Reducing Low-Volume Road Impacts on the Environment: Success in the United States Department of Agriculture Forest Service

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Principles for low-impact roads have been under development since the 1960s. Observation of roads after storms and floods showed minimal damage occurring to well-located roads, with less environmental impacts in adjacent areas. Roads should have rolling grades and should be located to be self-maintaining and to "lay lightly" on the land. These roads minimize modification of existing drainage patterns. A sufficient number of properly located and designed cross drains should be provided. Location in the best spot is not always possible, however, and roads-related erosion, failures, and environmental damage can still occur. Also, road work may be planned and executed to promote healing of the scars of the past. Raising cross-drain pipe inlets encourages water ponding, soil conservation, the healing of gullies, and increased soil moisture. Road fills may serve as gully plugs or may be constructed with porous characteristics to reduce water concentration on broad, relatively flat meadows. Finally, a "less is better" approach to road maintenance may aid in sediment reduction. Providing for adequate drainage with the minimum disturbance during ditch pulling, heeling, and surface blading activities also has economic benefits. Tailoring ditch geometries to actual drainage needs, as well as compacting and armoring the soil in the ditch, can reduce sediment levels. Flavel bars are useful in breaking up the concentration of water.

The United States Department of Agriculture (USDA) Forest Service, organized in 1905, administers a network consisting of approximately 552 000 km (343,000 mi) of road, of which 75 percent is functionally classified as local, 20 percent collector, and 5 percent arterial (*1*). The Forest Service is considered one of the foremost authorities on low-volume roads in the free world, mainly due to the large mileage of locals managed. Local roads typically have little or no surfacing and serve relatively low traffic volumes.

USDA Forest Service employees are striving to reduce the agency's transportation system impacts on the environment. The material presented in this paper is based mainly on the reflections of Forest Service engineers on some of their experiences. The paper presents material on low-impact roads, the healing of environmental scars of the past through road work, and reduction of sediment through road maintenance.

A common theme to be derived from the experiences of the engineers is the importance of careful study and planning before beginning any transportation system activity. Performance of tasks in accordance with textbook methods and attitudes such as "that's the way we've always done it" are giving way to an awareness of environmental concerns. In addition, it has been realized that all factors must be carefully weighed to obtain optimal solutions from engineering, economic, and environmental standpoints.

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PRINCIPLES OF LOW-IMPACT ROADS

By the 1960s in the Pacific Northwest Region, road engineers and locators began to take note of low-impact roads, roads that weathered storms and floods while others suffered severe damage and even failure. Location was a common denominator among these roads; minimum impact on the environment was achieved by well-located roads. It was realized that location is the single most important phase of transportation system development (B. Sawyer, unpublished data). Forest Service experience in the Pacific Northwest Region allows for formulation of general principles of low-impact roads, and they appear valid for other geographical areas as well.

Heavy rains and floods in the early 1960s damaged roads and caused failures that highlighted several roads-related problems:

- Roads concentrate water and alter the natural drainage patterns that exist on and below the surface of undisturbed topography.
- Road surfaces resist infiltration, leading to increased runoff that can saturate fills and contribute to slides, slumps, and washouts.
- Road ditches collect surface water and intercept subsurface flow, concentrating and depositing it as runoff in spots not always well suited to handle it.
- Roadway cuts and fills disturb vast areas of soil, exposing it to weathering action and the elements. Road construction accelerates surface erosion more than any other forest management activity (*2*). Protective cover on soil is removed and the natural hillside is replaced by an artificial "flat" that provides the traveled way. This flat is compensated for by steeper-than-natural cut and fill slopes.
- Controlling the movement of water on slopes presents unique difficulties.

Two basic principles for low-impact roads emerged from careful study of different road segments and their weathering of storms and floods. The first is that of proper location. No amount of extra effort in design work or construction technique makes up for a poor location, but a good location facilitates subsequent road development activities. Inspection after heavy storms reveals survival of well-located segments and, generally, failure of or damage to those in poor locations.

The proficient road locator possesses considerable experience in transportation system development activities and must develop an in-depth knowledge of the characteristics of the area in which the road is to be located. Proper location requires the locator to have expertise in the following areas: transportation planning, including road design elements and standards and design criteria; road surveying, design, cost estimating, construction, and maintenance; aerial photograph interpretation and the use of contour maps; drainage structure design for surface and subsurface flow; materials engineering and soil mechanics; and application of newly emerging construction materials and techniques.

In addition, the locator should have the following knowledge of the area: types of land use planned, including land and property ownership; natural resources (also cultural, visual, and recreational resources and any associated constraints); the existing transportation system; geomorphologic, topographical, and geological characteristics; and hydrology and climate.

The second principle of low-impact roads is locating and designing a road to minimize the alteration of existing drainage patterns (B. Sawyer, unpublished data). Almost any modification of the natural drainage process results in water concentration and increased erosion potential.

- Ridgetop roads require less provision for drainage than side hill or canyon bottom roads. Roads close to streams face greater risk of road-related sediment entering the stream.
- Care must be taken to ensure proper cross-drain location and design and that adequate drains are provided to minimize water concentration and other impacts on the hydrology of the area (R. A. LaFaette, unpublished data).
- Pipe outlets should be designed to prevent damage to fills, erosive soils, meadows, and streams and to encourage the spreading of outflow.
- Full bench construction alleviates the problems associated with saturated fills but still modifies natural slope and hydrological characteristics and can actually intensify the interception of groundwater. The "toe of the cut" is made further into the hill, since all required road width is provided by the cut and none by the fill.
- A southern aspect provides for faster melting of snow and quicker drying of road surfacing and subgrade.

Other important considerations for low-impact roads are as follows:

- Roads should be located on rolling rather than straight or uniform grades. A roll in the grade constitutes a dip that facilitates the shedding of water, helping to prevent water concentrations.
- Roads should be located, designed, and built to be as self-maintaining as possible. To be self-maintaining, a road resists runoff concentration, erosion damage, and vehicular damage such as surface rutting. Observation of road survival on a case-by-case basis suggests that self-maintaining roads inflict the least damage on the environment.
- A carefully thought-out road location that allows a road to "lay lightly" on the land by minimizing cuts and fills and other disturbed areas can reduce the area affected and other environmental impacts.
- Roads should be located on as gentle a side slope as possible, although some side slope facilitates drainage.
- Drainage of water from the road surface is more easily provided for on flatter grades; thus water concentration and erosion potential are reduced.
- Wetlands, bogs, and areas experiencing exfiltration of groundwater should be avoided during road location. These areas require costly mitigation and result in increased potential for environmental damage.

Other useful considerations that are not directly related to road location are as follows:

- Tailor road design standards to actual needs. Building the minimum standard road required to meet resource and access needs can have economic as well as environmental benefits.
- Steepen cut and fill slopes to reduce the total area affected and the disturbed area exposed to weathering and erosion.
- Optimize construction equipment to the job to prevent unintended overbuilding, extra road width, and excessive disturbance of adjacent areas. Hydraulic excavators allow for increased control over placement of excavated material, with the possibility of a more stable end product (*3*).
- Plan and conduct road construction activities to minimize disturbances (*4*).
- Plan and implement erosion control measures during and after construction. A seeding plan that includes a specially designed seed mixture to ensure reestablishment of vegetation before the rainy season is important.
- Provision for surface drainage should be carefully planned through the use of outslope, inslope, crown sections, and berms to control the flow of water off the road (see Figure 1).

It is not possible to locate every segment of every road perfectly. Difficult road-building situations will present themselves, and decisions will have to be made between alternatives that result in undesirable end products from environmental, economic, or engineering standpoints.

Road locators and designers are not always able to foresee or provide for all repercussions resulting from road construction activities. Whereas careful location, design, and construction of roads will minimize adverse effects, not all road-related erosion is preventable, and environmental damage and failures will occur (*5*). It is important to approach transportation facility development with these facts in mind.

HEALING THE ENVIRONMENTAL SCARS OF THE PAST THROUGH ROAD WORK

In the Southwestern Region, an increasing awareness of the environmentally detrimental aspects of transportation system–related activities and practices has resulted in a multidisciplinary approach to healing the scars of the past. Resource specialists initially recognized the contributions of roads to

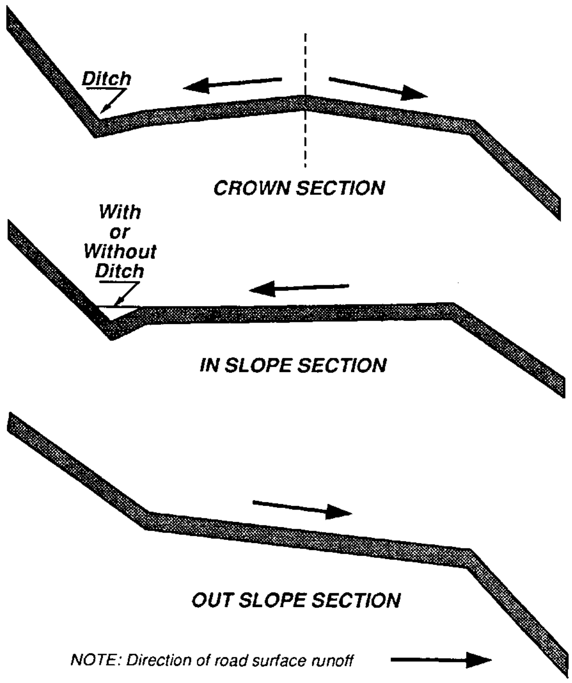

FIGURE 1 **Types of road surface sections.**

man-caused damage inflicted on riparian areas, meadows, drainages, vegetation regimes, and wildlife habitat. Hence, investigations into its causes and possible cures were initiated.

Personnel in related disciplines at the Cibola National Forest, Albuquerque, New Mexico, are working together to identify areas damaged by human activities and devise ways to promote healing through road-related activities. Recognizing the damage done and identifying its causes and consequences are the first steps to be taken. Careful consideration of all aspects of the problem often leads to innovative solutions. Experimentation shows what works well and indicates procedures that require modification.

Meadow invasion by ponderosa pine, juniper, rabbit brush, and other mesic vegetation, along with reduced hydric biomass, indicates the drying of soil and lowering of water tables (F. Jackson, unpublished data). By considering road cross-drain pipes installed with inlet elevations below the natural meadow surface, part of the reason for the damaged environment becomes clear. The practice of lowering a pipe inlet effectively removes water from the roadway but can initiate gully headcutting; relieving the pipe outlet usually requires cutting long trenches, also initiating gully erosion and concentrating water. Both practices result in dryer soil and a lowered water table, with disastrous results to wetland areas and hydric vegetation.

Raising the inlet of a cross-drain pipe, either by installing an elbow on the pipe inlet or by removal and reinstallation of the pipe at a higher elevation, circumvents its soil moisture draining and water table lowering characteristics (J. Fehr, unpublished data). The pipe inlet is generally raised to the natural meadow elevation; thus, runoff ponding occurs on the uphill side of the pipe, encouraging sedimentation and slowing headwall retreat. Downstream treatments include splash aprons and gully plugs. Aprons are used to reduce the force of falling water on soil and retard gully deepening and downcutting, whereas plugs encourage ponding and soil preservation.

Roadway embankments across drainages may be specifically designed to function as gully plugs (J. Fehr, unpublished data). Drainage structures are sized to pass the peak flow associated with the design recurrence interval required for the facility in question. The structure is placed so that its invert is at the elevation desired for water ponding and sediment deposition levels (Figure 2) rather than in accordance with the standard installation procedure of bedding the pipe at the natural ground elevation in the drainage bottom. Generally, the road surface should be at least 0.6 m (2 ft) above the water level to prevent increased moisture from decreasing the road's bearing capacity. Embankments are specifically designed and constructed to provide an impervious dam to prevent piping and possible loss of the fill, although in some cases large, uniformly sized rock is used to provide a pervious layer that allows seepage. The purposes of such embankments include wetlands creation and restoration; providing wildlife drinkers; the retardation of bank cutting, gully erosion, and incision; and sediment preservation.

Roadway embankments across broad, relatively flat meadows may be constructed in a manner that reduces the concentration of water (Figure 3). The fill is designed and constructed with a pervious layer as described above, allowing for seepage of surface water and sheet flow in a manner imitating the natural drainage pattern. Water need not be collected for passage through a pipe; it remains spread across a relatively large area, encouraging infiltration and soil moisture recharge. This application works best in broad, flat meadows without defined low spots or canyons that concentrate water.

Gully plugs may be constructed of Jersey barriers (Figure 4), treated timber, or on-site materials. Placing the plugs at carefully arranged intervals optimizes their sediment-preserving capabilities and economic benefits. A grade of approximately plus 2 percent from the top of one plug to the toe of the next one upstream has been successfully used. Installing plugs in conjunction with increasing the infiltration capacity of surrounding upland soils increases both plug survivability and the soil's biomass production potential.

FIGURE 2 **Cross drain with inlet installed at the desired elevation for ponding and deposition.**

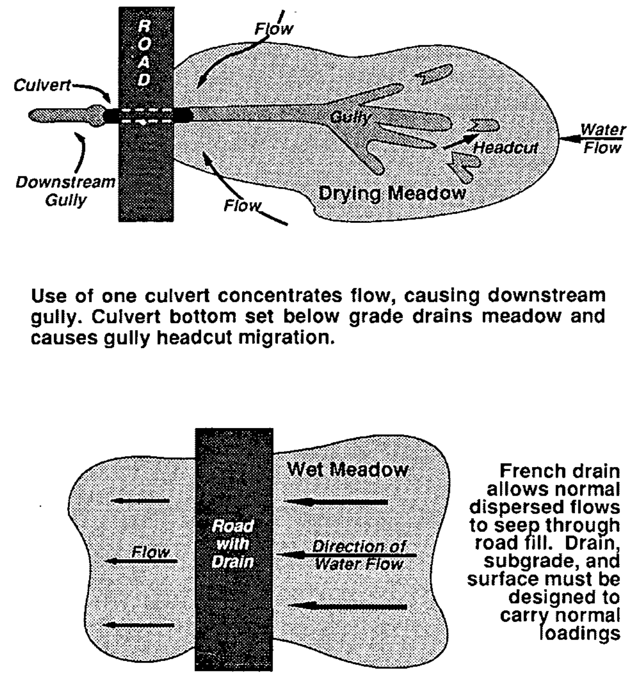

FIGURE 3 Improper and proper meadow crossings.

REDUCING SEDIMENT THROUGH ROAD MAINTENANCE

By 1961, Intermountain Region engineers had recognized the importance of road maintenance in the fight against erosion and sedimentation. Basic concepts had surfaced, including "keep the soil where it is" and "build maintenance into the road" (J. J. Wise, unpublished data). The problems inherent in managing many kilometers of road built to low standards—some on poor locations, with steep grades, little or no surfacing, and a lack of drainage provision—had been realized. Also, the realization that no two roads and no two erosion problems are exactly alike made it clear that instructions for equipment operators could not be written to cover all situations and that much would be left to the judgment of the on-site maintenance supervisor and equipment crew. It became apparent that each problem area should be analyzed separately before determining the proper corrective action for the situation and that operators should be trained in erosion control measures and effective equipment operation. During road maintenance activities, it is important to take into consideration all factors relevant to the situation rather than to routinely perform the maintenance. Familiarity with forest roads and the terrain, soil and vegetation, climate, and roadway characteristics provides the basis for making sound decisions that will allow for adequate drainage, safe travel, and resource protection.

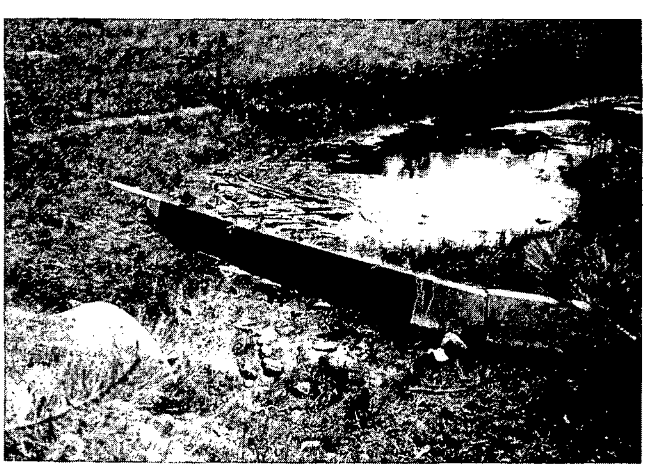

FIGURE 4 Jersey barrier plug installation.

(The material presented in the rest of this section is a condensation of a pamphlet by J. Firth.)

During ditch pulling activities, a "less is better" approach may sometimes be the best policy for sediment reduction. Selectively pulling ditches where required rather than routinely pulling all ditches has economic and environmental benefits. Lessening the amount of disturbance to the soil and vegetation in the ditch while still providing for adequate drainage will minimize sedimentation. During maintenance, stable cut slopes can be undermined, possibly causing slopes steeper than the material's natural angle of repose, with resulting slides and slope failures contributing to blockages and sedimentation. Tailoring ditch geometries to actual drainage needs can also alleviate slope undercutting in oversize ditches or in ditches with small flow volumes.

Ditch heeling, which consists of storing accumulated ditch waste against the cut slope toe during successive operations until the amount of material bermed requires removal, is an alternative to ditch pulling. Heeling the ditch is effective when dealing with smaller material volumes and can result in savings in maintenance time and money while providing for adequate drainage and resource protection. The heeled material aids in cut slope stabilization and helps prevent material moving down the cut slope from reaching the ditch bottom, where it subsequently would be transported downstream.

Areas in which large volumes of material move from the cut slope into the ditch may require special treatments rather than simple removal and disposal of the material. When realignment of the ditch away from the slope is such that slope stabilization is not feasible, drainage may be provided through the slough material by placing two logs side by side but with a gap, then bridging the gap with a third log. Sloughing material covers the logs, while a limited amount of drainage can occur between the logs.

Compaction of soil in the ditch, with resulting reduced erosion potential, may be obtained by tilting the mold board forward during ditch pulling and heeling operations and also by running the grader tires in the ditch and on the foreslope. Accumulated rock may be spread out in the ditch bottom as armoring material to combat scour. Gully plugs constructed in steep ditches slow the flow, reduce its erosive potential, and encourage the deposition of sediment. Grass and scattered rocks left in the ditch also slow flowing water.

The decision to leave or place obstructions in a ditch must be carefully weighed so that they remain assets and do not become liabilities. Impeded drainage may cause flow over the road or standing water in the ditch, both of which represent ditch malfunction and possible safety and operations problems.

Culvert inlet basins often present what appear to be "man-made slide areas" due to the toe of the cut being made farther into the hill to provide room for the catch basin. As the pipe inlet and catch basin are cleaned, the slope above may be undermined, causing more material to slide downslope. Culvert extensions have been successfully used to raise the inlet elevation, allowing material stabilizing the toe-of-slope to remain while providing for flow into the pipe. The new flowline is maintained at an elevation low enough to prevent subgrade saturation and drainage bypassing the culvert. A ditch dam may be placed downstream of the inlet to retard flow-by.

Settlement basins are dug to provide a pool for deposition of sediment before entry of ditch water into a live stream. Not intended for large volumes of water, they are relatively small and lined with rock to prevent erosion.

One primary objective in road surface maintenance is to provide for drainage of surface water. Poor drainage leads to saturation of road surfacing and base, erosion, and sedimentation. Maintenance of the surface section (be it outsloped, insloped, or crowned) and of surface smoothness is necessary to proper surface drainage. Surface cross drains are useful in removing water from steeper sections of road and those prone to surface rutting. Breaking up the concentration of water is especially important in these situations. Surface cross drains include open-top culverts, intercepting dips, cross ditches, and flavel bars. Flavel bars are a cross between interceptors and water bars, consisting of a shallow V-shaped ditch that runs at approximately a 20-degree angle to the road centerline for a length of 15 to 23 m (50 to 75 ft). The berm is placed on the downhill side, and the water may be directed to either side of the road, depending on surface section. Flavel bars are used mainly on roads with limited traffic volumes and low vehicle speeds.

Preventive measures are sometimes required to limit erosion on fill slopes. Riprap at culvert outlets armors the ground, retards the formation of gullies, and allows water to disperse. Filter windrows composed of logging slash and vegetative material, when placed on fill slopes, are effective at passing water but preserving sediment. Perhaps the most effective erosion preventive is seeding. Straw, mulch, or erosion control blankets may aid in protecting highly erodible areas until the seed germinates and takes root.

CONCLUSIONS

Many success stories may be found in the annals of the USDA Forest Service concerning the efforts of its employees in reducing transportation system-related impacts on the environment. Roads are being planned, located, built, and maintained with environmental concerns as a top priority. Engineers have found that, with careful planning, road work may be executed in a way that minimizes adverse effects while still providing the required access to an area.

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