The Three Rs of Roads

All too often, unpaved forest access roads in the southern Appalachian Mountains were located near streams and rivers, thereby contributing storm flow and sediment to the aquatic ecosystem. Landowners and managers may not have the resources to reconstruct and relocate all these roads to protect water quality. However, simple techniques for redesign of storm water drainage structures can provide low-cost alternatives where the forest floor can absorb and filter runoff from roads. These practices could apply not just in the Appalachians but wherever storms and roads are placing sediment in the stream. Land managers and consultants who assist nonindustrial forestland owners can use the principles for maintenance, reconstruction, or restoration of problem roads.

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We believe that the evolving concept of ecosystem management is a broadened view of the established discipline and practice of watershed management. In watershed management the stream or river catchment is an integrated unit of physical and biological components linked by the delivery, storage, transport, and use of water. Ridgeline is linked to midslope, which is linked to bottomlands, which are linked to the aquatic zone. Water carries nutrients, assists in the spread and nourishment of organisms, and is a key agent in the formation of topography and soils that support a watershed and its ecosystem. As in any linked system, management actions that affect any single part of an ecosystem are, in turn, likely to affect other parts. Traditionally, watershed management has focused on water quality and the human activities that affect it. Ecosystem management broadens that focus to emphasize, equally, other elements of the forest ecosystem that have often been ignored or overlooked.

In the Appalachian Mountains, large storms that initiate landslides are the major, albeit infrequent, natural cause of disturbed ecosystems (Neary et al. 1986), and these events do result in lowered water quality from forested lands (Patric 1976). Of the various forestland management activities, road management poses the greatest risk of ecosystem disturbance as revealed by degradation of water quality. Best management practices (BMP) are derived from the concept that by controlling water volume and velocity on the land, we can maintain water quality in the aquatic system.

Road management in the Appalachian Mountains is complex be-

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The local community had used this orphan road for a long time, but it was not maintained by any organization or desired by the landowner. Efforts to halt erosion by closing this roadway were resisted by the county government, which initially was also unwilling to assume responsibility for its restoration and maintenance.

REDESIGN RECONSTRUCTION RESTORATION

cause of the mixture of ownerships and the age of the roads, some of which were laid more than 100 years ago. Often, these older roads were built along river and stream bottoms on sites that today would not even be considered, given present BMPs. However, such streamside roads still exist in the Appalachian landscape, and many are still in use. How can a land management unit containing such roads redesign, reconstruct, or restore roads that cause major ecosystem disturbance?

Problem Roads

Some forest roads were designed, or have been redesigned, to meet established BMPs. Road design guidelines have evolved as our understanding of the forest hydrologic system has improved. Over the past 30 years, significant progress has been made by managers who have used BMPs to locate, construct, and maintain forest roads in ways that protect water quality. Changing attitudes, experience, and technical expertise have raised the quality of new and reconstructed roads. Government agencies, industries, and public interest groups now have hydrologists, soil scientists, geologists, fisheries and wildlife biologists, and archeologists who bring talent and excellence to road planning. They can work with the foresters and engineers who implemented road management policies in the past. Agencies and industries without such resources have training and consultants available.

Some roads now in use were not built on the best locations, or they were constructed and maintained using designs not acceptable by today's standards. Despite our technical expertise, forest road systems built before BMPs may be prohibitively expensive to move to better locations, even though their impacts on ecosystem health are unacceptable. Within Forest Service jurisdictions, sufficient financing has not been available for major replacement or reconstruction of below-standard road systems, even roads necessary for public access or for forest management and protection. Available funds can only partially remediate high-priority problem sites.

Abandoned "orphan" roads often have negative impacts on both terrestrial and aquatic ecosystems. Isolated sections of problem roads that are no longer accessible because the road was closed or partially obliterated may be causing undesirable impacts on ecosystem health. Historic-use rights block the legal closure of some roads, many with unclear ownership, even when they are causing unacceptable damage.

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This long-established road is too close to a stream, and sediment flowed from the roadbed into the channel during storms. The roadside berm was constructed of gravel during regrading and now prevents storm runoff from entering Curtis Creek. Runoff and sediment flow along the road's edge to a disposal site away from the stream.

Classes of Roads

Rural roads are classified by use level and physical condition. *Arterial or collector roads* form a connecting transportation network that carries high volumes of traffic. Usually two-lane roads with an all-weather gravel surface, they may be open to traffic year-round and interconnect other roads. *Local roads* generally are single-lane graveled or dirt roads that usually carry little traffic and may dead-end. They may be open year-round but impassable in wet weather. Many are rough-surfaced and suitable only for high-clearance or all-wheel-drive vehicles. *Orphan roads* are abandoned or not maintained by any landowner, government entity, or group of users. They may be passable only for off-road vehicles, if at all. They may receive only the minimum maintenance required for

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A turnout intercepts storm runoff in a roadside ditch and directs water into a sediment trap away from the road and stream. The pit was dug by backhoe during scheduled maintenance and reconstruction of the roadbed.

passage provided by infrequent users. Because of this lack of attention, sections of orphan roads commonly cause substantial adverse impacts to adjacent water resources.

Road class directly influences our choice of treatment option: relocation, reconstruction, or closure. Arterial and collector roads will seldom be closed, even in resource-damaging locations. As long as the costs for relocation and new construction are higher, reconstruction is the likely choice. For local roads, permanent or seasonal closure may be the choice, if such action is legally feasible. Designing a replacement in a better location is preferable to attempting to repair a poorly designed road on an inappropriate site. Orphan roads should be permanently closed, if legally possible, unless a responsible individual or organization is willing to reconstruct and maintain them.

Reconstruction

When the decision is made to upgrade a road, portions may be reconstructed, other sections relocated, and the abandoned sections closed. The treatment selected will depend on road type, cost of implementing treatment, and funding. Closing an abandoned road section without restoration to a more natural hydrologic condition may not arrest the adverse impacts. A road analysis procedure can help landowners and managers decide between relocation and reconstruction and determine which would have the most positive or least negative effect. For instance, light reconstruction may have fewer negative impacts if less soil would be disturbed.

The landowner or manager must consider several factors when selecting treatments for roads that must be kept open. Experience and studies have established that early application of grass and gravel on forest access roads greatly reduces sediment output (Swift 1984). The type of vehicle and traffic volume using the road will determine road width and grade, season of use, and surfacing needed to reduce erosion and provide safe passage.

The basic objective is to eliminate or minimize each direct connection between storm flow from the road and nearby streams. One method is to disperse storm water from the roadway as often as possible to minimize the volume of runoff leaving the road at any one point. Another method is to divert storm water into a sediment trap before road runoff reaches the stream channel.

In the past, when roads were constructed adjacent to streams and rivers, drainage was intentionally designed to dump storm runoff and sediment into the channels. A better design will direct storm water to places where it can infiltrate the soil and drop most of its sediment load before reaching the stream. The undisturbed forest floor is an excellent buffer to trap and filter sediment from storm water (Swift 1986). Generally, soils in the Appalachian Mountains are porous and exhibit high infiltration rates. Storm runoff can be handled by forcing it off the road in reduced volumes that limit impacts at each outlet and by diverting it to areas where it cannot reach the stream.

Small volumes of water are easier to control and have lower sediment transport capacity. Where a road is close to a stream, runoff should be kept on the road until it can be released onto a filtering site. Berms—low mounds of soil or gravel built along the edge of a road—keep the storm water temporarily on the roadway and extend along the road until a suitable infiltration or sediment trap site is reached. Berms are constructed high enough to contain the storm water and with enough width and coarse material to withstand the eroding force of flowing water. Berms also are used over culvert crossings to keep storm runoff from going directly into the channel. Unless there is grade sag at the crossing, runoff may be routed along the roadbed to a functioning infiltration site away from the stream.

Natural berms may develop with use along roads at undesirable locations and will trap runoff on the road instead of allowing drainage to dispersed places on the forest floor. Natural berms may develop from improper road grading or gradual entrenchment of the road below the surrounding terrain. During maintenance, a manager may choose to remove an entire berm or cut channels or weeps through it at sites selected to release runoff away from a stream.

Sediment traps, or settling basins, placed in ditches or at the ends of turnouts will reduce the velocity of the storm water so that much of the suspended sediment will be deposited. These structures simply may be holes dug into the ground, but one should avoid the temptation to pile the loose soil removed from the hole around its edge to gain greater capacity; such a "dam" could fail when overtopped. Basin size depends on the volume of water to be treated (which can be estimated), but larger traps last longer. The greater the capacity of the trap relative to the volume of storm flow, the finer the sediment particles that will be trapped. Ideally, traps should be designed not to overflow during an expected storm, thus keeping all the sediment out of the stream. To be ready for all but the larger storms, traps should be cleared of sediment when they are half full.

Insloping and crowning a roadbed for drainage are typically used to force storm water to a ditch on the inside edge of the roadbed. However, inside ditches require maintenance and are additional sources of eroded soil. Adding large rocks to the ditch base can reduce erosion. Alternatively, storm water can be removed from the road if a short section of reverse grade is created to intercept water and sediment moving along the roadbed and force it off the outside edge of the road; from there it infiltrates the forest floor. A reverse grade can be constructed as the hump section of a broad-based or rolling dip or by following the terrain to undulate the road grade (Hewlett and Douglass 1968). Inslopes or outslopes—road surfaces that angle toward the inside or outside road edge—and reverse grade sections can be created when the road surface is regraded or by importing new roadbed material.

Ditches concentrate storm flow and commonly are designed to direct water into streams and intermittent channels. We prefer to direct water into sediment traps or onto areas where it will infiltrate. The objective is to minimize the amount of ditch water that flows directly into streams. Long ditch lines should be broken into shorter sections by constructing additional drains that will both reduce the volume of flow and generate smaller amounts of transported sediment. Ditch outlets or turnouts should be constructed where they will empty into selected areas where water cannot immediately reach the stream. Relief culverts may be needed to pass water from one side of the road to infiltration areas or sediment traps on the downslope side.

Stream crossings are the major source of sediment. Road sections near crossings were often constructed with ditches that drain directly into the channels. Additional ditch outlets or relief culverts installed outside the stream-crossing zone will intercept ditch runoff and minimize sediment carried to the stream. Roads often have a low point—a grade sag—at the channel crossing that causes storm runoff on the roadbed to flow from both directions toward and into the stream. Raising the road surface over the crossing will direct road runoff away from the stream and reduce sediment loading. Where there is no grade sag, berms can be built to pass the road runoff across the channel area to a suitable disposal site.

Water and sediment control practices used on local or lower-class roads are similar to those used on arterial or collector roads. However, because local roads typically have less traffic, and the vehicles may have more ground clearance and travel at slower speeds, the road surface on a lower-class road may be rougher and grade changes more abrupt. With slower speeds, outsloping and broad-based dips can be used safely. Dip outlets should be located to avoid placing road runoff into intermittent or flowing channels.

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The broad-based dip is a road drainage structure that places a reverse grade in the roadbed. The dip is designed to intercept and turn storm runoff from the outsloped roadbed and onto the forest floor, where the water infiltrates and sediment is trapped. The broad-based dip, a less abrupt structure than the typical waterbar, may be traversed by highway vehicles when the roadbed is dry.

Restoration

Restoration of an orphan road by closure assumes that the landowner can legally and permanently close the road to further use. Available treatments are similar to those used for open roads, except that practices can be more abrupt. A water bar, for example, can be very high if no vehicles need to cross it. Although only portions of a road are causing problems, the entire road should be treated before closure while its full length is accessible.

Primary objectives during restoration are to eliminate surface erosion and create a more natural site hydrology. Exposed bare soil must be revegetated to protect it from accelerated surface erosion. The existing roadbed is loosened to prepare a seedbed. Vegetation, seed, fertilizer, and lime selections should be based on climate and soil analyses for the site. Vegetation might not become established if surface runoff is not controlled by practices described earlier.

Revegetation will increase soil infiltration rates. When increased infiltration and runoff dispersion reduce storm runoff and lengthen the time rain takes to reach the channel, peak stream flow rates will decline and the watershed's hydrologic function effectively will be restored.

Each stream crossing must be restored to a stable, noneroding condition and restructured to safely pass projected storm flows. Occasionally, stream flow has been "captured" by a road crossing and the old roadway becomes an eroding channel. Restoration includes placing the flow back in its natural channel.

Conclusion

Although the experience and examples noted here are from the southern Appalachians, the principles and practices could apply wherever storms and roads are placing sediment in the stream and where the forest floor has the capability to absorb and filter runoff from roads. Formal road analysis procedures, soon to be applied to national forest lands, also may be a useful tool on other government and industrial ownerships, as well as for consultants who assist nonindustrial forestland owners. Analysis procedures can be used not only to identify roads that cause problems within a watershed ecosystem but also to help landowners and managers weigh possible ecosystem damage against the demand for the road and the costs of various treatment and management alternatives. As management challenges grow more complex, we must strike an acceptable balance between reasonable cost and tolerable resource damage. Such information can help form the basis for setting priorities and seeking funding for redesign, reconstruction, or restoration actions. In some cases, high-priority action will be indicated for a road, but traditional sources of funding may not be available.

Some will find the task of identifying harmful road design and construction—even road system repair—discouraging. Forest road problems may be hidden in the woods. Society must recognize that ecosystem damage wrought by forest roads cannot be reversed overnight. Old sediment deposits in the streams and rivers will take a long time to flush. We must identify established gullies or erosion pathways that lead to forest streams, facilitate their healing, and allow disturbed riparian zones to recover. Such conditions have left long-term wounds that will be slow to heal.

Proven methods for road repair and minor redesign can help restore aquatic ecosystem function and improve water quality. Actions to divert sediment-carrying storm flow away from streams, lakes, and rivers can be accomplished with low-cost, supplemental spending during routine maintenance activities. In short, the technology exists to raise the quality of watershed and ecosystem management in the Appalachians.

Literature Cited

HEWLETT, J.D., and J.E. DOUGLASS. 1968. *Blending forest uses.* Research Paper SE-37. Washington, DC USDA Forest Service.

NEARY, D.G., L.W. SWIFT JR., D.M. MANNING, and R.G. BURNS. 1986. Debris avalanching in the southern Appalachians: An influence on forest soil formation. *Soil Science Society of America Journal* 50 465–71.

PATRIC, J.H. 1976. Soil erosion in the eastern forest *Journal of Forestry* 74(10):671–77.

SWIFT, L.W., JR. 1984. Gravel and grass surfacing reduces soil loss from mountain roads. *Forest Science* 30(3):657–70.

———. 1986. Filter strip widths for forest roads in the southern Appalachians. *Southern Journal of Applied Forestry* 10(1):27–34.

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