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MITIGATION OF ENVIRONMENTAL IMPACTS FROM UNSURFACED ROADS

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MITIGATION OF ENVIRONMENTAL IMPACTS FROM UNSURFACED ROADS

1. Purpose.

a. Environmental impacts of 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 Army land manager. This Public Works Technical Bulletin (PWTB) provides guidance for environmentally sensitive road management, less sediment pollution, and lower costs at Army installations. Additionally, it seeks to minimize nonpoint source (NPS) pollution resulting from erosion and sediment discharge from unsurfaced dirt and gravel roads.

b. In forested areas, the US Forest Service estimates that gravel and dirt roads are responsible for over 80% of sediment transport generated from dirt, unsurfaced roads, and trails into the nation’s rivers, lakes, and estuaries. Uncontrolled runoff from farming operations is another major source of pollutants.

c. All PWTBs are available electronically at the National Institute of Building Sciences’ Whole Building Design Guide webpage, which is accessible through this link:

http://www.wbdg.org/ccb/browse_cat.php?o=31&c=215

2. Applicability. This PWTB applies to all US Army facilities engineering activities.

3. References.

a. Army Regulation (AR) 200-1, “Environmental Protection and Enhancement,” 28 August 2007.

b. Clean Water Act, 33 U.S.C. §1251 et seq. (1972) as amended 1977.

4. Discussion.

a. AR 200-1 contains policy for environmental protection; addresses federal, state, and local environmental laws and Department of Defense policies for preserving, protecting, conserving, and restoring the quality of environment; and develops and implements pollution prevention and soil erosion control strategies in accordance with applicable and appropriate federal laws and regulations.

b. The Clean Water Act of 1972 and its subsequent amendments establish the basic structure for regulating discharge of pollutants into the waters of the United States.

c. There currently is no Army policy specifically directed to the subject matter of this PWTB. However, there is Army guidance on or closely related to the subject. This PWTB supports and is specifically in accordance with guidelines specified in TM 5-626 "Unsurfaced Road Maintenance Management", TM 5-822-12 "Design of Aggregate Surfaced Roads and Airfields", and TM 5-822-5 "Pavement Design for Roads, Streets, Walks, and Open Surfaces.”

d. Unpaved dirt and gravel roads are common across all military installations and span tens of thousands of miles. They provide not only basic military mission support but also transportation to logging and recreational facilities. These active, unsurfaced secondary and access roads are a significant source of sediments and NPS pollution at military installations. The extent and form of roadway degradation may vary, but the cause frequently can be attributed to intensity of use or improper road location, design, or drainage.

The ability to identify the eroded condition and the complexity of a road section along with the cause of its unstable conditions can significantly enhance the timeliness, placement, and effectiveness of mitigation measures.

e. This PWTB provides guidance for maximizing road safety and accessibility, while protecting the unique environmental characteristics of the natural setting. It also provides land managers with supplementary information to promote better understanding of the geomorphic condition of the roadway, thereby enhancing prevention and mitigation of environmental degradation to roads.

f. Appendix A discusses soil erosion, surface water effects on roads, and general erosion-control principles.

g. Appendix B provides a discussion to prevent environmental impacts from problems that are inherent to unsurfaced roads.

h. Appendix C summarizes this PWTB.

i. Appendix D contains references used in this PWTB and other resources for information related to mitigating environmental impacts from unpaved roads.

j. Appendix E lists abbreviations used in this document. A table of conversions from the inch-pound system of measure to the international system (SI) is also provided, along with a glossary of terms used.

5. Points of Contact.

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APPENDIX A
UNSURFACED ROADS: ENVIRONMENTAL IMPACT

Objectives of this Guidance

This PWTB will enable the reader to achieve the following objectives.

1. Recognize that environmentally sensitive, safe roads promote sustainable installations and good-neighbor relations with adjoining lands.
2. Recognize sources of erosion, sediment, and dust pollution associated with roads and the importance of preventing these pollution sources.
3. Gain a better understanding of environmental problems that can result from unpaved roads and provide guidance on corrective measures.
4. Recognize that standards cannot fit every situation and that sound decisions require knowledge of basic principles and practices.
5. Obtain knowledge of basic principles of nature and natural systems related to achieving good roads and a healthy environment.

Any effective roads program needs to address safety because a safe transportation system is essential and remains part of the Army’s overall goal. Maintaining military roads to support a sustainable environment, however, need not come at the expense of safety. In fact, roads maintained in an environmentally friendly way have more structural strength, suffer less deterioration, and have fewer defects — all of which combine to make the roads safer.

Unsurfaced Roads and Erosion

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

The terms gravel road, unsurfaced road, dirt road, and secondary road are used interchangeably in this PWTB to describe roads that are typically used by military vehicles and tanks. These roads are typically narrow, unpaved, and constructed of native soil materials. While this PWTB is focused on dirt and gravel roads, most of the information (particularly on ditches), can be used as guidance for paved roads as well.

Aggregate-surfaced roads are classified as unsurfaced. 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 (Figure A-1).

Figure A-1. Addition of aggregate to earthen surfaces improves road stability and durability.

Erosion of unpaved roadways occurs when soil particles are loosened and carried away from the road surface, ditch, or road bank by water, wind, traffic, or other transport means. Also, exposed soils, high runoff velocities and volumes, sandy or silty soil types, and poor compaction will increase the potential for erosion and road degradation.

Any unsurfaced road system on military installations will display some degradation, irrespective of its location or physiographic region. The form, complexity, or extent of such degradation may vary, but the cause most frequently can be attributed to one or more of the following factors:

- intensity of use,
- improper location, design, or drainage, or
- inadequate and untimely maintenance.

These factors cause loosened soil particles to be carried from the roadbed to the roadway drainage system. Some of these particles settle out satisfactorily in the road ditches, but most often the particles settle out where they will diminish the carrying capacity of the ditch. The diminished ditch capacity in turn causes roadway flooding, which leads to more roadway erosion and degradation. Most of the eroded soil ultimately ends up in streams and rivers (Figure A-2) where it diminishes channel capacity, which then causes more frequent and severe flooding, destroys aquatic and riparian habitat, and has other adverse environmental effects on water quality and water-related activities.

Figure A-2. Runoff from an unpaved road results in sediment-laden flow on an Army installation.

Thus, erosion of unpaved roads and their drainage systems is the single-most significant factor in costs involved with these types of roadway systems (Gesford and Anderson 2006).

The most frequent source of road degradation on Army lands is shoulder erosion, as shown in Figure A-3. Additional causes of erosion on unpaved roadways include:

- erosive road-fill soil types,
- shape and size of coarse surface aggregate,
- poor subsurface and/or surface drainage,
- wet and dry road-fill moisture extremes due to atmospheric conditions,
- freeze/thaw cycles,
- poor roadbed construction,
- roadway shape,
- roadway shading/sunlight exposure,
- traffic parameters such as vehicle speed, volume, weight, and lane pattern,
- untimely road and drainage system maintenance,
- excessive off-site runoff, and
- lack of adequate numbers of runoff discharge outlets (turnouts) from the roadway.

The above list of erosion factors is not all-inclusive; however, it should make apparent the scope of the problem and the need for comprehensive guidelines to reduce roadway costs through erosion control on unpaved roads (Figure A-4).

Figure A-3. Shoulder erosion is the most frequent source of degradation to dirt and gravel roads on Army lands.

Figure A-4. Lack of timely repair to an eroded shoulder can result in expensive maintenance.

Military range roads are usually found along topographic high points. Uncontrolled drainage from these roads (Figure A-5) may lead to accelerated erosion and degradation of downstream water bodies. Secondary dirt roads and tertiary trails found within forests and across rangelands are often located without regard to topography and drainage patterns. Too frequently, roads traverse slopes on a path that is perpendicular to the contour and, thus, a perfect candidate for accelerated erosion, gullying, and sedimentation.

Improperly designed road surfaces hinder effective drainage, lead to excessive surface problems, and promote sedimentation of water bodies or other sensitive areas. Improper design of roadway drainage ditches — or a lack of them altogether — may result in gully development and extension, roadbed damage, sediment pollution, and the flooding of road reaches (Figure A-6).

Active secondary and tertiary roads also are often a significant source of sediment production from military lands. The roadway (surface and ditches) can convey 25%–80% of the sediment produced by erosion on disturbed sites to adjacent properties or water bodies (Rivas 2006). The eroding roadway itself can often produce more sediment than disturbed areas adjacent to the roadway.

Figure A-5. Military roads can be sources of uncontrolled drainage from topographic high spots.

Figure A-6. A low-lying area in a road with poor drainage ditches results in a flooded road.

Concerns over damage by sediments to wetlands, navigable waterways, sensitive areas, and threatened and endangered species habitats have resulted in the development of nonpoint source (NPS) pollution regulations by federal, state, and local agencies. Fortunately, yields of sediment in drainage ditches and gullies can be prevented or reduced as much as 60%–80% when appropriate land rehabilitation and maintenance efforts are combined with vegetative practices and structural erosion and sedimentation control measures.

Several publications developed by the US Department of Transportation, other agencies, and individual states are excellent sources for guidance. For example, the US Department of Agriculture's (USDA) Forest Service (USFS) publication, *Low-Volume Roads Engineering: Best Management Practices Field Guide* (Keller and Sherar 2003), the Pennsylvania manual on *Environmentally Sensitive Maintenance for Dirt and Gravel Roads* (Gesford and Anderson 2006), and South Dakota's *Gravel Roads: Maintenance and Design Manual* (Skorseth and Selim 2000) provide comprehensive and explicit guidance on the most important aspects of road construction, drainage, and maintenance.

Water and Water-Related Road Issues

It is often said that the worst enemy of roads is water, and that the three most important factors affecting the life of any roadway are "drainage, drainage, drainage." This is certainly true of unpaved dirt roads, since most road degradation problems originate from a form of water on the roads. Thus, understanding the fundamentals of drainage (or runoff) is imperative to good unpaved roads.

Too much surface water can weaken a roadbed and result in rutting, potholes, shoulder erosion, ditch washouts, and clogged culverts. Water flowing too slowly deposits sediments and clogs channels and culverts. Standing water can weaken the sub-base and lead to surface failure. Although 80% of existing roadway problems can be traced to the presence of water from poor drainage either in or on the roadway, not all water is bad for a road.

Positive Effects of Water:

- aids in unpaved road surface compaction,
- assists in establishing and maintaining vegetation for erosion control, and
- allows unpaved road surfaces to be graded more easily.

Negative Effects of Water

- increases the disintegration of unpaved and gravel surfaces,
- softens and reduces the load-carrying ability of subgrades and shoulders,
- erodes roadside surfaces, and
- deposits sediment and debris in roadside ditches and culvert.

Figure A-7 shows a typical water-related road problem encountered by installation personnel at Army facilities.

Figure A-7. An example of issues with water on unsurfaced roadways as a road inspection crew slipped off the roadway under wet clay conditions.

How Water Enters Road Structures

1. Road surfaces are not impervious to water, so water can seep through them. The longer water lays on the surface, the more seepage takes place.
2. Water may enter as lateral flow from the roadside or higher ground. The water table may rise and enter the road base.
3. The water table is at a level higher than the road base, meaning personnel should look at ways to lower the water table in the vicinity of the roadway by using underdrain systems.
4. Even if the water table is low, the water may get into the road by "capillary flow" through the soil. The soil acts like a wick in a kerosene heater, drawing the water upward and into the road. This capillary flow also aids the freezing process as additional water is drawn up from below. Capillary rise can be quite substantial depending on soil type, season, and geographic location.

Figure A-8 demonstrates the four ways water can seep into road structures.

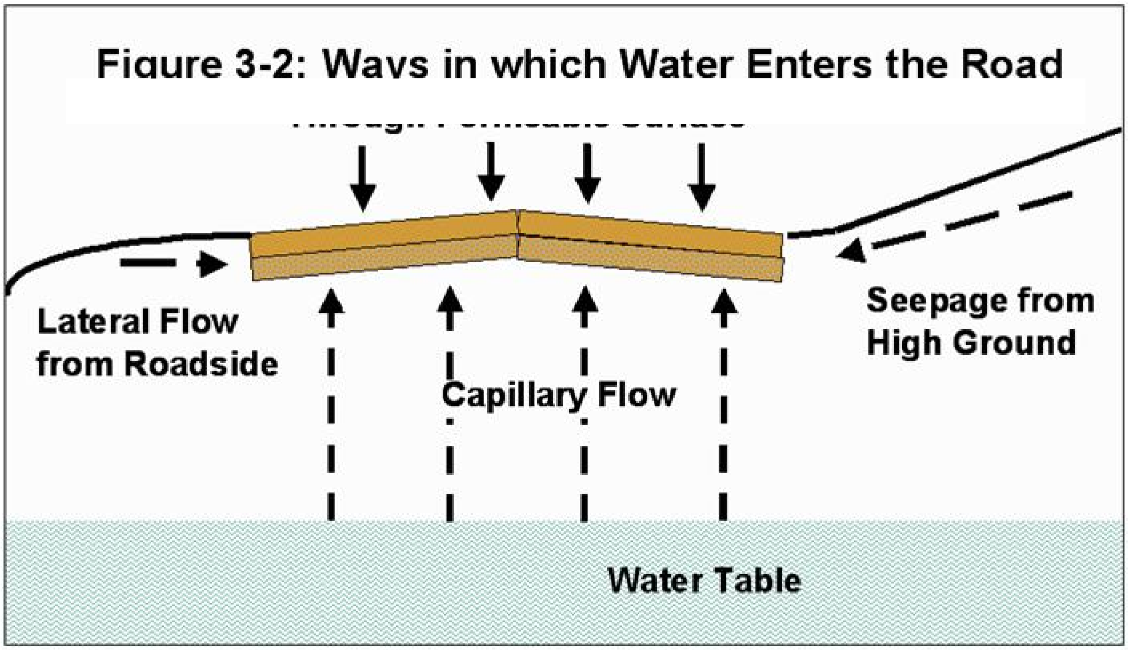


Figure A-8. How water gets into the road structure (from all sides).

Environmental Impacts of Roadway Degradation on Water Quality

Erosion and subsequent sediment movement into lakes, streams, reservoirs, ponds, or wetlands can have significantly adverse effects on water quality, fish and wildlife habitat, downstream property, vehicle and roadway maintenance, and safety. Sediments suspended and transported in runoff from NPS, such as roads and ditches, are a primary source of both pollutants and unwanted nutrients. Up to 80% of the total phosphates and 73% of the nitrogen compounds in streams today can be attributed to eroded sediments. As a result, fish-kills due to deoxygenation have become increasingly prevalent. Nitrogen and phosphorus compounds used in soil amendments and fertilizers stimulate aquatic plant growth, which causes algal blooms and noxious conditions.

Proper and timely surface preparation, selectively performed, will help reduce the amount of roadway being disturbed. Minimizing erosion problems thereby lengthens the life of the road surface (lessens road costs) and decreases the amount of sediment carried into surface waters.

Road Structure

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 of activity also provides planning information for widening roads and the strengths needed for the subgrade, sub-base, base, and surface course of existing roads. Definitions of these and other road-related terms are listed in the glossary in Appendix E.

Surfaces

The terms “firm” and “stable” have never been clearly defined, nor has there been a readily available means of technical measurement to determine what constitutes a firm or stable surface. The general definitions below are used in this PWTB.

Firm – Roadway is not noticeably distorted or compressed by the passage of a military vehicle under normally occurring weather conditions. Surface firmness should be determined and documented during the planning process for the seasons for which a trail is managed, under normally occurring weather conditions.

Stable – Roadway is not permanently affected by normally occurring weather conditions between maintenance cycles. It is able to sustain normal wear and tear caused by military vehicular traffic.

Crushed or natural stone, clay fines, packed soil, and other naturally occurring materials can provide a firm or stable surface. Natural materials bonded with synthetic materials can also provide the required degree of stability and firmness.

Materials

For an unpaved road to shed water properly, it should have a tight, impervious surface. This requirement calls for a higher percentage of fines than the base gravel under asphalt pavement. Unpaved surfaces with a small amount of fines do not have enough binder to hold the surface together when the weather is dry. As the surface falls apart, traffic throws loose material to the shoulders and ditches and into the air as dust. Ruts, corrugations, and potholes then appear.

Military unpaved dirt roads are usually constructed of native soils obtained from the immediate vicinity or from material hauled from borrow pits at the installation. Adding aggregates (road surface material) to the road base is usually accompanied by blading and dragging, although light applications of medium-sized and fine aggregates may be made occasionally to correct slippery conditions. When increasing the depth of the surface, filling depressions, restoring crown and profile, or correcting other problems that require coarse aggregates, an aggregate mix (with a maximum size of 1 in.) should be dumped in windrows and spread with a grader.

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.

Vegetation

A grass surface will work well on infrequently used roads or trails. The soil must be well-drained and the grades less than 4%. 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 stone ranging from 1–1.5 in. diameter is suitable for use on medium to high traffic road surfaces located on soft soils (silty or loamy). Crushed stone works very well on naturally sandy or gravely roadbed soils. It is recommended for use on grades of 15% and less.

Crushed stone overwashed gravel

In poorly drained areas, use crushed stone with filter fabric to enhance drainage and stabilize the roadbed.

Crown

The crown and cross slope are not only important for the road surface and shoulders, but also for the road base and subgrade, or the soil on which the road is built. A proper crown is invaluable in keeping water-related road issues under control (Figure A-9).

Figure A-9. A proper road crown is the first line of defense against water.

Problems develop quickly when a gravel road has no crown (Figure A-10). Water will quickly collect on the road surface during rain, softening the surface crust. This will lead to rutting, which can become severe if the subgrade also begins to soften. Even if the subgrade remains firm, traffic will quickly pound out smaller depressions in the road where water collects, and the road will develop potholes. A dirt and gravel road must have a crown.

The crown can sometimes become rounded. The term for this is a “parabolic crown,” and it is virtually always a problem. The middle portion of the road will have considerably less crown than the outer portions. This center area is somewhat flat, and water will collect and not drain from the middle adequately. Traffic will form potholes and ruts. A parabolic crown is often caused by a worn grader blade. Grader blades which are worn down through the center portion of the blade should be replaced or cut straight with a torch. With curves, the road needs to be sloped from one side to the other to “bank” the curve. This banking of the curve, called superelevation, provides for vehicle safety in traveling around the curve. Of course, the steeper the curve is banked, the faster the vehicles can go.

Figure A-10. Water quickly collects when the road crown is lost.

Shoulders

Road shoulders serve a number of useful functions related to environmental concerns. They transfer water accumulated on the traveled portion of the road to the side slope and ditch, serve as a safety zone and parking area for motorists, help to support the road surface, and help separate the traveled way from the side slopes and ditches. Unpaved shoulders are sloped about twice the rate of the traveled way and often consist of less suitable material than the traveled way. Degradation to shoulder surfaces happens over a period of time as winter sand and debris accumulate or as ditches are maintained.

Most dirt and gravel roads do not have defined shoulders. However, any shoulders or berm areas should be kept flush with the road edge and have a slightly steeper cross slope to avoid “shoulder drop-off,” which becomes a safety hazard for motorists when the errant driver leaves the road’s travel way and drops to the shoulder area.

Roads without a properly sloped shoulder or berm area often develop a “secondary ditch” that will not allow the water to drain away from the road (Figure A-11). This secondary ditch develops when road material moves toward the edge of the road and catches in the vegetation, forming a barrier to road drainage. Improper grading techniques can also leave a windrow of road material along the edge that acts as a dam, keeping water on the roadway. A shoulder or berm area also supports the road structure, preventing road edge breakdown. Look at a road where the roadside slope drops immediately from the road edge into the adjacent road ditch, and you will probably find road edge deterioration. Shoulders also allow the water to flow farther away from the road to maintain better drainage.

Figure A-11. When water cannot drain off the road, the result is a secondary ditch.

With all these advantages, developing shoulders along dirt and gravel roads, where feasible, should become a high priority in environmentally sound road management.

Roadway Drainage

General Ditch Principles

As shown in Figure A-12, ditches may have many shapes, with different advantages and disadvantages for each.

- A trapezoidal or parabolic-shaped ditch cross section is desired for purposes of erosion prevention and the environment. These shapes tend to spread water flow and slow it down, which will reduce the erosion potential and subsequent sedimentation.

  - 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-lined or paved channels, the trapezoidal shape permits high volume and high velocity along steeper reaches.

- U-shaped ditches actually have as much as 30% less drainage capacity than other shapes, and they tend to look messy. Their steep sides make maintenance difficult and the sides tend to cave in, compounding maintenance problems and adding to erosion and sedimentation.

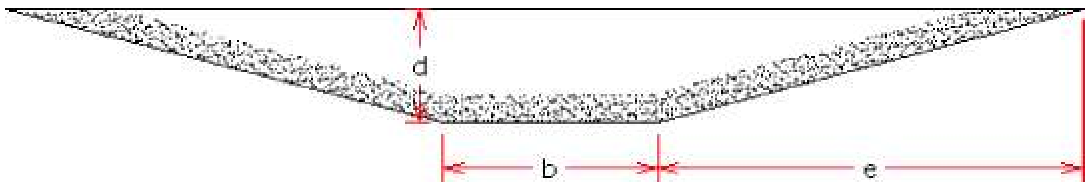
- V-shaped ditches are common in dirt and gravel road maintenance due to motor grader use and may not be a problem if the V-shape is rounded. A deep V-shape, however, concentrates water flow, increasing its velocity and possibly eroding the ditch's bottom. Deep, sharp V-shaped ditches are more prone to bottom erosion and should be inspected regularly. If water flows and velocity are starting to cause erosion, the ditch can simply be flattened to a wider V-shape. This will again spread the water out and slow it down, diminishing the energy and thereby the erosion potential.

A well-designed ditch (Figure A-13) will help with environmental-related road issues. Managers should keep the following points in mind.

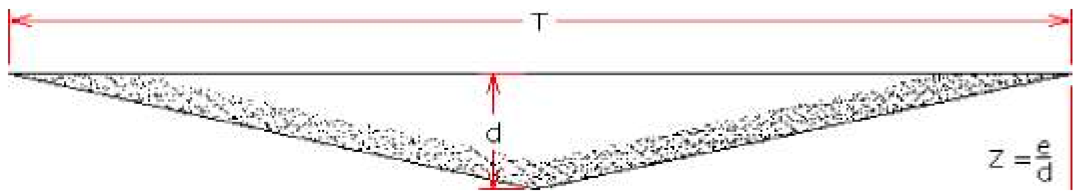
- Ensure that the ditch is properly lined to prevent erosion.

- Work regularly to keep ditch clear and stable and to maintain channel capacity.

Parabolic Cross Section: A = 1.5* T*d



Trapezoidal Cross Section: A = (b+zd)*d



V-Shaped or Triangular Cross Section: A = (zd^2)

A = Channel cross-section area, d = water depth of channel, T = top width, and Z = 1/S_o
S_o is channel bank slope

Figure A-12. Typical ditch shapes: cross section and corresponding cross-section areas for parabolic, trapezoidal, and V-shaped (triangular) channels.

Figure A-13. Riprap and grass-lined ditches along road shoulders can provide good drainage.

Ditch Profile and Lining

Roadside ditches are constructed to convey water from storm runoff to an adequate outlet without causing erosion or sedimentation. A good ditch requires shaping and lining (using the appropriate vegetative or structural material) and maintenance. Constructed properly, ditches will remove runoff quickly and reduce seepage into the road subgrade.

Roadside ditch location, profile, shape, lining, and outlets affect how efficiently water will be removed from the roadway. Ideally ditches should resist erosion, be self-cleaning, and discharge to nearly level vegetated areas, thus maximizing the time between regrading and reducing maintenance costs. Ditches should be located on the uphill side of the roadway to prevent runoff water from flowing onto and over the road surface.

Using the correct ditch profile and lining techniques will help remove water from the road and through the ditch more quickly. This will help to decrease erosion and cut road maintenance costs. For best drainage, observe the following guidelines.

- Locate ditches on the uphill side of the road to prevent runoff water from flowing onto and over the road surface.
- Design and grade ditch and bank side slopes at a maximum ratio of 2H:1V.
- Excavate a ditch deep enough to drain the road base, generally 1.5–2 ft deep.
- Shape the ditch bottom so that it is rounded or parabolic shaped and at least 2 ft wide to help slow and disperse water.
- Line ditches that have less than 5% slope with grass to filter sediments.
- Line ditches that have greater than 5% slope with riprap.
- Line ditches as soon as possible to prevent erosion and to maintain the ditch profile. See Table A-1 for recommended lining specifications.
- Prevent water from standing in a ditch; standing water weakens roads.

Table A-1. Ditch lining specifications.

Channel Slope Lining	Material Lining	Thickness
0 – 5%	Erosion control blanket and seeding	N/A
5 – 10%	2–6-in. diameter riprap	8 in.
>10%	3–12-in. dia riprap	12 in.

Ditch Cleaning

Ditch cleaning is one of the most important elements to maintaining good drainage and environmental control along any type of road.

- Inspect ditches regularly and schedule cleaning every few years. The bottom of the ditch should remain compact and rounded.

- Clean ditches when they become clogged with sediments or debris to prevent overflows and washouts.

- Check ditches after major storm events as fast-moving water may have developed obstructions, erosion, or bank collapse.

- Regrade ditches only when absolutely necessary and line with grass (or stone) as soon as possible. Seed, mulch, and use fiber mats to assist revegetation.

Routine Inspection Checklists

Spring and summer

- Clean and remove fallen brush, leaves, trash, sediment, and other debris from the ditch.

- Reshape the ditch to improve flow capacity.

- Re-establish and/or improve the cover type with the following suggestions.

  – Earth – Seed, mulch, and apply erosion control matting to prevent erosion.

  – Grass – Reseed, mulch, and apply erosion control matting. Mow and trim out brush.

  – Stone – Add stone to slopes and low spots, if necessary. Place or form stones to fit ditch shape. Patch broken or washed out areas to prevent further damage and erosion.

Fall and winter

- Remove accumulated debris.
- Keep critical sections free from snow and ice to prevent spring flooding.

Surface Deformation

Surface deformation problems are almost solely the end result of excessive moisture in the road fill; thus, deformation can be reduced with proper road surface and ditch drainage.

Ruts and rutting

Longitudinal depressions occurring in earth-aggregate surfaces tend to grab and direct vehicle wheels and can be safety hazards. 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.

Areas of sustained and repeated rutting may require more aggressive measures. An elaborate drain system and/or geotextile fabric foundation with a crushed stone road fill may be used to correct severe rutting problems.

Depressions

Depressions are localized low areas that are 1 in. or more below the surrounding road surfaces. Depressions are caused by settlement, excessive moisture content, and improper drainage. Larger depressions, however, are not to be confused with potholes.

Depressions should be corrected by filling them with a well-graded aggregate, then grading the affected road surface and compacting. Underdrains or cross drains may be necessary to improve drainage and prevent recurrence.

Potholes

Potholes are small depressions or voids in the road surface 1 in. or deeper which are caused by excessive moisture content, poor drainage, poorly graded aggregate, or a combination of these factors. Large areas of potholed road surface indicate a poor road-fill condition over an extended section of roadway, and thus may require the regrading, recrowning, and recompacting of the affected roadway section to mix aggregates into a well-graded road fill and improve road surface drainage. Underdrains may also be necessary in these areas to drain the subgrade.

Soft spots

Soft spots are areas of the road surface and/or subgrade made weak by either poor drainage or physical soil characteristics. These areas depress under vehicular weight and almost always develop one or more of the other types of surface deformations. Drainage problems may be due to a high water table, hydrostatic head, capillary action, or groundwater seepage. Saturated subgrade materials should be removed and replaced with a subgrade or coarse-graded material. Depending on the cost effectiveness and feasibility of each, the following methods may be used to correct soft spots.

1. Improve the drainage of the road fill and/or subgrade with an underdrain; this method is outlet dependent.
2. Improve the drainage of the road fill and/or subgrade by grading road ditches low enough to remove water from beneath the problem area. This may involve piping to move water from one side of the road to the other; this method also is outlet dependent.
3. Patch the soft spot with a suitable material such as well-graded stone or gravel.
4. A combination of methods 1–3.

Corrugations

The progressive growth of lateral corrugations (also known as washboards) in earth-aggregate roadways is caused by traffic. These surface irregularities can cause inconvenience, damage vehicles, and become a safety hazard. By mixing suitable stabilizing materials into the pulverized soil, the ability of the roadway to resist corrugations can be substantially increased.

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. For example, logging roads in the western part of the country respond very well to surface application of 4–6 in. of 1.5 in. diameter crushed stone. Roads treated in this manner have up to a 90% reduction in sediment yield.

Waterbar

A waterbar is a “speed bump” or a ridge of compacted soil, loose rock, or gravel constructed across a dirt road at an angle of 30–45 degrees to the road (Figure A-14). The main purpose of a waterbar is to intercept and limit the accumulation of concentrated runoff water by diverting surface runoff at pre-designed intervals (Table A-2) into stable vegetated areas to dissipate water flow energy.

When properly constructed, a waterbar slows the speed of flowing water and diverts it from the road. Although waterbars are a simple and effective means to control water speeding down gradient, an improperly constructed waterbar can do more damage than good.

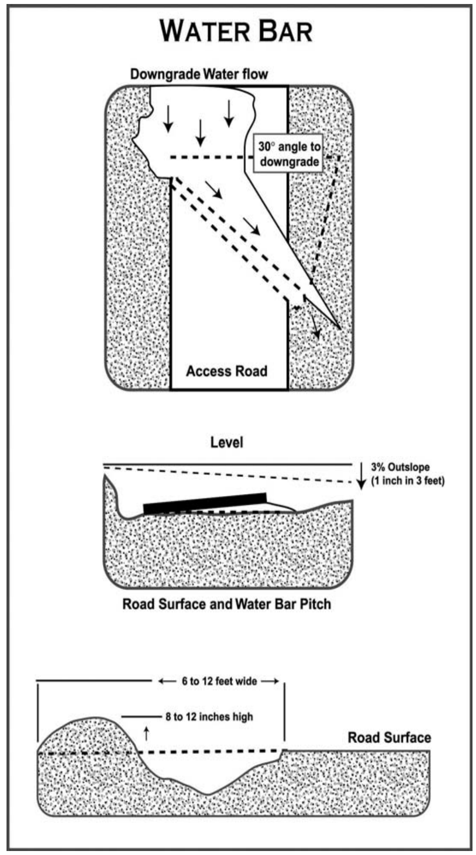


Figure A-14. Typical details of a waterbar (source: Virginia Department of Forestry).

- Side slopes where vehicles cross should be 4:1 or flatter and not less than 8:1. Base width of the berm should not be less than 6 ft, whereas the top width should not be less than 18 in.

Table A-2. Spacing needed between waterbars.

Slope	Waterbar Spacing (ft)
<5%	125
5%–10%	100
10%–20%	75
20%–35%	50
Source: North Carolina Forest Service.	

- Rehabilitation – Check after each storm event to ensure that the material behind the structure is not eroding.

- Construction tips – A dozer equipped with a 6-way blade is the best choice for constructing waterbars. A dozer equipped with a manual adjustable blade can also be used effectively. Using a skidder to build waterbars is not recommended, but is done quite often with varying results. The upper end of the waterbar must be tied into the road bank to prevent water going around the bar. The lower end should have an open outlet to allow water flow out of it into a vegetated area below.

Rolling dip

A rolling dip is kind of waterbar that collects stormwater runoff and diverts it safely off the road to prevent buildup of surface runoff and subsequent erosion, while allowing the passage of traffic. They should be constructed on secondary gravel and haul roads having a gradient of 15% or less. Recommended rolling dip spacing is about twice that for waterbars as given in Table A-3 for respective road slopes.

Turnouts/tail ditches

As shown in Figure A-15, turnouts or tail ditches outlet water from roadway ditches to maintain a stable flow volume and velocity within the ditches. They can be placed at specific selected sites to protect down-gradient structures such as bridges and culverts, or to utilize specific erosion control or stormwater discharge facilities.

Figure A-15. Turnout to divert water away from the road.

Turnouts are beneficial because they disperse runoff before it becomes concentrated flow. They can direct water to filtering areas or into a vegetated buffer if there is adequate outlet protection at the end of the turnout area — either a structural (rock) or vegetative filtering area.

Turnouts should be located so that they use the natural contours of the land and should be installed frequently enough to prevent large volumes of water from accumulating in road-shoulder ditches. Turnouts with less than 5% slope can be seeded for vegetation establishment. On steeper slopes, angular riprap placed over nonwoven geotextile fabric can be used to line the structure for erosion control. Table A-3 lists general spacing criteria that may be used in constructing turnouts.

Table A-3. Turnout spacing.

Road Grade (%)	Distance (ft)
2	250
5	135
10	80
15	60
20	45
25	40

Dust Pollution

Problem

When a vehicle travels on an unpaved road, the force of the wheels on the road surface pulverizes surface material. The quantity of dust emissions from a given segment of unpaved road varies linearly with the volume of traffic.

Soil particles are lifted and dropped from the rolling wheels, and the road surface is exposed to strong air currents in turbulent shear with the surface. The turbulent wake behind the vehicle continues to act on the road surface after the vehicle has passed. The dust generated is in the form of coarse material known as particulate matter (PM). Inhalable PM includes particles both fine (PM2.5) and coarse (PM10). These particles can accumulate in the respiratory system and are associated with numerous health effects. Exposure to coarse particles is primarily associated with aggravation of respiratory conditions such as asthma.

In addition to health problems, PM is the major cause of reduced visibility in many parts of the United States. The type of equipment used by the military on unpaved installation roads causes PM pollution that is a major safety concern. Fatal accidents have been reported by trailing/following vehicles during regular training operation as a result of reduced visibility. Dust also is a cause of excessive wear to vehicles and damage to paints and building materials.

Solution

Using aggregate materials in the presence of such conditions is definitely suggested on roads having a substantial amount of traffic. Ways to control dust from these sources include applying gravel, chemical, or other organic soil stabilizers, or paving unpaved roads frequently traveled.

The US Environmental Protection Agency (EPA) has developed a federal implementation plan to control dust from paved roads. The EPA is not requiring dust from every unpaved road to be controlled. In fact, unpaved roads do not need to be stabilized unless vehicles drive on them at least 250 times a day. This number equals about three vehicles every 5 min over a 7-hr period or two vehicles every 5 min over a 10.5-hr workday.

Control

Listed below are tips to control dust from affecting the environment.

- Sprinkling water on the road surface is only a very short-term solution.

- Calcium chloride is a commercial chemical product used to control dust on gravel roads. It is available in liquid or dry form. However, liquid applications are more cost-effective on large sites.

- Calcium chloride application rates vary depending on the relative quality of road surface material. As a general rule, apply 1 lb of calcium chloride per square yard of surface area or abide by the supplier’s recommended application rate. Do not apply in excess amounts because “more is not always better.” It is best to apply calcium chloride when the road is somewhat wet or moist.

- Calcium chloride is generally sprayed as a 35% solution using a tank truck with a rear-mounted distribution bar that spreads the liquid evenly over the road. One pass will cover an 8- to 12-foot-wide road. Two passes are needed on roads 16- to 18-ft wide.

- Spray-on adhesives such as latex emulsions or resin in water are not recommended, as a potential exists for water quality impacts from this practice.

APPENDIX B
MITIGATION OF ENVIRONMENTAL IMPACTS FROM UNSURFACED ROADS

A total of more than 1.6 million miles of dirt and gravel roads crisscross rural areas of the United States (Anderson and Gesford 2007). Keeping the military's share of these roads in usable condition requires a plan for mitigation of environmental impacts.

Mitigation Objectives

The objective should be to complete as much of the following as possible in relation to secondary roads and trails.

- 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.

Mitigation Principles

- Any rehabilitation should begin by determining the source and cause of the particular damage or degradation. For example, work done on a defective subgrade is a waste of time.
- Mitigation of the cause should be undertaken before repairs are made. Ignoring the cause of the degradation will only exacerbate the problem.
- When rehabilitation is carried out, the existing surfaces should conform to the original surfaces as designed.

Mitigation 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. 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 water bodies.
- 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 impassable or hazardous.
- Effectiveness of repeated temporary repairs versus permanent rehabilitation.

Operations

Do not disturb roadway sections which do not need maintenance while repairing, blading, or grading those sections that do. When routine maintenance is being performed, limit the amount of disturbed areas to that which can be re-established to the desired final shape by the end of the work day. To minimize opportunity for degradation of the roadway, it is best not to blade, grade, or drag if rain or freezing temperatures are favorable within the 48-hour forecast. As much as possible, avoid non-essential or non-emergency work near streams or stream crossings during the “wet” months of the year. Save this work for drier seasons.

Erosion Control

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 non-erosive 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.

Erosion is minimized largely by the use of the practices listed below.

- flat side slopes, rounded and blended with natural terrain
- drainage channels designed with due regard to location, width, depth, slopes, alignment, and protection treatment
- proper facilities for groundwater interception
- dikes, berms, and other protective devices
- protective vegetative cover and planting

Routine Restoration

In contrast to alteration, restoration does not change the original purpose, intent, or design of a road. Restoration includes, but is not limited to, the following ideas.

- Removal of debris and vegetation such as downed trees or broken branches on a road, clearing road of encroaching brush or grasses, and removing rock slides.
- Rehabilitation of road tread, such as filling ruts and encroachments; reshaping of a roadbed; repairing a trail surface and washouts; installing rock to retain cut and fill slopes.
- Erosion control and drainage; replacing or installing necessary drainage structures, such as drainage dips, waterbars, or culverts; and realigning sections of roadway to deter erosion, washouts, or boggy areas.
- Repair of trail or trailhead structures, including replacing deteriorated, damaged, or vandalized parts of structures, such as sections of bridges, boardwalks, fencing, painting; and removing graffiti.

Because of infrequent use, secondary roads exhibit little or no significant degradation problems if routine grading/blading operations are performed regularly (Figure B-1).

Figure B-1. Secondary roads.

Mitigation Frequency

No matter when operations are performed, remember that moisture will discourage dust and aid in proper compaction. If a water truck or water source is not available, work should be planned after a rainfall if at all possible. As already stated, the more a roadway is bladed or smoothed, the less often it will need to be regraded or reshaped and the less often new material will need to be added.

Mitigation operations are performed as needed depending on a number of variables such as road type and condition, drainage conditions, the weather, traffic volumes, and number of storms since the last maintenance was performed. Special events may dictate needs, requiring preparation before the event to put the roads in good shape or after the event to repair damage.

In the “as needed” scenario, the roads must be inspected frequently. Routine inspections, supplemented by special inspections after major storm events, are essential to determining road needs and performing the required maintenance at the right time.

Equipment operators play key roles in road inspection. While working on the road, the operator can note other existing problems on the road or roadside, such as damaged drainage pipes, fallen trees, broken signs, and crushed culvert ends. Operators should communicate problems along with location details so that issues can be taken care of later (but in a timely fashion) to prevent any major problems or costs.

Clearing Debris

Environmental concerns with unsurfaced roads arise because manmade items, from bottles and car parts to household appliances and car bodies, are often dumped along roadways in ditches or other drainage paths. These disposed items inhibit or redirect runoff that can erode and/or weaken the roadway system. Promptly haul away or properly bury this material on site (if permitted by law). If left, dumped debris will encourage more dumping and will eventually have a negative effect on the roadway, its drainage system, the environment, and public perception. Roadside adornments, such as wildflowers, can discourage some illegal dumping.

Note that even naturally occurring debris such as tree limbs, stumps, leaves, grass, rocks, and other natural materials from other locations are dumped along unpaved roads in ditches or other drainage paths. This also inhibits or redirects runoff which, in turn, erodes and weakens the roadway system.

Roadside Vegetation Management

Proper roadside vegetation will enhance and protect the roadway system, improve traffic safety, and improve public perceptions and attitudes. Thinning tree canopies over and alongside unpaved roads and removal of select trees will hasten drying and encourage growth of grasses and smaller plants.

Be careful not to remove mature trees unless absolutely necessary. Also, be careful not to grade or excavate too close to trees. A safe distance is outside the canopy drip line. Inside this distance can damage or kill the tree.

Be careful not to cut or expose tree roots if possible. Cutting or exposing tree roots may cause a hazard by making the tree more easily uprooted. When roots are exposed, cover them as quickly as possible or cut them cleanly below the soil surface to prevent disease or other damage. Tree limbs broken during roadway operations should be pruned close to the main trunk or branch.

APPENDIX C: SUMMARY

Proper structure and condition are the keys to environmental control of an installation's unpaved roads. The first and most basic thing to understand is proper shape of the roadway's cross section. The road surface must have enough crown to drain water to the shoulder, but not an excessive crown that would make the road unsafe to travel. Secondly, the shoulder area must not be higher than the edge of the traveled portion of the road. A high shoulder prevents water from draining to the ditch and therefore needs to be eliminated. Third, a ditch must be established and maintained to drain water away from the roadside. In addition, culverts and bridges at the right location and elevation are essential for carrying water under and away from the road.

Once the correct shape is established on a roadway and drainage matters are taken care of, attention must be given to dust control and surfacing materials. When using gravel as surfacing material, it is very important to understand the makeup of good gravel to minimize dust. Simply stated, it is a proper blend of stone, sand, and fine-sized particles. Proper handling and calculation of volume needed is also important to get the desired depth of surfacing on the road.

Any road rehabilitation of environmental concerns should begin by identifying the cause of the damage or degradation. Identification of the problem's source is more important than making routine repairs to address the problem at road surface level. Ignoring source identification and the cause of the degradation will only exacerbate the problem over time.

A safe transportation system, including unpaved roads, is essential to the military's main goal. In fact, roads maintained in an environmentally friendly way may have more structural strength, suffer less deterioration, and have fewer defects, all of which combine to make them safer. A low-cost, environmentally sensitive road safety assessment should consider the following:

- environmentally sensitive areas surrounding the road, including the potential for sedimentation or damage to adjacent or nearby sensitive areas or water bodies;

- extent of costs to military training operations in terms of personnel safety, downtime, and equipment damage if the repairs are deferred;

- extent of future costs of rehabilitation in terms of money, labor, and time if the problem is allowed to worsen;
- potential for inconvenience based on present or anticipated intensity of use if the road or trail becomes impassable or hazardous; and
- effectiveness of repeated temporary versus permanent rehabilitation measures, even where the latter may be more expensive.

Table C-1 summarizes road surface problems, from minor to major.

Table C-1. Matrix of unsurfaced road problems (ranging from minor to major), and suggested solutions to avoid environmental consequences.

Problem	Severity	Solution
Improper drainage	Minor	Grade shoulders and ditches; clean ditches; install waterbars if appropriate
Improper drainage	Major	Clean ditches; reconstruct surface, base, and drainage; and install waterbars if appropriate
Dust	Minor	Apply water; liquid or solid dust control chemicals such as calcium chloride
Dust	Major	Add minor gravel, regrade, compact
Improper cross section	Minor	Reshape (blading or dragging); reshape with minor added material
Improper cross section	Major	Regrade; add major gravel, regrade, compact
Potholes	Minor	Spot regraveling
Potholes	Major	Add major gravel, regrade, compact
Rutting	Minor	Reshape (blading or dragging); reshape with minor added material
Rutting	Major	Regrade; add major gravel, regrade, compact
Loose aggregate	Minor	Reshape (blading or dragging); reshape with minor added material
Loose aggregate	Major	Regrade; add major gravel, regrade, compact

Problem	**Severity**	**Solution**
Corrugations	Minor	Reshape (blading or dragging); reshape with minor added material
Corrugations	Major	Regrade; add major gravel, regrade, compact
Soft Spots	Minor	Reshape (blading or dragging); reshape with minor added material
Soft Spots	Major	Regrade; add major gravel, regrade, compact
Depressions/Washouts	Minor	Reshape (blading or dragging); reshape with minor added material
Depression/Washouts	Major	Regrade; add major gravel, regrade, compact

APPENDIX D:
RESOURCES AND REFERENCES

References

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Resources

The following are among the Department of Army documents used in preparing this document:

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FM 5-410, “Military Soils Engineering.” 1992. http://faculty.unlv.edu/mjnicho/military soils fm5 410.pdf

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

TM 5-624, “Maintenance and Repair of Surface Areas, 27 October 1995.

Unified Facilities Criteria (UFC) 3-250-01FA, “Pavement Design for Roads, Streets, Walks, and Open Storage Areas,” 16 January 2004.

UFC 3-250-11 – “Soil Stabilization of Pavements,” 16 January 2004.

UFC 3-250-18FA, “General Provisions and Geometric Design for Roads, Streets, Walks, and Open Storage Areas,” 6 January 2006.

UFC 3-260-02, “Pavement Design for Airfields,” 30 June 2001.

UFC 3-260-17, “Dust Control for Roads, Airfields, and Adjacent Areas,” 16 January 2004.

NOTE: In addition to the above documents, information on aggregate-surfaced roads, prepared by the US Department of Transportation (USDOT), US Department of Agriculture Forest Service (USDA FS), USDA Office of Surface Mining, and USDA 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. 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.

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APPENDIX E:
OTHER USEFUL INFORMATION

Acronyms and Abbreviations

Term	**Spellout**
AR	Army Regulation
CECW	Directorate of Civil Works, U. S. Army Corps of Engineers
CEMP-CE	Directorate of Military Programs, U. S. Army Corps of Engineers
CERL	Construction Engineering Research Laboratory
EPA	Environmental Protection Agency; also USEPA
ERDC	Engineer Research and Development Center
FM	Field Manual
FS	Forest Service (under USDA)
HQUSACE	Headquarters, United States Army Corps of Engineers
NPS	nonpoint source
NTIS	National Technical Information Service
PM	particulate matter
POC	point of contact
PWTB	Public Works Technical Bulletin
SI	International System of Measurement
UFC	United Facilities Criteria
USACE	United States Army Corps of Engineers
USDA	United States Department of Agriculture
US DOT	United States Department of Transportation

Unit Conversion Factors

Multiply	By	To Obtain
feet	0.3048	meters
inches	0.0254	meters
miles (US statute)	1,609.347	meters
pounds (lb)	0.45359237	kilograms
square yards	0.8361274	square meters

Glossary

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 sub-base is required. Base course construction criteria are more stringent than for the sub-base.

Broad-based dips – Broad-based dips are an alternative to cross drain culverts to remove water across and off a secondary gravel road; they work best on road grades of less than 10%.

Corrugations – Regular lateral bumps in the road surface (also called washboarding), like ripples on sand dunes, which result from poor road surface materials. These surfaces most likely result from fines lost due to dust and wind erosion and/or being washed away by rain.

Depressions – Localized low areas 1 or more inches below surrounding road surface caused by settlement, excessive moisture content, and improper drainage.

Ditch or road ditch – Ditches may be trapezoidal or parabolic in shape. They are typically constructed by excavation along and parallel to the roadway. Ditches may require protective lining to prevent erosion by runoff. Typical linings include native soil, vegetation, riprap, cement, erosion fabric, or matting.

Fines – Silt and clay soil particles that are very small in diameter and have excellent structural binding characteristics. Silt particle size ranges between 0.0008 in. to 0.002 in. diameter whereas clay particles are <0.0008 in. in diameter.

Firm – Roadway that is not noticeably distorted or compressed by the passage of a military vehicle under normally occurring weather conditions; see also “**Stable**.”

Maintenance – The routine or periodic repair of roads or road sections to restore them to the standards to which they were originally designed or built. In contrast to alteration, maintenance does not change the original purpose, intent, or design of a road.

Particle pollution or particulate matter (PM) – Particle pollution (also known as particulate matter) in the air includes a mixture of solids and liquid droplets. Some particles are emitted directly; others are formed in the atmosphere when other pollutants react. Particles come in a wide range of sizes.

- **PM10** – Particles less than 10 micrometers in diameter are so small that they can get into the lungs, potentially causing serious health problems. Ten micrometers is smaller than the width of a single human hair.

- **PM2.5 –** These fine particles are less than 2.5 micrometers in diameter. These particles are so small they can be detected only with an electron microscope. Sources of fine particles include all types of combustion, including motor vehicles, power plants, residential wood burning, forest fires, agricultural burning, and some industrial processes.

- **Coarse dust particles –** Particles between 2.5 and 10 micrometers in diameter are referred to as "coarse." Sources of coarse particles include crushing or grinding operations and dust stirred up by vehicles traveling on roads.

Pavement structure – The pavement structure consists of the subbase, base course, and surface course.

Potholes – Potholes in the roadway are caused by excessive moisture content, poor drainage, and poorly graded aggregate.

Rehabilitation – As used in this document, rehabilitation is the restoration of roadbeds, surfaces, ditches, and adjacent slopes to a usable 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.

Repair – 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.

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

Rolling dip – A rolling dip is kind of waterbar that collects stormwater runoff and diverts it safely off the road to prevent buildup of surface runoff and subsequent erosion while allowing the passage of traffic.

Ruts and rutting – Ruts are longitudinal depressions in the wheel paths caused by high moisture content in the subsurface, inadequate surface course thickness, and/or heavy traffic loads.

Secondary road – A secondary road is a route that is designed, constructed, or designated solely for military vehicular use within the military transportation system.

Shoulder – Shoulders are surfaces parallel and contiguous to the roadway to which they provide lateral support.

Stable – Roadway not permanently affected by normally occurring weather conditions and able to sustain wear and tear caused by the uses between maintenance cycles. See also "**Firm**."

Sub-base – The sub-base consists of either a compacted granular material 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.

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

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

Surface drainage – Surface drainage on and along the roadway surface is the most critical for road maintenance. 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. Shaping the roadway surface to drain by itself will reduce degradation and maintenance requirements.

Turnouts – Intermittent runoff discharge points (also called tail ditches) from roadside ditches.

Waterbars – Waterbars are narrow, bermed structures constructed by forming a ridge or a ridge and channel diagonally across the sloping roadway. Waterbars are an inexpensive way to control and divert runoff from a road surface at selected intervals.

Washboarding – See “**Corrugations.”**