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23. Forest Access Roads: Design, Maintenance, and Soil Loss

L.W. Swift, Jr.

The Regional Guide for the South (United States Department of Agriculture 1984b) recognizes that roads and skid trails are the major sources of sediment from forestry-related activities. The overall environmental impact statement for Region 8 (United States Department of Agriculture 1984a) estimates an existing national forest road network of 56,300 km (3 1,000 miles) with approximately 200 km (125 miles) of new construction or reconstruction each year. About 70% of this annual construction is classed as local road; i.e., the low-standard, limited-use road that terminates the transportation system. Local roads are often developed for access to timber sales. More than 40 years of road studies and land management demonstrations at Coweeta show both an early recognition that roads were a problem and a continuing effort to describe the magnitude of soil loss and develop technologies to control it. This chapter gives a history of road-related research at Coweeta and summarizes the findings of that research.

Roadbank Stabilization Tests: 1934-1958

About the same time that Coweeta was established, C. R. Hursh began a long series of roadbank stabilization tests and demonstrations. This was a period of greatly expanding road construction, stimulated by Federal and state programs of the Depression era. The use of newly developed earthmoving equipment in the Appalachians exposed large areas of soil in cuts and fills, creating problems not visualized by construction engineers. Hursh recognized the maintenance and environmental costs of these eroding slopes, and, in the spirit of the times, used natural materials and labor-intensive methods to stabilize them. Cut grass or weeds were laid on slopes and held in place with stakes cut from local materials (Hursh 1935, 1939). This mulch broke the eroding force of raindrops, halted the sloughing due to frost action, and encouraged growth of planted grass or naturally seeded vegetation. In forested areas, brush from trees was laid on top of leaf or needle litter collected from the forest. Sometimes, poles were laid horizontally across the slopes and pinned by stakes to hold down weeds or brush. Another technique was to move topsoil to the slope, encouraging growth of local plants (Hursh 1942c). Shrubs and trees provided more permanent stabilization (Hursh 1945). Many of the publications describing these methods contained instructions and photographs to aid work crew supervisors (Hursh 1938, 1939), while others were directed to decision makers (Snyder and Hursh 1938; Hursh 1942a, 1942b, 1949).

Bank stabilization work continued at Coweeta in the 1950s. Test plots of orchard grass, fescue, and ladino clover mixtures were planted at Chestnut Flats. These hay mixtures were then utilized as mulch on Coweeta roads. Bank stabilization by planted grasses was tested when the Dryman Fork roads were built. Rye and love grass were sown in 1957 on cut slopes after contour furrows were cut in relatively steep banks with fire rakes. Love grass provided the densest cover.

Exploitative Logging Demonstrations: 1941-1956

In 1940, Coweeta began a series of watershed treatments to demonstrate three typical but poor land management practices common on homesteads in the southern Appalachian Mountains. The mountain farm and woodland grazing demonstrations were reported elsewhere (Dils 1952, 19.53; Johnson 1952; Sluder 1958). The exploitative logging demonstration (WS 10) continued for 15 years (Lieberman and Hoover 1948a, 1948b; Dils 1957). Few requirements were placed on the logging contractor; he only had to confine his operations within the watershed boundary and was not allowed to construct a road or skid trail through the weir site.

Initially, logs were skidded from the area by horse teams. About 5.6 km (3.5 miles) of road and skid trail were constructed between 1946 and 1956 on the 85.8 ha watershed, with most of the roadway lying in or adjacent to streambeds. Skid trails and spur roads were often steep, and little effort was made to divert storm waters off the roads or to vegetate disturbed soil. Logs skidded downslope, often in the natural drainages, further contributed to soil erosion. Based upon transects across roads, about 408 m^3 of soil were lost from each kilometer of road length (860 $yards^3$/mile) (Lieberman and Hoover 1948b). Because of road proximity to flowing and intermittent streams, most of the eroded soil entered the stream. Turbidities were high, sediment concentrations peaking at 5700 ppm during a storm in 1947. Tebo (1955) reported reductions in stream fauna in Shope Fork below the junction with the muddy WS 10 stream.

By 1958, the eroded roads had become impassable and were closed, cross-ditched, fertilized, and stabilized with grass. The exploitative logging demonstration clearly showed that logging, using the methods typical of the times, severely degraded water quality. Observers concluded that watershed damage had little to do with the poor silviculture of exploitative logging, but was principally due to road design and methods used to remove logs from the woods.

Integrated Forest and Watershed Management Demonstration: 1954-1955

The next logical step was a demonstration that logging roads could be built in the mountains without diminishing water quality. Two treatment watersheds (40 and 41) were selected for this demonstration. Both were marked for sale under standards for individual tree selection silviculture, but with the intent that WS 41 would be managed primarily for intensive timber production (Jones 1955) and WS 40 primarily for water production. After the first cutting, Walker (1957) surveyed the residual stands and reviewed potential future management options. He observed that "the similarity of treatments for the two watersheds, though for contrasting reasons, illustrates the point that good timber management will usually imply good watershed management."

Road construction and logging operations were tightly controlled in order to protect water quality. Skid trails were not permitted; all logs were winched to the road by A-frame skidder or tractor. In this way, most soil disturbance occurred on or adjacent to roads where exposed soil easily could be seeded to grass. Uphill skidding was preferred, because downhill skidding disturbs more soil and creates converging channels which concentrate surface flow during storms. Confining logging equipment to the roadway required the construction of a series of regularly spaced contour roads across the pair of watersheds. Road density was 8 km/100 ha (2 miles/100 acres).

The intent was to develop a road design which protected streams, yet could be laid out with hand level and compass to avoid the expense of a complete engineering design. Contour roads did not parallel the streams, but crossed at right angles with a slight dip or lowered road elevation at the crossing point. All streams, perennial or intermittent, were carried through corrugated metal pipe. The dip at the crossing prevented the stream from flowing down the road if the pipe became blocked. Roads were relatively narrow, 3 m (10 feet) wide, slightly outsloped without an inside ditch, and seeded with grass after logging was completed. Fills were covered by brush, with grass planted on those exceeding 2 m in slope length. Surface drainage was achieved by opentopped culverts or narrow water bars.

These drains required weekly cleaning by shovel during use. Sometimes a water bar had to be reinforced by imbedding a log in the raised berm. This road system successfully met water quality goals, but the weekly maintenance demand and high initial cost discouraged its acceptance by managers and loggers.

Management Tests: 1956-1960

The practicality and economics of this Coweeta road design were tested in two sales on national forest ranger districts. Research personnel served as consultants to the districts for road layout and water sample collection, but were not active in sale administration. A change in personnel reduced district interest in one of these demonstrations, and the logging contractor deviated from the road plan.

On the Tallulah District in North Georgia, both the national forest personnel and the operator remained interested in completing the Stamp Creek sale as planned. Black and Clark (1958) described the road design, logging methods, and site rehabilitation actions. The logger found the road costs acceptable because his savings in lower equipment maintenance and higher work efficiency compensated for the initial construction investment. Turbidity measurements showed water quality was unimpaired, but the success of the demonstration was best shown in a statement by the operator: "All the time we were logging, my men and I drank water out of the stream." Apparently this was an unusual work experience for them.

The Stamp Creek sale demonstrated the feasibility of having district personnel lay out and control a transportation system, and of expecting the logging operator to economically build roads and log an area without destroying water quality. Conversely, the companion sale clearly demonstrated a need for commitment and supervision by all involved to implement changes in roading and logging methods on National Forest lands.

Multiresource Management Demonstrations: 1962-1964

The demonstrations described to this point have dealt with only two resources of the mountain forest, the timber and the water. The Multiple-Use Sustained-Yield Act of 1960 established a legal requirement for that concept of management, often talked about in general terms, but difficult to demonstrate on the ground. Coweeta selected the 144 ha, high-elevation WS 28 for a demonstration of the concept of multiple-use management.

The decision was made to conduct this demonstration as if it were part of a municipal watershed-but not one where access, timber management, and recreation uses were excluded. If all resources in the watershed were to be made available, then access should be provided to most of the basin, not just to some limited area scheduled for the next timber sale. Thus, an important part of the WS 28 demonstration was an early illustration of transportation planning for long-term access into forested mountain land. Hewlett and Douglass (1968) described the transportation plan and design criteria used. Road density was somewhat less than on WS 40 and 41; about 5.2 km/100 ha. Goals were (1) to improve earlier designs so that maintenance requirements such as frequent cleaning of narrow-based water bars could be reduced, and (2) to demonstrate that timber access roads are permanent investments and not temporary expedients.

A solution was the broadbased dip, the design feature that has become a part of nearly every forest road guideline in the eastern United States and has influenced logging road standards internationally. Instead of the partial obstruction to traffic that the water bar presented, the broad-based dip was a gentle roll in the centerline profile of either a contour or climbing road (Figure 23.1). A 3% reverse grade over 6 m provided a relatively permanent block to any water flowing down the road. The dip was outsloped 3% to divert storm waters off the roadbed and onto the forest floor, where transported soil would be trapped by forest litter. Dips are not effective for draining wet soils or cutbank springs. The broadbased dip is similar in concept to the intercepting dip in the

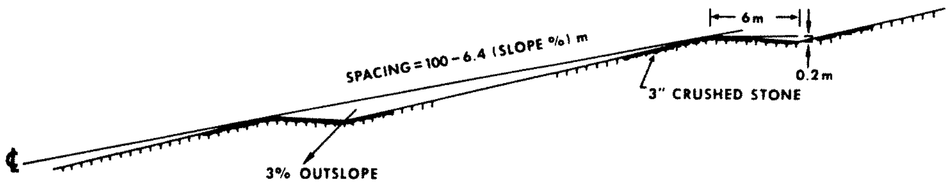

Figure 23.1. Diagram of the broadbased dip design for forest access roads.

California Region supplement to the Forest Truck Trail Handbook (United States Department of Agriculture 1935). Guidelines for the critical placement of the dip have developed with experience. The average spacing between dips is about 60 m. Initial standards for dip spacing proved impractically short on grades steeper than 8%, but even on steep sections dips are recommended at the top of a grade. Water diverted off a roadbed may flow across loose fill, but erosion is reduced if a dip is placed where the fill is short. Dips should not be placed to drain into perennial or intermittent streams where sediment would be carried further by storm waters.

The broadbased dip was linked to two other design features of the Coweeta road—vertical cut banks and no inside ditches. By its very nature, a ditch collects water, and the volume and velocity of storm runoff erodes the ditch and undercuts the bank. Sometimes the ditch carries this sediment to a stream. If a culvert empties onto loose fill, the concentrated water creates even more erosion. For a ditch to remain effective, debris must be scraped out, often disturbing the vegetation protecting the ditch and undercutting the cut slope above the ditch. The road width must allow for the ditchline, thereby exposing more disturbed soil during construction. However, where the roadbed can be drained by outsloping and broadbased dips, the problems of inside ditches can be avoided. Outsloping is most effective when roadbed rutting is controlled. Sometimes a short ditch may be needed to intercept seepage from the cut and drain the roadbed.

If the road has no inside ditch, then the cut bank can slough onto the inner edge of the roadbed without contributing loose soil into the path of storm runoff. Vertical cut banks are less expensive because less right-of-way clearing is required, less soil is moved, and smaller fills created. Cut bank soils slump to the angle of repose carrying roots, seeds, and topsoil to vegetate the exposed surface. At Coweeta, vertical cuts up to 2 m high have stabilized naturally on moist, fertile sites, but 1 m seems to be the limit for drier, less fertile banks. Although clearing a narrow right-of-way lowers construction costs, other factors argue for wider road clearings. For example, "'daylighting" accelerates the drying of roads in wet and winter weather (Kochenderfer 1970), and wide right-of-way clearings can be linear wildlife openings (Arney and Pugh 1983).

Although each of the Coweeta road demonstrations was installed to test improved construction methods, they also served to train and educate private citizens and land managers, field technicians, and policymakers from industry and government. As a group, forest industries seemed quickest to adopt the concepts embodied in the Coweeta road design. A significant step was taken by Forest Service Region 8 at the Timber, Water, and Road Work Conference held in October 1968. Staff officers from each national forest and the region reviewed newly issued road design guidelines, saw a presentation on Coweeta WS 28, and visited demonstration roads on several ranger districts. Two goals were achieved: (1) the Conference encouraged wider use of broad-based dips and other design features to raise the standard of timber purchaser-built roads and (2) participants agreed that well-built timber access roads could be accepted into the permanent Forest Service road system without requiring full engineering design services and supervision.

Best Management Practices

The 1972 Amendments (Section 208) to the Federal Water Pollution Control Act require the management of nonpoint sources of pollution from forest activities. The Environmental Protection Agency encouraged each state to identify Best Management Practices (BMP's) as a voluntary means to reduce nonpoint sources of pollution. The principal source was recognized as soil disturbance and erosion. BMP's were chosen as superior to expensive regulation and rigidly defined practices because the individual timber producer could develop methods best for his terrain, equipment, and size of operation and achieve a practical balance between water protection and economic production of wood products.

Most states produced one or more pamphlets promoting and describing BMP's. These documents are illustrated and designed for use by loggers and small timberland owners. Some states further encourage adoption of BMP's through active extension service programs, county forester and consulting forester contacts, and inducements such as tax advantages for managed forest lands. BMP's deal with pollution from pesticides, fertilizers, other chemicals, and increased water temperature as well as soil erosion. However, the greatest effort is directed to encouraging BMP's for erosion control caused by roading, logging, and site preparation. Almost without exception, BMP guidelines for forest access roads include design features based on Coweeta experience. Use of the broadbased dip is not limited to the eastern United States, but also appears in state, industry, and national forest guidelines in the West.

Transportation Planning

One outgrowth of the multiresource management demonstration on Coweeta WS 28 was a realization that long-range planning of a forest transportation system should include intermittent-use access or local roads along with fully engineered forest development roads. Managers have been accustomed to referring to these two broad and sometimes poorly defined classes of roads as temporary and permanent. With the recognition that even the lowest class of road could be a permanent capita1 investment came the understanding that planning was necessary to assure that each mile of road was constructed on the best possible location. In the 1960s, the Southeastern Forest Experiment Station proposed to cooperate with Forest Service Region 8 in a major demonstration of multiresource management, with the key first step of planning and initiating development of a forest access system. The Upper Nantahala River basin adjacent to Coweeta with its then-maturing second forest was proposed as the demonstration site. The proposal was not acted upon and, thus, 16 years later a portion of the area could be reserved by the 1984 North Carolina Wilderness Law.

In an allied effort, Yandle and Harms (1970) produced a computer model which identified the best alternatives for each successive increment of road construction as active forest management developed over a unit of land. Decisions were driven by timber, wildlife, and recreation management opportunities. The model required a transportation plan and management information on timber stand maturity, location, and value as well as parameters describing other resource values and road construction costs.

Although research on many of these early ideas for transportation planning never passed the proposal stage, the principles which were raised and discussed are now being used operationally by timber, engineering, and other resource staffs working together on both short- and long-range plans for the National Forests.

Bridge and Culvert Size

Capitalizing on the large amount of streamflow data from small watersheds at Coweeta, Douglass (1974) developed relationships between flood frequency and the area and elevation of a watershed. These two factors accounted for 98% of the variation in discharge data. Because a standard method of estimating storm flows, Talbot's formula, gave considerably larger values than the Coweeta equations, new tables were presented to aid in selection of culvert and bridge sizes to handle maximum storm flows with recurrence intervals of 2.33, 5, 10, 20, 30, and 50 years. The value and applicability of this work is further strengthened by the agreement and overlap with flood frequency equations presented by Jackson (1976) and Whetstone (1982) for the mountains, Piedmont, and Coastal Plains of North and South Carolina. Larger structures are indicated for the shallow-soil watersheds of the central Appalachians (Helvey 1981).

Operational Application of Road Design Guidelines: 1976-1984

The elements of road design standards developed at Coweeta have stood the test of time and have been adopted in variation by many government and industry groups. The broadbased dip has found the widest acceptance, while the concept of vertical road cuts has less application. Since 1976, Coweeta's road-related research effort has been devoted to measuring the success of operational applications of current design standards rather than developing new designs (Douglass and Swift 1977).

In cooperation with the engineering staff of Region 8 and the National Forests in North Carolina, Coweeta measured the amount and timing of soil loss from several collector-class roads on the Wayah Ranger District. A collector is a light- to medium-traffic road that connects several local roads to primary or arterial routes and is generally constructed to a higher standard than the local road. Questions asked in this study were:

- In general, how effective are the current design standards for controlling soil loss from roads in steep mountain land?

- Which portion of the total soil loss comes from cut slopes, roadbeds, or fill slopes and how much can each loss be reduced by grass and gravel?
- When during the life of a road does major soil loss occur and what is the influence of season on rate of soil loss?
- How much and what type of surfacing is required for intermittent-use roads?
- How far downslope from the roadway does soil move and are present filter strip standards appropriate?
- If funds or time are limited, what critical part of a road should receive erosion control action first?

These roads were wider, 4.5 to 6.5 m, with deeper cuts and longer fills than the local roads previously studied at Coweeta. They were typical of currently constructed national forest access roads designed for sales using larger trucks. The details of study findings are given elsewhere, so only a summary is presented here. Soil loss rates differed among cut slopes, fill slopes, and roadbeds and were influenced by season and vegetation. Predictably, a graveled roadbed with well-grassed slopes had the lowest soil loss (Swift 1984b). Without any grass cover in early winter, freeze and thaw cycles loosened the cut slopes and large amounts of soil accumulated at the toe of the slope. Without an inside ditch, the debris stabilized and contributed little to sediment leaving the roadway. With the ditch, however, road maintenance and storm runoff moved the loose soil off the site, undercut the newly formed debris pile, and increased the potential for further soil loss. In four winter months, 150 to 360 t/ha were lost from the ungrassed cut slope. After grassing, soil loss was negligible.

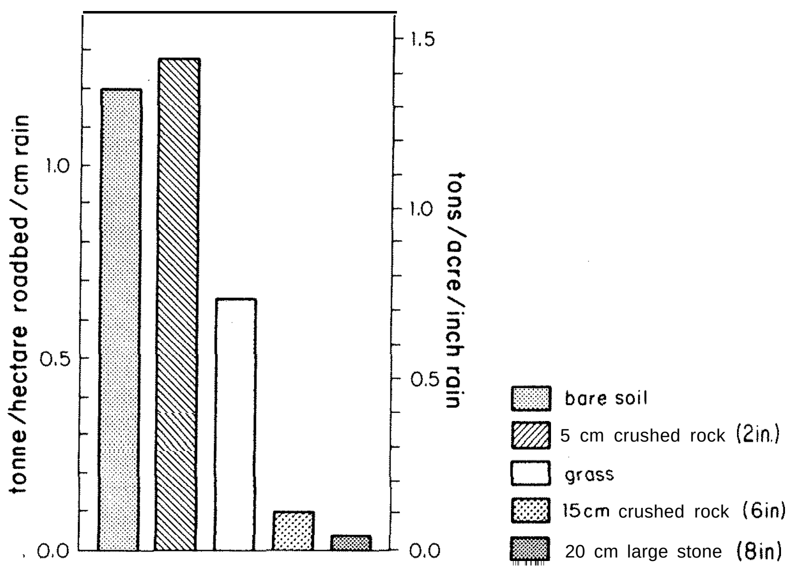

Figure 23.2. Soil loss rate for roadbeds with five surfacing treatments. Roads all constructed of sandy loam saprolite.

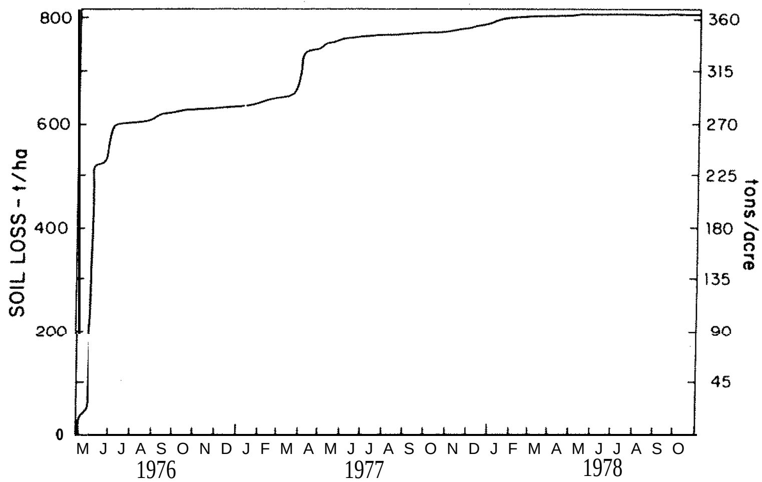

Figure 23.3. Cumulative soil loss from a forest road at a stream crossing in the first 2.5 years after start of construction.

Fill slopes, although uncompacted and unvegetated, eroded only where storm runoff from culverts or dips flowed over loose soil. In early spring, however, when high soil moisture levels are typical, some fills did slump onto the forest floor or against an obstruction downslope such as a brush barrier. Size of fill, steepness of the terrain, and texture of soil influenced slump occurrence and how far soil would move. Slumps were much fewer and smaller in volume on well grassed fill slopes.

Less soil was lost on a unit area basis from an ungraveled roadbed (< 8% grade) than from either cut or fill slopes. After graveling, only small soil loss occurred from storm wafer flowing in ruts or along the lightly graveled shoulder of the roadbed.

Gravel surfacing is the largest single cost item for forest roads; consequently, lower standard, intermittent-use roads often receive only thin coatings of gravel, spot treatments, or no gravel at all. Soils with high coarse fragment content, such as occur in some roads in the central Appalachians (Kochenderfer et al. 1984) can develop a natural gravel surfacing after an initial loss of finer soil particles. Test sections on a collector-class road at Coweeta (Swift 1984b) showed that soil loss from a lightly graveled roadbed was equivalent to loss from an ungraveled one (Figure 23.2). In contrast, soil loss from a grassed roadbed was half that of the bare soil road, both carrying the same traffic load. Soil loss from fully graveled roadbeds (15 to 20 cm thick) was only 3 to 8% of that from the bare soil roadbed of otherwise similar construction.

Typically, newly constructed roads lose the most soil, primarily during the short period before grass becomes well established and the roadbed is graveled or compacted. Three-quarters of the soil eroded during 2.5 years of observation was carried into the stream immediately below a road crossing in the first two months. Another 15% was measured a year later during the 3 months when the road was used for yarding and hauling logs (Figure 23.3). Thus, 90% of the soil loss from this road section occurred during only 15% of the 2.5year period.

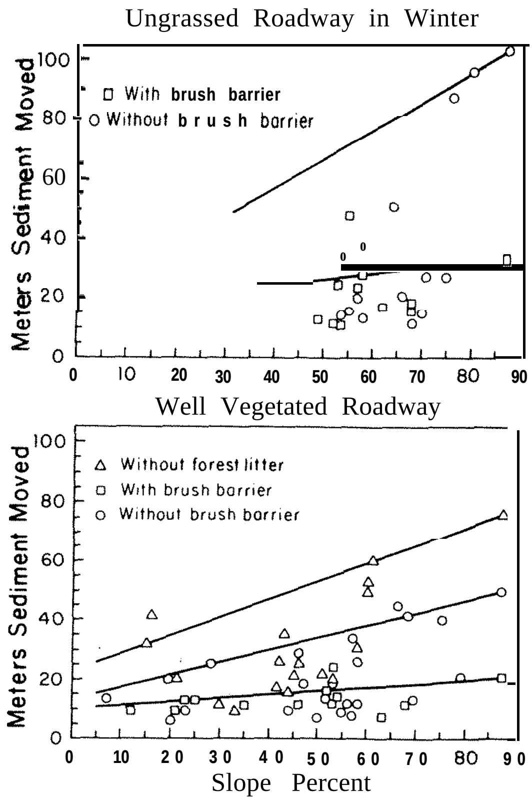

Figure 23.4. Lengths of sediment deposits downslope from roads are greatest where roadway is unprotected by vegetation, and least where brush barriers and forest litter trap sediment flows.

The outsloped road with broadbased dips protects water quality, because sediment-laden storm water is dispersed onto the forest floor rather than into a stream. The method is reasonable if the forest floor is protected by root mat and litter and has high infiltration rates typical of Appalachian Mountain soils. To protect water quality, sediment should be deposited on the forest floor before it reaches a stream channel.

Existing guidelines specify the width of undisturbed forest floor to be reserved for filter strip. Improved road construction methods allow reductions in filter strip widths from past guidelines if certain practices are followed (Swift 1986). A survey of 3.4 km of newly constructed forest road in the vicinity of Coweeta identified 76 major sediment deposits (longer than 7 m) (Figure 23.4). The longest three deposits extended over 85 m downslope, but these drained from portions of road left unfinished and ungrassed throughout the winter. Current management guidelines call for filter strip of 84 m on a 60% slope in moderately erosive soils. Where the road was finished and cuts and fills grassed before winter, deposits were all less than 45 m long, even on slopes over 60%. Brush barriers at the toe of fills held all but the longest deposit to less than 30 m for all slopes and to under 20 m if fills were vegetated. The lack of forest litter or brush barrier in a burned area allowed sediment to move up to 60 m on a 60% slope. These results emphasize that mitigating practices will reduce movement of sediment downslope, thus allowing greater flexibility when selecting road locations.

Wherever a road is built across a perennial or intermittent stream, loose soil falls into and around the channel. There is no filter strip, so unless vegetation or erosion-resistant materials cover the road fill, storms unavoidably wash soil directly into the stream system. Brush barriers extend only to a stream's edge. Thus, road crossings over defined channels are the most critical points on a road because fills are larger, the road drains directly into the stream system, and opportunities for mitigating practices are limited.

In 1976, three roads were built on WS 7 at a density of 5 km/100 ha. During the first year, all sediment collected in the weir originated from the roads; most of it from eight stream crossings during the first 2 months after construction began. For example, sediment measurements immediately below one crossing showed a cumulative total of 600 metric tons of soil entering the stream from each ha of roadway (Figure 23.3). A storm on May 27-29, 1976, produced the maximum streamflow event for the 50-year history of WS 7. Most of the sediment came from fill erosion before it was covered with grass. About 80% of the soil washed into the stream remained in the channel and had not reached the weir 720 m downstream after 2.5 years. However, portions of these deposits are still being transported out of the stream system 8 years later. The sections of roadway observed to contribute storm water and sediment directly into the stream are only 1% of the entire watershed area.

Based on these findings, practical water quality protection can be achieved by (1) designing roads with near vertical cut banks, no inside ditches, and broadbased dips; (2) completing construction and revegetation of cut and fill slopes before winter; (3) installing brush barriers at the toe of fills if the fills are located within 150 feet of a defined stream channel; and (4) fully graveling roadbeds that drain into stream channels.

Road Maintenance

Coweeta research has emphasized design and construction of forest roads, but, in the course of these studies the influence of road maintenance upon soil erosion also has been noted.

A goal of the intermittent-use road design incorporating the broad-based dip was to reduce costs. The design reduces maintenance costs during the period of heavy use, the long-term costs for standby maintenance, and the expenses of reopening a closed road. Experience has shown that grassed roadbeds carrying under 20-30 vehicle trips a month require a very low level of maintenance; primarily annual mowing of roadbed and periodic trimming of encroaching vegetation. The outlet edges of broadbased dips need to be cleaned of trapped sediment to eliminate mudholes and prevent the bypass of storm waters. The frequency of cleaning depends upon the traffic load. WS 28 roads required servicing every 5 to 10 years, but the roads on WS 7 carried more traffic and dip cleanout was required after only 2 years.

Maintenance by motor grader is difficult for this type of road. Scraping tends to fill in the dips, and often the blade cannot be maneuvered to clean the dip outlet. Cut banks are destabilized when the blade undercuts the toe of the slope. Small bulldozers or front-end loaders appear to be more suitable for periodic maintenance of intermittent-use forest roads.

Summary

The design and construction of, and soil loss from forest roads have been continuing areas of research and demonstration by the Southeastern Forest Experiment Station since Coweeta Hydrologic Laboratory was established. The low-cost, low-maintenance intermittent-use road pioneered by Coweeta is widely accepted and adapted to local conditions by government and industry land managers, and strongly recommended by state agencies with the aim of reducing sediment, the principal nonpoint source of pollution from forestry activities.

Several principles can be drawn from the Coweeta studies. An inexpensive design and field layout procedure can produce a serviceable and environmentally acceptable road. The most effective road system results from a transportation plan developed to serve an entire basin rather than the sum of individual road projects constructed to serve short-term needs. Soil exposed by construction should be revegetated quickly. Where possible, storm waters should be removed from the road at frequent intervals and in small amounts by outsloping and dips, rather than by consolidation into ditchlines and culverts. Contour roads and gentle grades require less maintenance and produce less sediment. Gravel surfacing is best, but a grassed roadbed is good where traffic is light and can be controlled to exclude use in wet weather. If only a small quantity of gravel is available, it should be applied on climbing grades, poor trafficability soils, in dips, and near stream crossings. The stream crossing is the most critical part of the entire road, and every effort should be made to protect and vegetate fill slopes and divert storm waters on the road away from the stream. Filter strips and brush barriers prevent sediment from reaching streams. Unnecessary maintenance must be avoided.

Guidelines for forest road design are available which minimize the impact of construction and use on water quality. The task is to apply these in land management.