stabilize both the bottom gradient and headcut(s) within the ditch.

Over time, most ditches that have not been hydraulically-designed to convey the peak flow of their individual subbasin will become unstable. Being aware of potentially unstable locations within the road/ditch system and acting to avert degradation through preventive maintenance activities is important.

It is equally important to recognize that mitigation measures will be most successful when implemented at the proper stage of development and at selected places within unstable ditches. The structure or technique must act with the evolving ditch system rather than opposing it or failure is likely.

Principles of Erosion Control:

- Reduce raindrop impact on the soil.
- Reduce runoff volume and velocity.
- Increase the soil's resistance to erosion.

Erosion control or maintenance practices designed to reduce the detachment of soil particles and the transport capability of the runoff flow will be the most successful in reducing overall sedimentation.

Vegetative Control. Effective erosion control depends on successful revegetation. The development of a good vegetative cover significantly increases surface resistance to erosive forces. Where an effective vegetative cover will grow, plants may be established without supplemental physical measures.

The most effective cover will consist of perennial, maintenance-free species in a mixture tested for

effectiveness on critical sites in a given area. Good cover in ditches may be characterized by high plant density, deep and dense root systems, and low plant height. Long, flexible plants such as certain tall grasses will lie down on the ditch bottom under impact of concentrated flow. This will provide a smooth interface between the flow and the ditch bottom, allowing substantially increased flow velocity.

When allowed to grow uncontrolled within ditches, trees may restrict flow and cause erosive diversions of water against the ditch banks or flooding of the road. However, trees grown along the adjacent slopes may serve to increase slope stability and infiltration.

The velocity of runoff can be reduced by encouraging grasses, wildflowers, or even grain crops to increase the roughness coefficient of the channel.

Structural Measures to Aid Vegetation Recovery. If the ditch is critically eroding or the site does not favor establishment of vegetation, structural measures will be required. These will be applied at those critical locations where changes in ditch morphology take place. These might be a knick-point migrating up a ditch bottom, a gully headcut within a ditch, or reaches of the ditch near convergence with a second order channel.

Critical locations are easily identifiable on steeper slopes, as the ditch bottom and banks are often in a raw, disturbed condition. Vegetative recovery can be aided by the installation of physical erosion and sedimentation structures within those critical reaches. Alluvial deposits accumulating behind these structures make excellent aquifers, increase channel storage capacity, decrease channel gradient, and thus, peak flows. These conditions are all more favorable to plant growth.

Structural measures should aid in the establishment and rehabilitation of vegetation. If the ditch gradient is stabilized, vegetation can become established on the ditch bottom. If the bottom is stable, the ditch banks can be stabilized since the toe of the sideslope is at rest. This process can be speeded up mechanically by sloughing steep banks or

constructing hydraulically-designed ditches. The ditch bottom must be stable before the side slopes are sloughed (if oversteepened).

While established vegetation perpetuates itself and represents a permanent form of control, structural measures will always require some degree of maintenance. Planning these measures to reduce cost, labor, and long-term maintenance efforts is critical.

Selection of Erosion and Sediment Control Measures: Erosion control methods are selected to reduce soil movement by limiting soil disturbance and exposure, controlling slope gradients to reduce runoff volumes/velocities, and providing adequate drainage to protect the trail surface and adjacent side slopes.

Sediment control measures are based on interception and detention of sediment-laden runoff and removal of soil particles by filtering or settling. These measures are intended to protect downstream water quality and adjacent properties from sediment damage.

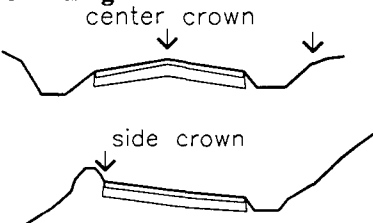
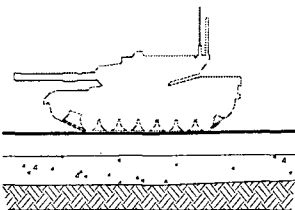
Both types of controls can be either temporary or permanent. Temporary measures are often set up before or during disturbances and remain in place until permanent measures become effective. For example, a sediment trap may be required to collect excessive sediment from a newly excavated trail section, but following trail construction, revegetated slopes and controlled drainage may provide the necessary degree of control. The selection of appropriate controls is based on the cause and extent of soil movement and site specific factors and activities influencing erosional rates.

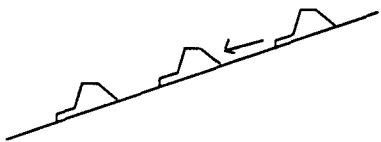
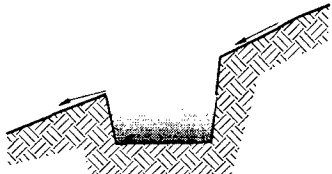
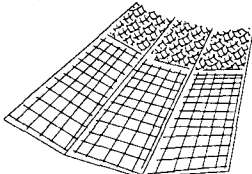
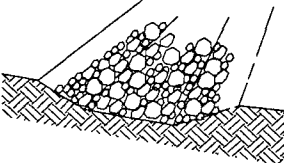
A benefit of incorporating a geomorphic approach into roadway management lies in the increased recognition of the nature of a particular problem. That is, whether an area of increased erosion is naturally-occurring system behavior and is therefore just local adjustment within the road/trail system or if it is a change due to a human disturbance. Since road/trail drainage system adjustments can be readily comprehended in both engineering and geomorphic terms, appropriate strate-

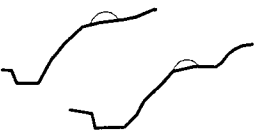
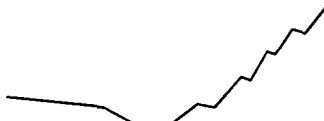
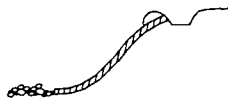
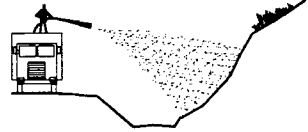
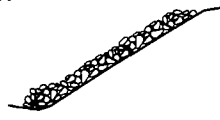
gies for rehabilitation and/or maintenance can readily be developed for use by installation personnel.

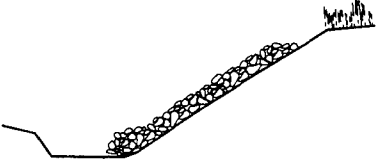
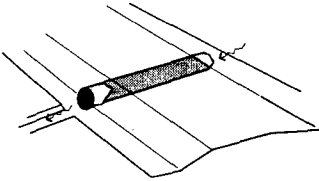
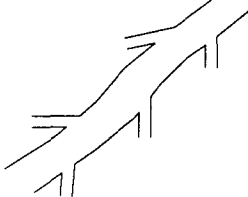
Table 3-2 illustrates some fundamental strategies used in effecting erosion and sedimentation control on and along the roadway.

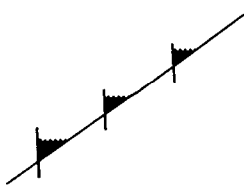
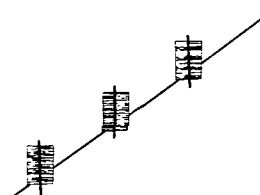
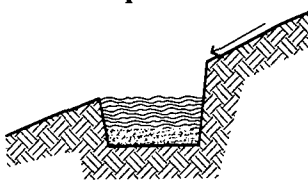
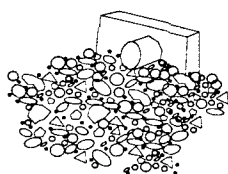
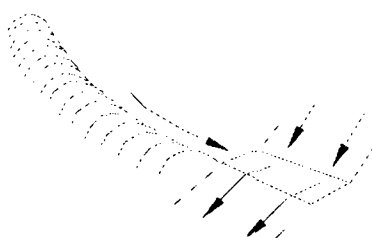
Table 3-2. Summary of treatment practices for erosion and sedimentation control on installation trails.

Treatment Practice for ROAD SURFACE	Advantages	Disadvantages
Center Crowning or Side Crowning: 	Directing the surface water to a prepared or protected drainage ditch minimizes erosion and maintenance effort.	NONE - Should be part of good trail/road construction and maintenance procedures.
Compaction: 	The final lift of each day's work should be well compacted and bladed to drain runoff to a ditch or diversion berm.	NONE - Should be part of good trail/road construction and maintenance procedures.
Aggregate Cover: 	Surfacing with aggregate minimizes surface erosion; Permits variable traffic loads during inclement weather; May be part of the permanent trail/road design.	Requires grading and compaction if used for long periods; Anticipate loss of aggregate and replacement requirements; Aggregate can be sidecast into ditches and drainage channels.
Seed/Mulch: 	Minimizes surface erosion; Useful on minimally traveled trails or trails used seasonally.	NONE.

Treatment Practice for DITCHES	Advantages	Disadvantages
Check Dams: 	Maintain low velocities on steep sections; Filter and retain sediment; Can be constructed of available materials: logs, stone, brush, fencing, lumber, concrete.	Close spacing on steep grades; Require maintenance and cleaning; Must be keyed into sides and bottom of ditch to prevent undercutting.
Sediment Traps: 	Can be located as necessary to collect sediment; Clean out can be accomplished with standard equipment; Simple to construct.	Requires hydraulic calculations for volume and placement; Specifications must provide for occasional removal of sediment.
Ditch Sodding: 	Easy to place with minimal preparation; Can be repaired during construction; Immediate protection; May be used to provide increased capacity for paved ditches.	Requires water during first year; Sod not always available; Will not withstand high velocity or severe abrasion from sediment load.
Seeding with Mulch and Matting: 	Least expensive channel protection; Effective for ditches with low velocities; Easily placed in small quantities with inexperienced personnel.	Will not withstand medium to high velocities flows.
Paving and Riprap: 	Effective for high velocity flows; May be part of a permanent drainage plan.	Cannot always be installed when needed; Initial cost may be high.

Treatment Practices for CUT SLOPES	Advantages	Disadvantages
Berm or swale at top of cut: 	Diverts water from cut; Collects runoff for slope drains; May be constructed before grading is initiated.	Access to top of cut may be limited; Difficult to construct on steep natural slopes; Drainage channels may require erosion protection; May promote slope seepage.
Diversion Dike: 	Collects and diverts runoff at a location selected to reduce erosion; May be incorporated into the permanent drainage plan.	Access for construction may be limited; May be continuing maintenance problems if not protected; Disturbed material or berm is subject to erosion.
Slope Benches: 	Slows velocity of surface runoff; Collects sediment; Provides access to slope for maintenance; Collects runoff for slope drains; Diverts runoff to natural areas.	May cause sloughing of slopes if seepage occurs; Requires maintenance to be effective.
Slope Drains: 	Prevents erosion; Can be temporary or permanent; Can be constructed as grading progresses.	Requires supporting effort to collect runoff; Requires energy dissipation.
Seeding/Mulching: 	Vigorous vegetative cover protects slope; Mulch provides temporary protection; Anchor mulch.	Difficult to seed critical slopes; May require supplemental water.
Sodding: 	Provides immediate protection; Will protect adjacent areas for sediment and turbidity.	Difficult to place until cut is constructed; May be costly or unavailable.
Temporary Cover: 	Wide rolls of synthetic matting in long sections; Easy to piece onto slope; Immediate protection of critical slopes.	Provides only temporary cover; Must be anchored to prevent wind damage.
Riprap: 	Provides immediate protection.	Difficult to place on critical slopes.

Treatment Practices for STREAM/POND PROTECTION	Advantages	Disadvantages
Riprap: 	Can be installed as required; Promotes channel bank stability; Easy to stockpile and place.	NONE.
Culverts: 	Eliminate stream turbulence and turbidity; Provide unobstructed passage for fish and other wildlife; Capacity for normal flow can be maintained while permitting higher flows over a hardened trail surface.	May be expensive; Requires hydraulic design; Subject to washout; Subject to damage by vehicles. Require periodic clean out/maintenance.
Low-Water Crossing: 	Minimizes disturbance to aquatic ecosystem; Minimizes stream turbidity; Inexpensive; Provides safe access during higher flows than normal.	May not be fordable during periods of very high water; May require clean out and periodic maintenance.
Turnouts: 	Easy to install; Diverts concentrated flow away from trails/ditches; Reduces incision within ditches; Protects trails from rilling and gully development.	Requires periodic maintenance; Sediment must be removed before runoff is released onto stable area. Must be adequate room for turnout installation.

Treatment Practice for PROTECTION OF ADJACENT PROPERTY	Advantages	Disadvantages
Brush Barriers: 	Can use materials from on-site; Can be covered and seeded instead of removed; Eliminates need for burning or disposal of debris.	NONE.
Straw Bale Barriers: 	Material is readily available; Filter sediment and reduce turbidity when properly installed.	Require removal; Subject to vandal damage; Flow through straw is slow and use requires considerable ponding area.
Sediment Traps: 	Collect most of sediment from runoff; Inexpensive; Can be readily cleaned; Can be expanded to meet needs.	Do not eliminate all sediment and turbidity; Space is not always available; May require removal at some point.
Energy Dissipators: 	Reduce erosive velocities of runoff, filter sediment, protect channels from degradation.	Collect debris and require cleaning; Require special design and construction materials.
Level Spreaders: 	Convert collected ditch flow to sheet flow over a zero% grade; Simple to construct.	Adequate spreader length may not be available; Sodding of overflow berm may be required; Must be part of a permanent drainage plan; Maintenance required to prevent degradation.

GENERAL ROADWAY MAINTENANCE OR REPAIR PRACTICES

AGGREGATE SURFACE REPAIR OR MAINTENANCE	69
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EXAMPLES OF TYPES OF DUST PALLIATIVES CURRENTLY AVAILABLE	86

AGGREGATE SURFACE REPAIR OR MAINTENANCE

DESCRIPTION: The repair or maintenance of sections of the road surface where there is a loss of aggregate surfacing, a change in the condition or durability of the aggregate or earth surface, or a change in the road or trail surface composition. This includes correcting minor failures in the surface, soft spots, or surface irregularities by grading and/or adding comparable aggregate.

PURPOSE: Repair or maintenance is necessary to provide a proper crown and/or a smooth surface that will promote drainage and improve trafficability. Efforts may include replacing surface materials or surface crowns; recompact for stability; cutting backslopes, cleaning ditches, and shaping foreslopes, and removing material from ditches that may contaminate aggregate surfaces.

MAINTENANCE OF PIT-RUN GRAVEL SURFACES: The same procedures apply for pit-run gravel surfaces as for earth surfaces. Continual shaping is required to maintain a smooth, well-draining and properly crowned surface.

Grading. Any gravel surface receiving intensive and prolonged use will require constant, or at least frequent, maintenance. Maintenance will consist of periodic grading to remove irregularities.

- Blade or drag surfaces very shortly after rain until all ruts and holes are filled. Do not work dry gravel surfaces.
 - Maintain a crown of not less than $\frac{1}{2}$ per ft.
 - Motor graders are required for heavy reshaping, while drags can handle more routine maintenance.
 - Any excess of gravel at the edge of the roadway should be bladed uniformly over the road surface in wet weather. This small windrow should not interfere with good road surface drainage, however.
 - Stockpile additional material in anticipation of prolonged wet periods and seasonal rain activities.
 - The addition of material during warm, dry weather is not an effective use of time or materials.
 - Potholes can be refilled by blading when the surface is moist. Deeper holes may require fill material. When filling potholes in dry weather, the fill material should be moistened and compacted.
- Corrugations.* Corrugations can readily turn into deep ruts if not corrected promptly. Certain pieces of equipment tend to chatter when moving a heavier cut and this can cause corrugations. A poor subgrade, poor grading of the gravel, poor binder material, and incorrect amounts of binder material are also causes of corrugations. More frequent grading can prevent corrugations. If corrugations have been allowed to develop, they can only be removed by thoroughly scarifying, reshaping, and compacting the road section following a thorough cleaning and reshaping of the shoulders and ditches.
- Dust Control.* Calcium chloride has long been used to control or eliminate dust on gravel roads, and to prevent the loss of material and to maintain a dense surface.
- One pound of calcium chloride per square yard of road surface is applied in the late spring, followed by two later applications of $\frac{1}{2}$ lb per square yard during the summer season. The amount of rainfall, volume of traffic, and character of the gravel can affect the quantity of calcium chloride required.
 - This product is applied following a rain event and after completion of required blading or dragging. If the period is dry, water may be sprinkled before application of the calcium

chloride. Where possible, apply the material before the road surface becomes dry and dusty.

MAINTENANCE OF AGGREGATE SURFACES: The same methods used to maintain gravel roads can be used on processed aggregate (crushed stone) surfaces. Surface failures in aggregate courses typically include sharp-edged holes caused by poor drainage. Clean the hole down to solid subgrade and remove all silt, mud, and water. Repair the subgrade with a well-graded soil aggregate. Repair the surface course with a coarse-graded aggregate of the same gradation as the original surface material. Thoroughly compact the repaired layers.

Grading. Remove high spots along the disturbed reach with the first pass of the grader and fill low areas with additional aggregate. Apply additional aggregate at regular intervals suitable to the needs of the site.

NOTE: Aggregate surfaces depend on a blend of stone and soil binder. Where there is adequate soil, repairing with additional granular material will be satisfactory. However, if there is adequate rock on the surface, rather than adding more, reshape the soil and rock to obtain a better blend of the two materials.

- Using as many passes with a grader as required to accomplish the task, spread the surface aggregate evenly and shape to a proper crown of 0.25 to 0.50 in. per ft. Add water as necessary to achieve suitable density. Roll or compact the surface with suitable equipment. Repair and/or replace culverts as necessary.
- When reshaping ditches, scarify the aggregate surface and windrow to the side opposite of the ditch being reshaped to prevent contaminating aggregate. Reshape ditch, backslope, and foreslope using ditch materials to bring up the subgrade. If ditch materials are unsatisfactory for the subgrade, they should be windrowed and disposed of properly.
- After reshaping, move windrowed materials back to the side of the road where ditch work

has been finished. Repeat scarification and windrowing for the other side of the roadway/-trailway. Clean inlet and outlet basins after grading.

MAINTENANCE OF EARTH SURFACES:

- Natural earth surfaces require shaping of the cross section to maintain adequate drainage and to provide a compact, smooth surface.
- Lightly scraping earth surfaces with grader blades, drags, or similar equipment is usually adequate. Drags are often used to float mud and water off a damaged earth road.
- Materials removed from ditches, except silts, can be used to repair shoulders and road surfaces. Remove silts from culverts, ditches, and sediment traps and dispose in a proper location.
- Light blading is usually sufficient to prevent or remove irregularities and keep road surfaces and shoulders free of potholes, ruts, corrugations, and rills. Bridge and low-water crossing approaches should be smooth and level with the surface of the structure.
- The most opportune time to drag or blade is during or immediately following rains as loosened dry material cannot be compacted. When the surface material is too dry to compact, material that is more moist may be brought up from lower in the surface layer with a roto-tiller, plow, or scarifier and blended with the upper surface material. Water should be added to the surface if necessary. Rubber-tired rollers are used for preliminary compaction, with the final rolling being accomplished with a steel-wheeled roller to provide a smoother surface.
- Loose, sandy soils may be bladed smooth with a flat crown to retain moisture. In arid areas, loose material may be pushed off the traffic area; however, this will cause sedimentation of the ditches, culverts, and second order channels.
- Clay or silty soil should not be bladed while it is saturated. Rutting suggests soft spots caused

by too much moisture or an unstable material. Correcting the drainage problem is important. Stabilize small unstable areas with cobbles or clean crushed rock or gravel until a proper repair effort can be undertaken to correct the subgrade, base and surface course at the site of the failure. With muck or peat, the undesirable material must be removed and replaced with a durable, well-draining material.

- Natural earth surfaces must be kept crowned to prevent water from remaining on the surface and saturating the soil. Maintain the crown and superelevation with graders or drags.
- Dust control may be effected through the application of water or dry or liquid chemical stabilizers.

Specifications for Earth Surfaces:

- Clean, repair, or replace culverts as necessary.
- Reshape ditch, backslope, and foreslope, using ditch materials to bring up subgrade and grade. If ditch materials are unsatisfactory for this purpose, they must be removed and replaced with suitable material. This is necessary to return the roadway to, or slightly above, the original grade-line.
- After completion of grading, clean culvert inlet and outlet basins.

AGGREGATE SURFACE GRADING OR BLADING WORK

DESCRIPTION: Smoothing or reshaping aggregate or earth surfaced roadways by means of blading or dragging without adding aggregate or other materials.

PURPOSE: To maintain a proper crown; to fill low spots or corrugations; to remove high spots; to destroy rills, tracks, or ruts; and to promote proper surface drainage.

SPECIFICATIONS:

Dry. In dry weather, blade or drag the surface material from the road edges toward the center by tilting the mold board forward and pulling loose material into place.

Wet. In wet conditions, blade or drag the surface materials from the road edges toward the center of the road. When soil moisture is high, tilt the mold board back and cut and remix the material as it is bladed into place.

- The front wheels of the grader should be tilted 10 to 15 degrees from vertical in the direction the aggregate rolls across the mold board.
- Make additional passes as necessary to pull loosened materials back into surface depressions such as corrugations, ruts, or potholes.
- Remove corrugations greater than 1 in. deep; all stones more than 4 in. in diameter pulled to the surface; windrows greater than 4 in. tall, particularly those at the edge of the road surface; and loose aggregate or other surface materials.

Crown: Make additional passes as necessary to achieve the proper crown on the road surface.

- On a flat grade, establish a crown at 3/4 in. per ft.
- On a steeper grade, establish a crown at 0.25 to 0.50 in. per ft.

- To prevent aggregate from drifting onto bridge approaches, cattle guards, intersections, railroad crossings, etc., schedule periodic blading of road surfaces against the direction of traffic.
- During regular maintenance activities, be prepared to make on-the-spot repairs to potholes, ruts, and rills. Carry a hand shovel on board.

BLADING WITH A MOTOR GRADER:

- The bond between the surface material and the base material can be broken because of blading with an incorrect wheel angle on curves, with an incorrect blade height on hills or rises, or with an incorrect blade height edge setting on the straight sections.
- To prevent breaking of this bond, tilt the blade forward as shown:

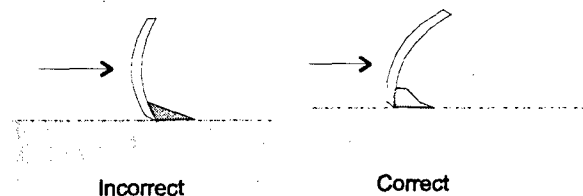


Figure 3-15. Blade positioning.

- To avoid cutting too deeply on a rise or hill, lift the blade.

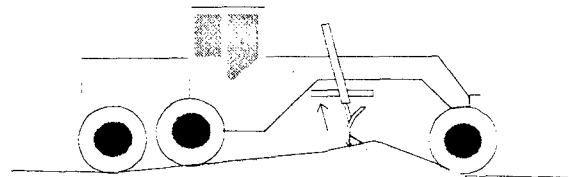


Figure 3-16. Lift the blade on a rise to avoid cutting too deeply.

- To reduce the turning effort on curves, and to make curves shorter, lean the front wheels to lower the frame thereby requiring the blade to be raised to avoid breaking the bond between the surface and base and to maintain a smooth and uniform surface.

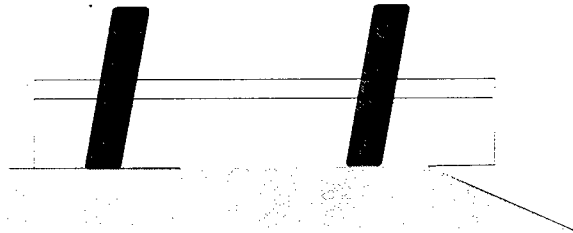


Figure 3-17. Lean the wheels into a curve to reduce the turning effort and make the curve shorter.

- Leaving loose aggregate piled on the road surface will lead to ineffective surface drainage. Ponding, rutting, and degradation of the surface or base will result. Sediments from the road surface will be flushed into the ditches leading to sedimentation of waterways.
- Lower the blade to maintain contact with the surface when blading dips to facilitate removal of loose material.

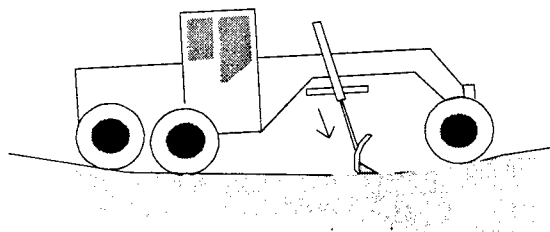
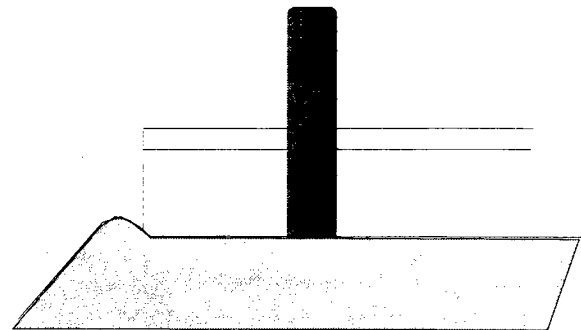


Figure 3-18. Lower blade slightly in dips to maintain contact with the surface to remove loose material.

- Extend the blade out over the road edge when blading the outside edge of the roadway. This will prevent creating a double ditch on the road surface and will remove loose material that may be flushed into the ditches.



Incorrect blade placement at edge of road

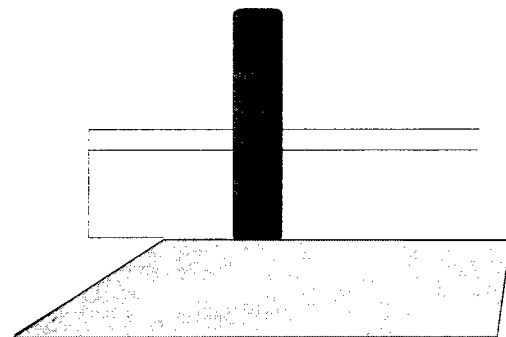


Figure 3-19. Blade correctly placed, extending over the edge of the road.

- On curves, avoid cutting the corner by applying pressure to the toe of the blade if it is on the inside of the curve and to the heel of the blade if it is on the outside of the curve. The pressure applied will cause the rear of the motor grader to skew somewhat, aiding the operator in making a sharper turn.

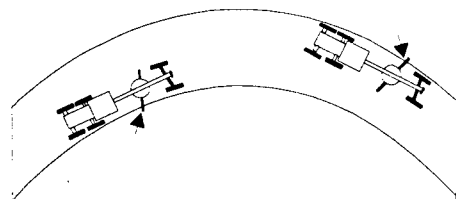


Figure 3-20. Blading on a curve.

- At the intersection of aggregate roads, eliminate crowns at the point of intersection to prevent vehicle bouncing. Gradually reduce the crowns on each road about 50 to 100 ft before the roads intersect. Make a final blading pass to ensure that the crowns have been eliminated and that

the shoulders have an adequate slope at the road where the roads intersect.

- At the intersection of an aggregate road with a paved road, eliminate the crown on the aggregate road some 50 to 100 ft from the point of intersection. Ensure that the grade of both roads is the same at the point of intersection. Use caution to prevent blading loose material onto the paved surface. Remove loose material by pulling it onto the pavement, dropping the blade, and pulling the material back onto the aggregate surface.

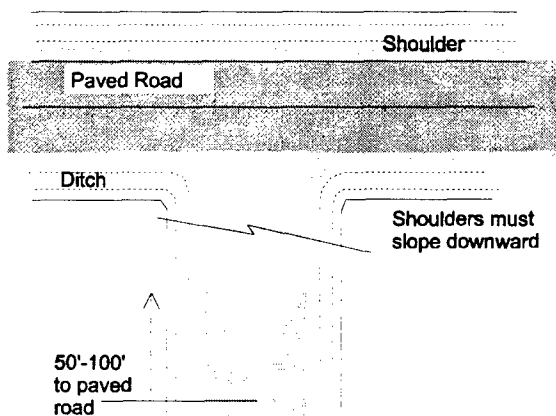


Figure 3-21. Blading at an intersection.

- At a railroad crossing, again, eliminate the crown some 50 to 100 ft from the railroad crossing. Use caution to prevent blading loose aggregate onto the railroad tracks as this could lead to a derailment. Walk the tracks after blading and remove any material with a broom or hand shovel.

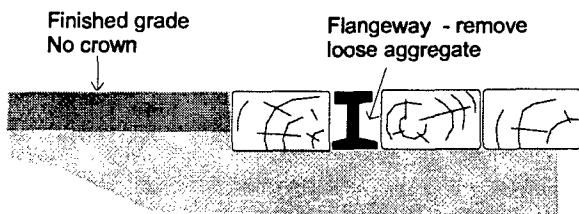


Figure 3-22. Road section at railroad crossing.

- At a bridge or low water crossing, conform the crown of the aggregate surface to that of the bridge or low-water crossing. Shape the crown gradually over 50 to 100 ft to fit that of the bridge or low water crossing. Smooth the approach and pull any loose materials off the bridge or low water crossing using a reverse motion.

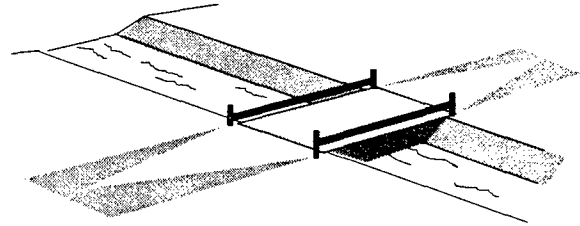


Figure 3-23. Grading at a bridge.

- At access roads or drives, ensure that no drop-off occurs between the access road and the road surface. Both surfaces should be at the same grade. No loose materials should be deposited between the access road and the edge of the roadway. Blade the aggregate to a smooth finish from the roadway into the access road or drive.
- The outside edge of a curved road is higher than the inside edge. This banking or superelevation keeps the vehicle on the road as it travels through the curve. Do not bank materials so steeply that vehicles may slide when the surface is wet or icy or vehicular speed is slow. Bank the curve enough to ensure that vehicles traveling at speed will not drift to the shoulder on the outer edge of the curve. The tighter the curve, the greater the superelevation. Shift the road crown from a center crown about 50 to 100 ft before and after the curve to a side crown (crown to the outer edge of the road). The outside edge of the road should be at approximately the same elevation above the center of the road as the curve on the inside edge is below the center. The surface should describe an almost straight line, tilted from the outer edge to the inside edge.

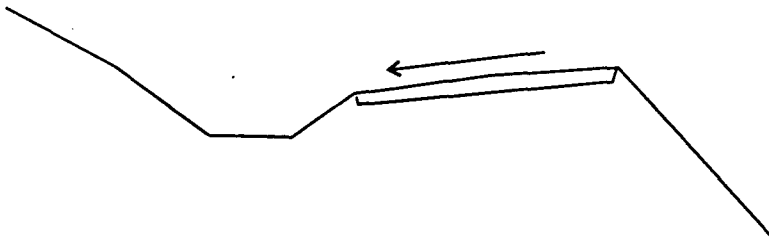


Figure 3-24. The crown on a curve.

AGGREGATE ROADWAY DRAINAGE DITCHES

DEFINITION: A channel adjoining a road or trail road shoulder, having natural, vegetative, or erosion-resistant linings of riprap, paving, or other materials, and constructed to design cross-section and grade for the conveyance of runoff from road surfaces and adjacent slopes.

PURPOSE: Ditches are intended to convey and disperse concentrated surface runoff from road surfaces and adjacent slopes without damage from erosion, deposition, or flooding.

APPLICABILITY:

- Where concentrated runoff will cause damage to trail surfaces or adjacent areas from erosion.
- Where continuous or prolonged flows occur parallel and/or next to roadbeds.
- Where soils are erodible and soil properties are not suitable for handling concentrated flows.
- Where space is available for the ditch cross-section.
- Where slopes are 0 to 2 percent, install an unlined ditch.
- Where slopes are 2 to 5 percent, install a grass-lined ditch.
- Where slopes are >5 percent, install a riprap-lined ditch.
- In rolling or flatter terrain, drainage ditches are generally constructed on either side of the roadbed.
- Drainage ditches should be constructed to the inside of roads routed on the contour of a slope with a berm constructed at the outside edge. Runoff can be reduced by construction of a crest cut or diversion and swale at the top of the slope.

PLANNING CONSIDERATIONS: Due to the effectiveness of mitigation practices on traveled-ways and adjacent slopes, cleaner water is flowing through roadside ditches. The reduction of sediment in the runoff increases the capacity of the water to detach soil from the ditch bottom and sides and transport it to streams or other water-bodies.

For low-volume roads, the unprotected ditch may be a greater source of sediment than the unsurfaced traveledway.

A variety of methods are available to reduce erosion within the ditch. Check dams, erosion mats, jute, riprap, or combinations of natural and artificial materials are among techniques in use.

Tests on erosion mats reveal less than 0.25 in. of soil loss with flow rates up to 9 cu ft/s on a 12 percent slope. Velocity reduction using the mats ranges from 56 to 78 percent, allowing grass to become firmly established within the ditch bottom. These mats can be subject to damage by mowers and graders.

- The most common method of erosion control within ditches is the placement of rock liner or riprap. The size of the required riprap is designed as a function of the flow rate, channel slope, and channel shape. Highway Research Board Report 108 (1970) and USDA Forest Service General Technical Report INT-264 (1989) each provide graphical solutions and basic design equations, respectively, for a design procedure suitable for determining riprap size for unpaved roads.
- Using the design equations, the initial flow depth (d) for trapezoidal channels is estimated by a regression equation solving for d using flow rate, channel slope, channel side slopes, and a Manning n of 0.03. This procedure calculates the required d_{50} (diameter of 50

percent of the material) for riprap to maintain channel stability for the selected design factors.

- Riprap or other channel liners should be employed when design flow velocities exceed the tolerance of grass or where grass lining is inappropriate.
- Ditches combining grass banks with riprap bottom lining may be used where velocities are within allowable limits for grass lining along the channel sides, but long-duration flows, seepage, or a high velocity flow would damage vegetation in the channel bottom.
- Where drainage area exceeds 10 acres, it is recommended that riprap and grass-lined ditches be designed by an engineer experienced in channel design.
- The establishment of dense, resistant vegetation is essential in and around ditches, to include road shoulders. Grass, legume, wild flower, and crop seed or seed mixtures should be considered.
- On long or steep slopes, it may be necessary to divert runoff from the ditch via turnouts or crossroad drainage culverts to prevent erosion.

Ditch Locations: Ditches perform optimally when placed in undisturbed soils or rock, therefore avoid installation of ditches in fill areas.

- In a cut and fill section, the road surface will be side-crowned so the runoff drains into a single ditch at the toe of the highwall.
- In a section that is cut on both sides, ditches should be constructed on both sides of the road.
- In fill sections, the toe of the slope must be protected with parallel interceptor ditches.

Cross-Sectional Slopes: The ditch slope from the edge of the road surface to the ditch bottom (fore-slope) should be 4:1 or flatter to allow maintenance mowing and to provide a safe travel surface for

emergency purposes. The slope should never exceed 2:1.

- The outside ditch slope varies with the soil type. If the material is rock, the slope may approach vertical. If the material is less consolidated, the outside slope should be 2:1 or flatter.

Ditch Outlets: All outlets must be stable. The exit velocity for the design flow must be non-erosive for the existing field conditions. Turnouts, level spreaders, and energy dissipation structures (aprons) are typically used to reduce degradation from runoff.

- The thickness of riprap channel linings must not be less than 1.5 times the maximum stone diameter for optimal erosion protection.

Area of Drainage: Where the ditch conveys the runoff from an area of drainage that exceeds 10 acres, both the grass-lined and riprap-lined ditch should be designed by an engineer experienced in channel design.

DESIGN CONSIDERATIONS: Soil type, depth of the road base, storm design frequency, percent grade, and estimated runoff contributing water to the ditch must each be considered when designing the drainage ditch.

Ditch Design Shapes: Ditches may be constructed in one of three different shapes:

- *V-shaped:* V-shaped ditches are the simplest to construct, but should only be used where the quantity of runoff is very small and within short, grassy reaches. This is the most unstable ditch type and will require continuous maintenance and repair if not properly hardened against erosion. Where V-shaped ditches are paved, the velocity of concentrated flow is extremely high and energy dissipation and erosion control can become costly and labor intensive.
- *Parabolically-shaped:* Parabolic-shaped ditches are more difficult to construct BUT are the

easiest to vegetate and will convey the largest volumes of water with the least erosion. The swale-like shape is easy to maintain, aesthetically pleasing, and usually best suited to site conditions.

- **Trapezoidally-shaped:** Trapezoidal-shaped ditches are also simple to excavate and are often used where runoff volumes may be large. They are the preferred channel shape due to minimal maintenance requirements, ease in stabilization, and accessibility. Grass-lined, trapezoidal ditches can be used where runoff volumes are high and the slope low enough to reduce the potential for erosion. Riprap-lined trapezoidal ditches permit high volume, high velocity flow along steeper reaches.

Design Dimensions: The design dimensions of the ditch vary with the percent grade, ditch shape, and depth of flow. The depth of flow is dependent on the percent grade and texture of ditch materials.

- Dimensions may be determined by using design tables with appropriate retardance factors or by using Manning's formula using an appropriate "n" value. When retardance factors are used, the capacity is usually based on retardance (C) and stability of retardance (D).
- The depth and width of the ditch should be proportioned to meet the needs of drainage, soil conditions, erosion control, carrying capacity, and site conditions.

Design Velocity: The allowable velocity within the ditch is based on the liner material.

See the design approach based on erosion resistance of various liners developed by the Federal Highway Administration presented in the appendix.

Compute the velocity of runoff in a ditch section using Manning's equation with an appropriate "n" value for the selected lining.

Design Gradient: The design gradient of the ditch can be determined by the Froude Number. If the Froude number is between 0.7 and 1.3, flows may become unstable and the designer should consider modifying the road and ditch slope. If ditches must be designed for supercritical flow (Froude number >1), they should be straight unless special design procedures are used.

The ditch grade should be uniform or gradually increasing to avoid sedimentation. Where the grade is excessive, channel liners or grade control structures will be required to prevent incision.

Design Slopes: Banks on grassed ditches are typically constructed at 3:1 or flatter slopes to aid in the establishment of vegetation and for maintenance. The banks of riprap-lined or paved ditches are typically constructed at 2:1 or flatter.

Design Depth: Wherever a subbase is placed, the depth of flow in the ditch must not exceed the lower level of the subbase material. Wherever a freeboard is required, the depth of the ditch should exceed the center depth of flow by no less than 0.5 ft. Wherever a ditch lining material is installed, increase the depth of the ditch by 0.5 ft on each side.

Ditch Protection: Ditches constructed on steeply sloping lands may require protection to prevent erosion and sedimentation. Grass, sod, coarse gravel, crushed stone, riprap, and concrete are among the preferred ditch liners for erosion protection.

Erosion Mats or Fabric. The various mat-style channel liners can effectively reduce soil loss while sustaining runoff flow rates up to 9 cu ft/s on a 12 percent slope. Runoff velocity can be reduced from 56 to 68 percent while seeded grasses are protected until they have established a good root mat. A primary disadvantage with mats, nets, or liners is that during regular road and ditch maintenance, the grader or mower may snag the material and rip it out of the ditch.

Riprap Lining. Probably the most common and durable ditch lining material is riprap. The flow

rate, ditch slope, and ditch shape must all be considered in the design of the riprap thickness or degradation could be exacerbated. It is recommended that riprap be applied to a depth of 1.5 times the maximum stone size, but no less than 6 in. The maximum stone size is determined to be 1.5 times the design d_{50} .

Filter fabric laid down between the riprap and the erodible surface will greatly reduce the potential for degradation or failure of the riprap protection.

There are a number of computer programs available to aid in the determination of appropriate riprap size for roadside ditches. To decide if a filter layer is required, determine the d_{50} of the underlying material.

$$\frac{D_{50} \text{ Riprap}}{D_{50} \text{ Underlying Soil}} < 40 \text{ No filter required}$$

Example: The underlying soil has a d_{50} of 1.1 mm and the design d_{50} of the riprap was calculated to be 2.4 in. or 61 mm. The ratio of $61/1.1 = 55$. This is greater than 40 so a filter fabric will be needed to protect against degradation. A single layer of a durable plastic filter fabric will probably be sufficient.

To continue this example, assume that the road to be surfaced will receive crushed stone with a d_{50} of 1 in. (AASHTO standard aggregate No. 4). It is determined that the peak flow rate in the upper 150 ft of the ditch is only 0.07 cu ft/s. Repeating the calculation for riprap size using this new peak flow rate yields a d_{50} of 1 in.. Since the road surfacing aggregate is 1 in. also, it can be used to line the upper 150 ft of the ditch while the lower 350 ft are lined with the larger 2.4 in. riprap.

Sediment traps: Traps should be used to filter sediment-laden runoff conveyed through ditches from disturbed road surfaces or adjacent slopes.

Check dams: Check dams constructed within ditches reduce the velocity of flow and encourage sediment deposition. They may be used instead of channel linings or with them. Construction materials include riprap, logs, planks, or straw bales.

Silt fencing is designed to filter sediment from sheet flow and should not be used for a check dam.

Culverts: Culverts are used to convey runoff from ditches to constructed drainage channels, natural channels, or stabilized outlets. They must be hydraulically designed to convey runoff from a 10-year, 24-hour storm at a minimum, although the 25-year, 24-hour event may be more practical in areas subject to significant rain events. An engineer or experienced erosion control specialist should determine culvert pipe shape, size, and spacing, although many nomographs and computer programs are currently available for use by non-engineers.

Road Grade (%)	Maximum Culvert Spacing (ft)
0-3	1000
3-6	800
6-10	500
10 +	300

Table 3-3. Spacing of culverts by road grade.

- Many culvert rehabilitation or maintenance problems can be avoided if care is taken to install culverts at a minimum 1 percent grade to assure drainage, compact 12 to 18 in. of fill over the culvert following installation, protect inlets and outlets with headwalls, trap debris before it reaches the culvert inlet, and install discharge aprons at the outlet to prevent erosion.

Ditch Design Capacity: At a minimum, ditches should be designed to carry the peak runoff from the 10-year, 24-hour rain event. In areas subject to seasonal storms, it may be advantageous to design for the 25-year, 24-hour event. Where flood hazard exists, increase the capacity according to the potential damage.

Roadbed Design to Ensure Proper Drainage:

Roadbeds should be designed, constructed, and maintained to safely handle the peak runoff for a 10-year, 24-hour storm at the minimum, although it may be more practical to design for the 25-year storm if the area is subject to significant storm events. Roadbeds prone to repeat washouts following seasonal rain events, have not been adequately designed or constructed.

- Roadbed surfaces need to be sloped toward the drainage ditches to minimize surface degradation.
- Roads on a slope contour or diagonal have a side crown and one full-width crossfall. Roads on flatter lands often have a center crown and two equal crossfalls. The crossfall or cross-slope of the roadbed should be 0.25 to ½ in. per ft.

Example: On a single-lane, side-crown roadway, the fill-slope side would be about 6 to 12 in. higher than the cut-slope side. The runoff would flow from the outer-edge to the inner edge and into a stabilized drainage ditch.

Example: On a single-lane, center-crown roadway/trail on flatter terrain, the crossfall would be about 3 to 6 in.. Runoff will flow over half the trail width, from the center to ditches on either side.

CONSTRUCTION CRITERIA: Ditches should be constructed and maintained to the lines, grades, and cross sections shown on the construction or rehabilitation plans.

- Shape the ditch to neat lines and dimensions plus a 0.2-ft overcut around the ditch perimeter to allow for bulking during seedbed preparation and sod buildup.
- Excavate ditches at the toe of fill slopes and at the top of cutslopes.
- Material excavated from ditches at the top of cut slopes should be placed in a windrow

between the ditch and the top of the cut slope to create a berm and swale.

- All suitable materials excavated from inlets, outlets, and intercepting ditches should be used in construction, maintenance, or rehabilitation of the roadway.
- Remove and properly dispose of all excess soils to protect surface waters from sedimentation.
- When constructing or rehabilitating ditches, clear the right-of-way of trees, stumps, roots, loose rock, and other objectionable materials and backfill holes with suitable material.
- Place filter or bedding materials as required to line and grade in the manner specified immediately after ditch preparation.
- Perform all ditch construction to keep erosion and sedimentation to a minimum. Immediately upon completion of the ditch reach, vegetate all disturbed areas and/or otherwise protect them from soil erosion.
- Where ditch construction will take more than 30 days, stabilize by reaches.
- Protect ditches from sedimentation by the effective use of diversions, turnouts, sediment traps, protected side inlets, and vegetative filter strips.
- The revegetation method is determined by the severity of site conditions and selection of species.

DRAINAGE STRUCTURE MAINTENANCE:

Studies suggest that up to 80 percent of the total annual sediment contributed to a water body via the roadway is conveyed through the ditches.

- To prevent degradation, maintaining the ditches and associated drainage structures free of weeds, brush, sediment, and debris that can constrict or hinder flow is important. Sources of sediment within and next to the ditches must be mitigated promptly.

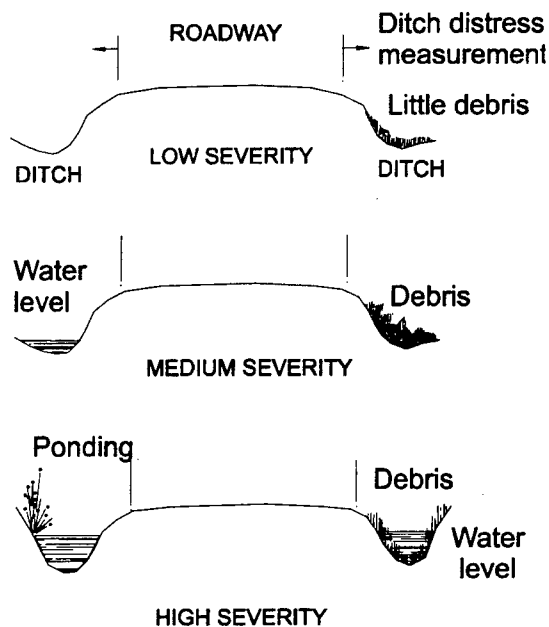


Figure 3.25. Inadequate roadside drainage - levels of severity.

- Check all road shoulders for bank stability and evidence of piping or scour holes. Rills on the shoulder or road surface may preclude gully extension.
- Periodically smooth and shape the ditch and shoulders using a motor grader to ensure uninterrupted and broad-based flow of runoff. This is necessary to maintain the original bottom, cross-section, grade, and line of the ditch and shoulder
- Maintenance passes should be adequate to shape and dress the foreslope (shoulder side) and backslope (opposite side) of the ditch to design banks of not less than 2:1.
- Banks should be maintained at 3:1 or 4:1 if mowing is used to control vegetation, if shoulder/base materials are unconsolidated (loose), or if vehicles may travel on the shoulder/bank.
- Ditch bottoms should be maintained in a flat or gently rounded shape because V-shaped cuts inevitably lead to incision and erosion.
- Avoid any unnecessary cutting or blading that destroys natural ground cover during cleaning and shaping.
- Where moisture or soil conditions are less favorable, mitigate erosion by lining the ditch with riprap or appropriate channel lining fabrics.
- Inspect check dams regularly and clean often. It is important that the weir notch on check dams be kept free of debris or the check dams will be subject to lateral erosion. Ensure that the apron below the check dam is intact and add or replace materials as necessary to prevent degradation.
- Erosion of the ditch bottom can be reduced by installing channel lining or protection materials.
- One disadvantage to reducing the sediment load to roadside ditches is that the cleaner runoff has an increased ability to detach soil particles from the ditch bottom and banks and to transport that soil downslope to water bodies. Therefore, control of the velocity and volume of runoff within the ditches becomes essential.

Specifications for Ditch Maintenance:

- Inspect grass-lined channels after every rain event during the establishment period and correct minor erosion promptly.
- Give special attention to outlet and inlet sections and other points where concentrated flow exists.
- Remove all significant accumulations of sediment to maintain the designed carrying capacity. Find the source of extraneous sediment and take corrective actions.
- Maintain a vigorous vegetative cover in and beside the ditch to protect the area from erosion and scour during out-of-bank flow and significant rainfall.

Specifications for Sediment Trap Maintenance:

- Schedule periodic removal of debris and sediment from traps, particularly after significant rain events.
- Dispose of sediment in proper disposal area. Do not pile sediment near the trap.
- Inspect and clean debris from around risers or spillways.
- Inspect channel inlets and outlets and repair damaged areas promptly.
- Inspect sediment trap spillway or weir for damage and correct promptly.
- Repair or replace damaged structures.
- Remove sediment traps that have served their intended purpose and rehabilitate the immediate area.

Specifications for Culvert Maintenance:

- Frequent inspections are critical to learn if culverts are adequate to convey the volume of runoff received.
 - Clean culverts by hand following rain events. They are only effective when kept free of debris and sediment.
 - Clean debris from 100 ft above the inlet to 100 ft below the outlet to prevent pooling.
 - Debris-trapping devices should be installed up-channel from culvert inlets as required and periodically cleaned to remove accumulated debris.
 - Headwalls will prevent undermining or lateral degradation at the inlets and outlets, thereby reducing the maintenance effort.
 - At sites where scour holes or plunge pools have developed, install properly designed discharge aprons to reduce the erosional energy of the discharge.
- Harden or line approach ditches with riprap or other appropriate channel protection materials.
 - Properly dispose of removed sediments.
 - Cut back or remove undesirable vegetation interfering with inlet or outlet flow.
 - Promptly repair or replace culverts that show evidence of settling, are degraded, or have been crushed by vehicles.
 - Where culverts must be replaced, excavate a trench at least as wide as the culvert diameter plus 2 ft to allow thorough compaction of the bedding material under and around the culvert.
 - Where culvert foundation material is unsuitable, excavate to a depth of 2 ft below the culvert invert and one width of the culvert diameter plus 4 ft. Replace the unsuitable material with appropriate granular material. Compact replacement material thoroughly.
 - Where rock or hardpan is found, excavate to a depth of 1 ft below the foundation grade and a width of 2 ft plus the diameter of the culvert. Replace rock with suitable granular material and compact thoroughly.
 - Culverts under roads should have a minimum of 12 to 18 in. of base and surface materials over them to protect from the weight of vehicles.

Specifications for Maintenance of Paved Ditches:

- Periodically inspect ditches and remove debris, undesirable vegetation, and sediment.
- Seal breaks and cracks.
- Inspect outlets for degradation and make repairs promptly.

Specifications for Maintenance of Underdrains:

- Periodically inspect drains and remove debris, undesirable vegetation, and sediment.

- It may be necessary to flush silt and sediments with high-pressure water.
- Repair or replace damaged underdrain pipes.

Specifications for Maintenance of Adjacent Slopes:

- Control of erosion and sedimentation on adjacent slopes is most commonly accomplished via the following methods: straw with asphaltic tack, straw with a mat or net, straw alone, erosion control mats, wood chips or rock, or hydromulch.
- The steeper the slopes and the more silt in the soil, the less effective the treatment.
- Proper installation is a critical factor in the effectiveness of erosion control materials.

Specifications for Roadside Mowing:

- Roadsides are mowed to control the growth of natural and planted grasses for safety reasons, scenic enhancement, drainage improvement, weed and brush control, and to reduce the hazard from fire.
- Schedule semiannual or annual mowing activities depending on the length of the growing season in the region.
- Mow in August where snow drift lines must be eliminated and/or to improve roadside aesthetics.
- Fall mowing is recommended where field mowing is limited to once a year. Avoid springtime mowing of field grass because of the damage that mowing equipment can do to loose or wet ground. The first mowing of the season should occur after the plant has bloomed. Avoid cutting wild flowers until the seeds have matured.
- Mowing 15 ft out from the edge of the roadway is generally recommended to promote good drainage. Areas outside the mowing limits should be allowed to return to their native state by encouraging natural growth or by the plant-

ing of indigenous trees, shrubs, flowers, and ground cover appropriate to the immediate environment.

- Avoid mowing newly planted roadsides until the second year. After the first cutting of the season, avoid cutting until field grass has reached 8 in in height. Do not cut closer to the ground than 4 to 6 in until a good sod has been established. Slopes steeper than 2.5:1 within 20 ft of the roadway should be encouraged to grow native grasses, flowers, and other low profile vegetation.
- Mowing efforts should extend a minimum of 20 in from the road surface ONLY where mowing is required to control weeds, eliminate a snow drift line or to improve visibility where a hazard may exist.
- Appearance and delineation mowing should be performed to approximately 10 ft from the surface edge. An exception would be for instances within 0.25 mile from the cantonment area (or as specified by the installation) where the full width of the mowable right-of-way should be mowed.
- Measure the mowing width and acreage of each roadway and establish sections by width of each side of the roadway.
- Designate and prepare a written schedule for each mower operator by type of mower on each roadway mowing width section to reduce turning, unnecessary passes, and mower congestion.
- Use 8 ft (plus) mowers on the wider sections and schedule for an odd number of passes to avoid deadheading when moving to the next section and to reduce the number of turn-arounds.
- Rotary mowers of 5, 7, or 8 ft in width are most suitable for mowing wide shoulders and fore-slopes and for tight work around obstacles.

- Slope mowers are effective, but may be considered special equipment.
- Sickle bar mowers may be less than productive except for cleaning up around obstructions, or narrow shoulders, or within V-shaped ditches.
- Space mowers at a minimum of 0.25 mile apart and keep teams to less than three mowers.
- Hand mowing should be minimized, but weed-eaters and hand mowers may be required around culverts, checkdams, discharge aprons, etc.
- Mowers should be set to 4 to 6 in. in height. The optimum cutting height is 5 in.
- Do not schedule mowing unless the grass and weeds are a minimum of 12 to 14 in. tall.

Avoid mowing the following areas:

- Wetlands, swampy areas, boggy areas, or ponded water.
- Areas next to gully heads or banks.
- Areas with large rocks or other obstructions.
- Shoulder edges where shoulder material has been left in a windrow.
- Adjacent slopes.
- Slopes steeper than 2.5:1 unless side-mounted slope mowers are used. NOTE: Newer mowers have been recently developed that can accommodate slopes approaching 1.5:1.

Avoid the Following Mowing Practices:

- Mowing too often.
- Mowing at the wrong time.
- Mowing too short.
- Mowing steep slopes — unless a need is definitely indicated.

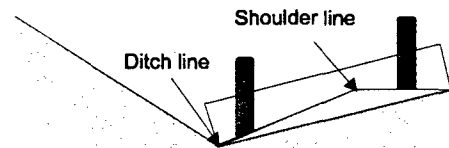
- Inconsistent mowing patterns and incomplete mowing of a regularly mowed area.
- Mowing when wet.
- Damage to trees and shrubs due to careless mowing.

Specifications for Shoulder Maintenance:

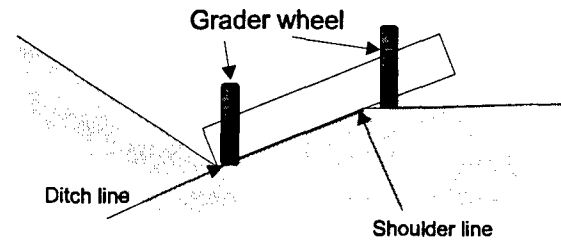
- Shoulder maintenance involves the reshaping and smoothing of shoulders between the road surface and the ditch with addition of material as required to provide a satisfactory drainage surface and safe surface for emergency driving or stopping.
- The first pass will be to remove high spots and pull material against the aggregate road or trail surface.
- Add additional material as required to fill low areas or at regular intervals along the shoulder.
- The slope of the shoulder should not be less than 3/4 in. per ft nor greater than 1 1/2 in. per ft, depending on the surface texture and roadway grade.
- Enough passes should be made to ensure a smooth shoulder surface and to blend the shoulder surface elevation with the road surface.
- Where soil moisture is low, add water and compact the shoulder with a roller or suitable equipment.
- Keep shoulders smoothly graded so they drain water away from the surfaced area and toward the ditch.
- Material cleaned out of ditches can often be used to rebuild shoulders.
- Establishment of a vegetative cover on shoulders can greatly reduce the amount of sediment conveyed into ditches from road surfaces, and provide a more stable shoulder slope.

Grading Work in Ditches:

- Placing the blade at an incorrect angle or dips in the ditch or shoulder can result in narrower shoulder widths.
- Undercutting the backslope while cleaning the ditch will cause slope toe failure and slumping of the materials back into the ditch. This problem can be remedied by tilting the blade back and running with the toe of the blade on the ditch line. Riding with the wheels in the ditch should keep the blade on the ditch line.
- When the operator is running with the wheels in the ditch and is not watching the blade, variations in the ditch line can develop. The blade rises when the wheels roll over high spots and then digs down into the ditch bottom when the wheels drop back down.
- Before blading, mark ponded water or wet spots in the ditch. Correct these problems by lifting the blade slightly at low spots and digging in a bit deeper at high spots.
- Dips in the road grade are a problem similar to that of ditch ponding. The problem arises in the ditch at the low point in the dip. This can be corrected by blading a new ditch line that effectively removes the low spot.



Incorrect grading pattern leading to reduced shoulder width



Correct grading pattern

Figure 3-26. Proper grading at the shoulder.

EXAMPLES OF TYPES OF DUST PALLIATIVES CURRENTLY AVAILABLE

Liquid or solid calcium chloride
 Liquid magnesium chloride
 Asphaltic emulsion
 Petroleum resin emulsion
 Ammonium ligno-sulfonate
 Plant-based emulsion
 Polymer resin
 Acrylic resin
 Resin-modified emulsion
 Biodegradable organic chemical

Descriptions of Various Products Commercially Available as of 1995:

Soil Stabilization Products Company, INC.
 Merced, CA

Road OYL: A resin modified emulsion that has been field tested in Desert Storm, Somalia, Fort Leonard Wood, and Fort Carson. It is produced from the combination of selected fractions of natural tree resins to form a strong and versatile bonding agent. This product is a high bonding strength emulsion that is not water soluble. Developed for use in dust control treatment, erosion control, and pavement applications. It can be diluted for surface penetration purposes such as dust control, erosion control, prime coats, tack coats, fog seals, seal coats, and sand seals.

EMC Squared: A biocatalyst formulation designed to improve, economically, the cementation and stability of compacted aggregate and earth materials for bearing strength applications or for resistance to erosive forces of traffic or weather. It is supplied as a highly concentrated liquid catalyst and applied in dilute water solutions. It acts to reduce moisture infiltration, frost heave, rutting, washboarding, unraveling, gravel loss, and dust on unpaved roads. It can also be used to stabilize road shoulders, apron areas, test ranges, slopes and embankments for resistance to wind and water erosion and dust.

Dustrol: A biodegradable, organic chemical formulation. A proprietary blend of complex surfactants. This product provides a low cost protective treat-

ment to improve the effectiveness of water truck programs to control dust on unpaved roads.

DEI Emulsions, Inc., Mansfield, OH

Dust Bond: A petroleum-based resin emulsion produced from a base resin extracted at the refinery so that it does not constrain any polluting factors. This product acts as a dust suppressant and surface stabilizer. It has been effective on haul roads, for slope stabilization, and in control erosion on coal and coke piles.

Having many of the better qualities of an oil-based product, it is effective, practical, long lasting, and can be diluted with fresh or salt water. It has been tested and found effective on steep, sandy slopes and embankments as well.

Flambeau Paper, Park Falls, WI

Ligno-sulfonate: A water-soluble by-product of the paper processing industry. This product has been used on mining haul roads across the country for decades. It has been found to work well in glacial tills and any other soil containing no less than 15 percent fines or any soil with clays. It is approved by the EPA as environmentally safe, however, it has a high BOD content and a 200 ft buffer between waterbodies and the application area is required. This product is also used to make gum, hard candies, and potato chips.

Base Marketing Intl., Merrit Island, FL

Base Seal: A nonpetroleum-based, water-soluble resin with a proprietary formula. This product has been designed and field tested specifically as a dust palliative and soil stabilizer for unpaved roads. This resin provides dust control and stabilization of the uppermost 2 to 4 in. of surface material. It is effective only on soils with 15 percent fines passing the No. 200 sieve.

Top Coat: A water-soluble acrylic resin. This product is an environmentally safe and low-cost chemical solution that is mixed with water and applied to soil. It provides up to 100 percent dust-abatement, soil sealing, and soil erosion control. It will resist degradation from alkaline materials and

sunlight and will not redisperse in water after curing.

Liquidow, Kawkawlin, MI

Liquidow or DowFlake: Solid or liquid calcium chloride is used to control dust and provide base stabilization for unpaved roads. It is a hygroscopic material that absorbs humidity and keeps road surfaces moist to control dust. Chlorides can be corrosive. The liquid form affords a more even distribution of the product. The solid form can be spread directly on unpaved surfaces as long as water is added to the surface immediately before or after application. This product provides greater density with less compactive effort, maintains optimal moisture control, maintains minimal required binders, provides better surface uniformity, prevents dust and protects against frost heave. It has been found to reduce aggregate loss up to 80 percent and maintenance costs up to 33 percent.

No endorsement of products is intended.

4 Vegetative Erosion Control

4.1 Introduction

Vegetative soil stabilization is the preferred method of preventing erosion and sedimentation within ditches, on road shoulders, and on adjacent slopes. It is cost-effective, self-perpetuating, easily maintained, and aesthetically pleasing. Vegetation reduces runoff velocity, absorbs raindrop energy, increases infiltration, binds soil with roots, and protects exposed slopes from the wind and intense solar radiation.

Grass mixtures are typically the most effective type of plant for erosion control. Grasses germinate quickly to provide a lush ground cover. Trees and shrubs are not as effective for initial erosion control because they do not protect enough of the soil surface. Herbaceous plants (wild flowers) provide better protection than trees and shrubs. However, they are a bit less effective than grasses because many produce tap roots. Effective soil stabilization requires a dense mat of roots. A seeding mixture with grasses and legumes, to include some wild flowers, will produce the most effective and attractive ground cover in a short period.

4.2 Vegetative Control

Grass-lined ditches are less prone to erosion because the grass reduces the velocity of the runoff and binds the soil with a fibrous root mat. A well-maintained grass-lined ditch is safe and aesthetically pleasing. Ditches lined with grass are only appropriate on slopes less than 15 percent or 9 degrees. Beyond that, the erosive velocities of runoff exceed the resistance potential of the grass, and degradation will occur. One problem with

grass-lined ditches is that they require more space than paved or rock-lined ditches.

Design Criteria: Ditches should be designed to accommodate the 10-yr, 24-hr storm at a minimum. If the potential for roadway damage, flooding, or closure is high, consider the 25-yr, 24-hr storm design.

Ditch Shape: Ditches typically exhibit three shapes: V-shaped, parabolic, or trapezoidal. V-shaped ditches are appropriate along short sections of gently sloping roadbed. The V-shape can handle higher volumes of runoff and is easy to maintain. However the v-shaped ditch is prone to greater erosion and maintenance requirements. The broad-bottomed trapezoidal ditch requires less depth of excavation than the other shapes. Sediment may accumulate in the trapezoidal ditch during low flow periods. They require thorough cleaning periodically. Trapezoidal ditches should have banks with slopes no greater than 2:1. The flatter the ditch bank is, the easier it is to cross with a vehicle, to seed and to maintain. Over time, trapezoidal ditches have a tendency to become parabolic in shape.

Parabolic ditches can be easily cut with a bulldozer or scraper. While a grade-all cuts a very clean trapezoidal ditch, a dozer or scraper can also be used, provided the blade is the width of the bottom of the ditch. Excavation of the V-shaped ditch can be accomplished with any blade-type equipment.

4.3 Plant Selection

Plants should be selected based on their effectiveness for erosion control on the site that requires stabilization. Important selection factors include the following items:

- Dense growth and fibrous root mass
- Rapid germination and growth
- Ease in planting
- Adaptation to critical sites or poor soils
- Self-perpetuating species
- Seed availability

- Low maintenance requirements
- Low risk of a fire hazard
- Drought tolerance

Annual Grasses: Including annual varieties of grasses or cereals into the seed mixture is beneficial because they are quick to germinate and provide ground cover. They serve as a 'nurse' crop for the establishing perennial seedlings. Barley (*Hordeum vulgare*), annual ryegrass (*Lolium multiflorum*), and oats (*Avena sativa*) are effectively used in the eastern and western parts of the country for erosion control.

Perennial Grasses: Perennial species can take longer to develop and require more moisture and soil than the annuals mentioned above. They may not compete well with annual grasses initially. However, they do produce thick, long-term ground covers for disturbed areas. Red fescue (*Festuca rubra*), tall fescue (*Festuca arundinacea*), and perennial ryegrass (*Lolium perenne*) are examples of perennials commonly used for erosion control.

Legumes: Legumes are included in the seeding mixture because of their ability to fix nitrogen from the air. This makes them very important in areas with deficient soils. Seed mixtures for erosion control frequently incorporate red clover (*Trifolium pratense*), rose clover (*Triflorium hirtium*), and some birdsfoot trefoils (*Lotus corniculatus* and *Lotus tenuis*).

Flowers: Use wild flowers only on the poorest soils with the least weed growth or in areas where no grass seeds will be planted. Wild flowers are intolerant of competition from grasses.

Lists of plant species found suitable for erosion and sediment control are available from many state and Federal agencies involved in erosion and sedimentation control efforts. The USDA Natural Resources Conservation Service (NRCS) has Plant Material Centers in 22 states. The NRCS can often provide the most effective plant list for erosion control in specific areas.

4.4 Seed Application

Seeding can be accomplished by hand-casting, mechanical seed drill, or hydraulic jet (sprayer). The most important considerations with seeding are uniform distribution and coverage of the seed by no more than 1 in. (2.54 cm) of soil. When possible, seed should not be covered by more than 0.25 to 0.5 in. (.635 to 1.27 cm) of soil.

Whirligig spreaders are effective on smaller, steeply sloping, or rocky sites. Approximately 1 to 3 acres (.4047 to 1.21 ha) per hour can be covered using the whirligig spreader. Once seed is cast, covering the seed lightly by raking or dragging a chain over the seedbed is important.

Hydroseeding works best for seeding and mulching steep slopes, rocky slopes, or critical areas where vehicular traverse is difficult. A slurry of seed, fertilizer, mulch, water, and a tackifying agent can be sprayed from a vehicle-mounted tank (200 to 20,000 gal or 757.2 to 75722 liters) onto those areas.

Drilling seed is common on farmlands and the same methods are used to seed disturbed areas that are gently sloping and not too rocky. Drilling provides the most efficient and effective seeding method. In one step, fertilizer is applied and the seed mixture planted and covered with the proper amount of soil. With drilling, it may be possible to reduce the fertilizer and seed rates significantly.

4.5 Use of Fertilizers and Amendments

Without proper selection and application of fertilizer, most seeding projects will be subject to failure. If any of the three elements (nitrogen, potassium, phosphorus) found in fertilizers are absent from the disturbed soil, the seed will fail to thrive. The amount and composition of the fertilizer required on any specific site is entirely dependent on the soil conditions at that site. Field personnel can conduct onsite chemical soil tests to determine nutrient needs. Occasionally, the local soil conservation office can provide an analysis

and recommendation for fertilizer composition. No matter the method of testing, a variety of soil samples should be analyzed, because of the wide variability in soils across a disturbed site.

Assess the acidity, or pH, of the disturbed soil when the soil composition is determined. If the soil is too acid for plant success, ground agricultural lime (pulverized limestone) can be added to the fertilizer mix. Alternatively, lime can be applied separately to raise the pH to a more suitable level. In arid areas, salinity may be an issue to deal with also. Salt-tolerant plants must be considered in these areas and drainage should be manipulated to leach salts from the surface soils.

4.6 Mulch Application

Properly applied mulch will help keep seed, soil, and fertilizers in place and protected from, high winds, rains, runoff, solar radiation, high temperatures, and moisture loss. Many materials have been used for mulch; investigating local variations may be beneficial. The most commonly used mulch materials are straw and wood fiber.

Straw is considered the most effective mulch at present. Spreading straw by hand over small areas or blowing it across seeded areas is common. To prevent straw from blowing away in high winds, it is anchored in place by crimper, roller, disk, or punch. Straw is usually covered with a net or anchored by spraying with a chemical tackifier.

Wood fiber with green dye added for visibility is also inexpensive, commercially available, and easy to apply by means of a hydroseeder. While it does not provide much erosion control itself, wood fiber does serve to bind or hold seeds to the soil surface until they can establish themselves. Wood fiber is recommended in place of straw in several situations. Among these are sites with steep slopes (2:1 or greater) and sites where it is unsafe for vehicular traverse within 50 ft (15.24 m) of the seeded site. Wood fiber also works well on sites where weed growth or fire hazards are potential problems, or where high winds may hinder straw application.

One of the most cost-effective mulching techniques involves blowing straw, at a rate of about 3000 lb per acre (1360.8 kg per .4047 ha), then applying a chemical tackifying agent. Although the cost of applying straw may initially be greater than hydroseeding, over time, straw provides much greater plant protection before germination and longer erosion protection.

**GENERAL VEGETATIVE EROSION CONTROL PRACTICES
USEFUL ALONG THE ROADWAY**

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SEEDBED PREPARATION

DEFINITION: Preparation of the area of disturbance before revegetation.

PURPOSE: Seedbed preparation provides the most optimal growing environment for establishing plants.

APPLICABILITY: Preparation is applicable to any disturbed site that is subject to erosion and sedimentation or any site that can be revegetated using seeding techniques.

PLANNING CRITERIA: Seedbed preparation can be accomplished by a number of methods including mechanical and chemical tilling, controlled burning, and growing a crop of grain or another annual plant. Tilling, partial tilling, not-tilling, constructing microridge relief, pitting, and provision of special treatment to road cuts are individual possibilities.

- The choice of method depends on the amount and type of vegetation present and on relevant soil factors. Soil erosion susceptibility, slope, salinity, stoniness, texture, and depth each must be considered.

For purposes of planning, seedbed slopes can be separated into five types:

- Very Steeply Sloping: > 2:1
- Steeply Sloping: 3:1 to 2:1
- Sloping: < 3:1
- Benched or serrated
- Rocky: Untillable surface. Do not disturb the soil if there are sufficient cracks into which the seed may fall. On rocky terrain or slopes too steep for contour traverse, a tracked or cleated crawler-tractor can be walked up and down the slope to open or create crevices.

Preparation of Different Slope Types:

- Roughly grade slopes, shoulders, and banks next to the roadway to 3:1 or less to reduce risk of erosion and sedimentation. This will also

provide a more stable slope for vegetation. Do not over-smooth surfaces.

- A bulldozer or crawler-tractor can be driven along steeper slopes leaving a pattern of tread imprints parallel to the slope contour. Tread indentations will trap seed and moisture.
- A serrated wing blade attached to the side of a bulldozer can roughen small cut-and-fill slopes along the roadway. A spike-toothed harrow can also be used with a tractor to roughen the soil on a cut slope.
- Slopes graded greater than 3:1 may require stair-stepping or benching to aid in establishing vegetation.
- Benched or serrated slopes need little preparation as sloughing of soil from the bench above will generally cover the seed.
- Sloping areas can be prepared with conventional equipment such as a disk, ripper, or patrol. Fill slopes 3:1 or flatter may not require much preparation.
- On very short and steep slopes it is effective to till the soil to a depth of 2 in. (5.08 cm) and on sloping areas till to a depth of 3 in. (7.62 cm).

On areas to be drilled, prepare soils to a condition in which a drill, and possibly a crimper disk, will function properly.

- On areas to be seeded by broadcast methods, tackifying agents can be incorporated into the seed and mulch slurry to bind it to the slope.
- Slopes to be topsoiled should be roughly finished. After spreading the topsoil, prepare the soil surface for seeding as specified above.
- On critical areas, the extent of seedbed preparation should not exceed the area on

which the entire seeding and mulching can be applied within one day's operation.

Preparation of Seeding Areas:

- Use mechanical means or chemical application to keep disturbed areas free of weeds before seeding. If possible, prevent weeds from going to seed on the disturbed site.
- Where compaction is in the upper 6 in. (15.24 cm), use a chisel plow, then disk and seed.
- Where soil is compacted more than 6 in. (15.24 cm) down, use a subsoiler, then disk and seed.
- Always till on the contour or across the slope (where feasible) to reduce erosion.
- Wheat, sorghum, or other annual crops can be grown as a preparatory (nurse) crop to prepare the land for seeding perennial grasses. The benefits are significant, because this method reduces weeds, encourages water infiltration, minimizes erosion, and provides a firm seedbed for perennials. Because the stubble and litter will provide moisture-holding capacity, reduce erosion (including blowing sand), and serve as protection to newly established grass seedlings, the nurse crop should receive minimal disking.
- In the northern intermountain region, areas without dense stands of *Bromus* can typically be drilled without cultivation, cropping, or chemical tillage. *Bromus* can be eliminated with a lister or double mold-board drillhead that scrapes or turns back a 5- to 10-cm wide strip of soil including the *Bromus*, other plants, and existing surface seed. Burning, harrowing, and spring-toothing are not effective.
- Freshly plowed land must be packed with a cultipacker before seeding to prevent rapid drying and provide a firm seedbed.
- While drilling is the preferred method of seeding over plowed land, broadcasting ahead of the cultipacker may also give favorable results for perennial grasses.
- Mechanical brush control disturbs the soil. Seeds broadcast onto this roughened surface lodge in cracks and depressions. Seeds are typically covered by wind and water-borne sediments.
- Burning disturbed areas provides adequate seedbeds for many grasses and legumes.
- Heavy woody litter should be incorporated into the soil before grasses are planted because seed must be in physical contact with the seedbed for germination.

Moderate amounts of surface litter or mulch from grain crops are beneficial to seedling establishment and reduction of wind erosion.

- Cultivate areas to be seeded by drilling to a minimum depth of 3 in. (7.62 cm). The soil should be worked to a condition suitable for the operation of seed drilling equipment.
- Till areas to be broadcast-seeded to a roughened condition immediately before seeding. Loosen to a depth of 2 in. (5.08 cm). The soil condition should be similar to that obtained by walking a cleated or tracked tractor up and down slopes.
- Benched slopes require no additional preparation.

Preparation of Seedbed on Abandoned Roads:

- If the roadway is densely compacted, rework the surface with a subsoiler to a depth of 8 to 10 in. (20.32-25.4 cm) with ripping bars spaced about 18 in. (45.72 cm) apart.
- Rip along slope contours with each pass in opposite directions to avoid a buildup of material at the trailway/roadway edges.
- Do not move rocks or boulders if encountered when subsoiling.
- The construction of slope-face interrupter trenches or waterbars will break up long or uninterrupted slopes.

MECHANICAL SEEDBED PREPARATION:

- Where soils have been compacted, prohibiting good seed establishment, the preliminary step in seedbed preparation is to break up or loosen the soil sufficiently to reduce compaction. Depending on the size of the disturbance, hand labor or machinery can accomplish seedbed preparation.
- In the Southeast, Northeast, and Midwest, clean seedbeds work well where wind and water erosion are not a problem and rainfall is not a severely limiting factor. In the Northern Great Plains, drilling into fallowed seedbeds is effective. In California grasslands, light disking after the first fall rains, followed by clover seeding produces a suitable seedbed for perennial grasses.
- On sandy soils or on erosive slopes, drilling is preferred as clean tillage will exacerbate erosion. Proper seed placement is difficult when drilling on rough-plowed soils. On medium to heavy (clay-rich) soils in arid regions, the most effective methods of seedbed preparation include pits, basins, or interrupted furrows to catch and hold moisture.
- On deep soils in mountain meadows, soils are plowed and seeded to annual hay before seeding to a grass-legume mixture. The hay aids in development of a level, firm seedbed and serves as a nurse crop for the grass-legume seedlings. In shallow soils in mountain meadows, soils are disturbed by chisel plow or tandem disking, leveled in a limited manner, and seed is drilled or broadcast into the tilled soil.

Loose Soils: Loose, soft soils interfere with proper seed placement and typically have low moisture-holding capacity. Soil firming is required in loose soils to retain moisture content in the surface 2 in. above the wilting coefficient for sufficient time to allow the seedlings to establish. Some natural packing may occur if rainfall is adequate on sites left undisturbed for several weeks before planting.

Rolling. Rolling can be used to firm seedbeds before and after seeding.

- Rolling reduces the risk of seeding failures on light-textured soils if adequate soil moisture is present at the time of treatment.
- Drilling following rolling results in improved seed placement and seed emergence.
- Rolling after broadcasting is effective on freshly plowed seedbeds where compaction above the seed is not excessive.
- Under wet conditions, rolling can be very detrimental and it is only slightly beneficial to roll extremely dry soils.
- Small diameter rollers may skid, increase soil density, and reduce water intake.
- Rolled seedbeds may be more subject to wind and water erosion.

Cultipacking. The flexible cultipacker adapts better to uneven terrain, providing greater packing action below the seed placement zone, and leaving a more mellow soil surface.

- Cultipacking allows the depth bands on the drill disks to be more effective on loose soils.
- Drag harrows and rod weeders are useful where surface litter or mulch is not excessive.
- Wind erosion may be reduced by packing small ridges in sandy soils that cannot be controlled by deep plowing alone.
- When packing a sandy loam soil, the soil moisture should be between 9 and 12 percent to obtain a surface condition most resistant to wind erosion.

NURSE CROP METHOD: Nurse or companion crops are effective in humid and irrigated areas. The nurse crop is seeded at the same time or near the time when the perennial species are sown. The purpose of the nurse crop is to reduce wind and

water erosion, reduce weed competition, and protect emerging seedlings from wind and sun.

- Grain crops such as oats, rye, barely, and wheat are commonly used as nurse crops.
- To make nurse crops more effective, it may be helpful to limit seeding rates to 7 to 10 lb per acre. Drill nurse crop seed crosswise to the direction of perennial seed or in alternate rows. Irrigate lightly and frequently until the perennial species are well established. Harvest the companion crop early to control competition in establishment of the perennial species.
- In the Central Great Plains, where the precipitation is within the 10 to 15 in. range, the use of cover crops or nurse crops may reduce soil moisture availability for new seedlings. Nurse or companion crops should not be used where soil moisture availability during establishment may be lacking or where soil fertility is low.

PREPARATORY CROP METHOD: Planting a residue-producing crop during the growing season, after seedbed plowing, and before seeding perennial species, can produce a residue-rich, firm seedbed suitable for direct seeding.

- Benefits of this method include control of wind and water erosion, reduction of evaporation and soil moisture loss, and control of weedy species. Crop residue protects emerging seedlings from wind and water erosion, exposure of roots, solar radiation, and serves to hold soil moisture.
- The preparatory crop method has been effectively used in the Northern Great Plains, Intermountain region, and Southern Great Plains under dry land conditions, where wind and water erosion or surface crusting are common problems.
- This method is less effective in areas of the Great Plains with precipitation less than 17 in. per year, and in the Intermountain Regions in areas receiving less than 14 in. of annual precipitation.

- Species most effectively used as a preparatory crop include sudangrass, grain and forage sorghums, and millet. Other species may be more suitable to a specific area. The local NRCS office may be able to provide assistance.
- Preparatory crops should be seeded in rows spaced less than 20 in. apart. They should not be allowed to set seed since the volunteer plants may compete with establishing perennial species the following season. Grazing or plowing are effective, as is seeding late in the growing season (late June or early July in the Central or Southern Great Plains).

BURNING FOR SEEDBED PREPARATION:

Burning can be an effective method of seedbed preparation where the resident plant species are readily eliminated by fire. Sprouting shrubs or forbs may not be completely susceptible to fire. Burning leaves a generally firm but mellow seedbed.

- The most effective fire for seedbed preparation is a hot fire that consumes all leaves, twigs, and small stems of shrubs and all ground litter leaving a white ash over mineral soil. Spotty burns provide ineffective seedbeds.
- Drilling is recommended on burned sites. On most sites the ash left is inadequate for broadcast seeding of perennial species unless followed by chaining or pipe harrowing. Seed burned sites as soon as expected precipitation allows.
- Dense cheatgrass sites are suitable to seedbed preparation by burning if perennial species are quickly established.
- On sagebrush sites, burning is as effective as plowing.

CHEMICAL SEEDBED PREPARATION:

Chemical seedbed preparation and direct seeding into the killed mulch without further soil treatment can be effective. The herbicide must control a broad spectrum of undesirable plants, dissipate rapidly after weed control is accomplished, and

break down or leach away by the time seeded species germinate or not be toxic to the seedlings of the seeded species.

- On low-rainfall sites, chemical fallow during the previous growing season is more effective than spring herbicide treatment and seeding.

Advantages:

- Chemical seedbed preparation leaves a firm seedbed.
- Good erosion control since litter and mulch are left in place.
- Can be used on land too rocky, steep, erosive, or wet for mechanical preparation.
- Does not invert the soil profile, which is undesirable on shallow, poorly drained, or poorly structured soil.
- Allows selective plant kill.
- Averts most soil crusting and reduces frost heaving.
- Conserves soil moisture and nitrogen similar to mechanical treatment.
- Improves moisture penetration and retention of moisture because of mulch.
- Allows spraying, drill seeding, and fertilization in a single operation.
- Protects grass seedlings by means of standing residue.
- Permits seeding an entire field of erosive soils at one time.
- May be less costly than mechanical preparation.
- Control of resident cover is affected by drought.
- There may be competition during the seedling year from uncontrolled resident vegetation.
- May kill insufficient weed seeds resident in the soil unless used as chemical fallow during a growing season.
- Tillage following chemical application may bring undamaged weed seeds to the surface.
- Standing dead shrubs may restrict grazing.
- Hazard of killing desirable broadleaf herbs and shrubs.

Disadvantages:

- No single chemical completely kills all resident plants and dissipates quickly afterwards.
- Dead mulch and litter may be excessive.

FERTILIZER USE

DEFINITION: A guide to the selection of fertilizer type and application rates.

PURPOSE: Appropriate fertilizer selection is necessary to prevent improper and excessive use of fertilizers and resultant water quality deterioration, while providing for the success of revegetation and landscaping efforts.

APPLICABILITY: Fertilizer selection is necessary in all revegetation efforts and in routine maintenance of revegetated sites.

PLANNING CRITERIA: Fertilizer should only be incorporated when soil nutrient deficiencies exist and impair the establishment of desired vegetative growth.

- Application of fertilizer on disturbed sites is beneficial to new seedlings if the proper kinds and quantities of fertilizer are specified.
- Failure to apply needed nutrients may result in poor establishment or complete failure of the seeding. Analysis of soil samples will detect nutrient deficiencies and provide information on the appropriate type and rate of application to mitigate those deficiencies.
- Soil samples should be collected for testing at each disturbed site to detect specific fertilizer needs. Contact the Cooperative Extension Service, Natural Resources Conservation Service District Office, or private labs for analysis of soils. These analyses provide essential amendment and fertilizer needs.

General Applications:

Slow-release fertilizers use either bacterial action in the soil or osmosis to release nutrients. Slow-release fertilizers provide the most reliable method of providing plant nutrients. They work most effectively by application during seeding, vegetative planting, and maintenance of established vegetation.

Fast-release fertilizers include various forms of nitrogen, phosphorus, and sulphur. Both root establishment and initial plant growth benefit from application of phosphorus. Nitrogen maintains the growth of the plant. Select a fertilizer with some sulphur content as it is a common deficiency in soils. The best fast-release fertilizer for this purpose is ammonium phosphate sulfate (16-20-10). Granite dust is an excellent source of potassium where available. Fast-release or conventional fertilizers release nutrients rapidly, making them available for immediate use. The fast-release form is best adapted to maintenance operations. If applied before seeding, nutrients can be leached out before seeds germinate.

Application of Amendments:

- Soil type or texture will affect the ease of alteration of soil pH. The more organic matter in the soil, the more buffered or resistant to change it is. Therefore it takes less lime to alter the pH of a very sandy soil than a loam soil. For significant changes in soil pH, split the total quantity required and apply over several seasons. Adjustment of free hydrogen requires lime and sulphur.
- Acid soils require application of lime as ground limestone or dolomite. The following treatment will raise the soil pH about one point:

Very sandy soil. Add 30 to 50 lb of ground limestone per 1000 sq ft.

Sandy loam. Add 50 to 75 lb per 1000 sq ft.

Heavy clay. Add 70 to 80 lb per 1000 sq ft.

For alkaline soils, the following treatments will lower the pH about one point:

Sandy soils. Add 10 lb of ground sulfur per 1000 sq ft.

Heavy clay. Add 20 lb of ground sulfur per 1000 sq ft.

Organic Matter and pH. When added to any soil, organic matter (compost or humus) will bring the pH closer to neutral by lowering the pH of alkaline soils or raising the pH of acid soils. Organic matter (sawdust, composted oak leaves, wood chips, leaf mold, or peat moss) is effective in lowering high pH values. Wood ashes, crushed marble, and crushed oyster shells are effective for raising the pH of acid soils.

- Problem soils often have low moisture holding capacity or are poorly developed soils exposed on disturbed sites. Cost-effective organic soil amendments such as manure, treated sewage sludge, and composted organic wastes provide slow-release plant nutrients, act as mulches, and add organic matter.
- Because organic amendments may have some nutrient deficiencies, apply fertilizer at the recommended rates.
- Incorporate lime before seeding on the west coast. The recommended application rate is 500 lb per acre (226.8 kg per .4047 ha) of 16-20-0 with 15 percent sulfur.
- For erosion control seeding on the east coast, the NRCS in Virginia recommends application of 450 lb (204.12 kg) of 10-20-20 per acre. The NRCS in Maryland recommends 10-10-10 at 600 lb (272.16 kg) per acre.
- In the absence of a soil test, application of 1000 lb (453.6 kg) of 12-12-12 fertilizer per acre may be beneficial.
- Ground or pulverized agricultural lime can be applied to soils with pH less than 6.0 at the rates shown in Table 4-1.

pH	Soil	Application Rate (tons/acre)
6.0	Sandy Loams	2
	Clays	2
5.5	Sandy Loams	3
	Clays	4
5.0	Sandy Loams	4
	Clays	5
4.5	Sandy Loams	5
	Clays	6
4.0	Sandy Loams	6
	Clays	7

Table 4-1. Amendment application rates.

Application with Seeding:

- Several options may be considered during initial seeding operations on slopes 3:1 or flatter:
 - Dry cattle manure may be applied at a rate of 10 tons (10,000 kg) per acre and incorporated into the top 4 in. (10.16 cm) of soil
- OR
- Apply a granular slow-release fertilizer, i.e., (20-10-5)
- OR
- Apply a minimum of 500 lb per acre (226.8 per 0.4047 ha) or 10 lb per 1000 sq ft (4.536 kg per 92.9 sq m) of 10-10-10 fertilizer (or equivalent).
- During initial seeding operations for areas with slopes steeper than 3:1, the options include:
 - Apply granular slow-release fertilizer (20-10-5)
- OR
- Apply pelleted or granular conventional fertilizer (16-20-0).
- When applied near water, use only slow-release fertilizer.

MAINTENANCE: Apply fertilizer when loss of color or vigor or lack of plant growth suggests a nutrient deficiency. Maintenance application of fertilizers is commonly done in the spring.

- Maintenance inspections should include plant or soil testing to detect nutrient deficiencies.
- Apply pelleted or granular conventional fertilizer (16-20-0 or as soil tests indicate) as required.
- Schedule a follow-up application of conventional fertilizer for the late spring following the initial application.
- Some seedings may require additional top dressing with nitrogen.

DRILL SEEDING

DEFINITION: Use of an agricultural or rangeland seed drill for planting seed and applying fertilizer on disturbed sites.

PURPOSE: To plant seed at a uniform depth and ensure proper coverage with soil to enhance rooting after germination.

APPLICABILITY: Seed drilling is most effective on relatively flat slopes with few rocks to limit the use of a tractor and seed drill.

PLANNING CRITERIA: Grass, herb, forb, legume, shrub, and tree seeds that are drilled have an optimal chance of germination and establishment with a minimum expenditure in labor, seed, and fertilizer.

- Accurate seed and fertilizer mixture proportions are maintained and uniform planting at the prescribed rate is achieved when seed is drilled.
- Drill seed immediately upon completion of site preparation or grading.
- Lack of seeding success is often attributed to improper drilling technique. Seeds are frequently placed too deeply (more than 1 in. [2.54 cm]) or too shallowly in the soil, or are placed in a location with a moisture deficit. Failures may also relate to improper seedbed preparation, incorrect disk spring pressure, failure to use depth gauges, spreading drilled seed too rapidly, or use of the incorrect type of drill.

MATERIAL APPLICATION: The seedbed must be loose enough to allow drill disk penetration, but not so loose that depth control is lost. The pressure of the springs on the disks controls the depth. However, depth gauges may be required where spring adjustment is too limited.

- When the drill is pulled at too great a speed, the seed will be left on the surface.

- When mulch will be crimped into the soil, cross-slope furrows should be just deep enough to hold the seed in place. A maximum coverage of 0.5 in. (1.27 cm) of soil is preferred until the crimping is complete. The crimping action will cover the seed even more.
- The goal of drill seeding is to place the seed just under the soil with provision for moisture holding. Both the furrows and the mulch serve to accumulate moisture.
- After adjusting the drill, be alert to the speed of application and spout flow.
- Observe where the seed is being placed in the soil. Seeding rates should also be checked periodically and adjusted as necessary.
- Should there be intermittent rocky areas included in the area to be drill seeded, raise the drill when going over those sites. If the drill is such that the discs can be raised just enough to clear the rocks and the seed delivery system still remains in gear, this can serve as a broadcast method on these areas. If not, the seed should be broadcast on the rocky areas later by hand or mechanical method.
- All seeds and fertilizer may be mixed before planting, unless extreme differences in size would prevent the proper operation of the drill.
- When seed sizes differ radically, separate passes should be made to plant seed groups of different size.
- Uniform distribution of seed and prevention of equipment clogging may be accomplished by separating the seed into alternate bins in the drill or diluting the seed with rice hulls. These techniques may be used in simplifying drill calibration procedures, keeping seed mixtures in constant proportion.

BROADCAST SEEDING

DEFINITION: Broadcast seeding involves the process of uniformly casting or spreading seed/-fertilizer on the prepared seedbed site by hand or with mechanical equipment.

PURPOSE: Broadcast seeding is used to provide a uniform covering of seed and fertilizer across the disturbed site.

APPLICABILITY: Broadcast seeding is intended for use when revegetation specifications call for seeding grasses, legumes, herbs, shrubs, or tree species on slopes that are too steep or rocky for using drill seeders, or for seeding smaller disturbed areas. Seeding may fail on cut slopes that are too hard or too smooth for seed establishment or where unconsolidated soils are too loose to hold sufficient moisture for seed germination.

PLANNING CRITERIA: Grass, legumes, herbs, forbs, shrubs, or trees may be seeded at the same time or may be sown separately.

- Broadcast seeding can provide a uniform coverage of seed across the disturbed site.
- Broadcasting seed is particularly well-adapted to use on steep or rocky slopes, abandoned roads, or sites with limited access or where hand labor is used.
- For germination to occur, seeds should be lightly covered with soil for about two weeks when the soil temperature is above 50 °F.
- Survival of the seeds depends on selecting the proper season for seeding and on the appropriate seeding mixture.

MATERIALS APPLICATION: Prepare the site for seeding by first applying the appropriate quantity and type of fertilizer and working it well into the soil to a depth of at least 3 in. (7.62 cm).

- On slopes next to roads, cat-walk up and down the slopes to (1) loosen soil on cut slopes, (2) compact soil on fill slopes, and (3) provide cross-slope depressions for moisture retention.
- Wet or dry broadcasting may be used for seed application, however, it is important to use seed within 30 minutes after it is wetted.
- Apply appropriate type and quantity of mulch to provide necessary protection against erosion and to aid in the establishment of plant cover.

General Application Information: While grass, legume, forb, shrub, and tree seed may be mixed for application, it is critical that all seeds are approximately the same size, otherwise separate passes will be required for each seed size.

- Hand-carried or vehicle-mounted automatic seeders are preferred for broadcast seeding as they result in a more uniform application than seeding by hand.
- Broadcasted seed should be lightly raked and covered with a shallow layer of soil between 0.25 to 0.5 in. (.635 and 1.27 cm) in depth. The soil will protect the seed from solar radiation, drying, and allow germinating seeds to take root more readily. Agricultural rakes or harrows set very lightly are adequate for large, flat to gently sloping areas. Hand or garden rakes are suitable for small areas or steep slopes where equipment cannot maneuver.

EFFECTIVENESS: Broadcast seeding provides an effective method of scattering seed uniformly. When the seed is properly covered with soil and appropriate mulch, germination and establishment are generally better than that from seed sown by hydroseeding. However, it is less effective than the germination and establishment of drilled seed because of the difficulty of proper seed coverage when using broadcast methods.

HYDROSEEDING

DEFINITION: Application of a slurry of seed, fertilizer, tacking agent, and water onto a prepared seedbed by means of spraying.

PURPOSE: To apply a uniform and economical slurry mixture to a disturbed site, bare slope, or critical area at a rate that will not cause or promote erosion.

APPLICABILITY: Large, reasonably stable bare slopes (those at their natural angle of repose), areas next to the roadway, ditches, or other areas that can be reached by truck. Areas smaller than ½ acre can be more economically seeded by other methods.

PLANNING CRITERIA: Hydroseeding involves placing seed, fertilizer, a tacking agent, and water with a small amount of dyed wood fiber into a tank and agitating the mixture into a uniform slurry. This slurry is then sprayed onto the site.

- Hydroseeding applies the seed directly to the soil surface. Mulch must then be applied over the seed and raked to cover the seed with soil.
- Hydroseeding and hydromulching can be used in two separate operations on the same site. This will ensure the most effective application of seed and a mulch blanket. However, the cost increases with two-stage seeding and mulching.
- When mulch is incorporated into the slurry, it usually consists of a dyed wood fiber, allowing the workers to see the areas of coverage more readily, which aids in uniform application. The primary problem in this method is that the seed is then suspended among the mulch fibers and may not come into contact with the soil. This may reduce the effectiveness of the seeding method.

MATERIALS APPLICATION: Hydroseeders are equipped with a gear-driven pump and a paddle agitator. Agitation by recirculation from the pump is undesirable. Agitation should be sufficient to

produce a homogenous slurry of seed, fertilizer, and tacking agent in the designated proportions.

- Water should be applied at a rate of 3,000 gal (11370 liters) per acre (0.4047 ha).
- Add 150 lb (68.04 kg) per acre of wood fiber to aid in uniform slurry application.
- Apply 200 gal (758 liters) of wet or 80 lb (36.29 kg) of a dry tacking agent per acre.
- Ensure proper application of fertilizer to prevent seed burning.
- Slow-release granular fertilizers may sink rapidly and cause clogging of the pump or hoses. Both the hydroseeder manufacturer and the fertilizer manufacturer should be consulted regarding the appropriateness of the fertilizer for hydroseeder applications.
- Seed mixtures should be included at the specified rate. No seed should be added to the slurry until immediately before beginning the seeding operation.
- Legume seed should be pellet-inoculated with the appropriate bacteria. Inoculation rates should be four times that required for dry seeding. Legume seed should be placed in the mixing tank AFTER all other ingredients have been included, as pellet-inoculated legumes may have the coating washed off in the mixing tank.
- The time allowed between placement of seed in the hydroseeder and emptying of the hydro-seeder tank should not exceed 30 minutes or seed damage is likely to occur.

EFFECTIVENESS: On ideal sites, hydroseeding and broadcast seeding are equally effective in uniformly scattering seed, however, it is not as good as drill seeding. Hydroseeding is applicable to a wider range of disturbed sites than is drill

seeding and on steeply sloping sites it can provide a more uniform application than broadcast seeding.

MULCHING

DEFINITION: Application of a protective blanket of straw or other plant residue or a synthetic material to newly seeded soil surfaces. Mulch is any suitable cover applied to a soil for protection. It may be inorganic or organic, temporary or permanent.

PURPOSE: Mulching artificially recreates the organic horizons present within forested areas of wooded soils. Mulch serves to enhance soil stabilization and improve soil microclimatic conditions. It aids in establishment of vegetative cover and protects the soil surface from the erosive forces of wind and water. Mulch fosters the growth of vegetation as it reduces evaporation, insulates the soil, protects new seedlings from solar radiation, and suppresses weed growth.

APPLICABILITY: Mulch is necessary on any newly seeded slope or disturbed site that may be subject to erosion by wind or water. It is also required on areas that cannot be immediately seeded as they will benefit from a protective cover until seeding can be completed. Soils around trees, shrubs, or new ground covers should be mulched to stabilize the soil.

BENEFITS OF MULCH:

- Conservation of moisture
- Reduction of soil compaction
- Moderation of soil temperature
- Protection of soil from raindrop impact
- Reduction of soil erosion
- Improvement of soil structure
- Reduction of weed growth
- Protection of roots

PLANNING CRITERIA: Mulch application provides the most effective and practical means of controlling both erosion and runoff before establishment of vigorous vegetative cover on disturbed sites. Mulch inhibits soil moisture loss by evaporation, prevents crusting and sealing of the soil surface, moderates soil temperatures, provides a microclimate suitable for seed

germination, and may increase the infiltration rate of the soil.

- Mulch materials should not be spread any thicker than 6 in. The optimal depth of mulch around plants is 3 to 4 in. Blown mulch should provide 75 percent coverage of the surface.
- Organic mulch materials such as straw, wood chips, and shredded bark are the most effective. Care must be taken not to use materials that may be sources of competing weeds and grass seeds.
- A variety of mats and fabrics have been developed for use as mulch, particularly in critical areas such as waterways and channels (ditches). A variety of netting materials are available to anchor organic mulch.
- Chemical soil stabilizers or soil binders are often less effective when used alone than other types of mulch. They are, however, useful for tacking wood fiber mulches.
- Select mulch materials by soil conditions, season, type of vegetation, and size of area. Consider locally available mulch materials.
- Always properly apply and tack mulch. Mulch materials are particularly useful when conditions for germination are not optimal. These include midsummer and early winter, or on difficult areas such as cut slopes, or slopes with southern exposures.

MULCH MATERIALS: Most mulch is derived from an organic residue like sawdust, bark, composted leaves, wood chips, hay, straw, peanut hulls, coconut fibers, etc. Because they are organic, they will decompose over time.

Hay

Available from local farms, garden centers
Durability is about 1 year
pH of hay is 5.5

C/N ratio: legume 19:1, grass 19:1 or less
 Must be tied down
 May contain weed seeds

Straw

Available from local farms, garden centers
 Durability is about one growing season
 pH of straw is 5.6 to 7.1
 C/N ratio: wheat 128:1-150:1, oats 48:1
 1 ton per acre can reduce soil temperature by 10 to 15 °F.
 May cause slow spring warming due to light color
 Requires about 30 to 35 lb of nitrogen to prevent nitrogen depletion

Wood chips

Available from sawmills or timber harvesting
 Durability is about 5 to 15 years
 pH of wood is 4.1 to 6.0, average 5.3
 C/N ratio: 615:1
 Chips are resistant to weathering and blowing

Manure

Available from animal husbandry operations
 Durability of 6 to 12 months
 pH is about 6.6
 C/N ratio: 25:1 or less
 Straw manure is best for erosion control
 Manure increases worm and other soil organism levels
 Excellent when used on depleted soils

Wood Cellulose Fiber

Available as a commercial product
 Durability of about 30 days
 pH is around 4.8 to 7.0
 C/N ratio: about 200:1
 Product is mixed with water, fertilizer, and seed in a slurry and applied during hydromulching

CRITERIA FOR MULCH SELECTION: The objective of the application is of primary concern, followed by site characteristics, site size, economic factors, availability, types of plants and/or seed mixture, wind and rain characteristics, etc.

If the soil structure is unacceptable or lacking in organic matter, organic mulch would be the best choice.

Large areas probably require hydromulch application of hay or straw.

Site characteristics such as slope length, aspect, soil drainage, and exposure to the wind will also be factors in mulch material selection. Bark and wood chips wash readily on slopes. A hemp mat may be more appropriate on slopes.

On northern slope aspects, dark colored mulch materials will aid in retaining solar radiation. While on slopes that face to the south, light colored materials will reflect heat and moderate the soil temperature.

- Impervious plastic mulch materials are inappropriate on moist northern slopes or where slope drainage is poor. In these conditions, using a coarser mulch material is more effective. Plastic mulch materials are most appropriate for weed elimination.
- Geotextiles placed under mulch can impede interaction between the soil and the mulch material.

Organic Mulch:

Straw is the most commonly applied mulch used with seeding. Use straw where the mulch effect is required for more than 3 months. It is subject to wind blowing unless kept moist, anchored, or crimped. It will provide erosion control, moisture conservation, weed control, and reduction of soil crusting. The source of the straw should be weed-free wheat or oats that may be spread by hand or with a mulch blower. Straw breaks down rapidly and is incorporated into the soil. If application rates are too heavy, reduction of soil nutrient levels, particularly nitrogen may occur during decomposition. Straw requires stabilization by covering with a mulch net like jute, by punching it into the soil with a roller, or by spraying with a tackifying agent.

Wood chips are suitable for areas that will not be closely mowed and around shrub and tree plantings. Chips do not require tacking. Due to decomposition, chips require application of

nitrogen to prevent nutrient deficiency in plants. If chips are prepared on or near the sites, they can be a very cost effective mulch material.

Bark chips and shredded chips are by-products of timber processing. They are suitable for areas planted to pasture and not closely mowed. Apply by hand or with a mulch blower. Bark does not require additional nitrogen application.

Wood fiber or short cellulose fibers can be applied in a slurry during hydroseeding. Although wood fiber does not provide sufficient erosion protection alone, it may be used to tack straw mulch on steep slopes, critical areas, and where harsh climatic conditions prevail.

Dried sewage sludge, corn stalks, animal manure, pine boughs, peanut hulls, and hay are other forms of regionally available mulch that may dramatically reduce the cost of mulch application.

Nets, Mats, and Roving:

Netting is very effective in holding mulch in place on waterways, in ditches, and on adjacent slopes before grasses become established.

Mats promote seedling growth in the same way as organic mulches and are very useful in grass establishment in ditches and other waterways. A variety of synthetic and organic materials are available. Excelsior is a wood fiber mat and should not be confused with a wood fiber slurry. Mats require a firm and continuous contact between the mat material and the soil during installation to prevent erosion

Fiberglass roving consists of continuous strands of fiberglass that, when blown onto the soil surface from a compressed air ejector, form a mat of glass fibers. Roving must be tacked down with asphalt.

CONSTRUCTION SPECIFICATIONS:

Application of Organic Mulch: Select the application rate that will best meet the use and performance requirements. Spread organic mulch uniformly, by hand in small areas, or by mulch blower. When spreading by hand, divide the area

into sections of approximately 1000 sq ft and place 70 to 100 lb (31.75-453.6 kg) of straw in each section **OR** apply 2 tons (2000 kg) per acre when using a mulch blower. Apply to ensure a minimum of 75 percent coverage of the soil surface. If more than 90 percent of the soil is covered, seeds will receive inadequate sunlight for germination.

Anchoring Organic Mulch: Anchor straw mulch immediately following spreading to prevent excessive moisture loss and possible damage to newly sprouted seedlings. Determine the anchoring requirements to most effectively meet the specific job requirements.

Mulch Anchoring Tool: A tractor-drawn implement designed to punch (crimp) mulch into the soil about 3 in. (7.62 cm) to ensure maximum erosion control. A regular farm disk, weighted and set nearly straight, may also be used, but is less effective than the anchoring tool. Both methods are to be used on slopes less than 3:1 on the contour.

Liquid Mulch Binders: Application of liquid mulch binders and tackifiers (asphalt and various synthetic binders) should be heaviest at the edges of areas and at crests of ridges and banks to resist the wind. A binder should be applied uniformly to the rest of the area. The most effective method of application is to use straw and binder together. Apply asphalt at 0.10 gal per sq yd (0.379 sq m) or 10 gal per 1000 sq ft (37.9 l per 92.9 sq m).

Mulch Nettings: Lightweight wood fiber, plastic, cotton, jute, wire, or paper nets may be stapled with pegs, stakes, or pins over spread mulch according to manufacturers specifications.

Peg and Twine: A labor-intensive method useful in small areas. Drive 8- to 10-in. (20.32-25.4 cm) wooden pegs to within 3 in. (7.62 cm) of the soil surface every 4 ft (1.22 m) all directions. Secure mulch by stretching twine between the pegs in a criss-cross within-a-square pattern. Turn twine two or three times around each peg. Further tighten by driving the pegs another inch into the ground.

Vegetation: Annual rye or ryegrass may be used to anchor mulch in fall plantings and a German millet is equally effective used in the spring. Broadcasting at 50 lb (22.68 kg) per acre (0.4047 ha) before mulch application, has shown to be effective.

Fiberglass Roving: Roving is wound into a cylindrical package so that it can be continuously withdrawn from the center using a compressed air ejector. The roving expands into a mat of dense fibers as it contacts the soil surface and must be tacked in place with asphalt.

Application of Fiberglass Roving. Apply roving at a rate of 0.25 to 0.35 lb (0.1134 to 0.1588 kg) per sq yd. Anchor with asphalt. Apply at a rate of 0.25 to 0.35 gal per sq yd (0.9475 to 1.33 L per 0.836 sq m).

Nets and Mats: Nets alone provide little erosion or seedling protection and should be applied over a layer of spread mulch. Dense mats, including excelsior blankets, can be considered protective mulches and can be used alone on seeded, erodible soils. They can be used year round. Mats and nets are not designed or intended for use alone as ditch bottom protection.

Installation of Nets and Matting. Apply lime, fertilizer, and seed BEFORE laying the net or mat.

- Start by laying the net from the top of the channel or slope and unroll it down the grade. Allow netting to lie loosely on the soil or mulch cover without wrinkles — do not stretch.
- Secure the net by burying the upslope end in a slot or trench no less than 6 in. (15.24 cm) deep, cover with soil, and tamp firmly.
- Staple the net every 12 in. (30.48 cm) across the top end and every 3 ft (.9144 m) around the edges and bottom. Where two strips of net are laid side by side, the adjacent edges should be overlapped 3 in. and stapled together. Each strip of netting should also be stapled down the center, every 3 ft (0.9144 m).

DO NOT STRETCH WHEN STAPLING.

- To join two strips, cut a trench to anchor the end of the new net. Overlap the end of the previous roll 18 in. (45.72 cm) and staple every 12 in. (30.48 cm) just below the anchor slot.

MAINTENANCE: Inspect all mulch periodically and particularly after rain events to check for rill erosion, dislocation, or failure.

- Where damage is detected, apply additional mulch. If a washout occurs, regrade the slope, reseed, and reinstall mulch.
- Continue inspections frequently until vegetation is vigorous.

VEGETATIVE FILTERS OR BUFFER STRIPS

DEFINITION: An undisturbed, stable, natural strip of vegetation left as a barrier between a sediment-producing or sediment-conveying road and sensitive areas such as water bodies or threatened and endangered species habitats.

PURPOSE: The vegetative strip acts as a buffer area to catch or filter out sediment before it enters a water body or sensitive area.

APPLICABILITY: Vegetative strips are necessary wherever a sediment-producing site is located upslope from a sensitive area.

PLANNING CRITERIA: All roadways and adjacent disturbed areas located above a water body or sensitive area require vegetative buffers. The width of the buffer depends on the slope of the land between the roadway and the sensitive area.

- Where vegetative filters are required, but do not exist, follow the procedures for stabilization and revegetation of critical areas. Establish a vigorous vegetative cover or buffer zone of appropriate width between the disturbed site and the sensitive area.

MAINTENANCE: Maintenance of vegetative buffers should be the concern of installation foresters and Roads and Grounds personnel.

- Use caution not to disturb any woody growth at the edges of the buffers with maintenance equipment.
- Prohibit vehicular operation within the buffer.
- Periodically check for sediment damage within the buffer.
- Take immediate steps to mitigate any erosion or degradation in the areas.

Slope Between Water and Disturbed Site	In Forested Area (feet)	In Critical Areas (feet)
0 %	25	50
10 %	45	90
20 %	65	130
30 %	85	170
40 %	105	210
50 %	125	250

Table 4-2. Determination of filter strip or buffer zone width.

WATTLING

DEFINITION: (1) Placing vertical or horizontal bundles of live riparian tree or shrub cuttings into the soil to stabilize the slopes, or (2) live cuttings of riparian trees and shrubs tied into cigar-shaped bundles averaging 5 feet long and 8 inches in diameter, staked end-to-end to form rows on eroding slopes.

PURPOSE: Use wattling in revegetation and stabilization of adjacent slopes that are too steep for effective seeding methods. Wattling encourages favorable seed germination sites, reduces slope lengths, increases water retention on slopes, stabilizes the slope by binding the soil with abundant roots, decreases damage by rain splash by providing increased canopy cover, and produces additional organic matter.

APPLICABILITY: Wattling is best applied to slopes that are no steeper than 2:1. Rows of wattling can effectively reduce slope lengths that produce long uninterrupted paths for surface runoff. Wattling cannot be used as a substitute for retaining walls or similar structures to stabilize oversteepened slopes. While wattling is most effective on moist slopes, it can be applied to dry slopes provided an appropriate species is selected.

PLANNING CRITERIA: Wattling is effective on slopes subject to erosion due to runoff, sheet flow, or creep.

- Bundles can root and grow and continue to stabilize slopes as revegetation plantings. Adequate water is required at the time of planting and for the first few seasons of growth.
- Wattling acts to reduce slope length and therefore modifies the SL (slope-length) factor in calculating expected soil loss.

MATERIAL APPLICATION:

Preparation of Bundles:

- Prepare wattling bundles from living branches of shrubby material, preferably of species that

will root readily and provide maximum shoots. Willow and Alder are commonly used species.

- Bundle lengths should be at least 5 ft and should taper at the ends. Bundles should be 1.5 to 2 ft (0.4572 to 0.6096 m) longer than the average length of the branches to achieve this taper. Butts of individual branches should be no more than 1.5 in. (3.81 cm) in diameter.
- Alternate the branches so that one-half of the butts lie at each end of the bundle.
- When compressed and tied, the bundle should be no more than 6 to 10 in. (15.2- 25.4 cm) in diameter.
- Tie bundles on 16-in.(40.64 cm) centers with two wraps of binder twine or wire.
- Prepare bundles not more than 2 days before placement, unless they can be kept covered and moist (for up to 7 days).

Installation:

- Existing gullies and rills should be filled and compacted before installation of wattling. Minimize the disturbance of the slope face and existing vegetation.
- The grade for the wattling trenches should be staked with the assistance of an Abney level or similar device and should follow slope contours.
- Bundles should be placed in contour trenches dug 3 to 5 in.(7.62 to 12.7 cm) in depth and 6 to 10 in.(15.2 -25.4 cm) across.
- Place stakes, on 16-in. (40.64 cm) centers, on the downslope lip of the trench. Stakes should be either live wattling material with a diameter greater than 1 in. (2.54 cm), or 2 by 4 in. (5.08 cm by 10.16 cm) lumbers. Live stakes are preferred. Lumber stakes may be used on compacted soils that prohibit effective use of live stakes. Stakes will be 24 to 36 in. (60.96

cm to 91.44 cm) long. Steel re-bar can be substituted.

- Bundles should be placed within trenches so that the ends of the bundles overlap at least 1 foot. The overlap should be as long as necessary to permit staking as specified.
- Bundles of wattling should be staked through the center on approximately 30-in.(76.2 cm) centers. Place extra stakes on the downslope lip of the trench and through the bundles at each overlap of two bundles. Stakes can also be placed between rows of wattling to aid in revegetation.
- All stakes should be driven in a minimum of 18 in.(45.72 cm) to provide a secure hold. Where soils are soft, use longer stakes. Where soils are so compacted that 24 in.(60.96 cm) wooden stakes cannot be driven in 18 in.(45.72 cm), use 24 in.(60.96 cm) sections of 0.375 in. (.953 cm) re-bar.
- Work should progress from the bottom of the slope to the top. Each row of wattling should be covered with soil and packed firmly on the uphill side by tamping or walking on the wattling as the work continues upslope. The downslope lip of the wattling may be left exposed when staking and covering with soil are complete.
- Additional wattling should be placed as necessary for stability in seeps or other wet areas. Revegetate the slope according to procedures for steep slopes.

SITE WORK: Have one crew gather wattling material and prepare it in bundles before moving to the site. Prepare all wattling for smaller jobs.

- When work on the site begins, stake the first trench lines with stakes on 16-in.(40.64 cm) centers using an Abney level to maintain proximity to contour.
- Dig the trench to a specified depth and width just above the line of stakes. Do not move large

rocks in the path of the trench. Instead, the trench should end at the rock and begin again on the other side.

- Lay wattling bundles in the trench and stake them down. Place additional stakes through overlaps between bundles and on the downslope side of all overlaps of bundles.
- When bundles are in place, stake out the next trench line while standing on the first line of wattling.
- The material excavated from the second trench should be cast on top of the first line of wattling. Compact this covering by walking upon it while placing the bundles in the second trench and staking them. The greater the traffic that the placed wattling receives, the greater the number of rooting locations in the bundles.
- Work up the slope using the last placed line of wattling as a base from which to apply the next line.

TREE AND SHRUB PLANTING

DEFINITION: The planting of trees or shrubs along roads or trails and on adjacent slopes to aid in revegetation or soil stabilization.

PURPOSE: Trees and shrubs are planted for erosion control on and along roads and trails and on adjacent slopes. Trees and shrubs enhance training realism, improve aesthetics, and provide stability.

APPLICABILITY: Trees and/or shrubs are planted in many disturbed area situations. These may include sites where similar vegetation has been damaged, removed, or disturbed; where the loss of the canopy is detrimental; where training realism has been lost due to removal or lack of vegetation; or where canopy cover and organic matter at the surface are required to promote stability and reduce erosion and sedimentation.

CONSTRUCTION CRITERIA:

Planting Seasons: Do not transplant or plant trees or shrubs in frozen ground, when snow covers the ground, or when the soil conditions are unfavorable.

Plant Selection: Only trees and shrubs indigenous to the installation/disturbed site are recommended for transplanting or planting. See the local NRCS office for species identified for critical areas, roadsides, or eroding sites in the immediate area.

Protection of Plants Stored Temporarily: Keep all plant material moist and protected from the sun and wind while in transit or awaiting planting.

Location: Unless the roadway has been abandoned and will be rehabilitated to a natural condition, do not plant trees or shrubs on road/trail shoulders or within ditches. They are appropriate to adjacent slopes and areas above the ditch or within the area providing runoff to the ditch.

Preparing Holes to Receive Trees or Shrubs:

- Excavate a hole no less than 2 ft (0.6096 m) wider than the diameter of the root ball. If the root mass is more than 4 ft (1.22 m) in diameter, the hole should be 1.5 times greater than the diameter of the root ball.
- Remove all sod, weeds, roots, and stone from the hole to receive the tree/shrub. Remove all objectionable materials from the backfill as well.
- The depth of the hole should be adequate to allow no less than 6 in. (15.24 cm) of loam-humus backfill UNDER the root ball.
- Loosen the soil at the bottom of the hole to a depth of not less than 6 in. (15.24 cm) before adding the 6 in. (15.24 cm) of loam-humus.

Backfill Mixture: A recommended mixture consists of 4 parts topsoil, loam (or choice soil), and 1 part peat moss or peat humus.

Planting the Trees or Shrubs: Set trees or shrubs into the prepared hole so that they are each even with or not more than 1 in. (2.54 cm) lower than the depth in which they were grown.

Bare Root Stock: Place backfill material with objectionable objects removed in the bottom of the prepared hole to the required depth. As the root ball is centered in the hole, spread the roots outward. Where roots have been damaged, clip them back to an undamaged section of the root. Work the remaining backfill around the root ball and firmly tamp the soil. Soak the backfill thoroughly and leave a water basin 4 in. (10.16 cm) deep around each tree and 3 in. (7.62 cm) deep around each shrub. The diameter of the water basin should be no less than the diameter of the planting hole.

Balled Root Stock: Carefully place the balled plant in the prepared hole. It should be resting on a firmly tamped backfill soil base. Add backfill to

cover one-half the root ball. Thoroughly tamp the backfill. Cut away and remove the exposed burlap from the upper half of the root ball. Leave a water basin 4 in.(9.6 cm) deep around each tree and 3 in.(7.62 cm) deep around each shrub. The diameter of the water basin should be no less than the diameter of the planting hole.

Fertilizing Plants: Within 5 days of planting the tree or shrub, uniformly distribute the fertilizer specified for the soil and plant around the hole. Thoroughly cultivate or mix the fertilizer into the upper 2 in.(5.08 cm) of the soil. Appropriate fertilizer can also be worked into the backfill before or during planting. Apply fertilizer BEFORE mulching each tree or shrub.

Plant Watering: Ensure adequate water during and immediately following planting activities. Newly planted trees or shrubs should receive water at regular intervals during establishment. Thoroughly saturate the soil around each planting when watering.

Tree Staking: Immediately after planting, each tree should be guyed and staked.

Tree Protection: The trunks of deciduous trees should be either wrapped or sprayed with an antidesiccant.

Plant Pruning: Prune immediately after or before planting using appropriate horticultural practices. Take care to preserve the character of the tree.

Tree or Shrub Mulching: Place mulch material to a depth of not less than 6 in.(15.24 cm) over the backfilled hole, water the base of each tree, and over the entire shrub bed area. Apply mulch within 24 hours of planting trees or shrubs.

NOTE: Incorporate an additional 8 lb of nitrogen per cubic yd of mulch along with the commercial fertilizer if bark or wood chips are to be used as mulch.

Tree or Shrub	Planting Depth
Deciduous tree < 1-1/2 in. diameter	24 in.
Deciduous tree > 1-1/2 in. diameter	36 in.
Evergreen tree < 5 ft in. height	8 in. + hgt of root ball
Evergreen tree > 5 ft in. height	12 in. + hgt of root ball
Deciduous shrubs < 24 in. height	12 in.
Deciduous shrubs > 24 in. height	24 in.
Evergreen shrubs	18 in.

Table 4-3. Planting depths for trees and shrubs.

MAINTENANCE: Plant establishment should be monitored and encouraged for a minimum of one full growing season.

- Watering, cultivation, pruning, adjustment of guy wires and stakes, etc., may be required to promote establishment of healthy plants along the roadway.
- During periodic inspections, any dead, significantly damaged, or diseased plants found should be immediately removed and disposed of properly.
- During the next growing season, replace those removed plants with viable replacement plants in the same manner as previously described.
- If the mortality rate is high, replacing plants with alternative plant species may be prudent.

MAINTENANCE OF REVEGETATED AREAS

DEFINITION: The process of irrigating, fertilizing, and repairing revegetated areas.

PURPOSE: Maintenance is necessary to ensure the success of revegetation efforts and the establishment of vegetative cover.

APPLICABILITY: All slopes and areas revegetated require periodic maintenance.

PLANNING CRITERIA: The success of the revegetation effort strongly depends on maintenance. Prompt repair of damage caused by runoff can prevent the development and spread of rill and gully networks that can rapidly destabilize the entire area. Periodic fertilization will help new grasses develop extensive root systems that will aid in soil stabilization.

MAINTENANCE: Delay mowing for 1 year to promote grass establishment and seed source development. Remove heavy residues to prevent damage to establishing grasses.

- Mow on a regular maintenance schedule after the first year to reduce weeds, improve appearance, or to maintain a stand of desired vegetation. As much as possible, mowing should be done after August 15 to prevent destruction of wildlife habitats with nests or immature fauna.
- Maintenance crews should be equipped with shovels, grass seed, rakes, and straw to allow repair of small-scale erosional damage without the need to send for erosion and sediment control crews.
- Inspect trees and shrubs monthly during the growing season and periodically during the dormant season. Watch for inadequate plant establishment or physical damage. Repair as necessary.
- Inspect revegetated sites after every significant rain event.

- Prevent erosion on slopes, in ditches, on revegetated sites, or other locations through prompt repair of any failure, incipient gullies, rills, or other erosion. Prevent surface water degradation by prompt regrading and mitigation efforts where significant erosion has or may occur.
- Limit or prohibit all foot and vehicular traffic across revegetated sites. Use berms, fences, signage, or other means to prevent traffic until plant establishment is satisfactory.

REPAIR: Early detection and maintenance are critical to successful revegetation efforts. Inspect frequently following maintenance activities.

- Reseed, replant, and fertilize areas of inadequate plant establishment or damage by surface runoff to original specification.
- Water to a depth of 4 in. (10 cm) where possible.

MATERIALS USED IN VEGETATIVE REHABILITATION

TOPSOIL: Topsoil is that portion of the soil profile identified as the "A" horizon by the Soil Science Society of America. It should be friable, sandy loam, free of subsoil, debris, rocks, or plant materials that would prohibit or restrict vegetative establishment. The pH of the soil should be between 5 and 8. Organic content should be between 3 and 20 percent.

The grading analysis of the topsoil should be as shown in Table 4-4.

The topsoil selected should also meet the particle size criteria shown in Table 4-5.

Sieve Size	% by wgt passing square mesh sieve
1 inch	100
1/4 inch	97-100
No. 10	80-100

Table 4-4. Grading requirements.

Material	Size (mm)	Min. % in Topsoil	Max % in Topsoil
Sand	0.075-2	20	75
Silt	0.002-0.075	10	60
Clay	0.002-less	5	30

Table 4-5. Particle size criteria.

LIMESTONE (PULVERIZED, GROUND, OR AGRICULTURAL): Specify calcitic or dolomitic limestone containing no less than 85 percent total carbonates (calcium or magnesium).

- The sieve analysis of the limestone should meet the following criteria: Not less than 40 percent passing a No. 100 sieve and not less than 95 percent passing a No. 8 sieve.
- Appropriate natural sources of limestone may be specified IF the rate of application can be adjusted to equal the total neutralizing capability of the specified ground limestone.
- Soil analysis should specify rates of application.

FERTILIZER: Use standard commercial grade fertilizer meeting the minimum percentage of specified nutrients.

- Clean and sealed containers of fertilizer should arrive clearly marked with the name, weight, and guaranteed analysis of contents. Adequate amounts of additional fertilizer may be added to supplement existing supplies to provide the specified amount of fertilizer to a specific site.
- Fertilizers may be granular, pelleted, or liquid.

SEEDS: Seed mixtures as specified for roadside or critical area use in the immediate region should consist of grass, legume, and cover-crop seeds. Each container of seed or seed mixture should arrive in standard containers with the following information marked on them: seed name, lot number, net weight, percentages of purity and of germination, and percentage of maximum weed seed content. Seed should have proof of testing by a certified lab within 6 months of date of delivery. Inoculate legume seed with approved cultures according to manufacturer instructions.

WOOD CHIPS: Stockpiles of wood chips can be created at many installations using available green hardwood. Chips should be no less than 0.125 in. (0.3175 cm) thick, with no more than 50 percent having a surface area of not less than 1 sq in. (6.45 sq cm) and not more than 6 sq in. (38.71 sq cm). Wood chips should be free of leaves, twigs, shav-

ings, bark, or materials that may be damaging or detrimental to plant establishment.

STRAW: Use only straw made from grain crops, air-dry, ready for use in blowers, and free from noxious weeds, mold, or other objectionable materials.

HAY: Use only hay resulting from herbaceous mowing, air-dry, suitable for placing in a blower, and free of noxious weeds, mold, or other objectionable materials.

WOOD CELLULOSE FIBER: Use natural wood cellulose fiber mulch made from clean, whole-wood chips, readily dispersible in water, free of weed seed, and heat processed. A dye, typically green, that fades with light and is not harmful to plants may be incorporated with the wood fiber.

SAWDUST: Sawdust that is free of toxic substances and has been aged is acceptable.

PEAT MOSS: Granulated sphagnum peat moss virtually free of woody particles and made up of not less than 75 percent partially decomposed stems and leaves of sphagnum and displaying a primarily brown color should be acceptable. The pH should be between 3.5 and 5.5. The texture of the peat moss may vary from porous-fibrous to spongy-fibrous and be free of sticks, stones, and mineral matter. Peat moss should arrive in an air-dry condition.

PEAT HUMUS: Natural peat or peat humus from fresh water areas should consist of sedge, sphagnum, or reed peat and be passable through a 0.5-in. (1.27 cm) sieve. Humus should be free of sticks, stones, roots, or other objectionable material. The pH range should be between 4.0 and 7.5. Minimum organic content should be no less than 60 percent when oven-dried at 105 °C.

GRASS STRAW CELLULOSE FIBER: This should be readily dispersible in water and have no toxic effects when combined with seed or other materials. A harmless green dye made be added to

the product. The pH range should be between 6.5 and 7.5. The moisture content should be no less than 8 to 12 percent. Organic matter content should be 90 to 100 percent. This product should arrive in new, clean, sealed containers in an air-dry condition.

PLANT MATERIALS: Tree and shrub stock may be either nursery stock or transplanted from an appropriate site. It is beneficial if the stock has been transplanted or root-trimmed at least twice. The branches should be of normal development and free of knots, broken terminal growth, sunscald, injuries, abrasions, etc. Trees to be selected should have generally straight stems and be well balanced and symmetrical.

Balled and Burlapped Plants: Plants should be dug to retain as many fibrous roots as possible. Care should be taken to retain the natural soil within which the tree or shrub has grown. Take care when wrapping and transporting to minimize loosening the soil around the roots or disturbing the small feeder roots.

EROSION CONTROL NETTING OR BLANKET MATERIAL: All erosion control materials should arrive clean, free of rips or tears, and in lengths of not less than 200 ft (60.96 m).

Burlap: Burlap should consist of a standard weave with a weight of 3.5 to 5.0 ounces per sq yd.

Jute Mesh: Jute mesh should consist of a uniform weave with warp and weft yarns of approximately the same diameter. Widths should be 45 to 48 in. (114.3-121.9 cm) with 78 warp ends per width and 41 weft ends per yd. The weight of jute mesh should be between 1.80 and 1.20 lb (.8165-.544 kg) per running yd with a 5 percent tolerance.

Woven Paper or Sisal Mesh Netting: Netting should be made from twisted yarns woven into 45-in. (114.3 cm) wide rolls. The mesh should have a 3 in. by 3 in. (7.62 cm) maximum opening. Shrinkage after wetting should be less than 20 percent of the surface area. The minimum weight

of the netting should be no less than 0.8 lb per sq yd (+/- 10 percent).

Excelsior Blanket: Blankets should consist of a machine-produced mat or curled wood excelsior of 80 percent, 6 in. (15.24 cm) or longer fiber length, with consistent thickness and the fiber evenly distributed over the entire area of the blanket. Dimensions of the fiber should be 0.021 by 0.042 in. (+/- 25 percent). The average weight of the fiber per sq yd should be not less than 0.974 lb (+/- 10 percent).

Biodegradable Plastic Mesh Netting: Mesh netting material should consist of extruded, rectangular mesh with a weight of approximately 3.0 lb (1.36 kg) per 1000 sq ft (92.9 m²).

Staples: Staples used to secure erosion control materials should consist of wire, 0.091 in. (0.231 cm) in diameter (11 gauge) or greater. They should be U-shaped with a 1 in. (2.54 cm) throat and legs not less than 6 in. (15.24 cm) long. Stakes made of wood should be of sound wood, at least 8 in. (20.32 cm) long and with a cross-sectional area of about 1 in. (2.54 cm).

5 Physical Erosion Control Practices

The physical erosion and sediment control practices used along the roadway are generally classified as either temporary or permanent, according to how they are used. Temporary physical practices may be implemented at freshly disturbed or damaged sites or during road construction, repair, or rehabilitation efforts to prevent sediment from entering water bodies or sensitive areas. Permanent physical practices are used to convey sediment-free surface runoff to a nonerosive outlet. The permanent measures are intended to provide long-term control of runoff along the roadway. The length of time that both types of practices are functional varies from region to region and site to site.

Proper design and grading techniques can significantly reduce the amount of sediment generated during construction or maintenance on cut and fill slopes. Roadway design should take into consideration slope length, slope steepness, soil type, and the drainage area generating runoff to the roadway. Leaving soil surfaces on disturbed slopes or other adjacent areas in a roughened condition is beneficial. Rough soil surfaces do not erode as easily as smoothed soil surfaces. Water diversions should be constructed at the top of slopes beside the roadway to reduce the volume of runoff on the slope and within the drainage ditch.

Some general guidelines apply to the selection and placement of physical practices to reduce erosion and sedimentation along the roadway.

1. To prevent sediment-free water from picking up material for transport, divert runoff away from disturbed slopes and ditches (where possible).

- The diversion of runoff away from ditches and adjacent slopes can be accomplished by installing ditch turnouts and slope dikes or berms, swales, combined berms and swales, or diversions. These measures serve to redirect sediment-free runoff to stable areas for infiltration.

2. Prevent sediment-laden runoff from discharging into streams, water bodies, or sensitive areas via the road surface or drainage ditches.

- Where sediment-laden runoff is concentrated within drainage ditches, diverting that runoff to a sediment-trapping structure is necessary. There, the suspended sediment is allowed to settle out and the clean water is safely discharged. Runoff may be diverted into sediment traps via dikes or swales or a combination of both. At times, a temporary sediment trap may be installed within, or next to a ditch to prevent discharge of sediment-laden materials into water bodies. This structure is removed as soon as the source of the sediment has been rehabilitated.

3. Where runoff is flowing as sheet or surface flow off slopes or disturbed areas next to the roadway and sediment transport is a concern, it is important to filter the sediment from the sheet flow as soon as possible.

- Most frequently, straw bale check dams or dikes, silt fences, or vegetative buffer strips are used to filter the sediment transported by sheet flow.

Many practices are used to prevent or reduce erosion and sedimentation on and along the roadway. Whatever the type of practice, once selected and implemented, proper installation and maintenance are critical to assure functionality.

The effectiveness of any practice can be enhanced if several factors are considered before implementation.

- Locate the source or cause of changes within or beside the roadway system that have led to

erosion or sedimentation. Many problems can be resolved easily if mitigation measures are undertaken at the source.

- When selecting a site for installation of a practice, make sure that the site is not so unstable that the practice will fail or lead to even more erosion. Select each practice for effectiveness on a specific site.
- Evaluate natural drainage patterns close to the roadway before implementing practices to avoid modifying or disrupting the natural system by an increase or decrease in water. Water diverted into a seemingly stable channel or gully can initiate a rapid and often dramatic erosive episode.
- Evaluate the need for the hardening of the practice. This is most often done in response to damage by vehicles and military training activities.
- Most states offer detailed manuals that provide standards, specifications, and designs for those erosion and sediment control practices determined to be most suitable for the entire state or portions of it. These documents can be very beneficial in developing effective roadway maintenance and repair programs.

Regardless of the efficiency of the roadway maintenance program, secondary roads and tertiary trails subjected to intensive and prolonged traffic by tracked vehicles may require much more than standard roadway maintenance practices. The development of site-specific, innovative practice designs, the hardening of practices against military training activities, and the testing and evaluation of new products and techniques are mandatory. Installation roadway engineers may benefit from interaction with other installations and state and regional agencies handling similar programs. Assistance is also available from the three U.S. Army Corps of Engineers research laboratories at Champaign, IL (CERL); Vicksburg, MS (WES); and Hanover, NH (CRREL).

**GENERAL PHYSICAL EROSION CONTROL PRACTICES APPLICABLE TO
ROADWAY MAINTENANCE AND EROSION CONTROL**

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ACCESS ROAD ENTRANCE/EXIT

DEFINITION: A short, stabilized or hardened road section surfaced with crushed stone and located where tracked or wheeled vehicles enter or leave a disturbed area. The access road is similar to a construction entrance/exit.

PURPOSE: The road entrance provides access to range areas used for training, testing, maintenance, and management for conservation purposes while controlling runoff and sediment to prevent erosion and sedimentation.

- To prevent clods of mud or excess soil that may be sticking to tracks or wheels from flowing or being tracked onto secondary or paved roads.
- To reduce sedimentation from a disturbed area.
- To reduce roadway maintenance requirements.
- To improve access to training/testing areas.

APPLICABILITY:

- At entrance or exit points where tracked or wheeled vehicles traverse wet, muddy terrain or terrain lacking in vegetative cover.
- Where tertiary trails intersect with secondary or paved roads.

PLANNING CRITERIA: Select points of access or degrees that are most frequently used and close off the remainder.

- Close or avoid construction of access pads that have steep grades or entrances or exits at curves.
- Consider the location of the access pad in relation to streams or other water bodies.
- If the site is wet, filter fabric should be considered for the subgrade.
- Consider the width and number of vehicles using the access pad at one time.

- If the existing access pad is degraded, remove it and reconstruct it from the subgrade to the surface course.

DESIGN CRITERIA: Design access roads or trails according to the expected use and vehicular traffic of the roadway they are supporting.

- Where access for the public is anticipated, design roads to meet applicable state or Federal standards.

Width: The minimum width of the roadbed should not be less than 14 ft (4.2 m) for one-way traffic and 20 ft (6 m) for two-way traffic. Special-purpose roads have a minimum width of 10 ft (3 m).

Length: The minimum length of the access road should not be less than 100 ft (30.48 m).

Drainage: The type of drainage structure will depend on the runoff characteristic of the site and the use of the road.

- Provide culverts, low water crossings, or dips (waterbars) at all natural drainage ways.
- Roadside drainage ditches should be adequate to provide surface drainage for the roadway, ditch, and adjacent slopes.
- Drainage to sediment traps should be provided for each access road.
- Prevent any sediment from entering ditches or water bodies with straw bales or sandbag sediment barriers.

Surfacing. Provide a wearing course or surface treatment as required by traffic, climate, erosion control, or dust control needs. The type of treatment will depend on the conditions at the site, materials available for surfacing, and the existing roadbase.

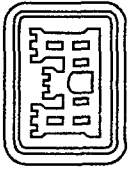
- The aggregate surface course should consist of 2- to 3-in. (5- to 8-cm) diameter crushed stone. The thickness of the surface course should not be less than 6 in. (15 cm) after compaction.
- In areas of high soil moisture content, seepage, or other wet conditions, filter fabric should be used between the base course and surface course to promote drainage and enhance the stability of access road foundation (roadbed).
- Roads that receive no surface treatment will require controlled access at the point of entrance to prevent damage or hazardous conditions during inclement weather.

CONSTRUCTION CRITERIA:

- The subgrade, base course, and surface course should be laid in 8-in. (20-cm) lifts and be thoroughly compacted to within 95 percent of density for the material used.
- Revegetate disturbed areas immediately.

MAINTENANCE:

- Periodic top dressing with additional stone is required.
- Inspect, clean, and repair sediment traps associated with access pads periodically or after significant rain events at a minimum.
- Periodically maintain the access pad to prevent mud or sediment from leaving the disturbed area.
- Access roads to be closed or used only intermittently or on a rotational basis can be vegetated to provide erosion control.



**US Army Corps
of Engineers.**

Construction Engineering
Research Laboratories
P.O. Box 9005
Champaign, IL 61826
1-800-USA-CERL

PROJECT:

Roadway
Maintenance and
Drainage Control

DRAWING NAME:

Access road entrance
or exit

DRAWING NUMBER:

5-1

DESIGNED BY:

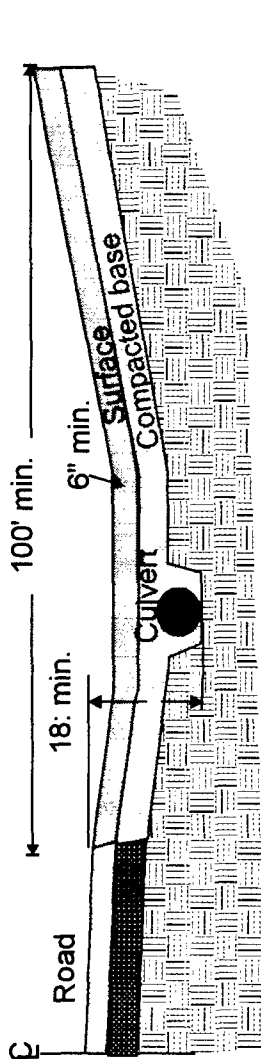
Sara J. White

DRAFTED BY:

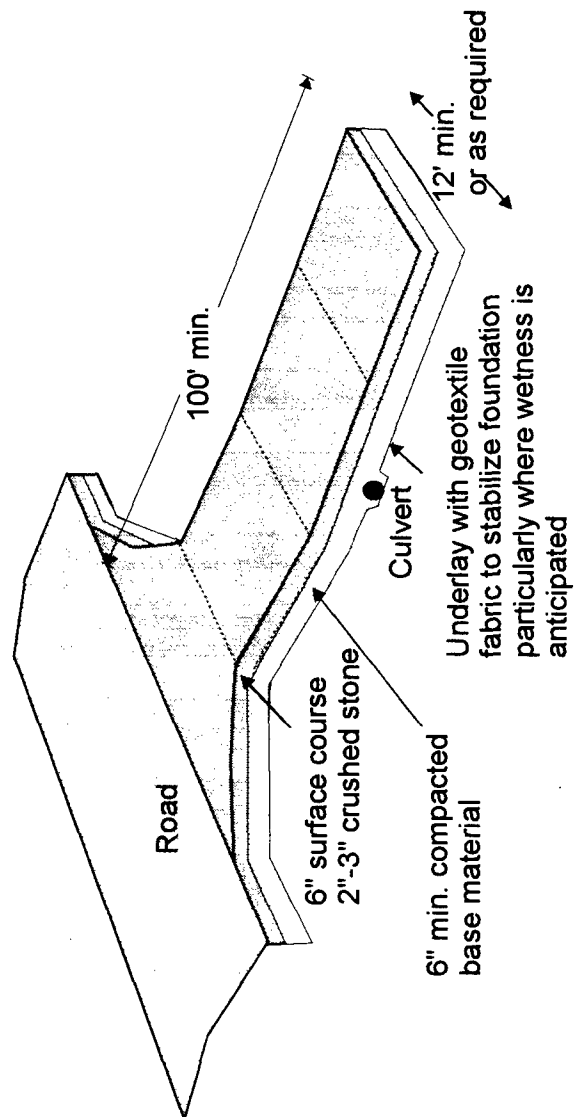
Sara J. White

DATE:

8-25-96



Access road entrance/exit - construction detail



Typical access road entrance - oblique view

CHECK DAMS (Riprap, Log, Straw Bale)

DEFINITION: A small temporary dam built across a drainage ditch, swale, or gully.

PURPOSE: Check dams are used to reduce or prevent excessive bank and bottom erosion within the drainage ditch by reducing the runoff velocity. While a check dam will trap some particles, it is not intended as a sediment-trapping structure. The check dam acts as a temporary grade control structure until vegetation can become established or the channel otherwise stabilized.

APPLICABILITY: Check dams are only applicable in ephemeral channels with a contributing drainage area less than 5 acres (2 ha). Check dams should only be used AFTER efforts have been made to control, divert, disperse, or retain runoff above the ditch or gully.

- As required in ditches to reduce long and/or steep grades and velocities.
- To prevent erosion by effectively reducing high- energy turbid flows to more tranquil low-energy flows.
- As a temporary or emergency measure to limit erosion and sedimentation within newly constructed or recently seeded ditches.
- Where slopes are steep, ditch bottom incision or gullying are problems, and channel lining or diversion with turnouts or culverts are not practicable.
- Where channel lining or a flow diversion is not practicable.

PLANNING CRITERIA: Design by an engineer is helpful, although no formal design is required if certain guidelines are followed in construction.

- Check dams must be constructed in series.
- Check dams must be placed in flow paths to slow velocity and reduce channel bed erosion.

- Sediment capture is a secondary function of check dams. Sediment barriers are more properly used to intercept runoff and capture sediment before it reaches a channel.
- Overfall materials may include concrete, metal, riprap, gabions, wood, logs, or other durable materials.
- Check dams must be placed in reasonably straight reaches of the ditch.
- When selecting construction materials, consider site and foundation conditions and aesthetics.
- Evaluate the design channel grade above and below the check dam carefully to determine the potential for erosion or sediment deposition.
- In gullies with gradients less than 20 percent, the slope of the expected deposits is 0.7 percent of the original gully gradient. In gullies with gradients greater than 20 percent, the slope of the expected deposits should be reduced to 0.5 percent of the original gradient.

NOTE: Straw bales, straw bale/filter fabric, silt fabric/wire fence, or silt fabrics alone are forms of sediment barriers. They are to be used along the base of exposed slopes or for inlet protection. They may be used temporarily across or within gentle swales with low flow to trap sediment, BUT, they should NOT be placed across a drainage ditch that carries a high volume flow or high velocity flow.

If the flow in the ditch exceeds the capacity of a grass lining, DO NOT place sediment barriers across the ditch or outlet.

DESIGN CRITERIA:

Spillway. The maximum height of the spillway (center of check dam) should be no more than 2 ft (0.609 m) above the bed of the ditch.

- The center of the spillway crest (weir notch) should be 9 in. (23 cm) lower than the ditch banks at natural ground level, and at least 6 in. (15 cm) lower than the adjacent edges of the structure.

Keying. Key the check dam 12 in. (30 cm) into the bottom and 18 in. (46 cm) into the sides of the channel at a minimum. This entrenchment provides stability and prohibits undermining or side scour.

Spacing. The maximum spacing of the dams places the toe of the upstream dam at the same elevation as the top of the spillway of the downstream dam.

Apron. Proper design and installation of a stable outlet apron on the downstream side of the check dam is critical no matter what construction material is used.

MATERIALS: Check dams can be constructed of materials on-site or readily available nearby. Sandbags, logs, rock or riprap, gravel filters, and straw bales can be used to construct check dams.

CONSTRUCTION SPECIFICATIONS:

Marking. Mark the centerline of the dam and the key trenches on each bank. Set the stakes away from the ditch edge to protect them during construction.

- Designate the crest of the spillway by a temporary benchmark in the ditch side slope to aid in installing the dam.
- Mark the downstream end of the check dam apron.
- Flag the upstream and downstream toes of the dam itself.

Excavate. Excavate the key trenches, the apron, and the bank protection. A narrow backhoe or hand shovel can be used for this step.

Filter Fabric. Underlay riprap with geotextile suitable for the purpose. Lay it loosely without

creases or wrinkles. Overlap adjacent sections at joints and secure with staples or pins at 3-ft (0.91-m) intervals no closer than 2 in. (5 cm) to the edge. Use caution to avoid displacement of the filter fabric when installing riprap. Do not drop riprap from higher than 3 ft (0.91 m) above the filter fabric.

RIPRAP CHECK DAM: Use 4- to 15-in. (10- to 38-cm) well-graded stone (check design specifications) for construction of riprap check dams and energy dissipation structures.

- The keyway should be excavated a minimum of 2 ft (0.61 m) wide, 12 in. (30 cm) deep, and 18 in. (46 cm) into the side banks.
- Install a heavy-duty filter fabric between the keyway, the apron, and the riprap
- Maintain side slopes of 2:1 or flatter for riprap check dams.
- Check the riprap fill for voids and hand place stones as necessary to minimize the voids. Voids will reduce the effectiveness of the dam.
- Dumping the riprap onto the check dam allows the stones to attain their natural angle of repose more readily.
- Finished riprap slopes will be fairly regular and uniform and not steeper than shown on the design/specification.

WOOD POST CHECK DAM: Durable post material, of a smaller diameter, trimmed of small branches, can be used to construct post check dams.

- Lay the poles or logs across the gully in layers, the bottom layer being two to four posts wide and the topmost layer being one post wide.
- The lower posts are laid into a keyway trench one post deep and extending into the banks 18 in. to 24 in. (46 to 61 cm) minimum.

- The posts should be fastened with wire and spikes or suitable binding materials.
- A post apron is constructed for a distance of 3 to 4 ft below the dam to protect the ditch bottom from erosion.
- The weir notch should be 2 to 4 ft (0.61 to 1.21 m) wide and 6 to 12 in. (15 to 31 cm) deep, depending upon the size of the ditch or gully.
- Use filter fabric or thoroughly tamp or compact the soil around the dam to prevent undermining.

LOG CHECK DAM: Where timber is abundant, use 4- to 6-in. (10- to 15- cm) diameter, durable post wood trimmed of small branches, to construct the check dam.

- Drive posts across the channel at intervals of about 4 ft (1.22 m), and set about 2 to 4 ft (0.61 to 1.22 m) into the ground, with tops extending 2 to 3 ft (0.61 to 91 cm) above the channel bottom.
- Excavate a keyway trench across the ditch or gully the width and 3/4 the diameter of a log that will be placed within the trench. Extend the trench into the ditch or gully banks a minimum of 18 to 24 in. (46 to 61 cm).
- Continue to lay logs on top of the anchor log until they reach the top of the upright posts.
- Secure the horizontal logs by either nailing them to the upright posts, by driving small stakes on the upstream side near the ends, or compacting the bank soil against the trenched ends.
- Cut a weir notch at the center of the dam with a chain saw or hand tools.
- Install a dissipation apron below the dam. Logs can be laid side by side and secured with stakes at the lower end. Loose rock can also be used if secured by a log set 3/4 of the diameter into

a trench 4 to 6 ft (1.21 to 1.82 m) below the dam.

- Line the dam and apron with filter fabric to prevent undermining.

STRAW CHECK DAM: When using straw bales as temporary check dams, place them in a single row, within a keyway trench, tightly fitted end to end, and perpendicular to the flow.

- Extend the straw bales across the ditch far enough to prevent sediment or water from going around the ends.
- Lay straw bales at least 4 in (10 cm) into the keyway trench.
- Fill any gaps in the straw with more straw, rocks, or filter fabric and tamp well to prevent undercutting.
- Secure straw bales with two stakes each or rear driven through the bales. The first stake in each bale is driven toward the previously laid bale to tie them together. Stakes should be driven a minimum of 18 in. (46 cm) into the ground.
- Remove all debris from the site during excavation to reduce sedimentation.

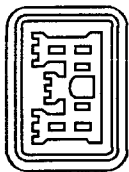
Each check dam, despite material, requires an energy dissipation apron to prevent erosion on the downstream side.

MAINTENANCE: Inspect check dams periodically and particularly after each significant rain event.

- Correct damage to check dams immediately. One failed or damaged check dam can jeopardize an entire series of check dams.
- Should incision occur between check dams after installation, either remove and reinstall with better spacing or use riprap to line/protect the ditch bottom.

Incision suggests improper check dam design or spacing.

- Remove sediment accumulated behind dams when they are no more than 60 percent filled if that is the intent of the structure. Runoff should pass through the stones, straw, or logs of the dam, filtering sediment behind, so eventually excessive sediment may flow over the dam.
- If the trapped sediment is intended to modify the channel grade and reduce headway cutting of a gully within a ditch, immediately revegetate the depositional material to stabilize it.
- A drop structure may be required if the gradient of the ditch is too steep for the check dams to handle.



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PROJECT:

Roadway
Maintenance and
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DRAWING NAME:

Riprap check dams

DRAWING NUMBER:

5-2

DESIGNED BY:

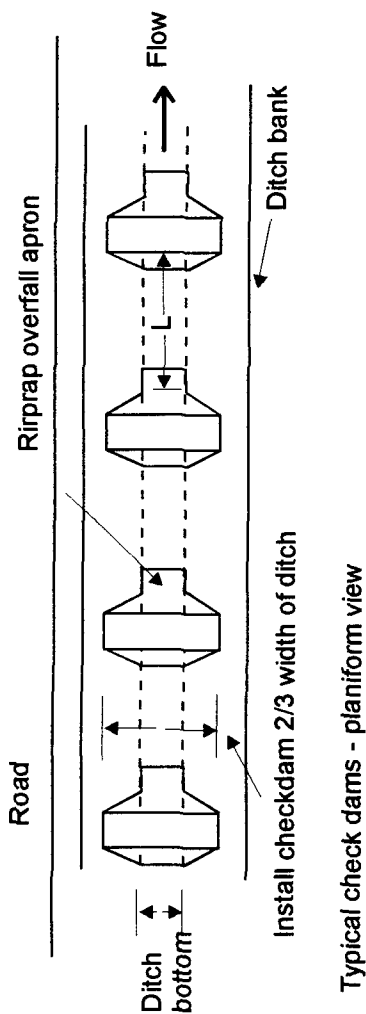
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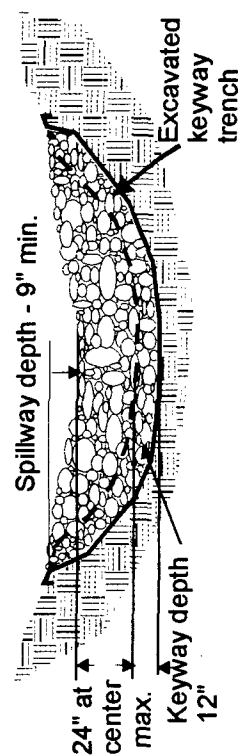
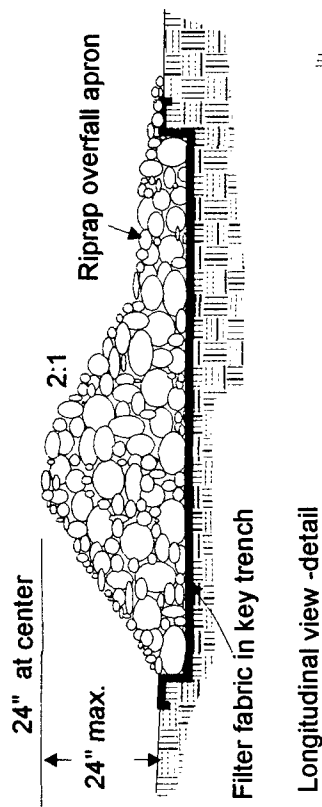
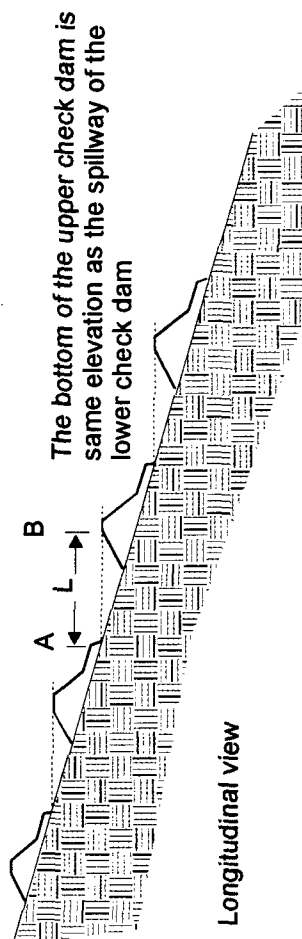
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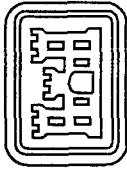
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Length (L) = the distance between A and B
given that A and B are of equal elevation





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PROJECT:

Roadway
Maintenance and
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DRAWING NAME:

Straw bale checkdams

DRAWING NUMBER:

5-3

DESIGNED BY:

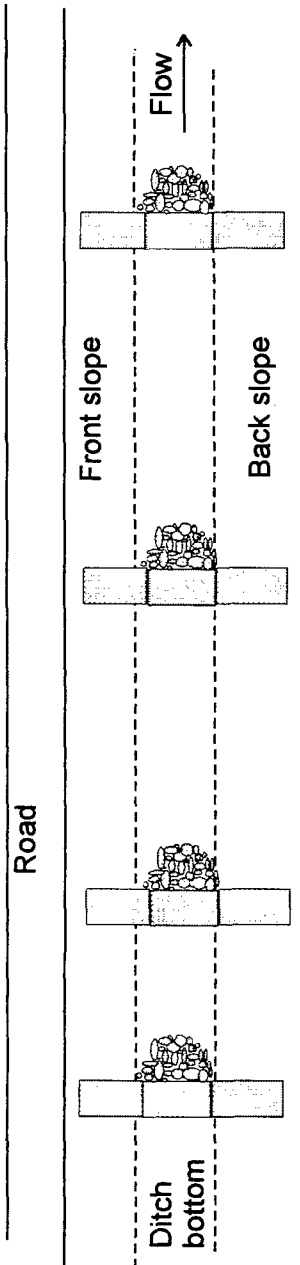
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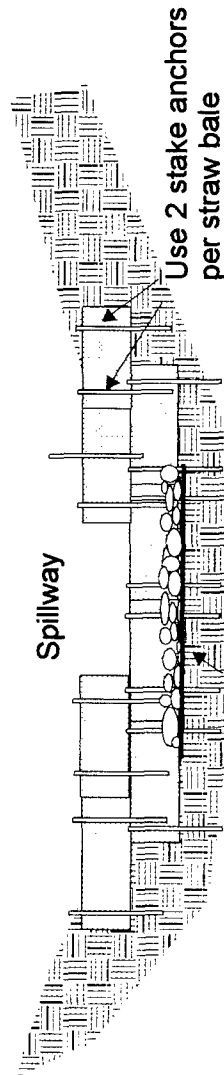
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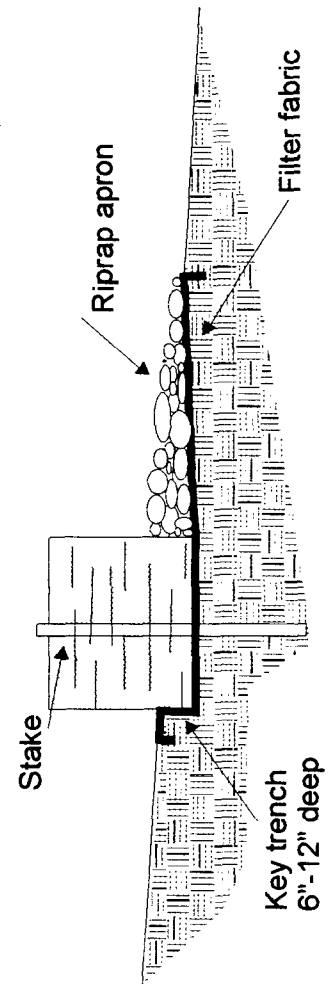


Straw bale check dams - planform view

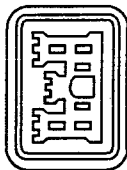


Riprap apron at base
of spillway

Straw bale check dam - cross-sectional view - detail



Straw bale check dam - longitudinal view - detail



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PROJECT:

Roadway
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DRAWING NAME:

Sand bag sediment
barriers or checkdams

DRAWING NUMBER:

5-3a

DESIGNED BY:

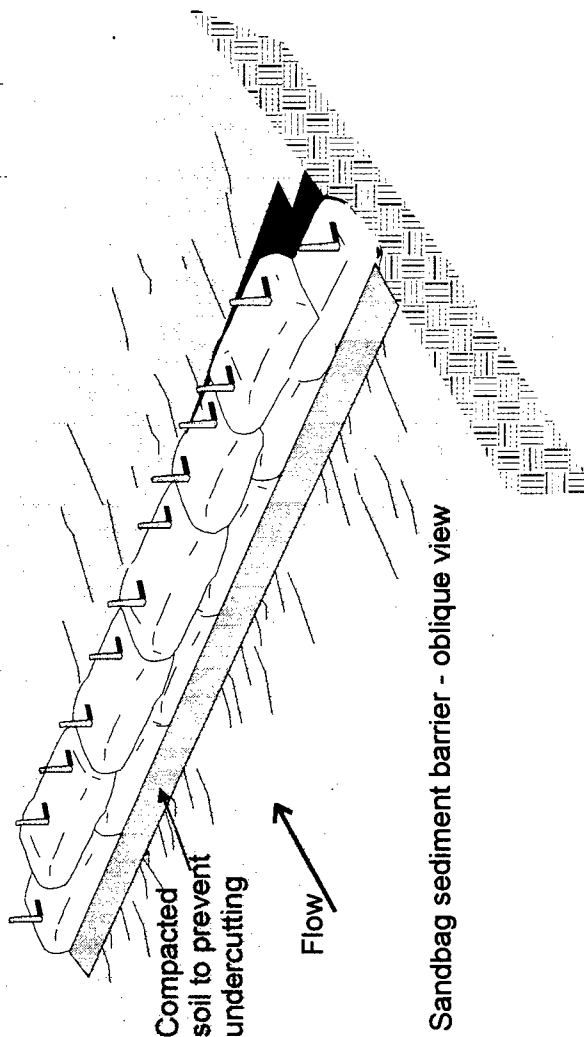
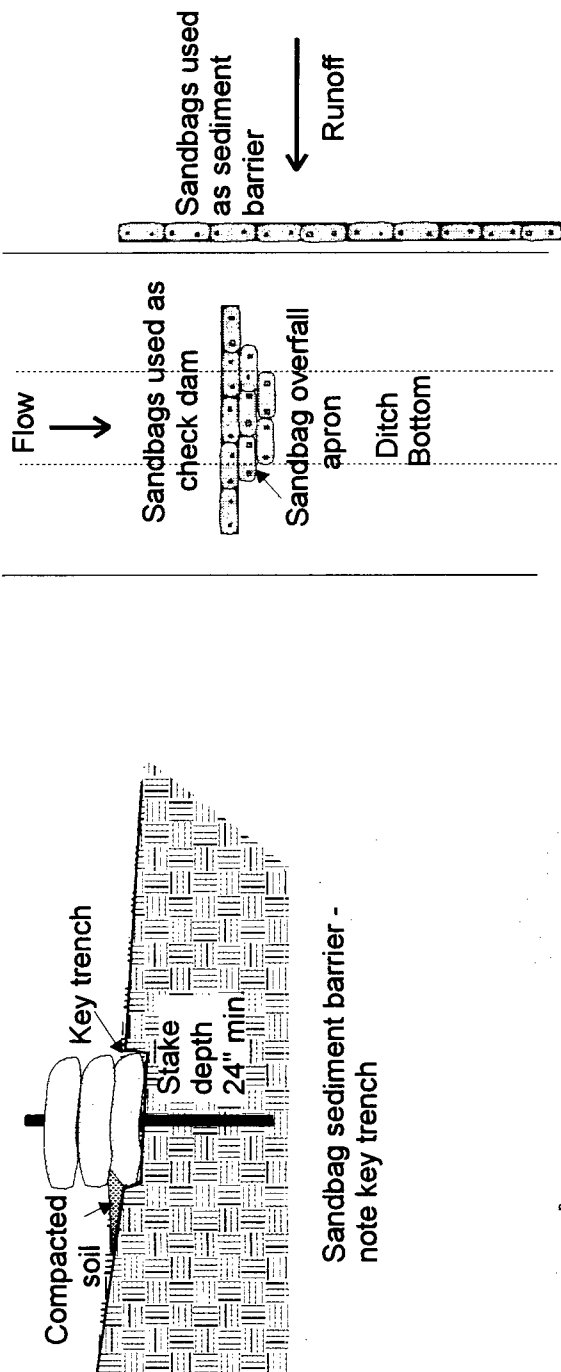
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Sara J. White

DATE:

11-13-96



CROSSROAD DRAINAGE

DEFINITION: A structure to provide nonerosive drainage across or through an embankment or roadway. Variations include the broad-based dip, rolling dip, crossroad culvert, open-top or box culvert, waterbar, or right-of-way diversion.

PURPOSE: To reduce erosion on and along the roadway by limiting the accumulation of runoff on the road or within the ditch by diverting it at designed intervals.

APPLICABILITY: Wherever excessive runoff must be conveyed from one side of the road to the other to reduce the potential of erosion or flooding or to maintain natural low-flow drainage.

- On roadways on slopes or on sloping curves.
- On roadways receiving low to moderate traffic.
- Where rills or gullies have developed in ruts or tread tracks in trail surfaces.

PLANNING CRITERIA:

Broad-based Dip. The broad-based dip is a depressed, outsloped section of roadway that acts as a water catchment and drainage channel. It can be used for culverts for cross-drainage in areas without intermittent or perennial channels. It is not the same as a low water crossing or ford. A dip has an initially low cost and can be used without a ditch line in place. However, equipment operators need special training to properly construct the broad-based dip to design specifications.

- A poorly constructed dip can result in erosion, sedimentation, rutting, or ponding of the dip or roadway. Where erosion occurs it becomes necessary to protect the fill slope and down-slope channels. Accumulated sediments must be removed. Surface irregularities require the roadway and/or dip to be reconstructed.
- A dip performs best when the road grade is less than or equal to 3 percent. A failure rate of

more than 32 percent can be expected for a dip on a road grade between 3 and 9 percent.

- A dip that is surfaced or hardened with crushed stone or gravel will perform better than an unprotected dip. The failure rate may be almost 40 percent for an unprotected dip. Review of typical designs suggests both 3/4 in. crusher run aggregate and 3 in. crushed stone are appropriate for hardening a dip.
- Dips and culverts on horizontal curves have a higher frequency of failure than structures on a tangent to the roadway. The failure rate for dips on curves is 40 percent vs. 8 percent for culverts.

Rolling Dip: The rolling dip is a swale that is shallow and broad and constructed on a slight diagonal to the roadway. The rolling dip is also more difficult to construct and maintain. It is more suitable to winter use when the road or trail surface is less susceptible to degradation due to wetness. It may be hardened by filling with coarse gravel. Care must be taken that mud puddles do not develop in the swale. A rolling dip can be hard on vehicles and operators, particularly if group movements create dust that obscures the road surface.

Waterbar: A waterbar is a berm and swale combination built diagonally across a road or trail. The maximum height of a waterbar should be no more than 18 in. (45 cm) from the channel bottom to the berm top.

- Side slopes should be 2:1 or flatter and 3:1 where vehicles cross. Base width of the dike should not be less than 6 ft (2 m).
- A waterbar is somewhat more stable than a rolling dip. Both berm and swale must be broad and neither too deep nor too high. Repeat impact from vehicles may destroy it if it is not properly constructed. Care must be taken to prevent impact to, and damage from vehicles,

particularly those with low clearance. A waterbar becomes less effective when traversed during wet weather.

Dike: A dike or berm looks like a broad-based, low speed bump placed diagonally across the road. Base width of the dike should not be less than 6 ft (2 m). It is subject to damage by wheeled and tracked vehicles, particularly if traffic is intense or prolonged. It can be readily destroyed by grading activities. When breached by wheels or tracks, road surface degradation and even gullying may occur. A dike can be hard on vehicles and operators, particularly if group movements create dust that obscures the road surface.

Crossroad Culvert: Crossroad culverts spaced equally and frequently under the road are a low maintenance, but more costly means of conveying runoff from one side of a road to the other. They have a fairly low failure rate and have a greater longevity than dips.

Open-top Box Culvert: This structure is constructed of wood and is installed flush with the surface of the roadway. It is relatively inexpensive to construct and maintain, but may be subject to damage by tracked vehicles.

Wood and Rubber Waterbar: Set at a slight diagonal across the roadway, the waterbar is constructed of a length of wooden board to which a length of rubber (conveyor belt rubber for example) has been secured. The wood and rubber waterbar is set into the trailbed with the rubber elevated above the surface of the trail. Water flowing along the road is diverted to the outslope and vehicles can pass over the rubber with minimal damage. For roads receiving low traffic, this is a cost-effective, low-maintenance method of diverting runoff from the surface.

DESIGN CRITERIA: The spacing of the crossroad drain depends on the slope and type of soils the roadway is built on. However, the general spacing rule is shown in Table 5-1.

- To check for appropriateness of spacing, determine the distance it takes for an unsurfaced

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

Table 5-1. Spacing of waterbars and rolling dips.

road to develop a rill with a depth of 1 in. (2.54 cm). That distance is the spacing required at that location.

- The positive grade is not to exceed 2 percent.
- Stable outlets are mandatory on all crossroad drains. Use energy dissipators where and if necessary.

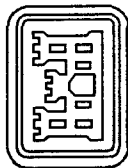
CONSTRUCTION CRITERIA:

- Install as soon as the right-of-way has been cleared or graded when building a new roadway.
- Build cross road drains at an angle of 30 to 45 degrees from the centerline.
- Compact by machine or hand in 4- to 8-in. (10- to 20-cm) lifts.
- The outlets of crossroad drains or alternatives must be stabilized or the water discharged onto undisturbed, well-vegetated areas.

MAINTENANCE:

- Schedule regular or periodic maintenance and inspections to prevent breaching or damage to the crossroad drains by either runoff or vehicles.
- Monitor for ponding during or following rain events. Correct problems as soon as possible.

- Monitor for traffic driving around the ends of the diversion to avoid the bump or ponded water. Install barriers as required to prevent avoidance.
- Check outlets and repair in a timely manner.



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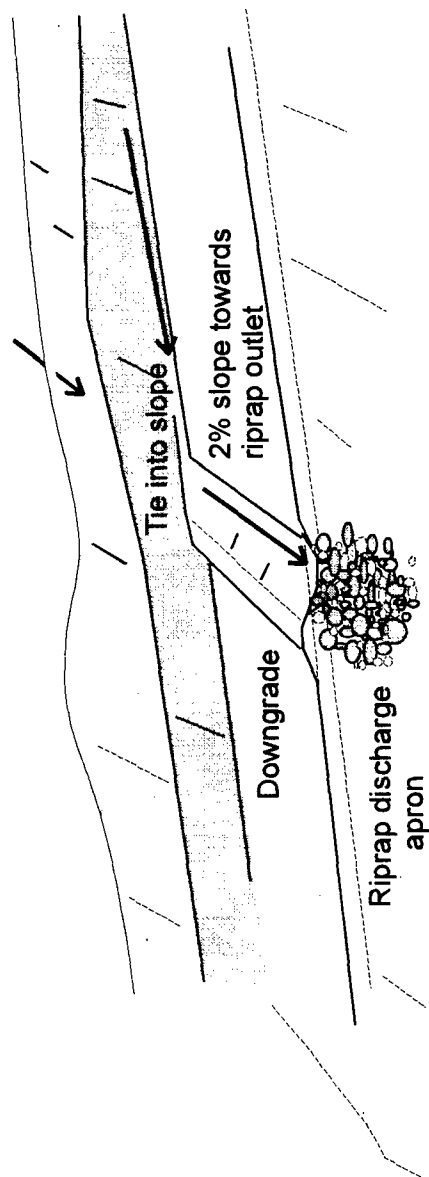
DRAWING NAME:
Water bar

DRAWING NUMBER:
5-4

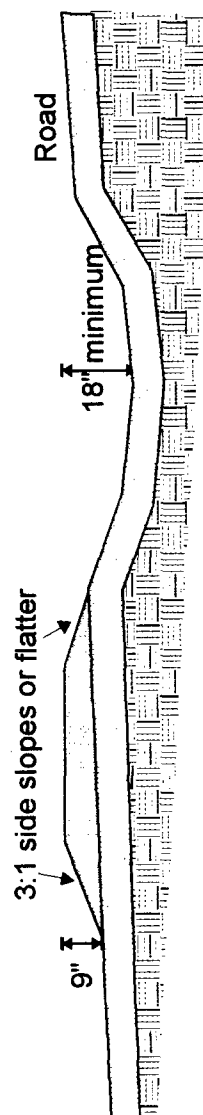
DESIGNED BY:
Sara J. White

DRAFTED BY:
Sara J. White

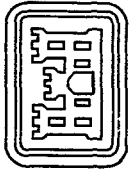
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10-14-96



Water bar - oblique view



Water bar - construction detail



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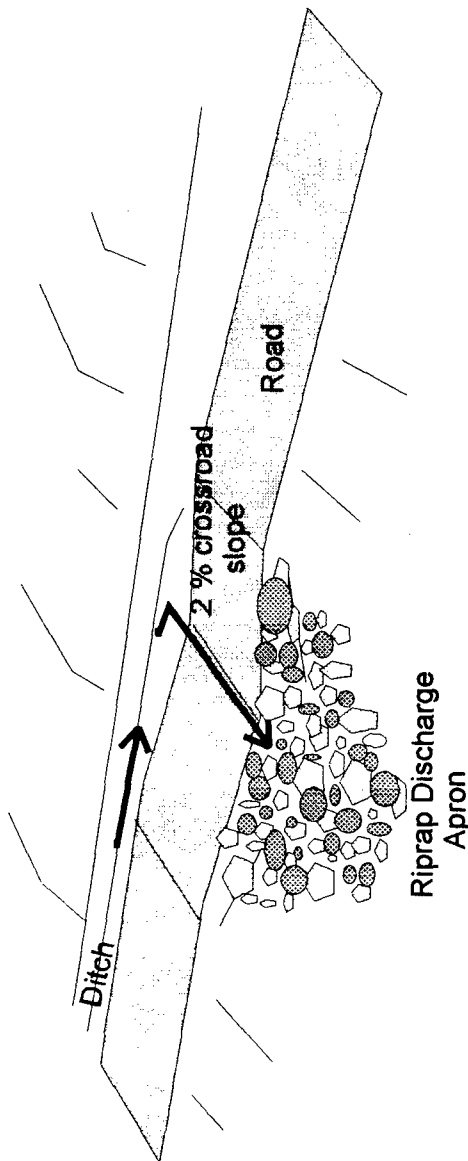
DRAWING NAME:
Rolling Dip

DRAWING NUMBER:
5-5

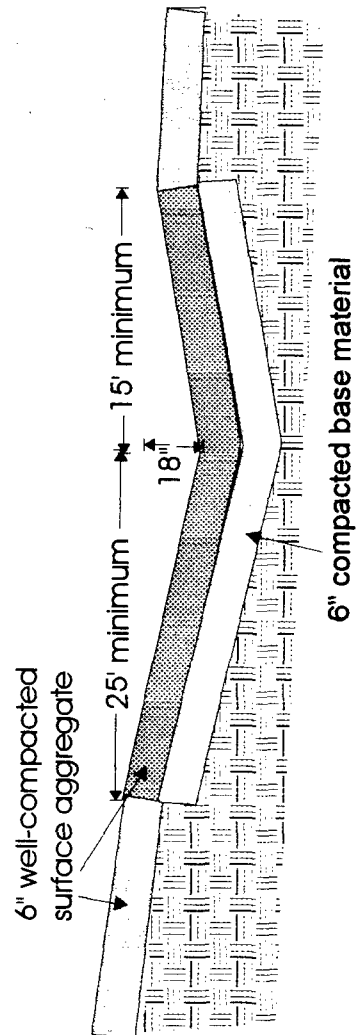
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Sara J. White

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10-14-96



Oblique view of Rolling Dip



Cross-sectional view of Rolling Dip

Not to Scale

CULVERTS

DEFINITION: A conduit of corrugated metal or plastic or reinforced concrete piping.

PURPOSE: Culverts convey water through embankments or roadbeds, thereby reducing erosion caused by diverted overland flow.

APPLICABILITY: Culverts are used in areas where embankment or roadbed construction would otherwise disrupt existing drainage patterns. They are used to convey water from ditches or drainages on one side of a road to a nonerosive outlet on the other side.

PLANNING CRITERIA: Culverts should be designed and installed according to the standards set by each state.

Materials: Culverts in common use are constructed of corrugated metal, corrugated aluminum, and heavy-duty plastic. Concrete culverts are not as commonly used due to cracking and failure.

Capacity: Culvert capacity is based on peak runoff calculations. A 10-year flood capacity without static head at the entrance or a 100-year flood using available head at the entrance is standard. The shape of the culvert (circular, pipe-arch, arched open-bottom) and the number of openings will directly influence design capacities. To be self-cleaning, culverts should be aligned and graded to provide minimum flow velocity of 3 ft per second.

- Many computer programs are available for the sizing of culverts, while Hydraulic Engineering Circular 5 (HEC 5), 1964, provides the charts for manual determination of culvert size and number for highway applications.

Alignment: Culvert alignment should provide water with a smooth transition at the inlet and outlet. Sharp turns at the inlet may cause erosion or blocking of the inlet by debris. Sharp turns at the outlet will lead to embankment scour. Abrupt

changes in flow direction that retard velocities may require design of a larger structure.

- Ditch relief culverts, particularly on long descending grades, should be installed at an angle to the roadway to prevent retarded flow at the inlet. Accepted practice is to align the culvert at a 30-degree angle to the roadway. Minor modifications in the existing channel may be required to improve inlet or outlet flow and/or shorten the required length of pipe.

Grade or Slope: The culvert grade should be slightly greater than the natural grade to ease flow and aid in self-cleaning. If the culvert grade is causing erosive conditions, the grade of the culvert can be reduced by either lowering the inlet or raising the outlet. Accepted practice is to set the grade at approximately 1 percent (not less than 0.5 or greater than 2 percent)

- On steep slopes where the grade is greater than 2 percent, protection is needed against undercutting at outlets. Culverts placed on high fills or a settleable base should be slightly cambered.

Culvert Length: The length of culvert pipe should be determined by alignment and grade, in addition to roadbed width, fill height above flow line, and fill slope grade. It has been common practice to extend the downstream culvert a minimum of 2 ft beyond the toe of the embankment to prevent erosion. This may allow crushing of the culvert end by mowers or vehicles, accelerated degradation by exposure to the elements, and typically has not been successful in preventing erosion. Often a plunge pool will form at the point of discharge. A gully head will extend from the pool upslope until it meets the culvert pipe and then undercuts the culvert itself. This may lead to piping, slope instability, and even roadbed erosion.

Inlet and Outlet Protection: Headwalls and aprons serve to guide water into the culvert, prevent erosion, reduce seepage or piping, provide

slope stability, and support the ends of the culvert within the embankment or roadbed. Maximum benefit is seen with headwalls at both ends of the culvert. While simple headwalls are effective, headwalls with wing walls or angled retaining walls provide the best protection. The upstream wingwall guides the water into the culvert and acts to improve culvert hydraulics. The downstream wingwall, in combination with an apron, reduces the velocity of the discharge lessening the erosion potential at the outlet.

- Steel end sections, reinforced concrete, mortared stone, sandbags, sandbags with cement and sand, lumber, logs, riprap, or paving can be used in constructing headwalls, wingwalls, and aprons.

Debris Control: Debris control measures should be developed as part of culvert design before construction. The type of control selected will depend on anticipated debris. Channels above and below culverts should be clean of debris for a distance of 100 ft (30 m).

Discharge Aprons: Energy dissipation is required at both inlets and outlets to protect against erosive velocities. Riprap, sandbags, sodding, concrete discharge aprons, and gabions are measures commonly used.

CONSTRUCTION CRITERIA: Transport and place culverts carefully to prevent structural damage.

Excavation: Accurate excavation to line and grade are necessary to ensure efficiency. Trenches should be 12 to 24 in. (30 to 61 cm) wider than the diameter of the culvert to allow tamping of backfill.

Bedding: The foundation should afford a uniform, firm bed free of projecting roots, stones, or other irregularities for a depth under the culvert of not less than $\frac{1}{2}$ in. per foot of the height of the fill over the pipe. Bed the pipe to a depth of not less than 10 percent of its total height. The minimum allowable thickness of the bed should be 4 in. (10 cm).

The foundation surface must be well-compacted and shaped to fit the pipe. The foundation should also be cambered (curved slightly upward) along the centerline of the culvert to allow for settlement and to ensure tightness in the joints.

- Unstable soil (muck, silt, large material) under the culvert should be removed and replaced with good granular bedding material, well-compacted to support the culvert without settling.
- Where the bearing strength of the foundation is completely unsuitable, provide cradle footings.
- Where the culvert is to be installed within a rock foundation, trench the rock and backfill with a firmly compacted soil on which the culvert will be bedded.

Culvert Placement: Culvert pipe should be laid with sections joined firmly with overlaps **pointing upstream**. Joints should be galvanized or coated with a suitable material for protection. No reverse grades should exist after placement.

Backfilling: Backfill material must be carefully placed and well-compacted to prevent settling and washouts and to ensure maximum stability. Carefully selected backfill material (suitable to the subbase, base, and surface courses) should be placed over the prepared bed and culvert in uniform layers not to exceed 6 in. (15 cm) in depth. Each layer should be thoroughly compacted by either hand or mechanical means. No highly plastic materials (clays) or rocks more than 3 in. (7 cm) in diameter should be permitted within 1 ft (0.30 m) of the culvert.

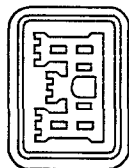
- Backfill layers are placed and compacted separately until the fill is 12 in. (30 cm) or one half the culvert diameter (whichever is greater) over the pipe.
- Thoroughly compact the area to extend one diameter of the culvert on either side of the culvert. Compact backfill to not less than 95 percent density.

No heavy equipment should be permitted to traverse culverts until a 6-in. (15 cm) aggregate surface course has been applied over the backfill.

Erosion Control: Erosion protection as discharge aprons, riprap, gabions, or sod should be provided at inlets and outlets to prevent scour, plunge pools, and slope instability.

MAINTENANCE:

- Any culvert that has been improperly designed, crushed or damaged by traffic, or that has experienced settling, thereby decreasing design flow efficiency, should be relaid or replaced.
- Besides conducting periodic windshield inspections, culvert pipes should be closely inspected for damage and plugging, particularly after each significant rain event.
- Headwalls or inlet and outlet protection measures should be inspected for damage frequently, and repairs undertaken promptly.
- Prevent damage to culvert ends by using headwalls, proper signage, or barrier protection.
- Prevent plunge pool damage by using riprap and fabric discharge aprons below outlets.



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PROJECT

Roadway
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DRAWING NAME:

Common culvert
end protection
structures

DRAWING NUMBER:

5-6

DESIGNED BY:

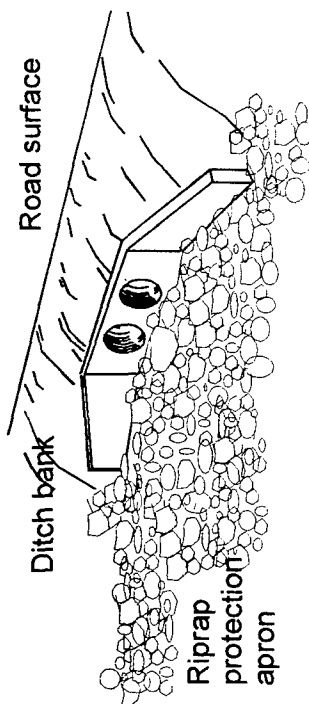
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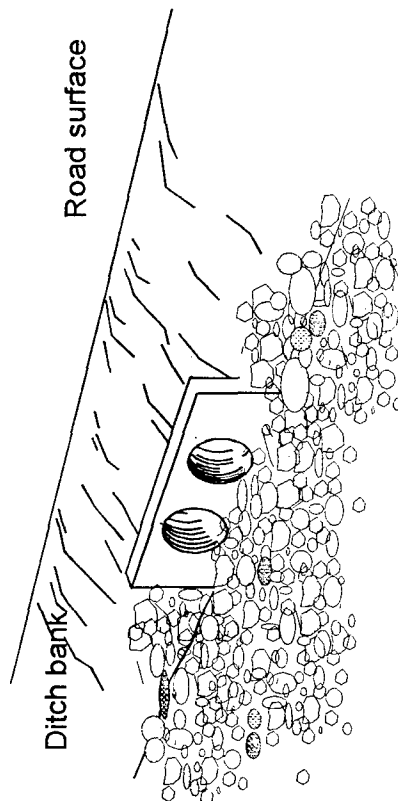
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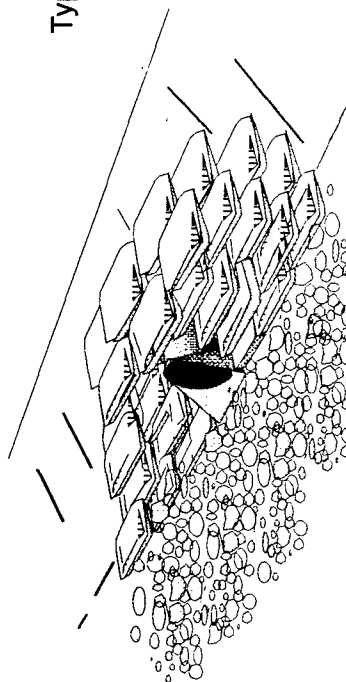
9-12-96



Typical concrete headwall with wings
and riprap discharge apron



Typical concrete headwall with riprap discharge apron



Typical sandbag headwall structure

DITCHES

DEFINITION: A channel adjoining a trail or road shoulder with natural, vegetative, or erosion-resistant linings of riprap, paving, or other materials constructed to design cross-section and grade for the conveyance of runoff from trail surfaces and adjacent slopes.

PURPOSE: Ditches are installed to convey and dispose of concentrated surface runoff without damage from erosion, deposition, or flooding.

APPLICABILITY:

- Where concentrated runoff will cause erosion damage to trail surfaces or adjacent areas.
- Where slopes are greater than 2 percent.
- With grass-lined ditches on slopes between 2 and 5 percent.
- With riprap-lined ditches on slopes greater than 5 percent.
- Where continuous or prolonged flows occur.
- Where soils are erodible and soil properties are not suitable for handling concentrated flows.
- Where space is available for the channel cross-section.

PLANNING CONSIDERATIONS:

- Riprap or other channel liners are used when design flow velocities exceed the tolerance of grass or where grass lining is inappropriate.
- Channels combining grass slopes with riprap lining may be used where velocities are within allowable limits for grass lining along the channel sides, but long-duration flows, seepage, or a high velocity flow would damage vegetation in the channel bottom.
- Where the drainage area exceeds 10 acres, it is recommended that riprap and grass-lined

channels be designed by an engineer experienced in channel design.

- Establishment of dense, resistant vegetation is essential in and around ditches.
- Diverting runoff from the ditch via turnouts or cross-trail drainage culverts may be necessary to prevent erosion.

Ditch Shapes:

V-shaped, grass-lined ditches generally only apply where the quantity of runoff is very small, such as in very short reaches along the roadside. This is the least desirable ditch type because it is difficult to stabilize the bottom where velocities are high.

- Where V-shaped ditches are paved, the velocity of concentrated flow is extremely high and energy dissipation and erosion control becomes costly and labor intensive.

Parabolic ditches are often used where larger flows are expected and space is available. The swale-like shape is easy to maintain, aesthetically pleasing, and usually best suited to site conditions.

Trapezoidal ditches are used where runoff volumes are large. In grass-lined channels the trapezoidal shape is used where runoff volumes are high and the slope is low enough to reduce the potential for erosion. In riprap lines or paved channels, the trapezoidal shape permits high volume, high velocity flow along steeper trail reaches.

Ditch Outlets: All outlets must be stable. The exit velocity for the design flow must be non-erosive for the existing field conditions. Turnouts, level spreaders, and energy dissipation structures are typically required.

Area of Drainage: Where the area of drainage exceeds 10 acres, both the riprap and grass-lined channel should be designed by an engineer experienced in channel design.

DESIGN CONSIDERATIONS: At a minimum all roadway ditches should be designed to carry the peak runoff from the 10-year storm. Where a flood hazard exists, increase the capacity according to the potential damage.

- Channel dimensions may be determined by using design tables with appropriate retardance factors or by using Manning's formula using an appropriate "n" value. When retardance factors are used, the capacity is usually based on retardance (C) and stability of retardance (D).
- The allowable velocity is based on liner material.
- Compute velocity using Manning's equation with an appropriate "n" value for the selected lining.
- The channel gradient is determined by the Froude Number. If between 0.7 and 1.3, channel flows may become unstable and the designer should consider modifying the trail/ditch slope. Reaches designed for super-critical flow (Froude number >1) should be straight unless special design procedures are used.
- Channel side slopes on grassed ditches are generally constructed at 3:1 or flatter to aid in the establishment of vegetation and for maintenance. Side slopes of V-shaped channels along short trail reaches are constructed at 6:1 or flatter for safety.
- Channel side slopes on riprap-lined or paved channels are typically constructed at 2:1 or flatter.
- The thickness of riprap channel linings must not be less than 1.5 times the maximum stone diameter for optimal erosion protection.
- The depth and width of the ditch are proportioned to meet the needs of drainage, soil conditions, erosion control, carrying capacity, and site conditions.
- Ditch grades should be uniform or gradually increasing to avoid sedimentation. Where the grade is excessive, channel liners or grade control structures will be required.
- Protect ditches from sedimentation by the effective use of diversions, turnouts, sediment traps, protected side inlets, and vegetative filter strips.

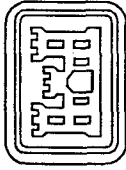
CONSTRUCTION SPECIFICATIONS:

- Clear the right-of-way of trees, stumps, roots, loose rock, and other objectionable materials.
- Excavate the cross section to the lines and grades as shown on the plans. Shape it to neat lines and dimensions. Include 2 inches around the channel perimeter to allow for bulking during seedbed preparation and sod buildup.
- Remove and properly dispose of all excess soils to protect surface waters from sedimentation.
- The revegetation method will be determined by the severity of site conditions and by the plant species.
- Place filter and bedding materials as required to line and grade in the manner specified immediately after channel preparation.
- Perform all channel construction to keep erosion and sedimentation to a minimum. Immediately upon completion of the ditch reach, vegetate all disturbed areas and/or otherwise protect them from soil erosion. Where channel construction will take more than 30 days, stabilize by reaches.

MAINTENANCE:

- Inspect grass-lined channels after every rain event during the establishment period and make repairs promptly.
- Give special attention to outlet and inlet sections and other points where concentrated flow exists.

- Check all trail shoulders for bank stability and evidence of piping or scour holes. Rills on the trail shoulder or surface may preclude gully extension.
- Remove all significant accumulations of sediment to maintain the designed carrying capacity.
- Maintain a vigorous vegetative cover in and next to the ditch to protect the area from erosion and scour during out-of-bank flow and significant rainfall.



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PROJECT:

Roadway
Maintenance and
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DRAWING NAME:

Drainage Ditch with
grass or riprap
lining

DRAWING NUMBER:

5-7

DESIGNED BY:

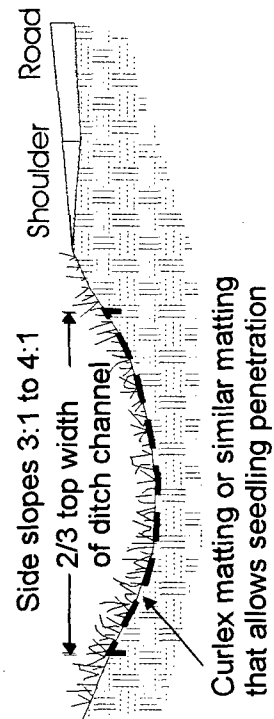
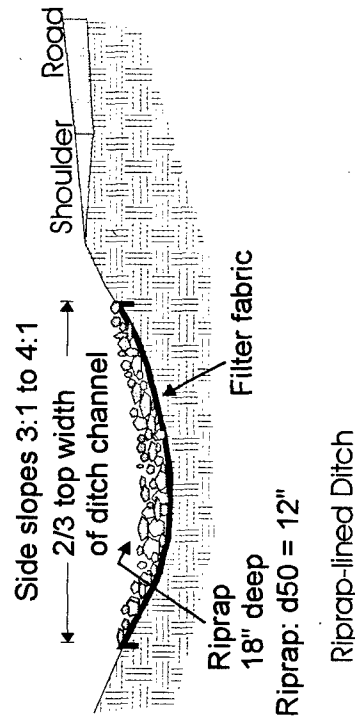
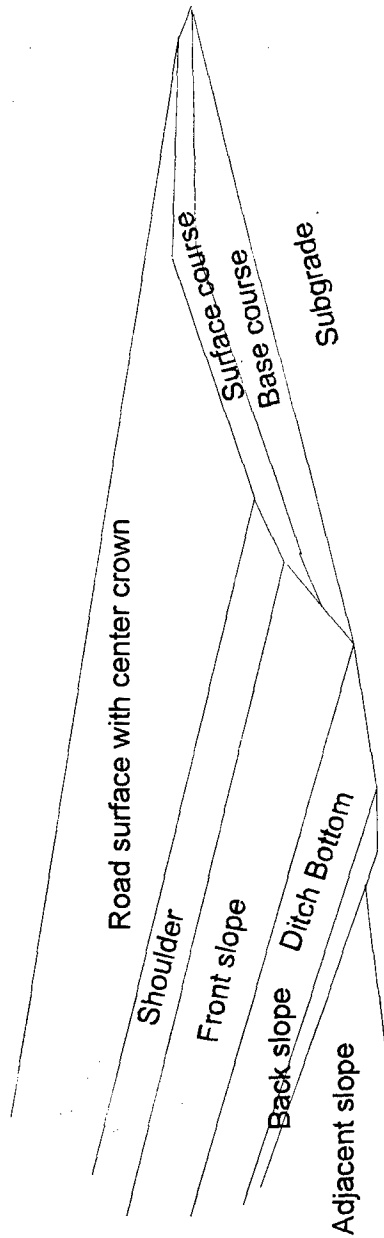
Sara J. White

DRAFTED BY:

Sara J. White

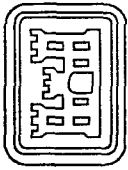
DATE:

10-14-96



Curlex matting or similar matting
that allows seedling penetration

Grass-lined Ditch



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PROJECT

Roadway
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DRAWING NAME:

Typical drainage ditch
cross-sections

DRAWING NUMBER:

5-8

DESIGNED BY:

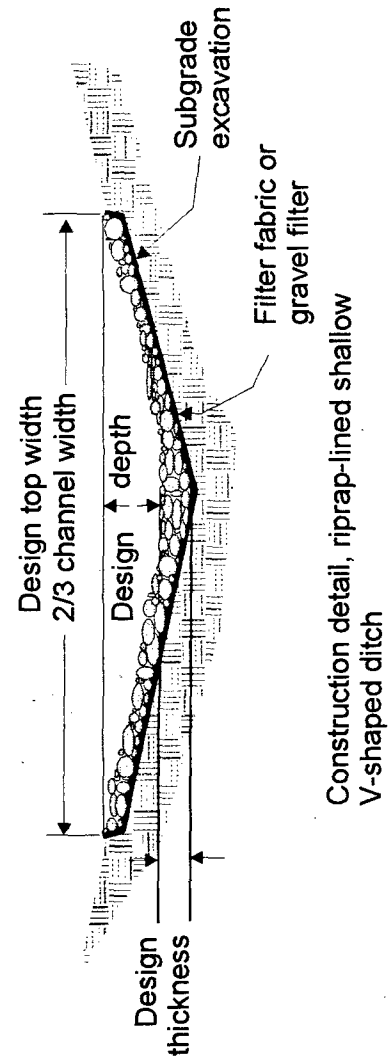
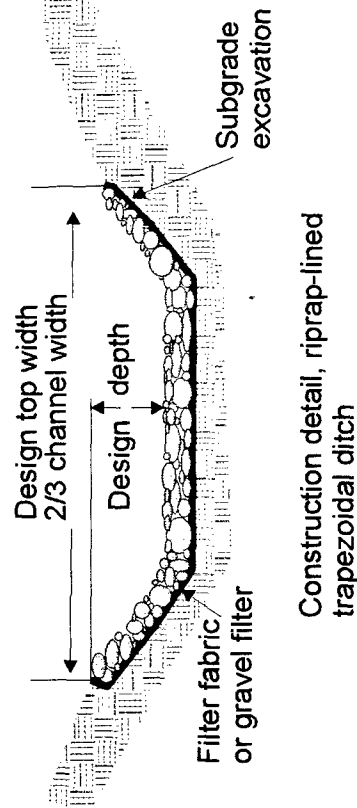
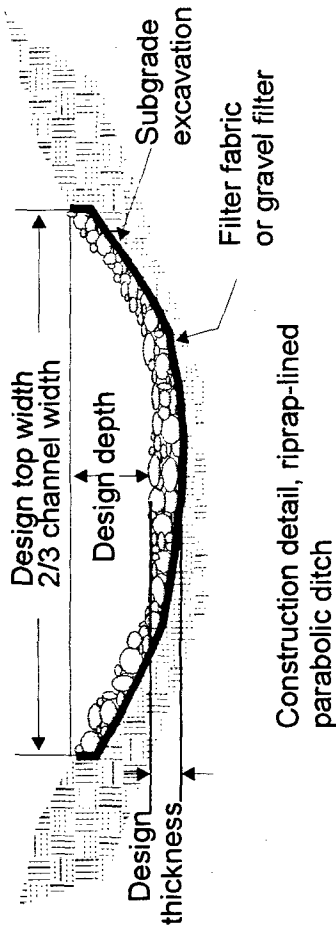
Sara J. White

DRAFTED BY:

Sara J. White

DATE:

8-25-96



ROADSIDE DRAINAGE DITCH LINING

DEFINITION: Soil stabilization or protection measures applied to ditches and other drainage channels using a protective lining of grass, gravel, riprap, or concrete.

PURPOSE: Ditch linings stabilize, harden, or protect ditches and other drainage channels against the erosive volumes or velocities of runoff conveyed through them. Grass and riprap linings are preferable as both reduce erosive velocities of runoff because of their irregular surface.

APPLICABILITY: Where water velocities are high enough to erode the ditch bottom (incision) or banks (sloughing).

PLANNING CONSIDERATIONS: Determine the design peak flow the section of ditch will be expected to convey and select the appropriate channel lining material according to Table 5-2.

Grass-lined Ditches: Grass-lined ditches are the most common forms of channel protection. They require minimum expense and effort to construct, but do have limitations. Until vegetation is established, the ditch may be subject to extensive erosion. Following establishment, vegetation is

subject to damage by uncontrolled sediment. Grass-lined ditches are unable to handle higher velocity flows. The appropriate seeding mixture to be applied is best selected from state-tested and accepted critical area seeding mixtures or roadside seeding mixtures.

Gravel-lined Ditches: Most soil materials are unaffected by runoff velocities less than 1.5 ft per second. The potential for ditch degradation increases rapidly as velocities exceed 2.0 ft per second. Fine gravel can be transported by runoff at 2.5 ft per second while coarse gravel is transported by runoff at 4 ft per second. For ditches with lower velocities, a gravel-lined channel is less expensive and requires less effort to construct than riprap-lined channels. A 6-in. liner course of coarse gravel may be enough to provide the protection needed.

Riprap-lined Ditches: These ditches are usually wider and shallower than grass-lined channels. They typically exceed 4 to 5 ft in width. A deep ditch requires more erosion protection than a shallow one at the same mean velocity of flow.

Channel Type	Min Permitted Velocity (ft/sec)	Max Permitted Velocity (ft/sec)
Unlined Earthen Ditch	<1	2
Grass-lined Ditch	2	4
Riprap-lined Ditch	3	10
Grouted Riprap-lined Ditch	2	12
Asphalt- or Concrete-lined Ditch	2	15

Table 5-2. Channel lining velocities.

- Parabolic or trapezoidal shaped ditches are preferred to V-shaped ditches. V-shaped ditches concentrate the runoff in the lowest portion of the channel; incision is rapid and often extreme.
- Wider channels with gentle side slopes of 3:1 are preferred overall. Riprap will adjust to settlement along the channel while protecting against erosion. A well-graded selection of riprap should be applied a minimum of 1.5 times the thickness of the largest rock fragments. Stones should be hard, angular, and weather-resistant.
- A filter layer or filter fabric should be securely installed between the ground surface and the riprap.

- Riprap should extend to a height of 6 in. (15.24 cm) above the design waterline. The selection of the appropriate size and volume of riprap depends on a variety of factors and should be determined by an experienced designer or engineer.

Grouted riprap, sacked concrete, concrete, and asphalt: These materials require a firm, compacted, stable foundation. Concrete-liners should not be less than 4 in. thick. A 6-in. by 6-in. wire concrete reinforcement mesh should be placed in the middle of the structure.

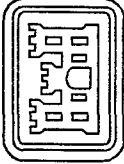
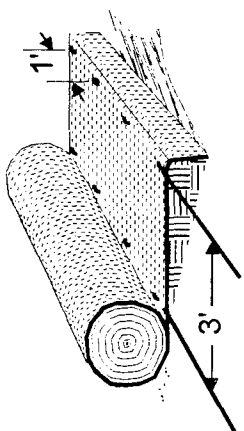
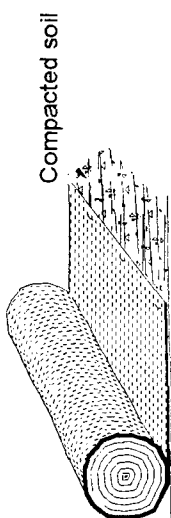
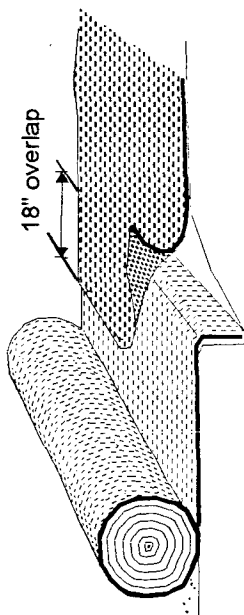
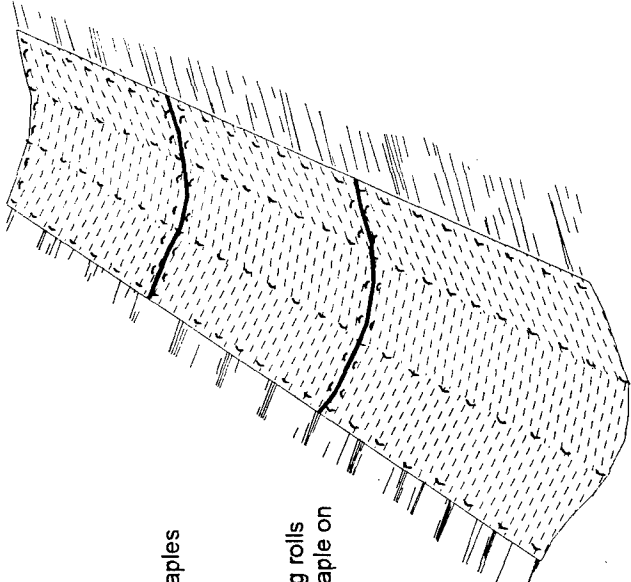
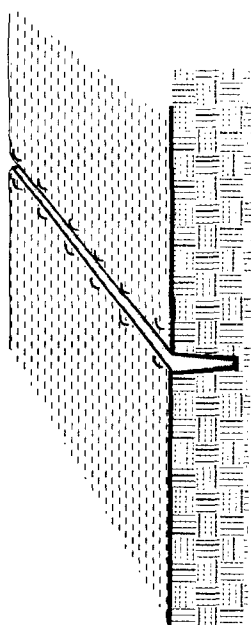
- Grooved joints for crack control should be provided at 20-ft intervals and when 45 minutes have elapsed between the times of consecutive concrete placement.
- Expansion joints should also be installed every 100 ft using ½-in. joint filler. Joints should be stabilized with No. 4 re-bar tie-rods, each 18 in. long.
- Provide weepholes on 8-ft centers.
- Ensure adequate curtain walls on both the inlet and outlet.
- Adequate design of the outlet structures for ditches lined with nonpermeable materials is critical due to the potential for erosion. Side slopes should not exceed 1:1.

CONSTRUCTION CRITERIA:

- Design flows must be identified to select the appropriate channel lining and shape.
- Remove all stumps, brush, obstacles, and debris and dispose of properly.
- Excavate the ditch and shape to the designed grade and cross-section.
- Compact all fills to prevent unequal settlement.
- Remove excess materials and dispose of properly.

MAINTENANCE:

- Regularly scheduled maintenance is important to keep the waterway in good working condition.
- Fertilizing and mowing or spraying for weed control should be done frequently enough to keep vegetation in a vigorous condition.
- Vehicular traffic should be excluded from the grassed ditch.
- Schedule periodic inspection and routine maintenance as required to prevent degradation.
- Inspect outlet structures frequently for indications of scour or gullyng. Initiate prompt mitigation.

 US Army Corps of Engineers. Construction Engineering Research Laboratories P.O. Box 9005 Champaign, IL 61826 1-800-USA-CERL	PROJECT: Roadway Maintenance and Drainage Control	DRAWING NAME: Channel lining with matting or netting fabric	DRAWING NUMBER: 5-10	DESIGNED BY: Sara J. White	DRAFTED BY: Sara J. White	DATE: 8-25-96
 Bury the top end of the matting in a 6" deep anchor slot or trench.  Compacted soil	Tamp the trench full of soil. Secure matting with a row of staples with a 6 inch spacing, 4 inches below the trench.  18" overlap	Anchor slot Overlap the second roll of matting over the buried end of the first roll. Install the beginning of the second roll as shown above. Overlap the end of the second roll 18" and staple.  Overlap adjoining rolls 12 inches and staple on 18 inch centers  Erosion stop - bury a 36" long fold of fabric in a 6" deep silt trench and tamp. Install a double row of staples, 3" from the edge of the matting Install under matting every 50' and at all grade changes.				

DIVERSIONS

DEFINITION: A runoff interceptor constructed at the top of a road cut or on an adjacent slope for diversion of surface runoff.

Diversions consist of a ridge/berm/dike with or without an accompanying swale. A dike or berm is shaped by grading equipment to a roughly trapezoidal contour. Swales are ditches cut into the soil in a roughly parabolic or trapezoidal shape.

PURPOSE: Diversions intercept and divert excess surface or overland flow (1) away from erodible areas, (2) to stable outlets, (3) to where it can be used or released without degradation, and (4) to reduce uninterrupted slope length. Because diversions convert sheet flow to channel flow, increasing erosion potential, they require some design consideration.

APPLICABILITY:

- Where runoff can be diverted or released without erosion or sedimentation damage.
- On or above steep or long slopes to prevent gully erosion.
- On or above steep or long slopes that provide runoff and sediment to drainage ditches.
- Below steep or long grades where sediment deposition may occur.
- Around areas subject to damage from runoff or sediment deposition.
- Around areas subject to internal degradation (training or testing activities, for example) to prevent movement of sediment-laden runoff to adjacent property or water bodies.

PLANNING CRITERIA: Diversions can be used to subdivide the landscape into smaller drainage areas that provide smaller volumes of runoff to drainage ditches.

- Preliminary considerations include function, need, velocity control, outlet stability, and site aesthetics.
- Landscape features, such as points of elevation, natural swales, or ridges, can be used as effective diversions.
- The location, method of stabilization, and shape of the diversion should be based on final site conditions.
- The capacity of the diversion should be based on the runoff characteristics of the site and on potential for damage to the site (road/trail, ditches, adjacent areas) following installation.
- The drainage area contributing runoff to the diversion should be less than 5 acres (2 ha).
- Immediately following construction, stabilize diversion bottoms with vegetation, channel lining fabric, or riprap as design flows require.
- An emergency spillway or overflow should be planned to reduce damage to the diversion when design storms are exceeded. A riprap spillway with an apron may be adequate to handle the overflow.

DESIGN CRITERIA: While the assistance of an engineer would be helpful, diversions can be designed and constructed by nonengineering personnel. However, certain design criteria must be followed to prevent damage or failure.

Location: When deciding where to install slope diversions, consider topography, soil conditions, outlet conditions, length of slope, seepage planes, and the need for storage of sediment-laden runoff.

Capacity: The capacity of the diversion must be adequate to convey the peak runoff from the 10-yr, 24-hour rain event at a minimum. The level of protection and minimum design storm are shown in Table 5-3.

Level of Protection	Area to be Protected	Minimum Design Storm
Low	All erosion control facilities, open areas, parking areas, recreation/wildlife areas	10-yr, 24-hr
Medium	Low-capacity roads and trails , training sites, minor structures, recreation/wildlife areas, sensitive sites	25-yr, 24-hr 50-yr, 24-hr
High	High-capacity roads and trails , training areas, major structures, sensitive sites	100-yr, 24-hr

Table 5-3. Minimum design requirements.

Berm/Dike Design:

Side Slope: 2:1 or flatter (3:1 or flatter, if mowed)

Top Width: 2 ft minimum

Freeboard: 0.5 ft minimum

Settlement: 10 percent of total fill height minimum

Swale Design:

Material: To meet velocity requirements and site aesthetics

Shape:

Parabolic or trapezoidal – to fit site conditions

Side Slope: 2:1 or flatter (3:1 or flatter, if mowed)

Compaction: The berm or dike material should be compacted to 85 percent of maximum density.**Velocity:** Permissible velocities within diversions are generally the same as for grassed water ways. (See Table 5-4).

Channel Type	Minimum Velocity (ft/sec)	Maximum Velocity (ft/sec)
Unlined Earthen Channel	1	2
Vegetation Lined Channel	2	4
Riprap Lined Channel	3	10

Table 5-4. Maximum nonerosive velocities for ditch or channel lining.

Grade: The overall grade of the diversion should be uniform or gradually increasing.

- For grass-lined swales, the minimum grade downslope is 0.5 percent and the maximum grade downslope is 2 percent.
- For grades greater than 2 percent, or if large flows are anticipated, the swale requires stabilization with channel lining fabric or riprap.

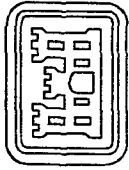
Outlet: The outlet must be designed to accept flow from the diversion plus from other contributing areas. Sediment-laden runoff must be diverted to a sediment trap and then released at nonerosive velocities. Concentrated flows must be conveyed from the slope using either chutes, drop structures, pipe and riser, or flumes, or it must be transitioned through an energy dissipation apron or onto a level spreader where it will be released as sheet flow onto a stable, vegetated area.**Stabilization:** The diversion must be vegetatively stabilized immediately following construction. Channel lining or slope stabilization may also be required as determined by on-site conditions. Disturbed areas contributing runoff and sediment to the diversion must be seeded and mulched as soon as possible.

CONSTRUCTION SPECIFICATIONS:

- Remove and properly dispose of all trees, brush, stumps, and other debris.
- Fill and compact all natural ditches, swales, or gullies that will be crossed by the diversion to the height of the natural ground level.
- Disk the base or foundation of the berm immediately before placement of fill material to enhance soil binding.
- Excavate, shape, and stabilize the diversion to line, grade, and cross section as required in the design plan.
- Place the diversion at least 2 ft (0.6 m) upslope from the top edge of the exposed slope.
- A simple swale with a dike or berm on the downslope side is easily constructed by running a grader or small bulldozer with its blade tilted to one side near the edge of an exposed slope. The berm must be compacted.
- Compact the diversion material to 85 percent density. Machine or hand-compact in 8-in. (20-cm) lifts. This will prevent unequal settlement and provide stability against seepage.
- Construct the dike/berm to a uniform height along its entire length.
- Immediately following construction, seed and mulch the berm/diversion and any adjacent disturbed sites.
- Diversions can be constructed with a grader, dozer, or even hand labor as site conditions permit.
- In wooded areas or where the access to the top of slopes may be limited and the anticipated interception of runoff will produce only small volumes, construct diversions with the dozer. The dozer can carry soil upslope and place it at the slope crest. Compaction may be completed by hand equipment.

MAINTENANCE:

- Inspect diversions periodically; and particularly after heavy rainfalls.
- Periodic maintenance should include removal of obstructions from the flow area and repair of the berm.
- Incision within the swale is an indicator of a need for modification of design or a problem farther upslope.
- Check outlets and make prompt repairs as required.
- Maintain vegetation in a vigorous condition.
- All repairs should be completed before the next rain event.



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PROJECT:

Roadway
Maintenance and
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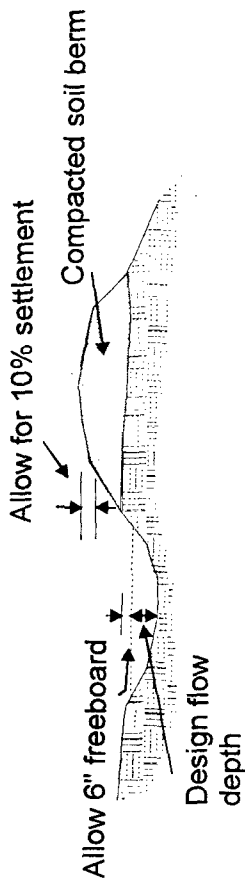
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Runoff diversions
/Berm and swale

DRAWING NUMBER:
5-9

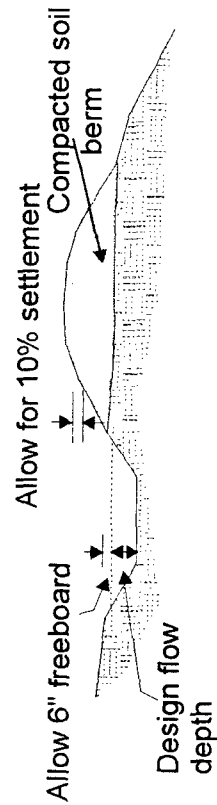
DESIGNED BY:
Sara J. White

DRAFTED BY:
Sara J. White

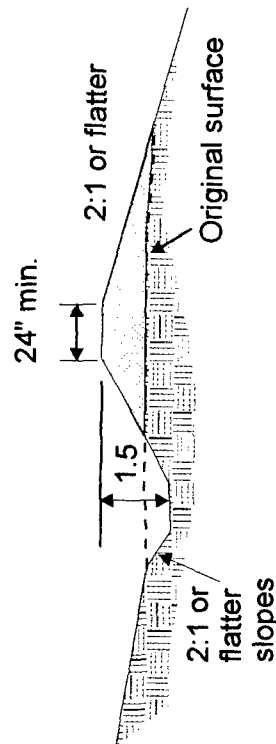
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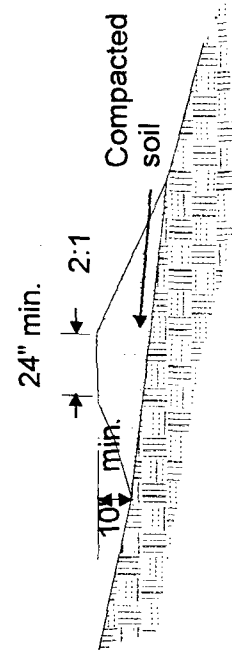
Parabolic-shaped diversion



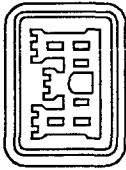
Trapezoid-shaped diversion



Construction detail - Crest-cut diversion



Construction detail - Interceptor diversion (dike)



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PROJECT:

Roadway
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DRAWING NAME:

Slope or crest cut
diversion ditch

DRAWING NUMBER:

5-11

DESIGNED BY:

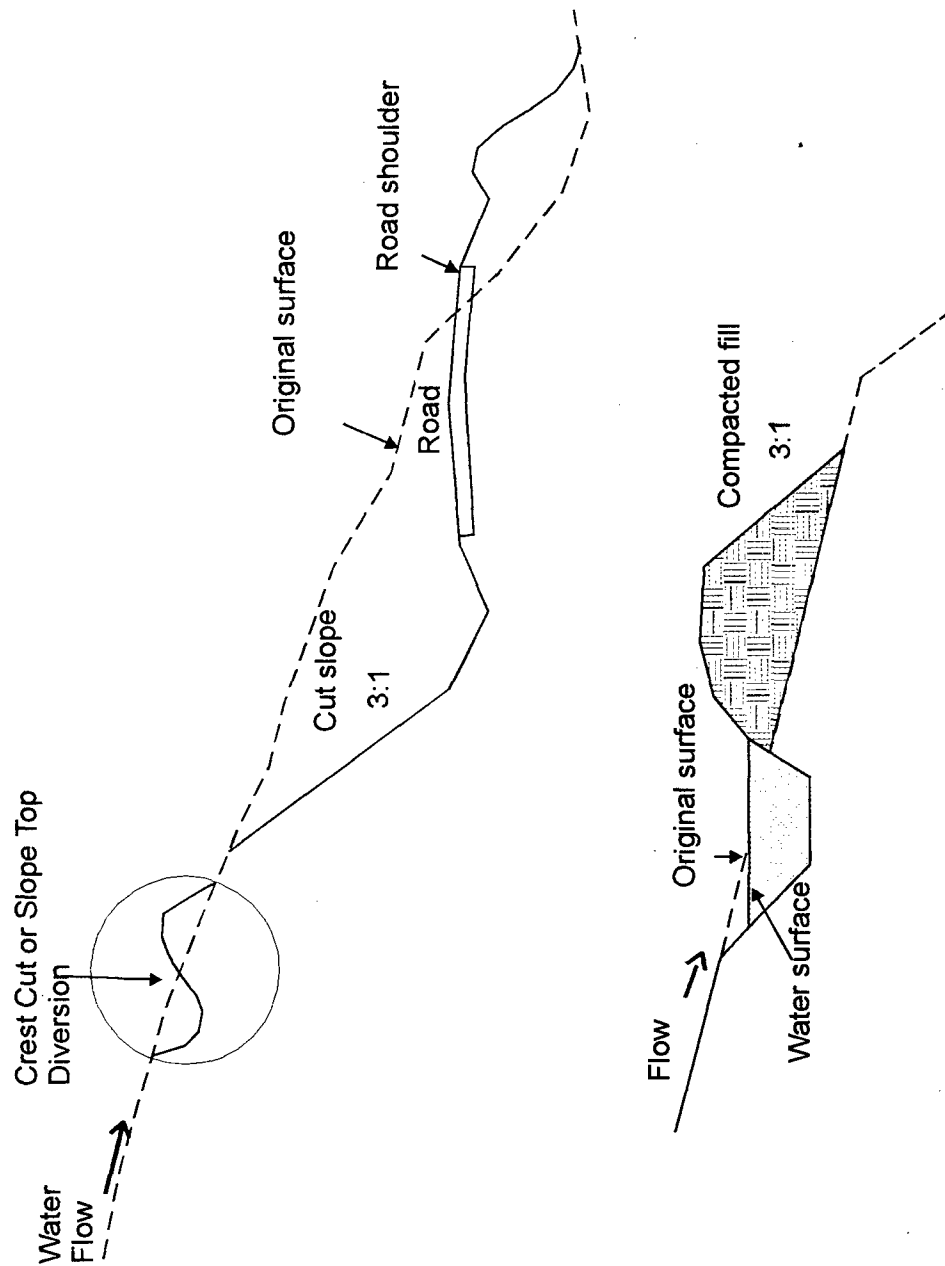
Sara J. White

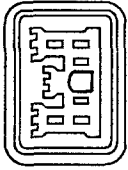
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DATE:

8-25-96





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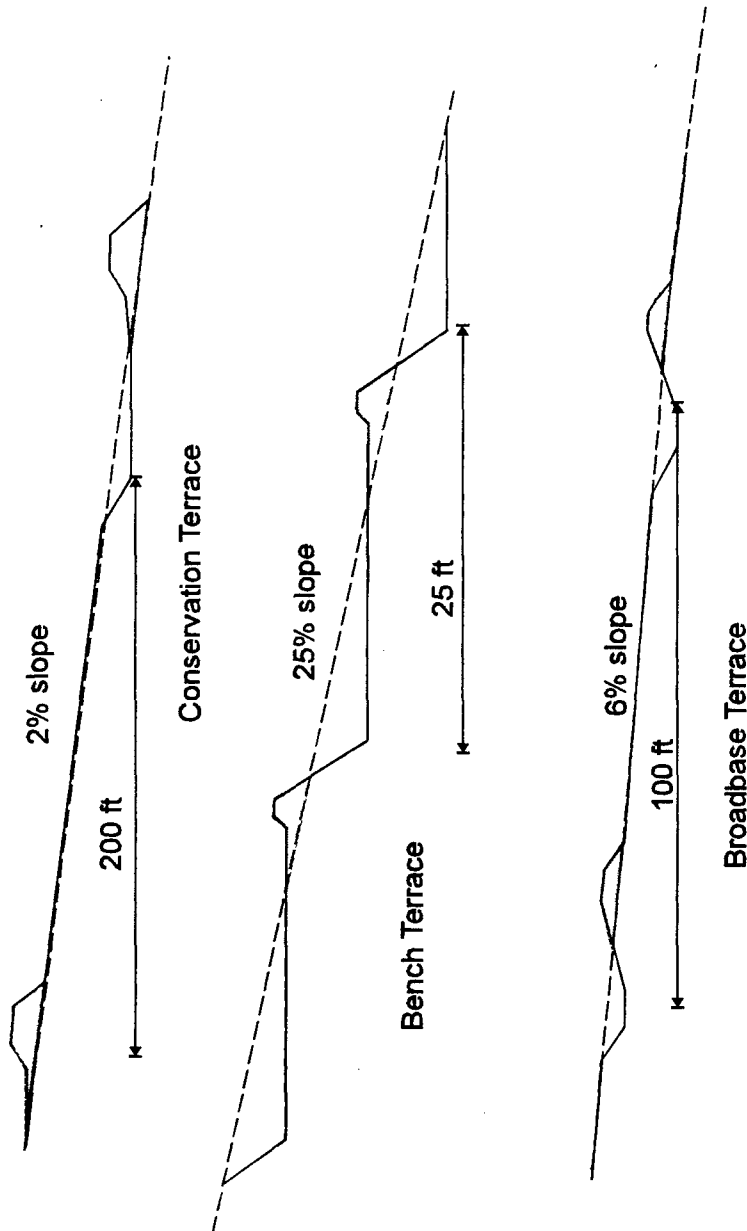
DRAWING NAME:
Diversion terraces

DRAWING NUMBER:
5-12

DESIGNED BY:
Sara J. White

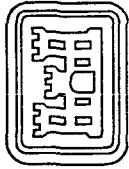
DRAFTED BY:
Sara J. White

DATE:
12-15-96



VERTICAL SPACING OF TERRACES		
AVERAGE LAND SLOPE (PERCENT)	HORIZONTAL SPACING (FEET)	VERTICAL SPACING (FEET)
2	125	2.50
4	75	3.00
6	58	3.50
8	50	4.00
10	45	4.50
12	42	5.00
14	39	5.50

LONGITUDINAL GRADIENTS FOR TERRACES	
LENGTH OF TERRACE (FEET)	TERRACE CHANNEL GRADE (PERCENT)
0 — 300	0.10
300 — 600	0.15
600 — 900	0.20
900 — 1200	0.30
1200 — 1500	0.40



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PROJECT:

Roadway
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Drainage Control

DRAWING NAME:

Slope drain

DRAWING NUMBER:

5-13

DESIGNED BY:

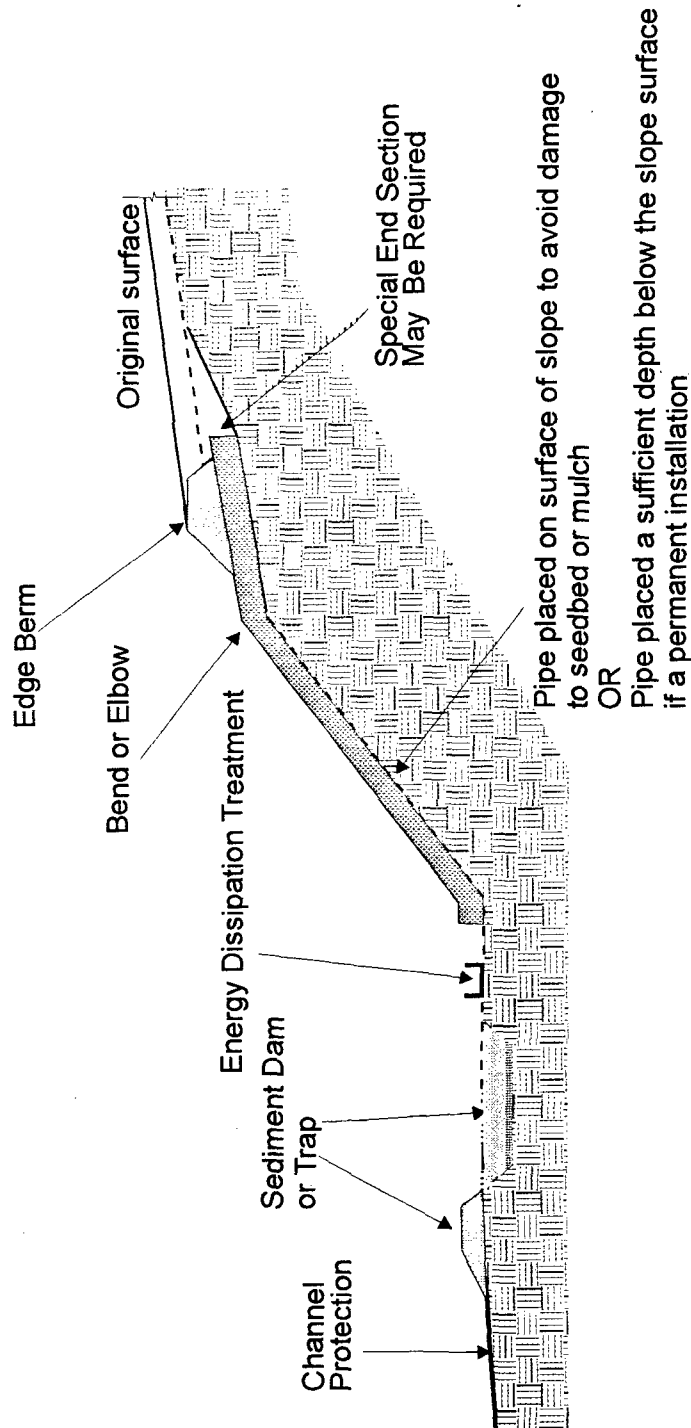
Sara J. White

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Sara J. White

DATE:

11-13-96



Typical slope drain and erosion control measures

GULLY CONTROL

DEFINITION: The stabilization of active gullies by vegetative or structural measures, or a combination of both.

PURPOSE: To prevent land voiding, disruption of roadway drainage, encroachment upon roadways, loss of aesthetic values, and/or reduction of training area or rangeland use.

APPLICABILITY: Wherever concentrations of water or changes in elevation have lead to the development of gullies within or next to drainage ditches or at points of discharge.

PLANNING CRITERIA: Gullies are caused by concentrations of runoff flowing at velocities sufficient to detach and entrain soil particles. Each rain event causes additional erosion and gully development. Gullies can be easily managed if proper measures are applied before they become too large.

- Gully development can be directly attributed to improperly located roads and trails, up- and down-slope trail development and subsequent rutting, unprotected ditches and outlets, un-repaired breaks in terraces and diversions on adjacent slopes, rills allowed to develop on bare slopes, improperly designed and placed road or trail drainage structures, improper land use, or damage to vegetation.
- Planning to manage or stabilize gullies within ditches or on adjacent slopes involves a watershed approach. Management measures may include the following efforts.
- The construction of a terrace or diversion above the gully head, laid out on a grade that counters erosion, can be used to intercept, hold, divert, or disperse runoff.
- Consider retention of runoff on the drainage area by vegetative and structural measures.

- Consider reshaping the gully by filling and/or bank sloughing with earthmoving equipment.
- Consider natural or artificial revegetation of the drainage area using critical area planting methods and seed mixtures to increase infiltration capabilities.
- Control the slope of the gully with grade control or grade stabilization structures.
- Convey runoff through hydraulically-designed and well-maintained drainage ditches at non-erosive velocities.
- Use sediment traps to control sediment from active gullies.

CONTROL OF GULLIES BY DIVERSION OR RETENTION OF RUNOFF: The most practical and effective method to control gullies is simply to reduce the runoff entering the headcut. Diversion or retention should be attempted before other control measures.

- Gully erosion can be halted or at least significantly slowed down by diverting all or most of the runoff to a stable, vegetated area or a stable outlet. Runoff may also be retained to infiltrate or pond on the slopes of the drainage area.

Runoff Diversion: Never divert runoff to unprotected outlets or bare slopes as this will only encourage erosion in those areas.

- Diverting runoff from several areas into one stabilized channel or infiltration area for economy of effort and cost may be possible.
- When diverting runoff from the gully head or banks, construct diversions or terraces a minimum distance of three times the depth of the gully away from the gully edges to allow for gully stabilization.

- Construct terraces or diversions from the upper side to provide a broad channel cross-section and ease construction.
- "Eyebrow" diversions may be useful above the headcut of a small gully developing on a slope with sparse vegetation. Care must be taken to divert the runoff to well-vegetated or stable outlets to prevent the development of additional gullies. Revegetate the entire slope as soon as possible.
- Where gullies are developing in ditches, turn-outs or crossroad drains can be used to divert the runoff to stabilized outlets or natural drainages before it can reach the gully head.

Runoff Retention: Runoff diversion measures can be supplemented by holding the runoff on the drainage area. This can only be accomplished where good land management practices provide well-vegetated or undisturbed areas for ponding or infiltration.

- Impounding terraces can be constructed on slopes to provide storage of excess runoff and, if properly hardened, can still accommodate occasional traverse by tracked or wheeled vehicles.
- If terraces are to retain all water, they should be constructed only on gentle slopes on permeable soils.
- Risers can be used to drain ponded water from terraces to stable outlets lower on slopes if needed.
- Where stock or wildlife water is wanted, terraces can be used to retain excess runoff from rain events.
- With larger gullies, runoff can be retained within the gully itself by constructing check dams. These must be carefully placed to reduce the channel gradient. This will, in turn, reduce headcutting and downward incision. Sediment will be trapped behind the dams causing the bottom gradient to level out and provide more stable areas for artificial or natural revegetation with grasses, trees, and shrubs. Risers or protected spillways may be required to release some or all of the stored runoff to prevent overflows during later rain events.

CONTROL OF GULLIES BY RESHAPING:

The intent of reshaping and filling gullies is to reduce the sidewalls and smooth the slopes so the area can be revegetated and maintained by mowing. Reshaping the gully to a cross-section and size that provide for stable runoff velocities would be practical.

- Thorough compaction is essential when reshaping and filling gullies to prevent rapid erosion.
- Reducing gully banks can be accomplished with standard farm implements or land management equipment such as plows, disks, or dozers, depending on the size of the gully.
- Gully sidewalls should be reduced to 3:1 to 4:1 slopes to simplify maintenance and mowing.
- When gullies next to roads are to be vegetated with trees and shrubs only, side wall reduction to 1:1 or 2:1 may be adequate. The slope should be reduced to the angle of repose of the soil at a minimum. NOTE: Attempting gully stabilization using only trees and shrubs may be less than effective as they provide inadequate soil protection during establishment.
- Reshape and fill gullies during or immediately preceding the growing season to ensure the quick establishment of a healthy cover crop after disturbance.
- Never attempt partial reshaping or filling of a gully as this will only destabilize the system even more and cause greater erosion and sedimentation.
- In some areas, once gully banks are reduced to a more stable slope, natural revegetation may provide adequate grasses, shrubs, vines, or native trees for erosion control. However,

applying amendments and fertilizer to stimulate growth may be necessary.

- Do not dump debris or loose rock into the headcut of a gully. Water falling over the headcut will quickly undercut the rock or debris and destabilize the entire headslope. If headcut control is to be attempted, the abrupt slope of the headcut must first be reshaped to a more stable slope and compacted thoroughly. A filter fabric is then firmly secured within the channel from above the headcut to below the toe. Riprap of appropriate dimensions to dissipate the energy of the runoff is placed over the filter fabric.

CONTROL OF GULLIES WITH

VEGETATION: A quick vegetative lining is the key to successful and effective ditches. The prime requisites for successful establishment are precipitation, temperature, and soil nutrients.

- Lining ditches with vegetation modifies the regime of the flow by decreasing the erosive forces of the runoff. By widening the cross-section and providing low-angle ditch banks (as seen with parabolic or trapezoidal shaped ditches) flows are more shallow and the vegetation increases the roughness parameter, which substantially decreases flow velocities and erosive forces.

Establishment of Vegetation: Reduce runoff to the gully before implementing revegetation efforts.

- Amend and fertilize the gullied area.
- Mulch sideslopes wherever possible to protect seedlings from raindrop erosion.
- Protect the revegetated area from fire and trampling, and from vehicular activity.
- Schedule revegetation efforts for the optimal planting and growing season.
- Schedule regular maintenance activities to ensure establishment of vegetation.

CONTROL OF GULLIES BY PHYSICAL STRUCTURES: Occasionally structures are required to control the headward migration of the gully head, to drop runoff from a higher elevation to a lower elevation, or to provide for the conveyance of runoff through gullies.

- Structures permit the reduction of the channel gradient and reduce the erosive energy of runoff. Structures may be required at abrupt changes in elevation such as gully headcuts or knickpoints, at the confluence of side gullies or channels, or at outlets or discharge points to perennial channels or other water bodies.

Headcut Control: Headcuts within ditches can be stabilized by a variety of structures. The porous-type control structures function to prevent the buildup of excessive pressure and eliminate the need for large, structural foundations. The structure requires some type of inverted filter that leads seepage gradually from smaller to the larger openings in the structure. This will prevent underlying soils from being carried through, resulting in erosion.

- Construction of an inverted filter involves reshaping the gully headcut to a stable angle and then placing layers of materials, in increasing particle size from fine sand to coarse gravel, on that new slope. Filter fabric can be used in place of the fine sands with gravel and rock placed in layers over it.
- When stabilizing a headcut with loose rock, first reshape the headcut to a stable angle. Lay and securely attach filter fabric within the channel ensuring coverage from above the top of the slope to below the toe of the slope. The size, shape, and size distribution of the loose rock is critical in the effectiveness of the structure. To function properly, the erosive energy of the runoff must be dissipated and sediment must be retained within the structure. This will provide soil for establishing vegetation and enhance slope toe stabilization. Slope toe stabilization must be carefully addressed when designing any rock fill structure to prevent failure.

Check dams: The most commonly applied physical structure to control gullies or prevent degradation in ditches is the check dam. No formal design is required for a check dam, however, certain guidelines must be followed.

- Check dams modify the regime of the flow in the ditch by decreasing the erosive forces of the flow. They are typically installed in narrow, incising ditches along steep sections of the road/trail.

Basic requirements:

- The drainage area of the ditch should not exceed 10 acres (4 ha), except in areas of low-rainfall.
- Straw bale check dams are only applicable for drainage areas less than 2 acres (0.8 ha).
- The maximum height of the check dam should not exceed 2 ft (0.6 m), and the center or spillway should be at least 6 in. (15 cm) lower than the outer edges.
- Space check dams so the toe of the upstream dam is at the same elevation as the top of the dam immediately downstream.
- Begin check dam construction at the mouth of the gully and work upchannel toward the head-cut.
- Check dam spillways must be designed for the 25-yr, 1-hr storm.
- Protect gully side slopes or banks with free-boards of not less than 24 in. (60 cm).
- Key check dams at least 12 in. (30 cm) into the gully bottom and at least 18 in. (46 cm) into side slopes.
- Check dams typically require toe aprons and bank protection to prevent scour and undermining.
- Place check dams at the estimated upstream toe of the sediment deposits to be retained behind the next check dam downstream.
- Estimates of the upstream toe of the sediment deposit can be approximated as follows. In gullies with gradients < 20 percent, the slope of the expected deposits is 0.7 percent of the original gully gradient. In gullies with gradients > 20 percent, the slope of the expected deposits should be reduced to 0.5 percent of the original gradient.
- Place check dams at the narrowest possible gully cross section to reduce material requirements.
- Check dams can be constructed of any materials found on-site or brought in that can withstand the flow of the runoff in the ditch.
- Check dams of stone or timber are among the sturdiest. They are also the simplest to construct and repair.
- When using straw bales, centering the bales in the channel is important so that runoff cannot flow around the ends. The bales must be well-staked. Use keyway trenches to seat the bales.

Loose Rock or Riprap Check Dam: The riprap check dam is the most commonly used porous check dam. Since riprap check dams are not reinforced, the angle of repose of the rock should determine the slopes of the check dam sides. This depends on the type of rock, the weight, size, and shape of the individual rocks, and their size distribution. If the dam sides are constructed at an angle steeper than that of repose, the structure will be unstable and may lose its shape during the first heavy rain. For the design of check dams, the angle of repose for angular stone corresponds to a slope ratio of 1.25 to 1.0, and for rounded rock the ratio is 1.50 to 1.0. Check dams can have effective heights up to 7 ft (2 m).

Log or Timber Check Dams: Log check dams are very common in forested areas where 4- to 6-in. (10- to 15-cm) post timber can be readily stocked.

The life expectancy of the log or timber check dam can be as much as 15 years if regularly maintained. They can be constructed by unskilled labor with hand tools or with small entrenching machinery.

Grade Control Structures: Where check dams are not suitable or a more engineered structure is required, the following measures are recommended:

Straight Drop Spillway: Used in the lower reaches of ditches, terraces, diversions, outlets, or other waterways or for high overfalls where erosion is probable. This is a weir structure. Runoff flows through the weir opening, drops to a level apron or stilling basin, and then flows into the downstream channel. This is the simplest structure to design and construct. It can be used for grade stabilization, grade control, erosion protection for roads, ditches, and gullies, or outlets for discharge from ditches (particularly where the channel width is limited downstream of the control structure) or culverts.

Box Inlet Drop Spillway: Similar to the straight drop spillway, but used for greater volumes of runoff and sites with limited channel width.

Hood Inlet Spillway: The hooded inlet uses a straight-pipe principal spillway on steep slopes, in earthen embankments to control gully headcutting, or to drop runoff to a lower level in a manner that is less erosive.

Drop Inlet Spillway: The drop inlet is used similarly to the hood inlet spillway, but it also allows drainage of ponded water or adjustment of water levels for wildlife or land management purposes.

Chute Spillway: The chute spillway is used where the head or drop and spillway capacities are relatively small. These can be constructed without forms if the temperature and soil conditions are suitable for forming the chute in the soil.

Pipe Spillway: The pipe spillway is used as a culvert to provide passage for water under an embankment. When combined with a riser, it

serves to lower water through significant changes or drops in elevation and dissipate the energy of the falling water. It is frequently used as a gully control structure.

DESIGN CRITERIA: Grade drop structures must have a stable downstream grade with no degradation occurring after the protective measures are applied. If topography permits, the drop inlet is more suitable than an overfall structure on sites with a steep grade below the structure location.

- The type and placement of structures will often be controlled by the availability of materials.
- Soil conditions may determine the type and size of structure to be used because of the foundation requirements. Drop inlets may be used in place of large concrete structures in wet or seedy soils, while almost any type of structure can be constructed in dry, unstratified soils.
- Placement is critical when constructing structures to control gully heads. The crest of the structure should be placed at an elevation that precludes the headward migration of the gully head during the healing period.
- Scour at the outlet can precede the failure of an overfall structure. Scour is influenced by the stability of the grade below the structure, velocities in the channel downstream, tailwater elevations, and dissipation of water energy in the outlet.
- Scour at the outlet of drop inlets can be reduced by extending the pipe outlet, cantilevered on pipe supports, beyond the toe of the fill or by using an energy dissipation apron.
- Gullies that produce a large amount of sediment may require a sediment trap with a drop inlet. The sediment capacity should be designed to store the eroded sediment rather than allow it to damage areas downstream.
- Avoid extreme size in gully control structures.

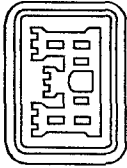
- Single check dams are useless and may do more damage than installing too many check dams.
- Install check dams from a lower stable gradient to a higher stable gradient or a natural control such as a bedrock outcrop.
- The required number of check dams increases with increasing ditch gradient, but decreases with increasing dam height.
- Check dam spacing is determined by the slope of the ditch/gully and the height of the check dam. The bottom of the next check dam upslope is at the same elevation as the top of the spillway of the check dam immediately below it.
- In the east, using slightly greater spacings between dams may be more beneficial.
- Headward migration of a knickpoint may be controlled by constructing a grade drop structure. Shape the spillway of the structure like the channel, with the crest and side slopes level with the bed and banks, respectively. This will provide minimal sediment accumulation while preventing advancement of the headcut or knickpoint upstream.
- When setting priorities for treatment of ditches with gullies, target the gullies with the steepest slopes and rawest banks as they tend to erode faster with greater land voiding and resultant sedimentation.

CONSTRUCTION CRITERIA: Before construction, conduct a field survey to obtain the gradients and cross sections of gullies to be treated with vegetation and/or shaping. This can be accomplished with a tape, measuring rod/stadia, hand level, and two people. The longitudinal and cross-section surveys will show the characteristics of the ditch above and below planned physical structures. Geologic, hydrologic, and soil information is also collected during the field survey.

- Careful clearing and excavation of the site are critical. Excess materials must be removed and properly disposed of.
- All backfill must be well-compacted.
- Place structures such that the discharge from the spillways will not cause embankment damage or undermining.

MAINTENANCE:

- Periodic inspections are required to ensure adequate functioning and determine maintenance requirements.
- Protect reseeded areas from trampling, vehicular damage, and fires.
- Make immediate repairs to terraces, diversions, or other structures.
- Regularly schedule cleaning of ditches, outlets, weirs, or inlets.
- Immediately repair damaged seeded areas.
- Schedule regular mowing of ditches and slopes. Mow and rake waterways several times per season to stimulate new growth and control weeds.
- Schedule periodic inspections of structures to include sides, corners, and wingwalls, and conduct repairs promptly.
- The provision of frequent, minor maintenance and repairs can save a great deal of time, effort, and money over time.
- Any vegetated waterway may fail because of insufficient capacity, excessive velocity, or inadequate vegetal cover.



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PROJECT:

Roadway
Maintenance and
Drainage Control

DRAWING NAME:

Gully control
structures

DRAWING NUMBER:

5-14a

DESIGNED BY:

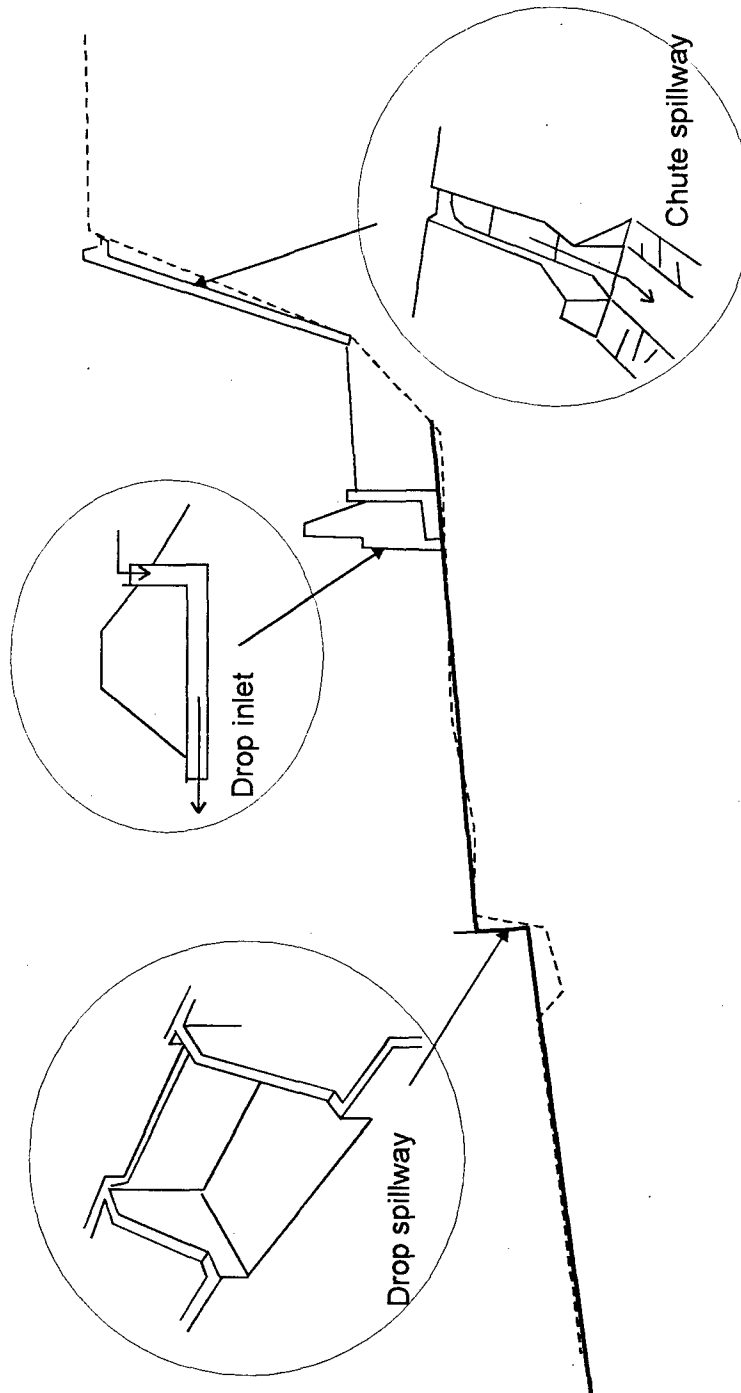
Sara J. White

DRAFTED BY:

Sara J. White

DATE:

8-15-96



Gully profile with with forms of permanent control structures

GULLY HEAD CONTROL STRUCTURE

DEFINITION: A structural control measure constructed of resistant materials and installed at the head or uppermost portion of an active gully.

PURPOSE: The structure is intended to prevent the upslope or upchannel migration of a gully. This is accomplished by reducing the erosive impact of runoff falling over an abrupt change in elevation (headcut).

APPLICABILITY:

- Where a gully headcut approaches a road or trail with a raw and abrupt scarp.
- Where a gully is advancing or extending within a ditch or on an adjacent slope.
- Where piping or seepage has destabilized the gully headwall.

PLANNING CRITERIA:

- Determine the source of the runoff causing the headward migration of the headcut and effect mitigation (if possible).
- A permeable or porous headcut control structure will be required if subsurface flow at the headwall is the destabilizing factor.
- A nonporous or more rigid structure will be required if channelized flow at the headcut is the destabilizing factor.
- Structures must be installed so that firm contact is made between the reshaped soil and the filter fabric that lies between the soil and the structure.
- Before installing any structures, the headcut must be reshaped to a stable slope. That slope is usually equal to the natural angle of repose of the soil (at a minimum).
- Where the site of the headcut has a high soil moisture content, live hardwood stakes may be used to enhance vegetation establishment.

DESIGN CRITERIA:

- Reshape the headcut with a minimum of disturbance to the surrounding soil.
- Determine if roots, encountered while reshaping the slope, will be more beneficial if left in place to stabilize the slope.
- Design the structure to handle significant rain events or spring thaw runoff.
- Determine the life expectancy of the structure. Will it be temporary until a rehabilitation project mitigates a degraded area? Will it be a permanent form of grade and gully head control?
- Construction should be scheduled to occur during dry periods of the year.
- When installing sandbags, use live hardwood stakes or willow, cottonwood, or regionally applicable species where the headcut has a high soil moisture content.
- Revegetate the reshaped gully headcut and adjacent banks to promote a quick protective cover.

MATERIALS: Materials for construction of gully headwall structures can be locally available or brought to the site, but ease in handling, cost effectiveness, and replacement should be taken into consideration.

- A heavy-duty filter fabric must be laid in firm contact with the reshaped soil to provide a base before the structure materials can be installed. Without the filter fabric, water will flow under the structure causing more degradation than before treatment efforts.
- Riprap is the preferred material for construction of a porous structure.

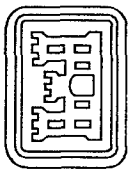
- Geotextile sandbags filled with native soils, sand, gravel, or any combination of the above are suitable.
- Burlap sandbags filled with cement and sand are also very effective.

CONSTRUCTION CRITERIA:

- Reshape the gully banks to a smooth and stable 2:1 slope (at a minimum) to permit laying of the filter fabric.
- Reshape the gully headcut to 2:1 or the angle of repose (at a minimum) to ensure a stable and secure slope upon which to place the riprap or sandbags.
- After reshaping, excavate adequate surface material (overcut) to permit the top of the structure to be at the final grade. Cut down to a depth the thickness of the sandbags or riprap layer.
- Extend the filter fabric a minimum of 2 ft (0.61 m) above the top of the reshaped headcut. Anchor the fabric securely within an excavated keyway trench.
- Excavate a similar keyway trench at the base of the headcut slope. Sandbags or riprap placed in this keyway will provide toe support for the entire structure and prevent slippage.
- Cut filter fabric long enough to cover the bottom of the channel and three sides of the two trenches. Leave a tail 12 in. (30 cm) long at the upper end, and a tail 4 to 6 ft (1.21-1.82 m) at the lower end.
- Measure and cut fabric to extend up the sides and over the tops of the banks for additional stability.
- Lay the filter fabric in the gully bottom from the upper trench to the lower trench. Leave 4 to 6 ft (1.21-1.82 m) of extra fabric at the lower end.
- Lay the fabric to cover the banks. Ensure an adequate overlap of material.
- Staple filter fabric with 11 in. (28 cm) landscape staples (U-shaped or with heads) every 1 ft (0.3048 m). Where soil moisture is high, it is possible to alternate live wood stakes with staples.
- Pull the fabric over the tops of the banks and staple every 6 in. (15 cm). Bury the edge of the fabric to ensure a firm contact and minimize water running under the fabric.
- Fill sandbags with native soil or cement and soil mixture.
- Place graded riprap over filter fabric, taking care to NOT puncture the membrane.
- With sandbags, fold the open end over twice and staple 6 to 8 times across the top. Alternate the staple direction for added strength.
- The stapled end of the sandbag should be laid pointing upstream to reduce the stress placed on the unsewn side.
- Place sandbags in an overlapping pattern, staggering the joints from the bottom to the top of the headcut.
- Leave 4 to 6 ft (1.21-1.82 m) of filter fabric uncovered to provide erosion control between the headcut and the channel.
- Secure the tail of the filter fabric with staples.
- When sandbags are used, drive pilot holes through every **third** sandbag and into the headcut slope with a straight bar.
- Rebar, wooden stakes, or live wood stakes can be used to secure the bags to the slope.
- Where adequate soil moisture exists, drive additional live wood stakes into the banks around the headcut structure.

MAINTENANCE:

- Inspect periodically for rips in the filter fabric, degradation of bag material, or slippage or movement of bags or riprap.
- Check for degradation downstream of the control structure and make immediate repairs.
- Maintain a healthy vegetative cover on and next to the site.
- Check for piping or headwall instability above the headcut structure. If observed, find and treat sources of concentrated water.



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PROJECT:

Roadway
Maintenance and
Drainage Control

DRAWING NAME:

Gully headcut control
structures

DRAWING NUMBER:

5-14b

DESIGNED BY:

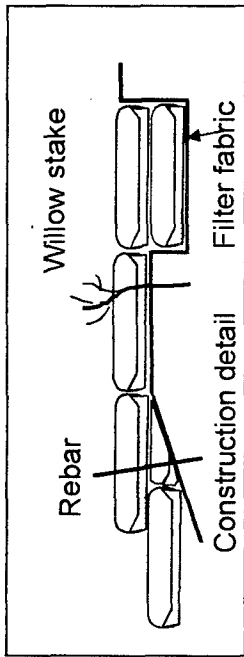
Sara J. White

DRAFTED BY:

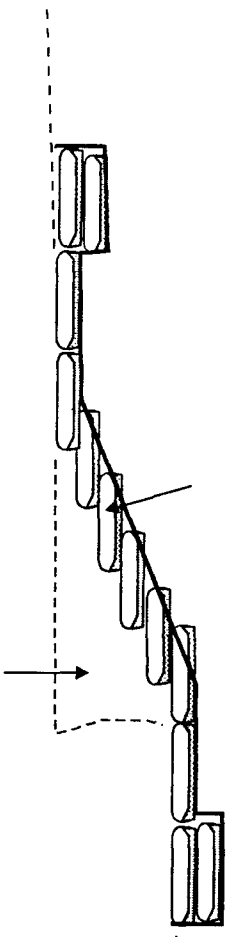
Sara J. White

DATE:

8-15-96

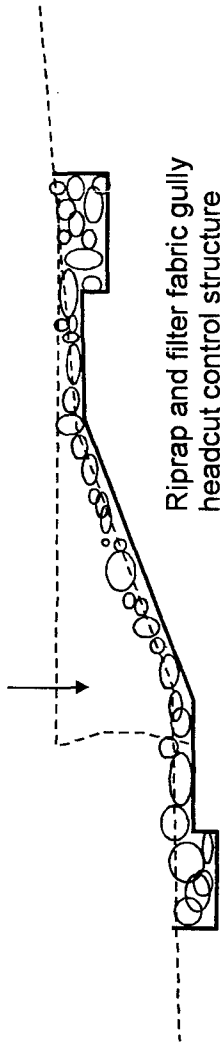


Excavate headcut to 2:1 slope



Burlap bags filled with 4 parts sand to
1 part cement or geotextile bags with
sand/soil

Excavate headcut to 2:1 slope



Riprap and filter fabric gully
headcut control structure

Gully profile with sandbag or riprap headcut control structure

LEVEL SPREADER

DEFINITION: A nonerosive outlet for concentrated runoff constructed at zero-grade to disperse flow uniformly across a stable area.

PURPOSE: The level spreader converts concentrated flow into sheet flow and then releases it at nonerosive velocities onto areas stabilized by vegetation.

APPLICABILITY:

- Used at locations where concentrated runoff from unstable areas, diversions, dikes, channels, ditches, or turnouts can be diverted onto stabilized areas under sheet flow conditions.
- Used where a level lip can be constructed without requiring fill.
- Used where the area below the spreader lip is uniform with a slope of 10 percent or less and is stable for anticipated flow conditions (preferably well-vegetated).
- Used where released water will not re-concentrate.
- Used where there will be NO TRAFFIC over the spreader.

PLANNING CRITERIA:

- Careful evaluation is required to ensure that no reconcentration of runoff occurs below the spreader lip.
- Ensure that the spreader lip is constructed completely level.
- Sediment-laden runoff must be intercepted and filtered in a sediment trapping structure before release in a level spreader.

DESIGN CRITERIA:

Capacity: The capacity of the spreader is determined by estimating the peak flow from the 10-yr storm. Restrict the drainage area so that maxi-

mum flows into the level spreader do not exceed 30 cubic feet per second.

Spreader Dimensions: Use Table 5-5 to decide the appropriate length, width, and depth of a spreader that receives runoff from one end (as from a turnout, diversion, or dike).

Diversion. Construct a 20-ft transition section in the diversion channel so the width of the diversion will smoothly meet the width of the spreader to ensure a uniform outflow.

Turnout. Construct the turnout such that the initial width is that of the ditch it is diverting flow from and the outlet width will smoothly meet the width of the spreader to ensure uniform flow. The length of the turnout should be 20 ft at a minimum.

Grade: The grade of the last 20 ft of the turnout or diversion should provide a smooth transition from the channel grade to a level grade at the spreader. The grade of the spreader should be 0 percent.

Spreader Lip: Construct the level lip on undisturbed soil to a uniform height and zero grade over the length of the spreader. Protect the lip with an erosion-resistant material such as fiberglass matting to prevent erosion and allow vegetation to become stabilized.

Design Flow (cfs)	Entran. Width (ft)	Depth (ft)	End Width (ft)	Lgth (ft)
0-10	10	0.5	3	10
10-20	16	0.6	3	20
20-30	24	0.7	3	30

Table 5-5. Specifications for level spreader.

Outlet Area: The area that sheet flow is released onto should be smooth, well-vegetated, and with a maximum slope of 10 percent.

- When discharge is to a slope steeper than 4:1 or the soil is highly erodible, the length of the spreader should be increased and slope stabilization measures applied on the spreader lip to ensure the stability of the discharge area.

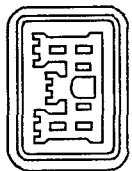
CONSTRUCTION SPECIFICATIONS:

The erosion control matting should be a minimum of 4 ft wide and extend 6 in. over the lip. The opposite edge should be buried 6 in. deep in a vertical trench within the lower portion of the spreader. The edge over the lip should be securely held in place with closely spaced, heavy duty wire staples at least 12 in. long.

- Ensure that the level lip is uniform.
- Construct the level spreader on undisturbed soil.
- Ensure a smooth 20-ft transition from the turnout or diversion to the level spreader.
- Release sheet flow across a smooth and properly stabilized slope of less than 10 percent grade.
- Immediately following construction, initiate a revegetation program to include seed and mulch.

MAINTENANCE:

- Inspect spreaders after every significant rainfall until vegetation is established.
- Make repairs promptly.
- After establishment of vegetation, conduct periodic maintenance and inspect for erosion or degradation.



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PROJECT:
Roadway
Maintenance and
Drainage Control

DRAWING NAME:
Turnout from ditch and
level spreader

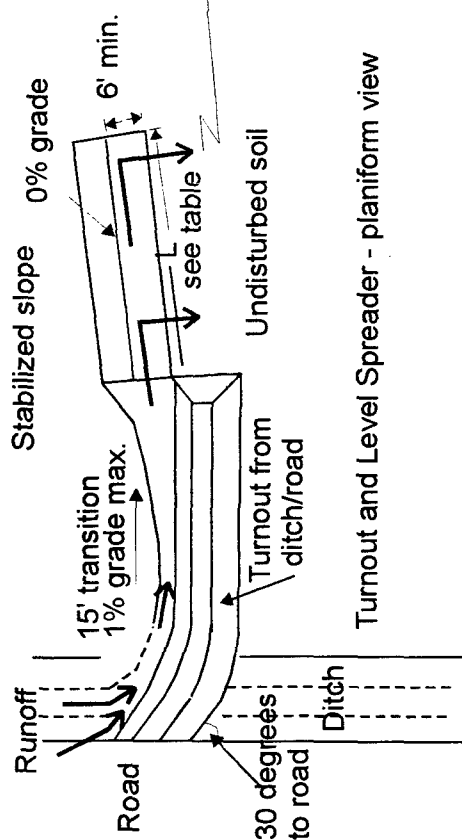
DRAWING NUMBER:
5-15

DESIGNED BY:
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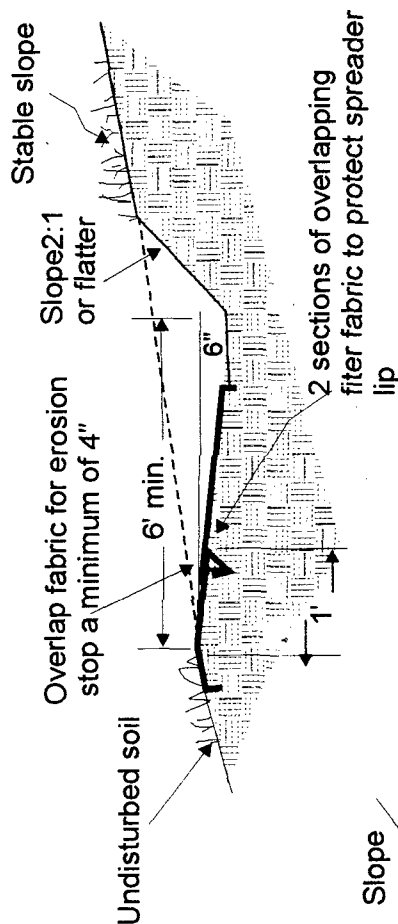
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Sara J. White

DATE:
10-08-96

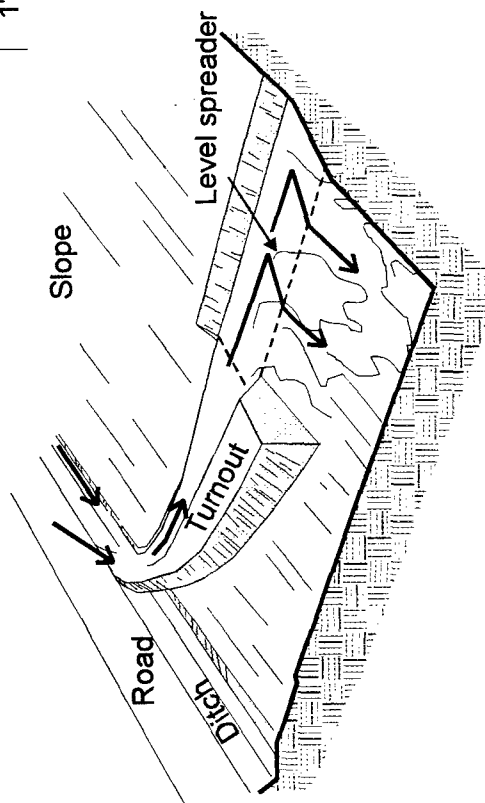
Design Q (cfs)	Minimum length (L) in feet
0-10	15
10-20	20
20-30	26
30-40	36
50	44



Turnout and Level Spreader - planform view



Construction detail - Level Spreader



Turnout from ditch and Level Spreader - oblique view

LOW-WATER CROSSING

DEFINITION: A structure, specifically a hardened culvert and road section, placed across an ephemeral or low-flow perennial channel with a minimum of disturbance to streambank or aquatic ecosystems.

PURPOSE: The crossing provides access across intermittent or small perennial channels and drainage ways. To provide a secure, low-maintenance channel crossing for wheeled and tracked vehicles with a minimum impact on stream bank and bottom environments. A properly designed and constructed low-water crossing (LWC) will reduce sedimentation and disturbance of aquatic ecosystems by vehicular traverse.

APPLICABILITY: They are generally applicable to channels with drainage areas less than 1 square mile or of a fairly narrow and shallow cross section. They may constrict the flow of water during significant rain events that can lead to flooding or washouts if the design flow is inadequate. They are particularly applicable to ephemeral channels with intermittent low flows or any perennial channel with a continuous low flow.

- The unvented LWC is applied primarily at intermittent streams that are dry for a significant portion of the year. If the flow of water is continuous, normal vehicle traffic may encounter problems at the wet crossing. Four-wheel drive vehicles may only encounter problems during high flows. The unvented LWC requires considerable maintenance.
- The vented LWC has more applications because the design can limit the flow over the roadway to a few days of the year. Where the LWC can be temporally closed for high water, the LWC may offer significant savings over a culvert with a roadway fill designed to provide for a 25- or 50-year discharge without overtopping.
- The LWC is suitable for any secondary or tertiary road with low-volume traffic. During

good weather, a well-designed, vented LWC can perform adequately for any traffic using the road.

- The size of the drainage area also affects the applicability of the LWC. During significant rain events on a small watershed, flood waters will rise and fall rapidly. On a larger watershed, the water will rise more slowly and flow over the LWC for a longer time. The need to access the LWC is a determining factor.
- The LWC may be applicable when used with an existing obsolete or low-weight bridge. This allows the passage of heavy vehicles the bridge is unable to support.

PLANNING CONSIDERATIONS: A low-water crossing is a road that crosses a small ephemeral or perennial channel. The flow of the channel occasionally overtops the roadway. The two groups of LWCs are the vented ford and the unvented ford.

Unvented LWC: An unvented ford is a roadway that crosses the stream without the use of any culverts. Low flows in the stream may pond and flow over the roadway if the channel conveys water intermittently, or low flows may overtop the roadway most of the time. A roadway can be constructed above minor streams but a channel must be provided near the center. On larger streams, the ford may only consist of approach ramps that lead to a hardened stream bottom.

Vented LWC: A vented ford consists of a cross section for the roadway above the stream bed, and one or more culverts under the roadway that will provide for low water flow without overtopping the roadway. High water will periodically overtop the roadway because the culverts are deliberately sized to convey only the normal low flow.

Low Water Bridge: A third type of LWC is a low water bridge. This is a flat-slab (reinforced concrete) bridge deck at the approximate elevation

of the adjacent banks, with a smooth cross-section that is designed to allow intermittent high water to flow over the slab without damaging it. When the water recedes, the bridge can be used again.

GENERAL CRITERIA: The LWC must be nonerosive and structurally stable, and must not introduce any flooding or safety hazard.

- For the vented LWC, the design must be sufficient to convey the flow rate expected from a 10- to 25-year frequency storm adequately. The design will depend on the intensity of rain events in your area and potential for flood damage.
- Culverts are used to ensure conveyance of the lowest flow through the structure. Proper installation is critical. The compacted soil cover around and over the culvert(s) should be equal to $\frac{1}{2}$ the diameter of the culvert or a minimum of 18 in., whichever is greater, to prevent crushing by heavy vehicles.
- The culvert should lie on a grade or slope of a minimum of 0.25 in. per ft.
- Large angular rock or riprap should be placed over any earthen fill used in construction of the bed or banks.
- Surface the compacted fill used in construction of the LWC with the same surface material used in the construction of the roadway or 6 in. (minimum) of suitable aggregate. An alternative surfacing material is 6 in. of reinforced concrete (minimum).
- The approaches to the LWC should be not less than 50 ft long and should adjoin the crossing smoothly and be surfaced with a suitable surface course of aggregate or concrete.

Flow Capacity: Several alternative methods of determining the capacity of the culverts are available. One requires the culvert design to carry bankfull flow or a 10-year peak discharge, whichever is less, without an overflow. Another requires that base flow be handled, but permits

overflow a specific percentage of time. (See Table 5-6.)

- Overflow areas must additionally be protected from erosion from the 10 to 25 year peak flow.

Velocity Control: The design discharge velocity at the LWC culvert outlet must be nonerosive for the channel. Hydraulically-designed riprap or concrete aprons or other energy dissipation structures must be properly installed to ensure adequate protection from scour below the LWC.

DESIGN CRITERIA: The following design criteria should be viewed as general guidelines that can provide a well-designed, safe crossing.

Components of the LWC: Construction of the LWC is a simple project, requiring readily available equipment and materials. The components of the LWC consist of core materials, foreslope surface, roadway surface, culverts (if vented), and either cutoff walls or riprap to protect against erosion.

- The core can consist of native soil, sand, gravel, riprap, concrete, or a combination of these materials. A well-graded, well-draining, coarse aggregate is the best choice. For example, the material used in construction of the roadbed is satisfactory.
- The surface of the LWC can be either coarse aggregate surfacing material, as used on the road surface, or a reinforced concrete slab.
- Channel banks can be protected against erosion with riprap, soil cement, gabions, sod, or vegetation from seed.

Design Considerations: The decision to use a vented LWC vs. an unvented LWC depends on whether water over the road can be tolerated.

Very-Steeply Sloping (acres)	Steeply Sloping (acres)	Sloping/Rolling (acres)	Gently Rolling (acres)	Standard Round Culvert (Diameter - inches)
1.4	0-2.5	0-4.2	0-9.3	12
1.4-2.6	2.25-4.2	4.2-7.5	9.3-16.5	15
2.61-4.1	4.2-6.7	7.5-12	16.5-27	18
4.1-6.2	6.7-10	12-18	27-40	21
6.22-8.8	10-14	18-25	40-57	24
8.8-16	14-26	25-46	57-104	30

Table 5-6. Typical pipe diameters for low-water crossings on small watersheds.

- Access to some training or testing areas may be denied where the flow over the LWC causes the road to be closed, perhaps for long periods.
- A determination must be made for the acceptable overtopping duration and frequency. Once the percentage of the probability of overtopping has been determined, the over-topping discharge can be calculated. The number and size of culverts are selected so that the head water depth for the calculated discharge is at the lowest point in the LWC design.
- The crossing grades and elevations depend on the physical features of the channel and its banks. They are related to the overtopping discharge headwater depth. The number and size of culvert pipes are adjusted to the headwater depth and the vertical curve length for a given speed.
- The overtopping velocity of the discharge running over the LWC surface is critical until tail water submerging occurs.
- Each LWC must be adequately protected against erosion and seepage.
- testing areas subject to more frequent use will require greater accessibility than others.
- An examination of previous training schedules should provide a reasonable estimate of the percent of time each year that the LWC could be functionally unusable due to high water. For example, if the range schedule could accommodate a closure period of 35 to 37 days per year, that would result in a design discharge of $Q_{10\%}$ (where 10 percent of 365 days is between 35 and 37 days).
- Compute the discharge in cubic feet for the determined closure probability. A flow-duration curve can be used if the daily discharges are recorded at the location of the LWC. A curve can be prepared by arranging the collected daily discharges in class intervals of ascending order of magnitude. The percent of time during which the flow was equal to or greater than the lower limit of each class is determined and the results are plotted as a flow-duration curve. The probability is selected and the discharge determined from the curve.
- Low flow records may also be available for the stream from the USGS, if the stream is gauged.

Overtopping Frequency: The need to have access to and across the LWC is based on the characteristics of the roadway users. Training or

Determining Number and Size of Culvert Pipes: There are a number of user-friendly computer programs available that can be useful in

determining the appropriate size and number of culvert pipes to handle the discharge at the LWC. Hydraulic Engineering Circular 5, *Hydraulic Charts for the Selection of Highway Culverts*, (GPO, 1964) provides a useful collection of charts that can be used to manually determine the number and size of culverts.

- Several factors must be considered when selecting culvert pipes: (1) the headwater depth controls the low point in the LWC, (2) the culvert may operate under either inlet or outlet control, (3) culvert lengths may be short, but differences in friction losses because of culvert material could still be significant, (4) a significant difference between the lowest elevation of the LWC and the downstream water surface increases the potential for serious erosion on the downstream channel bed and foreslope, and (5) a large difference between the lowest elevation of the LWC surface and the stream bed increases the volume of material needed in the crossing and, therefore, the overall cost.
- The final culvert selection will be based on these factors and the alternatives provided by the charts or computer programs. Where the lowest point of elevation of the LWC is higher than the calculated headwater depth because of LWC criteria, reducing either the size or number of culverts may be possible.

Roadway to LWC Geometry: The approaches to the LWC will be either at or slightly above the adjacent surface elevation at the stream or channel banks. The lowest elevation of the LWC surface will be much closer to the surface of the water in the channel. This is because the inherent design of the LWC is to allow occasional overtopping with flood waters.

- In designing the "dip" in the roadway to accommodate the LWC, several factors must be considered: (1) the tangent grades, (2) the length of sag vertical curves, and (3) the length of crest vertical curves at the edges of the channel.

Tangent Grades. This is dependent on the height of the channel banks, the slope of the terrain next to the channel, and the amount of cut allowed into the channel banks. Grades up to 12 percent are acceptable; however, the steeper the grade, the greater the stopping distance, reduction in speed, and possibility for hazard to a vehicle and/or operator at the LWC.

Vertical Curve Lengths. The length of crest vertical curves is determined by the stopping sight distance. Headlight sight distance, driver comfort, and appearance can be used to determine the length of sag vertical curves.

- A sufficient length of vertical curve must be provided to enable the operator to stop the vehicle safely after the headlights illuminate the LWC ahead.
- Using a lower friction factor in the stopping sight distance formula is appropriate because the LWC surface may be wet, muddy, algae covered, or slippery in another way.

ALTERNATIVE DESIGNS:

Barrier LWC: Precast concrete barrier LWCs (Jersey or median barriers) have been successfully used on low-volume, aggregate roads maintained by the U.S. Forest Service roads across the desert and mountainous regions of the Southwest. These LWCs have been effectively used on soils composed of highly erodible sandy clays, decomposed granite, and plastic clays.

- The barriers are used to stabilize the road grade at the LWC where flashy, rainstorms cause short term impassability and damage to the LWC.

Installation. A series of precast barriers is embedded at a right angle to the stream channel, pinned and tied together with a length of 9/16 in. cable and clamps. The end sections are sloped upward to provide a weir at the center of the structure.

- A 1-ft wide strip of 70 to 100 EOS geotextile fabric is placed over each joint to retain the fine

particles on the upstream side of the wall and prevent undermining.

- The USDA Forest Service sizes these structures for a 25-year flow using the appropriate weir formula or Manning's equation.
- Energy dissipation is provided by riprap or gabions on the downstream side.
- A 0.375-in. thick steel cap is placed on the structure to prevent bed load movement of large rocks from eroding the top of the concrete barrier. This is typically accomplished at the casting yard. The barriers are cast upside down and a C 6 x 10.5 steel channel is laid in the bottom of the form and anchored to the concrete.
- The barriers are readily installed using a backhoe and a front-end loader that can handle a 5000-lb load.
- Barriers are laid in a trench excavated to the designed shape of the weir. The barriers are anchored with cable.

Benefits. The use of barriers allows installation in perennial and intermittent channels with no diversion or dewatering. Transportation and installation is very easily accomplished. The foundation requirement is reduced because the barrier has a wide base. The precast barriers can be salvaged and reinstalled in case of displacement by large floods.

Simple LWC: A simple LWC designed and used in mountainous regions is the aggregate-surfaced ford. These are suitable to low-volume, lower-weight roads or trails such as firebreak roads or perimeter fence trails. They can be installed with or without a culvert to support the base flow. They are most suitable to low-flow or intermittent channels.

- On a flat or low slope, a 12- to 18-in. deep trench is excavated the width the road and breadth of the channel. A foundation is compacted. A key is excavated at the outer

edge of both sides of the trench. The key foundation is compacted. Excavate the keys 6 to 12 in. deeper than the trench and 18 to 24 in. wide. The entire excavation should be no greater than the width of the road surface.

- Filter fabric is laid within the trench and keys, and properly anchored. Riprap with a diameter between 8 and 18 in. is placed in the keys until it is flush with the bed of the channel. Between the keys, place 2- to 6-in. diameter stone, in compacted 4-in. layers, to a depth of 12 to 18 in. or until flush with the channel bed.
- On a road crossing that crosses a small channel on a slope, a trench is excavated the width of the road surface. However, the bottom or foundation is graded to permit a keyway, 4 to 5 ft deep and 3 to 4.5 ft wide, on the downstream shoulder.
- Compact the foundation and lay filter fabric over the firm soil. Anchor the fabric according to manufacturer instructions.
- Riprap (18 to 24 in.) is placed in the keyway trench. Another 4 to 8 in. of riprap is placed in the trench upstream from the keyway. A mixed grade of stone (4 to 24 in.) is placed downstream of the keyway to provide an energy dissipation apron.

MATERIALS: Materials for stabilizing the embankments on either side of the LWC depend on the velocity and tractive forces of the overtopping water. Most commonly, riprap is used for bank stabilization, although concrete may be required under certain conditions.

- The material used in constructing the low-water crossing must also withstand the expected maximum loads from heavy vehicles.

Stabilizing Fabric: A geotextile fabric specific to stabilization should be placed under the foundation of the low-water crossing. Apply well-graded, weather-resistant riprap (3 to 6 in. diameter) over the fabric.

Riprap: Riprap consisting of a durable, resistant stone can be hand-placed, dumped, or grouted. Multiple layers of dumped riprap provide the most stable and economical fill. Grouted riprap is the most vulnerable to undermining and failure. Well-graded riprap provides its own filter layer to prevent outwash. A thinner course of well-graded riprap can be installed than can a uniformly graded course with a separate filter layer.

Soil Cement: Where riprap is not readily available, soil cement may be substituted. Soil cement blocks can be cast and placed by hand at the site of the LWC, but the labor may prove costly. Soil, sand, and cement may also be used to provide an erosion-resistant surface. It must be installed under dry conditions and be thoroughly compacted. It is susceptible to shrinkage cracking and displays a low flexural strength.

Gabions: Wire-bound rock can be successfully used on the LWC. Gabions are flexible and tend to accumulate silt that may support vegetation. Riprap must be available. The wire baskets are subject to failure due to metal decay. They must be hand-filled or filled in place by backhoe or payload.

Reinforced Concrete: While this is a costly form of construction, it provides the most durable and low-maintenance LWC.

Jersey (Median) Barriers: Precast barriers are readily available in new and used condition in lengths up to 20 ft. A standard section 12.5 ft long and about 5000 lb is readily handled by equipment used in low-volume road maintenance.

CONSTRUCTION CONSIDERATIONS:

- Construct the low-water crossing during seasons of low flow.
- All required construction and erosion control materials should be on the site before construction begins.
- Minimize clearing and excavation of stream banks, bed, and approach sections. Restrict the

crossing of the channel with heavy equipment or vehicles during construction.

- Install the low-water crossing at right angles to the channel. Limit surface runoff into the channel by installing diversions.
- Align the road approaches with the center line of the crossing for a distance of 50 ft minimum.
- Where the potential for sedimentation is high, install an instream sediment trap before excavating or grading the approaches to a low-water crossing.
- Excavate the trap 2 ft (minimum) below stream bottom and approximately twice the channel width for a minimum distance equal to one half the length of the crossing. Remove all spoil to an area outside the flood plain and properly stabilize with vegetation.
- Culvert pipe should extend well beyond the fill side slopes (which should be 4:1 or flatter).
- Protect disturbed channel banks, fill slopes, and overflow areas with riprap, sandbags, or other suitable methods. Stabilize other disturbed areas as specified in the revegetation section.
- Good surface stabilization is particularly important at channel crossings as all eroded sediment directly enters the channel.

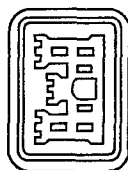
COMMON PROBLEMS:

- Inadequate flow capacity and /or lack of overflow area around the structure, resulting in the washout of culverts.
- Inadequate stabilization of overflow area, resulting in severe erosion around culverts.
- Exit velocity from culverts is too high and there is no discharge apron, causing stream channel erosion and may eventually cause erosion of fill material.

- Debris not removed after a significant rain event. Resultant clogging may lead to culvert washout and/or flooding.
- Inadequate compaction under or around the culvert pipe. The resultant piping or seepage around the pipe causes washout of the fill material.
- Riprap or crushed stone that is too small will result in washouts.
- Culvert pipes too short, resulting in a crossing supported by steep, unstable fill slopes.

MAINTENANCE:

- Inspect low-water crossings regularly; particularly after every significant rainfall.
- Periodically remove accumulated sediment and debris that may have washed up against the culvert opening.
- Periodically clean the channel 100 ft both up-channel and downchannel from the low-water crossing to prevent debris accumulation.
- A well-secured fence placed upchannel from the culvert inlet may be used to catch debris before reaching the culvert inlet, however, the debris and sediment accumulated behind the fence **MUST** be periodically cleaned and disposed of properly.
- Repair any damages to the low-water crossing immediately. Reinforce damaged areas. If a hazard to safe crossing exists, close the crossing until it can be restored to a safe condition.



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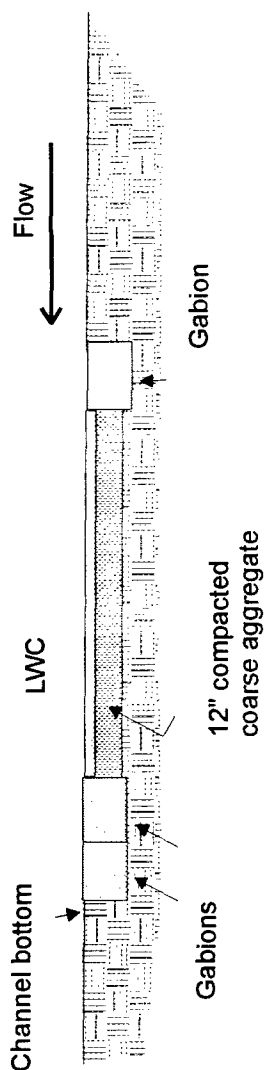
DRAWING NAME:
Low water crossings
without culverts

DRAWING NUMBER:
5-16

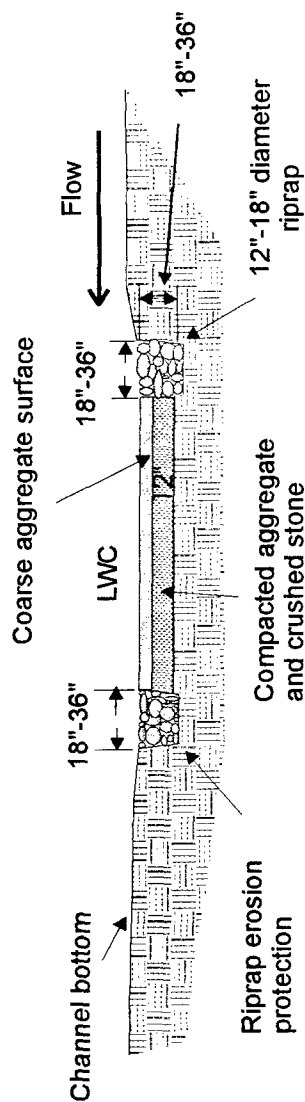
DESIGNED BY:
Sara J. White

DRAFTED BY:
Sara J. White

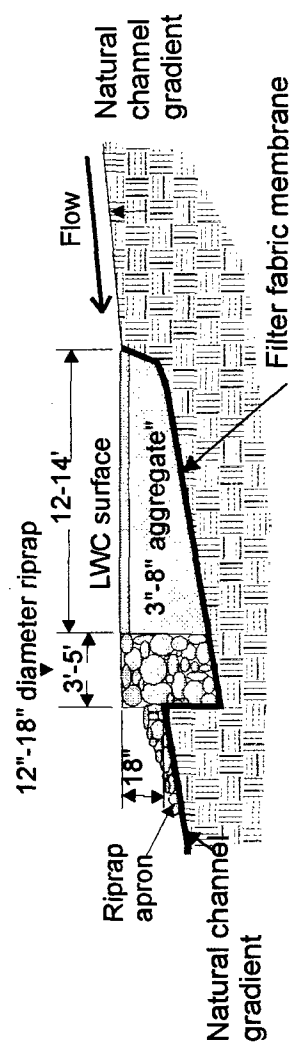
DATE:
9-12-96



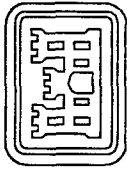
Typical low water crossing with no culverts and gabion erosion protection



Typical low water crossing with no culverts and riprap erosion protection



Typical low water crossing with no culverts and channel on a slope



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PROJECT:

Roadway
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DRAWING NAME:

Low water crossing
with Jersey barrier
and aggregate
surface

DRAWING NUMBER:

5-17

DESIGNED BY:

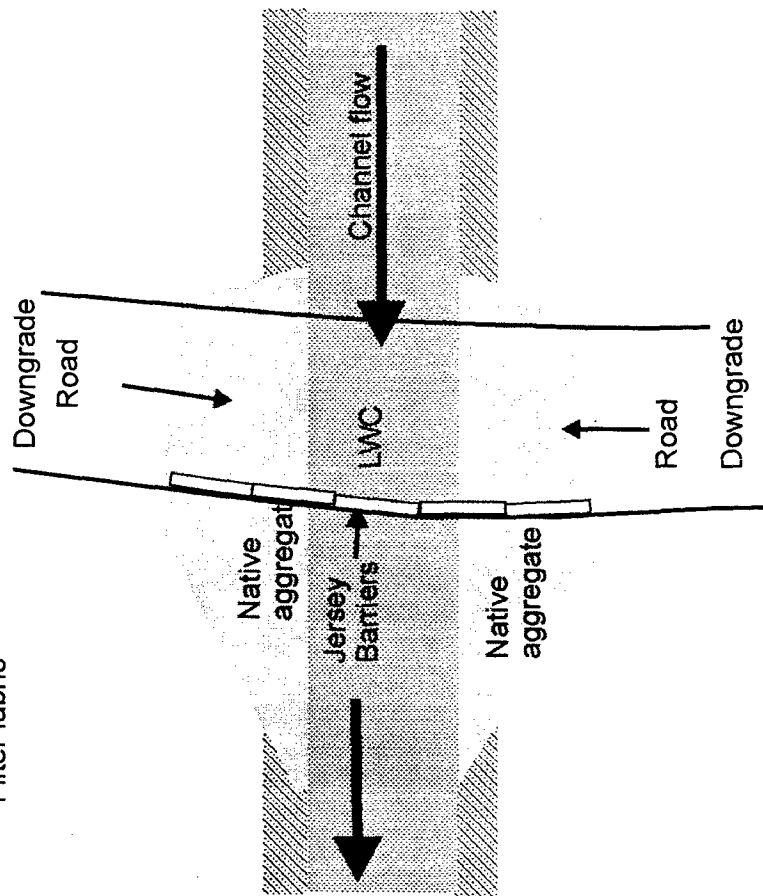
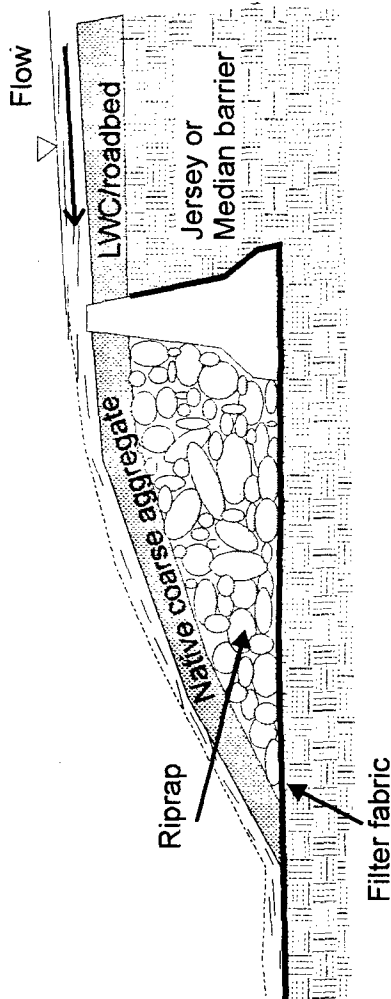
Sara J. White

DRAFTED BY:

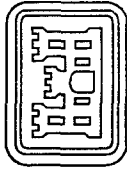
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Typical low water crossing with Median or Jersey barriers and no culverts



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PROJECT:

Roadway
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Drainage Control

DRAWING NAME:

Culvert crossing
with variations

DRAWING NUMBER:

5-18

DESIGNED BY:

Sara J. White

DRAFTED BY:

Sara J. White

DATE:

9-23-96

Aggregate surface with 1-1.5" diameter crushed stone

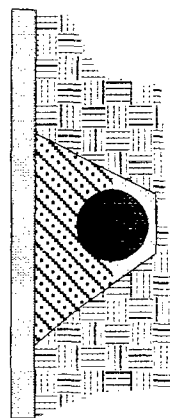
4" -6" thick surface course

Culvert must be covered by 18" compacted fill, minimum

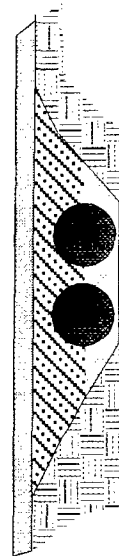
Compact sand to 1/2
diameter of culvert

Base flow

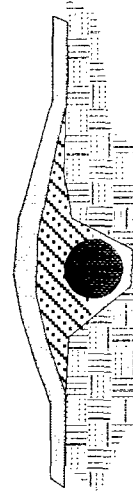
Typical low water or culvert crossing on a small channel on a lower weight road



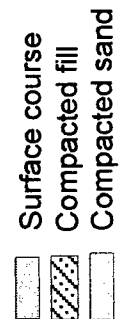
Narrow deep channel



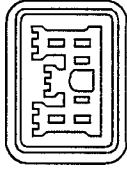
Wide channel



Narrow channel close to the surface



Variations based on channel type



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PROJECT

Roadway
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DRAWING NAME:

Low water crossings
concrete surfaces and
erosion protection

DRAWING NUMBER:

5-19

DESIGNED BY:

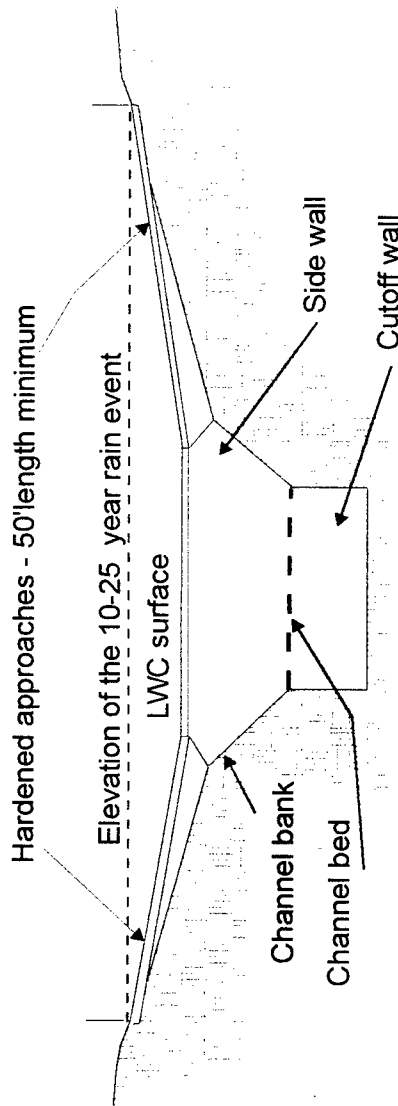
Sara J. White

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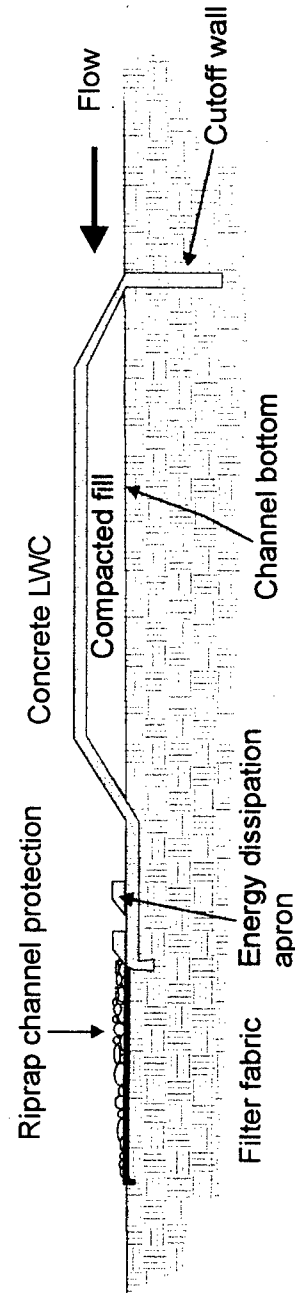
Sara J. White

DATE:

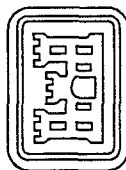
10-10-96



Typical concrete low water crossing without culverts - water flows over LWC surface



Typical concrete low water crossing- with or without culverts - perennial flow at height of LWC at minimum



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PROJECT:

Roadway
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DRAWING NAME:

Low water crossing
with concrete surface
and culverts

DRAWING NUMBER:

5-20

DESIGNED BY:

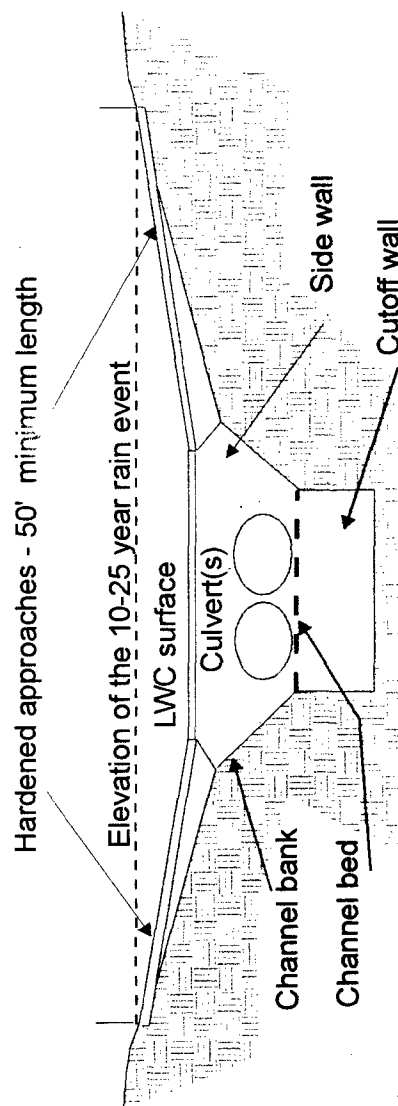
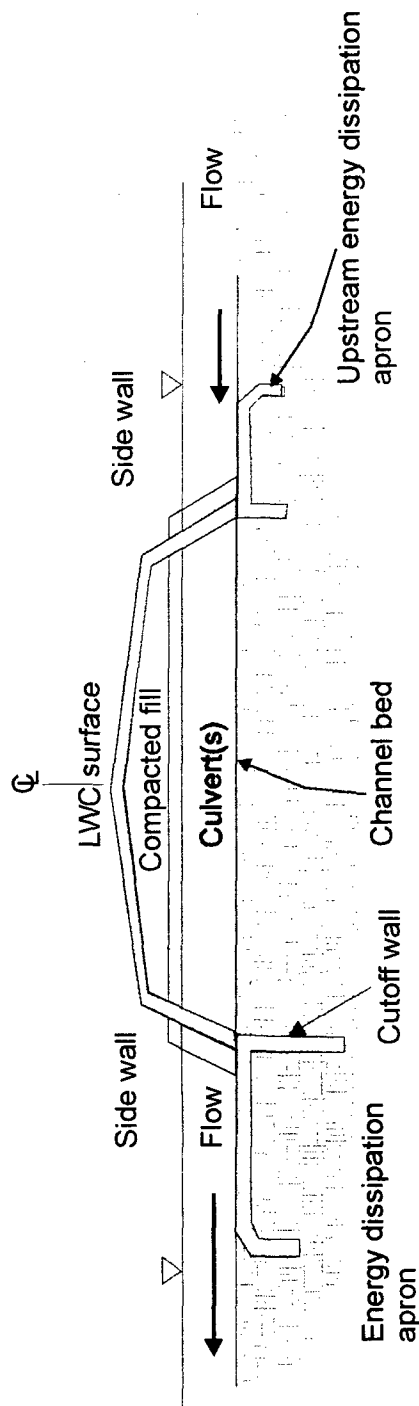
Sara J. White

DRAFTED BY:

Sara J. White

DATE:

10-12-96



Typical low water crossing with culverts to handle base flow

RIPRAP ENERGY DISSIPATION APRONS (Inlet/Outlet Protection)

DEFINITION: A rock- or riprap-lined apron at the discharge outlet of a drainage structure. A permanent structure requiring engineering designs to accommodate the velocity and volume of flows generated by runoff from the roadway.

PURPOSE: Aprons provide low cost and easily constructed energy dissipation. They serve as a transition structure to reduce the erosive energy of concentrated runoff at discharge outlets allowing the safe conveyance of low energy water to vegetated slopes or erodible channels.

APPLICABILITY: Where the discharge velocity of the pipe, culvert, ditch, diversion, or channel is greater than the permissible velocity of the receiving channel or dispersal area. These areas often exhibit signs of scour or undermining.

PLANNING CRITERIA: In designing the protection structure, it is important to consider the two types of erosion that typically occur at the downstream end of culverts or outlets. The difference between the two can be determined by comparing the original ground slope at the outlet to the slope required for stability.

Gully erosion: Where the velocity of the runoff in a ditch exceeds the natural resistance of the soil gully, scour may occur. Precipitating factors may include an increase in runoff to a ditch, the discharge of a concentrated flow onto a slope or a natural swale, or an abrupt drop in elevation at a pipe or ditch outlet. The fall of water causes headcutting to begin and the gully will enlarge as it seeks to downcut to a stable base level. Slope failure will occur around the pipe or ditch outlet as the gully expands.

- Gully scour can be prevented by either installing a drop-structure where significant changes in elevation occur within the ditch or to line the receiving channel with riprap to a point downslope where the slope is gentle and the channel wider. It will not be enough merely to

provide protection at an outlet if the slope BELOW the outlet is too steep.

Scour Hole: Scour holes occur below outlets even when the receiving channel is nearly level. Because the channel cross section is typically wider or larger than the discharging outlet, velocities tend to be greater at the culvert or pipe outlet than within the receiving channel. Erosion below the culvert is caused by the impact of high-velocity, concentrated flow and by the turbulence as the water loses energy and slows to the flow of the receiving channel. If the developing scour hole poses no particular threat to the culvert or slope, allowing it to form may be beneficial as it will act as an energy dissipator. Nevertheless, culverts and outlets must be protected against undermining by cutoff walls.

NOTE: Riprap stilling basins or plunge pools will reduce velocity more rapidly where high flows require very long aprons or where there is an excessive overfall at the outlet of a pipe or culvert.

DESIGN CRITERIA: The riprap discharge apron or energy dissipator can be constructed without formal engineering design, although a properly designed apron will be much more effective and longer lasting.

- Design aprons to accommodate the 10-year peak runoff or the design discharge of the water conveyance structure at a minimum.
- Design the apron to reduce the velocity of the discharge to the permissible velocity of flow for the receiving channel or area.
- The apron should have a level or zero grade with NO overfall at the end of the apron.
- The top of the riprap at the downstream end of the apron should be flush with the surface of the receiving area.

- The minimum thickness of the riprap should not be less than 1.5 times the maximum stone diameter.
- Ensure that field stone or quarry stone is hard, angular, weather resistant, and with a specific gravity of at least 2.5.
- The underlying filter should consist of a graded gravel layer or a synthetic filter fabric.
- Half the riprap stones should be larger than 0.5 times the diameter of the inlet pipe.
- No matter the design, a sturdy filter fabric or a 6- to 9-in. (15- to 23-cm) course of filter sand/-gravel should be installed before placement of riprap.
- A properly designed apron is based on the minimum or maximum tailwater conditions at the pipe outlet. The tailwater condition is the relation between the elevations of the water surfaces in the outlet pipe and the receiving channel.
- Under minimum tailwater conditions, the depth of the water in the receiving channel is less than one half that of the outlet pipe diameter. The energy of the water discharged will be dissipated by spreading on the apron and by turbulence from impact with the riprap.
- Under maximum tailwater conditions, the depth of the water in the receiving channel is greater than one half that of the outlet pipe diameter. The energy of the water will be dissipated by turbulence due to the impact of the discharge flow with both the receiving tailwater and the rocks in the riprap apron.
- The width of the upstream end of the apron should be three times the diameter of the pipe outlet (3 x 12-in. pipe = 36 in. [91 cm] width at the upstream end of the apron).
- The width of the downstream end of the apron should equal the pipe diameter plus the apron

length (12-in. pipe + 15 ft length = 16 ft wide at the downstream end).

- For the apron that is not formally designed, the general shape of the apron should be rectangular. The minimum dimensions should be three times the diameter of the pipe outlet at the upstream end with each of the other sides equal to 4 to 6 times the pipe diameter. The depth of the apron should be equal to the pipe diameter. Slope the sides of the apron inward. Extend riprap up the channel banks to the top edge. The layer of riprap should have a thickness of at least 12 in. (30 cm). The downstream end should not be less than the width of the receiving channel. Extend the discharge apron downstream until stable conditions are reached.

Example: Outlet pipe = 24 in. (61 cm),
Side lengths = 8 ft (2 m),
Riprap d_{50} = 12 in. (30 cm).

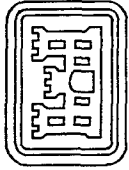
CONSTRUCTION CRITERIA:

- Compact any fill required in the subgrade to the density of the surrounding undisturbed soil.
- Low areas in the subgrade can be filled by increasing the thickness of the riprap as well.
- Both riprap and filter fabric must conform to design/specifications.
- Protect filter fabric from punching or tearing during installation. Repair damaged fabric by removing the riprap and placing another section of filter fabric over the damaged area. All connecting joints should overlap a minimum of 12 in. (30 cm).
- Replace any filter fabric that is extensively damaged.
- Place riprap by machine or hand. Take care to avoid damage to the fabric.
- Ensure that the apron is properly aligned with the receiving channel or slope.

- Ensure that the top of the riprap at the downstream end is flush with the surrounding surface.
- Reseed all disturbed areas immediately following installation.

MAINTENANCE:

- Inspection and maintenance are required following significant rain events.
- Schedule regular or periodic inspections throughout the year.
- Remove excess sediment during regular maintenance activities.
- Return dislodged stones to the apron.



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PROJECT

Roadway
Maintenance and
Drainage Control

DRAWING NAME:

Discharge aprons

DRAWING NUMBER:

5-21

DESIGNED BY:

Sara J. White

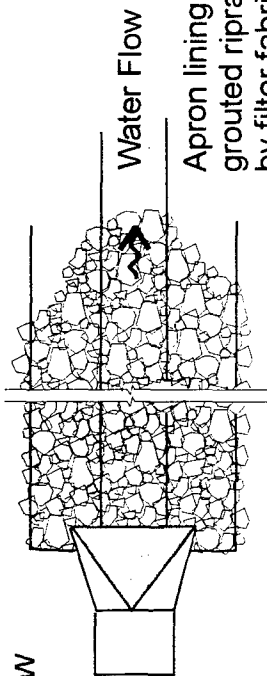
DRAFTED BY:

Sara J. White

DATE:

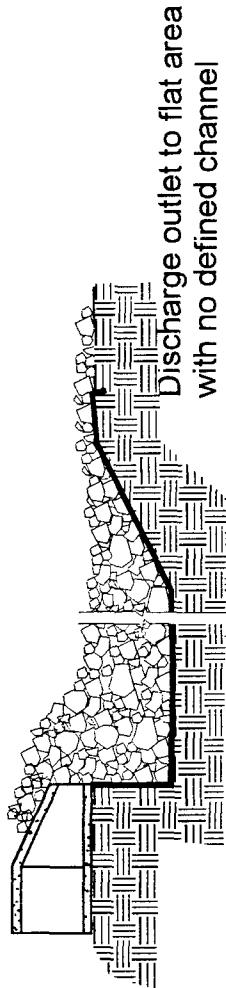
11-25-96

PLAN VIEW

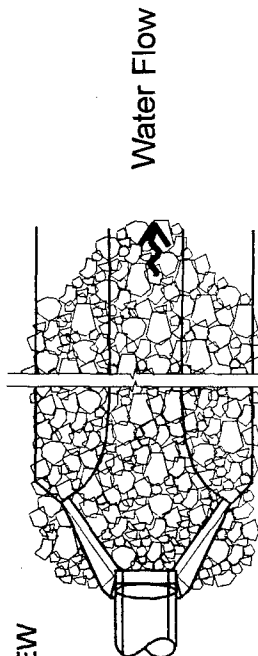


Apron lining may be riprap,
grouted riprap, or concrete underlain
by filter fabric or sand

LONGITUDINAL SECTION

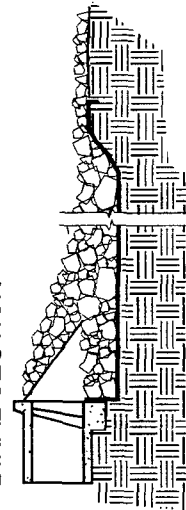


PLAN VIEW

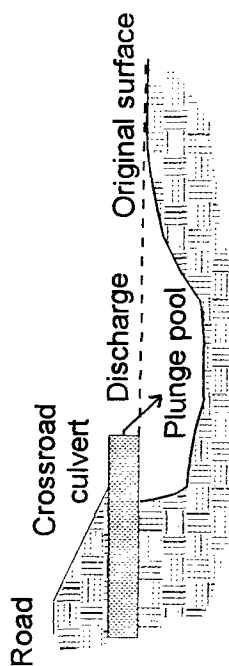


Water Flow

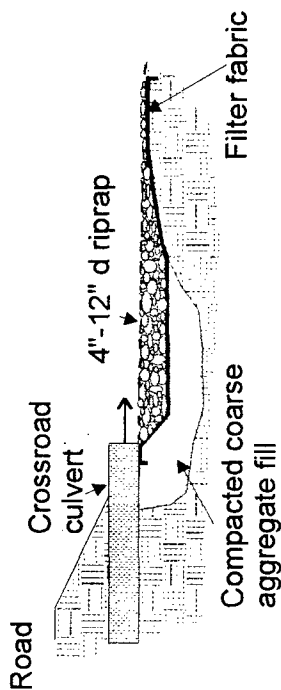
LONGITUDINAL SECTION



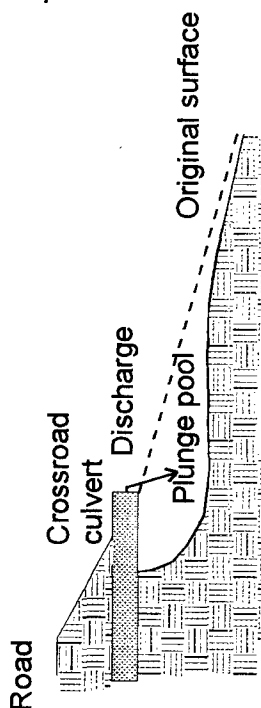
Outlet discharges to well-defined channel



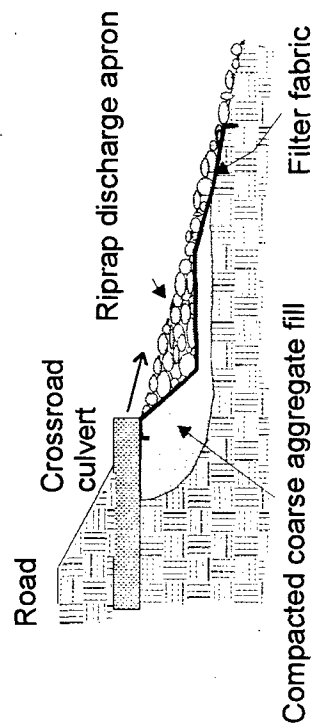
Scour-type erosion at culvert discharge outlet on a level surface



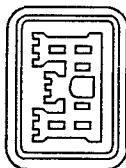
Typical discharge apron to mitigate scour erosion



Gully-type erosion at culvert discharge outlet on a slope



Typical discharge apron to mitigate gully erosion



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PROJECT:

Roadway
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Drainage Control

DRAWING NAME:

Culvert outlet
protection aprons

DRAWING NUMBER:

5-22

DESIGNED BY:

Sara J. White

DRAFTED BY:

Sara J. White

DATE:

8-05-96

SILT FENCE SEDIMENT BARRIER

DEFINITION: A temporary barrier to sediment-laden runoff constructed of filter fabric stretched between posts and buried into the substrate.

PURPOSE: The retention of sediment transported by sheet flow from a small disturbed area. The silt fence retards the velocity of sheet flow permitting filtering of sediment behind the barrier.

APPLICABILITY: Use silt fences only where sediment-laden runoff can safely be stored behind the barrier without damage to the fence or the area immediately behind the fence.

- Silt fences are NEVER to be installed ACROSS streams, ditches, gullies, or waterways.

PLANNING CRITERIA:

- Silt fences are not to be used along ridges or drainage divides as they serve no purpose at those locations.
- The use of a silt fence to confine or divert runoff may encourage erosion and sedimentation.
- The silt fence is intended to confine sediments on a disturbed site before they enter waterways (including ditches).
- Ponding occurs behind the silt fence as openings in the fabric become clogged with fine sediments and the flow rate is reduced. Plan for ponding to occur and design overflow outlets to prevent overtopping of the fence.
- Because silt fences are not designed to withstand high heads, place them where only shallow ponds can occur.
- It is critical to tie the ends of the silt fence into the landscape to prevent flow around the end of the fence.

- Provide stabilized outlets (riprap aprons) to protect the fence system and to release flows that exceed the design flow.
- Deposition can be encouraged behind the silt fence by excavation of a sediment trap. Ensure that adequate access to the trap exists for periodic maintenance.
- Silt fences installed slightly off the contour can be used to divert shallow sediment-laden flows from disturbed areas into deposition areas.
- Care must be taken that all runoff passes through the filter fabric and does not flow over, pass under, or flow around.
- The use of filter fabric is not recommended on sites subjected to vehicular traffic.
- The spacing of barriers is determined by the slope as shown in Table 5-7.

DESIGN CRITERIA:

- Silt fences must be stable enough to handle a 10-yr peak storm at minimum.
- Where all runoff is to be stored behind the silt fence, ensure that the maximum slope length behind the fence does not exceed the specifications in Table 5-8. The impounded water should never exceed a depth of 1.5 ft along the fence.
- Provide a riprap slash pad or apron for any point where flow may overtop the silt fence.

Percent Slope	Distance Between Barriers (ft)
2-8	110-92
8-12	92-75
12-18	80-60
18-24	60-52

Table 5-7. Distance between barriers.

PHYSICAL PROPERTY	REQUIREMENTS
Filtering Efficiency	85% (minimum)
Tensile Strength at 20% Max. Elongation	Standard-strength 30 lb/linear inch (minimum)
Tensile Strength at 20% Max. Elongation	Extra-strength - 50 lb- linear inch (minimum)
Slurry Flow Rate	0.3 gal/sq ft/min (minimum)

Table 5-8. Silt fence specifications.

- At any protected, reinforced outlet, the maximum height of the fence should not exceed 1 ft.
- Support post spacing should not exceed 4 ft.
- The design life of a synthetic silt fence is 6 months. The anticipated life of a burlap silt fence is 60 days.

MATERIALS:

Silt Fence. Silt fences should be composed of a synthetic filter fabric or pervious sheet of polypropylene, nylon, polyester, or polyethylene yarn certified by the manufacturer as conforming to the specifications in Table 5-8.

Synthetic Filter Fabric. Synthetic filter fabric should contain ultraviolet ray inhibitors and stabilizers to provide a minimum of 6 months of expected usable construction life at a temperature range of 0 to 120 °F.

Posts. Posts for silt fence support are typically made of 4-in. diameter pine, 2-in. diameter oak, or 1.33 lb/linear ft steel. They should have a minimum length of 4 ft. Steel posts should have projections to facilitate fastening the fabric.

Wire Fence. Galvanized, 14-gauge wire, with a mesh opening of 6 in. is most typically used to reinforce a silt fence.

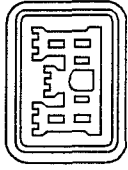
CONSTRUCTION:

- Ensure that the height of the silt fence barrier does not exceed 18 in. above the ground surface. Higher fences may cause impoundment of water sufficient to cause structural failure.
- Avoid joints by using filter fabric from a continuous roll cut to the length required. If a joint is required, secure it at a support post and overlap to the next post.
- Wire fencing used as support for standard-strength filter fabric should be securely fastened to the upslope side of the support posts using tie wires or heavy duty wire staples at least 1 in. long.
- When a wire fence is required for additional support, space posts a minimum of 8 ft apart. Drive posts securely into the ground to a depth of 18 in. minimum.
- Extra-strength filter fabric has a post spacing of 6 ft and does not require additional support fencing. Staple or tie the fabric directly to the posts.
- Delineate the alignment of the barrier with string or chalk. Excavate a trench 4 in. wide, 8 in. deep along and upslope of the line. Line the trench with the lower 12 to 18 in. of the silt fence and back fill with compacted soil or gravel. If a support fence is used, place the lower portion of the fence in the bottom of the trench before installing the filter fabric.
- Never attach silt fences to existing trees.

MAINTENANCE:

- Inspect silt fences on a regular (weekly) basis and particularly after significant rain events.
- Immediately repair damaged fences.
- Fences subjected to excessive flow and the elements may collapse, tear, decompose, or become ineffective.

- Replace damaged fences promptly. Replace burlap fences every 60 days.
- Remove trapped sediments regularly to provide adequate storage volume for the next rain event and to reduce pressure on the silt fence.
- After the contributing area has been stabilized, remove silt fence barriers and posts, bring the area to grade, and revegetate.



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PROJECT:

Roadway
Maintenance and
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DRAWING NAME:

Temporary silt fence
placement

DRAWING NUMBER:

5-23

DESIGNED BY:

Sara J. White

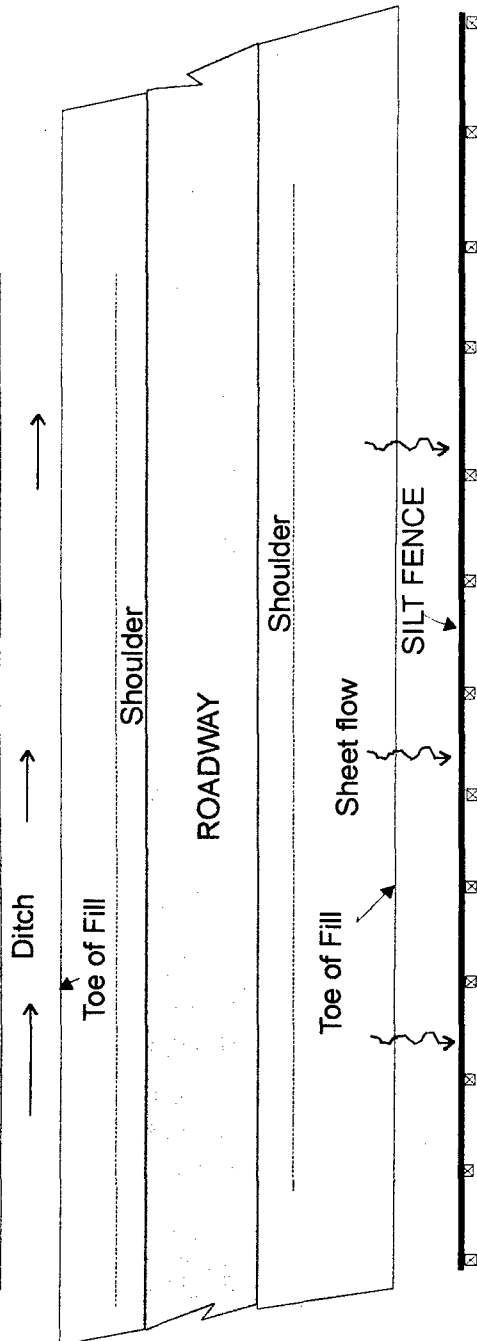
DRAFTED BY:

Sara J. White

DATE:

10-13-96

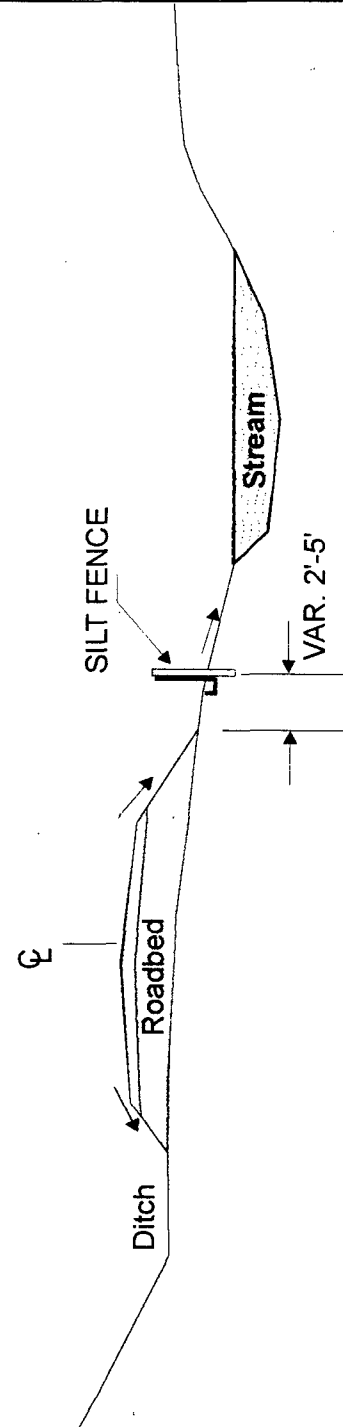
Original surface



Original surface

STREAM

Silt fence placement along a road section - planiform view



Silt fence placement along roadside - cross-sectional view

STRAIGHT DROP SPILLWAY

DESCRIPTION: A weir structure in which the flow through the ditch/gully passes through the weir opening, drops to an energy dissipation structure and then passes into the downstream channel. Variations on the drop spillways include straight, arched, and box inlets. The energy dissipator may be a level apron or a stilling basin.

PURPOSE: The drop structure is used to control the velocity of runoff in a ditch by lowering the water abruptly from one level to another. Spillways are used to establish a series of shorter and lower reaches within a steeper and erosive reach of a ditch or gully. The purpose of the drop spillway is to establish a permanent base elevation below which an eroding channel cannot lower the channel floor. Spillways control the channel grade not only at the spillway crest, but also through the ponded reach upstream.

APPLICABILITY: Drop spillways are specified for drops of less than 10 ft (3 m). They are used where a permanent, low maintenance, easily constructed, and very stable structure is required. This type of spillway is only applicable where the grade below the structure is stable or can be stabilized.

- For grade stabilization in lower reaches of channels and outlets.
- Erosion control for protection of fields, roads, ditches, etc., from gullies.
- Grade control for stabilizing ditches or gullies.
- Outlets for culverts or surface runoff at the upper end and along drainage ditches.
- Control of tailwater at the outlet of a spillway or culvert.
- Protection of the outlet end of grassed waterways and chutes.

PLANNING CRITERIA:

- Field surveys must be conducted to include soils and geomorphic data.
- The site for the spillway should be on a relatively straight section of the ditch/gully, with no curvature in the channel for at least 100 ft (30 m) above and below the structure.
- Channel straightening is beneficial to smooth the alignment of the spillway with the existing channel, or embankment scour is probable.
- The foundation material must have the required supporting strength, be resistant to sliding and piping, and be adequately homogeneous to prevent uneven settlement of the structure.

MATERIALS: Drop spillways can be constructed of reinforced concrete, plain concrete, rock masonry, concrete blocks (with or without reinforcement) or sheet piling of steel, timber, and prefabricated metal.

DESIGN CRITERIA: The design of a spillway usually requires the assistance of an engineer although other personnel can be trained to plan and install small structures when standard plans are available.

- The free flow capacity for the drop spillway is given by the weir formula:

$$q = 0.552CLh^{3/2}$$

q = the discharge in m/s,
 C = weir coefficient (English units), this is 3.2
 L = weir length in m,
 h = depth of flow in m.

L is the crest length of a straight inlet (or the sum of the three sides of a box inlet or the circumference of an arch inlet).

The inlet should have a freeboard of 0.15 m above the height of the water surface (h). The chart for weir capacity for straight drop structures (in standard units) found on page 6-11 of the NRCS/SCS Field Manual can also be used to determine weir capacities for low-overfall straight drop spillways.

STRAW BALE SEDIMENT BARRIER

DEFINITION: A barrier to sediment-laden runoff flowing from slopes or within channels and constructed of secured, baled straw.

PURPOSE: Barriers retain sediment within the channel or near the disturbed site. The straw bales retard the movement of sediment-laden runoff thereby permitting the passage of clearer runoff through the barrier while sediment is filtered out behind it.

APPLICABILITY: Wherever temporary barriers are required to prevent sediment from moving off-site or into sensitive areas. Straw bales can be used as barriers at culvert inlets, across minor swales and drainage ditches, within minor gullies, or as dikes or berms to temporarily redirect sediment-laden runoff.

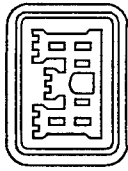
PLANNING CRITERIA:

- Bales should be secured with wire or nylon ties, rather than with twine or string that biodegrades rapidly.
- Prepare a keyway trench. This trench should be at least 6 in. deep and the width of the straw bales. It should extend along the entire length of the planned barrier.
- Lay bales on their sides in the keyway trench. Stake in place using not less than two wooden or metal stakes per bale. Each stake should be driven not less than 18 in. into the substrate. The first stake driven in each bale should be angled toward the previously laid bale and penetrate both bales.
- To increase structural stability, standard fencing and metal fence stakes can be used on the downstream side of the barrier to provide support. Stakes should be spaced no more than 4 ft apart and driven at least 3 ft into the substrate.
- For bales used as sediment barriers within channels or ditches, a spillway can be

constructed with sand and gravel, crushed stone, or small riprap placed at the lowest point in the channel. The height of the spillway should be no more than half the height of the bales.

MAINTENANCE:

- Frequent inspection and maintenance is required with straw bales, particularly after significant rain events.
- Replace disintegrating straw bales with new ones and use the old straw for mulch in the immediate area.
- Remove sediment deposited behind the bales following each heavy rain event and dispose of it properly.



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PROJECT:

Roadway
Maintenance and
Drainage Control

DRAWING NAME:

Straw bale sediment
barrier with and without
a riprap spillway

DRAWING NUMBER:

5-24

DESIGNED BY:

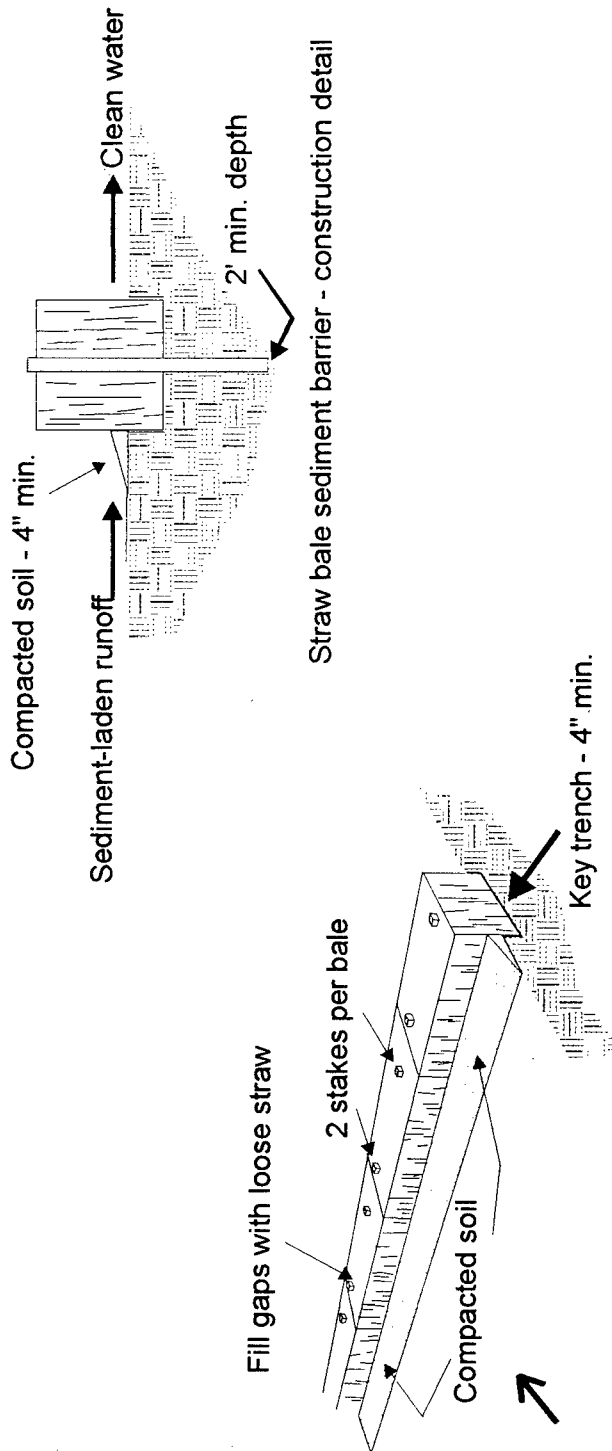
Sara J. White

DRAFTED BY:

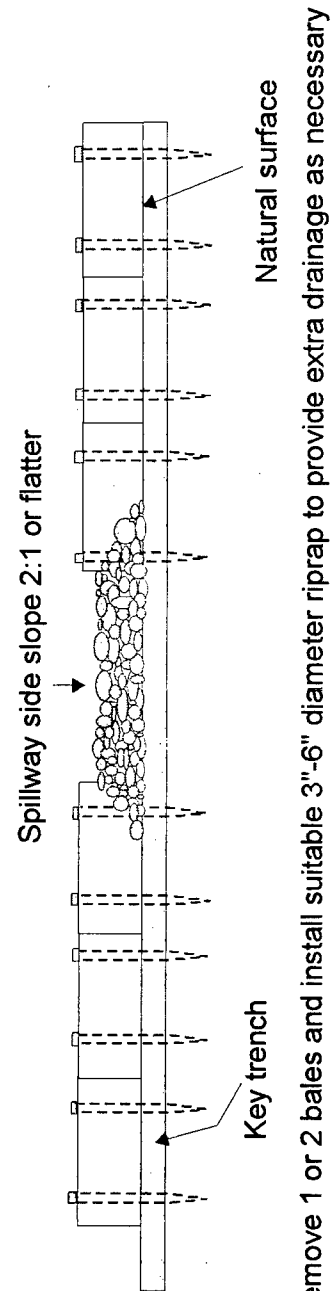
Sara J. White

DATE:

11-28-96



Straw bale sediment trap - oblique view



Remove 1 or 2 bales and install suitable 3"-6" diameter riprap to provide extra drainage as necessary

Bales are to be located on the contour

Straw bale sediment barrier with riprap spillway or sediment filter

TEMPORARY SEDIMENT TRAP

DEFINITION: A small storage basin or detention ponding basin formed by excavation or an embankment to capture sediment transported by running water.

PURPOSE: Used to detain sediment-laden runoff until particles have settled out. Runoff is released down-channel while sediment is trapped within the channel or nearby to protect ephemeral and perennial channels, ponds, wetlands, drainage systems, and off-site properties.

APPLICABILITY:

- At the outlets of diversions, ditches, channels, slope drains, or other runoff conveyances that discharge sediment-laden runoff.
- At the lower end of borrow pits.
- Below areas less than 5 acres in size.
- At locations where access can be maintained for sediment removal and proper disposal.
- Before culvert inlets as part of inlet protection system.

PLANNING CONSIDERATIONS:

- Select the location for the sediment trap during the assessment of the site. Sediment traps are constructed by excavating a depression, using a natural depression, or creating an impoundment with a low head dam. Where possible, the construction of several small traps is preferred to avoid constructing a sediment basin.
- Ensure that traps are readily accessible for periodic inspection, maintenance, and removal of sediment.
- When designing the sediment trap, consider a provision for embankment failure during periods of significant rainfall. A nonerosive emergency bypass or spillway will protect the structure from storm flows exceeding the design capacity.

In designing the sediment trap in the field, estimate the size of the trap required to remove sand-sized sediment and hold the expected volume of sediment to be trapped. The expertise of a hydraulic engineer is required if the trap is to retain silt-sized particles. The sediment-trapping efficiency depends on the surface area and inflow rate. Maximizing the surface area in the design is critical. Designs giving settling pools large length-to-width ratios will allow greater surface area for settling.

- It is critical that sediment traps are installed in the first stages of project development.

DESIGN CRITERIA: Ensure drainage area for a sedimentation trap does NOT exceed 5 acres.

Storage Capacity: The minimum volume of the sediment trap should be maintained at 1800 cu ft per acre based on the area draining into the trap. The volume of a natural sediment trap can be approximated by the following equation:

$$\text{Volume (ft}^3\text{)} = 0.4 \times \text{surface area (ft}^2\text{)} \times \text{maximum pool depth (ft)}$$

Trap Efficiency: Maintain a high length-to-width ratio.

Excavation: Maintain side slopes at 2:1 or flatter for safety.

Embankment: A maximum height of 5 ft; a minimum top width of 5 ft; side slopes of 2:1 or flatter for safety.

Outlet Section: Install a riprap section at the lowest point in the trap. The riprap will provide a nonerosive emergency spillway and permit dewatering of the trap between runoff events.

Protection From Undercutting: Excavate a keyway trench across the riprap foundation and up the slides to the height of the embankment. Place a filter cloth on the foundation between the key and the riprap.

Riprap Selection: Use 9 in. d_{50} riprap with a 14-in. maximum size. A 12-in. layer of 0.5- to 0.75-in. gravel should be placed on the inside face of the embankment to reduce the rate of drainage flow through the riprap section.

Side Slopes: Maintain side slopes of 2:1 or flatter. The sides of the spillway above the crest notch should be maintained at a thickness of 21 in.

Depth: Install the crest of the spillway outlet not less than 1.5 ft below the settled top of the embankment.

Trap Cleaning: Remove sediment from the trap and restore the capacity to original trap dimensions when sediment has accumulated to one-half the design depth.

CONSTRUCTION SPECIFICATIONS:

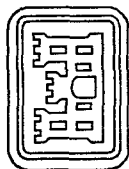
- Clear, grub, and strip the channel of all vegetation and root mats. Remove all surface soil containing high amounts of organic matter. Haul debris to a designated disposal site.
- Fill material should be free of roots, woody vegetation, organic matter, and other objectionable material. Place clean fill in greater than 9-in. lifts and compact by machine. Overfill the embankment by 6 in. to allow for settling.
- Construct the riprap spillway. Excavate the keyway along the centerline of the spillway and extended it up the sides of the embankment to the top. The keyway should be at least 2 ft deep and 2 ft wide with 1:1 side slopes. Place the filter fabric between the soil and the riprap. Extend the fabric across the spillway foundation and up the sides to the top of the embankment. The bottom width of the riprap spillway should not be less than 3 ft, with maximum side slopes of 1:1. From the crest of the spillway to the top of the embankment, the riprap should be maintained at a thickness of 21 in. and a slope of 2:1.
- A well-graded riprap mixture should be selected with a d_{50} of 9 in. and a maximum

stone size of 14 in. The stone may be machine-placed and the smaller stones worked into the voids by hand. Riprap should be hard, angular, and weather-resistant.

- The spillway outlet section must extend downstream until stable conditions are reached and the channel can handle the outlet velocities. Install the stones flush with the surrounding soil surface and shape the riprap outlet to confine the outlet flow.
- Divert the flow from the emergency bypass to a stable, vegetated area.
- Immediately upon construction, stabilize embankments and all other disturbed areas above and below the sediment trap with a reseeding program.
- Mark the level of sediment for cleaning of the trap (one half the design depth) on a post or stake for reference.

MAINTENANCE:

- Sediment traps must be inspected after each period of significant rainfall. Clean and properly dispose of accumulated sediment when it reaches the designated cleaning level. Clean the filter gravel from the inner face of the spillway and replace with clean gravel as necessary.
- Inspect the embankments for signs of erosion, to include piping. Ensure that the spillway crest is 1.5 ft below the top of the embankment by immediately replacing any settlement. Replace any riprap dislodged from the spillway.
- Note all maintenance efforts with location, dates, and materials required in the trail and ditch maintenance log.



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PROJECT:

Roadway
Maintenance and
Drainage Control

DRAWING NAME:

Temporary sediment
trap with riprap
spillway

DRAWING NUMBER:

5-25

DESIGNED BY:

Sara J. White

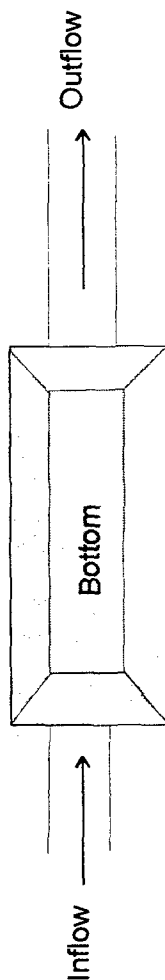
DRAFTED BY:

Sara J. White

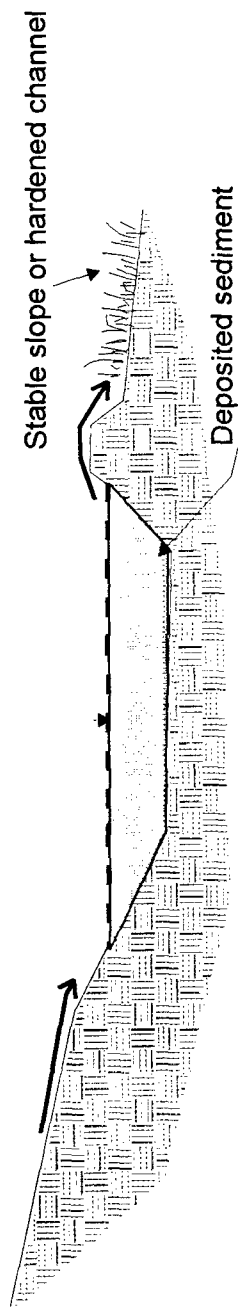
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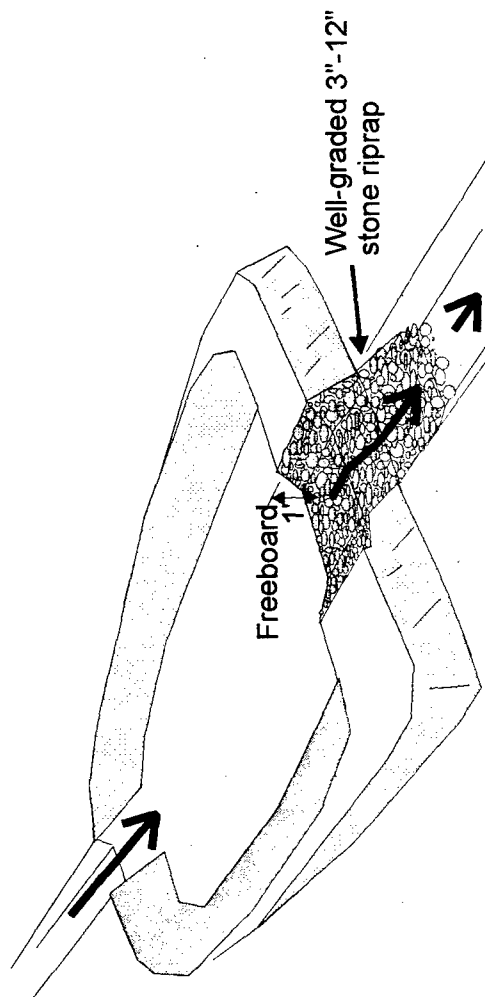
Sloping sides 2:1 min.



Temporary sediment trap - planiform view



Temporary sediment trap - construction detail



Riprap spillway on temporary sediment trap

TURNOUT

DEFINITION: A transitional diversion from a roadside drainage ditch to a stable outlet, prepared level spreader, or undisturbed, well-vegetated area.

The term turnout is also used to describe an area of the roadway used to park or pull vehicles off the traveledway.

PURPOSE: Turnouts serve to convert a concentrated flow of runoff to nonerosive sheet flow. This is accomplished via the diversion of the concentrated flow within a roadside ditch to a zero grade level spreader. The intent of the turnout is to prevent ditch bottom incision or gully development by diverting the flow of erosive volumes of runoff in the ditch to stable, well-vegetated, and/or undisturbed areas before the initiation of down-cutting.

APPLICABILITY: Wherever roads or trails traverse steeper grades, on grades where rill and gully development is present, and on sections of the roadway where sediment and water is flushing directly into a water body.

PLANNING CRITERIA:

- Install turnouts only where the area directly below the turnout outlet is stabilized by vegetation, has been adequately hardened against erosive volumes of runoff or where the drainage will not initiate erosion or flow directly into a water body.
- Installation is practicable on trails having slopes of 2 percent or greater.
- Ensure that turnouts are constructed with a 30- to 40-degree angle to the roadway and have an outslope of 2 to 3 degrees.
- The width should be a minimum of the width of the drainage ditch from which it is diverting runoff. The length of the transition from ditch to the level-spreader should be a minimum of 20 ft.

- The transition from the ditch to the grade and width of the outlet area (level spreader, stabilized outlet, undisturbed area) should be smooth and blend with the surrounding landscape.
- Sediment-laden runoff should be filtered by sediment barriers or traps BEFORE it is diverted to stable areas via the turnout.

Turnouts are NOT designed to transport sediment-laden runoff.

- The common spacing for turnouts is shown in Table 5-9, although site-specific modifications may be required based on soils, slope, vegetation, and area of watershed providing runoff to the trail section affected.

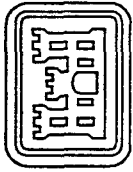
MAINTENANCE:

- Regularly scheduled inspections and maintenance are critical to turnout life expectancy.
- Regrade turnouts during regularly scheduled trail maintenance.
- Inspect turnouts following rain events and restore when damaged.
- Do not grade excess sediment from ditches into turnouts.

Slope (In Percent)	Spacing (In Feet)
2	200
5	125
10	80
15	60
20	45

Table 5-9. Turnout spacing.

- Turnouts are designed to convert concentrated flow into sheet flow, NOT to filter or retain sediments.
- If excessive sediments are being transported to turnouts, a problem exists with sediment delivery upslope from the turnout. Check that disturbed areas are revegetated, turnouts have been adequately spaced, and sediment from the traveledway is not being sidecast into ditches.



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PROJECT:
Roadway
Maintenance and
Drainage Control

DRAWING NAME:
Turnout from ditch and
level spreader

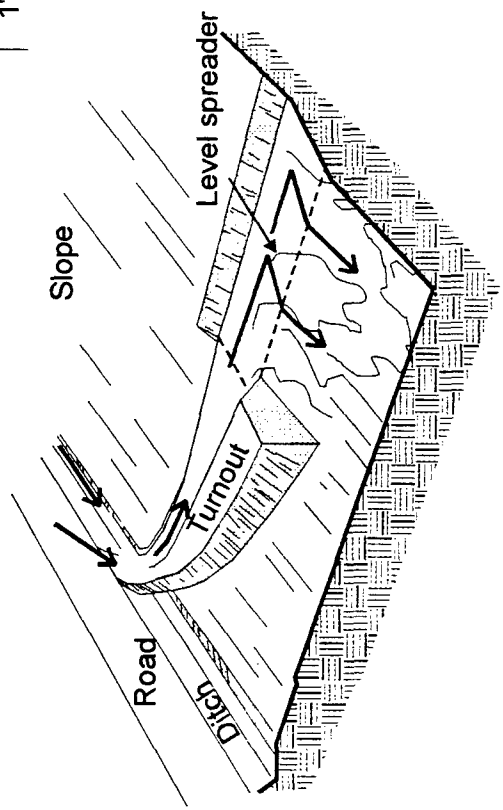
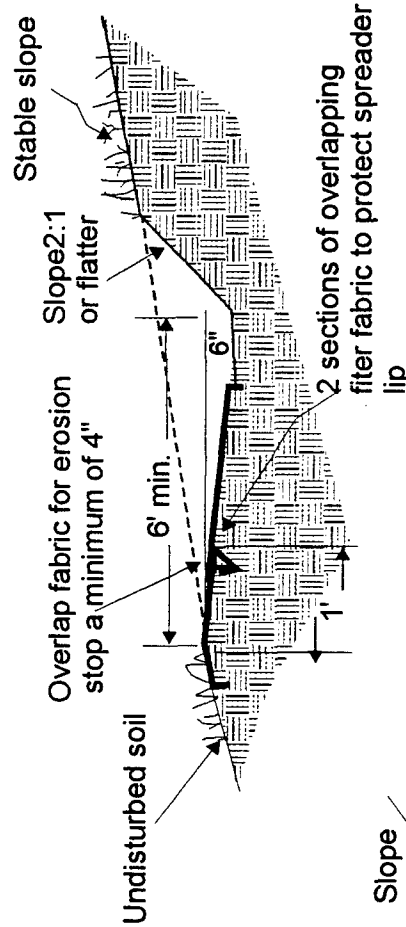
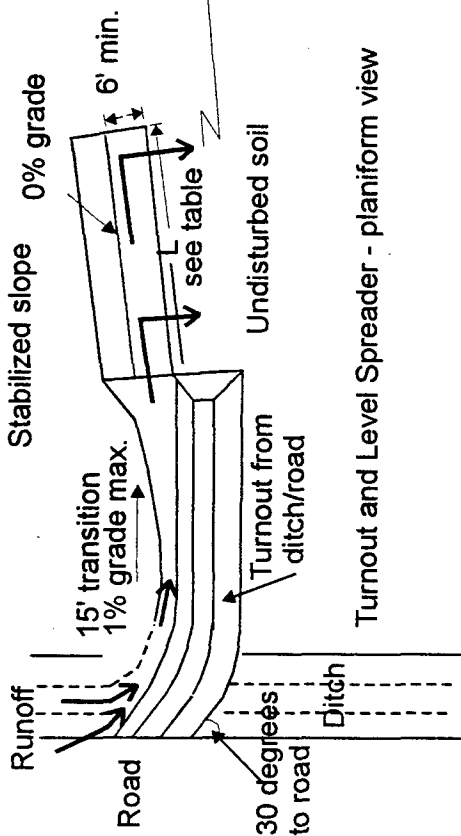
DRAWING NUMBER:
5-15

DESIGNED BY:
Sara J. White

DRAFTED BY:
Sara J. White

DATE:
10-08-96

Design Q (cfs)	Minimum length (L) in feet
0-10	15
10-20	20
20-30	26
30-40	36
50	44



Turnout from ditch and Level Spreader - oblique view

Appendix A: Properties of Soil

Significant Properties of Soil Components
(Adapted from FM 5-541 Military Soils Engineering)

SOIL COMPONENT	SYMBOL	GRAIN SIZE RANGE AND DESCRIPTION	SIGNIFICANT PROPERTIES
BOULDER	None	Rounded to angular, bulky, hard, rock particle, >12 in diameter	Very stable; used for foundation stabilization, fills, ballast, and slope stabilization
COBBLE	None	Rounded to angular, bulky, hard, rock particle, < 12 in >3 in	
GRAVEL	G	Rounded to angular, bulky, hard, rock particle, passing 3 in sieve, retained on No. 4 sieve	Gravel has similar engineering properties as sand; easy to compact, affected little by moisture; gravels are more pervious, stable, resistant to erosion and piping than sand; well-graded sands and gravels are less-pervious and more stable than those poorly-graded; irregularity of particles increases stability; finer, uniform sand acts like silt in that it displays a decrease in permeability and reduction in stability with increase in moisture
Coarse		3-3/4 in.	
Fine		3/4 in to No. 4 sieve	
SAND	S	Rounded to angular, bulky, hard, rock particle, passing No. 4 sieve, retained on No. 200 sieve	
Coarse		No. 4 to 10 sieves	Inherently unstable; particularly when moisture is increased, with a tendency to become quick (semi-liquid) when saturated; relatively impervious, difficult to compact, very susceptible to frost heave, easily erodible, subject to boiling and piping; bulky grains reduce compressibility; flaky grains like mica, diatoms, increase compressibility producing and elastic soil
Medium		No. 10 to 40 sieves	
Fine		No. 40 to 200 sieves	
SILT	M	Particles smaller than No. 200 sieve, slightly to nonplastic regardless of moisture and exhibit little strength when air-dried	
CLAY	C	Particles smaller than No. 200 sieve, can be made to exhibit plastic properties within a certain range of moisture and exhibits considerable strength when air-dried	Cohesion increases with decrease in moisture; low permeability; compaction difficult when wet, drainage difficult, resistant to erosion and piping when compacted; subject to expansion and shrinkage; montmorillinitic clays have most adverse affect on soil properties, kaolinitic clay clays have least adverse impact on soil properties
ORGANIC MATTER	O	Organic matter in various stages of decomposition	Organic matter increases compressibility and decreases stability of soils; decay may cause voids or changes in soil properties via chemical alteration; do not use organic soils in engineering efforts.

Important Engineering Properties of Unified Soil Classes
(Adapted from FM 5-541 Military Soils Engineering)

Material Names	Unified Soil Class	Shear Strength	Ability to compress	Workability as a construction material	Permeability when compacted
Well-graded gravels, gravel-sand mix, little or no fines	GW	Excellent	Negligible	Excellent	Pervious
Poorly graded gravels, gravel-sand mix, little or no fines	GP	Good	Negligible	Good	Very Pervious
Silty gravels, gravel-sand-silt mix	GM	Good to Fair	Negligible	Good	Semi-Pervious to Impervious
Clayey gravels, gravel-sand-clay mix	GC	Good	Very Low	Good	Impervious
Well graded sands, gravelly sands, little or no fines	SW	Excellent	Negligible	Excellent	Pervious
Poorly graded sands, gravelly sands, little or no fines	SP	Good	Very Low	Fair	Pervious
Silty sands, sand-silt mix	SM	Good to Fair	Low	Fair	Semi-Pervious to Impervious
Clayey sands, sand-clay mix	SC	Good to Fair	Low	Good	Impervious
Inorganic silts and very fine sands; rock flour, silty or clayey fine sands or clayey silts	ML	Fair	Medium to High	Fair	Semi-Pervious to Impervious
Inorganic clays, gravelly, sandy, silty, or lean clays	CL	Fair	Medium	Good to Fair	Impervious
Organic silts or clays	OL	Poor	Medium	Fair	Semi-Pervious to Impervious
Inorganic silts, micaceous fine sandy or silty soils	MH	Fair to Poor	High	Poor	Semi-Pervious to Impervious
Inorganic clays of High plasticity	CH	Poor	High to Very High	Poor	Impervious
Organic clay of higher plasticity	OH	Poor	High	Poor	Impervious
Peat	Pt	Not Suited			

Important Engineering Properties of Unified Soil Classes — Embankments
(Adapted from FM 5-541 Military Soils Engineering)

Material Names	Unified Soil Class	Compaction Characteristics	Type of Roller Required	Standard Unit Density lb/ft ³	Resistance to Piping
Well-graded gravels, gravel-sand mix, little or no fines	GW	Good	Crawler Tractor (CT) or Steel Wheeled Vibratory (SWV)	125-135	Good
Poorly graded gravels, gravel-sand mix, little or no fines	GP	Good	CT or SWV	115-125	Good
Silty gravels, gravel-sand-silt mix	GM	Good	Rubber-tired (RT) or Sheepfoot (SF)	120-135	Poor
Clayey gravels, gravel-sand-clay mix	GC	Good	RT or SF	115-130	Good
Well graded sands, gravelly sands, little or no fines	SW	Good	CT or SW	110-130	Fair
Poorly graded sands, gravelly sands, little or no fines	SP	Good	CT or SWV	100-120	Fair to Poor
Silty sands, sand-silt mix	SM	Good	RT or SF	110-125	Poor to Very Poor
Clayey sands, sand-clay mix	SC	Good	RT or SF	105-125	Good
Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts	ML	Good to Poor	SF	95-120	Poor to Very Poor
Inorganic clays, gravelly, sandy, silty, or lean clays	CL	Fair to Poor	SF	95-120	Good to Poor
Organic silts or clays	OL	Fair to Poor	SF	80-100	Good to Poor
Inorganic silts, micaceous fine sandy or silty soils	MH	Poor to Very Poor	SF	70-95	Good to Poor
Inorganic clays of high plasticity	CH	Fair to Poor	SF	75-105	Excellent
Organic clay of higher plasticity	OH	Poor to Very Poor	SF	65-100	Good to Poor
Peat	Pt	Do not use			

Important Engineering Properties of Unified Soil Classes — Embankments, Cont'd

Material Names	Unified Soil Class	Relative Permeability	Relative Compressibility	Shear Resistance Under Load	Description and Use
Well-graded gravels, gravel-sand mix, little or no fines	GW	High	Very Slight	None	Very stable; pervious shells of dikes and dams
Poorly graded gravels, gravel-sand mix, little or no fines	GP	High	Very slight	None	Stable; pervious shells of dikes and dams
Silty gravels, gravel-sand-silt mix	GM	Medium	Slight	Poor	Stable; impervious cores or blankets
Clayey gravels, gravel-sand-clay mix	GC	Low	Slight	Fair	Fairly stable; impervious cores
Well graded sands, gravelly sands, little or no fines	SW	High	Very Slight	None	Very stable; pervious sections, slope protection required
Poorly graded sands, gravelly sands, little or no fines	SP	High	Very Slight	None	Stable; embankment with flat slopes
Silty sands, sand-silt mix	SM	Medium	Slight	Poor	Fairly stable; impervious core or dike
Clayey sands, sand-clay mix	SC	Low	Slight	Fair	Fairly stable; impervious cores
Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts	ML	Medium	Medium	Very Poor	Unstable; limited embankment use with proper control
Inorganic clays, gravelly, sandy, silty, or lean clays	CL	Low	Medium	Good to Poor	Stable; impervious cores and blankets
Organic silts or clays	OL	Medium to Low	Medium to High	Fair	Not Suitable
Inorganic silts, micaceous fine sandy or silty soils	MH	Medium to Low	Very High	Good	Unstable; not useful for rolled fill construction
Inorganic clays of high plasticity	CH	Low	High	Excellent	Fairly stable; flat slopes, thin cores, blankets
Organic clay of higher plasticity	OH	Medium to Low	Very High	Good	Not Suitable
Peat	Pt	Unsuitable			

Important Engineering Properties of Unified Soil Classes — Foundations and Channels
(Adapted from FM 5-541 Military Soils Engineering)

Material Names	Unified Soil Class	Resistance to Erosion	Use as Compacted Earth Lining	Seepage Tendency	Bearing Value
Well-graded gravels, gravel-sand mix, little or no fines	GW	Very Good	None	Very High	Good
Poorly graded gravels, gravel-sand mix, little or no fines	GP	Fair to Good	None	High	Good
Silty gravels, gravel-sand-silt mix	GM	Fair	Fair	Moderate to High	Good
Clayey gravels, gravel-sand-clay mix	GC	Fair to Good	Very Good	Moderate	Good
Well graded sands, gravelly sands, little or no fines	SW	Poor to Fair	None	High	Good
Poorly graded sands, gravelly sands, little or no fines	SP	Poor to Fair	None	Moderate	Good to Poor - depending on density
Silty sands, sand-silt mix	SM	Poor	Poor - Erosion Critical	Moderate to Low	Good to Poor - depending on density
Clayey sands, sand-clay mix	SC	Fair	Good	Moderate to Low	Good to Poor
Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts	ML	None	Poor - Erosion Critical	Low	Very Poor - Subject to Liquefaction
Inorganic clays, gravelly, sandy, silty, or lean clays	CL	Very Poor	Fair	Low to Very Low	Good to Poor
Organic silts or clays	OL	None	Very Poor	Very Low	Fair to Poor
Inorganic silts, micaceous fine sandy or silty soils	MH	None	None	Very Low	Poor
Inorganic clays of high plasticity	CH	Very Poor	Very Poor	Very Low	Fair to Poor
Organic clay of higher plasticity	OH	None	None	Very Low	Very Poor
Peat	Pt	None	None	N/A	Remove

Important Engineering Properties of Unified Soil Classes — Roads and Trails
(Adapted from FM 5-541 Military Soils Engineering)

Material Names	Unified Soil Class	Value as a Subgrade	Value as a Subbase	Value as a Base	Value as a Surface Course
Well-graded gravels, gravel-sand mix, little or no fines	GW	Very Good	Very Good	Good	Fair
Poorly graded gravels, gravel-sand mix, little or no fines	GP	Very Good	Very Good	Fair to Good	Fair
Silty gravels, gravel-sand-silt mix	GM	Good	Fair to Good	Not Suitable	Poor
Clayey gravels, gravel-sand-clay mix	GC	Good	Fair	Not Suitable	Excellent
Well graded sands, gravelly sands, little or no fines	SW	Fair to Good	Fair to Good	Not Suitable	Poor
Poorly graded sands, gravelly sands, little or no fines	SP	Fair to Good	Fair to Good	Not Suitable	Poor
Silty sands, sand-silt mix	SM	Fair to Good	Poor to Fair	Not Suitable	Not Suitable
Clayey sands, sand-clay mix	SC	Poor to Fair	Poor	Not Suitable	Not Suitable
Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts	ML	Poor to Fair	Not Suitable	Not Suitable	Not Suitable
Inorganic clays, gravelly, sandy, silty, or lean clays	CL	Poor to Fair	Not Suitable	Not Suitable	Not Suitable
Organic silts or clays	OL	Poor to Very Poor	Not Suitable	Not Suitable	Not Suitable
Inorganic silts, micaceous fine sandy or silty soils	MH	Poor to Fair	Not Suitable	Not Suitable	Not Suitable
Inorganic clays of high plasticity	CH	Poor to Fair	Not Suitable	Not Suitable	Not Suitable
Organic clay of higher plasticity	OH	Poor to Very Poor	Not Suitable	Not Suitable	Not Suitable
Peat	Pt	Not Suitable	Not Suitable	Not Suitable	Not Suitable

Basic Soil Characteristics as Influenced by the Texture of a Soil

(Adapted from Craul, P.J., 1992, *Urban Soil in Landscape Design*, John Wiley and Sons, Inc.)

CHARACTERISTIC	SAND TEXTURE	LOAM TEXTURE	SILT LOAM TEX- TURE	CLAY TEXTURE
IDENTIFICATION WHEN MOIST	Loose	Cohesive	Shows fingerprint	Shiny streak - ribbons
PERMEABILITY	Excessive	Good	Fair	Fair to poor
AVAILABLE WATER	Low	Medium	High	Medium to high
TILLABILITY	Easy	Easy	Moderate	Difficult
RUNOFF POTENTIAL	Low	Low to Medium	High	Medium to high
WATER DETACHABIL- ITY	High	Medium	Medium	Low
TRANSPORTABILITY	Low	Medium	High	High
WIND ERODIBILITY	High	Medium	Low	Low
NUTRIENT CAPACITY	Low	Medium	Medium	High
COMPACT ABILITY	Low	Medium	Medium to high	High

SOIL DRAINAGE

RUNOFF: Runoff is the water that flows over the surface of the soil and eventually winds up in the local drainage system. Runoff occurs when the amount of precipitation exceeds the ability of the soil to absorb the water falling on it (infiltration capacity). Soils with low porosity and high soil moisture content will tend to encourage runoff more frequently. As runoff flows from higher to lower areas, those lower areas receive not only the rainfall directly above them, but the runoff from the higher areas.

PERMEABILITY: The rate of saturated water flow through the soil profile is dependent upon the permeability of the soil and the presence of layers, or horizons, of soil with differing characteristics that may impede the vertical movement of water through the profile. Permeability is determined by the porosity and pore-size distribution of the horizons.

A soil with a compacted subsoil will have a low degree of internal drainage. Wet conditions will exist above the least permeable layer or horizon of any soil during the wet season or immediately following a storm event. A high water table, impermeable rock, or a lithologic discontinuity will have the same effect.

In a soil with high porosity through the profile, such as loamy sand, permeability would be high, and it would seldom exhibit saturated conditions in the absence of an impermeable layer. Medium and fine-textured soils with well-developed structure would also tend to have high permeability.

There are seven drainage classes determined by the depth to mottling (discolorations in the soil layer):

Excessively drained: water is removed from the soil very rapidly. Soils are porous, shallow, steep, or all of the above. Optimum amounts of moisture for plant growth are seldom present.

Somewhat excessively drained: water is removed rapidly from the soil. Soils are sandy and very porous. Irrigation is often necessary as the soils do not retain soil moisture very long after rains.

Well-drained: water is removed readily from the soil. Soils are commonly medium textures. Mottling may be present in the C horizon or below 24 to 36 inches from the surface. Soils will retain adequate soil moisture for plant growth after rains.

Moderately well-drained: water is removed from the soil somewhat slowly. Slowly permeable layer within or immediately below the column may exist. Mottling occurs below 18 to 30 inches. May be saturated during the dormant season.

Somewhat poorly drained: water is removed from the soil slowly enough that it is wet for significant periods. Mottling occurs below 8 to 18 inches.

Poorly drained: water is removed so slowly that the soil remains wet for a large portion of the year. Watertable is at or near the surface most of the time. Poor drainage is due to a high water table, a slowly permeable layer, seepage, or a combination of these conditions. Mottling occurs below 4 to 8 inches, but not to the surface.

Very poorly drained: water is removed from the surface so slowly that the watertable is at the surface most of the time. Soils occupy level or low areas and are frequently ponded. Mottling occurs to the surface.

Appendix B: Geomorphic Processes in Arid Regions

Winds are an active agent in the formation of the arid regions. However, other important factors such as the relative sparsity of vegetation and the distribution of water in both time and space must be given comparable consideration. Vegetative cover by cacti, shrubs, bunchgrasses, and other indigenous species leaves large, bare areas exposed to the direct impact of falling raindrops. The lack of detrital material also reduces soil resistance to erosive forces. As a result, the soil aggregates found in the arid regions are often weaker and the permeability slower than would be found under more humid conditions.

The local intensity of the infrequent rain events in arid regions causes runoff to rapidly accumulate and move into channels unimpeded by vegetative cover. The resultant flash flood is a moving wall of water that occupies the channel or arroyo for only a short period before dissipating into unconsolidated sediments on broad, flat areas. It is no surprise that these flat areas are made up of the deposited alluvium from countless flash floods. Low areas receive runoff from adjacent steep angular hills or nearby mountains so more moisture is available in the flat areas than in low hills.

Rock material within a few meters of the flat areas is often moist enough to weather and erode faster than the drier rock above. This softening of the lower rock layers works with flash floods and wind to produce angular topography so unique to the arid regions. Natural erosion is responsible for many wonders such as natural bridges and balancing rocks.

The geomorphologist defines the arid regions by the discontinuous flowing rivers, the lack of a continuous cover of plants, and the accumulation

of secondary minerals in the soil profile. In arid regions, semi-arid bunchgrasses give way to widely spaced shrubs and salt-tolerant bushes. Rivers flow only seasonally, and even when flowing, they decrease in discharge downstream unlike rivers in humid areas. Moisture deficiency causes ground water to move very slowly and upward rather than downward in the soil. As a result, secondary minerals accumulate in soil profiles, affecting soil structure profoundly. Wind becomes the significant agent of erosion and transportation.

Soils and Weathering: With a lack of water, arid soils fail to develop strong diagnostic horizons, except salt crusts or concretionary layers. Because precipitation is less than evaporation, soil moisture available by lateral infiltration (as in a desert basin flanked by more humid mountains) is drawn upward through the soil by capillary action. This moisture evaporates either in the soil profile or at the ground surface. Dissolved mineral matter is precipitated when the soil water evaporates. Calcium carbonates (caliche), gypsum, or alkali (sodium and potassium carbonates) may accumulate in this manner. These soils develop a strong columnar profile with no humus layer under the sparse vegetation. Soils in more semi-arid areas (steppe soils) have better defined horizons than desert soils. However, these soils are poorly developed and thin as compared to soils in humid regions. Some relatively insoluble calcium carbonate may form nodules or layers in the soil profile.

Mass-wasting and Erosion: Unlike humid areas, the movement of soils in arid regions is unhampered by thick, stabilizing root systems. Vertical desiccation cracks may break the desert soil into prisms or weakly indurated blocks. Therefore, mass movement tends to occur in blocks rather

than in granular layers. Slopes may present a series of small scarps and benches, even in hillslope deposits. Talus is apparent at the base of most cliffs and steep slopes. In more erodible materials, summits may appear convex in profile, while more resistant strata present angular forms.

With the great variation in precipitation patterns in the arid regions, the rate of landscape denudation can be quite rapid in the face of droughts and flash floods, often in the same year. Some geomorphologists believe that the mountains in the semi-arid areas are subject the highest rates of denudation.

Stream channels (arroyos) in both arid and semi-arid regions tend to be flat-floored, wide (to carry massive bed loads of sediment), and steep walled (because of the strong vertical columnar jointing in dry soils). They are long and steep in longitudinal profile. Coarse alluvium (water-carried sediment) typically covers the dry floors of the arroyos. The term *arroyo* is relative to the Spanish-speaking regions as in the southwest and Mexico. The term *wadi* is used in the Arabic-speaking arid regions, while the French used the term *ouadi* in Northern Africa to describe ephemeral channels.

DESERT LANDFORMS

Desert Varnish: A thin shiny coating that forms on stones in the desert. It is blue-black and consists mainly of iron and manganese oxides.

Playa or Sebkha: A saline lake forming where alluvial fans merge into a desert basin. Mud and salts accumulate to form the flattest surfaces on earth. Occasionally the salt crusts are hard enough to provide nearly perfect surfaces for high speed test activities. Brines can be pumped from these areas to be sprayed over areas subjected to wind erosion.

Reg: A residual or lag concentrate of gravel caused by winds blowing dust and silts from desert fans and plains.

Desert Pavement: Desert crust, a stable surface of closely fitted pebbles, each polished by sand blast, and often faceted as well. Wind action removes finer particles, leaving pebbles to accumulate on the surface, forming a protective mosaic.

Alluvial Fan: Landform created by the deposition of sediment from mountain rivers as they enter desert basins to evaporate or infiltrate.

Bajada: A massive apron of coalescing alluvial fans at a mountain front.

WIND EROSION

Wind erosion occurs either by **deflation**, the process of removing loose sand and dust, or by **abrasion**, using the entrained sand grains as tools against rock surfaces or other grains.

For many years it was believed that many of the undercut, mushroom-shaped pedestal rocks in desert areas were the product of wind erosion. However, it is now believed that desert weathering processes, involving exfoliation or spalling on sheltered surfaces, were the cause of the undercut surfaces. The only aeolian abrasional landforms are the chutes or flumes that notch the low escarpments around plays and other desert plains. They are aligned with prevalent winds and are more than likely the result of scouring by windborne sands being swept through gullies.

Deflation hollows form quickly by wind erosion on exposed sandy surfaces. Where vegetation is disturbed, **blowouts** can develop within months. When excavated below root depth, the blowout can grow as deeply as the effective winds can lift sand.

AEOLIAN LANDFORMS

Sand Ripples: Windblown sand structures developing transversely to the wind direction with a wave length of 1 m or less. They are characterized by coarse grains at their crests and finer grains in their troughs.

Dune: Larger accumulation of windblown sands considered a stable or growing landform. At a minimum, they are 4-6 m in downwind length. They are characterized by finest grains on the crest and coarser grains in the trough.

Draas: Larger-scale complex or multiple dunes.

Barchan Dunes: Crescent shaped dunes, the ends of which point in the direction in which the wind blows.

Longitudinal Dune: Long narrow dunes up to 80 km long and 200 m or more in height with the length parallel to the general direction in which the wind blows.

Parabolic Dune: A dune shaped in profile like an arc (parabola). The points of the dune face the direction from which the wind blows. They are formed where thick grass or other plants occur. The sand is blown away from the areas without the plants, but the sand on either side is held back by the plants.

SOIL CRUSTS AND MITIGATION IN ARID AREAS

In arid regions, soil horizons with naturally limited permeability form where calcium salts and silica accumulate rather than leach from the profile. The formation and management of duripans (silica cemented horizons), petrocalcic horizons (cemented calcium carbonates), and petrogypsic horizons (cemented gypsum) are documented in the works of Gile and others.* Although dense B horizons and fragipans are common in much of the country, silica, calcium carbonate, and gypsum-

rich horizons are unique to the semi-arid and arid regions.

Crusts form on most soils except those that are very sandy with little silt and clay content. Soils with sand content between 50 and 80% have been shown to produce crusts with high-runoff potential. In Israel, studies show the soils with around 20% clay have the highest crusting problems. Soils with <20% clay had an inadequate amount of clay to disperse and clog pores, while soils with >20% clay had a stable structure. In areas where saline water is used to irrigate soils, crusts formed more quickly in proportion to the higher amount of silt in the soils.

Crust formation is influenced by clay mineralogy because as clay minerals shrink or swell, they tend to reduce pore diameter and the water infiltration rate. Soils with high shrink-swell clays, such as montmorillonite, tend to crack upon drying, thereby improving the rate of infiltration of soils prone to crusting. Soils with vermiculitic or illitic clays will not crack as much upon drying and tend to remain crusted thereby slowing infiltration. Studies show that illite is the key mineral component in determining the flocculation-dispersion behavior of soils.

Soils in arid regions are likely to have a variety of clay types, including the high-activity clays such as the montmorillonites. This contributes to structural stability because the cracking clays will disrupt a crust and increase the total surface area for infiltration. Low organic matter is the primary cause for weak structural stability of many soils with significant smectite contents.

Aggregate stability varies with organic matter, clay, and oxide contents. As organic matter is increased from <1% to 2%, aggregate stability significantly increases. However, different kinds of organic matter are important for stabilizing aggregates of different sizes.

* Gile, L.H., J.W. Hawley, and R.B. Grossman, 1981, *Soils and Geomorphology in the Basin and Range Area of Southern New Mexico*, Memoir 36, New Mexico Bureau of Mines and Mineral Resources, Socorro; Gile, L.H. and R.B. Grossman, 1979, *The Desert Project Soil Monograph*, Document PB 80-135304, National Technical Information Service, Springfield, VA; Gile, L.H., F.F. Peterson, and R.B. Grossman, 1966, "Morphological and Genetic Sequences of Carbonate Accumulation in Desert Soils," *Soil Science*, v.99, p 74-84.

CRUST TYPES

Chemical crusts, like salt incrustations on soil surfaces, are often found in arid regions. Studies have shown that sulfate crusts formed from magnesium sulfate were the least porous to evaporating water and that chloride crusts formed from sodium chloride were the most porous. Between these two extremes are crusts formed by sodium sulfate and carbonate incrustations. Among the minerals that can be found in evaporite crusts are epsomite (epsom salts) and gypsum.

A form of nonnatural crust is also unique to arid regions, particularly in forest and brushland soils. Following prescribed burns, rangeland areas may suffer temporarily decreased infiltration rates for almost six months, before returning to normal.

Structural crusts appear in two different forms in the western regions, each with a unique origin, morphology, and management. Rainfall impacts upon the soil cause a physicochemical dispersion of the soil clays leading to a structural soil crust called a **disruptional crust**. Sedimentation of fine particles on the soil surface from the infiltration of turbid (silt or clay-carrying) water is responsible for a **sedimentational crust**. The source of the turbidity may be overland flow or irrigation water in furrows.

Depositional crusts are formed by transport and deposition of fine particles by surface flow. They are typically thicker than structural crusts and do not require rainfall as part of their origin.

MANAGEMENT ALTERNATIVES

Soil management to mitigate or prevent crusting includes adding amendments to the soil, altering tillage practices, and using cover crops and mulches.

Amendments: Amendments include chemicals such as gypsum and phosphogypsum that increase the electrical conductivity of irrigation water, chemical soil stabilizers that improve aggregate

stability, and cover crops or mulches that decrease water drop impact forces on soil surfaces.

Adding calcium salt to irrigation water helps to maintain clay flocculation, reduce dispersion, and stabilize soil structure. It may also aid in reducing shrink-swell activities.

Gypsum, ground to different grades before surface application and incorporation, and phosphogypsum, which is a by-product of phosphorus fertilizer manufacturing, have both proven effective in reducing the effect of structural crusts. Calcium, added to irrigation water, may triple infiltration rates over untreated low-salt water. Phosphogypsum, applied at rates of 2-5 tons per ha, in combination with organic mulch applied at rates of 4-8 tons per ha, may increase infiltration rates 3-5 times higher than those of untreated acres.

Management of depositional crusts depends on elimination or reduction of suspended sediment in the transporting water. Tillage can be more effective in dealing with depositional crusts than chemicals. Sediment reduction can be brought about by reducing the amount of fine particles available for transport. Structural crusts can be improved by adding phosphogypsum, which increases the electrolyte concentration in the soil solution and maintains a more open crust structure.

Many synthetic and natural soil conditioners are available. These products stabilize aggregates or create larger aggregates by glueing smaller particles together. A variety of products have been developed in the past 10 years to aid in aggregate stabilization. Resins, polymers, asphalts, lumber-mill by-products, and beet and potato processing by-products are among the currently used products available.

Tillage: Tillage is used to disrupt depositional crusts where other methods have failed. Tillage increased the infiltration rates by producing a roughened surface. On steeper terrain, a roughened surface can significantly reduce runoff under low-intensity rainfall events. Tillage can

also be effective for short term improvement of slow infiltration in clay soils.

Depositional crusts from traffic pans may be mitigated by standard implements for tillage. The paraplow has been designed to loosen the surface 25-50 cm without soil inversion or mixing. This produces more macropores for water infiltration. Tillage is most often used where soil compaction is a problem. Shallow tillage is used to loosen traffic compacted areas and to loosen naturally dense clays.

Organic Matter: One of the most important stabilizing materials in soil aggregates is organic matter. Among the methods for an organic matter increase are the use of green manure crops, mulches, summer or winter crops, and manure.

The incorporation of leguminous crops has not increased the amount of organic matter in semi-arid soils.

The growth of alfalfa in long term rotation may increase infiltration rates.

Manure added to the soil does increase the infiltration rate, but must be continued or rates will fall.

Living plants or mulch are very effective in reducing raindrop impact and subsequent structural crust development.

Chiseling, in combination with plant residue, may be effective in reducing surface sealing and increasing infiltration rates in a fine sandy loam soil.

Vetch and oats as a cover crop may produce increased infiltration rates in a clay loam soil.

Plant material left protruding through the soil surface enhances surface cracking as well as provides biomass that can be utilized by the soil.

Appendix C: Geologic Field Tests to Aid in Material Classification

The classification of unconsolidated (loose) materials for engineering, construction, or maintenance efforts are typically accomplished using the Unified Soil Classification System (USCS). Although formal identification and classification of materials requires lab analyses, field tests can provide useful information.

SOIL TEXTURE: Texture can be roughly approximately in the field through the sense of feel in the fingers. Basically, a handful of soil is worked between the palm and fingers to determine its ability to form casts or ribbons.

Sand: Single-grained and loose. The individual grains of sand can be felt or seen easily. Squeezed dry in the hand, it will fall apart when pressure is released. Squeezed moist in the hand it will hold together in a cohesive structure (cast), but crumbles when touched. It will not form a ribbon.

Sandy Loam: Much like sand, but has a bit of silt and clay making it more coherent. Individual sand grains can be seen and felt. Squeezed dry it will form a cast that readily falls apart, but squeezed moist, it forms a cast that can withstand careful handling. It will not form a ribbon.

Loam: Soil having equal parts of sand, silt, and clay, with the sand having an even mixture of different grades. Relatively smooth or soft (silt) with a somewhat gritty feel (sand) and slightly plastic (clay). Squeezed when dry, it forms a cast that can withstand careful handling. Squeezed when moist, a cast is formed that can be freely handling without breaking apart. It will not form a ribbon.

Silt Loam: Predominantly silt, but with a moderate amount of fine sand particles and a small amount of clay. Appears cloddy when dry, but lumps can be readily broken and when pulverized, it feels soft and floury. When wet, this soil readily runs together and puddles. It forms a cast readily whether dry or moist that can be freely handled without breaking. However, when moistened and squeezed between the finger and thumb, it will not ribbon out, but rather will break easily.

Clay Loam: Fine-textured soil that breaks into lumps or clods that are quite hard when dry. A sample worked between the forefinger and thumb will form a thin ribbon that breaks readily, as it cannot support its own weight. Moistened, it is plastic and will form a durable cast. When kneaded in the hand, it will not crumble, but will become more stiff until it is a heavy compacted mass.

Clay: A fine-textured soil that usually forms very hard lumps when dry and is quite sticky and plastic when wet. A sample will form a long and flexible ribbon when worked between the forefinger and thumb.

Texture by touch of moistened and worked golf-ball sized soil sample:

Extremely sticky and stiff
One of the CLAYS

Sticky and stiff to squeeze
One of the CLAY LOAMS

Soft, easy to squeeze,
only slightly sticky
One of the LOAMS

Is an adjective required to refine the above description?

Soil feels very smooth or talc-like
Use SILT or SILTY

Soil feels somewhat gritty
Use no adjective

Soil feels very gritty
Use SANDY

ACID TEST: The presence of calcium carbonate, (aragonite, calcite, dolomite, etc.) may be detected by placing a drop of diluted hydrochloric acid (1:10) on a rock or soil. Vinegar can be substituted in some cases.

TRAILING FINES: To aid in determining the relative proportion of grain sizes, shake a small sample of pulverized dry soil in the palm of the hand at a slight angle. The fine portion (silt or clay) will be left behind.

SHINE TEST: When a dry to moist lump of soil is cut or scraped with a sharp knife, the presence of plastic clay is indicated by a shiny surface.

TASTE TEST: Dry soil with a high clay content will adhere to the tongue. Halite (salt) is identified by a salty taste, epsomite is bitter, and borax is sweetly astringent.

SMELL TEST: Some minerals give off characteristic odors. Arsenopyrite gives off a garlic or arsenic odor when struck. Pyrite smells sulfurous.

Kaolinite and other clayey minerals give off an earthy odor when moistened or breathed upon.

MAGNETISM TEST: Some of the iron-bearing minerals react to a magnet in varying degrees. Lodestone (magnetite), Franklinite, some Hematites, Pyrrhotite, Chromite, and Ilmenite are among the more common minerals that may be attracted by a magnet.

RADIOACTIVITY TEST: Radioactivity occurs in certain elements that are in a state of radioactive disintegration such as uranium and thorium. Small, inexpensive Geiger counters can detect energy in the form of gamma rays produced by the mineral decay. Often, radioactive minerals can be identified by their rich orange, green, or yellow color.

RIBBON TEST: Plastic clays will form a ribbon when squeezed between the finger and thumb. The strength of the ribbon, determined by its length, is an indication of the plasticity.

ACETONE TEST: Gypsum or gypsiferous soils can be detected by the following test:

1. Place 0.20 lb of air-dried soil in a 1 quart glass bottle and fill with distilled water.
2. Shake the bottle for about 20 minutes and then allow to settle for 10 or more hours.
3. After the sediment has settled, the solution above the soil will be clear if the soil contains significant amounts of gypsum. Cloudy water indicates that gypsum is insignificant or not present.
4. Carefully pour 0.5 ounces of the clear solution into a glass container. Take care not to disturb the settled material in the bottom of the bottle.
5. Add 0.5 ounces of acetone to the 0.5 ounces of clear solution. The presence of gypsum will be indicated by the presence of a milky, cloudy precipitate.

FOR FINE-GRAINED SOILS THAT PASS THE NO. 40 SIEVE

DRY STRENGTH TEST: Crushing characteristics can be determined after removing particles larger than No. 40 sieve size from the sampled material. Mold a golf-ball sized sample of the soil to the consistency of putty by adding drops of water as necessary. Allow the sample to completely dry either by oven, sun, or air-drying. Test for strength by crumbling between fingers. The dry strength increases with increasing plasticity (clay content).

High dry strength is characteristic of clays in the CH group. A typical inorganic silt possesses very slight dry strength. Silty fine sands and silts have about the same slight dry strength, but can be distinguished by the feel when powdering the dried sample. Fine sand feels gritty, while silt feels like flour.

Calcium carbonate or iron oxides may cause higher dry strength in dried material. If acid causes fizzing on the sample, then calcium carbonate is present.

DILATENCY OR REACTION TO SHAKING:

Prepare another golf-ball sized sample from the collected material. Moisten with drops of water. The soil should be soft but not sticky. Place the sample in the open palm of one hand and strike that palm horizontally against the open palm of the other hand several times.

A positive reaction consists of the appearance of water on the surface of the sample which changes to a livery consistency and becomes glossy. When the sample is then squeezed between the fingers, the water and gloss disappear, the sample stiffens, and finally it cracks or crumbles.

Very fine clean sands give the quickest and most distinct reaction, whereas a plastic clay has no reaction, and inorganic silts (rock flour) show a moderately rapid reaction.

PLASTICITY or TOUGHNESS TEST: Prepare another golf-ball sized sample from the collected

sample; mold to the consistency of putty by adding water as necessary. Roll the sample out by hand on a smooth surface or between the palms shaping a thread of soil about 1/8 of an inch in diameter. Repeatedly fold the thread and reroll thereby reducing the soil moisture content and gradually stiffening the sample. As the sample stiffens, it will lose its plasticity and finally crumble when the plastic limit is reached.

After the thread has crumbled, lump the pieces together and continue kneading the sample until the lump crumbles.

A higher clay fraction is indicated by the thread becoming tougher near the plastic limit and the lump becoming stiffer when it finally crumbles.

Inorganic clay of low plasticity or organic clays/kaolin clays are indicated by weakness in the thread at the plastic limit and a quick loss of coherence of the lump below the plastic limit.

Highly organic clays have a very weak and spongy feel at the plastic limit.

Nonplastic soils cannot be rolled into a thread at any moisture content.

Appendix D: Basic Erosion and Sedimentation Control Practices

The following represent the types of practices that can be most effectively and economically applied to minimize degradation.

- Properly time and limit ground-disturbing activities on or near the roadway.
- Repair and install culverts and low-water crossings when streamflow is lowest.
- Practice careful roadway maintenance to reduce movement of material into ditches.
- During rehabilitation, compact the road base at the proper moisture content, surfacing, and grading to give the designed road surface drainage shape.
- Use straw bales, straw mulch, grass seeding, hydromulch, and other biotechnical erosion control measures to protect recently disturbed areas until vegetation can be reestablished.
- Use sediment traps to prevent sediment from entering sensitive areas or water bodies.
- Use turnouts, wing ditches, and broad-based dips to disperse runoff and reduce road surface drainage from flowing directly into water bodies.
- Install surface drainage controls to remove stormwater from the roadway before the flow gains enough volume and velocity to erode the surface.
- Route discharges from drainage structures onto stabilized areas so that water can disperse and infiltrate.

Methods of Road Surface Drainage Management Along the Less-Intensively Used Roadway Include:

Broad-based Dip Construction: Used on roads with gradients of 10% or less, the broad-based dip is a gentle roll in the centerline profile of the road designed to be a permanent and self-maintaining water diversion structure. It can handle traverse by most vehicles with little damage to the structure. The dip should be outsloped 3% to divert discharge off the roadway onto a stable area.

Installation of Ditch-Relief or Cross-Road Culverts: These culverts are placed at varying intervals along a road section to conduct runoff safely from the inslope ditch to the outside portion of the road. Either pole, open box, or pipe culverts can be used effectively. All culverts require inlet and outlet protection from erosion and to prevent debris from clogging the structure. Riprap aprons are most commonly installed at inlets and outlets.

Open-top culverts can be very useful for intercepting runoff flowing down a road surface with an inadequate surface crown. They can also be used in place of pipe culverts on low-volume roads and trails if properly constructed and maintained. They cannot be used to handle intermittent or perennial streams, however. Install the open-top culvert at a 30° angle to the road to prevent both front wheels from hitting the culvert at the same time.

Road Outsloping and Surface Grading: Erosion and road surface failure can be minimized by reducing water accumulation on road surfaces through grading and outsloping. When outsloping a road surface, grade the road so that it slopes 3-4% downward from the toe of the road cut to the

shoulder. Outsloping in this manner will prevent runoff from flowing next to and undermining the cut banks. This technique is intended to spill runoff off the road in small volumes at many random sites along the road reach. Additionally, a short reverse grade should be constructed to turn water off the surface. Providing a berm on the outside edge of an outsloped road until a disturbed area can be revegetated, can eliminate adjacent slope erosion. Proper maintenance of berms and outsloped roads is critical during wet conditions when rutting and old berms can impede runoff.

Ditch and Turnout Construction: Install ditches wherever runoff accumulation along roadbeds causes incision or sedimentation. Runoff within properly constructed ditches should be diverted into vegetated or stabilized areas through turnouts. The less water the ditch carries and the more frequently the runoff is discharged from the ditch, the less degradation will occur, and the less maintenance will be required.

Stabilize ditches with grass, erosion control fabric, or rock. Without discharge points, additionally stabilized with riprap and filter fabric discharge aprons.

Ensure that roadside ditches are adequate to handle the 25- to 100-yr storm. Current standards suggest that the most efficient shape and dimension requiring the least maintenance is the parabolic shape. Minimum dimensions are 18 inches in depth, 2 ft wide at the bottom, and side slopes cut 3:1 to 6:1 (dependent on the soil type) While the minimum ditch gradient should be 0.5%, a grade of 2% is preferred to ensure adequate drainage.

Install appropriate sediment control structures: Install appropriate sediment control structures to trap suspended sediment transported by runoff and prevent its discharge into sensitive areas and/or water bodies.

Sediment Traps: These small structures can be temporarily installed within or adjacent to ditches to trap sediment from recently disturbed sites until revegetation or other stabilization measures can take effect. They can be used to trap runoff to

provide wildlife water if constructed with a clay liner and regularly maintained to remove excess sediment.

Riprap: Layers of rock can be placed over exposed soil to protect it from erosive forces. Riprap is most frequently used where vegetation cannot be readily established due to steep slopes, lack of water, velocity of runoff, or poor soil conditions. To ensure success, underlay riprap with a filter fabric or graded filter blanket of properly sized small gravel or sand. Riprap is not recommended for use on fine-grained soils.

Filter Strips: A filter or buffer of vegetation between streams and disturbed areas and/or roads can provide sediment control. All water bodies should be protected by adequate filter strips or buffers.

Revegetate or stabilize disturbed areas, particularly at stream crossings.

Ensure seed success by providing appropriate surface amendments and fertilizers on all disturbed sites. In addition, provide a proper seedbed for revegetating on slopes by scarifying cut slopes, rolling embankments, or otherwise manipulating the surface to provide niches for seeds to germinate within. Seed as soon as possible following a disturbance.

Protect access points to training areas from public or paved roads with stone access pads, wood chips, corduroy logs, or other material.

This will prevent mud or soil from being tracked onto the paved surface, thereby reducing the amount of sedimentation from the road during rain events.

Install low water crossings to minimize erosion and sedimentation.

Where possible, install culverts within the natural streambed to facilitate fish passage and/or to minimize flooding of the roadway.

Install culverts properly to facilitate natural drainage.

Culvert inlets should be firmly anchored and the sediment compacted at least halfway up the side of

the pipe to prevent water from leaking around it. Both ends of the culvert should protrude at least one foot beyond the fill. Large culverts should align with the natural course and gradient of existing streams. Use energy dissipators at the downstream end of all culverts to reduce erosion energy at the discharge point. Armor or harden inlets and outlets to prevent erosion.

Compact fill properly to minimize erosion and ensure road stability.

During repair or construction efforts, compact the entire surface of each layer with proper heavy equipment. If the road surface is to be grassed (low-volume road), the final layer or course should not be compacted to provide a suitable seedbed.

Surface Erosion Potential Classes Relative to Topography and Soils in Relation to Secondary Roadways or Trails

EROSION CLASS	DESCRIPTION	ROADWAY MANAGEMENT
Very Low Potential	Level to gently sloping lands, floodplains, organic soils	Stream disturbance via fording or road placement too close to stream bank may initiate channel and bank erosion.
Low Potential	Gentle and/or short slopes	Minor erosion and sedimentation from ditches and disturbed soils on and along the roadway. Care must be taken not to channel water from roadway onto more sensitive areas.
Moderate Potential	Moderately steep and long slopes; erodible soil textures; fine-textured materials	Both preventative and remedial actions are required for disturbed roadway sections; expect erosion and sedimentation of ditches and across disturbed areas; water management is critical; road closure may be required; revegetation of all disturbed areas important.
High Potential	Moderately steep slopes; highly erodible soil textures	Significant erosion and sedimentation with runoff and/or water channeled over these roadways; plan for complete road/trail mitigation and/or deactivation; immediate revegetation of all disturbed sites critical.
Very High Potential	Steep slopes; highly erodible soils; active surface erosion or gully erosion apparent	Severe surface and gully erosion problems exist; erosion concerns must take precedence over training activities

Relative Effectiveness of Road Surface Treatments on Controlling Soil Losses in West Virginia

(Adapted from: Kochenderfer, J.N., and Helvey, J.D., 1984, "Soil Losses from a "Minimum Standard" Truck Road Constructed in the Appalachians," in *Mountain Logging Symposium Proceedings*, June 5-7, eds., P.A. Peters and J. Luckok, West Virginia University.)

Surface Treatment	Average Annual Soil Losses (Tons/acre)
Ungraveled - Earth Surface	44.4
3-inch diameter crusher-run gravel	11.4
1-inch diameter crusher-run gravel	5.5
3-inch diameter clean gravel	5.4

Effectiveness of Several Road Construction Techniques on Watershed Sediment Yield in Idaho

(Adapted from King, J.G., 1984, *Ongoing Studies in Horse Creek on Water Quality and Water Yield*, NCASI Technical Bulletin 435.)

Watershed Area (acres)	Area in Roads (%)	Roadway Treatment	Increase in Annual Sediment Yield (%) Measured in Debris Basins
207	3.9	Earth roads; untreated cut slope; untreated fill slope	156
161	2.6	Earth roads; untreated cut slope dry seeded	130
364	3.7	Gravel-surfaced roads; filter; cut-and-fill slopes straw mulched and seeded	93
154	1.8	Gravel-surfaced roads; filter windrowed; cut-and-fill slopes straw mulched and seeded	53
70	3.0	Gravel-surfaced roads; filter windrowed; cut-and-fill slopes hydromulched and seeded	25
213	4.3	Gravel-surfaced roads; filter windrowed; cut-and-fill slopes hydromulched and seeded	19

Effectiveness of Soil Cover on Roadway Fill Slopes in Reducing Sedimentation to Roadside Ditches

(Adapted from: Swift, L.W., Jr. 1986. "Filter Strip Widths for Forest Raods in the Southern Appalachians" in *Southern Journal of Applied Forestry* 10(1):27-34.)

Degree of soil protection on roadway fill slope provided by surface treatment	Number of sediment deposits more than 20 ft long per 1000 ft of secondary roadway
Grassed fill: litter and brush burned	13.9
Bare fill: forest litter	9.9
Mulched fill: with forest litter	8.1
Grassed fill: with forest litter and no brush barriers	6.9
Grassed fill: with forest litter and brush barriers	4.5

Comparison of Downslope Movement of Sediment from Roads for Varying Roadway and Slope Conditions

Comparisons	No. Sites	Mean Slope (%)	Distance (ft) Mean	Distance (ft) Max.	Distance (ft) Min.
All Sites	88	46	71	314	2
Barrier					
Brush Barrier	26	46	47	156	3
No Brush Barrier	62	47	81	314	2
Drainage					
Culvert	21	40	80	314	30
Outsloped Without Culvert	56	47	63	287	2
Unfinished Roadbed With Berm	11	57	95	310	25
Grass Fill and Forest Litter	46	40	45	148	2
With Brush Barrier	16	39	34	78	3
With Culvert	4	20	37	43	30
Without Culvert	12	45	32	78	3
Without Brush Barrier	30	41	51	148	2
With Culvert	7	37	58	87	30
Without Culvert	23	42	49	148	2

Effectiveness of Surface Erosion Control Efforts on Forest Road Components

(Adapted from: Megahan, W.F. 1980. "Nonpoint Source Pollution from Forestry Activities in the Western United States: Results of Recent Research and Research Needs" in *U.S. Forestry and Water Quality: What Course in the 80s?* Proceedings of the Water Pollution Control Federation Seminar, Richmond, VA, June 19, 1980, and Megahan, W.F. 1987. "Effects of Forest Roads on Watershed Function in Mountainous Areas" in *Environmental Geotechnics and Problematic Soils and Rocks*, ed. Balasubramaniam, et al.

Component of Roadway Treated	Stabilization Measure	% Decrease in Erosion/Sedimentation
Road cut	Grass and legume seeding	71
Road cut slope	Terracing	86
Road cut slope	Straw mulch	32-47
Road cut slope	Straw mulch	97
Road tread	Bituminous treatment	99
Road tread	Dust oil	85
Road tread	Gravel surfacing	70
Road fill	Straw mulch	72
Road fill	Wood chip mulch	61
Road fill slope	Excelsior mulch	92
Road fill slope	Paper netting	93
Road fill slope	Asphalt-straw mulch	97
Road fill slope	Straw mulch. Netting, tree planting	98
Road fill slope	Straw mulch and netting	99

Practice Selection Guide

Practice Name	Problems that may be mitigated by application of practices					
	Sheet and Rill Erosion	Rill and Gully Erosion	Streambank Erosion	Sediment Damage	Dust Control	Road Maintenance
Access Road Entrance				X		X
Check Dams	X	X		X		
Ditches		X		X		X
Ditch Lining	X	X	X	X		
Diversion	X	X	X	X		
Diversion Dike	X	X	X	X		
Dust Control	X				X	X
Erosion Blanket	X		X	X	X	
Vegetative Filter Strip			X	X		
Gully Control		X	X	X		
Inlet/outlet Protection		X	X	X		
Level Spreader	X	X	X	X		
Mulching	X	X	X	X	X	
Permanent Seeding	X	X	X	X	X	X
Silt Fence	X	X		X		
Straw Bale Barrier	X	X		X		
Stream Crossing - LWC			X		X	
Temporary Sediment Trap		X		X		
Temporary Seeding	X	X	X	X	X	
Temporary Slope Drain		X		X		X
Temporary Swale		X	X	X		
Tree and Shrub Planting	X	X	X	X	X	

Practice Name	Problems that may be mitigated by application of practices					
	Sheet and Rill Erosion	Rill and Gully Erosion	Streambank Erosion	Sediment Damage	Dust Control	Road Maintenance
Vegetative Bank Stabilization		X	X	X		

Glossary

Accelerated erosion: Occurring when natural erosion is exacerbated by human interaction with the landform, inducing degradation requiring mitigation.

Acid Soil: A soil with a preponderance of hydrogen ions (and probably of aluminum) in proportion to hydroxyl ions. Specifically, soil with a pH value of less than 7.0. For most practical purposes, a soil with a pH value less than 6.6.

Acre-Foot (ac-ft): The volume of water that will cover 1 acre to a depth of 1 foot.

Alluvial Soils: Soils developed from transported and relatively recently deposited material (alluvium) characterized by a weak modification (or none) of the original material by soil-forming processes.

Alluvium: A general term for all detrital material deposited or in transit by streams, including gravel, sand, silt, clay, and all variations and mixtures of these. Unless otherwise noted, alluvium is unconsolidated.

Angle of Repose: Angle between the horizontal and the maximum slope that a soil or other material assumes through natural processes.

Annual Storm: The highest peak storm discharge expected in any given year. This storm has a 2-year frequency of occurrence.

Apron: A pad of nonerosive material designed to prevent scour holes developing at the outlet ends of culverts, outlet pipes, grade stabilization structures, and other water control devices.

Arch Pipe: An elliptically curved culvert that provides increased flow without the need for increased height.

Aspect: Direction a slope faces as a cardinal direction (N, S, E, or W).

Bedrock: The more or less solid rock in place either on or beneath the surface of the earth. It may be soft, medium, or hard and have a smooth or irregular surface.

Berm: Earthen mound along the outside edge of a road, the toe of an embankment or spoil pile, or a diversion.

Borrow Area: A source of earth fill material used in the construction of embankments or other earth fill structures.

Borrow Pit: The excavation resulting from the extraction of borrow soil materials.

Broadcast Seeding: Scattering seed on the surface of the soil. Contrast with drill seeding, which places the seed in rows in the soil.

Brush Matting: Brush wired together and staked onto stream banks to protect them from erosion.

Channel: A natural stream or excavated ditch that conveys water.

Channel Stabilization: Protecting the sides and bed of a channel from erosion by controlling flow velocities and flow directions using jetties, drops, or other structures and/or by lining the channel with a suitable liner such as vegetation, riprap, concrete, or other similar material.

Channelization: Alteration of a stream channel by widening, deepening, straightening, or paving certain areas to improve flow characteristics.

Check Dam: Small dam constructed in a gully or other small watercourse to stabilize the grade and control head cutting.

Chiseling: Operation to loosen soil that creates parallel slots on the contour in the soil surface to hinder water flow and greatly increase infiltration.

Chute: A high-velocity, open channel for conveying water down a steep slope without erosion; usually paved.

Clearing: The removal of vegetation, structures, or other objects.

Climate: Total effects of temperature, moisture, wind, air, pressure, and evaporation on the land, plants, and animals.

Closed Drainage System: Small watershed shaped so all runoff flows to one water body within the watershed.

Cohesion: The capacity of a soil to resist shearing stress, exclusive of functional resistance.

Compost: Organic residue or a mixture of organic residues and soil, that has undergone biological decomposition until it has become relatively stable humus.

Contour: An imaginary line on the surface of the earth connecting points of the same elevation.

Contour Lines: Lines on a topographic map that determine points of equal elevation.

Cool Season Crop: Crop that grows mainly in cold weather and is planted to protect the soil from erosion (nurse crop) until the permanent vegetation can be planted.

Creep: Slow mass movement of soil and soil material down relatively steep slopes primarily

under the influence of gravity, but facilitated by saturation with water, strong winds, and by alternate freezing and thawing.

Crest: Top of a spillway to where water must rise before flowing over it. Also top of a slope adjacent to a road.

Critical Areas: Areas subject to accelerated erosion due to human disturbance, soil type, or degree of slope (or combination of all).

Crossfall: Slope across the width of a roadbed.

Crown: The crown of a road is the difference in elevation between the centerline and the edge of the traveledway.

Culvert: Conduit for the free flow of runoff under a road or dam embankment.

Cut: Portion of land surface or area from which earth has been removed or will be removed by excavating; the depth below the original ground surface to the excavated surface.

Dam: A barrier to confine or impound water for storage or diversion, to prevent gully erosion, or for retention of soil, sediment, or other debris.

Debris Dam: A barrier built across a stream channel to retain logs, tree limbs, sand, gravel, silt, or other material.

Design Criteria: Information and calculations used to determine the dimensions, grades, velocities, etc., used to engineer plans.

Design Highwater: The elevation of the water surface at peak flow conditions of the design flood.

Design Life: The period of time for which a facility is expected to perform its intended function.

Design Storm: A selected rainfall pattern of specified amount, intensity, duration, and frequency that is used as a basis for design.

Dike: A berm of earth or other material constructed to confine or control surface water in an established drainage system.

Discharge: (Q) - The volume of fluid passing a point per unit of time, commonly expressed as cubic feet per second.

Disturbed Area: Area where vegetation, topsoil, or overburden is removed or stored; it is termed "disturbed" until reclamation is done.

Ditch: A means of conveying water away from road/trail surfaces and safely to natural drainage channels. Forms can be parabolic, trapezoidal, or V-shaped.

Diversion: A channel with a supporting ridge on the lower side constructed at the top, across, or at the bottom of a slope for the purpose of controlling surface runoff.

Diversion Dike: A barrier built to divert surface runoff.

Divide, Drainage: The boundary between watersheds.

Down Cutting: Stream channel erosion, eventually down to bedrock.

Downslope: Area downhill from the point under consideration.

Drainage: The removal of excess surface water or groundwater from land by means of ditches or subsurface drains.

Drainage, Pattern: The configuration or arrangement of streams within a drainage basin or other area.

Drainage, Soil: As a natural condition of the soil, soil drainage refers to the frequency and duration of periods when the soil is free of saturation. Soil drainage conditions are as defined:

- **Well drained** - Excess water drains away rapidly and no mottling occurs within 36 inches of the surface.

- **Moderately well drained** - Water is removed from the soil somewhat slowly, resulting in small but significant periods of wetness. Mottling occurs between 18 and 36 inches.

- **Somewhat poorly drained** - Water is removed from the soil slowly enough to keep it wet for significant periods but not all of the time. Mottling occurs between 8 and 18 inches.

- **Poorly drained** - Water is removed so slowly that the soil is wet for a large part of the time. Mottling occurs between 0 and 8 inches.

- **Very poorly drained** - Water is removed so slowly that the water table remains at or near the surface for the greater part of the time. There may also be periods of surface ponding. The soil has a black to gray surface layer with mottles up to the surface.

Drill Seeding: Planting seed with a drill in relatively narrow rows, generally less than a foot apart. Contrast with broadcast seeding.

Drop Spillway: Overall structure in which the water drops over a vertical wall onto an apron at a lower elevation.

Drop Structure: A structure for safely dropping water to a lower level and into a hardened conduit.

Earth Dam: Dam constructed of compacted suitable soil materials.

Ephemeral Stream: One which flows only during and after rainfall or snowmelt.

Erodibility: Relative ease with which a soil erodes compared to other soils.

Erosion (water): The movement of soil from the land through the actions of running water. Specific types of water erosion include: channel, gully, rill, sheet, natural, and accelerated.

Erosion and Sediment Control Plan: A plan that fully indicates necessary land treatment and structural measures, including a schedule of the timing for their installation, which will effectively minimize soil erosion and sediment yield.

Excavation: Any activity by which earth, sand, gravel, rock, or any other similar material is dug into, cut, quarried, uncovered, removed, displaced, relocated, or bulldozed and shall include the conditions resulting therefrom.

Excess Rainfall: The amount of rainfall that runs directly off an area.

Existing Grade: The grade prior to any changes.

Factoring Affecting Capacity: The capacity of a road to support a normal or a maximum vehicular movement is determined by a number of factors: vehicle types and average loads, traffic data, type and width of surface and shoulders, base type and thickness, subsoil type and condition, curves and gradients, moisture and temperature, number of traffic lanes, and operational factors.

Fertilizer: Any organic or inorganic material of natural or synthetic origin that is added to soil to supply certain elements essential to the growth of plants.

Fertilizer Grade: Guaranteed minimum (in percent) of the major plant nutrients contained in a fertilizer. For example, a fertilizer with a grade of 20-10-5 contains 20 percent nitrogen (N), 10 percent available phosphorus (P), and 5 percent water-soluble potassium (K). Micronutrients may also be included.

Filter Blanket: A layer of sand and/or gravel designed to prevent the movement of fine-grained soils.

Filter Cloth: Plastic cloth that water can pass through, but most sediment cannot. It is used in constructing silt fences and riprap filters.

Filter Fabric: A woven or non-woven, water-permeable material made of synthetic products such as polypropylene and used in erosion and sediment control applications to trap sediment or prevent the movement of fine soil particles. Often used instead of a filter blanket.

Filter Strip: Usually long, relatively narrow area of undisturbed or planted vegetation used to retard or collect sediment for protection of watercourses, reservoirs, or adjacent properties.

Flood Peak: The highest stage or greatest discharge attained by a flood event. Thus, peak stage or peak discharge.

Flume: A constructed channel lined with erosion-resistant materials used to convey water on steep grades without erosion.

Fluvial Sediment: Those deposits produced by stream or river action.

Freeboard: Distance between the maximum water level and the top of a dam or diversion. It is provided to prevent overtopping.

Frequency of Storm: The anticipated period in years that will elapse before another storm of equal intensity and/or total volume will recur: a 10-year storm is expected to occur on the average once every 10 years.

Gabion: A wire mesh cage, usually rectangular, filled with rock and used to protect channel banks and other sloping areas from erosion.

Gouging: Roughening method that leaves very small dips in the soil surface that trap runoff so it can soak into the ground instead of eroding it.

Gradation: The distribution of the various sized particles that constitute a sediment, soil, or other material such as riprap.

Grade: (1) The slope of a road, a channel, or natural ground. (2) The finished surface of a canal bed, roadbed, top of embankment, or bottom of excavation; any surface prepared to a design elevation for the support of construction such as paving or the laying of a conduit. (3) To finish the surface of a canal bed, roadbed, top of embankment, or bottom of excavation, or other land area to a smooth, even condition. (See slope.)

Grade Stabilization Structure: A structure for the purpose of stabilizing the grade of a gully or other watercourse, thereby preventing further head-cutting or lowering of the channel bottom.

Gradient: Change of elevation, velocity, pressure, or other characteristics per unit length; slope.

Grades: Slope. Road grades should have a maximum of 10 percent grade except under extreme topographical conditions that necessitate steeper grades.

Grading: The cutting and/or filling of the land surface to a desired slope or elevation.

Grassed Waterway: A natural or constructed waterway, usually broad and shallow, covered with erosion-resistant grasses and used to safely conduct surface water from an area.

Ground Cover (horticulture): Low-growing, spreading plants useful for low-maintenance landscape areas.

Grubbing: Operation of removing stumps and roots.

Gully: A steep-sided ephemeral water course with a steep headcut that is actively eroded headward, usually into a water-gathering basin. A gully is characterized by a headcut and various steps or knickpoints along its course. It has relatively greater depth and smaller width, carries large sediment loads, and displays very erratic behavior so that relationships between sediment discharge and runoff are poor. A gully is almost always associated with accelerated erosion and therefore

with landscape instability. The distinction between gully and rill is one of depth — although it should be noted that a gully is not merely an enlarged rill, but is initiated in a much more complex process. A gully is sufficiently deep that it would not be obliterated by normal tillage operations, whereas a rill is of less depth and would be smoothed by ordinary farm tillage. Any gully with bare soil exposed on its side slopes can be considered active.

Gully Erosion: Soil removal by running water, leaving channels (usually deeper than 1 foot) that cannot be smoothed out completely by normal tillage. Rate of gully erosion depends primarily on the runoff-producing characteristics of the watershed; the drainage area; soil characteristics; the alignment, size, and shape of a gully; and the slope of the channel. Gully cross-sections may be U- or V-shaped, depending on soil and climatic conditions, age of the gully, and type of erosion. U-shaped gullies are found in loessial regions where both the surface soil and subsoil are easily eroded. V-shaped gullies are found where there is a more resistant subsoil.

Habitat: A geographical area that can provide for the needs of wildlife.

Hardpan: Hard crust on a soil surface, which reduces infiltration and increases runoff. It is usually caused by working the soil when it is too wet.

Haul Road: A temporary road, generally unimproved, used to transport material to and from highway construction, borrow pits, and waste areas.

Head: Top of a slope, roadcut, embankment, pile or fill. Compare with Toe.

Hydrograph: A graph showing for a given point on a stream the discharge, stage (depth), velocity, or other property of water with respect to time.

Hydrology: The science of the behavior of water in the atmosphere, on the surface of the earth, and underground.

Hydroseeding: Sowing seed mixed into a water spray with or without mulch, lime, and fertilizer.

Impervious: Material that does not allow fluid flow nor infiltration.

Infiltration: Water soaking into the soil and/or into the groundwater system.

Inlet: The upstream end of any structure through which water may flow.

Interception Channel (diversion channel): A channel excavated at the top of earth cuts, at the foot of the slopes, or at other critical places to intercept surface flow; a catch drain.

Intermittent Stream: Stream or part of a stream that: (1) drains a watershed of 1 square mile or more but does not flow nonstop year-round, or (2) is below the local water table at least some part of the year, and obtains its flow from both surface runoff and groundwater discharge.

Jute: Strong fiber used for making burlap and erosion-control netting.

Key: A designed, compacted fill placed in a trench excavated in earth material beneath the toe of a proposed fill slope.

Keyway: A cutoff trench dug beneath the entire length of a check dam to cut through soil layers that may cause seepage and possible check dam failure.

Lag time: The interval between the center of mass of the storm precipitation and the peak flow of the resultant runoff.

Land Capability: The suitability of land use. Land capability classification involves consideration of: (1) the risks of land damage from erosion and other causes and (2) the difficulties in

land use due to physical land characteristics, including climate.

Land Disturbance: Any activity involving the clearing, grading, filling, and any other activity that causes land to be exposed to the danger of erosion.

Level Spreaders: A shallow excavation at the outlet end of a diversion with a level section for the purpose of diffusing the diversion outflow.

Lining: A protective covering over all or part of the perimeter of a reservoir or a conduit to prevent seepage losses, withstand pressure, resist erosion, and reduce friction or otherwise improve conditions of flow.

Mean Depth: Average depth; cross-sectional area of a stream or channel divided by its surface or top width.

Mean Velocity: The average velocity of a stream flowing in a channel or conduit at a given cross-section or in a given reach. It is equal to the discharge divided by the cross-sectional area of the reach.

Mulch: A natural or artificial layer of plant residue or other materials covering the land surface, which conserves moisture, holds soil in place, aids in establishing plant cover, and minimizes temperature fluctuations.

Natural Drainage: The flow patterns of storm-water runoff over the land in its pre-development state.

Natural Revegetation: Natural re-growth of new plants over an area.

Nonpoint Source: Pollution source that cannot be traced to a specific discharge point such as a pipe. A dusty field or an eroding hillside are examples.

Nonpoint Source Pollution: Pollution that enters a water body from diffuse origins on the watershed and does not result from discernible, confined, or discrete conveyances.

Open Drain: Natural watercourse or constructed open channel that conveys drainage water.

Operational Capacity: The maximum number of vehicles that can pass over a road in a 24-hour period, derived from estimates of basic capacity with allowances for driver characteristics, unforeseen operational developments, vehicle casualties, driver changes, and essential preventive maintenance enroute.

Outfall: The point where water flows from a conduit, stream, or drain.

Outlet: Point of water disposal from a stream, river, lake, tidewater, or artificial drain.

Outlet channel: A waterway constructed or altered primarily to carry water from man-made structures, such as smaller channels, tile lines, and diversions.

Overhead Clearance: A minimum of 14 feet is required between the road surface and any overhead obstructions.

Parabolic: A concave curve with gently sloping sides and a nearly flattened bottom. Very effective form for conveying water.

Peak Discharge: The maximum instantaneous flow from a given storm condition at a specific location.

Percolation: The movement of water through soil.

Perennial Stream: A stream that maintains water in its channel throughout the year.

Permeability: The quality of a soil that enables water or air to move through it. Usually expressed in inches/hour or inches/day.

Permeability Rate: The rate at which water will move through a saturated soil. Permeability rates are classified as follows:

- Very slow - Less than 0.06 inches per hour.

- Slow - 0.06 to 0.20 inches per hour.
- Moderately slow - 0.20 to 0.63 inches per hour.
- Moderate - 0.63 to 2.0 inches per hour.
- Moderately rapid - 2.0 to 6.3 inches per hour.
- Rapid - 6.3 to 20.0 inches per hour.
- Very rapid - More than 20.0 inches per hour.

pH: A numerical measure of hydrogen ion activity. The neutral point is pH 7.0. Values below 7.0 are acid and above 7.0 are alkaline.

Plunge Pool: A basin used to dissipate the energy of flowing water usually constructed to a design depth and shape. The pool may be protected from erosion by various lining materials.

Point Source: Any discernible, confined, and discrete conveyance, including but not limited to any pipe; ditch; channel; tunnel; conduit; well; discrete fissure; contained, rolling stock, concentrated animal feeding operation; or vessel or other floating craft, from which pollutants are or may be discharged.

Practical Daily Capacity: The maximum number of vehicles that can pass over a road per day, considering road characteristics and operating conditions.

Precipitation: Rain, sleet, or snow.

Radius of Curves: The desirable minimum is 150 feet. The absolute minimum is the minimum turning radius of vehicles scheduled to use the road.

Rainfall Intensity: The rate at which rain is falling at any given instant, usually expressed in inches per hour.

Rational Method: A means of computing storm drainage flow rated, Q , by use of the formula $Q = C/A$, where C is a coefficient describing the physical drainage area, and A is the area.

Reach: The smallest subdivision of the drainage system consisting of a uniform length of open channel. Also, a discrete portion of river, stream or creek, or road. For modeling purposes, a reach is somewhat homogeneous in its physical characteristics.

Receiving Stream: The body of water into which runoff or effluent is discharged.

Revetment: Bankside layer of stone riprap or staked brush mats that protect the bank from erosion.

Rill: A small, intermittent watercourse with steep sides, usually only a few inches deep.

Rill Erosion: An erosion process in which numerous small channels only several inches deep are formed; occurs mainly on recently cultivated soils.

Riparian: Of, on, or pertaining to the banks of a stream, river, or pond.

Ripping: Breaking compacted soils with a tractor-drawn ripper or long, angled steel teeth.

Riprap: Heavy stone used in channels and on slopes to reduce the erosive velocities of runoff.

Riser: Vertical pipe of a principal spillway.

Roadway: The roadway is the entire width that lies within the limits of earthwork construction and is measured between the outside edges of cut or fill slopes. Includes the roadbed drainage ditches and adjacent slopes.

Rounding, Slope: The modeling or contouring of roadside slopes to provide a curvilinear transition between several planes; e.g., tops, bottoms, and ends of cuts and fills.

Runoff: That portion of precipitation that flows from a drainage area on the land surface, in open channels, or in stormwater conveyance systems.

Saturation: In soils, the point at which a soil or an aquifer will no longer absorb any amount of water without losing an equal amount.

Scour: The clearing and digging action of flowing water, especially the downward erosion caused by stream water in sweeping away mud and silt from the stream bed and outside bank of a curved channel.

Sediment: Soil particles that are removed from a site via running water. They are transported to and through channels and settle out in waterways and reservoirs thereby degrading the quality and reducing the capacity of those bodies.

Sediment Delivery Ratio: The fraction of the soil eroded from upland sources that actually reaches a stream channel or storage reservoir.

Sediment Discharge/Sediment Load: The quantity of sediment, measured in dry weight or by volume, transported through a stream cross-section in a given time. Sediment discharge consists of both suspended load and bedload.

Sediment Pool: The reservoir space allotted to the accumulation of sediment during the life of the structure.

Sediment Storage: Volume within sediment pond where sediment collects.

Sedimentation: The process by which mineral or organic matter is removed from its site of origin, transported, and deposited by water, wind, or gravity.

Seedbed: The soil prepared by natural or artificial means to promote the germination of seed and the growth of seedlings.

Seedling: A young plant grown from seed.

Sensitive Areas: Geographic areas containing natural, ecologic, scientific, or aesthetic resources that could be damaged or destroyed by anthropogenic activities. Examples of fragile lands include valuable habitats for fish or wildlife, critical habitats for endangered or threatened animal or plant species, uncommon geologic formations, National Natural Landmark sites, wetlands, and buffer zones.

Sheet Erosion: The removal of a fairly uniform layer of soil from the surface by runoff water.

Sheet Flow: Water, usually storm runoff, flowing in a thin layer over the ground surface. Also known as overland flow.

Shoulder Slopes: The slope of the shoulder can be the same as that of the traveledway but generally should be a little greater as it is more pervious than the surface course.

Shoulders: The shoulder of a road is the additional width provided beyond the traveledway. Minimum width of 4 feet on each side. Minimum shoulder slope will be 3/4 inch per foot.

Sideslopes: The slope of the sides of a canal, dam, or embankment. It is customary to name the horizontal distance first, as 1.5 or 1, or frequently 1 - 1/2: 1, meaning a horizontal distance of 1.5 feet to 1 foot vertical.

Sight Distances:

Passing sight distances (PSD). The longest distances in which a driver, whose eyes are assumed to be 4.5 feet above the pavement surface, can see the top of an object 4.5 feet high on the road.

Stopping Sight Distances (SSD). The longest distances in which a driver, whose eyes are assumed to be 4.5 feet above the pavement surface, can see the top of an object 4 inches high on the road.

Silt: Very fine-grained particles that are removed from a site via running water. They are transported

to and through channels and settle out in waterways and reservoirs thereby degrading the quality and reducing the capacity of those bodies.

Slope: The degree of deviation from horizontal measured as a ratio, a percentage, or degrees.

To calculate ratio: Divide the horizontal distance (run) by the vertical distance (rise). For example: a 3-ft run in a 1-ft rise = 3:1 slope.

To calculate percentage: The vertical distance (rise) divided by the horizontal distance (run), multiplied by 100. For example, a 5-ft rise in 100-ft run would be $5/100 \times 100 = 5\%$ slope.

To calculate degree: The angle of the slope from a horizontal plane measured with a level.

Grade	Degrees	Percent
1:1	45	100
2:1	27	50
3:1	18.3	33
4:1	14	25
5:1	11.2	20
6:1	10.9	16.6
7:1	9.4	14.3
8:1	8.3	12.5
9:1	7.3	11.1
10:1	6.6	10

Slope characteristics: Slopes may be characterized as concave (decrease in steepness in lower portion), uniform, or convex (increase in steepness at base). Erosion is strongly affected by shape, ranked in order of increasing erodibility from concave to uniform to convex.

Slopes:

1. Classification of slopes.

Cut slope. Cut slope is the slope from the top of a cut to the ditch line or bottom of ditch.

Ditch Slopes. The ditch slope is the slope of the ditch that extends from the outside edge of the shoulder to the bottom of the ditch.

Fill slope. The fill slope is the incline extending from the outside edge of the shoulder to the shoulder to the toe or bottom of a fill.

2. Measurement of slopes. Slopes are commonly specified in terms of slope ratio, which is a measure of the relative steepness of the slope.

Slope stability: Resistance of a slope to sliding or collapsing.

Soil: The unconsolidated mineral and organic material on the immediate surface of the earth that serves as a natural medium for growing plants.

Soil survey: A general term for the systematic examination of soils in the field and in laboratories; their description and classification; the mapping of kinds of soil; the interpretation of soils according to their adaptability for various crops, grasses, and trees; their behavior under use or treatment for plant production or for other purposes.

Soil Texture: Soil texture class names are based on the relative percentages of sand, silt, and clay.

Sprig: Section of plant stem material (rhizome, shoot, or stolon) used in vegetative planting.

Sprigging: Planting of a portion of the stem and/or root of grass.

Steep Slope: Any slope steeper than 20 degrees (roughly equal to 37 percent or 1 vertical unit to 2.7 horizontal units).

Storm Frequency: The time interval between major storms of predetermined intensity and volumes of runoff, e.g., a 5-year, 1-year, or 20-year storm.

Stripping: Any activity that significantly disturbs vegetated or otherwise stabilized soil surfaces, including clearing and grubbing operations.

Subwatershed: A watershed subdivision of unspecified size that forms a convenient natural unit.

Succession Planting: Planting a temporary crop until it can be replaced with a permanent crop.

Superelevation: The transverse downward slope from the outside to the inside of the traveledway on a curve. The minimum superelevation of gravel and dirt roads is 0.04 foot or ½ inch per foot of width, and for paved roads is 0.02 or 1/4 inch per foot width. The maximum superelevation for all roads is 0.10 foot or 1-1/4 inches per foot of width.

Surface Course: The surface provides a smooth, hard surface on which the traffic moves.

Surface Runoff: Precipitation that falls onto the surfaces of roofs, streets, the ground, etc., and is not absorbed or retained by that surface, but collects and runs off.

Surfacing: Depth and type of aggregate material required to provide an all-weather surface.

Swale: An elongated depression in the land surface that is at least seasonally wet, is usually heavily vegetated, and is normally without flowing water. Swales conduct stormwater into primary drainage channels and may provide some groundwater recharge.

Toe: Base of an embankment, pile, or fill.

Toe of Slope: The base or bottom of a slope at the point where the ground surface abruptly changes to a significantly flatter grade.

Topography: General term to include characteristics of the ground surface such as plains, hills, mountain, degree of relief, steepness of slopes, and other physiographic features.

Topsoil: The dark-colored surface layer or "A" horizon of a soil. When present, it ranges in depth from a fraction of an inch to 2 or 3 ft; equivalent to the plow layer of cultivated soils. Commonly used to refer to the surface soil layer(s), enriched in organic matter and having textural and structural characteristics favorable for plant growth.

Traffic Lane: A traffic lane consists of that portion of the road surface over which a single line of traffic traveling in the same direction will pass.

Trap Efficiency: A measurement of the effectiveness of a basin to trap sediment.

Traveledway: The traveledway is that portion of a road surface upon which all vehicles move or travel.

Tributary: Stream that flows into a larger stream or river.

Turnouts (drainage): Structures used to outlet runoff from ditches draining steep slopes to more level, stable, vegetated areas thereby reducing ditch erosion and sedimentation of waterways.

Turnouts (vehicular): Pullover or parking space adjacent and parallel to the traveledway. Provided on one-lane roads where traffic must be routed in both directions and on two-lane roads where there is a necessity for vehicles to stop frequently. On one-lane roads they should be provided every quarter mile.

Unconsolidated Soil: Loose soil material.

Undercut: To erode away the base.

Vertical Curves: One hundred feet of length of curve for each 4 percent algebraic difference in gradients on inverted or SAG curves, 125 feet of curve length for each

Vegetative Stabilization: Protection of erodible or sediment-producing areas with:

- permanent seeding, producing long-term vegetative cover
- short-term seeding, producing temporary vegetative cover, or
- sodding, producing areas covered with a turf of perennial sod-forming grass.

Volunteer Plant: Plants that spring up on their own without being planted.

Watercourse: A definite channel with bed and banks within which concentrated water flows, either continuously or intermittently.

Water Quality: A term used to describe the chemical, physical, and biological characteristics of water, usually in respect to its suitability for a particular purpose.

Watershed: The region drained by or contributing water to a stream, lake, or other body of water.

Watershed Area: All land and water within the confines of a drainage divide.

Watertable: The upper surface of groundwater or that level below which the soil is saturated with water; locus of points in soil water at which the hydraulic pressure is equal to atmospheric pressure.

Watercourse: A permanent stream, intermittent stream, river, brook, creek, channel, or ditch for water, whether natural or man-made.

Watershed: All the land and water within the confines of a drainage divide.

Waterway: A natural course or constructed channel for flow of water.

Weir: Device for measuring or regulating the flow of water.

Weir Notch: The opening in a weir for the passage of water.

Width of Clearing: The width of roadway plus a minimum of 6 feet on each side. Greater widths may be required to meet sight distances specified.

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