REDUCING EROSIONAL IMPACTS OF ROADS

Prepared by Harold E. Hunter, State Staff Forester, Soil Conservation Service, Bozeman, Montana.
Reducing Erosional Impacts of Roads by Walter F. Megahan is an excellent capsulization of basic principles to keep in mind to minimize the erosional impacts of road construction including land use planning, route reconnaissance and location, road design criteria and stabilization measures. A review of the information contained in this Technical Note will help those of us concerned with erosion control on forest lands by serving as condensed overview of the subject and aid in the identification of relevant references to obtain which relate to subject matter areas for which we desire more information.
1. INTRODUCTION

Accelerated erosion may take place following road construction on forested lands. Some possible causes include: (a) removal or reduction of protective cover; (b) destruction or impairment of natural soil structure and fertility; (c) increased slope gradients created by construction of cut and fill slopes; (d) decreased infiltration rates on parts of the road; (e) interception of subsurface flow by the road cut slope; (f) decreased shear strength, increased shear stress, or both, on cut and fill slopes, and (g) concentration of generated and intercepted water.

Numerous reports substantiate the fact that road construction can accelerate erosion on forested lands (1, 2, 4, 6, 9, 14, 15, 18, 19, 20, 22, 24). Experience by FAO in developing countries has often shown that roads are the major source of erosion. As might be expected, effects vary considerably depending on the, geologic, climatic, landform, soil, and vegetation properties of the area or country in question and upon the care taken to reduce erosion in all phases of the road development project. Roads constructed on glaciated, metamorphic parent materials in Colorado, for example, exhibited slight accelerated on-site erosion, but no significant increases in sediment yields were detected downstream (14). In contrast, construction of low standard, temporary logging roads on high erosion hazard granitic slopes in Idaho greatly accelerated on-site surface and mass erosion, causing downstream sediment yields to increase an average of over 45 times (from 8.8 to 396 metric tons/km²/yr) for a 6-year study period (19).

The impacts of road erosion are many. The most direct is to the road itself; excessive erosion can, end often does inhibit road use or even make the road impassable until restored, often at great expense. Less obvious, but often more important, is the movement of eroded material off the site. This can cause sedimentation which may create excessive damage to downstream cultural and ecological values.

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Table 1 - Effect of harvest system and silvicultural practices on the percent area disturbed by road construction (reference 25).

<table>
<thead>
<tr>
<th>Logging System - Silvicultural system</th>
<th>Logged area bared by road construction</th>
<th>Location</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jammer ¹/ - Group Selection</td>
<td>25-30</td>
<td>Idaho</td>
<td>(19)</td>
</tr>
<tr>
<td>High lead ²/ - Clearcut</td>
<td>6.2</td>
<td>Oregon</td>
<td>(26)</td>
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<td>Helicopter ⁴/ - Clearcut</td>
<td>1.2</td>
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</table>

¹/ Jammer - a small, truck-mounted skidder-loader - maximum reach about 60 m.

²/ High lead - a cable system that drags logs to the loading area - maximum reach about 200 m.

³/ Skyline - a cable system that suspends logs during transport to the loading area - maximum reach about 800 m.

⁴/ Estimated by Virgil W. Binkley, Pacific Northwest Region, U.S. Forest Service, Portland Oreg., based on a maximum flying distance of about 1.5 kilometers.
2. EROSION PROCESSES

Recognition of the type of erosion occurring on an area and knowledge of factors controlling erosion are important in avoiding problem areas and in designing control measures. Erosion can be broadly classified into two types - mass erosion and surface erosion. Mass erosion includes all erosion where particles tend to move en masse primarily under the influence of gravity forces. It generally includes various types of landslides plus non-rainfall associated erosion (dry creep). Surface erosion is defined as movement of individual soil particles by forces other than gravity alone such as overland flow of water and raindrop impact. Here, dry creep will be considered a surface erosion process because many soil stabilization measures designed to control surface erosion are also effective in controlling dry creep.

Surface erosion is a function of three factors: (a) the magnitude of forces available (wind, raindrop splash, overland flow, etc.); (b) the inherent erosion hazard at the site in question (soil detachability characteristics, slope gradient, etc.); and (c) the amount of material available to protect the soil surface (vegetation, litter, mulches, etc.). Mass erosion is controlled by the balance between the shear strength and the shear stress within the soil or fill material at the site in question; as long as shear strength exceeds shear stress, the site remains stable.

3. BASIC PRINCIPLES

Fortunately, the erosional impacts of road construction need not be passively accepted; there are a variety of practices available to reduce impacts. These can be summarized as four basic principles:

(1) Minimize the amount of disturbance caused by road construction by: (a) controlling the total mileage of roads; and (b) by reducing the area of disturbance on the roads that are built.

(2) Avoid construction in high erosion hazard areas.

(3) Minimize erosion on areas that are disturbed by road construction by a variety of practices designed to reduce erosion.

(4) Minimize the off-site impacts of erosion.

All four factors must be weighed to reduce total erosional impacts. This is important because stress on individual factors may not meet this goal. For example, a shorter road may have to be lengthened to avoid high erosion hazards. In this case, total erosional impacts may be minimized although the area disturbed is increased. Erosion control practices are certainly beneficial and considerable effort has been and should be devoted to their development and implementation. However, prevention, rather than control, usually is by far the most efficient means to reduce erosional impacts. Prevention can have an added benefit by avoiding possible irreparable damages or costly repairs that may exceed original construction costs.

The first basic principle emphasizes measures designed for erosion prevention rather than control. Minimizing road mileage and areas of disturbance help reduce erosional impacts considerably. This is particularly true on forested lands where the total length of road required is often regulated by the distance capabilities of logging systems and the silvicultural practices prescribed for the timber stands (Table 1).

Reduction in the area disturbed by road construction can also be made by careful road location and design. For example, use of flexible horizontal and vertical alignment standards during road location to avoid steep slopes can decrease the width of area disturbed considerably. To illustrate, total width of disturbance by a road 4 m wide increases from about 7 m on a 40% slope...
Figure 1. Width of disturbance (projected to a horizontal plane) caused by road construction as a function of hillslope gradient. Assumptions: road width, 4 m; fill slope gradient, 67% (1.5:1); cut slope gradient, 200% (0.5:1); volume of material removed from cut = volume of material in fill ("balanced construction").

Figure 2. Ford construction stabilized by gabions placed on the downstream end.
to 16 m on a 60% slope; on a 65% slope the width increases to 32 m (Fig. 1). For a given slope, additional reductions in area disturbed can be made by minimizing road and ditch width and by maximizing the gradient of cut and fill slopes (assuming the steeper slopes do not increase other erosion hazards).

The second basic principle for reducing road erosion impacts is another matter of prevention rather than control and consists simply of avoiding high erosion hazard areas. Examples of serious erosion problems caused by road construction in high erosion hazard areas are common, especially where landslide hazards are high. Here even minor location changes of 10 or 20 m may eliminate a major erosion problem. Usually, problems of this type arise from adoption of, and strict adherence to, traditionally accepted road standards (e.g., alignment standards for speed purposes) rather than providing some flexibility in standards to allow the road location to be adjusted to the site properties of the particular landscape in question.

The third basic principle is to reduce erosion on the areas that are disturbed by road construction. This is the traditional approach using a multitude of practices to help reduce erosion. Successful design of erosion control practices requires considerable knowledge of erosion processes, including the major type of erosion that is occurring and the individual factors that control erosion. To illustrate, little benefit results from attempting to stop mass erosion by mulching or surface erosion by installing subsurface drains. Likewise, mulching a road fill slope may have little value if improper design, failure of the road drainage system, or both, cause large quantities of water to flow over the fill.

The fourth basic principle for reducing erosional impacts is to minimize the off-site impacts of erosion that does occur. Essentially this amounts to reducing sediment delivery to stream channels by: (a) keeping disturbed areas as far from channels as possible, (b) providing a maximum of obstructions to catch and retain sediment before it reaches the drainage system, and (c) recognizing that the efficiency of a downslope area to deliver sediment varies considerably depending upon its form and structure.

4. GUIDELINES FOR REDUCING EROSIONAL IMPACTS OF ROADS

These guidelines are based upon the four basic principles which have been described above. They are presented in the context of the entire road development process proceeding from broad land use planning through road location, design, construction, maintenance, and closure. Presentation in this manner is not intended to restrict the guidelines to those higher standard roads receiving such formal step-by-step development. To the contrary, the basic erosion control principles apply to any road development and should be used throughout the development process regardless of the intended purpose or standard of the road.

The guidelines are not all inclusive, but rather are based upon concepts and techniques that have been applied in the temperate climates of the United States. They were developed from experience and research mostly in mountainous terrain. Many of the principles and procedures in this paper will be useful in other areas; however, modifications will undoubtedly be needed to accommodate unique site conditions found in a particular location. Therefore, it is important to verify applicability with local experts (e.g., engineers, land-use planners, soil scientists, hydrologists, foresters, geologists) before applying the guidelines.

Much of the material presented here was abstracted from references (7), (10), (11), (12), (13), (21), (28), (29), (30), (31), (32), (33), (34), (35), (36), (37), and (38). The author acknowledges the excellent work of the various authors and institutions and recommends the original references for more in-depth consideration. Undoubtedly, many other excellent references have been developed and should be used where applicable.
5. LAND USE PLANNING

Land use planning with respect to road construction simply means anticipating the present and future uses of the transportation system to assure a maximum of service with a minimum of monetary and erosional costs. The objective of this phase of the road development process is to establish specific objectives and prescriptions for road development along with the broad location needs. This must be a coordinated effort among the land manager, road engineer, forester, geologist, soil scientist, and others who recognize specific problems and needs and recommend alternatives or solutions.

Land use planning is an important factor governing the total area disturbed by road construction. It is particularly important on forested lands where the total mileage of roads constructed is closely related to the timber harvest systems and silvicultural practices prescribed. Harvesting methods also affect the area of disturbance because width and alignment requirements vary with the type of practice used. Additional decisions related to all anticipated traffic, operating speeds, and safety requirements should be made at this time. All of these influence road width and alignment, which affect area of disturbance.

Future as well as present needs must be considered during the land use planning phase. This will help to avoid situations where the road is inadequate for future needs as, for example, in timbered areas where the road network is improperly located for second or third cuts.

The land use planning phase is the time to evaluate environmental and economic tradeoffs. This should set the stage for the remainder of the road development process. If an objective analysis by qualified individuals indicates serious erosional problems, then reduction of erosional impacts should be a primary concern. In some areas, this may dictate the method of land use for the area or may in fact eliminate a land use because reduction of erosional impacts is economically impossible at the time.

6. ROUTE RECONNAISSANCE AND LOCATION

Armed with the guides and constraints developed during the land use planning process, the next step is to determine the specific road location. Alternative routes should be carefully reviewed in the office and at the site, utilizing all available background information (soil survey, etc.) and technical expertise. Some important guidelines to help reduce erosional impacts during road location are:

1) Avoid high erosion hazard sites, particularly in areas where mass erosion is a problem. In such areas, slight location changes can often eliminate a major erosion problem.

2) Minimize the area of road disturbance by taking advantage of terrain features such as natural benches, ridgetops, and lower-gradient slopes,

3) If necessary, include short-road segments with steeper gradients (consistent with traffic needs) to avoid problem areas or to take advantage of terrain features.

4) Avoid mid-slope locations on long, steep, unstable slopes, especially where bedrock is highly weathered or soils are plastic.

5) Locate roads on well-drained soils and rock formations that tend to dip into the slope; avoid slide prone areas characterized by seeps, clay beds, concave slopes, hummocky topography, and rock layers that tend to dip parallel to the slope.

6) For timber harvest roads, take advantage of natural log landing area (flatter, better drained, open areas) to reduce soil disturbance associated with log landings and temporary work roads.
7) Avoid undercutting unstable, moisture laden toe slopes when locating roads in or near valley bottoms.

8) Vary road grades where possible to reduce concentrated flow in road drainage ditches and culverts and to reduce erosion on the road surface.

9) Select drainage crossings to minimize channel disturbance during construction and to minimize approach cuts and fills.

10) Locate roads far enough above streams to provide an adequate buffer area or be prepared to catch sediment moving downslope below the road. A number of guides have been developed for establishing width of buffer areas based upon hillslope gradient, parent material, cross drain spacing, etc. (e.g., 23, 27). The guide developed by Packer (23) is presented as Table 2.

7. ROAD DESIGN

Road design involves translating field location survey and other data into specific plans to guide construction. Design criteria must be flexible to allow for modifications to minimize erosion hazards under varying site conditions. This is the stage of development where various measures to control erosion and reduce off-site erosional impacts are incorporated into the road design.

Re-vegetation and associated practices are important considerations during the design process. In addition, future maintenance needs are an important consideration to assure stability and economical use of the completed road. If regular maintenance cannot be assured, this must be accounted for in the design so that undue erosion will not occur.

A number of possible erosion control practices can be included in the road design process:

1) Use as narrow a road as possible commensurate with traffic speed and safety requirements and erosion hazards. In certain situations it may be necessary to reduce speeds and provide for alternative safety measures (e.g., restricted road use) to assure a narrow road in high erosion hazard areas.

2) Attempt to balance the volume of cut and fill material to minimize excavation. Use proper layer placement and compaction techniques wherever possible on fills to assure stability against mass failure.

3) Use full bench construction (no fill slope) where stable fill construction is impossible. Haul excavated material to safe disposal areas. Include waste areas in soil stabilization planning for the road.

4) Where full bench construction is impractical, properly designed retaining walls provide an effective but costly alternative to hold fill material.

5) Use the steepest slopes possible on cut and fill slopes commensurate with the strength of the soil and bedrock material as established by an engineering geologist or other specialist in soil mechanics. Benching cut slopes in areas of weak or erodible bedrock (e.g., weathered granites) into a series of properly drained terraces provides opportunity for vegetation establishment and may even require less excavation.

Properly designed road surfacing is often required to prevent excessive roadway erosion and maintain a usable road. The surface required depends on many factors such as the type and volume of traffic, strength of subgrade, service life, and materials available. Often, locally available gravels or crushed rock will serve the purpose. It may be desirable to surface both the road tread and the ditch in one operation.
Table 2 - Protective-strip widths required below the shoulders of 5-year old logging roads built on soil derived from basalt, having 9 m cross-drain spacing, zero initial obstruction distance, and 100% fill slope cover density.

<table>
<thead>
<tr>
<th>Obstruction spacing</th>
<th>Depressions or mounds</th>
<th>Logs</th>
<th>Rocks</th>
<th>Trees and stumps</th>
<th>Slash and brush</th>
<th>Herbaceous vegetation</th>
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</table>

1/ For protective-strip widths from centerlines of proposed roads, increase widths by one-half the proposed road width.

2/ If storage capacity of obstructions is to be renewed when roads are 3 years old, reduce protective-strip widths 7 m.

3/ If soil is derived from andesite, increase protective-strip widths 30 cm; if from glacial silt, increase 1 m; if from hard sediments, increase 2.4 m; if from granite, increase 2.5 m; and if from loess, increase 7 m.

4/ For each 3 m increase in cross-drain spacing beyond 9 m, increase protective-strip widths 30 cm.

5/ For each 1.5 m increase in distance to the initial obstruction beyond zero (or the road shoulder), increase protective-strip widths 1.2 m.

6/ For each 10% decrease in fill slope cover below a density of 100%, increase protective strip-widths 30 cm.
Figure 3. Rock rip-rap protection for embankment at a culvert installation.

Figure 4. Culvert installation illustrating the use of a headwall, downspout, and a splash basin at the downstream end.
7.1 Road drainage

7.1.1 Crossing natural drainageways

There are three methods for crossing natural drainageways: fords, culverts, and bridges. Factors influencing the appropriate crossing include construction and maintenance cost, equipment and supplies available, debris potential, stream size, contemplated road use and life, foundation conditions, and vertical position of the road relative to the stream.

1) Fords are attractive alternatives for crossing small streams, particularly in areas where large amounts of rock, sediment, and organic debris tend to plug bridges or culverts. Fords cause minimal disturbance to the stream channel, are inexpensive, and avoid many of the problems associated with bridge and culvert installation. Fords require stable channel bottoms able to support vehicles or channels that can be protected by gabions or paving (Fig. 2).

2) Culverts (metal or wood) or bridges are required for channels where fords are impractical. Availability of construction equipment and materials, size of stream, potential for debris, terrain steepness, and reliability of the calculation for determining culvert capacity are some of the points to consider when deciding whether to use a culvert or a bridge at a given location. Other factors being equal, bridges are preferable, particularly in areas with debris or excessive sediment problems because the chances of failure are less.

Structures should be large enough to carry the flows to which they are subjected within acceptable limits of risk. Costs increase rapidly with size so adequate local hydrological studies are needed. It is important to base the size requirement on the anticipated risk of failure rather than on the return interval of the flow alone (Table 3). The percent chance of failure established for a given structure will depend upon the anticipated economic and environmental hazards.

3) Roads should climb away from channel crossings in both directions wherever practical so high water will not flow along the road surface. Surface sloped sections of the road if necessary to reduce sediment movement directly into the stream.

4) Where adequate maintenance can be assured, install open top culverts or dips in the road surface to direct road runoff onto filter strips rather than directly into the stream.

5) Use rip-rap (placed rock), masonry headwalls or otherwise protect embankment and channel sides at drainage structures (Fig. 3).

6) Increase the capacity of bridges or culverts in areas where debris, sediment, or both types of problem exist. In extreme situations, this may mean doubling the capacity of the structure.

7) Frequently maintained trash racks (grates) over the inlet and may be useful where floating debris tends to plug culverts.

8) If at all possible, use bridges in area where debris problems are severe and fords are impractical. Otherwise it may be necessary to construct rock - or gabion-protected fills with a dip to allow overflow in the event that culvert capacity is lost.

7.1.2 Drainage along the roadway

Drainage is needed along the roadway to remove water before it has a chance to concentrate and cause erosion. To help accomplish this, slope road surfaces laterally either outward or inward, depending on traffic needs and erosion hazards. Unfortunately, traffic can cause some rutting in the road surface that concentrates flow along the road in spite of the outsloping or insloping. Thus in many situations, additional cross-drainage measures are needed to interrupt this flow and divert it laterally before it has a chance to cause erosional problems.
Table 3. Design flood recurrence intervals (years) needed to provide a given project life with a given chance of failure\(^1\).

<table>
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\(^1\) Based on formula \(J = \frac{1}{1 - (1 - 1/T) N}\), where \(N = \) Design Life, \(T = \) Flood Recurrence Interval, \(J = \) Chance of Failure (reference 5).

* More than 99.

Example: If a culvert through a road is to last for 20 years with a 30% chance of failure, the culvert should be designed for 57-year flood recurrence event.
Table 4. Cross-drain spacings required to prevent rill or gully erosion deeper than 2.5 cm on unsurfaced logging roads built in the upper topographic position\(^1\) of north-facing slopes\(^2\) having a gradient of 80\(^{\circ}\)\(^3\) (reference 23, Table 2).

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<tr>
<th>Road grade (%)</th>
<th>Material</th>
<th>Hard Sediment</th>
<th>Basalt</th>
<th>Granite</th>
<th>Glacial Silt</th>
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1/ In middle topographic position reduce spacings 5.5 m; in lower topographic position, reduce spacings 11 m.

2/ On south aspects, reduce spacings 4.6 m.

3/ For each 10 % decrease in slope steepness below 80%, reduce spacings 1.5 m.
1) **Outsloping** (i.e., sloping toward the downhill side of the road) of from 3-5% is preferable to insloping because it eliminates the need to develop facilities to dispose of the water draining down the inside of the road. Outsloping can be unsafe in some situations because of particular traffic requirements or unusual site conditions such as clayey road surfaces that are very slippery when wet. In addition, outsloping should only be used where runoff will flow off the road onto stable surfaces. Normally, this precludes the use of outsloping on fill portions of the road unless fill slopes are small and low in erodibility or, are well protected by mulches, vegetation, or both.

2) **Insloping** (i.e., sloping toward the uphill side) of the road surface is preferred to outsloping in areas of unstable fills, except in the case of a contour road where there is no chance for lateral flow along the road. Water draining from the road is carried along the inside of the road either on the road surface itself or more commonly in a ditch. Culverts are installed periodically to carry the water under the road. Some points to consider when designing an insloped road are:
   a) Avoid using ditches or keep ditches to a minimum width and increase the number of cross drains to reduce the total area disturbed by construction.
   b) Plan ditch gradients steep enough (generally greater than 2%) to prevent sediment deposition.
   c) Install culverts frequently enough to avoid accumulations of water that will cause excessive erosion of the road ditch and the area below the culvert outlet. Surface the ditch in areas of erodible material (e.g., weathered granitics).
   d) Use a culvert size of at least 40 to 50 cm, depending on expected debris problems.
   e) Install culverts at the gradient of the original fill slope if possible: otherwise provide anchored downspouts to carry the water safely across the fill slope. Skew culverts 20° to 30° toward the inflow to provide better inlet efficiency and flow characteristics. Provide rock or other splash basins at the downstream end of culverts to reduce the erosion energy of the emerging water (Fig. 4).
   f) Protect the upstream end of culverts from plugging with sediment by using sediment catch basins, drop inlets, changes in road grades, headwalls, and recessed cut slopes.
   g) Install the culvert deep enough to assure that it will not be crushed by traffic loads. This requires a depth of about 1.2 m for metal culverts subjected to loads from large, loaded logging trucks.

3) In some areas, alternating inslope and outslope sections can be built into the road, especially if road grades are “rolled” (provide alternating adverse and favorable grades). In such instances, install dips or cross drains on the surface of the road to control erosion of the roadway.

4) It is usually necessary to construct cross drains in the road surface on either insloped or outsloped roads to help prevent erosion caused by water concentrations in ruts. Various types of cross drains are used, including open-top culverts and intercepting dips. Some points to consider when installing cross drains are:
   a) Spacing requirements - spacing depends on a number of factors such as road grade, and type of material. Guides for spacing are presented in Table 4.
   b) Open-top culverts are usually constructed of wood (Fig. 5). They should be installed at a 30° angle downslope to promote self cleaning and make crossing easier (Fig. 6). Culverts of this type must be properly maintained to prevent plugging and damage by traffic.
Figure 5. An open-top culvert constructed of wood. Spreaders on the bottom of the log maintain culvert shape and the 5-cm spaces between the boards prevent water from running down wheel tracks and across the culvert.

Figure 6. Installation of an open-top culvert. Culverts should be slanted at least 30° downslope to help prevent plugging.
Figure 7. Design of outsloped dips for forest roads. A to C, slope is 10 to 15 cm to assure lateral flow; B, no material accumulated at this point - may require surfacing to prevent cutting; D, provide rock rip-rap to prevent erosion; E, berm to confine outflow to 0.5 m wide spillway.

Figure 8. Design of insloped dips for forest roads. A to C, slope about 10 to 15 cm to assure lateral flow; B, no material accumulated at this point - may require surfacing to prevent cutting; D, provide rock rip-rap to prevent erosion; E, berm to prevent overflow; F, culvert to carry water beneath road; G, widen for ditch and pipe inlet.
c) Intercepting dips, when properly constructed, are cheaper to maintain and more permanent than wood, open-top culverts. Dip design depends on the kind and speed of the traffic using the road. The dip designs shown in Figures 7 and 8 allow road use by passenger autos traveling at speeds of approximately 30 kilometers per hour. On steeper roads it may be necessary to install open-top culverts (using the same design) in addition to dips to meet the cross-drainage spacing criteria shown in Table 4. A good discussion of dip design is given in reference 8.

d) In addition to cross drain spacing, location of cross drains is an important factor to consider in minimizing sediment delivery to stream channels from either insloped or outsloped roads. Some location guides are presented in Figure 9.

5) Berms are required on the outside edge of the road at specific locations where alignment and grade characteristics cause excessive runoff from the road tread over the fill slope. Use compacted soil, soil cement, or asphalt mixtures to construct stable berms. Where necessary, use downspouts in the berm to safely carry water to the bottom of the fill slope. Locate downspouts at safe water discharge points and provide energy dissipators (rock basins, etc.) to further reduce erosion hazards (Fig. 10).

8. SLOPE STABILIZATION MEASURES (REVEGETATION AND MULCHES)

Slope stabilization includes revegetation and other measures to control surface erosion on road cut and fill slopes and on waste and borrow areas. Usually the objective is to establish a dense vegetative cover to reduce forces available for erosion and increase surface protection.

Considerable evidence indicates that surface erosion on severely disturbed soils such as road fills is highest immediately after disturbance and decreases rapidly over time. On granitic slopes in Idaho, approximately 80% of surface erosion occurred within the first year following disturbance (16). This suggests two things: (a) it is mandatory that stabilization practices be applied immediately during and following construction; and (b) stabilization practices must provide rapid benefits. Thus, simply seeding disturbed areas may not be acceptable; transplanting or mulching may be required to achieve the desired results.

Stabilization of mass erosion is beyond the scope of this guideline; however, there is considerable evidence suggesting that deep-rooted vegetation (trees and shrubs) acts as a deterrent to mass erosion. Since deep-rooted vegetation also helps control surface erosion, its use is advocated for slope stabilization (17).

Some suggested guidelines for slope stabilization are described below:

8.1 Revegetation

1) Site factors governing air and soil temperature, soil moisture, and fertility are important influences on revegetation success. Large variations in these factors can occur throughout the length of a road, particularly in low precipitation zones or in areas with prolonged dry seasons. Such differences are often magnified in mountainous areas. Thus it is important to tailor revegetation measures to the specific site factors. Consider elevation, aspect, rain shadow effects, ground-water seepage, soil and bedrock properties, etc., in evaluating site differences. Be sure to include vegetation in the evaluation, both as an indicator of site potential and to serve as a guide for species selection.

2) Site preparation is often an important prelude to seeding and planting. This might include various practices such as: (a) spreading previously stockpiled topsoil; (b) chaining, harrowing, diskng or rolling to roughen the seedbed and break surface crusting; and (c) fertilizing.
Figure 9. Guides for locating cross drains. Several locations require cross drains independent of spacing guides. A and J, divert water from ridge; A, B, and C cross drain above and below junction; C and D, locate drains below log landing areas; D and H, drains located with regular spacing; E, drain above incurve to prevent bank cutting and keep road surface water from entering draw; F, ford or culvert in draw; G, drain below incurve to prevent water from coursing down road; I, drain below seeps and springs.
Figure 10. Construction of a downspout in a berm. Excess water accumulations on a berm must be drained by a downspout.
3) It is desirable to conduct seeding operations before mulching to attain maximum benefit from the mulch. However, this is not possible in some locations (e.g., areas with pronounced dry seasons) because the time of seeding or transplanting is critical. To illustrate, many locations on the west coast of the United States are influenced by a distinct Mediterranean climate causing a prolonged drought period in the summer. Seeding and planting operations during the drought period are usually failures; operations must take place in the fall to be successful. Transplanting through a previously applied mulch is often successful in these situations. Sometimes wattling (installing low barriers of soil and brush along the contour up and down the slope) is a successful substitute for mulching. Seeding, planting, or both, between the wattles can then be carried out at the proper time.

4) Species selection must be designed to meet local needs. Grasses have been most commonly used; however, forbs, shrubs, and trees alone or in combination should be considered. Legumes have particular benefits as nitrogen fixers as do some other plants. Deep-rooted plants including both trees and shrubs can help increase mass stability as well as reduce surface erosion. Rapid-growing, short-lived species (e.g., some of the ryes and oats) are often desirable for nurse crops for slower-growing vegetation.

5) Fertilization should accompany most revegetation operations. Proper types and amounts of fertilizer should be based upon soil analyses or experience in the area. Additional amounts may be required if organic mulches are used.

8.2 Mulches

In some areas, vegetation response is rapid enough to provide slope protection during the initial high erosion period. However, it is usually necessary to supplement the protection during the interim with mulches. Mulching provides additional benefits by reducing surface soil temperatures, water losses from the soil, and soil crust formulation.

1) Many kinds of materials ranging from logging slash to peanut shells have been used for mulching. Type of material is not as important as the need to use sufficient amounts in close contact with the soil.

2) On steeper areas it is often necessary to anchor the mulch into the soil by covering it with netting material that is pinned in place, spraying adhesive chemicals (e.g., liquid asphalt, various polymers) onto the mulch, or rolling it with a spike roller.

3) Machines have been developed that combine mulching material (straw or wood fiber are commonly used) with water, an adhesive, or both, and spray the mixture onto the slope. Usually, seed and sometimes fertilizers are added to the mixture to provide multi-benefits in one operation.

8.3 Other practices

Other types of stabilization practices have also been used:

1) Recent development of polymers permits stabilization of disturbed areas by spraying the material on the surface.

2) Sometimes, revegetation practices increase infiltration of water into the surface sufficiently to increase mass erosion hazards to the point of failure (11). In these cases, an impermeable material (e.g., asphalt, certain polymers, or even plastic sheeting) may be required to stabilize surfaces.
9. CONSTRUCTION

The construction phase is the moment of truth for a road development. The best planning and design is useless unless it is incorporated into the finished product. Competent planning and supervision of the construction phase is probably the single most important factor leading to success. This requires a thorough knowledge of construction methods, equipment, materials, and testing coupled with a sense of diplomacy to communicate with the individuals doing the work. Such background will not only enable the construction supervisor to develop the road as planned, but will also allow him to effectively deal with the inevitable design changes required during construction because of unforeseen circumstances (especially in earthwork and drainage installations).

Some important erosion control practices to consider during construction include:

1) Keep slope stabilization work as current as possible with road construction.
2) A thorough job of cleaning and grubbing is required to insure proper construction of fills. Overcasting onto brush and timber or incorporating brush and timber into the fill material can lead to serious surface and mass erosion problems. In addition, provide a good base for fills and assure proper compaction as fills are constructed.
3) Where possible, the cleared vegetation should be spread evenly over the soil surface beneath the toe of the road fill. The vegetation material should be cut up or somehow crushed into the surface to assure close contact with the soil. This practice should enhance the buffering qualities of the slope beneath the road (see Table 2).
4) When installing culverts, avoid channel changes and place culverts so they conform to the natural stream channel as closely as possible. Remove as much debris from the channel above the culvert as possible. Carefully compact the fill material around all culverts to prevent seepage and ultimate culvert failure.
5) Keep stream disturbance to an absolute minimum and avoid it altogether during high flow periods.
6) Vagaries in weather conditions are important factors leading to erosion during construction. In areas where the climate permits, plan jobs for completion during dry periods. Elsewhere, limit the work area to small sections that can be completed before proceeding further. This exposes a minimum of disturbed area to erosion forces in the event of weather changes. Light rains usually have limited erosional impacts. However, if obvious impacts occur during larger storms, be prepared to cease operations after installing emergency drainage as needed. It is advisable to install all designed drainage from the downstream end of the job to the upstream end in areas of unpredictable weather.

10. ROAD MAINTENANCE

Diligent maintenance is an absolute necessity to assure effective erosion control throughout the life of a road. Following construction, inevitable deficiencies in design and construction practices require modification or repair. Throughout the life of the road, traffic use and natural deterioration continue to make diligent maintenance a necessity.

Recommend maintenance practices are:

1) A maintenance record should be developed for each road consisting of the actual construction plans for the road and a tally of the kind and cost of maintenance operations required over time. The record will assist in training new personnel and provide a solid background of data to prevent extension of mistakes to roads in other areas.
Figure 11. Cross ditch construction for forest roads with limited or no traffic. Specifications are average and may be adjusted to gradient and other conditions. A, bank tie-in point cut 15 to 30 cm into road bed; B, cross-drain berm height 30 to 60 cm above the road bed; C, drain outlet cut 20 to 40 cm into the road; D, angle drain 30° to 40° downgrade with road centerline; E, height up to 60 cm, F, depth to 45 cm; G, 90 to 120 cm.
2) Culverts, cross drains, and dips should be cleaned regularly to assure proper functioning, especially before winter or expected rainy seasons. Debris should be removed from live drainages for a distance of 30 m upstream from the inlet. Cross drains and dips are often damaged during high use periods or sometimes even removed for more efficient traffic flow; they should be replaced before rainy seasons or snowfall.

3) Ditches should be cleared of debris and sediment accumulations with care being taken to avoid disturbing stabilized ditch bottoms. Avoid undercutting the roadcut when removing slide debris.

4) Grade the road surface as often as necessary to retain the original surface drainage (either insloped or outsloped). Take care to avoid side-casting graded material over the fill slope. Carefully monitor surface drainage during wet periods and close the road if necessary to avoid undue damage. Restore surfacing on the road tread and in the road ditch if necessary following damage caused by operation in wet periods.

5) Haul all excess material removed by maintenance operations to safe disposal areas. Apply stabilization measures on disposal sites if necessary to assure that erosion and sedimentation do not occur.

6) During large storms or excessive snowmelt it is beneficial to patrol roads to assure that road drainage facilities are functioning.

11. ROAD CLOSURE

Many roads, especially work roads associated with timber harvesting, are designed for use only for a short time. These roads should be closed along with any other roads that are needed only for intermittent travel to minimize maintenance expense and erosion hazards. Two possible situations exist: (a) the road should be closed, but the use is anticipated in the future; and (b) permanent closure is desired.

11.1 Temporary closure

Steps recommended for temporary road closure are:

1) Block the road to vehicles.
2) Remove all temporary culverts including brush and wood types.
3) Remove all temporary bridges.
4) Remove all other culverts and bridges that cannot be maintained.
5) Except on large fill slopes, outslope the road surface and remove all berms, taking care not to spill graded material over the fill slope. The best way to accomplish this is to grade material toward the cut bank. Outslope only enough to divert water over the bank (approximately 2 to 3% plus the slope gradient of the road in percent).
6) When removing culverts and bridges, be sure all fill material is removed from below the high water line of the stream. All material that is removed should be placed in a safe disposal area. The remaining fill material should be left at a stable angle.
7) Cross ditch the road tread in accordance with the cross ditch design shown in Figure 11, and the cross-drain spacing guides in Table 4 and Figure 9.
8) Revegetate the road surface and areas disturbed by road closure operations along with any other areas of exposed soil. Use all re-vegetation procedures necessary (including mulching) to stabilize the site.
11.2 Permanent closure

Similar procedures are used for permanent road closure except that all bridges and culverts are removed. In addition, it is also desirable to break up road surface compaction to reduce runoff and provide a better site for revegetation. Ripping with a hydraulic ripper is an effective way to accomplish this. Fill material should be removed from any area where mass failure is possible in the future. Place material in a safe disposal area and use erosion control methods at the disposal area.

12. REFERENCES


(5) Chow, Ven Te. 1964 Statistical and probability analysis of hydrologic data. In Handbook of Applied Hydrology, Sec. 8-1, McGraw-Hill Inc., NY


