A Good Road Lies Easy on the Land…

Water Harvesting from Low-Standard Rural Roads

By Bill Zeedyk

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Bill Zeedyk addressing a water harvesting workshop on the CS Ranch, Cimarron, NM. October 2004

"A Good Road Lies Easy on the Land…"

*"**A road lies easily on the land** if it is located on a landform where it can be readily and effectively drained (neither too steep nor too flat); is functional when used as intended (class of vehicle, season and suitable weather conditions); has appropriate drainage features (closely spaced, properly situated and adequately maintained); preserves the natural drainage pattern of the landform; conserves water; does not cause or contribute to accelerated soil loss, lost productivity or water pollution; does not encroach on wetland or riparian areas; and is scenically pleasing.*

***A road is not easy on the land** if it collects, concentrates or accelerates surface or subsurface runoff; causes or contributes to soil erosion; impairs or reduces the productivity of adjacent lands or waters; wastes water; unnecessarily intrudes upon key habitats, stream channels, floodplains, wetlands, wet meadows or other sensitive soils; and is aesthetically offensive."*

—Bill Zeedyk

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Introduction

This book addresses the construction and maintenance of unpaved rural roads including strategies, techniques and practices for dealing with problems frequently encountered by landowners, land managers and maintenance personnel. Running water is the primary force affecting road condition and generating the need for maintenance. Economical maintenance means dealing effectively with water, but not just surface runoff. Standing water, seeping water, rain, snow, ice, frost and even a lack of water can contribute to road maintenance needs.

Photo i-1: *Gully formation caused by surface runoff captured by an old wagon road.*

Water can be a nuisance, but is also a valuable natural resource. As the West becomes more populated, as the demand for water escalates and the available supply shrinks, practical measures for harvesting or conserving water become increasingly useful. This book introduces the concept of harvesting water from low standard rural roads as an important aspect of maintenance activities.

Roads alter water movement across the landscape, which can concentrate and accelerate flow and cause soil erosion and gully formation. Roads can divert surface and subsurface flows, causing affected sites to dry out and lose productivity. Sediment-laden runoff from road surfaces, and their associated ditch systems, can be a major source of water pollution and turbidity. The very practices aimed at maintaining roads and offsetting negative effects can be extremely valuable in conserving water and using it wisely. In other words, roads can be managed as tools for saving water, improving vegetative cover and increasing forage yields while protecting valuable soils from erosion.

"Roads alter water movement across the landscape, which can concentrate and accelerate flow and cause soil erosion and gully formation."

An acre of impermeable road surface can yield about 25,000 gallons of water from a one-inch rainfall event.

For the purposes of this book, low standard roads are loosely defined as single lane, constructed of native materials, unsurfaced and without permanent drainage structures other than the occasional cross drain culverts or ditches.

Low standard rural roads commonly are roads which have simply evolved over time without the benefit of engineering. Most take the direct or "logical" route across the landscape and "have always been there." Such roads include old wagon roads, ranch roads, driveways, subdivision roads, logging and mining roads, power and pipeline roads, fire access routes, hunter, woodhauler and four-wheeler tracks.

Photo i-2: *A low standard ranch road, unsurfaced and without permanent drainage features.*

In most cases where low standard roads were, in fact, engineered water was often treated as a nuisance to be disposed of as cheaply as possible. Unique values

"Low standard rural roads commonly are roads which have simply evolved over time without benefit of engineering."

associated with streams, wetlands, riparian areas, springs, seeps or ciénegas were seldom appreciated or protected in the road building process.

Low standard roads are normally constructed of native materials found locally on site and vary immensely in texture, erodibility, load-bearing strength and trafficability. Most lack proper drainage and require constant re-grading or other costly maintenance activities. Width, slope, location and alignment are haphazard.

Photo i-3: *Least-cost treatments rarely prove effective.*

The Achilles' heel of low standard roads is poor drainage. When water is disposed of as quickly as possible without regard to its source or where it goes, poor drainage results and water is wasted. Drainage structures are rudimentary, no more than the minimum required to get rid of excess water on the spot and without regard to off-site effects. Seldom do drainage features take into account the power of concentrated flow and accelerated velocity to magnify erosion rates. Ultimately, drainage structures fail due to accelerated erosion and accumulating sediment deposits. Unfortunately, accelerated off-site soil erosion and soil loss is the normal result of poorly designed drainage structures and improper maintenance. To make up for poor drainage, road managers are forced to grade and maintain roads more often and at increased cost.

Periodic maintenance is an essential part of road management. Even low-standard roads require occasional treatment but maintenance can be expensive. One purpose of this book is to describe how to design, locate and install efficient drainage features so that damage caused by runoff is minimized and the need for maintenance reduced.

"The Achilles' heel of low standard roads is poor drainage."

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By installing drainage features that not only protect the road from erosion, but also direct the water to buffered sites where infiltration can occur, landowners can realize the added benefit of harvested water while reducing maintenance costs.

This book addresses techniques for recognizing water harvesting opportunities, ways of managing roads to reduce off-site erosion and even ways of managing roads to restore damaged sites.

During one road reconstruction project, approximately 2.4 miles or 3.5 acres of road surface was effectively drained and the runoff diverted onto grassland adjoining the roadway. Thirty drains were installed that will irrigate approximately 1/2 acre of grassland per drain. Three and a half acres of properly drained roadway at this location receive about 15 inches of annual rainfall. This equates to approximately 875,000 gallons of water harvested per year going directly to irrigate grassland vegetation and not traveling down the roadway to the nearest gully to create more sediment and erosion.

Finally, road runoff is a major cause of "non-point source" pollution throughout the West. Sediment from roads and road-induced erosion gullies is a primary cause of stream turbidity. Sediment washed from roads impairs water quality, damages fish and wildlife habitat, silts in reservoirs and clogs irrigation systems. Reducing sediment yield from roads is an important part of the nation's clean water program.

There are, as we will see, many things to consider when assessing, planning, managing and treating a low standard rural road or road system. The issue is more complicated than simply, "what can I do to keep that road passable until the next time it rains?"

I. Assessing Needs and Opportunities

On-the-ground assessment is not just an academic exercise. It is essential to good planning and wise management. By conducting an inventory and assessment land managers can describe by segment, the road system under management including standard, length, status, condition, maintenance needs, water harvesting opportunities and priorities for maintenance, closure, relocation or reconstruction. Topographic maps, aerial photos, remote sensing or GIS can be helpful in identifying all roads in the system and classifying each by segment, condition and length.

Having once completed an inventory and assigning names or numbers to each route, consider the following questions:

Purpose

What is the purpose of the road and its primary use? How does the road fit into the system? How important is it to ranch operations or land management? Does it provide primary access to ranch headquarters or shipping pens, for example, or is it used only incidentally to ranch operations? Is it really needed at all? Is it the main artery or just a feeder road?

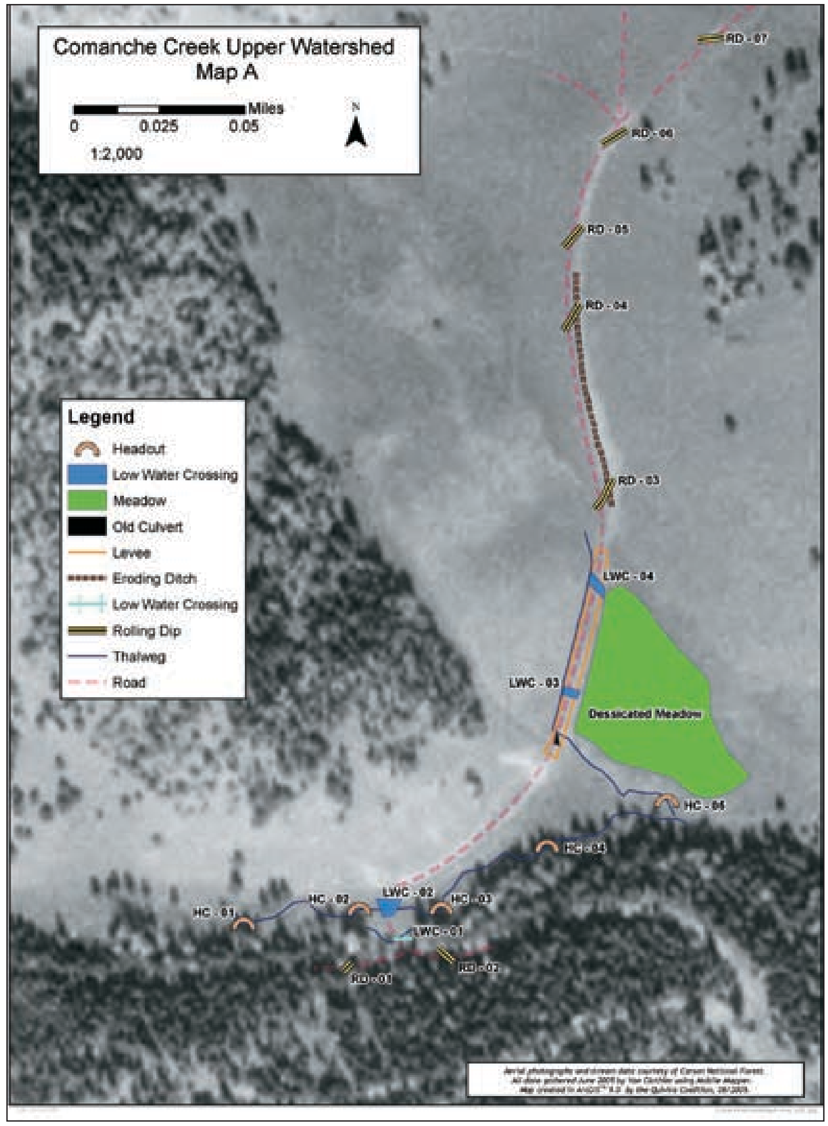

Photo I-1: *Example of a Road Survey Assessment Map.*

History

Why is the road where it is? Why maintain it? Has it been a maintenance problem in the past? Is it there only because it has always been there? Does it have emotional, aesthetic, or cultural value? Is it sometimes convenient to use but not really necessary? Is it there only because that is where the first wagon road went years ago?

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Standards

The purpose for which a road is used will define the proper standard. What is the intended use? What class of vehicle will be using the road and how often? What is the appropriate standard for the intended use? For example what is the correct width, maximum grade, clearance, bearing strength, surfacing and type of stream crossing needed to serve intended traffic. Will the road be used by low clearance vehicles for daily access to headquarters? Will it require all weather surfacing? Will it be used by livestock haulers (semi-trucks) with low clearance or logging trucks with high clearance? Pickup truck with livestock trailer? Wood hauling?

Legal Status

What is the legal status of the road? Sole ownership? Easement? Width of easement? Are there buried cables or pipelines? (*Call before you dig!* 1-800-424-5555 or www.callbeforeyoudig.com). Is there shared ownership or shared use? Public? If public, what agency maintains it? Is a permit required to maintain or modify the roadway or alignment? What permits are needed before work begins (county, state or federal)? Land ownership and/or the easement may belong to the United States Forest Service (USFS), the Bureau of Land Management (BLM), State Land Commission, State Highway Department or county. Required permits may include archealogical, endangered species or Clean Water Act (CWA) clearances (Appendix C).

Photo I-2: *A gate closing an old logging road within the Valle Vidal unit of Carson National Forest.*

Land Impacts

Does the road adversely impact other uses or resources? If so, how, where and when? Does it capture runoff, cause or contribute to soil erosion, degrade a stream channel, damage a wetland, or pollute a stream? Is it entrenched on the landscape and diverting water away from its natural landscape or watershed? Does it disturb wildlife or damage productive habitats? How about foraging areas and pastures? If so, how, where and when? Are there any chronic management or maintenance problems that need to be addressed?

Photo I-3: *Soil erosion resulting from concentrated runoff from an unpaved rural road.*

Photo I-4: *A rolling dip deflecting water from a ranch road to the adjacent grassland.*

Water Harvesting Options

Is road runoff being effectively returned to the soil and watering grass and other vegetation, or is it being lost to the nearest ditch, gully or arroyo? What options are available for restoring site productivity by enhancing water harvesting opportunities?

Location and Alignment

With the above assessment in mind, is the road on the best location and alignment for its purpose and use? What are the potential benefits and costs of closing, abandoning, relocating or reconstructing the road on the same or better location? Should troublesome segments be abandoned, relocated or reconstructed?

For example: Does the road divert runoff out of its natural subwatershed and into the next? If so, the added water could accelerate erosion at the receiving end while starving the natural drainage for moisture.

The above questions can assist the owner or manager in a clearer understanding of the road system in respect to its landscape. Information and concepts from Chapters I, II and III may be useful in developing a road management plan as discussed in Chapter IV. The result should be an increased ability to recognize opportunities and set priorities for road maintenance and water harvesting. After studying Chapters II and III, the reader may wish to revisit this chapter.

II. Reading the Landscape: Geology, Topography, Hydrology and Soils

A road serves at the pleasure of its landscape. Geologic formations, topographic features, drainage patterns, climate, soil texture and depth, vegetation, hydrologic and ecologic processes shape the landform. These factors set the ground rules and establish natural constraints that govern road building opportunities and maintenance realities. Some landscape features which favor initial construction may render maintenance more difficult in the long run. For example, a valley-bottom road can be easy to locate and construct but hard to drain because there is no place to put the water. Reading the landscape correctly can be helpful in predicting road related impacts on soil and water resources and an aid to understanding maintenance issues. Some considerations follow:

Photo II-1: *Valley-bottom roads can be difficult to drain.*

Photo II-2: *A forest road, Rowe Mesa, NM.*

Topography:

Topography describes terrain features such as elevation, relief, aspect, steepness of slope, length of slope and drainage patterns. The key topographic factors important to road maintenance are steepness of slope, position on slope, aspect and drainage pattern. Roads are best placed at the toe of the slope where cross slope is between 5 and 40% (Figure II-1). Steeper slopes are difficult to excavate. Flatter slopes are hard to drain. Ridgetop and valley-bottom roads can be too flat to drain efficiently. Aspect, or the direction that the land faces, especially northerly or southerly aspects, can be important. South facing slopes are warmer and tend to dry quickly. Therefore, roads on south slopes may be passable during periods of wet weather when north slope roads might be impassable. On the other hand, soils are usually deeper on northerly slopes, providing more material for road building activities. A gently rolling topography with deep soils and varying aspects may offer the best chance for low cost construction and ease of maintenance.

"A road serves at the pleasure of its landscape."

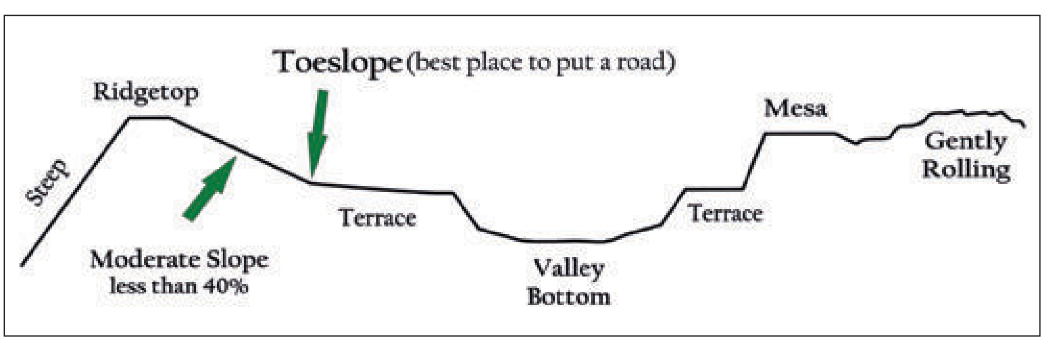


Figure II-1: *Topographic setting provides contrasting advantages and disadvantages for road locations.*

Soil Texture and Depth

Soil texture and depth are key factors in selecting road location and alignment. Soil texture refers to the size, composition and proportion of different sized particles in the soil column. Sizes include clay, silt, sand, gravel, cobble and larger particles. Medium to coarse textured soils (sand-sized particles and larger) are best suited for low-standard roads because they are readily worked, provide good traction, are permeable and resist erosion. Fine textured soils (silts and clays) may be easily worked but can be highly erodible, impermeable, muddy and slippery during wet weather. However, some finer particles are needed to bond larger particles together. For a smooth ride, it is important to preserve and protect the fine textured component of medium to course textured soils or the road will gradually, over time, become rougher, stonier and more difficult to maintain.

Soils can be derived in place by weathering of bedrock, deposited by running water (alluvium) or formed by soil particles rolling and tumbling down a slope under force of gravity (colluvium). Colluvial soils usually consist of a workable mixture of large, medium and fine textured particles, making them easy to work, shape, drain and compact for a smooth surface. Alluvial soils can be more variable and deeply stratified, ranging from sand and gravel (ideal) to silt, clay or loams, which can be easy to work but muddy or slick in inclement weather.

Local offices of the Natural Resources Conservation Service (NRCS), the County Extension Agent, or the Soil & Water Conservation District can supply important information on the distribution, properties and uses of local soils.

Climate and Precipitation Patterns

In the Southwest, precipitation patterns are typically seasonal, characterized by wintertime snowfall accumulation and summertime rainstorm events. Spring and fall tend to be drier. What are the implications for road maintenance and water harvesting opportunities?

The irrigation effect of harvested road runoff can be relatively more significant in drier climates and at lower elevations. Furthermore, the erosive effect of high intensity storms can be more damaging in drier climates than wetter climates.

Road maintenance activities should be scheduled to coincide with higher moisture content for ease of grading and better compaction. It is also easier to follow road runoff flow patterns during wet times to better determine and understand drainage needs.

Photo II-3: *The Chihuahuan Desert receives 4-6 inches of precipitation a year.*

Photo II-4: *Piñón-Jjuniper woodlands receive 10-14 inches of precipitation a year.*

Photo II-5: *Ponderosa pine forests receive 16-20 inches of precipitation a year.*

Soil moisture conditions favorable to road grading activities are more likely to occur during early spring or mid-to-late summer during monsoon season (common to the Southwest). Maintenance during drier times may require the service of a water truck.

Proper soil moisture at the time of grading leads to better compaction of soils on the road surface which leads to smoother, lower maintenance roads.

Hydrology

Of the total rainfall received in any given area, not all is available to support vegetation. Some is intercepted by above ground vegetation and evaporates or sublimates back to the atmosphere. A larger portion infiltrates the surface and percolates into the soil. Of that portion, some is transpired back to the atmosphere by plants, some evaporates and some penetrates deeper into the soil profile. The remainder runs off. Infiltration rate depends on porosity and soil structure and is affected by saturation due to previous rainfall. If the ground is saturated, rainfall can not be absorbed and runs off. If the surface is compacted or impermeable, a high proportion runs off. Runoff from paved roads may range upwards to 90%, from a graveled surface 50-70%, and from native soil only 10-20%. Therefore, runoff from a compacted road surface can be 5-10 times that of permeable native soil.

In terms of volume, runoff from an impermeable, paved road surface resulting from a one inch rainfall event would equal about 25,000 gallons per acre. In the piñón-juniper rainfall zone of 10-14 inches per year, this could total about one acre foot of discharge per acre of road per year (Appendix B). One acre foot of water is the volume of water necessary to cover an acre of land with water one foot deep (325,852 gallons). A 12-foot wide road equals about 1.5 acres of surface area per mile.

An increase in runoff from the road surface is not the only impact of roads on the hydrology of a watershed. More importantly, roads and road ditches intercept and capture hillslope runoff and divert it along the road corridor. Both surface and shallow subsurface flows are intercepted. The road and its ditches reroute and redistribute the runoff. The results are twofold: 1) soils downhill from the point of interception lose moisture and become drier and less productive than conditions prior to road construction, and 2) soils or drainage features downhill from the point of outflow receive concentrated and accelerated flows which can lead to accelerated soil loss, gully formation and excessive sedimentation. If the receiving soils or landforms have the ability to absorb the added runoff, then vegetation growth and productivity may be stimulated by the added moisture. The critical variable is in the capacity of the soil to absorb or convey the added runoff without eroding. Factors affecting absorption rates include soil texture and depth, compaction, permeability, vegetation cover and density, steepness of slope and saturation. Implications for good road hydrology are clear:

"The critical variable is in the capacity of the soil to absorb or convey the added runoff without eroding."

"...an increase in runoff from the road surface is not the only impact of roads on the hydrology of a watershed. More importantly, roads and road ditches intercept and capture hillslope runoff and divert it along the road corridor. Both surface and shallow subsurface flows are intercepted."

1. To reduce road runoff, minimize the area of impermeable surface by minimizing road width.
2. To reduce the effects of concentrated flows, minimize the connectivity of flow paths from disturbed soils.
3. To retain the capacity of the soil to absorb runoff, manage drainage outlets to return accumulated runoff to a natural, undisturbed soil surface as quickly as possible at low volume output.
4. Keep the water in the originating sub-watershed; do not divert runoff between watersheds.

Soil Erosion and Sediment Transport… A Two-Edged Sword

The power of runoff to erode a road, the land surface, a ditch bank, a gully or stream channel depends on the velocity, depth and volume of flow. Runoff velocity increases with steepness of slope. The capacity to transport dislodged and suspended sediments increases exponentially with increase in slope. The volume of sediment that can be moved increases 4 X when the velocity is doubled. The size of particles that can be transported increases by 8 X when the velocity is doubled (Figure II-2). As water depth increases, velocity increases because relative surface tension decreases. As flow velocity increases, shear force plucks larger and larger particles from the road or soil surface. Surface roughness, however, can reduce shear force and erodibility of the exposed surface. These relationships are true with both increasing and decreasing velocities. Therefore, as runoff accelerates, the suspended sediment load may increase exponentially, or as it decreases, the load will decrease exponentially. As flow decelerates, sediment will drop out of suspension and be deposited on the roadway or in the ditch.

The implications for good road design and maintenance are:

- ❒ As road grade steepens, drainage features must be closer together.
- ❒ Maintaining vegetative cover increases roughness and reduces erosion, reducing the sediment load being transported by road runoff and the amount of sediment available to clog ditches and drainage features.
- ❒ Drainage features need to be more closely spaced on fine grained soils.
- ❒ Drainage features with grades less steep than the road surface or road ditch will tend to become clogged with deposited sediments as runoff velocity decelerates.
- ❒ A well vegetated buffer zone at the edge of the road will tend to disperse flow, reduce runoff velocity and collect sediment from road runoff.

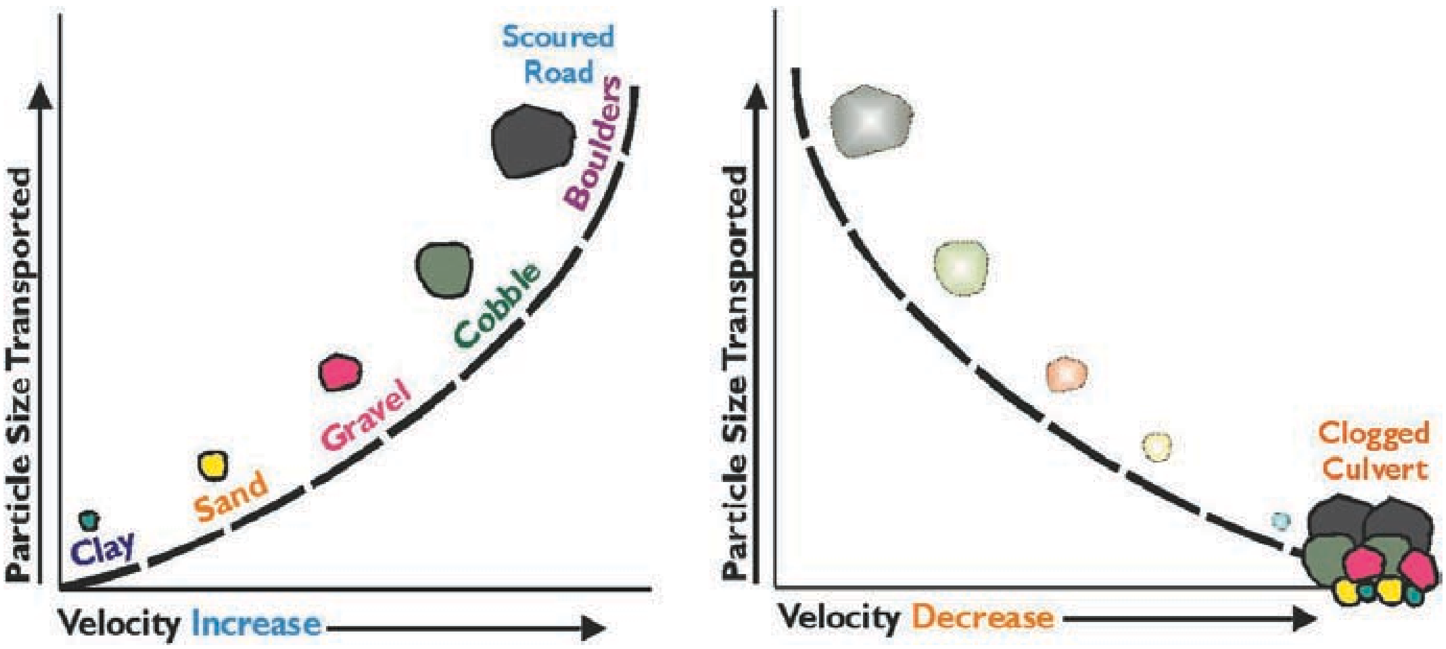


Figure II-2: *Graphic Representation of Velocity Rate Vs. Size of Particle Transported.*

The steeper the slope of the road, the faster the runoff and the larger the particles moved. Hence, the need for more and better drainage features as the road steepens. On the other hand, as the road flattens, runoff velocities decrease and rate of deposition of sediment on the roadway increases. This causes ditches and culverts to plug with sediment causing gravel, mud and other debris to be deposited on the roadway. To keep ditches self cleaning, ditches and the road surface need to have a slope equal to or greater than the contributing source of sediment. The faster the water, the more sediment it can transport at an increasing rate.

III. Reading the Roadway

Managing runoff to protect the roadway, prevent erosion and harvest water requires an ability to match road features with landscape features to ensure proper drainage. Sometimes it may be most informative to leave the roadway itself and follow drainage patterns to understand the effects that the road may be having on soil and water conservation, forage yields and other values. Key features and how they affect drainage include the following:

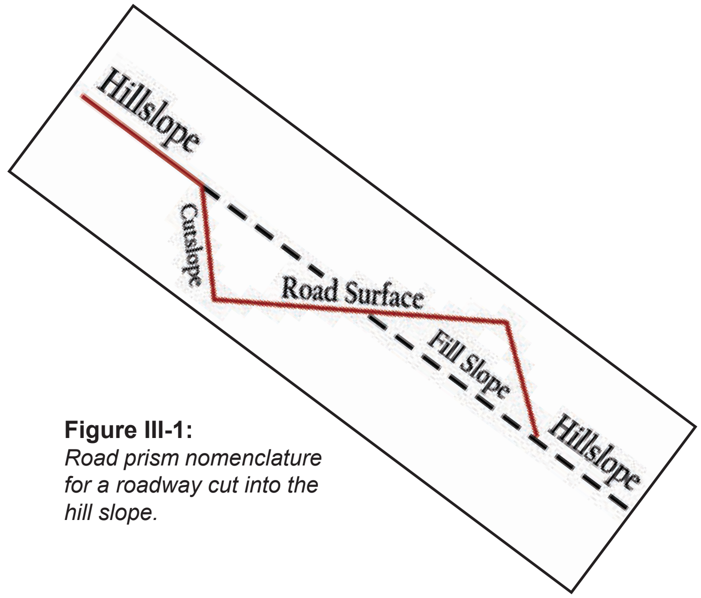


Figure III-1: *Road prism nomenclature for a roadway cut into the hill slope.*

Grade

The single most important feature regarding road maintenance and water harvesting from low standard roads is grade. Grade, or steepness, is measured in the direction of travel, up or down. Grade is usually expressed as percent slope, rise over run. A road that climbs 5 feet in elevation in 100 feet of length has a 5% slope. What is the average grade of the road? How steep is it? Too flat is as bad as too steep. How long are the slope segments between grade changes? The longer the segment, the greater the potential for erosion. Grades ranging from 4 – 10% are ideal, with frequent grade reversals. Drainage is assured if the road reverses grade every 200 – 300 feet. Water naturally exits the roadway at every grade reversal. Anything flatter than 2% is too flat to drain efficiently. Anything steeper than 15% is too steep to negotiate with two-wheel drive vehicles and presents a severe erosional potential (Figure III-1).

"Excess road width is the mortal enemy of low cost road maintenance. ...Roads should be no wider than necessary."

Width

Excess road width is the mortal enemy of low cost road maintenance. Most low standard roads are a single lane to a lane and a half wide with occasional wider spots for turnouts or passing. That translates to an average width of about 12 – 16 feet. Two-track jeep roads are not as wide, averaging 8 – 10 feet. Two lane roads range from 18 – 22 feet. The total disturbed area may be wider if backslope, ditch banks and berms are included. A 12-foot wide road equals about 1.5 acres per mile. Width is important. Roads should be no wider than necessary. The wider the road, the wider the exposed area available to capture and convey increased volumes of storm runoff. As the volume of storm runoff increases, so does the power for scouring and transporting sediment from the road surface. Increased sediment loading will increase the likelihood that ditches and drainage structures will be clogged with deposits whenever the rate of runoff slows.

Cross Section

A road's cross section is a vital aid to road drainage, helping to assure constant shedding of water from the road surface. A flat road with no cross slope tends to collect water, develop puddles and ruts, and stays soft and unstable following snowmelt or rainstorms. Problematic road

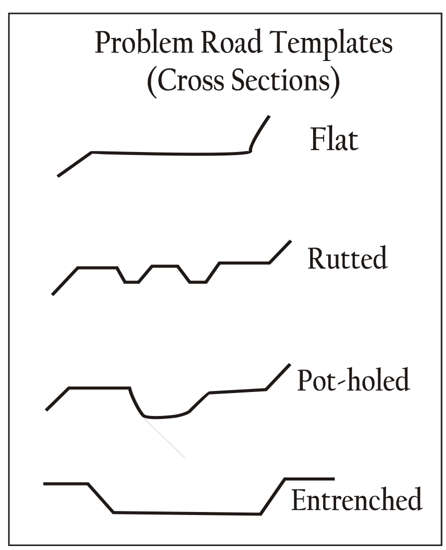


Figure III-2: *Typical cross sections with little or no cross slope.*

cross sections are shown in Figure III-2.

Typical cross sections or templates for types of cross slopes are shown in Figure III-3. An ***insloped road*** tilts toward the cut-bank or hillslope uphill from the roadway. Runoff runs down grade in a ditch at the base of the cut-slope. An insloped road needs frequent ditch relief outlets or cross drains. An ***outsloped road*** tilts gently away from the cut-bank and tends to shed water continuously; usually no ditch is necessary.

A ***crowned road*** slopes both left and right from the center line, like a pitched roof, and is usually flanked by a roadside ditch on one or both sides. Cross slopes should range between 2 and 4% to assure adequate drainage. Unfortunately, graded roads constructed with a cross slope can be compromised by wheel ruts that convey water down the ruts, negating the cross slope, and increasing the erosion hazard. Cross drainage can also be added to alleviate this problem.

Unpaved, two-track roads consisting of two parallel wheel tracks have a cross slope equal to the landform but the ruts may be flattened or cupped and may tend to intercept hillslope runoff.

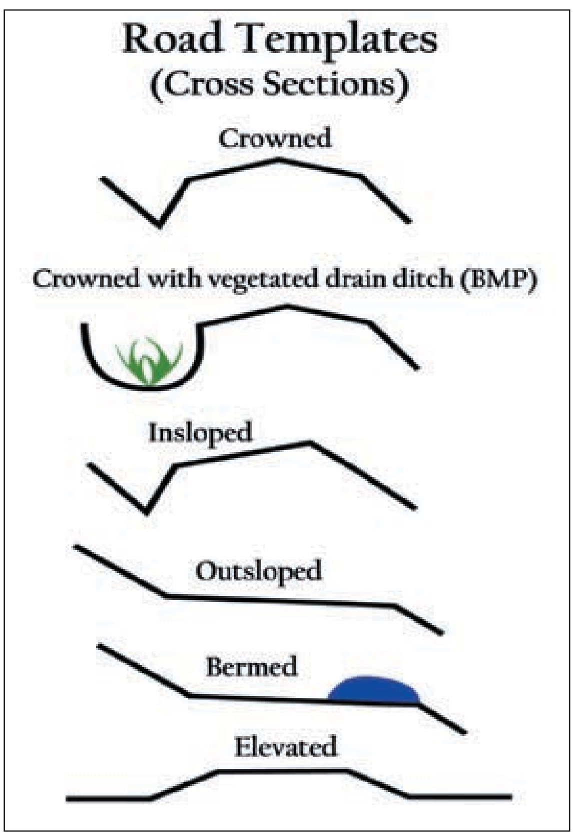


Figure III-3: *Alternative cross sections used to assure sufficient cross sloping and drainage.*

Photo III-1: *This berm keeps water from the road surface from spilling into the road ditch.*

<u>Berm</u>

Windrowed material may collect along the edge of the road as a berm. Berms can be deliberately placed at the road edge, or may develop inadvertently through careless maintenance operations or can accumulate as surfacing particles are spewed to the roadside by wheeled traffic.

Berms can be beneficial under special circumstances but are generally harmful as they tend to keep water trapped on the road surface, increasing surface erosion and sediment transport. A berm may be desirable to keep vehicles from sliding off a slippery road during wet weather. Berms are sometimes used to keep water on the roadway until it can be spilled safely onto a buffered area rather than directly into a gully, stream channel, spring or seep.

<u>Plan Form</u>

Plan form describes the horizontal shape of the road especially as it relates to adjacent features. Problematic plan forms include road intersections, switchbacks, stream crossings, spring seeps, or constrictions caused by obstacles such as rock outcrops.

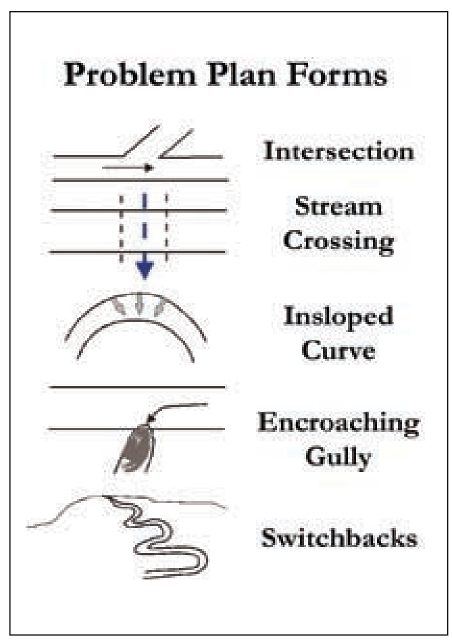


Figure III-4

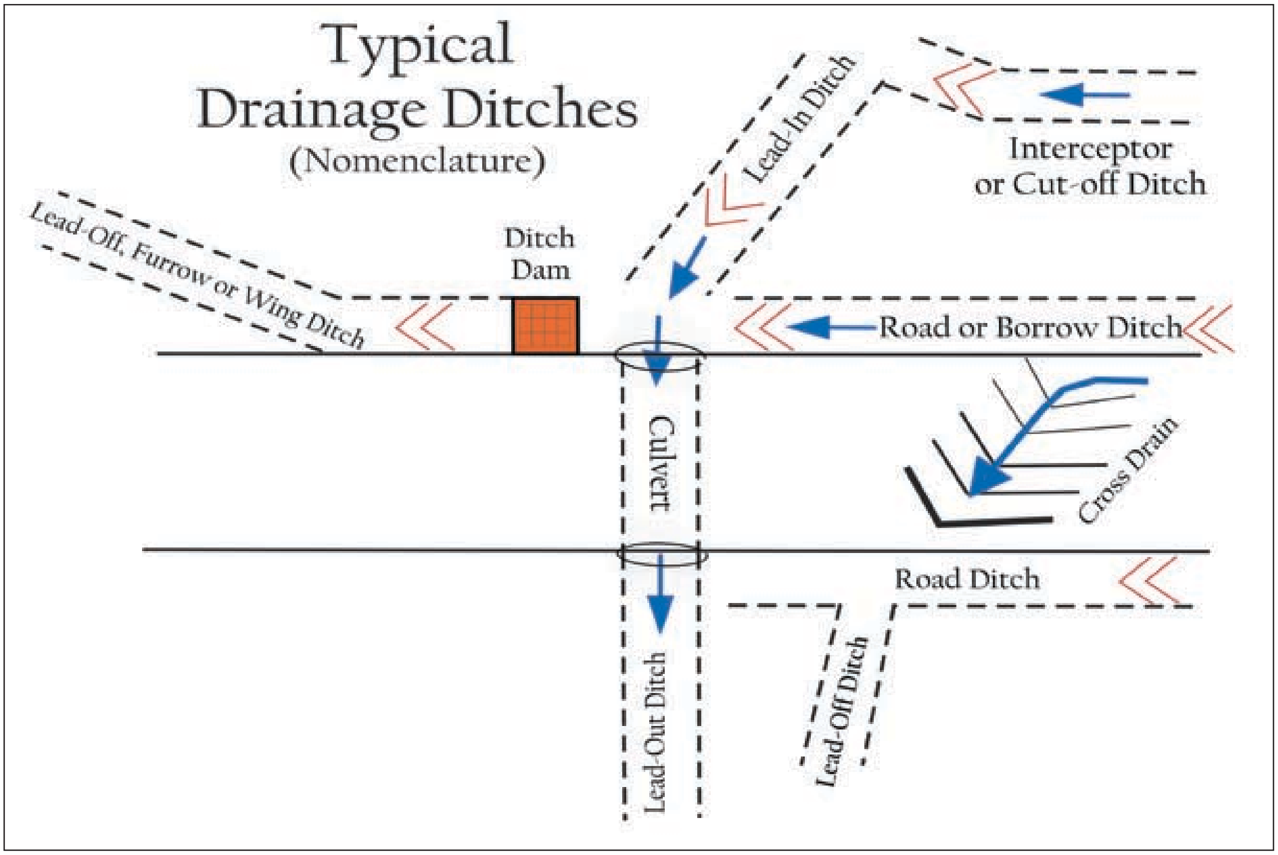


Figure III-5: *Nomenclature of typical drainage ditches.*

Special attention should be paid to plan form and how it relates to the collection, routing and disposal of runoff (Figure III-4).

Drainage Systems

The road drainage system may consist of an array of various ditch types that serve different purposes. Please refer to Figure III-5 for nomenclature and relative locations of various ditch types.

♦ ***Road or Borrow Ditch***

The road or borrow ditch runs parallel with the roadway collecting water from both the road surface and the hillslope, if any, for removal at the first available location. Road ditches can be "V" or "U" shaped. "V" shaped ditches concentrate flow and tend to erode quickly and produce sediment. "U" shaped ditches tend to spread flow and become vegetated and yield less sediment but may collect too much sediment which can impede flow and cause damage.

♦ ***Lead-Off, Furrow or Wing Ditch***

A lead-off, furrow or wing ditch leads water downslope and away from the road ditch. Again, these ditch types may be "V" or "U" shaped. If built on a flatter grade than the road ditch, or spaced too widely apart, these ditches tend to become plugged with sediment and require frequent maintenance. Placement of the lead-off ditch is critical relative to the ability of the soil to absorb or convey runoff from the ditch. The choice of lead-off ditch locations and the spacing between them will largely determine whether runoff water is harvested or wasted.

♦ ***Cross Drain and Lead-Out Ditch***

The road ditch may be drained by spilling ditch flow through a culvert or across a rolling dip to the downhill side of the road. A lead-out ditch may be required to insure that flow continues away from the road side. Flatter ditches tend to plug with sediment. Again, careful placement is important for efficient water harvesting. A poor choice of locations will result in accelerated erosion at the outfall. Cross drains must be maintained in order to function properly.

♦ ***Lead-In Ditch***

A lead-in ditch may be used to collect water from a gully or seep and lead it through the cross drain. Lead-in ditches accelerate flow and may initiate gully formation and headcutting.

♦ ***Interceptor or Cut-Off Ditch***

Interceptor ditches are occasionally used to collect sheet flow from a flat valley floor or hillside and direct it through a cross drain rather than relying on the road ditch to collect flow. Interceptor ditches accelerate flow and tend to initiate gully formation both upstream and downstream of the crossing. They may be used to drain spring seeps, wet meadows and ciénegas upslope of the roadway. Road surface, road bed and soils downhill of the ditch tend to dry out. Minimal use of interceptor ditches is recommended.

Stream Crossings

A stream crossing will be needed wherever the roadway crosses a natural stream channel, arroyo, wash or gully. Crossings can take the form of a bridge, a culvert, low water crossing (improved ford) or unimproved ford.

Various erosion hazards are associated with stream crossings but these hazards can be avoided by selecting the treatment and installing it properly. The common result of poorly designed stream crossings is channel straightening to accommodate the roadway. Straightening can lead to down cutting of the streambed as flow velocities increase. The road should be aligned to fit the stream, not the stream to fit the road.

A second hazard is road capture of the channel during flood events. This results in the stream flowing down the road instead of along its natural channel. Severe erosion may result. Issues associated with stream and wetland crossings are further discussed in Chapter VIII.

A third hazard is in making the crossing too narrow, constricting flow and accelerating flow rates, thus eroding the channel bed.

Photo III-2: *Straightening of the channel at an unpaved ford caused this channel bed to down cut.*

"The common result of poorly designed stream crossings is channel straightening to accommodate the roadway. Straightening can lead to down cutting of the streambed as flow velocities increase."

IV. Road System Planning and Management Strategies and Practices

By integrating information gathered from Chapter I with concepts outlined in Chapters II and III, managers can proceed with developing a road management and maintenance plan. The strategies and management practices listed below may be useful in guiding the planning process.

- ❒ Locate, construct and maintain the road system adequately to meet traffic needs by season of use. Frequently used roads, such as a headquarters road, or roads subjected to heavy loads should be built to higher standards than occasional-use routes.
- ❒ Keep road densities as low as practical. Carefully consider the purpose, value and frequency of use of every roadway. What is its history? Why is it needed? If a road really isn't needed, close it. Return the land to production and save maintenance dollars for a better purpose. Every acre of unnecessary road is an acre out of production.
- ❒ Reevaluate the purpose and need for any troublesome road or road segment which has, in the past, proven costly to maintain. Is it really needed on its present location or could it be relocated or even abandoned? Come up with a plan for scheduling modifications and stick with the plan. Planning will help save money, conserve water and restore damaged sites over the long run. Often more than one road serves the same location for no good reason other than a presumed convenience. Is the "convenience" really worth its cost in terms of lost production and increased maintenance expense?

Photo IV-2: *Bill Zeedyk and workshop participants plan a road treatment on the Thorpe Ranch, Newkirk, NM.*

Management Strategies

Here are some strategies for maintaining roads in good shape, conserving water and saving money.

- ❒ Manage low standard roads for maximum drainage, not speed. It is better to be able to use the road at low speed and in poor weather, than at high speed only in good weather.
- ❒ Prioritize treatments that accomplish both road maintenance and water harvesting objectives.
- ❒ Set aside a portion of the annual maintenance budget to improve problem roads or segments incrementally.
- ❒ Include a systematic approach to ditch maintenance in the annual program.
- ❒ "A stitch in time saves nine." Use hand tools as necessary and appropriate to repair or maintain drainage features in a timely manner in order to avoid more expensive repairs later. A few quick shovelfuls can often unplug a ditch or culvert to let it do it's job.
- ❒ If a road or road segment cannot be drained effectively, replace, relocate or rebuild it. Place emphasis on frequently used roads to save travel time, avoid future cost and reduce wear and tear on vehicles.

Photo IV-1: *Rural road leading to an oil well, Lindrith, NM.*

"Reevaluate the purpose and need for any troublesome road or road segment which has, in the past, proven costly to maintain."

Management Guidelines and Practices

By adopting a customized set of management guidelines, managers can reduce maintenance costs. For example:

- ❒ Avoid using roads during wet weather or when too soft to travel over. Passage by even one vehicle during these times can cause rutting that is costly to repair. If the road is too wet to travel, keep off, leave the pick-up at home and walk or ride a horse.
- ❒ Maintain drainage features in functional condition at all times. Remove blockages as they occur.
- ❒ Keep ditches open, but do not remove vegetation that does not impede drainage. Vegetation holds the soil in place and reduces sediment loading which is the greater problem.
- ❒ Watch for and remove accumulating sediment plugs and berms that interfere with proper drainage, keeping water trapped on the roadway. Determine the sediment source and correct the cause. Is the sediment coming from the road surface, a ditch bank, a slump, or from an off-site source? Why is it accumulating? Is there an obstruction? Is there debris in the ditch? Is the grade too flat?
- ❒ Keep road width as narrow as possible. Do not "back blade" ditches or cutslopes just to "dress them up" or control vegetation. Blading widens the road and increases surface runoff and erosion rates. Mining soil from the road edge will widen the road, subsequently increasing road runoff and sediment yield.
- ❒ When installing drainage features, always return intercepted runoff to its natural path at the first opportunity. Walk out the flow path and be certain that water spilled from the roadway is not causing an erosion problem somewhere else. If so, pick an alternate path.
- ❒ Sediment deposition, not erosion, is the primary reason why drainage features fail. Minimize drainage failures by reducing sediment yield and transport.
- ❒ Do not grade or disturb an established surface if the road is draining properly and is smooth enough for travel. Exercise self-restraint: "If it ain't broke, don't fix it!"
- ❒ Remember, a well intentioned but poorly trained maintenance operator can undo in a few minutes what it may have taken many years to achieve. Use trained operators.
- ❒ Keep the grade of drainage features as steep or steeper than the roadway. The increased runoff velocity will tend to flush sediment through the drain rather than depositing sediments that clog it.
- ❒ Install drainage features at closely-spaced intervals. If possible, select outfall sites that are buffered by vegetation and can absorb runoff or can accomodate concentrated flow with minimal erosion.
- ❒ Fix the easiest road segments first to keep them functioning properly at least expense.

"Do not 'back blade' ditches or cutslopes just to 'dress them up' or control vegetation. Blading widens the road and increases surface runoff and erosion rates."

Ditch Management

Ditch maintenance is essential to keeping the road system serviceable but is often neglected. Maintenance includes removing accumulated sediments from lead-out ditches, culverts and cross drains. Ditches that are improperly situated, are too flat or too steep, or that spill unnecessarily onto erodible soils should be systematically modified, relocated, supplemented or replaced.

Photo IV-3: *This cross drain culvert was installed at a point where the soil could not absorb concentrated runoff and should be relocated to a more favorable site that can filter and absorb road runoff.*

V. Treatments

The three most useful treatments used to initiate or improve surface drainage from low standard roads include outsloping, berm removal and the installation of cross drains such as rolling dips. Other treatments include blading, insloping, crowning and installing waterbars. Building grade reversals into the roadway helps to insure adequate drainage over the long term with minimal maintenance.

The choice of drainage treatments will depend upon knowledge gained from Chapter III: Reading the Landscape, Chapter IV: Reading the Roadway and should relate to the purpose of use (size and class of vehicle), frequency and season of use, water harvesting objectives and the maintenance schedule (frequency and timing).

Blading (smoothing)

Blading to maintain a crowned road is a multi-step process. First, the road ditch and any auxiliary drainage feature should be inspected and cleaned only if necessary. Excess accumulations of surface gravel can be salvaged and returned to the road surface but care should be taken not to place fine-textured soils and organic debris from the ditch back on the roadway. It may be possible to clean the ditch by "heeling the ditch," a process whereby loose material is pushed back against the toe of the backslope with the heel of the moldboard (blade).

Photo V-1: *A crowned road. The berm on the right must be removed to assure drainage to the road ditch.*

Once the ditch is in order, begin the blading operation by blading the surface material from the cutslope side toward the middle of the roadway. While keeping the moldboard in the upright position, travel at a constant speed and try to create a windrow of material of uniform height and volume on the road. Repeat from the opposite direction and blade material from the fillslope side back toward the center. Then blade the center windrow to complete the crown. Be sure the crown is actually cross-sloped and not flat. If necessary, go back and remove any berms that would prevent water from leaving the roadway.

Grade Reversals

The simplest and most effective technique for assuring adequate surface drainage over the long run is to build frequent grade reversals into the vertical alignment of the roadway In other words, build in frequent changes from uphill to downhill sections. A road surface that undulates between upslope and downslope at short intervals (200 – 400 feet) will drain itself without further treatment. This technique is most applicable to low speed, single lane roads built on rolling topography or the toeslope of a hill. The grade reversals will force any surface runoff to leave the roadway, but adequate lead-off ditches will be needed to avoid puddling at surface points where runoff collects on the roadway.

The technique of building grade reversals into the road alignment is most useful when locating a new two-track road. When driving downhill across rolling terrain or a uniform hillslope, simply turn gently upslope for a short distance (25 – 50 feet) and then turn and continue downslope for a distance of 200 – 300 feet and repeat the upslope maneuver.

"The simplest and most effective technique for assuring adequate surface drainage over the long run is to build frequent grade reversals into the vertical alignment of the roadway."

Outsloping

An outsloped road tilts outward from the cutslope toward the fillslope (Road Templates Figure III-3). Outsloping is a highly effective treatment when used on sloping terrain and course-textured road surfaces.

Outsloping should not be used on fine-textured surfacing that can become slippery when wet. To be effective, outsloped roads should have a cross slope profile of 2 – 5%. If the entire road cannot be outsloped, effective drainage can be established by simply outsloping short segments spaced at 200 – 300 foot intervals. Outsloped segments should be located where the fill slope is well vegetated or rocked and can resist erosion caused by accumulated or concentrated runoff.

Berms and persistent wheel ruts can negate outsloping as an erosion control or water harvesting technique. Even very shallow wheel ruts that are no deeper than mere depressions on the road surface can intercept runoff and direct it down grade and beyond the outsloped segment. Watch for flow paths, rills and sediment deposits on the roadway to determine if outsloping is effective or has been compromised by wheel ruts.

Outsloping is the most effective treatment for use on road grades that are too steep for water bars or rolling dips (roads steeper than 15% grade). Outsloping is the best treatment to use to spill runoff when rounding a point and to avoid diverting surface runoff from one sub-watershed to the next.

Photo V-2: *An outsloped road with coarse-textured surfacing and berm removal.*

Insloping

An insloped road tilts inward toward the adjacent hillslope and drains through a ditch running parallel with the roadway (Road Templates Figure III-3**)**. Insloping is most effective when used to drain a climbing turn, to improve user safety on a slippery roadway or to protect a stream, wetland, spring, or seep from sediment-laden runoff by directing runoff away from the sensitive area.

Photo V-3: *Blading to maintain an insloped road template.*

The cross slope should range between 2 – 5%. As with outsloping, the effectiveness of an insloped road or road segment, can be negated by wheel ruts and/or berms that keep runoff trapped on the roadway.

The difficulty in using an insloped road surface is in draining the roadside ditch at regular intervals. Ditch drainage is gained by leading the runoff to a cross drain such as a culvert or a rolling dip or by leading the runoff to a terrain break where a change in hillslope orientation provides an opportunity for a drainage outlet. It is essential to drain “early and often.”

> *“More often, berms result from careless or uninformed maintenance operations, and create serious drainage complications.”*

Berms

A berm is windrowed material piled as a continuous ridge along the edge of the roadway. Berms are sometimes purposefully created to meet one or more specific objectives such as traffic safety or to keep water from spilling from the roadway at an undesirable location. These are useful and desirable reasons for building or retaining berms in select situations.

More often, berms result from careless or uninformed maintenance operations and compromise drainage features built into the roadway. Berms keep water trapped on the roadway and contribute directly to increased volume, velocity and erosiveness of road runoff. The result is accelerated erosion and loss of fine textured surfacing materials which are essential to maintaining a smooth and well-compacted surface. Berms cause sedimentation of drainage features and increased turbidity, and increase the need for further maintenance as the roadway becomes rough, scoured and eroded. Berms increase the cost of road maintenance and should be removed routinely during any maintenance operation except where specifically needed to solve a particular problem.

Photo V-4: *Removing the unwanted berm will allow surface runoff to spill this outsloped roadway.*

Where a berm is specifically called for, as when used to direct runoff around a spring source or to protect a fragile embankment, openings should be placed through the berm at locations where the resulting spill will not create a problem. Such openings are called berm breaks.

Waterbars

A waterbar is a pushed up mound of earth or hump on the roadway used to deflect runoff from the road surface. It is quick, easy and cheap to build with a bulldozer, tractor or backhoe. Waterbars or "thank-you-ma'ams" are usually built at right angles to the roadway, but are more effective when built at an angle of 30% to the grade. Waterbars are normally built to a height of 6 to 24 inches above the road surface. Taller structures may be impassable to low clearance vehicles or vehicles towing trailers. While waterbars can be very effective when first built, there is a tendency for them to flatten with repeated use and to fail if used during wet weather. Waterbars require frequent maintenance.

Waterbars constructed perpendicular to the road grade tend to develop a mud puddle in the depression on the up slope side of the bar, especially if the road is relatively flat. Accumulating sediment fills the depression and compromises the bar, leading to its eventual failure.

Photo V- 5: *Water bars are easily flattened and only suitable for abandoned roads or roads closed to traffic when wet.*

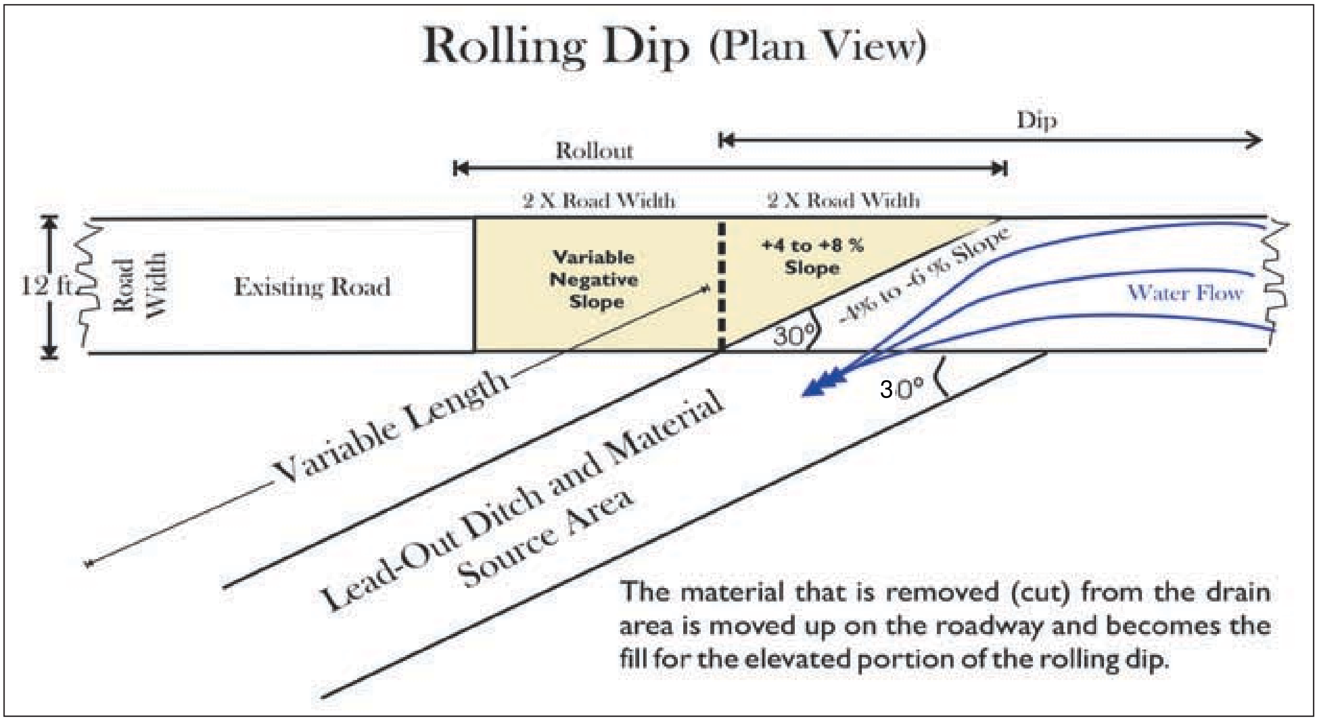
In short, the use of waterbars is seldom a satisfactory treatment for well traveled roads or roads used when wet. The use of water bars is generally not recommended. On the other hand, waterbars can be used very effectively to drain abandoned roads, roads closed to traffic or roads where traffic is effectively excluded during wet weather.

Cross Drains

♦ ***Rolling Dip***

The basic, most reliable cross drain for low standard roads is the rolling dip. The rolling dip was originally called the Coweeta dip, after the Coweeta Experimental Forest, North Carolina, where it was first developed. A rolling dip is an excavated cross drain. Rolling dips can be used to drain roads having grades between 3 and 15%. When properly built, rolling dips are highly reliable and

Figure V-1: *Rolling dip schematic.*



easy to maintain. Dips can be built using any type of excavating equipment if soil moisture conditions permit easy digging and good compaction. Soils that are too dry are difficult to "break-out" and move easily without heavy equipment. Soils that are either too wet or too dry may not compact at all.

For a plan view of a rolling dip, see Figure V-1. Rolling dips are not suitable for use on flat terrain or on roads designed for traffic speeds greater than 25 mph. The function of the rolling dip is to collect surface runoff from the roadway and/or road ditch and direct the flow across and well away from the roadway. The velocity of flow must be sustained through the dip to prevent puddling and to keep sediment moving through the dip drain. Sediment deposition will lead to failure of the structure. Secondly, the reverse slope of the roll-out must be steep enough and tall enough to prevent runoff from overtopping the roll-out. The most vulnerable portion

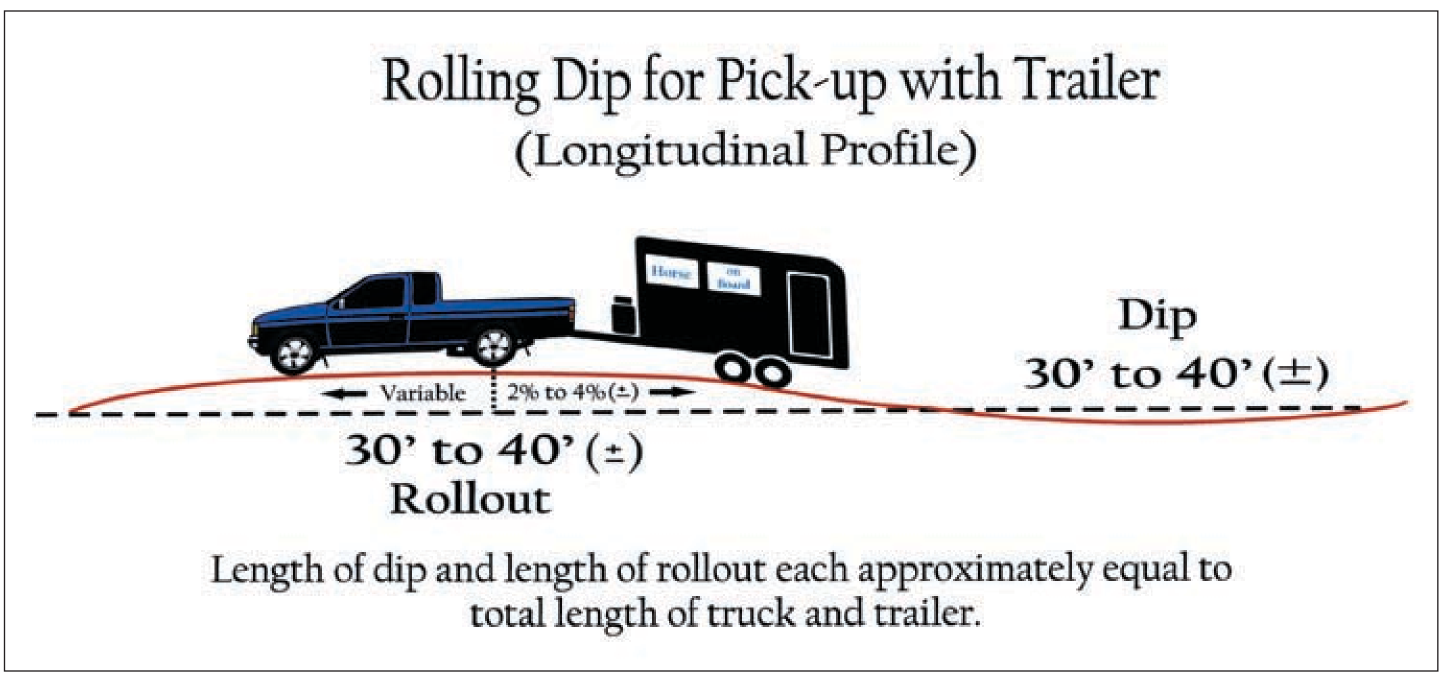


Figure V-2: *A rolling dip must be sized according to the dimensions and clearance for the type of vehicle with the strictest requirements.*

Photo V-6: *If the road will be used by a truck pulling a trailer, the dip and roll-out should be long and gentle.*

of the structure is the point where the uphill or high-side wheel rut crosses the roll-out.

If the terrain is too flat, the road grade less than 3% or cross slope less than 5%, it is difficult to build a dip drain that will not impound runoff. If the road grade is too steep (greater than 15%), the roll-out will be too steep on the downhill side to negotiate with a two-wheel drive vehicle and traffic will damage the structure.

It is critical that the rolling dip be adequate to divert all runoff from the roadway. Any flows bypassing the structure and remaining trapped in wheel ruts on the roadway will contribute to the potential failure of the next downgrade structure.

"The velocity of flow must be sustained through the dip to prevent puddling and sediment accumulation in the dip drain, which can lead to failure of the structure."

Photo V-7: *Minor modifications in treatment applications should reflect small changes in road conditions and land surface features.*

Finally, rolling dips must be sized according to the dimensions (wheelbase length) and clearance (height) for the type of vehicle with the strictest requirements. See Figure V-2. If the road will only be used by high clearance vehicles such as jeeps, pickups and SUVs, the dip and roll-out can be relatively short, steep and abrupt. If the road will be used by a truck pulling a trailer or by a semi-truck, the dip and roll-out should be long and gentle. The guideline is: total length of drainage structure from roll-in to roll-out should equal twice the length of the longest vehicle, including trailer, that will be using the road.

The essential features of a rolling dip are:

- ❒ adequate hillslope or crossing slope of at least 5% grade,
- ❒ road grade between 3 and 15%,
- ❒ a broadly angled dip drain with a cross slope of 4-8%, i.e., steep enough to flush away accumulating sediments,
- ❒ a beveled backslope, or "roll-out" with a positive reverse grade of 4-8%, and
- ❒ overall dimensions proportionate to the dimensions of the design vehicle.

To construct a rolling dip:

1. First, select the exact spill point where the water will be deflected from the downhill edge of the road. Choose the location carefully to avoid spilling runoff into an existing or potential erosion gully. Maximize every opportunity for dispersing surface runoff and/or taking advantage of an erosion resistant location for the outfall.

2. Next, lay out the course of the dip drain by marking it on the ground. A spray paint line, a row of stones, pin flags or any identifying marker will do as long as the operator will know what the marking means. The dip drain should cross the road at a 30° angle to the center line of the road in a down grade direction. A 30° angle is easily achieved by measuring the width of the road at the spill point and doubling the distance to identify the starting point (apex of the 30° angle) on the opposite side of the road.

3. Excavate the dip drain by using a bulldozer, grader, excavator, backhoe, farm tractor or pick and shovel. Stockpile the dredged material as fill on the down grade side of the dip drain and save it for building the roll-out.

4. If possible, go downslope from the spill point and excavate a lead-out ditch. Add the excavated material to the stockpiled fill collected during the previous step.

5. Once enough fill material has been gathered, start building the "roll-out." If the fillslope is too steep to borrow from, it may be necessary to borrow material from the roadway itself. In some situations it may even be necessary to haul material for the roll-out from another source. Begin working the fill material into the proper shape and dimensions for the roll-out (Figure V-1). The roll-out should have a reverse grade of 4 to 8% and be higher and broader on the upslope side of the road than on the downslope side. This will help to prevent rutting and keep runoff in the upslope wheel rut from bypassing the structure. Think of the roll-out as having the plan form of an equilateral triangle with its base parallel with the edge of the road opposite the spill point and one side parallel with the dip drain.

6. When complete, the rolling dip should have the proper dimensions to accommodate the design vehicle, a dip drain with a channel slope of 4 to 8% and a roll-out having a positive reverse grade of 4 to 8%.

See Figure V-3 for a completed rolling dip with key features noted.

Figure V-3: *Key features of a rolling dip are the dip drain, lead-out ditch and roll-out.*

♦ ***Flat Land Drain***

Flat land drains are used to drain roads having 0 to 3% slope and an adjacent hillslope less than 5%. These structures are most useful on slightly to moderately incised roadways where it is not feasible to rebuild or relocate the road.

Photo V-8: *A flat road on flat land. The stake marks the location of the planned drainage outlet.*

Photo V-9: *Material borrowed from lead-out ditch is stockpiled on roadway.*

"The principle difference between a rolling dip and a flat land drain is in the slope of the adjacent landform."

Photo V-10: *Tractor constructing reverse slope ramp beyond lead-out ditch using the stockpiled fill (photo V-9).*

Photo V-11: *Completed flat land drain and lead-out ditch on fine-textured soil. If needed, harden the surface with gravel hauled from another source.*

The principle difference between a rolling dip and a flat land drain is in the slope of the adjacent landform. Rolling dips are used on landforms with a cross slope greater than 5%. Flat land drains are structures especially designed for application on terrain with a flatter than 5% cross slope and road grades flatter than 3%. The concern with a flat land drain is that the slope of the lead-out ditch be steep enough to maintain runoff velocity well beyond road edge. With a flat land drain it is necessary to excavate downhill from the road to create this capacity.

The essential features of the flat land drain are:

- ❐ a long, wide, deeply excavated lead-out ditch,
- ❐ a slightly angled dip-drain spilling directly into the ditch,
- ❐ an elevated road surface down grade of the dip-drain and constructed from borrow material salvaged from the lead-out ditch or hauled from another location, and
- ❐ a graveled or rock-lined dip-drain if needed.

For a plan view of a flat land drain, see Figure V-4.

To construct a flat land drain:

1. First, select the spill point at the road edge where water will be drained from the roadway.
2. Next, using a hand level or clinometer, select the location for a proposed lead-out ditch having the greatest fall or slope leading away from the roadside. In flat land situations, the direction and steepness of slope can be very deceiving; it can be literally impossible to tell up from down. The use of an instrument is essential in locating the direction of maximum slope for the path of the lead-out ditch. Hand levels and clinometers are available from surveyor or forestry supply outlets.
3. Using a dozer or loader, excavate material from the path of the lead-out ditch and stockpile it temporarily on the roadway. Ideally, the lead-out ditch should be as wide as the dozer blade, 1 to 2 feet deep at roadside, 30 to 50 feet long and taper gradually downslope to a feathered edge at the downhill end of the ditch.
4. When digging is completed, roll the edges of the ditch with tractor treads to compact and smooth the break. This will facilitate revegetation and reduce erosion.
5. Next, use the stockpiled borrow material to build a reverse (positive) slope or ramp down grade from the spill outlet. The ramp should have a slope of 2 to 4 % and a height of 1 to 2 feet above the original road bed in order to force road runoff to exit the road surface at the spill outlet. Depending on the texture of excavated soils (gravel vs. silt, clay or loam) the spill point and raised bed may be firm and dry most of the time or soft and muddy. Fill material is borrowed from the lead-out ditch, temporarily stockpiled on the road surface and then used to build a reverse grade downslope from the spill point.

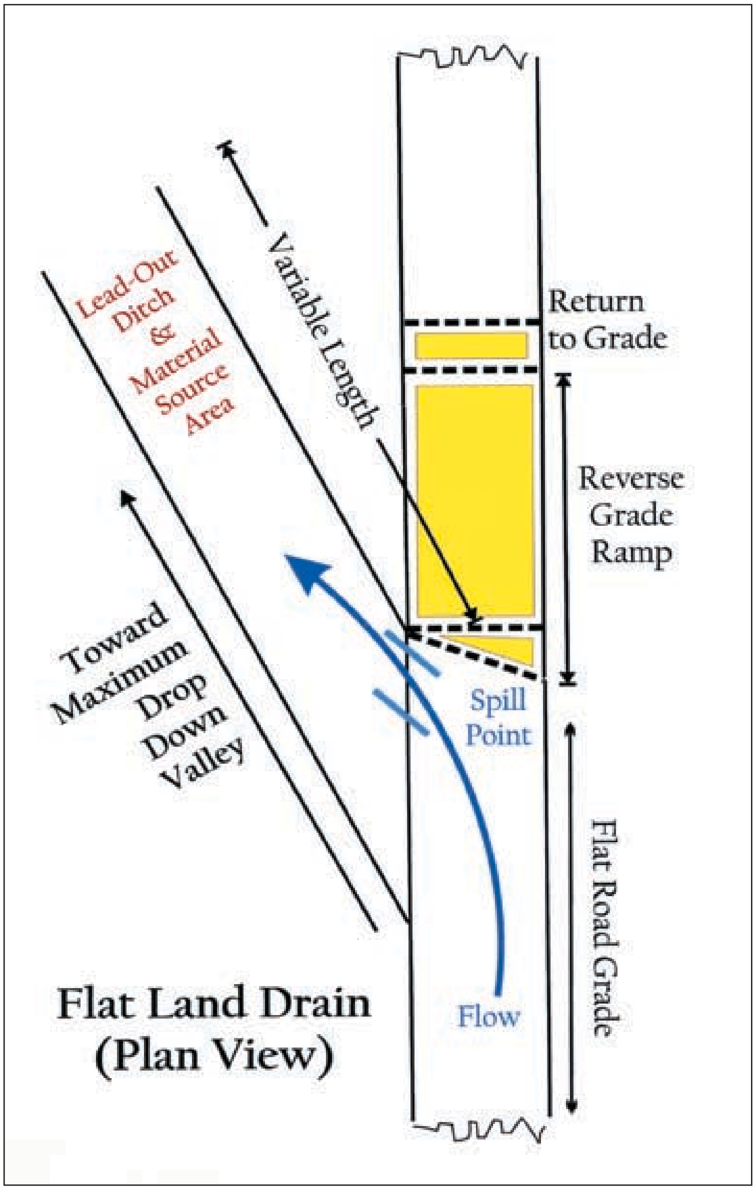


Figure V-4: *Flat land drain schematic.*

Flat land drains are especially useful in restoring dispersed overland flow or sheet flow to meadows and wetlands where V-shaped ditches might tend to concentrate runoff and initiate gully formation.

If the roadway tends to remain soft and muddy long after a storm event, it may be necessary to harden the surface with a layer of rock or gravel hauled to the site from elsewhere. Traffic should be excluded when the road is wet; if not, then hardening of the structure is essential. If using the road when it is wet cannot be avoided or controlled, hauling in rock or gravel can be well worth the added expense.

- ***Piped Drains (Culverts)***

Culverts or pipes are ideal cross drains for leading ditch water across the roadway, especially where the surface is insloped or crowned. The consideration is that if culverts are used, routine maintenance must be provided for the life of the road. If scheduled maintenance cannot or will not be done, culverts are not reliable and should be avoided in preference to rolling dips or flat land drains. Culverts must be cleaned periodically or they will become clogged with debris.

Photo V-12: *This 18-inch diameter corrugated steel pipe had adequate cross slope, but no energy dissipater.*

The essential features of an effective culvert treatment are:

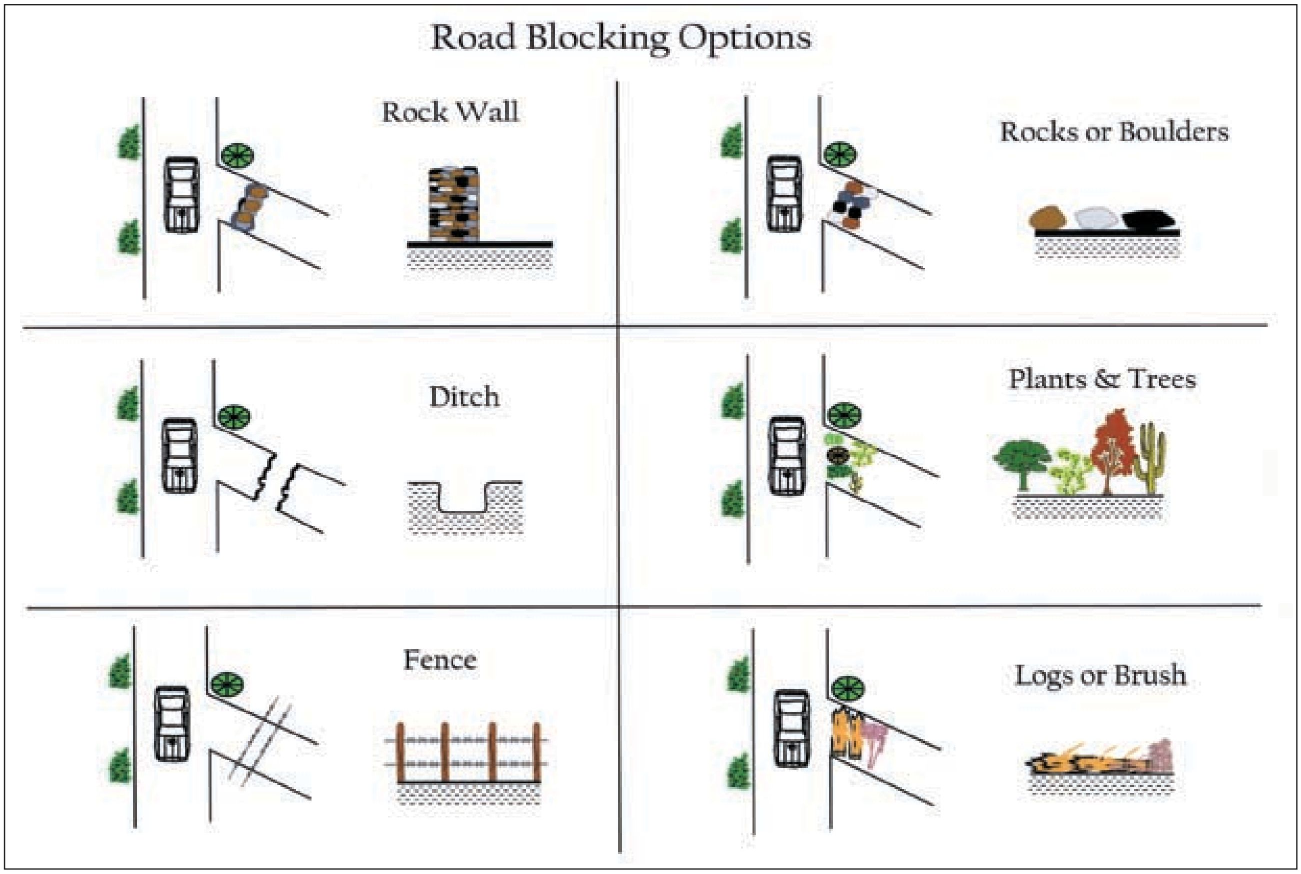
- ❒ Location: Properly sited to match the land form, resist erosion and disperse runoff (if possible).
- ❒ Diameter: Use a pipe large enough to carry expected discharge, minimum diameter of 18 inches, 24 inches is preferable. Installing an undersized pipe is false economics since smaller pipes can be easily plugged by sediment or debris and require more frequent cleaning.
- ❒ Cross Slope: Install pipes with a minimum cross slope of 2% to efficiently move water through the culvert.
- ❒ Energy dissipaters: Place riprap or rocks as energy dissipaters at the outlet to prevent scour on the downstream side.
- ❒ Earthen ditch dam: Use an earthen ditch dam to prevent ditch water from bypassing the inlet to the culvert.
- ❒ Spacing: Maximum spacing between cross drain features should not exceed 500 feet. Use less space between cross drains if the road grade is steep or the ditch carries substantial overland flow or groundwater discharge.

"Good management may call for purposefully closing an unneeded road or road segment. Closure by abandonment is not good management."

Road Closures

Good management may call for purposefully closing an unneeded road or road segment (Figure V-6). Closure by abandonment is not good management. An unneeded road should be actively put to bed, drained, obliterated and revegetated. Failure to install well planned drainage features at closing can lead to irreversible soil loss and continuing hydrologic and ecological impacts. Roads no longer useful to vehicular traffic may still intercept and convey runoff, concentrate flow, accelerate erosion, dehydrate wetlands, and pollute surface water. Such roads will invite unwanted traffic, attract livestock trailing, and channel runoff in harmful ways to the wrong places.

Figure V-5: *Options for blocking a closed road to unwanted traffic.*

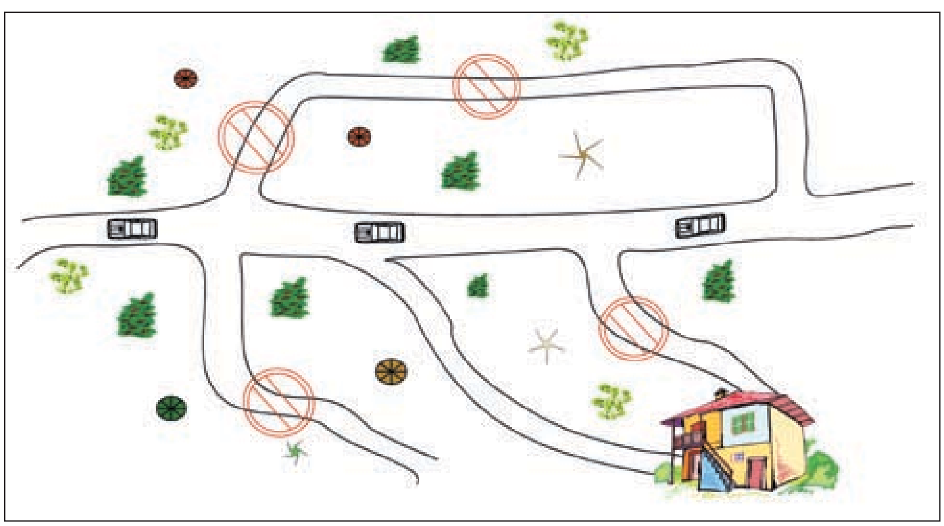


It should be noted that low standard roads used by livestock may need to be closed to trailing or treated the same as other roads to prevent erosion and assure good drainage.

Road closure is a three step process:

1. The first step is to block the road to further use of any sort, whether intentional or accidental. This step involves blocking, gating and/or signing the road against travel. Blockage can take the form of a gate, a fence or logs, boulders or tree stumps placed across the entrance; digging a ditch across the road; removing a culvert; erecting an earthen barrier, or even planting trees in the roadway (Figure V-5). Simply signing the road against entry may prove sufficient. In the case of public lands, an administrative closure order may be required to enforce a closure. Asking the public to "please cooperate" and providing them with a brief, well-reasoned explanation can be helpful in controlling use.
2. The second step may include the installation of well planned, properly positioned drainage structures that reestablish the natural drainage pattern characteristic of the pre-roaded condition. Simply removing berms and pushing up waterbars may suffice in establishing adequate drainage but most likely more elaborate

Figure V-6: *Reduce road density. Close or remove multiple roads serving the same destination.*



treatments will be needed to establish desirable flow paths across the land form. Often the proper treatment is to establish dispersed flow or "sheet" flow rather than channelized flow.

3. For the third step, special drainage features should be installed to protect or preserve sensitive sites such as springs and spring seeps from surface runoff intrusion and sedimentation. Former wetlands should be rehydrated to restore productivity. This sometimes can be accomplished by installing small dams at strategic locations and removing berms or ditches to reestablish natural drainage patterns across the landform.

Full bench recovery is a more intensive and expensive treatment used to obliterate a closed road and restore the landform to its original configuration and slope characteristic prior to construction. This is accomplished by retrieving earthen fill material from the fillslope (PhotoV-13) and placing it back on the road bench at the appropriate width, depth and angle to reestablish prior treatment conditions. Once replaced, the fill should be promptly mulched and reseeded for rapid revegetation and soil stabilization. Depending on local conditions such as soil texture and steepness and length of slope, fill retrieval can be done with a bulldozer, excavator or backhoe. Secondary drainage features may be needed to prevent rapid erosion of the newly placed material. Aspect, i.e. direction of slope exposure, may favor or delay revegetation due to drying effects of direct sunlight or prevailing winds. Full bench recovery may be used to obliterate or conceal the presence of a former roadway or to render further passage impossible.

Erosion Control and Revegetation

It is often quick, convenient and economical to reseed disturbed soils during time of treatment. It can be easy for the equipment operator to scatter a locally adapted seed mix. It is recommended that a native seed mixture be used that is appropriate for the soil type, precipitation pattern and elevation of the treatment area. You can use the tread of the equipment to track in the seed while work is in progress (Photo V-14).

Photo V-14:
Reseeding a disturbed area during treatment construction.

Photo V-13:
Full bench recovery is a more intensive and expensive treatment used to obliterate a closed road and restore the landform to its original configuration and slope characteristic prior to construction.

VI. Survey and Design: Placing Treatments on the Ground

Survey and design is where theory meets the road. Once a road has been selected for treatment, goals and objectives from the management plan, knowledge and experience of the planner and skills of the operator can come together and go to work. While a well trained operator can do much from the tractor seat to modify and improve substandard drainage features, best results are achieved by clearly separating the layout and design phase from the treatment phase. Planning and layout take total concentration. Tracing the flow path of water down the roadway, selecting suitable spill points, observing patterns of sediment deposition, checking the origin of inflow and disposition of outflow and selecting the best water harvesting treatment for the site is a full time job. Operating a dozer is a full time job as well. This is no place for "multi-tasking." Do not combine planning with implementation duties.

Survey Equipment

Tools of the planner include above all, a clinometer, a measuring device (tape, wheel or range finder), a map, aerial photo or GPS unit, a notebook and pencil, survey stakes, flagging and marking paint (photos VI-1 and VI-2).

Photo VI-1: *Clinometer, compass, notebook, maps and pencils.*

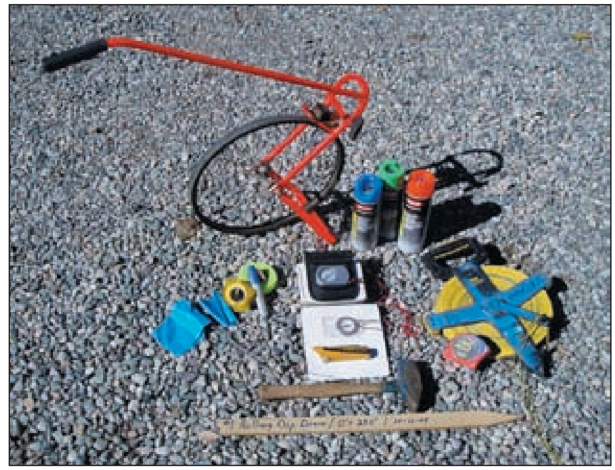


Photo VI-2: *Tools for survey, design and layout.*

"Once a road has been selected for treatment, goals and objectives from the management plan, knowledge and experience of the planner and skills of the operator can come together and go to work."

Standard Marking Procedure

Clear communication between the planner and the equipment operator is vital to a successful project. A simple and consistent method of identifying, marking and delineating treatments on the ground is critical to informing and directing the dozer operator.

An example of a planning protocol leading to a clear and consistent direction might be to:

- ❒ Place all survey stakes or flagging on the upslope side of the road.
- ❒ Number treatment site locations consecutively.
- ❒ Specify treatment on the survey stake or flagging, i.e. rolling dip, flat land drain, rolling outslope, remove berm, etc., or by using different colored flagging for different kinds of treatments.
- ❒ Delineate the orientation of the drainage structure and outfalls on the ground with a paint line or row of rocks, or delineate the location and extent of berm breaks with paint stripes or pin flags; be consistent.
- ❒ Use a standard dictionary of treatments and terms.
- ❒ Keep a map and inventory of treatments.

Procedure

Experience has shown that the most direct and time-saving approach for laying out drainage features is to travel on foot. Start at the top of a road segment and follow the water down. The advantage is that each new increment of runoff, whether from the road surface itself, a tributary, a spring, an intersecting road, trail or gully can be dealt with at its source and disposed of promptly with the proper treatments. Rills, ruts, slumps, slides, puddles, pot holes, sediment deposits, mud holes and vegetation provide clues to the drainage pattern, erosion problems and water harvesting opportunities encountered along the way. While proceeding downslope, opportunities will present themselves to spill and disperse road runoff onto soil sites and landforms capable of absorbing the additional runoff while maintaining a low erosion risk. Concentrated flows can be dispersed promptly and harmlessly. Vegetation growth, diversity and density can be stimulated by carefully selecting patches or stands to be irrigated with runoff water (Table VI-1).

Guidelines

Scientifically derived guidelines have been developed for calculating recommended spacing between drainage features such as water bars or dips (Table VI-1). Such guidelines are based on steepness of road grade and soil texture as related to erodability of the road surface.

A more pragmatic approach to selecting drainage points is based on the principle of dispersing runoff at every opportunity along the way rather than at some predetermined spacing interval. The working guideline to this approach for selecting spill points is the mantra:

First Chance, Last Chance, Best Chance, No Chance.

To interpret and apply this guideline, assume the maximum spacing between spill points is 250 – 300 feet for road grades less than 10%. For steeper grades, shorten the spacing as the grade increases. Starting at the top of the grade, spill accumulated runoff at every opportunity. Continue downslope and repeat, using the most appropriate treatment for the site as described in Chapter V.

Situations will be encountered where there is no opportunity for drainage within the overall spacing guidelines. In that event, carry on and spill accumulated runoff at the ***First Chance*.**

Other situations will be encountered where clearly there will be no feasible opportunity for drainage for some distance down grade, as when entering an entrenched road segment or steep downhill slope. In that case, spill all accumulated runoff before entering that segment. This is the ***Last Chance*.**

In other situations, the only available spill point may not offer an absorptive surface but may be the ***Best Chance*.**

Finally, it may be necessary to simply acknowledge that there is ***No Chance*** at all. In applying these rules, consider not only where the water is coming from but also where it will go. The need to compromise objectives may become evident.

Table VI-1:

Maximum Spacing of Cross Drain Structures Based on Road Gradient and Soil Type			
Soil Type	Road Gradient (%)		
	2%-4%	5%-8%	9%-12%
Highly Erosive Granitic or Sandy	500 feet	300 feet	200 feet
Intermediate Erosive Clay or Loam	700 feet	500 feet	350 feet
Low Erosive Shale or Gravel	900 feet	700 feet	500 feet

Low Maintenance Roads for Ranch, Fire & Utilities Access, Guenther, 1999.

For an effective drainage system ask yourself:

- Where is the water coming from?
- Where is the water going?
- Where should it be going?
- What treatment is needed to make it go there?

"A more pragmatic approach to selecting drainage points is based on the principle of dispersing runoff at every opportunity along the way rather than at some predetermined spacing interval."

Preferred Treatments

Of the various treatments described in Chapter V, the preferred treatment is always the one which will get the job done efficiently while requiring the least future maintenance. Choice of treatment, therefore, must call on knowledge of soil texture, soil depths, precipitation patterns, aspect, the relationship of slope steepness to runoff velocity, the bearing strength of soils under various moisture conditions, vehicle capabilities and limitations and the planner's ability to read the landscape and to choose accordingly. There are no preferred treatments, only relatively dependable ones.

See Appendix E for a chart listing treatments, when/where to use, purpose and conditions of use, and cautions.

Photo VI-3: *Using a clinometer to measure the percent slope of a landscape.*

VII. Monitoring: Are Maintenance Practices Effective?

Monitoring is not research. Monitoring is a tool of management. Monitoring provides timely information important to the land manager. Are objectives being met? Are the new practices working? Is maintenance effective? Is the vegetation responding to water harvesting treatments?

Monitoring can be simple, but never casual. To be most useful at any intensity, monitoring should be deliberate, disciplined, scheduled and consistently applied. Monitoring should lead to a better understanding of natural processes affecting the maintenance program while providing a basis for modifying treatments and scheduling maintenance operations.

Monitoring can be solely visual or carefully documented and supported by measurements and repeat photography. Weather records can be helpful in interpreting the knowledge gained from monitoring.

When monitoring road drainage and water harvesting features, the following are useful indicators of structure performance and maintenance effectiveness:

"To be most useful at any intensity, monitoring should be deliberate, disciplined, scheduled and consistently applied."

Flow Paths

The most informative monitoring technique is to simply watch water running on the roadway during a rainstorm. Flow patterns develop as water runs down, across or along the roadway. Where is the runoff coming from and where is it going? Where does it enter and leave the roadway? What road features modify the flow path? Which structures are effective in guiding the flow and which ones are not? Could some structures be modified to improve their performance?

Water moving downslope leaves trails. When it is not feasible to observe a storm event in progress, read the trails left by the storm. Flow paths can take the form of rills and gullies on the roadway or nearby, sediment deposits, stained rocks, disturbed soils, or trails of debris. Accumulation of twigs, leaves, pine cones, plastic bottles or drink cans can mark the flow path. Reading these "tracks" can provide useful information about the width and depth of runoff waters and ultimately about the effectiveness of various types of maintenance treatments. To learn more, follow the flow path beyond the edge of the road.

To document changes in the flow path, take photographs, make measurements, draw sketches and keep records of noticeable changes.

"When it is not feasible to observe a storm event in progress, read the trails left by the storm."

Photo VII-1: *Flow patterns show where drainage structures have failed.*

Cross Sections

Examining various cross sectional features along the roadway can help in evaluating the performance of typical treatments. Changes in the size, shape, depth, extent or positioning of wheel ruts, puddles, mud holes or debris fans on the road surface may indicate flaws in the size, shape or location of drainage structures. Such indicators relate directly to the effectiveness of drainage structures. A puddle in the roadway upslope from a rolling dip could mean that the dip drain is plugged or too flat. Should the drain be steeper? Wheel ruts cutting through a waterbar may indicate that the road was used during wet weather or that the waterbar was built with the wrong type of material. An evolving debris fan on the roadway may mean that the cross drain is too flat. An evolving gully may indicate that adjacent drainage structures were placed too far apart for the length and steepness of slope and soil stability.

"Changes in the size, shape, depth, extent or positioning of wheel ruts, puddles, mud holes or debris fans on the road surface may indicate flaws in the size, shape or location of drainage structures."

Photo VII-2: *Puddle formation due to too little slope in the dip drain.*

Erosional Features

Erosional features on the roadway, on cut and fill slopes, and on the adjacent landscape can offer important clues about structure performance. Tell-tale erosional features include rills, gullies, headcutting, pedestalling and erosion pavement.

Ditches and Cross Drains

When monitoring ditches and cross drains, the key performance indicators of an eroding ditch are: gully and rill formation, scour, headcutting, and slumping (ditch capacity may be too small for the discharge volume), sediment deposits in the ditch, and clogging by vegetation or debris.

Possible remedies for an eroding ditch are:

- ❒ to install additional lead-out ditches and cross drains;
- ❒ armor the ditch with cobble or energy dissipaters;
- ❒ widen the ditch, install additional or alternative outfalls; and
- ❒ encourage vegetation growth.

Remedies for an aggrading ditch could include:

- ❒ removing clogs, debris barriers or vegetation from the ditch bottom;
- ❒ installing additional lead-out ditches or cross drains;
- ❒ steepening cross drains or ditches; or
- ❒ reducing the width of the bladed road surface to reduce sediment yield to the ditch.

Photo VII-3: *Vigorous vegetative growth in response to water harvested at a newly placed lead-out ditch.*

"Possible remedies for an eroding ditch are to install additional lead-out ditches and cross drains; armor the ditch with cobble or energy dissipaters; widen the ditch, install additional or alternative outfalls; and encourage vegetation growth."

Vegetation Response

An important reason for monitoring is to detect change or lack of expected change in the vegetation growing along the roadway. Changes in species composition, height growth, stocking density, color, and vigor may indicate favorable change in soil moisture conditions resulting from water harvesting practices applied to the roadway. The correct interpretation of apparent change in vegetation response to treatment may require repeated monitoring over time.

Some indicators of successful treatments include:

- ❒ changes in species diversity, upland species being replaced by moist soil species,
- ❒ change in color and vigor of plant foliage,
- ❒ decadence or mortality among upland herbaceous and woody plant species growing on wet soil areas,
- ❒ replacement of woody species by sedges and grasses, and
- ❒ increase in plant densities and forage yield.

Ponderosa pines growing on wet meadow sites, for example, will turn yellow, weaken and die as meadow soils become more saturated. Apparent changes in plant species composition or growth patterns can be confirmed by measuring soil moisture levels or the accumulation of organic materials on the soil surface.

Water Quality

Improved water quality can be a goal of improved road maintenance or operations. Streams, spring seeps, ponds, stock waters and irrigation systems can benefit.

If so, some indicators of success or failure observed during monitoring may include:

- ❒ a change in suspended sediment (turbidity),
- ❒ change in bedload composition,
- ❒ increase or decrease in fine-grained sediment deposits coating the stream bed,
- ❒ change in the relative proportion of road surfacing material represented in bedload deposits, and
- ❒ erosion of stream or gully bed and banks.

These factors can be expressed qualitatively simply by visual observation (clear, muddy, very muddy, etc.) or quantitatively by conducting a "pebble count" or by measuring turbidity using a Seki disk or other instrument.

"An important reason for monitoring is to detect change or lack of expected change in the vegetation growing along the roadway."

VIII. Streams, Wetlands, Springs and Ciénegas

Special treatments are needed where roads cross streams, wetlands, wet meadows, spring seeps, and ciénegas or former wetlands. Management should, of course, focus on creating a serviceable road while mitigating any adverse impacts and taking advantage of opportunities to restore damaged sites. Carefully designed treatments can improve the road, protect existing wetlands and restore former wetlands to their natural potential (Managing Roads for Wet Meadow Ecosystem Recovery, Zeedyk 1995).

Photo VIII-2: *Headcutting caused by improper culvert installation.*

Maintenance problems commonly encountered with streams and wetlands include:

- establishing a firm road bed,
- keeping the road surface well drained,
- avoiding stream capture by the roadway during flood events,
- sizing culverts, bridges and fords to accommodate flood events, and
- crossing at proper elevation to avoid flood damage to roadway or approaches.

These concerns are important considerations in maintaining a serviceable road.

Other considerations critical to maintaining channel stability, site productivity, the water table and riparian health include:

- properly placing and sizing culverts,
- hardening fords to stabilize the channel bed elevation,
- controlling the propagation and expansion of erosion fans,
- preventing concentration and acceleration of surface runoff,
- restoring low velocity sheet flow across meadow surfaces,
- establishing the appropriate hydroperiod (duration of flooding) to sustain moist soil vegetation native to the area, and
- not impeding the movements of aquatic organisms unless the goal is to have a barrier to upstream migration of invasive aquatic species.

Photo VIII-1: *Unimproved fords are commonly used steam crossings on low standard roads. A road should cross at right angles to the direction of the flow to avoid stream capture.*

Guidelines for Stream Crossings

1. Always cross streams at right angles to direction of flow; cross at a straight reach or meander crossover. Never cross in a bend or meander apex.

2. Align the road to cross the stream at the right spot and angle. Do not build the road first and then channelize the stream to align it with the crossing (Photo VIII-1).

3. Place culverts, fords or bridges at the proper elevation to keep the streambed at the normal elevation and stabilize the channel slope. A culvert installed below grade will cause the channel to downcut, initiate headcutting and lower the water table. A culvert placed above grade will pond water and capture sediments.

4. Use a bridge, ford, culvert or culvert array of the right size to maintain natural bankfull channel width.

5. Use a low water crossing, improved ford or multistage culvert array to maintain the stream's access to its floodplain at bankfull flood stage.

Photo VIII-3: *A vegetated buffer zone between a closed road and Gold Creek, Valle Vidal, Carson National Forest, NM.*

Guidelines for Streamside Road Locations

1. Avoid encroaching on the active channel or its floodplain. Encroachment will narrow the channel, increase stream velocities, initiate bed scour and cause the opposite bank to erode (Photo VIII-4).

2. Maintain a vegetated buffer zone between the road and the stream bank (Photo VIII-3). Spill road runoff onto the buffer zone to filter sediments and reduce turbidity. Do not spill runoff directly into the stream. Buffer effectiveness increases exponentially with width.

3. Use berms to keep runoff on the roadway between buffered sites.

4. In the absence of a buffer zone, spill road runoff into a rock-lined ditch to avoid gaining additional sediment.

5. Keep the road high on the terrace and out of the floodplain to avoid capturing stream flow on the roadway during flood events.


Photo VIII-4: *Road encroachment on streambank.*

Guidelines for Roads Crossing Springs and Ciénegas

1. If at all possible, avoid crossing seeps and ciénegas; relocate the road to an upland site.

2. Where a crossing is unavoidable, approach the crossing from an elevated position on the hillslope and drop down to the elevation of the spring, seep or ciénega; cross and climb out quickly on the opposite side.

3. If an elevated road bed is needed to cross a seep or ciénega, haul embankment materials to the site from an upland borrow source. Do not take fill from a borrow ditch to build an elevated embankment. Digging a borrow ditch will lower the water table, trigger headcutting, create a gully and dehydrate the wetland.

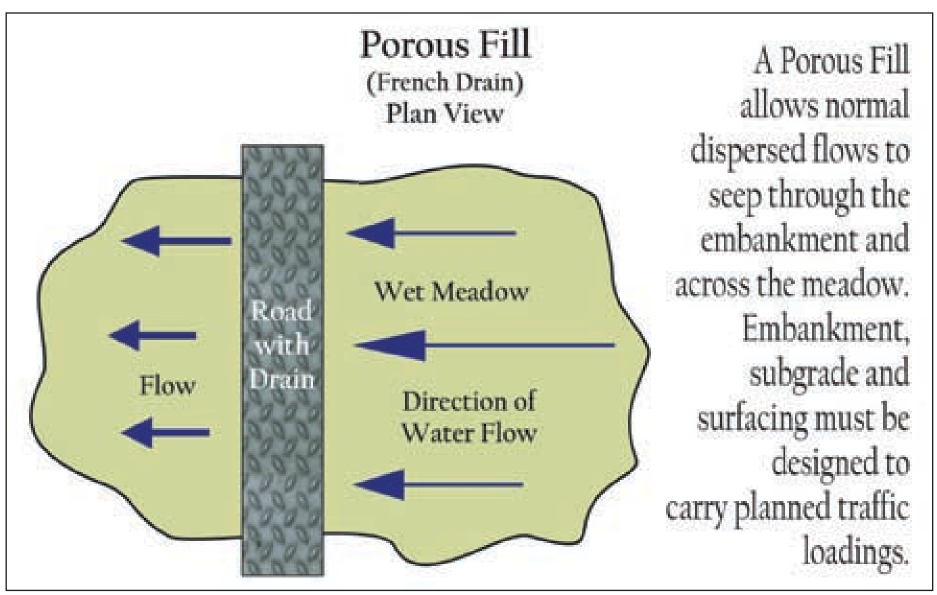
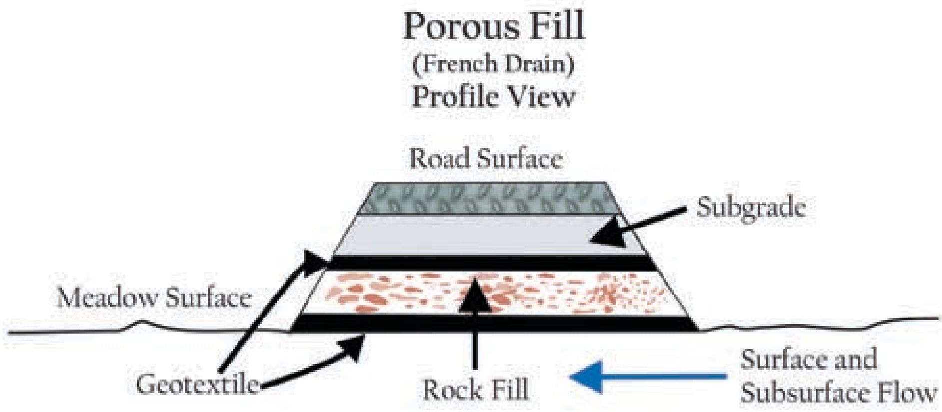


Figure VIII-1: *Porous fill, plan view.*



A porous fill uses rock or other permeable fill material sandwiched between layers of geotextile. A road built atop this drainage device promotes passage of dispersed flow through the embankment.

Figure VIII-2: *Porous fill, profile view.*

4. Use a porous road fill (French drain, Figures VIII-1 and VIII-2), not culverts as cross drains to carry water under an elevated roadway. A porous fill will maintain low velocity sheet flow on the surface of the wetland while wetting the entire width of the landform. By contrast, culverts tend to concentrate flows and foster gully formation on the wetland surface.

5. Avoid spilling runoff from an upslope roadway or road ditch directly onto the fragile soils of a seep or ciénega. The concentrated discharge from the ditch will accelerate flow velocities and trigger gully formation that will dehydrate the wetland. As an alternative, spill road runoff at the last available buffered location just upslope from the ciénega edge and disperse runoff evenly across the ciénega as sheet flow. Never spill road runoff into an existing gully but put it to use growing vegetation on intact soils.

6. Sand and gravel eroded from a road surface or ditch can bury wetland soils beneath a sterile blanket of sediment and convert the site from wetland to upland. Try to capture these materials on upland sites.

Guidelines for Roads Crossing Wetlands and Former Wetlands

1. When crossing a former wetland or wet meadow that has been dehydrated by road-related drainage structures and erosional processes, attempt to reestablish moist soil conditions in the wetland through the careful design and construction of replacement structures.

2. If the road or ditch system is incised beneath the meadow surface, attempt to relocate the road to a higher location. Install dams or berms across the abandoned location and backfill ditches to restore dispersed flow, raise the water table and increase storage capacity. Do not inundate the site, but saturate in keeping with seasonal runoff cycles and natural water depths.

3. If relocation/restoration is not feasible, consider backfilling incised road segments, plugging ditches and removing berms as above.

4. Examine stream and ditch crossings to determine if improper culvert installations have de-watered the site. If so, consider raising culverts or culvert inlets to the elevation needed to restore wetland function.

5. It has been customary in the past to dig culvert footings too deeply into the meadow bottom. This practice has been used to insure rapid drainage and minimize the amount of fill materials needed to cover the pipe. Unfortunately, this practice almost invariably causes headcutting and gullying, which lowers the water table, drains the soil and destroys wetlands. Improper culvert installation can be corrected by removing the pipe, backfilling the hole and replacing the pipe at the proper elevation to rehydrate the soil. A multiple-culvert array spread across the breadth of the meadow may be useful in some situations to restore sheet flow to the entire meadow surface. As an alternative, it may be feasible to simply raise the culvert inlet (invert) elevation without replacing the pipe by building a small dam at the inlet. Such a dam should be porous.

"If at all possible, avoid crossing seeps and ciénegas; relocate the road to an upland site."

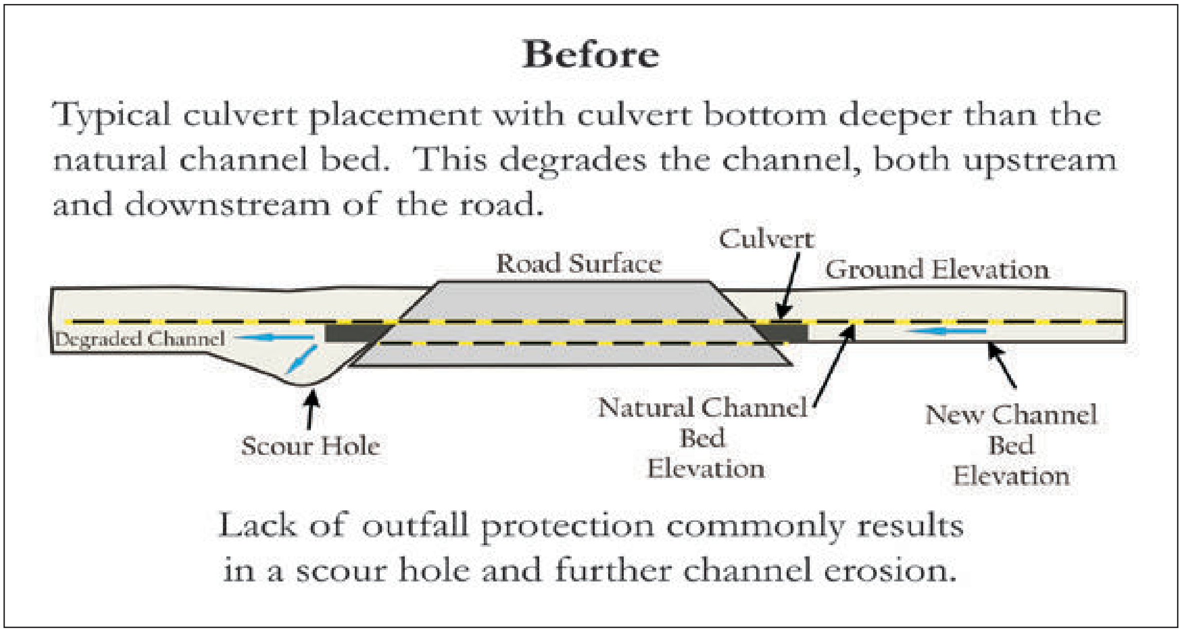


Figure VIII-3: *Improper culvert installation; culvert bottom beneath normal stream bed elevation.*

6. Depending on the size of the watershed and other features, a well defined stream channel may or may not be characteristic of the wetland under consideration. This may require further investigation. If a natural channel is indicated, the culvert should be sized and installed at the proper elevation to accommodate bankfull discharge and establish floodplain function. If it is determined that a defined stream channel is not characteristic of the site, then the culvert should be installed level with the meadow surface to restore sheet flow. Better still, a porous road fill (French drain) may be the proper treatment if the wetland is fed by a spring or spring seep; dispersed rather than concentrated flow.

Photo VIII-5: *A raised culvert inlet with recovering wet meadow vegetation.*

Wetlands are protected by the Clean Water Act (Appendix C). Permits may be required when modifying existing wetlands or stream channels and installing or modifying stream crossings, bridges, culverts or fords. Inquire at the US Army Corps of Engineers or your State Environment Department for guidance.

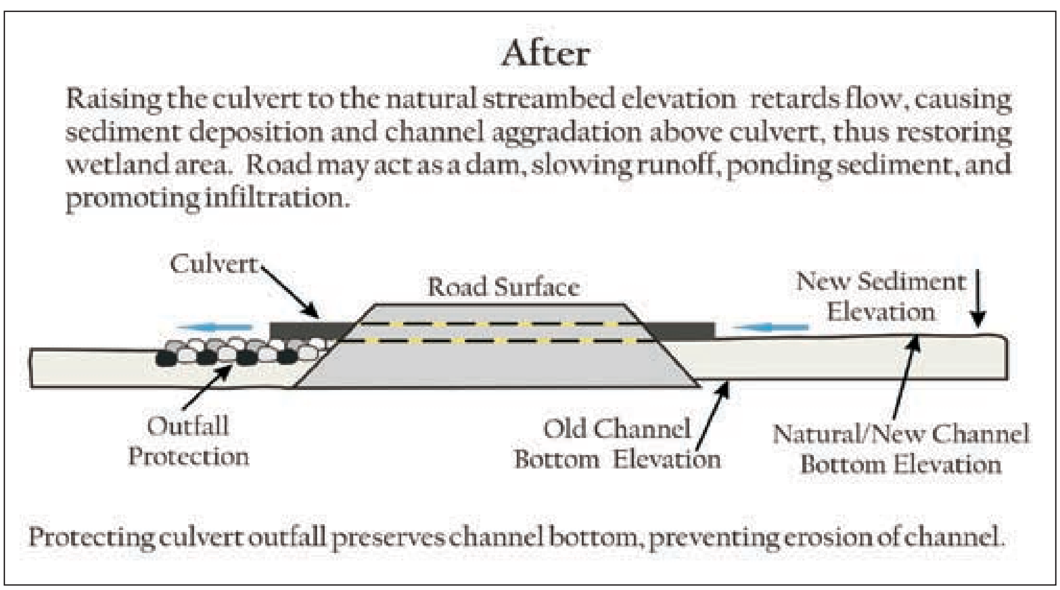


Figure VIII-4: *Proper culvert installation with culvert bottom installed even with the normal bed level. Culvert outfall armored to prevent bed scour.*

IX. Tools and Equipment - Getting the Job Done

Many factors should be considered in choosing tools and equipment best suited for maintenance or reconstruction of low standard roads.

From hand tools to farm machinery, skid-steer to motor grader, backhoe to bulldozer, capability varies. Each type of equipment has advantages and limitations which will bear on its usefulness. Obvious factors to consider include cost of operation, availability (on hand, rent or purchase) size and difficulty of the job ahead, type of material to be removed, weather conditions, operator skill and qualifications and any special equipment needs.

Can you accomplish the work to the correct standard using equipment on hand – within the operational capabilities of yourself or your employee? Or, must the needed equipment be leased and/or the job contracted out to get it done right? If contracted out, would the contractor know and understand the "what and why" of the requested work and be trained to do it?

Soil Type and Conditions

More than for other factors, the choice of equipment will relate to soil type and site conditions because these determine power requirements and the need for specialized equipment. The ability of any piece of equipment to move earthen material is known as break-out force or power. Break-out force is determined by 1) weight of equipment, 2) horsepower and 3) traction. Thus, the bigger and more powerful the machine, with good traction, the more earth it can move. Moist soils are easier than dry soils to break-out and compact better when placed on the roadway or fill. Steep, rough, rocky, terrain will require more power than toeslopes or gently rolling land with sandy-loam soils. Rippers used to loosen native soils or compacted road surfaces can greatly increase the effectiveness of equipment as can specialized tread and track designs, for example, wide flotation tracks for wet or very loose soils.

"The ability of any piece of equipment to move earthen materials is known as break-out force or power."

Equipment

♦ Bulldozer

A bulldozer is the most versatile machine for construction, reconstruction or maintenance of low standard roads. A large, powerful machine such as a D-7 or D-8 or equivalent, may be needed for rough, rocky terrain or situations where the existing roadway is tightly compacted or very dry. However, in most situations, a small to medium weight machine such as a D-4, D-5 or D-6 equipped with a six-way hydraulic blade and rear mounted ripper will prove powerful enough to do the job while at the same time being quicker and more agile than a larger machine. Speed, versatility and ease of operation may prove more useful than sheer size, weight and power. The cost and difficulty of transporting heavy equipment to the job can prove to be a very important consideration. Heavier equipment is more costly to transport and access routes may be limited. Finally, is the machine properly equipped to deal with very dusty, or very rocky or boggy situations as the case may be? Dozers are not well suited to leaving a smooth, even, high speed surface. A follow-up treatment using a grader or blade may be necessary to smooth the road surface.

Photo IX-1: *A medium sized bulldozer is ideal for building cross drains and for most maintenance situations.*

♦ Backhoes and Skid-steer Units

These rubber-tired tractors can be very versatile and efficient for periodic maintenance of low standard roads because of their maneuverability. Their usefulness can be limited by relatively small size, weight and power. They are best suited for ditch maintenance and culvert installation; however, with the right soil conditions, this type of equipment can be very effective in constructing cross drains. The backhoe can be used to break-up and loosen hard, native or compacted soils. To increase break-out efficiency, add digging teeth to the cutting edge of the loader bucket. Many farms, ranches and agencies already own this type of machinery, ready to go on a stand-by basis, so every day logistics may favor its use.

Photo IX-2: *Backhoe removing sediment from a culvert inlet.*

Photo IX-3: *Skid -steer units are relatively cheap, adaptable and easy to transport from site to site.*

♦ Motor Grader

These machines can be used effectively in the construction and maintenance of low standard road systems; however, they have some limitations. Motor graders can be limited on some locations by their size and length. Due to the size of the machine and the complexity of operation, the operator must be highly skilled for efficient use. Caution is advised that when low-standard road systems are maintained with a motor grader, the height of the roll-outs on rolling dip drains is maintained and not graded off. Motor graders are a very effective machine for removing existing berms to promote outsloping and essential in maintaining crowned surfaces. As with all types of equipment, motor graders are much more effective in moving native soil and compacted surfaces when they are equipped with rippers. Use of a water truck to moisten the road surface beforehand may render the motor grader more effective.

Photo IX-4: *Motor grader.*

♦ Small Farm Tractor

These light duty machines are especially useful in maintaining and cleaning drains, adding materials to roll-outs, light grading, and small scale construction duties. They will perform best with moist soil conditions. To increase their ability to move both native and compacted road materials, they should be equipped with a box scraper and ripper teeth.

Pre-ripping the soil will greatly increase the ability of these machines to move earthen materials and save much "wear and tear." If the tractor being used is a four- wheel drive type with a front loader bucket, break-out power

Photo IX-5: *Farm tractor with a box scraper and rippers.*

Photo IX-6: *Farm tractor using a box scraper to make a lead-out ditch.*

Photo IX-7: *Antique farm tractor making a lead-out ditch with a scraper blade.*

and traction can be greatly enhanced by filling the loader bucket three fourths full of dirt to increase weight and front wheel traction.

♦ **Chain Harrow**

The chain harrow can be pulled behind an ATV, pick-up or any type of tractor with a chain. It is especially

Photo IX-8: *Chain harrow pulled behind a bulldozer to smooth a rolling dip.*

Photo IX-9: *Chain harrow pulled behind a pickup to smooth the road surface. Such harrows can also be used to scarify the roadside for seeding.*

useful in smoothing newly constructed rolling dips, preparing and covering reseeded areas, small berm removal and general clean up.

♦ **Pick and Shovel**

A pick and shovel are the basic hand tools for maintaining cross drains on low standard roads. Keep them in your truck and utilize them whenever needed to keep drains and culverts open and functioning correctly. Five minutes of shovel work today could save hours of equipment time tomorrow.

Photo IX-10: *Trusty hand tools - pick and shovel.*

Equipment Operation Safety Tips

Read the equipment manufacturer's manual. Know and observe the safe operating limits of the equipment you are running and always wear your seatbelt and hearing protection. Warn everyone working with you to stand clear at all times and be careful to advise them of your blind spots and any other hazardous situations.

APPENDIX A: Glossary

Alluvium: Soils deposited by flowing water, usually uniformly sorted by size or texture.

Bearing strength: The relative strength of the road to support increased weight bearing down on the surface.

Bedload: The coarser component (sand and larger particles) of the sediment load that moves along the streambed as compared with the finer components which remain suspended in the water column.

Berm: A raised edge or shoulder running alongside and parallel to a road that prevents water from leaving. Berms may be intentionally installed to keep water off erodable fill slopes.

Ciénega: Riparian grassland characterized by low velocity surface and subsurface flows, fine-textured hydric soils with high organic content and sustained by groundwater discharge from deep, not alluvial, aquifers; infrequently flooded; an elevated hillside marsh containing springs (local in Southwest).

Colluvium: Soils formed by particles moving downslope under force of gravity; heterogeneous mixture, not sorted.

Cross Drain (relief drain): A culvert or pipe used to drain an upslope road ditch.

Cross Slope: The slope of a road perpendicular to the gradient of a road, either insloped towards the cutbank or outsloped towards the fillslope.

Culvert: A conduit, pipe, tube or passageway under a road used for the passage of water, debris, sediment, and aquatic life.

Cutslope (cutbank): The artificial face or slope excavated from soils or rock along the inside (upslope) of a road.

Ditch, cut-off: A ditch used to intercept and divert surface water away from the road ditch.

Ditch, flat-bottom: A "u-shaped" roadside ditch usually broader than deep; preferred for reduced sediment yield.

Ditch, lead-in: A ditch used to collect and lead surface flows into a culvert.

Ditch, lead-off: A ditch used to lead surface water away from a roadside ditch.

Ditch, lead-out: A ditch used to lead water away from the outfall of a cross drain or culvert.

Ditch, Road, Roadside, or Borrow: The ditch paralleling the roadway used to drain the road surface, road embankment and cut slopes; usually "V" shaped.

Ditch System (ditch works): The combination of all ditches, cross drains and channel crossings used to drain a road or road segment.

Dip Drain: The lowest portion of a rolling dip that carries water across a road surface.

Embankment: An artificially deposited bank of earth, rock or rubble used to support a road surface or hold back water (dyke).

Energy Dissipater: Rocks or other non-erodible materials placed where water is concentrated and used to blunt the force of flowing water and reduce its momentum.

Erosion: The wearing away of the land surface by detachment and transport of soil and rock fragments by wind or water.

Erosion Pavement: The hardened surface of coarse particles left after storm runoff has washed or eroded away finer textured soil particles (silt, clay, sand).

Fillslope: The artificial face on the downhill side of a road created by fill material excavated from the cutslope side.

Floodplain: That portion of a stream valley, adjacent to the channel, which is covered by water when the stream overflows its banks at flood stage.

French Drain: A road embankment constructed of porous rock fill for the purpose of efficiently conducting dispersed surface flows. Also called rockfill embankment, permeable fill embankment, stabilized natural drain and permeable fill and porous fill.

Geotextile: Synthetic fibers forming a woven, non-woven, or spunbonded fabric used to separate soil from engineered materials and add strength to a facility.

Grade: The slope of the road surface, usually measured in percent or degrees, as ascending or descending in the direction of travel.

Headcut: An encroaching escarpment associated with the extension of a stream channel into a previously unchanneled area or a point within an established channel where there is an abrupt and actively eroding drop in streambed elevation; a nick point.

Hillslope: The slope of the natural terrain upon which a road was constructed.

Hydric soil: A soil that is saturated, flooded or ponded long enough during the growing season to develop anaerobic conditions that favor the growth and regeneration of hydrophytic vegetation.

Hydrology: The science dealing with the properties, distribution and circulation of water, especially the study of water on the surface of the land.

Inslope: The amount or degree of steepness of inward sloping.

Insloped Road: A road surface that tilts inward toward the adjacent uphill side of the road or cut bank.

Nickpoint: The point of interruption of a stream profile.

Nonpoint Source (NPS) Pollution: Unlike pollution from industrial and sewage treatment plants, NPS pollution comes from many diffuse sources and by rainfall or snowmelt moving over and through the ground. As the runoff moves, it picks up and carries away natural and human-made pollutants, finally depositing them into lakes, rivers, wetlands, coastal waters, and even our underground sources of drinking water (www.epa.gov/owow/nps).

Outslope: The amount or degree of steepness of outward sloping.

Outsloped Road: A road surface that tilts outward toward the adjacent downhill side of the road or fillslope.

Percent (slope or gradient): The ratio of elevation change to the distance traveled. A 20% slope drops or gains 20 feet for each 100 feet of distance.

Permeable Fill, Porous Fill: See French drain.

Reverse Grade: A section of road that changes grade enough to cause water to flow in the opposite direction.

Riparian: A zone of transition between an aquatic ecosystem and an adjacent terrestrial ecosystem, usually identifiable by soil characteristics and by distinctive vegetation communities that require free or unbound water.

Riprap: A layer of coarse-sized rock fragments; cobble or small boulders spread on the ground surface to protect the soil from erosion by flowing water.

Road Gradient: The slope of a road along its alignment; referenced by direction of travel, positive when gaining elevation, negative when loosing it.

Road Template (cross section): The shape and cross-sectional dimensions of the roadway; cross sectional profile.

Rolling Dip: Excavated drainage structure designed to divert water off the road surface and consisting of two main features: 1) a below-grade drainage channel and 2) a reverse grade mound used to reinforce the drainage channel and ease vehicular travel across the structure.

Sedimentation: The deposition of detached soil and rock material that has been transported by water.

Waterbar: A low barrier, sometimes accompanied by a ditch, designed to divert water off of a road; usually installed after a road has already been built.

Wetlands: Those areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal conditions, do support a prevalence of vegetation typically adapted for life in saturated soil conditions. The current legal definition requires a site to have hydrophytic vegetation, hydric soil, and wetland hydrology.

Wet Meadow: Riparian (riverine) grasslands characterized by low to high velocity surface flows and low velocity subsurface flows with frequently flooded hydric soils, dominated by wetland obligate grasses and grass-like plants (especially grasses and sedges) and sustained primarily by incoming channel flows, shallow alluvial groundwater and overland flow.

Windrow: A ridge of loose soil, such as that produced by the spill off of a grader blade.

APPENDIX B: Weights and Measures

Water Facts:
1 inch of rainfall on 1 square foot of impervious material = 0.60 gallons
1 gallon of water = 8.34 lbs
1 cubic foot of water = 62.4 lbs and contains 7.48052 gallons
1 acre foot of water (43,560 sq ft X 1 ft deep) = 325,852 gallons
Water flow: 1 cubic foot per second (CFS) = 1,98374 acre foot per day or 646,319 gallons per day. 1 acre of impermeable road surface, on the average, will yield ~25,000 gallons (less transpiration) of water from 1 inch of rainfall.

Aproximate Weight of Earthen Materials per Cubic Yard:

Earth with 25% rock	= 2650 lbs
50% rock	= 2900 lbs
75% rock	= 3300 lbs
Gravel (1/4" – 2") dry	= 2850 lbs
wet	= 3400 lbs
Riprap stone (average)	= 2665 lbs

Lengths:

1 mile	= 5280 feet
	= 1760 yards
	= 320 rods
	= 80 chain
1 rod	= 16.5 feet
66 ft	= 1 chain

Square Measure:
144 sq inches = 1 sq foot
9 sq feet = 1 sq yard
30.25 sq yards = 1 sq rod
160 sq rods = 1 acre = 10 square chains
1 sq acre (208.71 ft X 208.71 ft) = 43,560 sq ft

Fuel Facts:
1 gallon of diesel = 7.1 lbs
1 gallon of gasoline = 6.5 lbs

Cubic Measure:
1 cubic foot = 1728 cubic inches
1 cubic yard = 27 cubic feet

APPENDIX C: Permits and Clearances

☑ **Clean Water Act (CWA):** The intent of the CWA is to restore and maintain the chemical, physical and biological integrity of the nation's waters.

☑ **Section 319(d):** The Nonpoint Source Pollution Program: Requires that states develop management programs for the control of nonpoint source pollution (http://www.epa.gov/owow/nps/cwact.html).

☑ **Section 401:** For federal-permitted or licensed activities that involve discharges to waters of the U.S. (http://www.epa.gov/owow/wetlands/facts/fact24.html).

☑ **Section 402:** The National Pollutant Discharge Elimination System (NPDES): Regulates the discharge of a pollutant (other than dredged or fill material) from a point source into waters of the U.S. (http://cfpub1.epa.gov/npdes/).

☑ **Section 404:** The wetland regulatory program: Establishes a program to regulate the discharge of dredged or fill material into waters of the U.S., including wetlands. The basic premise of the program is that no discharge of dredged or fill material can be permitted if a practical alternative exists that is less damaging to the aquatic environment or if the nation's waters would be significantly degraded. Questions can be directed to EPA's Wetlands Hotline at 1-800-832-7828 or e-mail: wetlands.helpline@epa.gov. Endangered species and archeological clearances may be required.

- 💻 http://www.epa.gov/owow/wetlands/
- 💻 http://www.usace.army.mil/inet/functions/cw/cecwo/reg/
- 💻 http://www.epa.gov/0202/wetlands/40cfr/part232.html

☑ **TMDL:** Total Maximum Daily Load is a calculation of the maximum amount of a pollutant that a waterbody can receive (http://www.epa.gov/owow/tmdl). DeBano, L.F., and L.J. Schmidt. 1989.

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APPENDIX E: Maintenance Treatments

Treat-ment Type	Where/When Used	Purpose and Conditions of Use	Cautions
Berm	Use to increase vehicle safety on slick, outsloped roads; also used to re-tain road runoff on road surface between suitable spill sites.	Berms should be high enough to keep runoff on the road surface or to pre-vent vehicles from sliding off roadway as case may be.	Runoff trapped on road-way by a berm can cause serious erosion or scour of road surfacing materi-als; divert runoff at close-ly spaced intervals.
Berm Removal	Remove unintended berms at every oppor-tunity from crowned, insloped and outsloped roads.	Keep water from becom-ing trapped on road surface; save fine-textured surfacing; protect road surface and reduce turbidity in receiving waterways.	Retain berms where needed to protect streambanks, springs and wetlands from silt-laden runoff; in special cases re-tain for vehicle safety on slippery outsloped roads.
Berm Breaks	Permit trapped or im-pounded runoff to drain through an intentional berm at regular inter-vals.	Drain intentional berms at 200-300 foot intervals at locations where runoff can filter through a vegetated or hardened buffer zone.	Select sites with filter zones or erosion resis-tant outfall sites or armor outfalls with riprap if nec-essary to prevent erosion.
Buffer Zone	Use to protect streams, springs and wetlands from sediment laden road runoff.	Prefer well vegetated porous soils with dense herbaceous (grassy) cover; upland sites preferred over wetland sites if available; performance increases exponentially with increased width.	Select best available sites to protect streams from direct runoff; use ditches or berms to direct flows to suitable sites but do not overload with excess amounts of runoff or sediment.
Road Profiles			
Crowned	High traffic, gravel sur-faced roads receiving frequent routine main-tenance where ditches and cross drains are well maintained.	Promote lateral drainage by maintaining a peaked or crowned surface with a 2-4% cross slope; increase average traffic speed and safety.	Do not "flat blade;" main-tain ditches and cross drains in good condition at all times; remove ruts and berms to prevent scour and loss of surfac-ing materials.

Treat-ment Type	Where/When Used	Purpose and Conditions of Use	Cautions
Out-sloped	Low to moderate traffic; coarse textured well-drained soils, "non-skid" surfacing; use on grades too steep for rolling dips.	Promote continuous lateral drainage with a cross slope of 2-4%.	Do not "flat blade;" remove ruts and berms; do not use on fine grained soils that become slippery in wet weather.
Insloped	Used to deflect and trap runoff in the upslope ditch for routing to a cross drain. Protect user safety.	Promote continuous lateral drainage with cross slope of 2-4%.	Do not "flat blade;" remove ruts and berms. Do not use on fine-grained soils that become slippery in wet weather. Must maintain ditches and cross drains at proper spacing and with suitable outfalls.
Cross Drains			
Culvert	Provide durable cross drain for a dry, even surface, especially for high speed or high traffic levels.	Provide ditch relief. Route surface runoff beneath the road.	Use adequate diameter, minimum of 18 inches; install at 2% cross slope, minimum; use ditch dams and energy dissipaters; keep inlets and outlets clean and stable.
Rolling Dip	Provide durable cross drain for lower speeds and lower traffic levels. Occasionally, too wet for travel. Use with hill-slopes greater than 5%, road grades greater than 3% but less than 15%.	Channel road runoff and ditch flows across the road; dip drain should have a minimum cross slope of 4%; roll-in and roll-out long enough to accommodate longest design vehicle; may need lead-out ditch.	Maintain roll-out in good condition; remove ruts; not suitable for road grade steeper than 15%; wet season use is discouraged.

Treat-ment Type	Where/When Used	Purpose and Conditions of Use	Cautions
Flat Land Drain	Provide durable cross drain for lower speed and lower traffic volume. Use with hillslope less than 5%, road grades less than 3%.	Use for flat land situations with poor surface drainage, low velocity runoff; excavate adequate lead-out ditch.	Drain may soften during wet weather; prevent wet weather use or harden structures with coarse gravel hauled to site.
Water-bar	Provide cross drainage for decommissioned roads, closed roads or obliterated roads only.	Not suitable for roads subject to traffic of any sort; can be damaged by routine livestock trailing, ATV or bicycle use.	Gate or block access to roads drained by water-bars.
Ditches			
Borrow or Road	Runs parallel with roadway; used to drain crowned and insloped roads.	Drain water from roadway and adjacent hillslopes; keep open, remove blockages and plugs; keep vegetated to minimize sediment yield.	Do not blade or remove vegetation from back-slope or ditch banks if not needed to maintain flow; "if it ain't broke, don't fix it!"
Lead-in	Leads water to a culvert or occasionally to a roll-ing dip.	Collect surface runoff and direct it toward a suitable crossing point.	Keep clean but well veg-etated to minimize sedi-ment supply; may need riprap.
Lead-out or Lead-off	Leads water away from a culvert, rolling dip, flat land drain or borrow ditch.	Grade of ditch must be equal to or greater than grade of tributary sources or ditch will clog with sediments; restores flow to dehydrated sites.	Do not spill runoff into sensitive sites such as springs if there is a buf-fer zone available. Keep grade steep enough to transport sediments (4% or greater).

Treat-ment Type	Where/When Used	Purpose and Conditions of Use	Cautions
Stream Crossings			
Low Water	Hardened road surface used to cross a stream channel or gully without a culvert or bridge.	Surface should be hardened with rock and the stream-bed armored or otherwise protected to prevent degra-dation (use cross vanes or weirs).	Keep channel cross section area as wide as feasible to accommodate peak flows at shallow depth; cross channel per-pendicular to direction of flow at riffle or meander crossover.
Culverts	Use to cross live or in-termittent or ephemeral streams; carefully place at natural streambed elevation	Use pipe(s) with sufficient capacity to accommodate a 25 year storm; use multiple-stage arrays to maintain stream access to floodplain; realign road to fit channel, not vice versa.	Cross at riffle areas only and perpendicular to direction of flow, do not cross in bend; do not channelize stream to fit culvert alignment.
Raised Culvert	Cross former wetlands at an elevation equal to historic wetland surface; used to restore wet-lands damaged by gullies; raise pool elevation to stop upstream headcut-ting.	Backfill former gully or raise incised streambed to proper bed elevation; install new culvert on fill material at proper elevation; armor outfall to dissipate energy.	Use only to restore wetlands, wet meadows and ciénegas to natu-ral surface elevation or streambed elevation if a channel was present; do not use to impound sites artificially.
Raised Culvert Inlet	Install drop inlet struc-ture at culvert inlet to restore historic stream-bed elevation or wetland surface; a minor modifi-cation of existing culvert installation.	Match top of structure with historic streambed or meadow surface only; used to remediate existing pipes short of replacement.	Be careful not to saturate road embankment; use for restoration of former wetlands only; use porous materials or techniques to assure that released flows mimic natural hydroperiod.

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