Drain Dips for Off-Highway Vehicle Trails

Roger J. Poff, Soil Scientist and James Scott Groenier, Project Leader

Collectively, off-highway vehicles (OHVs) include all-terrain vehicles (ATVs), motorcycles, and four-wheel drive vehicles that all use trails or primitive roads. OHV trails are generally wider, have faster traffic, and are more susceptible to wheeled erosion than non-motorized trails. Drain dips are used to shed water quickly from trails to help control erosion. This tech tip incorporates more than 20 years of incremental improvements to OHV trail design. It includes recommendations, drawings, and design construction notes about drain dips (figure 1) for ATV, motorcycle, and four-wheel drive vehicle trails. It also includes important information about how proper soil moisture affects compaction and how to evaluate soil moisture. Most of the information in this tech tip is specific to the narrower trails intended for ATVs and motorcycles for which OHV drain dips are appropriate. Some of the information also deals with drain dips designed for the specific drainage needs of four-wheel drive trails and primitive roads.

Figure 1—A typical all-terrain vehicle and motorcycle drain dip.

Highlights...

- Off-highway vehicle trails are generally more susceptible to erosion than non-motorized trails.
- Drain dips shed water quickly from trails to help control erosion.
- This tech tip includes recommendations, drawings, and design information about drain dips for off-highway vehicle trails.
Trail Drainage

Soil erosion on OHV trails is a major cause of tread loss, and sediment from eroded trails is a threat to water quality. OHV trails should be maintained in a condition that allows their continued recreational use without impacts to resources, including water quality. Trail drainage structures disperse runoff water before it concentrates and develops the energy to erode soils.

Providing drainage for OHV trails is different than providing drainage for roads. Compared to OHV trails, roads generally have a wider prism, are less steep, and have a well-compacted running surface. Runoff from roads generally contains less sediment and has more water volume, creating more erosion power. Roads are typically drained by outsloping, crowning, or insloping with inside ditches and cross drains. These drainage methods are not practical for most OHV trails. Compared to roads, OHV trails are typically narrower, steeper, and unsurfaced, and produce runoff with a high sediment content. Outsloping is ineffective on OHV trails, and inside ditches and cross drains are rarely used. Because OHV trails are narrow, they produce less runoff per unit length than roads. OHV trails require more frequent drainage because they are steeper and because traffic tends to loosen the tread, producing runoff that is more laden with sediment.

Development of Off-Highway Vehicle Drain Dips

Many OHV trails were originally constructed as logging roads, ranch roads, skid trails, fire lines, fuel breaks, and mining roads. They were not designed for OHV traffic. Trail alignment and gradient are often less than ideal for OHV use. Existing drainage structures that may have been suitable for the original purpose of the trail are usually not suitable for OHV traffic. The main problem with these inherited trails is that the grade does not include frequent dips to allow diversion of water from the trail. When trails are specifically designed for OHV use, a rolled grade is built into the alignment to provide drainage and to avoid long, sustained grades, unlike old roads that are converted to OHV trails.

Years ago, OHV trails were drained with waterbars; structures commonly used to divert runoff on skid trails and logging roads. While waterbars work well where there is occasional or no traffic, they cannot withstand OHV traffic. OHV traffic tends to cut through or around waterbars, causing them to fail. Waterbars may clog and fail without frequent maintenance.

Over time, OHV managers altered the design of the typical waterbar to withstand the wear of OHV traffic. They changed the angle of the waterbar to be more perpendicular to the trail, increased its height, elongated its profile, and greatly increased its length. These modifications allowed OHVs to ride up and over the drainage structure rather than cut through it. At the same time, managers paid more attention to compacting the core of the structure to make it more resistant to the wear of OHV traffic.

A common misconception is that outsloping can be used to drain OHV trails. Outsloping is ineffective on OHV trails because OHV traffic quickly causes a berm to build up on the outside edge of a trail, preventing the flow of water off to the side and forcing the flow down the trail instead. Trail gradient is also a factor. Outsloping only works when the out-slope gradient is at least as great as the trail gradient. Even on roads, this limits the application of outsloping to fairly gentle gradients; usually less than 6 percent. OHV trails typically have gradients greater than 6 percent.
**Drawings for Off-Highway Vehicle Drain Dips**

The key elements of this tech tip are the drawings of drainage structures for three types of trails:

- **ATV trails**
- **Single-track motorcycle trails**
- **Four-wheel drive trails and primitive roads**

The appendix to this tech tip includes the plan and profile drawings and oblique views for the following OHV trails:

- **Drawing 1**—Typical Drain Dip Illustration for ATV and Motorcycle Trails
- **Drawing 2**—ATV Trail, 8%, 6 Ft Tread; plan and profile views (grades 0 to 15 percent)
- **Drawing 3**—ATV Trail, 20%, 6 Ft Tread; plan and profile views (grades 15 to 25 percent)
- **Drawing 4**—Motorcycle Trail, 8%, 2 Ft Tread; plan and profile views (grades 0 to 15 percent)
- **Drawing 5**—Motorcycle Trail, 20%, 2 Ft Tread; plan and profile views (grades 15 to 25 percent)
- **Drawing 6**—Drain Dip for Use on Four-Wheel Drive Trails and Primitive Roads

The recommendations in the drawings incorporate the features that a properly constructed OHV drain dip should include, but will usually need to be fine-tuned to fit the landscape at each specific location. The dimensions in the profile and plan sketches are strongly recommended, but may also require modification for specific sites. Specific dimensions vary with the location, trail gradient, soil type, and type and speed of the OHV traffic.

**Off-Highway Vehicle Drain Dips Versus Waterbars**

A few features stand out when comparing OHV drain dips to the typical waterbars they evolved from:

- **Length**—OHV drain dips are much longer than a typical waterbar. The increased length allows OHV traffic to flow up and over the structure without cutting through it.
- **Height**—The height of the structure is greater than most waterbars. This allows some wear to take place between periodic maintenances. The increased height is also needed to attain an effective grade reversal on steeper trails.
- **Angle**—The angle across the trail has been reduced to about 5 degrees. This, like length, allows a smoother flow of OHV traffic up and over the structure.
- **Compaction**—The core of the structure is compacted during construction. A typical waterbar is cut into firm soil and the loose soil is piled up behind it. The cut below grade into firm soil diverts the water. In OHV drain dips, the compacted core and the reverse grade of the structure itself are also important for diverting water.
- **Sediment trap**—Waterbars and other drainage structures on roads typically have lead-off ditches at the outlets to disperse runoff. Road runoff is fairly clean and erosive. Rather than a long lead-off ditch, the OHV drain dip has a small sediment trap at the outlet. Runoff from trails is often heavily laden with sediment. The sediment trap allows soil eroded from the trail tread to be recycled into the tread or structure during maintenance.
Soil Compaction

The core of the drain dip structure must be compacted to the maximum extent possible in order to resist the wear of OHV traffic. A well-compacted OHV drain dip requires less frequent maintenance. Soils must be moist during construction and maintenance in order to get maximum compaction. Compaction is achieved by adding moist soil in small lifts and then making repeated passes over the soil with a trail tractor; preferably one with a sheepsfoot roller attachment. Additional information on the relationship between soil moisture and compaction and on how to make field evaluations of soil moisture content is provided under the “Soil Compaction and Soil Moisture” section of this tech tip.

Off-Highway Vehicle Traffic

The type of OHV traffic and its speed affect the design of OHV drain dips. Drain dips should be shaped so OHVs are either in the air when they cross the top of the dip, or at least cross the dip with less ground pressure and without spinning or digging into the structure.

The shape of the apex of the mound portion of the drain dip affects how OHVs ride over it. A 5-degree shoulder at the top of the dip smooths out the traffic flow and reduces wear on the top of the structure. Figure 2 illustrates correct and incorrect profiles at the apex of a drain dip.

Figure 2—Correct and incorrect profiles at the crest apex of a drain dip.
Sediment Traps

Installing a sediment trap at every OHV drain dip may not be practical, but sediment traps should be installed wherever possible. Sediment traps capture eroded soil so that the soil can be recycled back into the trail or drainage structure during maintenance. Any soil not recaptured is permanently lost from the tread and reduces the useful operating life of the trail.

Gradient Limitations

The drain dips shown in the drawings will not work on trails with gradients steeper than about 25 to 30 percent. On gradients steeper than 25 to 30 percent, the approaches and transitions of adjacent OHV drain dips begin to merge. Also, as the gradient increases, the height necessary to create a grade reversal over steepens the downhill approach.

Spacing and Location

There is no “cookbook” rule for spacing drainage structures on OHV trails. Drainage must be provided frequently enough to disperse water before it can concentrate and cause erosion. Spacing depends on trail gradient, the amount and type of OHV traffic, runoff from adjacent slopes, and soil types. Most trails require drainage every 100 to 200 feet, but steep slopes require closer spacing. The location of drainage structures is usually more important than the spacing.

Drainage should be provided as frequently as possible, particularly on landscapes with shallow soils that have a low capacity for absorbing additional runoff. Drainage is also needed on approaches to watercourse crossings. Natural breaks in grade should be used to locate drainage structures whenever possible.

Locating OHV drain dips requires evaluation of the site to determine where diverted runoff will drain and to analyze how the drainage structure will affect the flow of OHV traffic.

Trails with steep sections require drainage at the top, just before the slope break. The diverted runoff, whether through a drainage outlet or into a sediment trap, must drain onto soils with the capacity to absorb the runoff.

Climbing turns are a challenge to drain. Drainage is required just before and just after the turn, but water drained after the turn could run onto the trail below. Install pipes under the trail to help prevent this problem. Ensure that there is enough filtering capacity between the drainage outlet and the trail below. This example shows why location is more important than a set spacing interval.

Maintenance

Drain dips, if properly constructed with good compacted material and designed to shed water properly, can remain functional for 3 to 5 years before requiring maintenance, even on trails with heavy OHV traffic.

Drain Dips for Four-Wheel Drive Trails

OHV traffic is generally slower on four-wheel drive trails and primitive roads than on ATV and motorcycle trails. The drain dip (figure 3) is the most effective type of structure for draining four-wheel drive trails and primitive roads. The drain dip is also designed to allow a smooth flow of traffic. Drain dips are often used in conjunction with outsloping and rolling the grade. Challenging or highly technical four-wheel drive trails rarely have constructed drainage structures. Instead, drainage is provided by rolling the grade, making frequent grade reversals, keeping steep trail segments short, and choosing an alignment that takes advantage of landscape features, such as ridgelines or hard bedrock.
Soil Compaction and Soil Moisture

Soil compaction is important for constructing and maintaining sustainable trails that resist wear from OHV traffic. Proper soil moisture content is required to achieve maximum soil compaction.

Basic Principles of Soil Compaction

The core of a drain dip must be compacted to the maximum extent possible to resist the wear of OHV traffic. A well-compacted OHV drain dip also requires less frequent maintenance. For maximum compaction, soils must be moist during construction and maintenance. Compaction is achieved by adding moist soil in small lifts and making repeated passes over the soil with a trail tractor. Soil moisture content determines the degree of compaction that can be achieved during construction. This section explains how soil moisture affects soil compaction and describes some simple field observations to determine when soils are sufficiently moist for construction or maintenance.

Soil compaction is a process that increases soil strength and density by reducing soil pore space; essentially squeezing the air out of the soil. Soil is most easily compacted when it is moist and its pores are partially filled with water. Under moist conditions, the fine pores contain enough water to reduce internal friction, but the coarse pores are empty and compressible. When a load is applied to moist soils, soil particles are rearranged and packed tightly. This increases resistance to the wear of OHV traffic.

When a load is applied to saturated soils, a form of displacement called “puddling” occurs. Puddling is similar to squeezing toothpaste from a tube. It destroys soil structure and, although puddled soils may increase in density as they dry out, they do not have the strength of compacted soils.

Dry soils have high soil strength. Dry soils are difficult to compact because particle bonding is strong and the soil contains insufficient moisture to lubricate particles and facilitate packing. Mechanical disturbance of dry soils destroys the soil structure and shatters compacted soils. After being disturbed, dry soils cannot be recompacted as long as they remain dry, and additional disturbance merely displaces the soil.

Field Tests for Soil Moisture

To determine whether soils are moist enough to compact, take a handful of soil and squeeze it into a ball. If squeezing reduces the volume of soil and you can form a ball that holds together when you handle it, the soil is sufficiently moist to compact. If the volume of soil cannot be reduced and you cannot form a ball, or if the soil separates when pressure is released, the soil is too dry to compact. If water or wet soil oozes from between your fingers when you squeeze the soil, the soil is too wet to compact.

The moisture content at which compaction occurs varies by soil type. Size distribution of soil particles—or soil texture—affects the range of moisture content within which compaction occurs. Where the clay content is high, compaction occurs over a wide range of soil moisture. Where the clay content is low, compaction occurs within a narrow range of soil moisture. Table 1 indicates (by soil texture groups) some indicators of soil moisture levels at which compaction occurs.
Table 1—Field indicators of soil moisture contents suitable for compaction, categorized by soil texture groups.

<table>
<thead>
<tr>
<th>Soil moisture content</th>
<th>Coarse soils*</th>
<th>Light soils</th>
<th>Medium soils less than 35 percent clay</th>
<th>Heavy soils more than 35 percent clay</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sands, loamy sands, and very coarse sandy loams</td>
<td>Coarse, medium, and fine sandy loams</td>
<td>Very fine sandy loams, silt loams, sandy clay loams, light clay loams</td>
<td>Heavy clay loams, silty clay loams, sandy clay, clay</td>
</tr>
<tr>
<td>Dry</td>
<td>Loose, single grained; flows through fingers(^1)</td>
<td>Loose; flows through fingers(^1)</td>
<td>Powdery; sometimes slightly crusted but breaks down into powder(^1)</td>
<td>Hard, baked, cracked; sometimes has loose crumbs on surface(^1)</td>
</tr>
<tr>
<td>Slightly moist</td>
<td>Still appears dry; will not form a ball with pressure(^1)</td>
<td>Still appears dry; will not form a ball with pressure(^1)</td>
<td>Somewhat crumbly, but ball holds together after release(^2)</td>
<td>Somewhat pliable; forms a ball under pressure(^3)</td>
</tr>
<tr>
<td>Moist</td>
<td>Still appears dry, will not form a ball with pressure(^1)</td>
<td>Tends to form ball with pressure, but ball seldom holds together(^1)</td>
<td>Forms a ball and is very pliable; slicks readily if high clay content(^3)</td>
<td>Easily oozes out between fingers; has a slick feeling(^3)</td>
</tr>
<tr>
<td>Very moist</td>
<td>Tends to stick together slightly; sometimes forms a very weak ball(^1)</td>
<td>Forms a weak ball with pressure, ball breaks easily, will not stick(^2)</td>
<td>Forms a ball and is very pliable; slicks readily if high clay content(^3)</td>
<td>Easily oozes out between fingers; has a slick feeling(^3)</td>
</tr>
<tr>
<td>Wet</td>
<td>Free water may appear when squeezed; wet outline remains on hand(^1)</td>
<td>Free water may appear when squeezed; wet outline remains on hand(^1)</td>
<td>Can squeeze out free water; wet outline remains on hand(^1)</td>
<td>Puddles and free water form on surface; wet outline remains on hand(^1)</td>
</tr>
</tbody>
</table>

\(^1\) Soil too dry or too wet for compaction

\(^2\) Moisture level marginally suitable for compaction

\(^3\) Moisture level suitable for compaction

\(^*\) Coarse soils cannot be compacted by force when moist; compaction requires vibration

**Moisture Variability**

To determine whether a trail segment has sufficient moisture for construction or maintenance activities, examine soil moisture at several locations and depths. Under field conditions, soil moisture varies by soil type and depth, from place to place along a trail, and even from place to place within a single drainage structure. Aspect, elevation, vegetation type, shading, and surface drainage all affect soil moisture content.

**Adding Water**

Soils thoroughly moistened by rainfall or snowmelt generally provide the best conditions for trail maintenance. However, situations may occur where maintenance is required, but the soils are too dry to compact. If water is available, you may artificially moisten the soil to facilitate compaction. However, it is important to bring all the soil that you will use for construction up to the proper moisture content before it is compacted. Add moist soil to drainage structures in small lifts before compacting. Wetting down structures that are already constructed with dry soil will not result in compaction or an increase in soil strength.

**Assessing Results**

Observing how equipment interacts with the soil can indicate how well the soil is compacting. Equipment tracks without berms of soil along the tracks indicate compaction is taking place. Equipment tracks with berms of soil along the tracks indicate displacement without compaction.

You can test the effectiveness of soil compaction in the field with a simple T-handle probe constructed of ¼-inch rebar. The force required to push the probe into the soil is an indicator of soil strength. Comparing the resistance to penetration between the compacted drain dip and a nearby compacted trail tread can indicate how well the drain dip is compacted.
Appendix

- Drawing 1—Typical Drain Dip Illustration for ATV and Motorcycle Trails
- Drawing 2—ATV Trail, 8%, 6 Ft Tread; plan and profile views
- Drawing 3—ATV Trail, 20%, 6 Ft Tread; plan and profile views
- Drawing 4—Motorcycle Trail, 8%, 2 Ft Tread; plan and profile views
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Drawing 1—Typical Drain Dip Illustration for ATV and Motorcycle Trails

TYPICAL DRAIN DIP ILLUSTRATION FOR ATV AND MOTORCYCLE TRAILS

SECTION AA

NOT TO SCALE
NOTE:
1. ACTUAL WIDTH OF DRAIN DIP WILL VARY AS NEEDED TO FIT TERRAIN.
2. ANGLE OF SEDIMENT TRAP DEPENDS ON TRAIL GRADE AND SIDE SLOPE GRADIENT.
3. 15 FEET MAXIMUM LENGTH OF SEDIMENT TRAP DEPENDING ON MAINTENANCE EQUIPMENT USED TO REMOVE SEDIMENT.
4. SEDIMENT TRAP WILL HAVE A BERM AROUND THE SIDES AND END, THE BOTTOM OF THE TRAP TO THE TOP OF THE BERM WILL RANGE FROM 18 TO 36 INCHES. DEPTH OF THE TRAP WILL DEPEND ON SOIL AND SITE CONDITIONS.
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ATV TRAIL 20%
6 FT TREAD

ELEVATION VIEW

GRADE 20%

COMPACTED FILL

1.5 FT

GRADE REVERSAL @ 12.5%

EXCAVATION

CUT APPROXIMATELY 0.5 FT BELOW ORIGINAL GRADE

FLAT BOTTOM 4% OUTSLOPE

PLAN VIEW

CRET TREAD WIDTH 6 FT

APPROACH TRANSITION

COMPACTED CORE 9 FT WIDE

4 FOOT FLAT BOTTOM OUTSLOPE 1:1

SEDIMENT TRAP ANGLE

4 FT

15 FT MAX

SEDIMENT TRAP

40 - 50 FT

40 FT 10 FT 10 FT 4 FT 40 FT

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MOTORCYCLE TRAIL 8%
2 FT TREAD

CREST

15 FT 10 FT 10 FT 4 FT 25 FT

TREAD WIDTH
2 FT

APPROACH TRANSITION

COMPACTED CORE
4 FT WIDE

APPROACH TRANSITION

TREAD WIDTH
2 FT

SEDIMENT TRAP ANGLE

15 FT MAX

3 FT MIN

4 FT

SEDIMENT TRAP

GRADING 8%

COMPACTED FILL

GRADE REVERSAL @12.5%

EXCAVATION

CUT APPROXIMATELY 0.5 FT BELOW ORIGINAL GRADE

FLAT BOTTOM 3% OUTSLOPE

PLAN VIEW

ELEVATION VIEW

NOT TO SCALE
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MOTORCYCLE TRAIL 20%
2 FT TREAD

CREST

40 FT
10 FT
10 FT
4 FT
40 - 50 FT

TREAD WIDTH
2 FT

APPROACH TRANSITION

COMPACTED CORE
4 FT WIDE

BOTTOM DITCH

OUTSLOPES
3%

SEDIMENT TRAP ANGLE

3 FT MIN

15 FT MAX

4 FT

SEDIMENT TRAP

PLAN VIEW

40 FT
10 FT
10 FT
4 FT
40 - 50 FT

GRADE 20%

COMPACTED FILL

GRADE REVERSAL @ 12.5%

EXCAVATION

CUT APPROXIMATELY 0.5 FT BELOW ORIGINAL GRADE

FLAT BOTTOM 3% OUTSLOPE

ELEVATION VIEW

NOT TO SCALE
NOTES:
1. ENTIRE LENGTH OF DIP SHALL BE OUTSLOPED 7 TO 9 PERCENT.
2. ROLLING DIP STATIONS SHOWN ARE APPROXIMATE, FINAL STATION TO BE DESIGNED BY THE ENGINEER BEFORE CONSTRUCTION.
3. DIP SHALL BE CONSTRUCTED TO THE DIMENSIONS SHOWN.
4. FOR USE WITH OUTSLOPED ROADS, TYPICAL OUTSLOPE IS 6 PERCENT.
History of This Document

This document was originally prepared for the U.S. Department of Agriculture, Forest Service, Pacific Southwest Region, under Natural Resources Professional Services Contract 53-91S8-NRM11, North State Resources, Inc., Redding CA, January, 2006. This tech tip has been edited for clarity and the drawings have been replaced with new ones under the direction of James Scott Groenier, project leader at the Missoula Technology & Development Center (MTDC). The original report was also reviewed and endorsed by Trails Unlimited, a Forest Service enterprise team.

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Deb Mucci, Forest Service, Missoula Technology and Development Center, for illustrations and drawings.

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James Scott Groenier is a professional engineer who began working for MTDC as a project leader in 2003. Groenier started with the Forest Service in 1992 and has worked for the Ashley and Tongass National Forests and the Eastern Region.
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Keywords: all-terrain vehicles, ATVs, drain dips, erosion, erosion control, four-wheel drive vehicles, motorcycles, motorized recreation, off-highway vehicles, OHVs, recreation management, rolling grade, trails, trail maintenance, trail management

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