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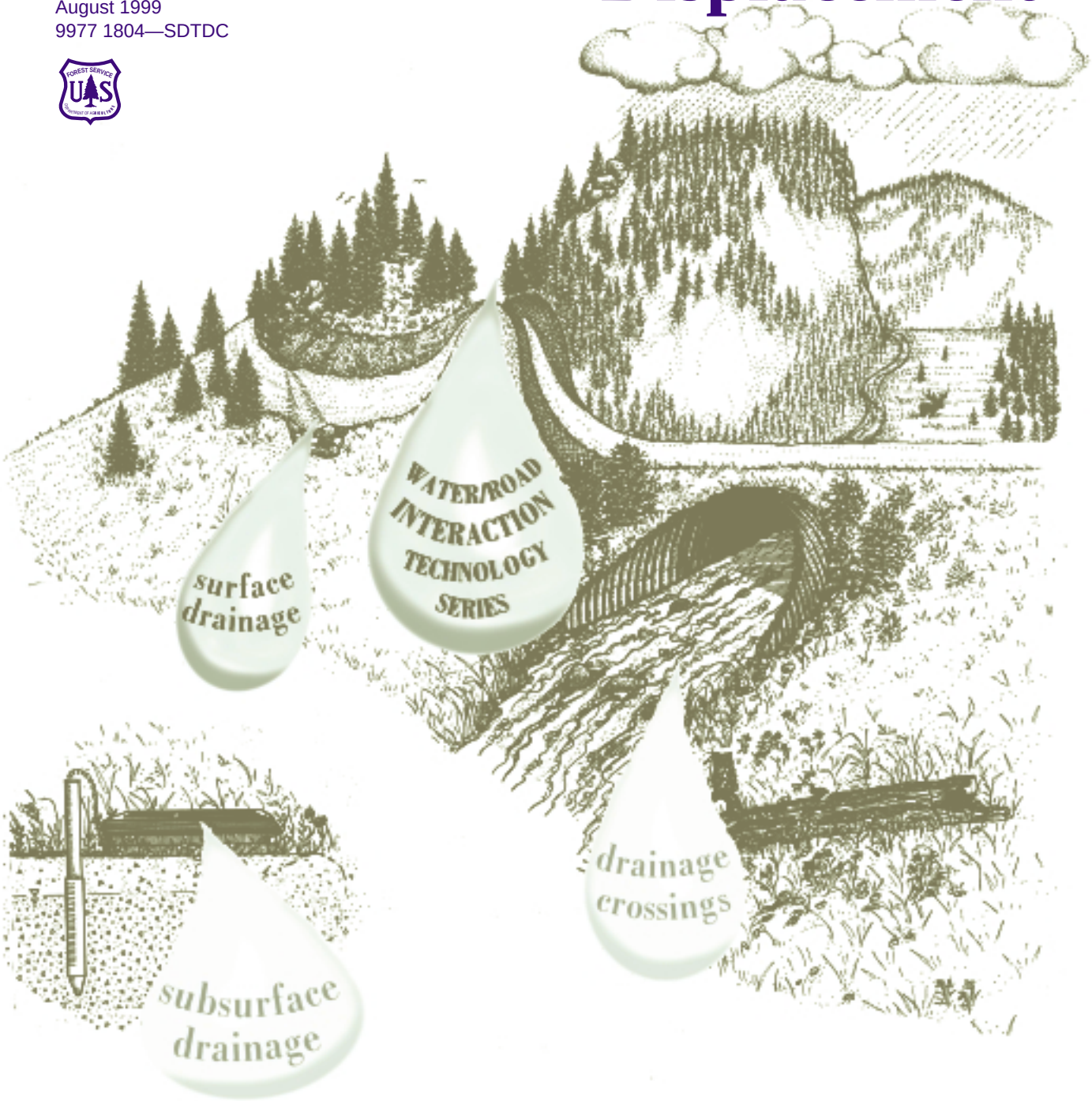
Minimizing Low Volume Road Water Displacement



Minimizing Low Volume Road Water Displacement

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August 1999

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INTRODUCTION

This paper discusses water/road interaction in terms of surface water concentrations on road segments and subsurface flows intercepted by road cuts. Background information on low volume road influences on hydrology is followed by a summary of existing methods for minimizing related water concentrations and flow distances away from the road corridor.

The notion of water *displacement* due to low volume road segments is introduced, as is the philosophy of *proper drainage provision*. Examples detailing these ideas appear in the appendix. Some new concepts and uses of emerging products for minimizing water displacement and attaining proper drainage provision are presented.

BACKGROUND FOR ROAD INFLUENCES ON HYDROLOGY

Precipitation falling on undisturbed forest soils is rarely converted directly to surface runoff. These soils are typically half mineral solids and half pore space, which contains air, water and organics. A perspective view of a soil sample is shown in figure 1. Vegetation and humus absorb rainfall energy, protecting mineral soil from raindrop impact and subsequent erosional processes. Moisture is intercepted by vegetation, evaporates, or is captured by organic materials on the forest floor and has the opportunity to infiltrate the ground surface and become stored in and move through soil pores. Here water is available to vegetation and the relatively slow release to subsurface flow, where it may contribute to baseflow or become deep or vertical seepage.

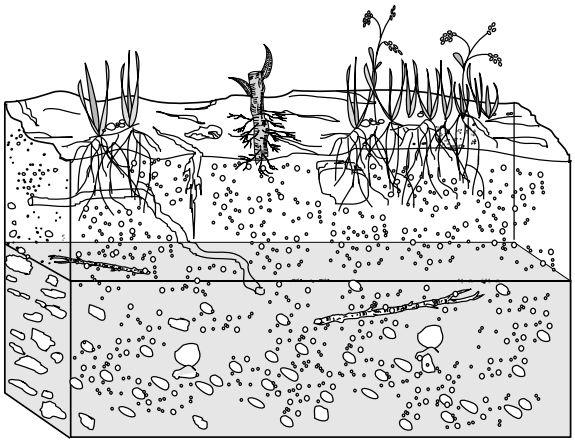


Figure 1—Perspective view of a soil sample.

Pristine forest cover promotes a higher quality water discharge in a less erratic manner than most other watershed conditions. Surface drainage in undisturbed forested areas rarely occurs outside of established channels or drainages fed by exfiltrating subsurface flow. The disposition of precipitation falling on undisturbed forest soils is characterized by its capture, storage, and safe release.

Traditional low volume road building techniques can impair the mechanisms that provide for this natural disposition of moisture on forested slopes, beginning with denuding of vegetation from the clearing width and stripping of duff and humus from ground surfaces within the roadway corridor. Excavation to provide the relatively flat traveled way width further exposes mineral soils and substrates and, for the typical self balanced prism, necessitates creation of cut and fill slopes steeper than the surrounding terrain. Alteration of natural drainage patterns inevitably follows, and can include introduction of sediment laden flows directly into stream courses.

Subgrade compaction, meant to increase soil density to provide bearing capacity for vehicle wheel loads with minimal rutting, in turn reduces ground surface capacity for infiltration, soil porosity, and groundwater conductance, and contributes to surface water concentrations and flows. Ditches at the back slope toe relieved by culverts under the roadbed facilitate removal of surface water from the prism but require a deeper cut into the hill and increase potential for subsurface flow interception by the excavation. These flows represent a more rapid movement of increased moisture quantities down slope than occur in the unroaded condition. Roads thus redistribute water by *displacement* from within the road corridor to areas lower in the watershed, out of the watershed, or by transfer to other watersheds.

Displacement as used here describes the relatively immediate change in map location a specific volume of water experiences due to road segment drainage after precipitation, snow melt, or subsurface flow interception. Displacement is undesirable as it results in less onsite moisture and increased accumulations down slope.

The change in location is defined as the horizontal distance of flow between the moisture's natural disposition had there been no road, and where the flow ultimately infiltrates the ground or exits the watershed as streamflow after leaving the road corridor as surface drainage. For an example illustrating water displacement from a road segment, see the appendix.

Displacement initiates a majority of water/road interaction. Hydrological modifications resulting from displacement can include increased drainage density (formation of new drainages and connectivity of road caused drainages to the natural network); increased drainage efficiency; changes to timing or magnitude of peak flows; increased moisture accumulations down slope; transfer of moisture between watersheds; and reduced onsite soil moisture, base flow, or groundwater.

EVOLVING ROAD DRAINAGE PHILOSOPHY

Philosophies surrounding transportation system development and the handling of subsequent hydrologic modification have evolved with increases in population and resource demand, and are influenced by economics, technological advancement, environmental concern, and political climate. Access to the forest was initially gained by the path of least resistance, usually up the canyon bottom in a corridor allowing easiest bypass or removal of obstructions with least construction effort and with little or no consideration for damage to surroundings. Excess water on the traveled way surface meant the road might wash out, or represented the possibility of getting stuck in the bog.

Increasing demand for forest commodities fueled developments in technology capable of economic mass timber harvesting and widespread utilization of other resources, while requiring systematic planning for infrastructure development. Many forested areas subsequently became heavily roaded. Design elements and standards brought improved consistency and repeatability to roadwork while ensuring access requirements were safely met, and provided a measure of user comfort and economy even under adverse climatic, topographic, or geologic conditions.

Handling displacement initially revolved around disposing of water that threatened road washout, loss of access, or increased operation and maintenance costs. More recently, the realization was made that emphasizing minimum impact on the environment by protection of surroundings from road drainage also resulted in a more durable and stormproof facility. Current thinking by some hydrologists and engineers in the Forest Service concerning water/road interaction is that minimizing displacement by a *proper drainage provision* philosophy applied to each unique road segment circumvents many undesirable hydrological effects on surroundings due to roads. Proper drainage provision, from a watershed standpoint, is minimizing the cumulative volume-distance quantity of displacement by appropriate road and drainage feature location and design, coupled with appropriate routine maintenance. Three proper drainage provision case studies are included in the appendix.

Three main components of proper drainage provision are: road location and design; drainage feature type, location, and design; and appropriate routine maintenance. Proper drainage provision is accomplished on each unique road segment by ensuring location and design of road alignments and drainage features minimize changes to natural disposition of precipitation and groundwater. Road location must consider alignments, template geometry, aspect, location on hillside, geology, climate, vegetation, operational requirements, season of use, and management activities on surrounding terrain. Drainage feature considerations include type, spacing and shaping, applicability of drainage schemes to site conditions, including investigation of opportunities on the ground for minimizing water concentrations and their effects on areas adjacent to the road segment. Appropriate routine maintenance ensures such drainage provision remains functional. Drainage features are tailored to site specific characteristics on each unique segment, within limitations dictated by access needs and safety requirements. Every opportunity is considered for minimizing water concentrations and related effects on surroundings by treatments that isolate contributing areas, whether on adjoining road segments or different parts of the cross section template on the same segment.

Eliminating displacement due to a low volume road segment would require preserving natural dispositions of precipitation and subsurface flow. Considering that the majority of water displaced by the typical low volume road initially concentrates on the traveled way, and that preserving natural moisture disposition on this part of the template presents difficulties involving safety, operations, maintenance, and slope stability, total elimination is not feasible, effective, or economical. Minimizing displacement, however, may be accomplished by various techniques depending on access and land management needs as well as site conditions and economics.

SUMMARY OF EXISTING METHODS FOR MINIMIZING WATER DISPLACEMENT

Generally, a typical low volume road segment for purposes here is a length of road with a specific water displacement problem or set of water displacement problems. Differing road or site conditions can also serve to define segment boundaries. The simplest, most economical, and most effective technique for minimizing water displacement due to the typical segment involves addition of surface cross drainage. Here, the total water volume displaced may not be reduced much, but it is broken into smaller increments, travels a shorter distance during displacement, and is more quickly and easily absorbed into down slope locations, potentially lowering cumulative volume-distance displacement. Separating contributions from individual parts of the road template can also break concentrations into smaller increments and reduce flow energy, and can be accomplished by alternative template configurations or by treatments to individual template parts.

Optimizing surface cross drainage is often more easily accomplished by site survey and analysis of an existing segment rather than during the preconstruction phase of road development, as concentration problems and opportunities for their reduction are then readily apparent. Field inspection of cross drainage needs is especially enlightening during intense climatic events. Analysis of a road segment from top to bottom allows dealing with concentrations as they develop, preventing any single concentration from reaching problematical proportions.

Traveled Way Surfaces

Traveled way surface shape (out slope, in slope, or crown) is used to drain concentrated surface flow off the traveled way. Out slope directs flow to and over the downhill shoulder, while in slope directs flow toward the back slope toe or ditch and requires a relief culvert or grade dip for removal from the prism. Crown is half in slope and half out slope, breaking surface water concentrations into two parts. See Water Road Interaction Technology (WRIT) Series document, *Traveled Way Surface Shape,* 9777 1808, September 1997 for more information.

Traveled way shaping may not effectively remove surface water on steep grades (5 percent or greater on unsurfaced roads) or on rutted surfaces, necessitating use of surface cross drains. These consist of devices such as open top drains and rubber water diverters, and shaping or grade dips, all designed, spaced, located, and armored to capture water draining down the road and release it as well as possible to minimize effects to adjacent areas and the watershed. See WRIT Series documents, *Cross Drain Update,* 9877 1804, July 1998, and *Introduction to Surface Cross Drains*, 9877 1806, September 1998 for more information.

Porous Fills

Porous fills used to cross meadows and for ramping over areas exhibiting exfiltration of subsurface flow are meant to provide a stable prism, support vehicle wheel loads, and pass sheet or subsurface flow with minimum concentration and maximum spreading. Porous fills have also been used for drainage crossings; these fills can incorporate a drainage structure or rely strictly on permeability through relatively large uniformly graded rock for flow passage (figures 2, 3, 4). Porous fills of large angular rock have a cap of material that provides a suitable riding surface, sometimes separated from the fill by geosynthetic material.

Figure 2. Downstream view of porous fill road-stream crossing.
Note the square culvert made of rough sawn dimension lumber (non-functional).
Stream is flowing under culvert.

Figure 3. View of porous fill looking up the road.
Note the retaining walls on each shoulder.

Figure 4. View looking down the road at the downstream porous fill retaining wall.

Back Slopes and Fill Slopes

Traditional back slope and fill slope treatments depend mainly on seeding for establishment of vegetation. In time plant litter and humus build up and function with the vegetation to protect soil from raindrop impact and other subsequent surface erosion processes (figure 5). Scarifying fill slopes to a depth of 10 to 15 mm after construction but prior to seeding increases success of revegetation and reduces erosion. Seeding prior to surface sealing on the soil also increases success rates. Stockpiling duff at the top of back slopes prior to excavation allows spreading of these organics over the newly constructed slope, further encouraging revegetation. Other methods for improving revegetation include fertilization; use of sterile non-native species that grow rapidly and hold soil in place while slower growing native species become established; and selectively planting, transplanting or plugging trees, shrubs, or other plants to stabilize high risk areas as quickly as possible.

Figure 5. Revegetated fill slope, stable and resistant to erosional processes.

Steps or terraces are used to break a slope into individual segments, pond and detain water, and provide planting benches or pockets. Logs placed and anchored on slope contours serve a similar purpose, as do geosynthetics, organic mats, and rolled straw bale products (figures 6, 7). Such treatments have limited lifespans and must be considered short term solutions to be coupled with complimentary long term fixes such as establishment of stabilizing vegetation. Construction of walls to retain back or fill slopes provide for slope moderation above or below, encouraging vegetation and reducing flow energies.

Slash windrows placed on fill slopes, sometimes lined with geotextile, provide economical disposal

of construction slash while detaining flows and trapping sediment (figure 8); geotextile silt fences, which are sometimes reinforced with wire mesh (figure 9), also provide short term detention of sediment.

Figure 6. Organic mat back slope erosion abatement.

Figure 7. Rolled straw bales placed on back slope to break up surface water concentration and reduce erosion.

Figure 8. Geotextile lined slash windrow at the fill slope toe to detain surface flows from the road and trap sediment.

Figure 9. Wire mesh reinforced silt fence.

Armoring cross drain outflows on fill slopes with appropriately sized rock riprap or grouted riprap (figures 10, 11), gabion structures (figure 12), sheet metal (figure 13) or plastic products, straw bales, construction slash, or geosynthetics will protect erosive soils and sensitive areas. This is especially true when surface flows are appropriately reduced by frequent drainage provision built into the road

Figure 10. Rock riprap protection for a cross drain outflow on the fill slope.

Figure 11. Grouted rock riprap protection for cross drain outflow.

Figure 12. Cross drain outflow armored by gabion structure.

Figure 13. Fill slope protected by corrugated sheet metal flume at a cross drain outflow.

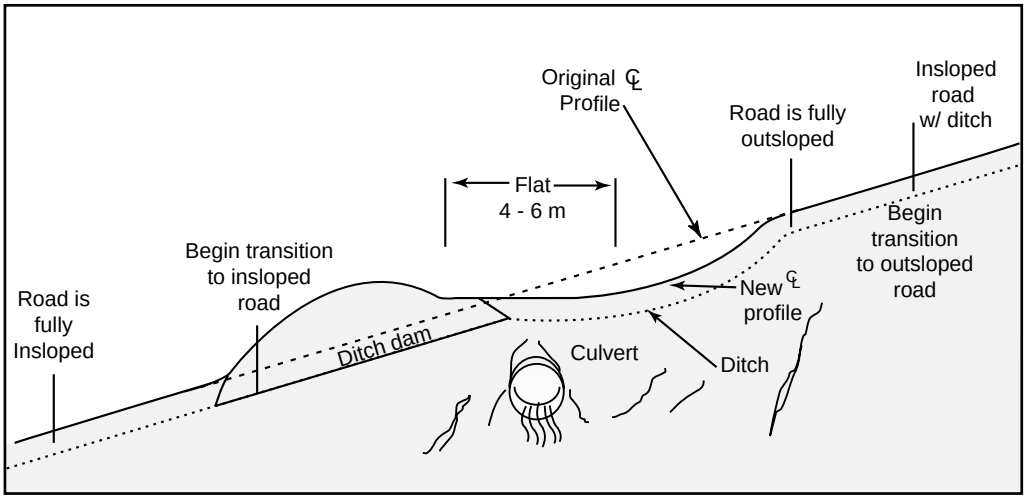
Ditches and Berms

Ditches, catch basins, ditch dams, and special inlet structures direct flow into relief culverts, which are spaced and located as dictated by ditch or culvert capacity or by site conditions. In erosive soils, ditches are check-dammed, armored with rock riprap, or paved with asphalt, concrete, or grouted riprap (figure 14).

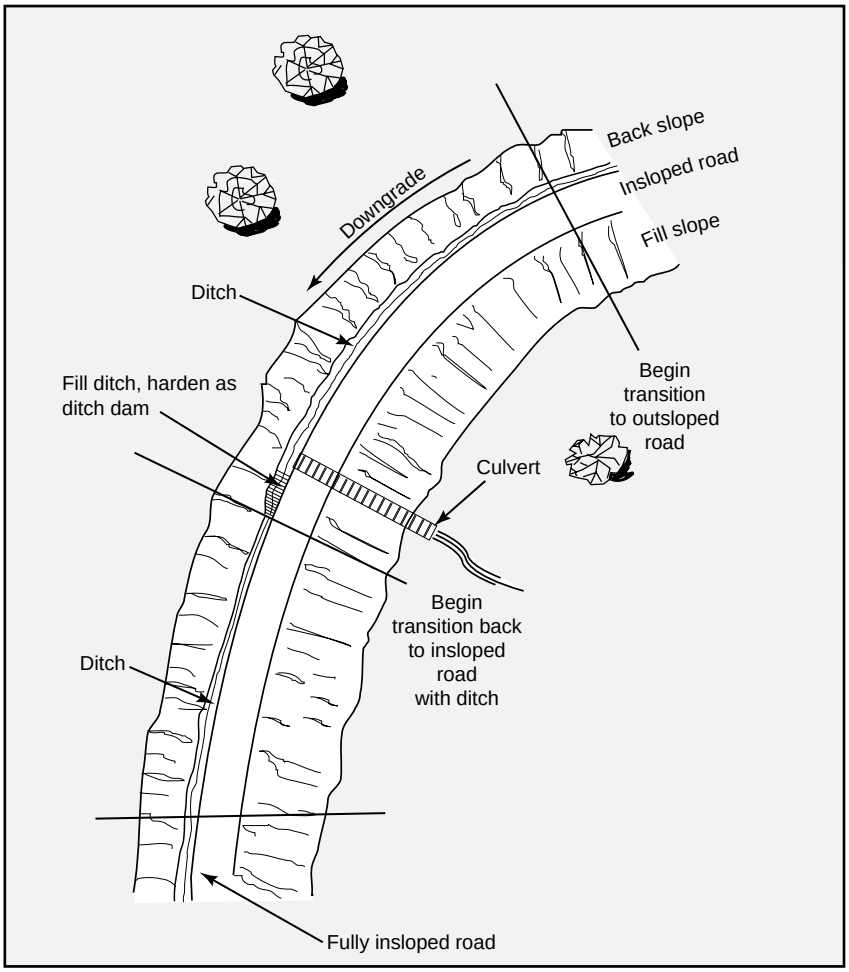
Figure 14. Paved ditch for erosion abatement.

A storm proofed ditch and culvert installation is constructed as shown in figure 15. The road profile over the culvert is flattened to act as an overflow perpendicular to centerline; should the culvert become plugged or presented with a flow greater than its capacity, the water will spread rather than become concentrated as it is directed off the road surface. The in sloped with ditch template transitions to an out sloped surface shape in the vicinity of the culvert, while the filled ditch is hardened and shaped sufficiently to act as a ditch dam to ensure ditch flow is directed into the culvert or overflow. This road surface configuration also functions well at sites with grade dips rather than cross drain culverts. The installation also helps prevent cascading failures involving several culverts or grade dips and the large amounts of sediment transported by the diverted flow.

Subsurface flow intercepted by the excavation is usually handled by allowing it to flow down the ditchline to a cross drain or by excavating a catch basin to collect the water and direct it into a culvert installed under the road surface for removal to points below the fill slope.



Profile view
(no scale)



Plan view
(no scale)

Figure 15. Storm proof cross drain culvert installation (profile and plan views).

French drains constructed the traditional way by installing perforated pipe in a trench backfilled with gravel and lined with geotextile—or made exclusively of geocomposites—can also effectively remove intercepted subsurface flow from the ditch or traveled way and direct it to locations below the road. These methods do not always aim to reestablish subsurface flow and can convert it to surface flow.

Berms are used on the downhill shoulder of the traveled way to direct surface flows away from erosive fill slopes or sensitive areas (figure 16). Existence of berms should be restricted to areas of need, as they require increased road corridor width and excavation quantities, while adding weight to fills. Berms on the downhill shoulder also concentrate water and should be removed unless specifically installed to protect down slope areas. Road maintenance operations perpetuating these berms need to be based on specialist input indicating that the berms are required. Berms are also used on hillsides above the road and on back slopes to break surface flow into smaller increments and direct flows to areas able to receive them.

Figure 16. Berm on downhill shoulder to protect steep fill slope from surface flows.

Adjacent Areas

Minimizing road drainage influences on adjacent areas begins by designing, building, and maintaining the lowest standard road consistent with access requirements, safety, and site conditions. Culvert end treatments—raised inlets and other structures—(figures 17, 18, 19, 20) are useful for ponding water, recharging soil moisture, preserving sediment, stopping headcuts, and generally improving watershed condition. Other structures including catch and detention basins are used to detain flow and keep sediment out of streams, while splash pads and energy dissipaters protect areas receiving flow off the road from further erosion.

Figure 17. Raised inlets on road stream crossing to pond water and preserve sediment.

Figure 18. Raised inlets on road stream crossing to pond water and preserve sediment.

Figure 19. Used railroad tie structure to pond water and preserve sediment upstream of a road stream crossing.

Figure 20. Used railroad tie structure to pond water and preserve sediment upstream of a road stream crossing.

CONCEPTS FOR MINIMIZING WATER DISPLACEMENT

Drainage provision for each unique road segment must be specifically designed according to site conditions to minimize displacement. Flows from adjacent segments should not be allowed to concentrate and those from various parts of the template on the same segment should be isolated if possible. Varying template configurations, appropriate surface cross drainage, and special or innovative treatments for back and fill slopes to make use of every opportunity to break up water concentrations and create opportunities when none occur naturally should be investigated. Use of new materials or products for drainage provision can also aid in minimizing alterations to hydrology.

Traveled Way Surfaces

The existing rubber water diverter design effectively removes water flowing down the road surface. Fatigue and wear of the rubber, however, can prematurely reduce effectiveness or cause failure, especially under heavy truck traffic. Doubling up the rubber strapping might increase durability, though possibly at the expense of drivability; research into materials alternative to rubber strapping, such as cast in place or precast concrete curbing is justified. Advantages over dips include the ability to closely space cross drainage without the problems associated with closely spaced grade dips, including excessive grade rolling and overlapping of one dip's longitudinal profile with the next.

A drivable and durable "hump" would divert surface flow off the road while requiring minimal modification to the road profile, in a manner similar to the rubber water diverter, (See WRIT Series document *Cross Drain Update*). Several stages would allow for sedimentation—as well as storage for mud fallen from vehicle undercarriages—while preserving diversion capability and extending periods between required maintenance. Hump length and height would be tailored to road grade, climate, expected flows, soil type, and should consider operational requirements (design and critical vehicle characteristics). Logical materials for experimentation include rubber, rubber strapping, plastic, concrete, and wood.

Chipped slash has been successfully used as a lightweight road surfacing in some areas (figures 21 and 22). The main advantage of this material is its capability to absorb and retain moisture that would usually run off the traveled way surface. Disadvantages include fire, decreased traction, short lifespan of the chips due to rot, increased occurance of saturated subgrades, and lack of capacity for much heavy traffic. Further investigation into use of lightweight surfacing in minimizing water displacement is justified.

Figure 21. Spreading chipped slash as a lightweight road surfacing.

Figure 22. Chipped slash road surfacing absorbs and retains moisture from precipitation events.

A traveled way surface 'grid' might work on problem road sections where traditional surface drainage schemes fail. The grid would support wheel loads and provide thousands of small ponds to store water and desynchronize or break up flows.

The grid would divert surface water flowing from upgrade sections off the road and prevent further concentration at the grid location. An important function is ponding (storing) water long enough to allow in place infiltration into the road surface, while "bridging" the possibly reduced bearing capacity of the subgrade.

In this way, the grid would circumvent a fundamental element of water/road interaction problems: the concentration of water on the road surface and its subsequent drainage down slope. The grid needs to support vehicular traffic over a saturated subgrade, resist movement under wheel loads, and be able to pond moisture from the design storm in addition to storage of sediment and mud fallen from vehicle undercarriages. A means of removing this material during maintenance operations to restore grid moisture storage capacity would also be required.

The grid concept would not be usable in areas with slope stability problems or where increased moisture in the embankment might lead to erosion in or mass wasting of the fill. Polymer cell confinement (geowebs) backfilled with clean aggregate, or interlocking precast concrete units forming a flexible concrete revetment are alternatives for traveled way surface grids. Clean, uniformly graded aggregate may be used to provide the same function. Open voids in the surfacing store moisture and desynchronize flows off the road. Placement of humps, grids, and aggregate should be over geotextile material to reduce contamination by subgrade materials.

Ditches, Back Slopes, and Fill Slopes

Reducing surface water concentrations on slopes may be accomplished by breaking contribution areas into smaller parts. Catch basins lined with geosynthetics or organic mats and with hardened outlets effectively store water and desynchronize flows, but are difficult to place in steep terrain. Ditches and berms have traditionally been used to collect and concentrate dispersed surface flows. They can be used on slopes to isolate flow from higher on the slope, temporarily storing it to encourage infiltration or transporting it to release points to separate it from other flows.

Removal of unneeded berms on the downhill shoulder reduces weight on the fill and reduces fill slope, increasing vegetation potential and reducing erosive energy of flows down the slope. Removed berm material can be used for filling ditches at the toe of the cut, providing similar benefits to the back slope. Such treatment of material imitates slope rounding the shoulders of the road.

Ditches or berms placed on or above a slope intersect and divert water from areas with high risk of erosion, slope instability, or sensitivity to sedimentation, and should have grades of between 2 and 5 percent. Ditches and berms can be used on disturbed ground until other stabilization treatments become effective. Flattening the back or fill slope may be required to accommodate the ditch or berm, and armoring may be needed to prevent erosion due to flow. An established grass cover provides good armoring. "Diversion dikes", made of geotextile covering a urethane foam core, are an alternative for berms and potentially can be installed without modifying the slope ratio.

Continuous berms have been successfully used for stabilizing overly steep or exfiltrating back slopes and in containment, filtration, directing, and diversion of surface flows. A continuous berm machine extrudes a geotextile contained berm of sand, rock, or native soil that conforms tightly to the ground, can be stacked, and resists movement. Choice of fill material is dictated by economics or function; a uniformly graded aggregate will freely drain, whereas a fill with fines overfilling the voids of the aggregate fraction will be much less porous and thus resist through flow.

Small ditch dams sized and installed at spacings based on water volumes dictated by the design storm to detain part of the flow will break water concentrations into smaller increments, desynchronize flows, and reduce erosion and encourage sedimentation. A spillway sized to pass over flows should be located such that the ponded

surface is sufficiently below the traveled way surface to prevent reductions in bearing capacity of the road due to increased moisture content, and to ensure flows do not spill over onto the traveled way. Ponding water in the ditch should not take place in areas prone to slope stability problems related to increased embankment moisture content.

In-ditch culverts sometimes fitted with sediment bags have been used on sites with chronic sedimentation or back slope slumping problems. The bag is a tube of geotextile material with grommets in both ends; one end is cabled to an attachment collar clamped to the outlet, while the other end is cinched partially closed with cable and anchored to a nearby stump or rock. An excavator prepares the ditch by digging a settlement pond at the in-ditch culvert inlet, smooths the ditchline, places the pipe, and covers the pipe with fill. The sediment bag is cleaned as needed by lifting and emptying with an excavator or backhoe. Seepage through the geotextile bag may not sufficiently pass high ditch flows; the end of the bag may be left partially open to allow overflow. Frequent inspection and maintenance of such installations is recommended.

Adjacent Areas

Constructed wetlands or silt traps can aid in storing or delaying flood flow runoff from roads. Sedimentation in the constructed wetland gradually reduces water capacity and buffering function over time.

Sediment bags may be attached to ditch relief culvert outlets to preserve water quality and reduce downstream deposition. A debris screen or trash rack may be installed on the pipe inlet at sites with woody debris passage problems. The sediment bag requires frequent inspection and maintenance to ensure required flowrate through the culvert exists. The bag is emptied by lifting with an excavator or backhoe when approximately half full.

Surface flows from roads can increase drainage density in a watershed. Treating the root of the problem involves reducing water concentrations from roads and disturbed areas with structural and/ or bioengineering treatments, then treating the new drainages themselves. This can be accomplished by reshaping the drainages with heavy equipment, revegetation, installing rock check dams, and/or using geosynthetics.

CONCLUSION

This paper summarizes existing methods and some new concepts for minimizing water concentration volumes and the distances they flow away from the road corridor, referred to herein as *water displacement*. This minimizing of water displacement is achieved by a proper drainage provision philosophy, involving good road and drainage feature location and design, and by appropriate routine maintenance.

APPENDIX

Example of Water Displacement

To illustrate the concept of water displacement, consider rain falling on an in sloped road segment that stretches from the top of the hill (line *l-l*) to the ditch relief CMP below (figure A1). For simplicity, assume the fill is of moderate slope and is well vegetated, and thus rain on this portion of the template infiltrates as typically occurs on undisturbed slopes in the area, and that no subsurface flow is intercepted by the road cut. Also, assume all surface flow from the traveled way and back slope between *l-l* and the CMP ends up in the ditch and subsequently flows through the culvert. Additionally, assume moisture that infiltrates the traveled way and back slope rather than running off as surface flow soaks into the same horizontal location it would have, had the road not been built on this site. Simplicity also requires the absence of saturated soils at this site.

Precipitation running off from the back slope and traveled way surfaces is concentrated in the ditch, flows through the culvert, and infiltrates the ground between the culvert outlet and point B. Point A' is the center of volume of infiltration while point A is the center of volume of the natural disposition of precipitation given the unroaded situation. Assuming 2 cubic meters of water is displaced the horizontal distance A-A' of 50 m, the cumulative horizontal volume-distance displacement would in this case be 100m [4]. The vertical distance of water displacement is not considered here.

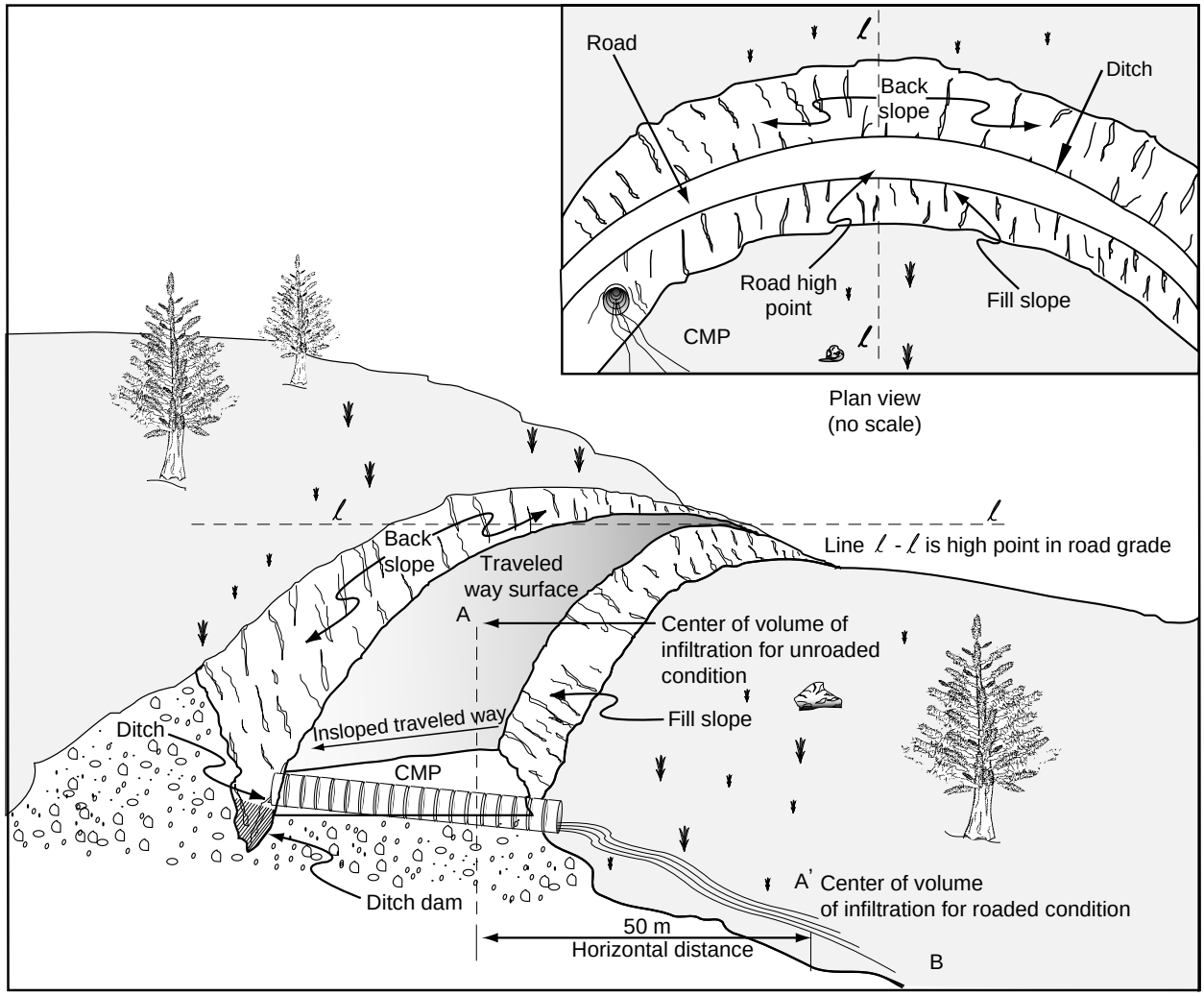


Figure A1. Water displacement from a road segment (perspective and plan views).

Should a prism exhibit surface flows from separate parts of the template with separate flowpaths, each volume-distance quantity would be calculated as above and summed to determine total displacement due to the segment. Proper drainage provision, from a watershed standpoint, is minimizing this cumulative volume-distance quantity by good road and drainage feature location and design, and appropriate routine maintenance.

Accurately measuring displacement in the field presents many difficulties, including uncertainty over moisture disposition given the unroaded condition, and a lack of instrumentation and methodology for tracking all components of a hillside's water budget. Determining displaced volumes and distances due to a road would thus prove time consuming and problematic. This paper does not advocate development of methods for such measurements and determinations, however, techniques for relative ranking of displacement potential for segments based on site conditions and road attributes should be developed and tested. Ranking methods would provide valuable information for transportation system development and maintenance prioritization, as well as identification of problem segments needing reconstruction or obliteration.

Three Examples of Proper Drainage Provision

The notion of proper drainage provision is illustrated by the following three examples. The importance of appropriate maintenance in proper drainage provision cannot be overemphasized.

Example 1.

This case study highlights the need to investigate contribution of drainage volumes from an adjacent segment and the breaking up of flows from template components in reduction of gully erosion.

The example involves two adjoining segments (A-B and B-C) on a low volume, single lane, native surfaced logging road (figure A2). The site (figure A3) is approximately 2740 m (9000 ft) in elevation in the Rocky Mountains of northern New Mexico and receives an average of 633 mm (25 in) of precipitation annually in the forms of summer

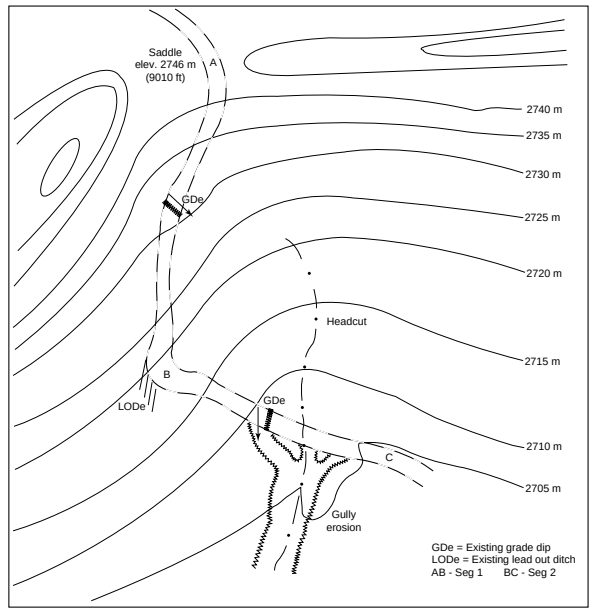


Figure A2. Logging road, northern New Mexico, plan view.

thunderstorms, winter snowfall, and rain on snow events. Vegetation consists of pine, fir, spruce, aspen, locust, oak, shrubs, grasses, wildflowers, ferns, forbs, and sedges. Limestone and sandstone parent materials lead to highly erodible soils. Surrounding mountainous topography exhibits side slopes to 100 percent, rocky peaks and ridges, and deep, erodible, low bearing capacity soils in drainage bottoms and meadows.

Figure A3. Low volume, single lane, native surfaced logging road in northern New Mexico.

Drainage is accumulating from the two segments (A-B and B-C) to cause and contribute to gully erosion as shown in figures A4 and A5. Both

segments are 3.7 to 4.6 m (12 to 15 ft) wide, rutted, with minimal drainage provision, no out slope, and a berm on the downhill shoulder (see figures A6 and A7). Soil loss due to road drainage and surface blading has resulted in a lowered template (prism entrenchment) leaving the remaining surface rough and rocky. Segment A-B has one grade dip and one lead out ditch as shown in figure A2, while segment B-C has one grade dip that concentrates surface water directly into the gully.

Figure A4. Gully erosion directly downhill of road segments A-B and B-C due to surface water concentration and flow.

Figure A5. Gully erosion further down the slope.

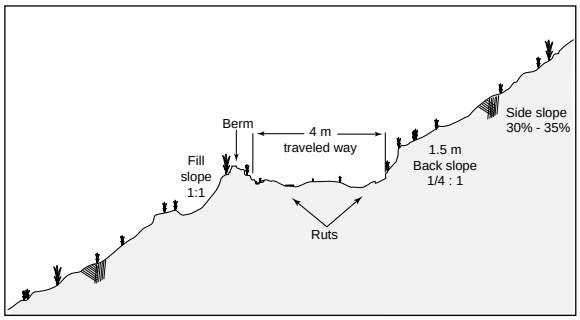


Figure A6. Cross section existing segment A-B, 6grade =17 percent.

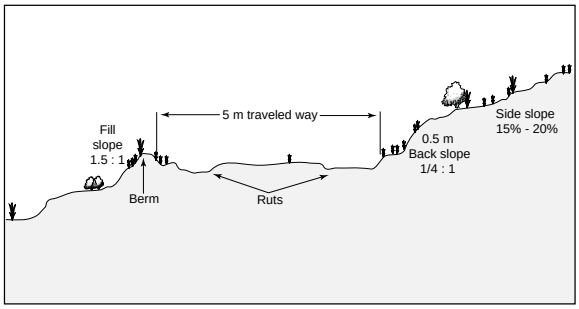


Figure A7. Cross section existing segment B-C, grade = 10 percent.

Proposed modifications encouraging proper drainage provision are shown in figure A8. The berms are removed and material used to smooth, grade, and out slope the traveled way to encourage shedding of surface flows. The road centerline is shifted into the hill slightly if needed to generate road building material for these purposes. Additional grade dips and lead out ditches are installed to break up concentrations and direct water to locations reducing overall displacement.

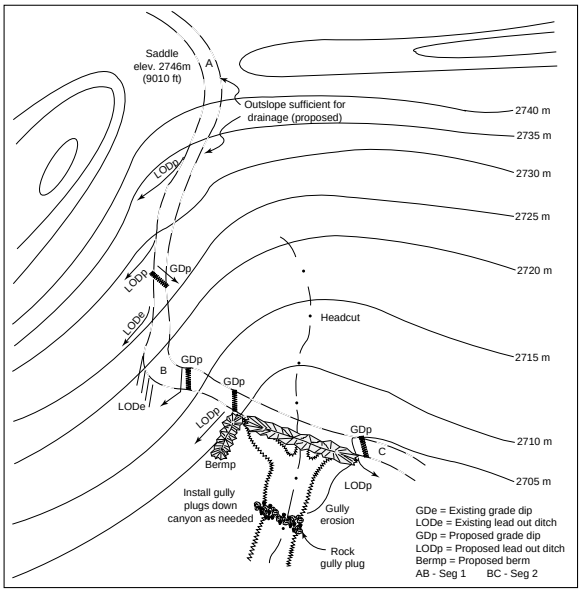


Figure A8. Proposed modifications to logging road, northern New Mexico, plan view.

Note the back slope lead out ditches. Surface flow is directed away from the gully rather than into it. Surface flows are also directed away from locations uphill of the gully where possible. Short term erosion abatement is provided, along with a long term revegetation plan for all disturbed areas. Appropriate maintenance is also performed.

Example 2.

This case study shows that building an out sloped rather than an in sloped template can help reduce prism dimensions and associated water displacement. Similar projects should consider template design options and affects routine maintenance have on template evolution.

The example involves a fire suppression access road at 500 m (1640 ft) in elevation in the San Gabriel Mountains of southern California. The area is characterized by steep topography and granitic parent materials. Ninety percent of the 510 mm (20 in) of annual precipitation falls as winter rain, the remaining in summer thunderstorm events. Vegetation includes chaparral, occasional pine and cedar, wildflowers, and various ground covers and grasses.

The cross section template is in sloped with a high berm, has excess roadbed width ranging from 3.7 to 6 m (12 to 20 foot), high back slopes, and fill slopes at the angle of repose that constantly ravel material down slope (see figure A9). Localized road grades reach 15 percent, well past the range of difficulty for removal of surface water by sloping of the traveled way. The area disturbed by the road is excessive, resulting in high moisture displacement and erosion rates (see figure A10). Brush and grasses serve to stabilize the berm and oversteepened fill slope; when the vegetation dies, however, the berm sloughs off down the slope (see figure A11). Excess material generated during maintenance operations is also wasted over the downhill shoulder. The berm increases fill slope weight and contributes to tension cracks appearing on the traveled way surface (see figure A12).

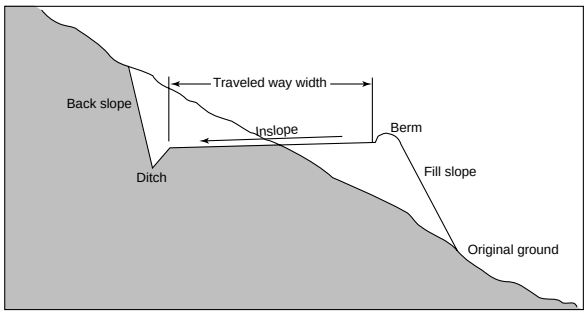


Figure A9. Typical cross section template for fire suppression access road in southern California.

Figure A10. In sloped traveled way with large berm on outside shoulder. Note the existence of rills running perpendicular to road center line even after surface blading.

Figure A11. Brush is holding berm on fill slope (top). When brush dies, berm material is available for movement down the hill slope.

Figure A12. Tension cracks in traveled way surface made worse by weight of berm on downhill shoulder.

Initial in slope design coupled with routine maintenance and loss of fines due to erosion has resulted in the back slope toe and traveled way surface lowering into the hillside (prism entrenchment) over time. Rilling and gully erosion remove fines from the roadway surfaces, and create the need for surface blading the traveled way surface or cutting down to the low spots, which loosens more material and makes it available for transport down slope. This blading lowers the road elevation, increases subsurface flow interception, and undercuts the back slope, increasing apparent back slope height and reducing its stability. Excess bladed material is incorporated into the berm. Revegetation on the steep (1/4:1) back slope is sparse and slumps frequently occur, providing more material for transport down slope.

Existing drainage provision consists of in sloped traveled way shaping with surface flow gravitating to the back slope toe where it combines with flows from the back slope. Grade dips (see figure A13) direct this water across the traveled way and into corrugated sheet metal inlet and 1/2-round downspouts meant to protect steep (1:1) fill slopes from erosion. Distances between grade dips average 110 m (361 foot), long enough to allow sufficient volume and flow energy during intense climatic events to erode the traveled way surface and ditchline to depths of 0.1 m (4 inches) or more. This loss of fines increases the entrenchment of the back slope toe and makes for rough traveled way surfaces.

Figure A13. Grade dip.

Proper drainage provision for such a road segment and site begins with minimizing changes to topography due to the road template. Roadbed width should be restricted to 3.7 m (12 foot) or 6 m (20 foot) for turnouts at points of need and opportunity. Out sloping the traveled way and removing the berm (figure A14) would reduce width of template parts, round slope breaks, shorten back slope height, allow for flatter and more stable fill slopes, reduce intercepted subsurface flow, and reduce surface water concentrations while lowering flow velocities and distances of displacement. Removal of the berm and use of the material in out sloping would help achieve these goals. Additional cross drainage can be installed at points of need. Future maintenance operations need to preserve the reshaped road template and disposition of soils. Out sloping is acceptable as icy conditions occur very infrequently at this site. Grade dip location and downspouts could remain the same under this scenario, as they would be required to handle less flow.

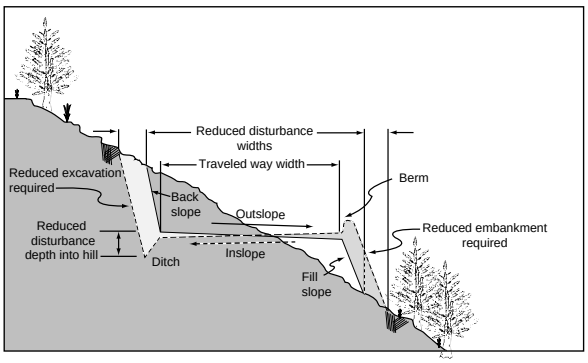


Figure A14. Reduced disturbance due to out slope template (———) compared to in slope template with ditch and berm (– – – –).

Example 3.

The third case study demonstrates the tailoring of traveled way width to access needs and site conditions, and the use of width unneeded for vehicular traffic as a buffer to the stream for surface flows off the traveled way. Similar projects should include investigation of potential slope stability problems due to increased moisture in the subgrade.

The example studied here is a double lane unsurfaced collector road at 900 m (2950 foot) elevation in the mountains of northeast Georgia. Road grades range from 3 to 10 percent with surface drainage dependent on crown, inboard ditches, and cross drain ditch relief culverts. Changing use and mounting environmental concern including sedimentation in the adjacent stream led to a reconstruction project to reduce traveled way width to one surfaced lane with turnouts; the subgrade width remains double lane, with the inside lane receiving clean, uniformly graded aggregate surfacing approximately 0.2 m (8 inches) deep. This surfacing will detain surface flows while supporting wheel loads on a moist subgrade. Geotextile was not used in this case, but investigation of need is recommended on similar projects.

The portion of the traveled way not receiving aggregate was smoothed, out sloped, and hydroseeded (figure A15) as a shoulder and acts as a buffer to slow surface flows and detain sediment off the rocked portion of the road. Each road segment was investigated for ditch and cross drain needs, with the result that some ditches were filled and surface drainage provided by out slope and grade dips. Other ditches were filled with relatively large, clean, uniformly graded rock that allows flow yet provides armor. Lead out ditches received rock armoring and silt fences (figure A16) to keep sediment out of the stream.

Figure A15. Hydroseeding unsurfaced shoulder of reduced width road.

Figure A16. Rock armor and silt fence at lead out ditch outflow to reduce erosion and sedimentation.