Appendix B

<u>Transportation & Forest Roads Element</u>

Adjara Forestry Agency Strategic Management Plan

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Transportation Planning

Road or transportation planning occurs at two levels, known as **strategic** planning and **tactical** planning. **Strategic planning** occurs on a large area, such as a district or a forest, while **tactical planning** is at a specific project level. At the strategic level, the Primary Access roads, such as the Arterial and Collector road system, that serves the entire management unit should be identified. This is primarily an office task, using terrain data from existing topographic maps or air photos, along with soils, stream-side management zone, or cultural data maps.

Tactical planning occurs on a periodic, project basis and involves the location and design of the specific Local Access roads and their infrastructure consistent with the strategic plan. These should be shown on the tactical plan and should be constructed the year before management activities begin, to serve the harvesting of the management area. Log landings, if needed, may be shown along the local roads in a tactical plan. Skid trails planned into the forest from the log decks may or may not be shown.

Road locations are displayed on a map to show the entire system of Primary, and some Local Access roads necessary for long-term management of the area. As a Best Roads Practice, roads are planned to meet several objectives, including the following:

- To minimize the number of stream crossings;
- To avoid areas of difficult and expensive road construction;
- To limit adverse environmental effects; and
- To serve the area economically and to facilitate management activities.

Throughout the road planning process, consideration is given to the location and spacing of roads and landings in order to minimize extraction costs. In fairly level terrain, optimization models can be used, whereas in steeper terrain, equipment capabilities, resource locations, and costs are used to determine road location.

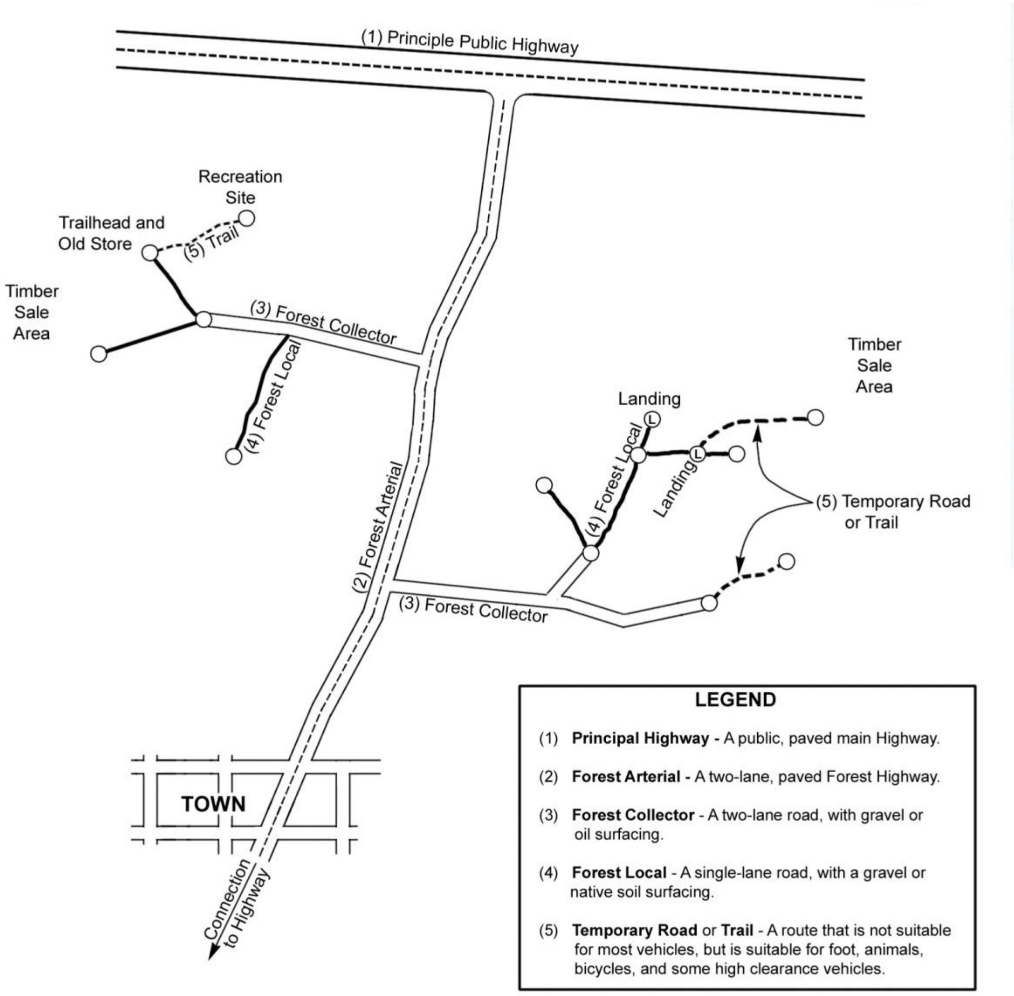
Collector roads connect the Local Access Roads from the harvest area to the point of exit from the management unit. These roads may be new or existing roads and should be shown on an approved management plan. They typically connect the Local roads to the main roads or highways outside of the management area.

Collector and Arterial roads must be located and designed for the hauling vehicles that will be used to transport logs or sawn material from the management area. Design and construction specifications for these roads must account for hauling vehicle weights and truck configurations. Vehicle speeds are important for hauling efficiency making road curvature and grade important considerations. Typical design speeds may be 45-60 kph. They are built with a crown for road surface drainage and often have an elevated platform. It is important that this class of road is properly located to avoid crossing terrain where construction and maintenance costs will be high

Local Access roads constructed in level terrain have similar considerations as Collector roads, but they are typically more narrow and designed for slower travel speeds. They may occasionally be surfaced with gravel if they are to remain open, but are typically native surfaced, particularly if they are to be closed after operations have been completed. They are typically single lane roads with additional widening area constructed for vehicle passing. They are typically outsloped or insloped with a ditch for road surface drainage with frequent cross-drains or leadoff ditches. Local Access roads should be constructed and allowed to set for one year before use. This allows for natural consolidation and settling of the fill material and will result in a more durable road surface

Road Design Standards

First, the road design standards depend on the classification of road. Most public roads and arterial routes already exist, and are the typical gravel or paved (asphalt pavement or an asphalt seal coat) or concrete roads. Most new road development will be for some collector roads and particularly the local roads. The transportation system should be thought of as shown in the drawing below of a typical, generic forest transportation network.



A typical forest road system developed through transportation planning

Typical road design standards needed for logging and firewood cutting and haul depend on the vehicles being used. The vehicles seen in Adjara are relatively small and have a short wheel base. However typical road standards suitable for a range of vehicles are shown below.

Single lane local roads typically vary from a width of 10 feet to 14 feet (3-4.4 meters). A ditch will add roughly another 3 to 5 feet (1-1.5 meters) of width, and curve widening often adds width. Inter-visible turnouts are often needed on the narrowest roads to allow vehicles to pass. Double-lane collector road width varies from 18 to 24 feet (5.5 to 7.5 meters), with the narrower width being typical of gravel collector roads and the wider roads being typical of paved arterial roads. The paved lane width is typically 11 to 12 feet (3.3 to3.6 meters) wide. Width is also dictated by safety, terrain, and amount of traffic, with wider roads constructed for higher traffic volumes.

Typical Forest Road Design Standards.

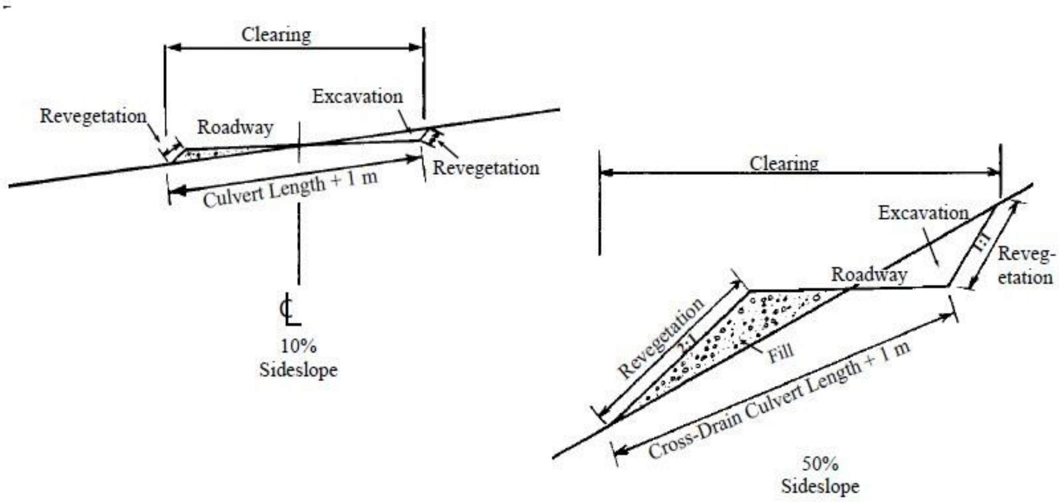
Aspect of Design	Type of Forest Road	
	Local Road Single Lane, Native Surface	**Collector Road Double Lane, Gravel Surface**

Design Speed	20 mph (35 kph)	40 mph (65 kph)
Design Load (AASHTO)	H 15	H 20
Road Width	14 feet (4.3 m)	18 feet (5.5 m) (minimum)
Shoulders	None	0.5 m
Road Grade: -Maximum Favorable -Maximum Adverse	 15% 12%	 12% 10%
Horizontal Curve Radius	50 feet (15 m) (minimum)	75 feet (25 m)(minimum)
Crown/Shape	Outsloped (5% minimum)	Crown (±3% minimum)
Types of Drainages	Transverse Pipes and Rolling Dips	Pipe Culvert Cross-drains
Riding Surface	Native Soil	±6 inch (15 cm) Gravel
Turnarounds	Every 1000 feet (300 m)	Every 1500 feet (500 m)

Basic Road Construction Costs

The actual cost of road construction depends on the unit costs of each activity, times the quantities involved. Unit costs are typically local or regional, and should be developed based upon local information and estimates from any recent construction projects. The quantities of materials and activities are more predictable and very sensitive to the ground slope. The figures below display typical road construction tasks (clearing, excavation, revegetation, culverts, and culvert cross-drains), the quantities associated with any road construction as a function of road width, and how dramatically they increase when the side-slope of the terrain increases (from 10 percent to 50 percent, as seen in the figure).

The quantities are purely geometrical and are a function of the road width and road template used. They can be developed for any road width and terrain side-slope. The unit cost to accomplish that quantity of work will depend on local labor and equipment costs. Thus cost will be a product of the quantity times the unit cost for that task. The total construction cost will be the sum of the costs for each task. Additional road construction costs will include the cost of major drainage crossing structures, such as culverts and bridges, as needed, and roadway surfacing materials as needed along the road.



Road quantity variation with ground slope.

Typical quantities for given sideslopes (14.5 foot (4.5 meter) road width).

	10 % SideSlope	**50 % SideSlope**	**% Increase**
Clearing	1.9 Acres/mile (0.48 ha/km)	4.8 Acres/mile (1.2 ha/km)	250 %
Excavation	549 C.Y./mile (261 m3/km)	6,579 C.Y./mile (3130 m3/km)	1,200 %
Revegetation (cut & fill slopes)	0.32 Acres/mile (0.10 ha/km)	3.94 Acres/mile (0.89 ha/km)	1,250%
Culvert Length (natural channel)	26 feet (8 m)	42 feet (22 m)	190%
Culvert Length (ditch relief)	18 feet (6 m)	36 feet (11 m)	200%

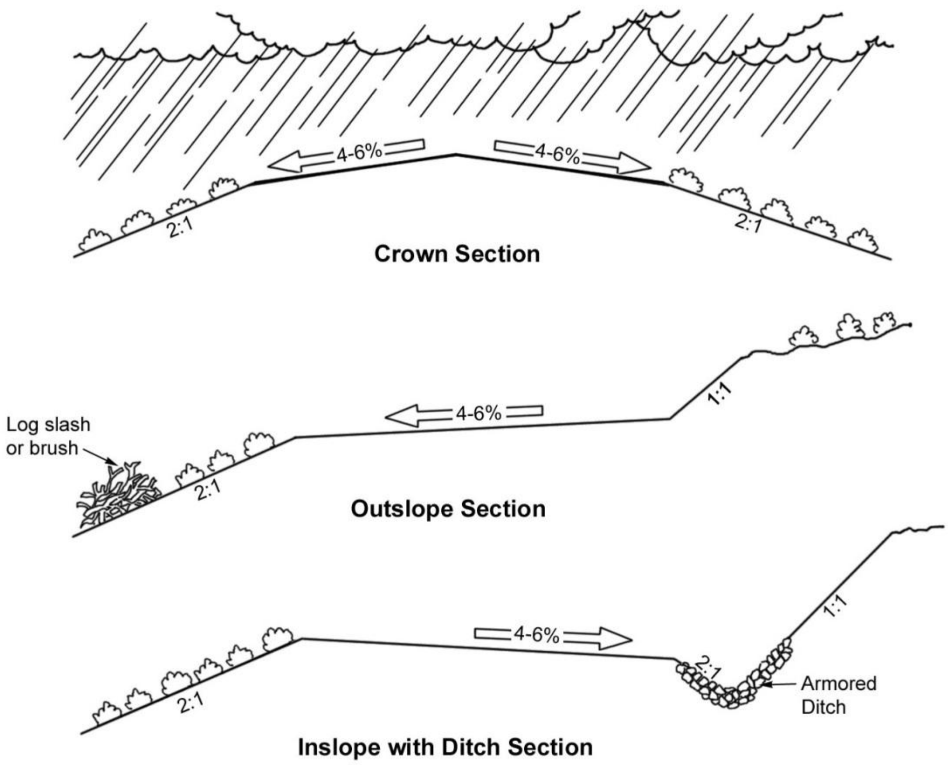
Note: Assuming a road cut slope of 1:1 and a fill slope of 2:1(H:V).

Road Design and Construction Issues

Road Surface Drainage Needs

Road surface drainage design is one of the most important aspects of roadway design and most cost-effective since many road surface drainage features are relatively inexpensive yet are important for the preservation of the road. The roadway surface needs to be shaped to disperse water and move it off the road quickly and as frequently as possible. Water standing in potholes, ruts and sags will weaken the subgrade and accelerate damage. Water concentrated in ruts or kept on the road surface for long distances can accelerate erosion. Steep road grades cause surface and ditch water to move rapidly, and make surface drainage difficult to control. This condition accelerates erosion unless surfaces are armored or water is dispersed or removed frequently.

Roadway surface water should be controlled with positive drainage measures using **outsloped**, **insloped**, or **crown** sections of road, as shown in the figure below. Outsloped roads best disperse water and minimize road width, but may require roadway surface and fill slope stabilization. An outsloped road minimizes concentration of water, minimizes needed road width, avoids the need for an inside ditch, and minimizes costs. Outsloped roads with clay rich, slippery road surface materials often require rock surface stabilization or limited use during rainy periods to assure traffic safety. On road grades over 10 to 12 percent and on steep hill slope areas, outsloped roads are difficult to drain and can "feel unsafe".



Typical road surface drainage shapes needed to remove water off the road surface.

Insloped roads best control the road surface water but concentrate water and thus require a system of ditches, cross-drains, and extra road width for the ditch. Cross-drains, using either rolling dips (broad-based dips) or culvert pipes, must be spaced frequently enough to remove all the expected road surface water before erosion occurs General spacing guidelines are shown below These maximum recommended distances should be used for guidance on location of cross-drains and ditch relief structures. Specific locations should be determined in the field based upon actual water flow patterns, rainfall intensity, road surface erosion characteristics, and available erosion resistant outlet areas.

Guidelines for maximum recommended distance between ditch relief cross-drains and rolling dip cross drains, with spacing in feet, based on soil type (Adapted from Packer and Christensen (1964), and Copstead, Johansen, and Moll (1998)

Maximum Recommended Distance Between Ditch Relief and Rolling Dip CrossDrains (feet)				
Road Grade (Percent)	**Low to Non-Erodible Soils**		**Moderate to Very Erodible Soils**	
	GW, GP Aggregate, Gravels	GM, GC Silty & Clay-Rich Gravels	SC, SM Silty Sand, Clayey Sand	SW, SP, ML Sand, Well to Poorly Graded, Silt
2	400	300	170	95
4	340	275	150	85
6	300	230	130	75
8	250	200	110	65
10	200	160	90	55
12+	150	130	75	50

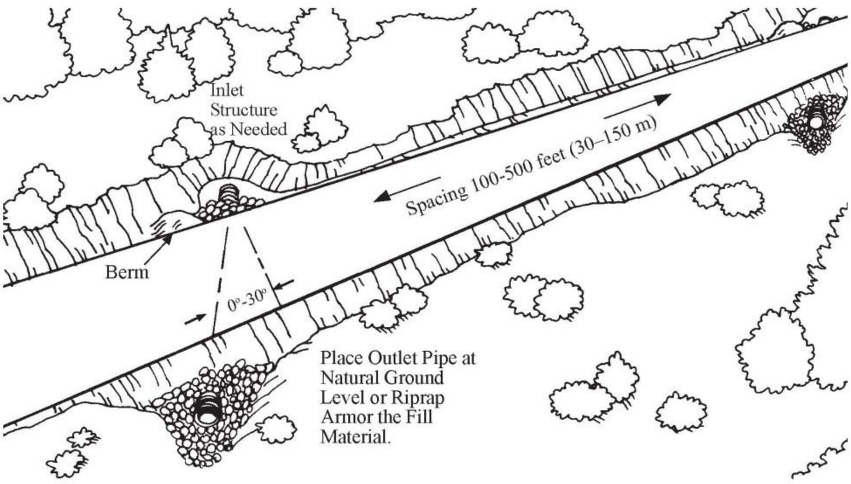
Conversion: 3.28 feet = 1 meter

Note: Soil types are listed by ASTM Unified Soil Classification System. Plastic clay rich soil (CH, CL, MH) types fall between the above range of values for Low to Moderately Erodible Soils.

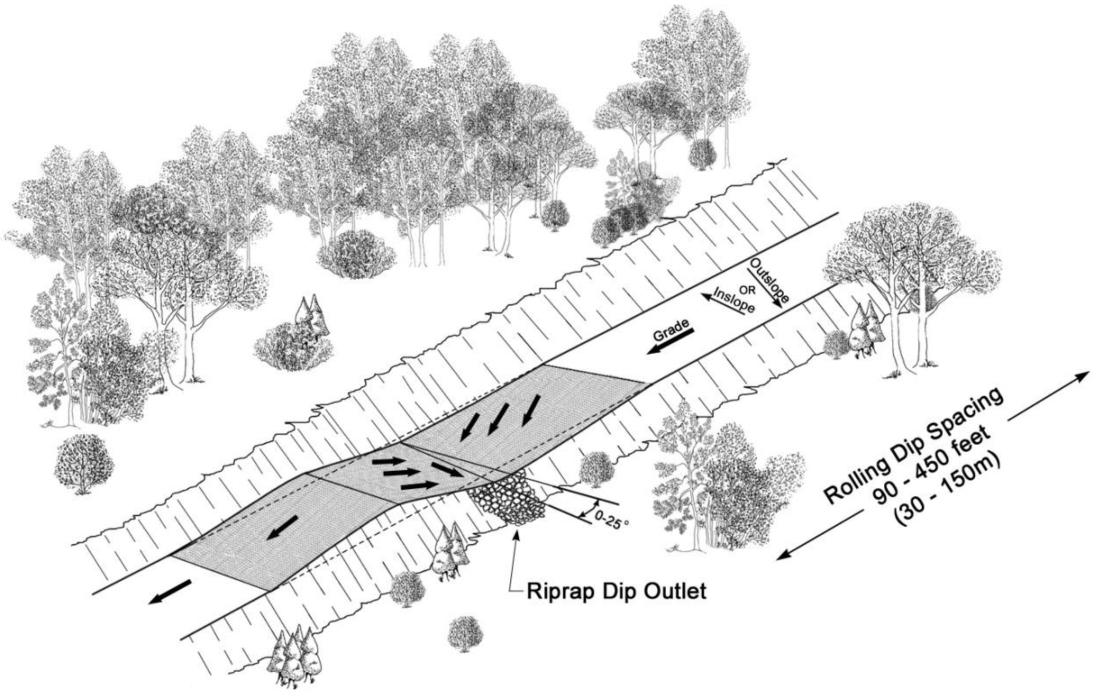
Note that rolling dips are very difficult to install on grades over 8 to 10 percent.

Crown section roads are appropriate for higher standard, collector or two lane roads on gentle grades. They also require a system of inside ditches and cross drains. It is difficult to create and maintain a crown on a narrow road, so generally insloped or outsloped road drainage is more effective.

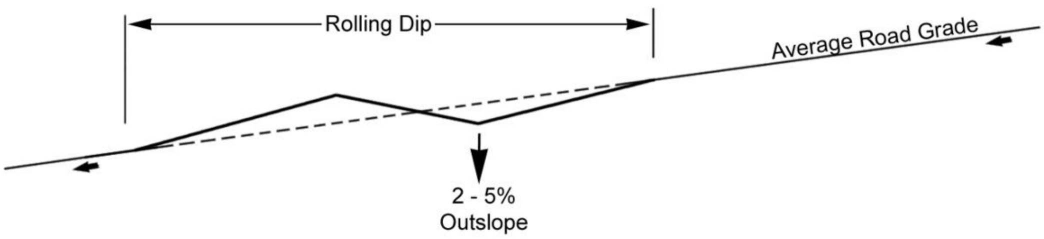
Culvert cross-drains are used to move ditch water across the road. They are the most common type of road surface drainage, and are most appropriate for high-speed roads where a smooth road surface profile is desired. However the pipes are expensive and the relatively small culvert pipes require cleaning and are susceptible to plugging. Rolling dip cross-drains (broad-based dips) are designed to pass slow traffic, while also dispersing surface water. Rolling dips usually cost less, require less maintenance, and are less likely to plug and fail than culvert pipes. Rolling dips are ideal on low volume, low to moderate speed roads (20-50 kph). Spacing is a function of road grade and soil type. Other types of roadway surface cross-drain structures occasionally used include open top wood or metal flumes, and rubber water deflectors.
Steep road grades are undesirable and problematic, but occasionally necessary. On grades up to 10 %, cross-drains with culverts or rolling dips are easy to use. Between 10 and 15%, frequently spaced culvert cross-drains work, often in conjunction with armored ditches. On grades over 15 %, it is difficult to slow down the water or remove it from the road surface rapidly. Here it is best to still use frequently spaced cross-drain culverts, with armored ditches, and the road surface also typically needs armoring or surfacing with some form of pavement to resist erosion.



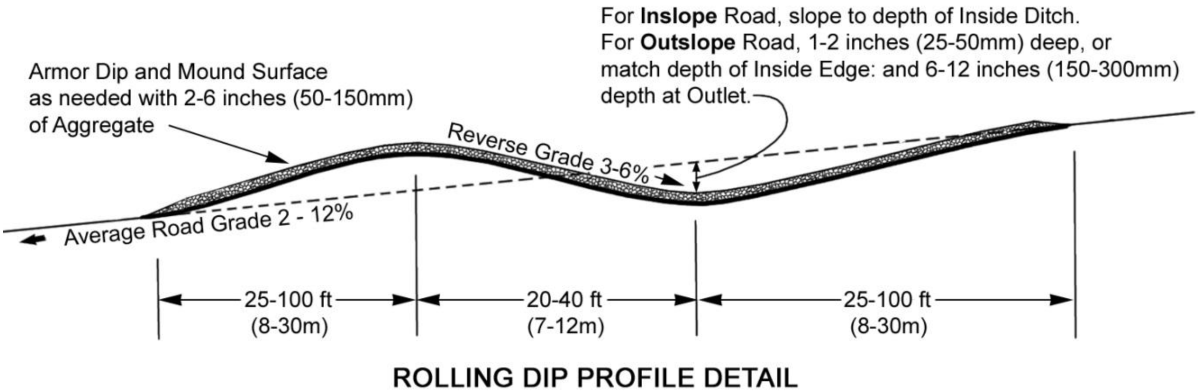
Typical configuration of a ditch relief cross-drain culvert.



PERSPECTIVE VIEW



PROFILE

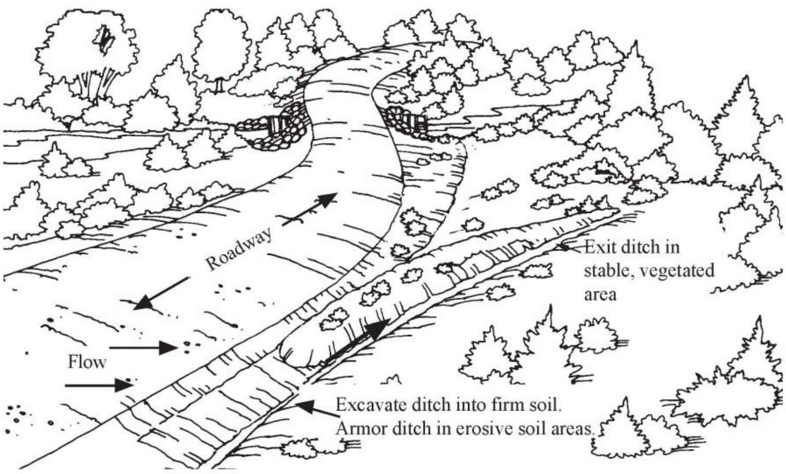


ROLLING DIP PROFILE DETAIL

Plan view and profile of a rolling dip to remove water off the roadway surface.

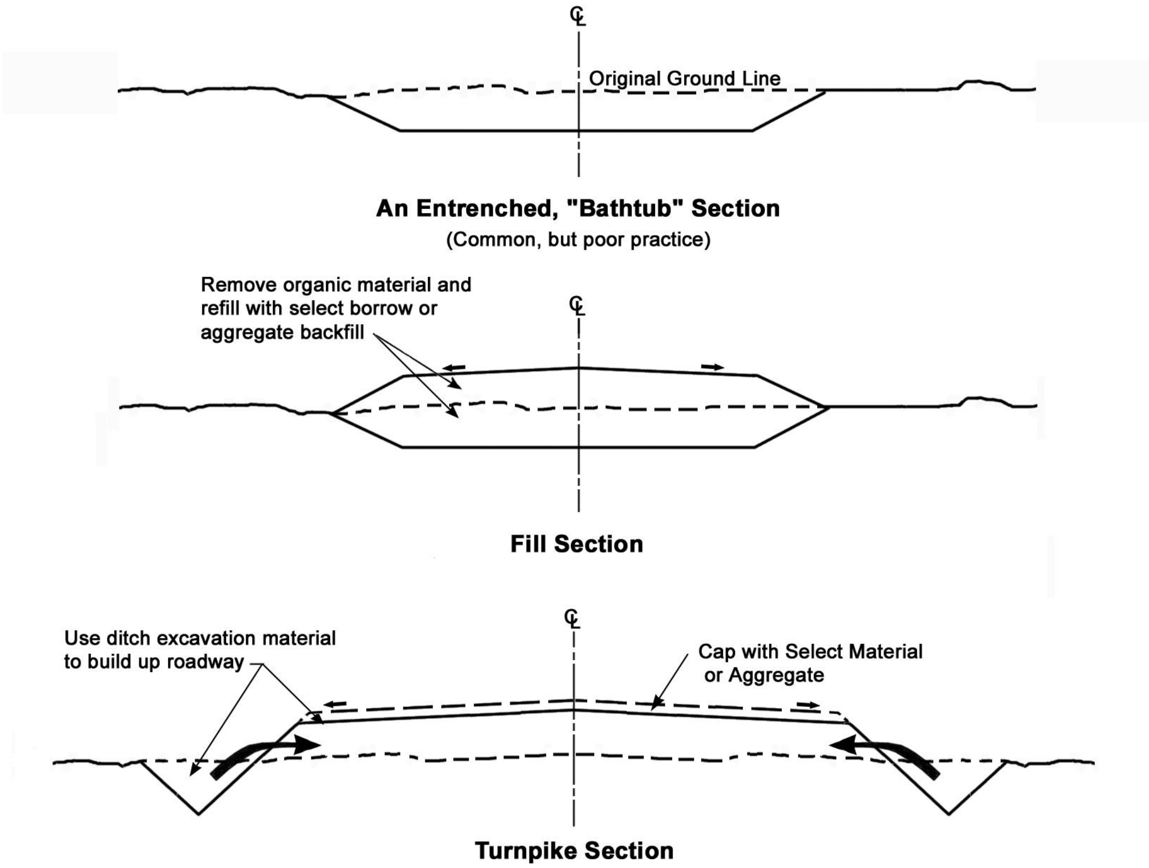
Photo of a road surface drainage dip that is working but that needs to be deepened to function during a major storm

Leadoff ditches are the alternative way to remove water from a roadway ditch when the terrain permits, as shown below. Leadoff ditches should divert water into a forested area to act as a sediment trap rather than carry the water and sediments on to a drainage channel. Thus the road can be somewhat “disconnected” from the local stream system.



Typical shape of a leadoff ditch used to remove water from the roadway ditch.

In very flat terrain, collector roads that must be used during the rainy season are often elevated above the ground level to ensure that the road surface can be drained. When the road level is below the level of the terrain, as with an” entrenched” road, it is very difficult to achieve good road surface drainage. An elevated roadway surface, or “turnpike section” allows for good drainage. It is achieved by using material excavated from the ditches or by importing new material to raise the road grade, as seen in the figure below. This elevated section also helps define the location of the roadway.

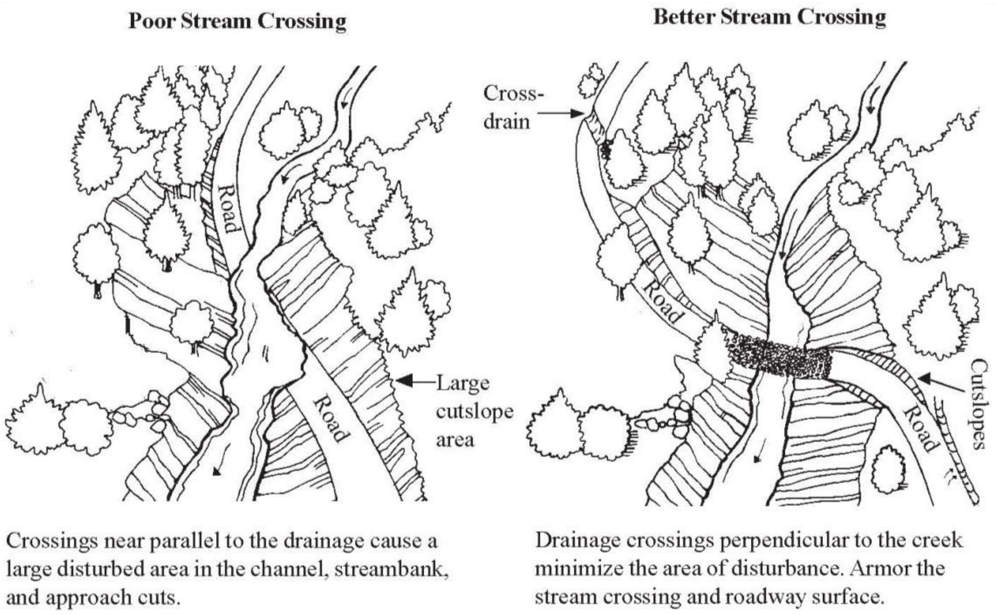


Road options for crossing very wet or swampy areas by raising the road grade.

An Adjara road in very flat, wet terrain, where the road needs to be elevated and one specific roadway defined.

Drainage Crossing Structures

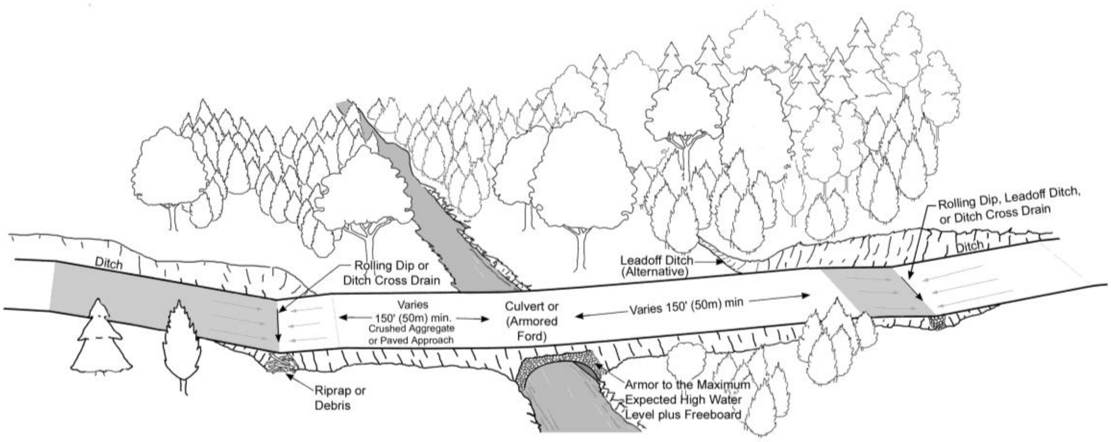
For natural drainage crossing structures, the choice of structure typically includes culvert pipes, arch or box culverts, low water fords, or bridges. Road crossings of natural drainage channels and streams require hydrologic and hydraulic design expertise to determine the proper size and type of structure. Because drainage crossings are at areas of running water, they can be costly to construct and they can have major negative impacts on water quality. Impacts from improper design or installation of structures can include degraded water quality, bank erosion, channel scour, traffic delays, and costly repairs if a structure fails. Also structures can greatly impact fish at all stages of life as well as other aquatic species. Stream crossings should be as short as possible, and cross perpendicular to the channel, as seen in the figure below.



The method of crossing drainages to minimize the area of disturbance.

An Adjara low water crossing that was washed out in a major storm. Note that the parallel crossing to the drainage has caused significant impact and damage to the road.

To minimize sediment that reaches drainages from the roadway surface or from roadway ditches, several best practices are recommended at road-stream crossings. These include armoring the roadway surface for some distance (at least 50 meters) on either side of the crossing with gravel or aggregate, properly armoring the culvert or structure against local scour, and diverting the roadway ditch water into the forest before it reaches the stream, as seen in the figure below.

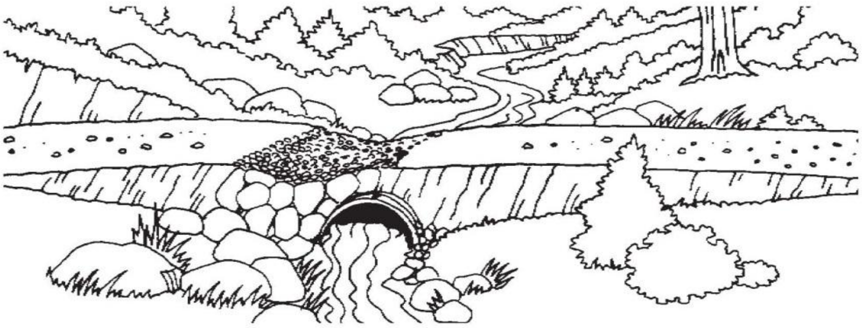


Armor or stabilize the actual stream crossing structure and add surface armoring to the roadbed and approach. Drain water off the road surface before reaching the crossing. Road surface armor should be a minimum of 150ft (50m) and should extend to the nearest cross-drain structure. Actual distance depends on road grade, soil type, rainfall, etc.
For fords, set stream channel armoring at the elevation of the natural stream bottom. Armor outlets and fills as needed.

Sediment protection measures at stream crossings

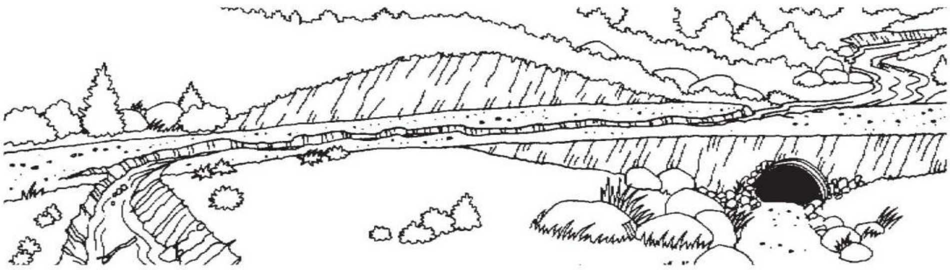
Large drainage crossing structures such as major culverts and bridges should receive site-specific analysis and design input, ideally by an experienced hydraulic engineer and other specialists. In drainages with uncertain flow values, large quantities of debris in the channel, or sites with existing undersized pipes, there is a high risk of a culvert pipe plugging and the site washing out or failing. In such areas, or in particularly sensitive watersheds, overflow protection is very desirable. A low point in the fill and an armored overflow “spillway”, as shown below, will protect the fill, keep the flow in the same drainage, thus reducing diversion potential, and usually prevent a failure. A plugged pipe that diverts the stream water down the road can cause a great deal of off-site damage, gullying, or cause landslides.

Good Installation

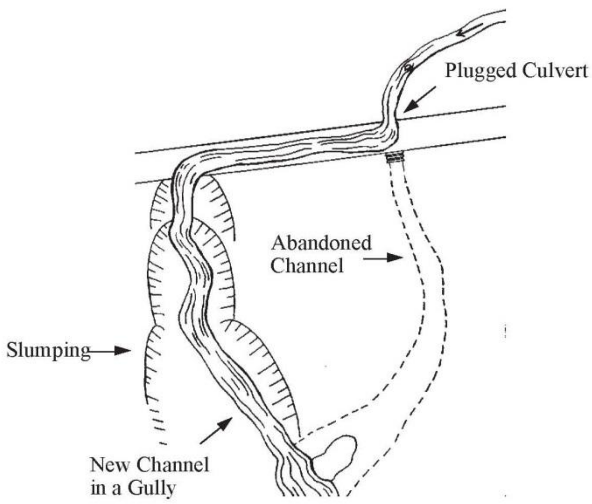


a. Armored dip over a low fill to prevent stream diversion.

Poor Installation



b. Sketch of a stream diverted down the road, forming a new channel.



c. Consequence of stream diversion out of its natural channel.

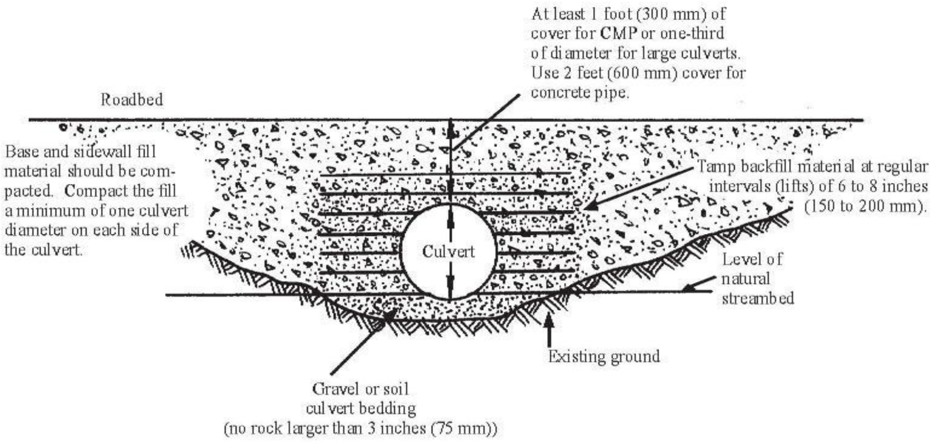
Existing undersized culvert fitted with an armored overflow dip to pass water without stream diversion or washing out the fill (upper figure). Lower figures show a stream diversion where a plugged culvert crossing sends water down the road rather than staying in its natural channel, causing considerable off-site damage (Adapted from M. Furniss et al. 1997).

Culverts are the most commonly used natural drainage crossing structure. Natural drainages need to have pipes large enough to pass the expected flow plus extra capacity to avoid plugging with debris. Fish passage may also be a design consideration. Discharge (design flow) will depend on the watershed drainage area, runoff characteristics, design rainfall intensity, and return period (frequency) of the design storm. Culvert design typically uses a minimum storm event of 20-years, and may design for as much as a 100-year event, depending on the sensitivity of the site. For larger drainages, specific site hydrologic and hydraulic analyses should be done. These analyses must consider the watershed and channel characteristics, high water levels, local rainfall data, and other available flow information.

Culverts are typically made of concrete or metal (corrugated steel or aluminum), and plastic pipe is occasionally used, as well as wood and masonry. The type of material used typically depends on cost and availability of the materials. However, corrugated metal pipe (CMP) and concrete pipe are typically more durable than plastic pipe. The shape of the culvert, such as a round pipe, pipe arch, structural arch, or box depends on the site, needed span, and allowable height of soil cover.

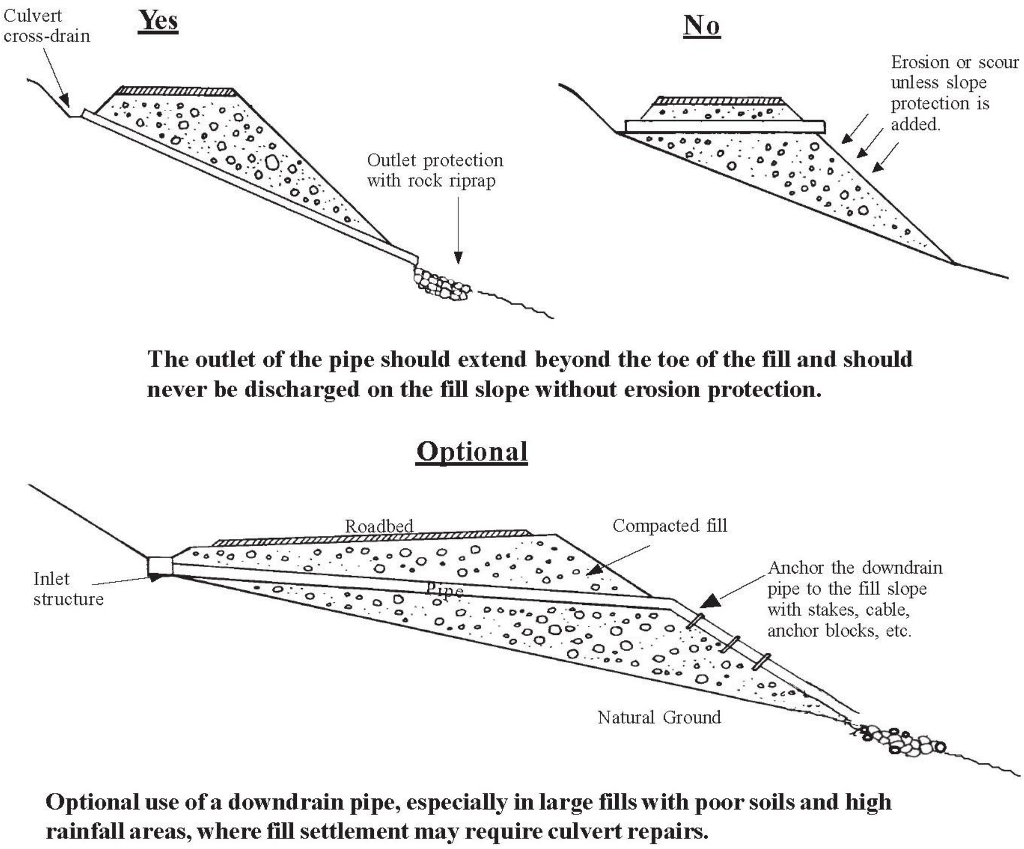
Important installation details include: minimizing channel modifications; avoiding constriction of the bankfull flow channel width; maintaining the natural grade and alignment; using quality, well compacted bedding and backfill material; and using inlet, outlet, and streambank protection measures. Trash racks are often desirable in channels with significant amounts of debris to prevent pipe plugging. Concrete headwalls help prevent culvert failures and also deter piping. Ideally a culvert will be of a size as wide as the natural channel to avoid channel constriction.

Bedding and backfill material for culverts is commonly specified as “select granular material” or “select mineral soil”. Actually most soils are satisfactory if they are free of excess moisture, muck, lumps of frozen soil or highly plastic clay, roots, or rock larger than 7.5 cm. Bedding material beneath the pipe should not have rocks larger than 3.8 cm. Clay soil can be used if it is carefully compacted at a uniform, near-optimum moisture content. **Ideal backfill material is a moist, well-graded granular or sandy gravel soil with up to 10 percent fines and free of rocks.** The material should be well compacted, at least as dense as the adjacent ground, and preferably to a density of 90-95% of the AASHTO T-99 maximum density, and placed in 15 cm thick layers (lifts), as shown below. A dense, uniform backfill is important to structurally support the lateral pressure from the pipe.



Construction techniques for proper installation of a culvert

Cross-drain culvert installation options and details are seen in the figure below. The cross-drain pipe should ideally be placed at the bottom of the fill, the inlet should be protected with a drop inlet structure or catch basin, and the outlet area should be protected against scour.



Proper installation of ditch relief cross drains through a roadway fill.

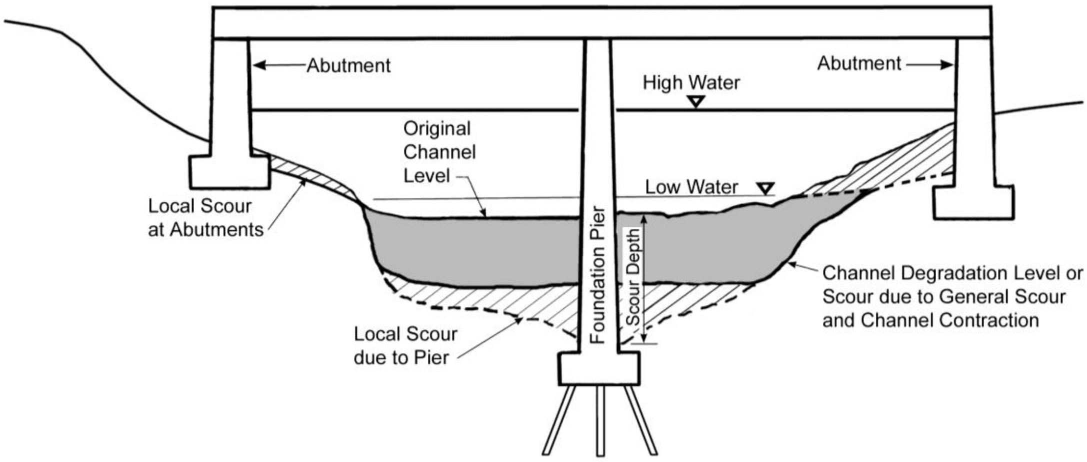
Bridges are relatively expensive but often are the most desirable stream crossing structure because they can be constructed outside of the stream channel and thus minimize channel changes, excavation, or placement of fill in the natural channel. They minimize disturbance of the natural stream bottom and they do not require traffic delays once constructed. They are ideal for fish passage. They do require detailed site considerations and specific hydraulic analysis and design. The bridge location and size should ideally be determined by an engineer, hydrologist and fisheries biologist, who are working together as a team. When possible, a bridge should be constructed at a narrow channel location and should be in an area of bedrock or coarse soil and rock for a bridge site with good foundation conditions. **Many bridge failures occur due to fine foundation materials that are susceptible to scour.**

Bridges should be **designed** to insure that they have adequate structural capacity to support the heaviest anticipated vehicle**.** Simple span bridges may be made of logs, timbers, glue-laminated wood beams, steel girders, cast-in-place concrete slabs, prefabricated concrete slabs, may be modular bridges such Bailey Bridges, or old railroad car beds may be used, as seen in the photo below. Many types of structures and materials are appropriate, so long as they are structurally adequate.

A used railroad car bridge being used on a forest road.

"Standard designs" can be found for many simple bridges as a function of bridge span and loading conditions. Complex structures should be specifically designed by a structural engineer. Bridge designs often require the approval of local agencies or governments. Concrete structures are desirable because they can be relatively simple and inexpensive, require minimal maintenance, and have a relatively long design life in most environments. Log bridges are also commonly used because of the availability of local materials, particularly in remote areas, but keep in mind that they have relatively short spans and they have a relatively short design life.

Foundations for bridges may include simple log sills, gabions, masonry retaining walls, or concrete stem walls with footings. Deep foundations often use drilled piers or driven piles. Most bridge failures occur either because of inadequate hydraulic capacity (too small) or because of scour and undermining of a foundation placed upon fine soils. The figure below shows common scour-susceptible areas around bridge foundations, particularly where a pier or caisson is place in the middle of the channel. **Mid-channel foundations should be avoided whenever possible!** Thus foundation considerations are critical. Since bridge structures are typically expensive and sites may be complicated, most bridge designs should be done with input from experienced structural, hydraulic, and geotechnical engineers.



Common scour problem areas with bridges, and particularly around mid-channel foundations.

Periodic bridge inspection and maintenance are needed to insure that the structure is safe to pass the anticipated vehicles, that the stream channel is clear, and to maximize the design life of the structure. Typical bridge maintenance items include cleaning the deck and "seats" of the girders; clearing vegetation and debris from the stream channel; replacing object markers and signs; repairing stream bank protection measures; treating dry and checking wood; replacing missing nuts and bolts; and repainting the structure.

Slope Stabilization Issues

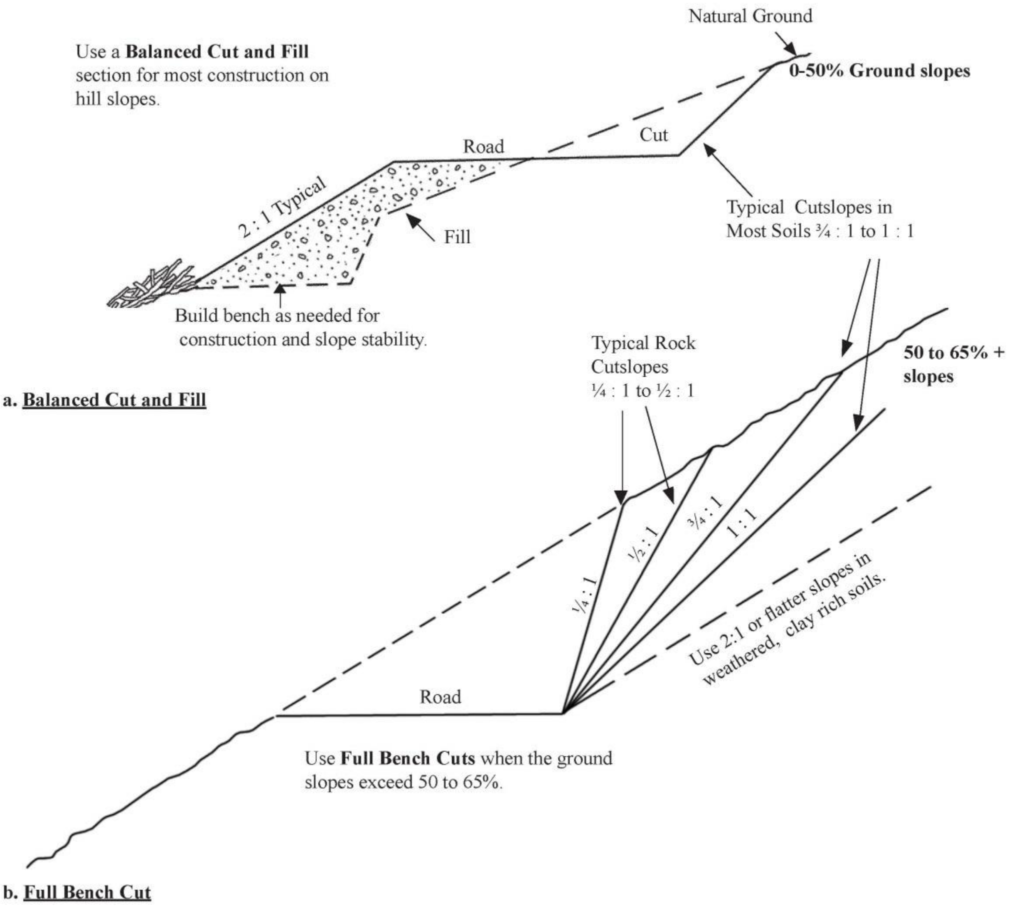
The objectives of routine road cuts and fills are 1) to remain stable over time, 2) to not be a source of sediment, and 3) to minimize long-term costs. Landslides and failed road cuts and fills can be a major source of sediment, they can close the road, require major repairs, and they can greatly increase road maintenance costs. Vertical cut slopes, as seen in the photo below, should not be used unless the cut is in rock or very well cemented soil. Long-term stable cut slopes in most soils and geographic areas are typically made with about a 1:1 or ¾:1 (horizontal:vertical) slope. Ideally both cut and fill slopes should be constructed so that they can be vegetated. Fill slopes should be constructed with a 1 ½:1 or flatter slope. Over-steep fill slopes (steeper than a 1 ½:1 slope), commonly formed by side-casting loose fill material, may continue to ravel with time, are difficult to stabilize, and are subject to sliver fill failures. A rock fill can be stable with a 1 1/3:1 slope. Ideally fills should be constructed with a 2:1 or flatter slope to promote growth of vegetation and slope stabilization.

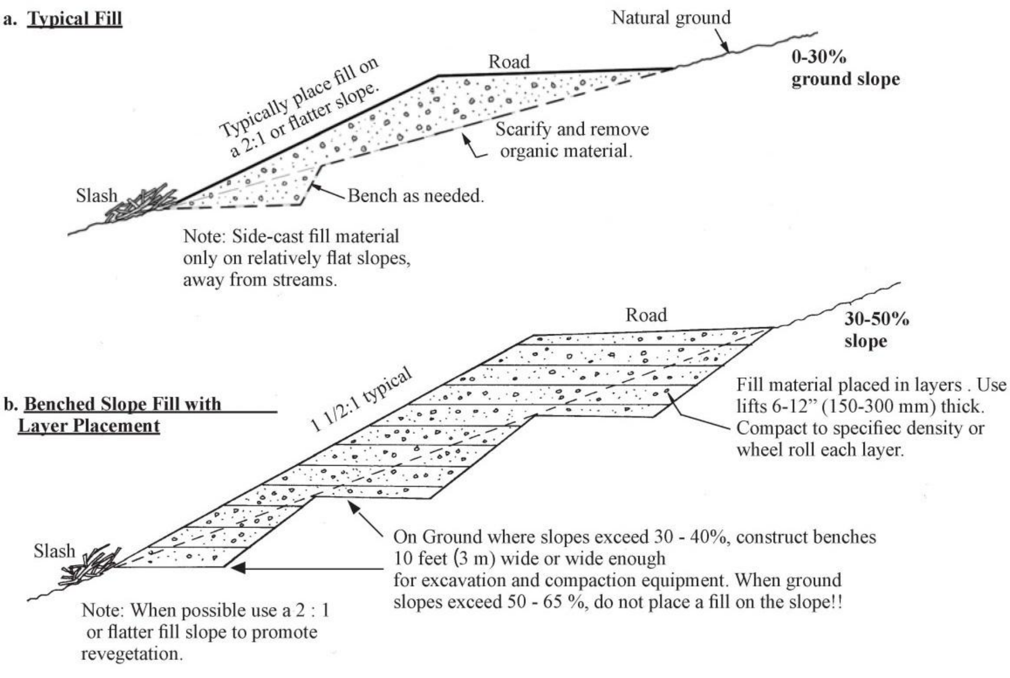

Vertical cuts and loose, sidecast fills used in local Adjara new road construction are both likely to cause some instability problems over time.

The table below presents a range of commonly used cut and fill slope ratios appropriate for the soil and rock types described. Also the figures show typical cut slope and fill slope design options, respectively, for varying slope and site conditions. Note however that local conditions can vary greatly, so determination of stable slopes should be based upon local experience and judgment. Groundwater is the major cause of slope failures.

TABLE 11.1
COMMON STABLE SLOPE RATIOS FOR VARYING SOIL/ROCK CONDITIONS

Soil/Rock Condition	**Slope Ratio (Hor:Vert)**
Most rock	**¼:1 to ½:1**
Very well cemented soils	**¼:1 to ½:1**
Most in-place soils	**¾:1 to 1:1**
Very fractured rock	**1:1 to 1 ½:1**
Loose coarse granular soils	**1 ½:1**
Heavy clay soils	**2:1 to 3:1**
Soft clay rich zones or wet seepage areas	**2:1 to 3:1**
Fills of most soils	**1 ½:1 to 2:1**
Fills of hard, angular rock	**1 1/3:1**
Low cuts and fills (<2-3 m. high)	**2:1 or flatter (for revegetation)**





Typical cut and fill slope configurations used to promote long-term slope stability.

Slope failures, or landslides, typically occur where a slope is over-steep, where fill material is not compacted, or where cuts in natural, in-place soils encounter groundwater or zones of weak material. Good road location can often avoid landslide areas and reduce slope failures. When failures do occur, the slide area should be stabilized, by removing the slide material, flattening the slope, adding drainage, or using structures, etc., as discussed below. Designs are typically site specific and may require input from geotechnical engineers and engineering geologists. Failures that occur typically impact road operations and can be costly to repair. Failures near streams and channel crossings have an added risk of impact to water quality.

A wide range of slope stabilization measures is available to the engineer to solve slope stability problems and cross an unstable area. In most excavation and embankment work, relatively flat slopes, good compaction, and adding needed drainage will typically eliminate most routine instability problems. Once a failure has occurred, the most appropriate stabilization measure will depend on site-specific conditions such as size of the slide, soil type, road use, alignment constraints, and cause of the failure. A range of typical slope stabilization options appropriate for low-volume roads, presented roughly from simplest and least expensive, to the most complex and expensive, are listed below:

- Simply remove the slide material.
- Ramp over or align the road around the slide.
- Revegetate the slope and add spot stabilization.
- Flatten or reconstruct the slope.
- Raise or lower the road level to buttress the cut or remove weight from the slide, respectively.
- Relocate the road to a stable location.
- Install slope drainage such as deep cutoff trenches or dewatering with horizontal drains.
- Design and construct buttresses, retaining structures, or rock anchors.

Retaining structures are relatively expensive but necessary in steep, narrow areas to gain roadway space or to support the roadbed on a steep slope, rather than make a large cut into the hillside. They can also be used for slope stabilization. Gabion structures are very commonly used for walls up to about 6 meters high, particularly because they use locally available rock and they are labor intensive. On most gravity retaining structures, the base width is commonly at least **0.7 times the wall height**.

For low to high walls in many geographic areas today, Mechanically Stabilized Earth (MSE), or “Reinforced Soil” structures are the least expensive type of wall available, they are simple to build, and often they can use on-site granular backfill material. They are commonly constructed using layers of geotextile or welded wire, placed in lifts 15 to 45 cm apart in the soil, thus adding tensile reinforcement to the soil. Most types of retaining structures provided by manufacturers are internally stable for the specified use, site conditions, and height. Most wall failures occur due to **foundation failure**. Thus structures **must** be placed on a good foundation, such as bedrock or firm, in-place soil.

Roadway Materials

Low-volume forest local roads are typically built from native materials that must support light vehicles, may have to support heavy commercial truck traffic, and should have a surface that, when wet, will provide adequate traction for vehicles. The surface of native soil roads is also an exposed area that can produce significant amounts of sediment, especially if rutted. It is usually desirable, and in many cases necessary, to add subgrade structural support or to improve the roadbed native soil surface with materials such as gravel, coarse rocky soil, crushed aggregate, cobblestone, concrete blocks, concrete, or some type of bituminous seal coat or asphalt pavement. Surfacing both improves the structural support and reduces road surface erosion. Selection of surfacing type depends upon the traffic volume, local soils, available materials, ease of maintenance, and ultimately cost. Collector and arterial roads typically receive an improved road surfacing.

A range of options exists for improving the structural capacity of the roadway in areas of soft soils or poor subgrades. These commonly include:

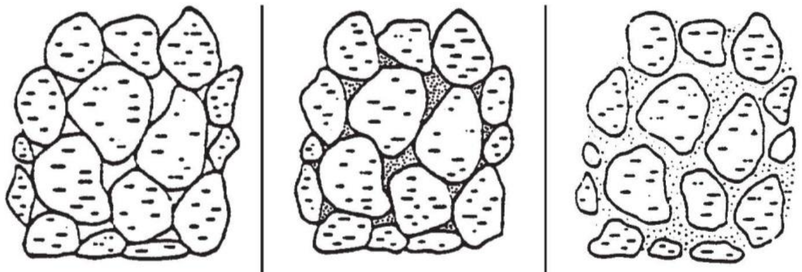
- Adding material of higher strength and quality over the soft soil, such as a layer of gravel or crushed aggregate;
- Improving the soft soil in place (in-situ) by mixing it with stabilization additives such as lime, cement, asphalt, or chemicals;
- Bridging over the soft soil, with materials such as geotextiles or wood pieces (corduroy);
- Removing the soft or poor soil and replacing it with a high quality soil or rocky material;
- Limiting the use of the road during periods of wet weather, when clay soils are soft
- Compacting the native soil to increase its density and strength; and
- Keeping moisture out of the soil with effective roadway drainage or encapsulating the soil to keep water out of it.

Various soil stabilization materials such as oils, lime, cements, resins, lignin, chlorides, enzymes, and chemicals may be used to improve the material properties of the in-place soil. They may be very cost-effective in areas where aggregate or other materials are difficult to locate or are expensive. The best soil stabilization material to use depends on cost, soil type, performance and local experience. Test sections are often needed to determine the most desirable and cost-effective product. However many soil stabilizers still need some type of wearing surface. A stabilized road surface improves traction and offers erosion protection as well as structural support.

Gravel, pit run rock, or crushed aggregate are the most common improved surfacing materials used on low-volume roads. Aggregate is sometimes used only as “fill” material in ruts, but most desirably it is placed as a full structural section. The roadway surfacing aggregate must perform two basic functions: (1) It must have high enough quality and be thick enough to provide structural support to the traffic and prevent rutting; (2) It must be well graded and mixed with sufficient fines, preferably with some plasticity, to prevent raveling and washboarding.

Aggregate thickness needed typically ranges from 10 to 30 cm, depending on soil strength, traffic, and climate. Specific aggregate thickness design procedures are found in the selected references. Over very weak soils (CBR less than 3), aggregate thickness can be reduced with the use of geotextile or geogrid subgrade reinforcement. Also geotextile layers are useful over soft soils to separate the aggregate from the soil, keep it uncontaminated, and extend the useful life of the aggregate.

The figure below presents some of the physical properties and tradeoffs of various soil-aggregate mixtures, first with no fines (no material passing the #200 sieve, or .074mm size), with an ideal percentage of fines (6-15%), and with excessive fines (over 15 to 30%). The desirable percentage of fines in an aggregate can be sensitive to the climate, or road environment. In semi arid to desert regions, a relatively high percentage of fines, such as 15 to 20 %, with moderate plasticity, is desirable. In a high rainfall "wet" environment, such as tropical, coastal mountain, or jungle areas, a low percentage, such as 5 to 10 % fines, is desirable to prevent rutting and maintain a stable road surface.



Aggregate with no Fines (0 % Fines)	Aggregate with Sufficient Fines for Maximum Density (Ideally 8-15 % Fines)	Aggregate with High Amount of Fines (> 25 % Fines)
• Grain-to-grain contact • Variable density • High permeability • Non-frost susceptible • High stability when confined, low when unconfined • Not affected by adverse water conditions • Difficult to compact • Ravels easily	• Grain-to-grain contact with increased resistance against deformation • Increased to maximum density • Low permeability • Frost susceptible • Relatively high stability in confined or unconfined conditions • Not greatly affected by adverse water conditions • Moderately easy to compact • Good road performance	• Grain-to-grain contact destroyed, aggregate is "floating" in soil • Decreased density • Low permeability • Frost susceptible • Low stability and low strength • Greatly affected by adverse water condition • Easy to compact • Dusts easily

The physical properties of aggregate mixtures with varying amounts of fines.

Ideally aggregate surfacing material is hard, crushed or screened to a minus 5 cm size, it is well graded to achieve maximum density, it contains 5-15% clayey binder to prevent raveling, and it has a Plasticity Index of 2 to 10. The surfacing applied to the road must be maintainable in order to prevent rutting and erosion. Significant deterioration of the road can occur if ruts, raveling, washboarding, or surface erosion are not controlled. Road damage can be greatly reduced by restricting road use during wet conditions if road management allows for this option.

Compaction is usually the most cost effective method to improve the quality (strength and water resistance) of subgrade soils and to improve the performance of aggregate surfacing. Thus compaction is useful to protect the investment in road aggregate, maximize its strength, minimize loss of fines, and prevent raveling. Also road performance has been excellent in some semi-arid regions with the use of blended local materials, very high compaction standards, and a waterproof membrane such as a bituminous seal coat.

The tables below show the specifications used by the US Forest Service for Aggregate Base material and Aggregate Surfacing material used on forest roads. The surfacing material has a somewhat finer gradation than the base aggregate, it has more fines, and ideally has some plasticity. Also the wear, durability, and plasticity test requirements are shown.

Roadway Material Gradation Requirements for Base and Surfacing Aggregate typically used by the Forest Service (FP-03 Special Project Specifications, Section 703.05).

Sieve Size	USFS B **(Subbase)**	USFS C **(Base)**	USFS D **(Base)**	USFS F **(Surface)**	USFS G **(Surface)**
2 ½ inch (63 mm)	-	-	-	-	-
2 inch (50 mm)	100	100	-	-	-
1 ½ inch (37.5 mm)	97-100			100	-
1 inch (25 mm)	-	80-100	100	97-100	100
¾ inch (19 mm)	-	64-94	86-100	76-89	97-100
½ inch (12.5 mm)	-	-		-	-
3/8 inch (9.5 mm)	-	40-69	51-82	56-68	70-80
No. 4 (4.75 mm)	40-60	31-54	36-64	43-53	51-63
No. 16 (1.18 mm)	-	-	-	23-32	28-39
No. 40 (425 µm)	-		12-26	15-23	19-27
No. 200 (75 µm)	4-12.0	4.0-7.0	4.0-7.0	10-16 (1)	10-16 (1)

Note:

(1) Range for No. 200 Sieve is 6.0 to 12.0 if the PI is greater than 0.

Aggregate Wear and Durability Requirements.

Test Requirement	Base and Subbase	Surfacing
Los Angeles Abrasion, AASHTO T 96	40 % maximum	40 % maximum
Sodium Sulfate Soundness Loss, AASHTO T 104	12 % maximum	12 % maximum
Durability Index (coarse and fine), AASHTO T 210	35 minimum	35 minimum
Fractured Faces, ASTM D 5821	50 % minimum	75 % minimum
Liquid Limit, AASHTO T 89	25 maximum	35 maximum
Plastic Limit, AASHTO T 90	Nonplastic	2 to 9 (1) < 2 (2)

Note:

(1) If the percent passing the 75 µm sieve is less than 12 percent.

(2) If the percent passing the 75 µm sieve is greater than 12 percent.

Erosion Control and Water Quality Protection

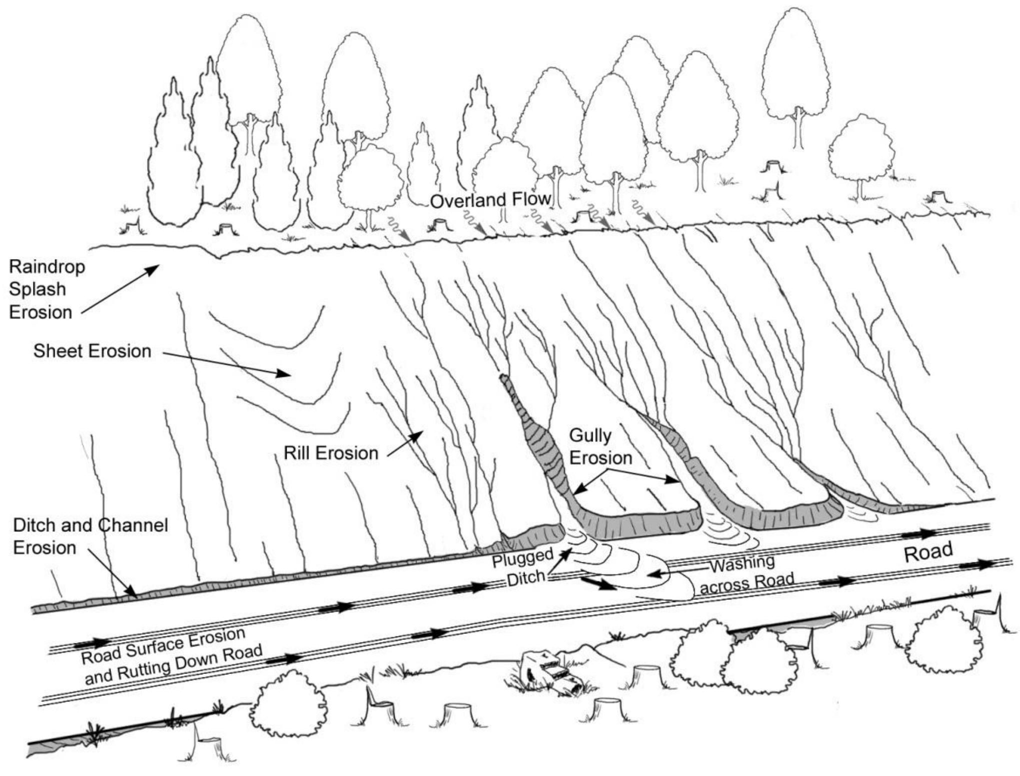
Erosion prevention on roads, the entire road prism, and on disturbed areas is fundamental for the protection of water quality, particularly during major storms. **The two main causes of erosion are concentration of flowing water and lack of ground cover over the soil**. Vegetative ground cover and good water infiltration are the primary long-term defenses against erosion.

Erosion control measures need to be implemented immediately following construction and every time an area is disturbed. They particularly need to be implemented before the first winter period following construction or ground disturbance, and before any major storm event. In areas of construction ground cover is difficult to achieve, so sediment is typically trapped around the site. The area of disturbance can also be limited and areas can be progressively rehabilitated.

Water flow concentration should be prevented or eroding channels should be armored or stabilized. Any sediment should be trapped before it enters natural drainage channels, but priority should be given to treatments at the source of the erosion. Bare ground should be covered with some form of matting or mulch to reduce initial erosion and promote growth of grass seed or other types of appropriate vegetation (ideally native) for long-term erosion control. Rapid growing annual grasses are often used to provide quick ground cover, and then they will be replaced with native vegetation over time.

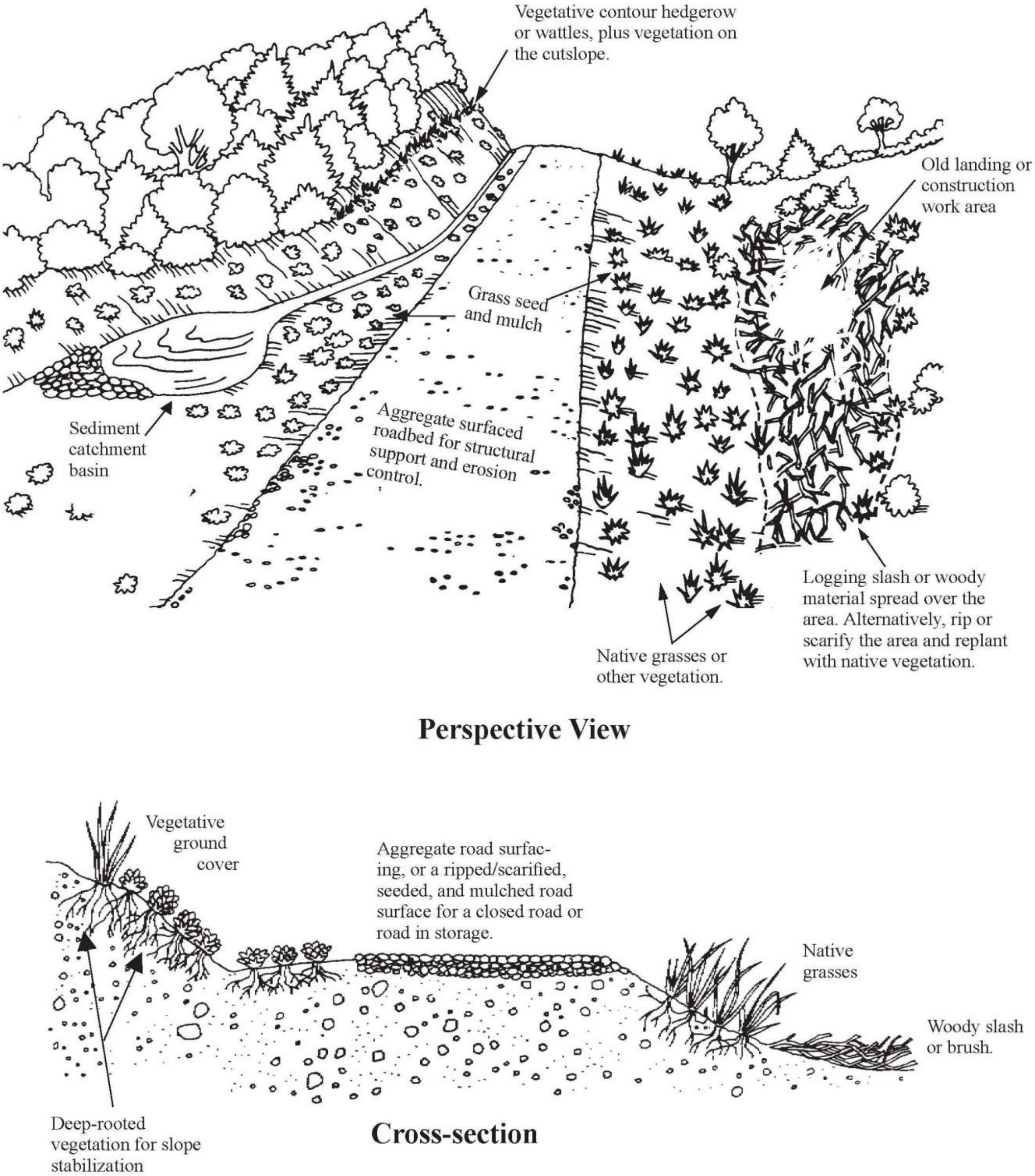
Most disturbed road areas, including the road surface, road fills, some road cuts, shoulders, and drainage ditches are exposed to erosion at some time, Other associated areas such as landings, skid roads, construction staging and storage areas, borrow pits and quarries, and other working areas all can erode and produce sediment. The figure below shows the common types of road erosion, including sheet and rill erosion on the cutbank (and fillslopes), ditch and road surface erosion, and gully erosion when water becomes concentrated.

Surface erosion from road surfaces, shoulders, cuts, and fills, can be significant. Movement of sediment can occur during and after road construction, after road maintenance, during logging or mining activities, as the road is being used, if a road is closed but not stabilized, or from poor land management practices near the road. Roughly half of the erosion from a logging operation, for instance, comes from the associated roads and skid trails. Mass erosion rates from roads are typically one to several orders of magnitude higher than from other land uses. Much of that erosion occurs during storm events!!



Types and areas of typical roadway erosion

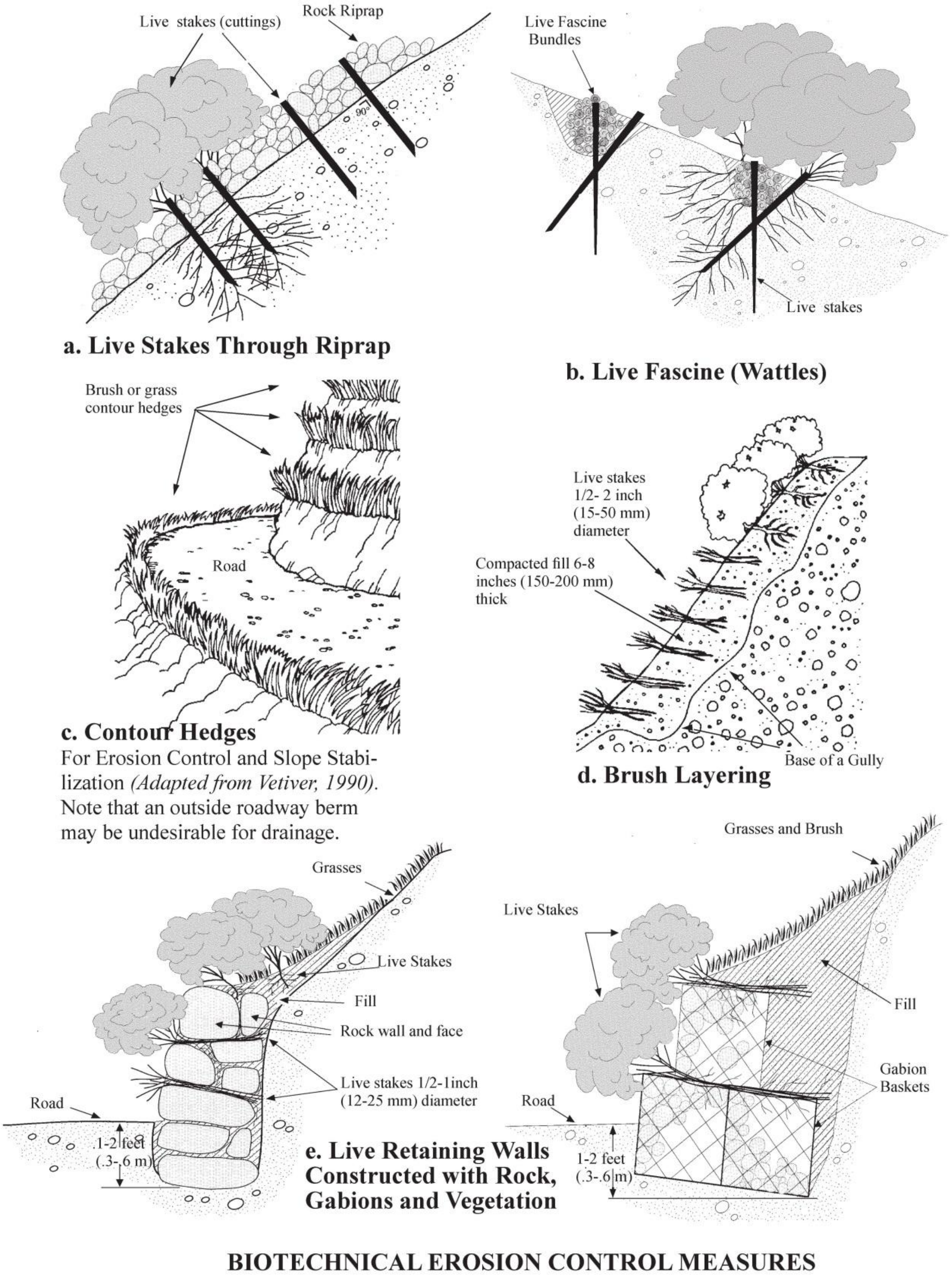
Erosion control is a two-step process; step one is to prevent short-term erosion from bare or exposed soil. Step two is control of long-term erosion through establishment of vegetation. Sometimes in steep or severe conditions, a structural solution, such as a retaining wall, ground armoring with rock, or a gully plug, is required. The ideal erosion control solution promotes the germination and growth of plants, and encourages the natural recruitment of the surrounding native plant community while it protects the soil from short-term erosion. Conserving native topsoil and re-spreading it over an area helps promote native plant growth. There are numerous treatments, combinations of treatments, and emerging products that may be suitable for a site or along a road, as shown below.



Various erosion control ground covers include seeding and straw mulch, grasses and other mulch, native vegetation, rock, slash, chips, or leaves.

Typical roadway erosion control measures used.

Erosion control practices include surface armoring and ground cover with netting, vegetative material or slash, rock, etc.; installing water and sediment control structures; and mulching, seeding, and various forms of revegetation. Effective erosion control requires attention to detail, and installation work requires inspection and quality control. **Physical methods** include armored ditches, berms, wood chips, ground cover mats, and silt or sediment fences, control of water, ground surface protection against erosion, or soil surface modifications to make it more resistant to erosion. **Vegetative methods**, using grasses, brush, and trees, offer ground cover, root strength, and soil protection with inexpensive and aesthetic "natural" vegetation, as well as help control water and promote infiltration. Ideally vegetation should be selected for good growth properties, hardiness, dense ground cover, and deep roots for slope stabilization. Local native species having the above mentioned properties should preferably be used. **Biotechnical methods**, such as brush layering, live stakes, and contour hedgerows, offer a combination of structures with vegetation for physical protection as well as additional long-term root support and aesthetics. A variety of Biotechnical erosion control treatments are shown below.



Biotechnical Erosion Control Measures ideal for use in roadway applications

An **Erosion Control Plan** and use of erosion control measures should be an integral part of any road construction or resource extraction project. Most disturbed areas, including landings, construction storage areas, skid roads, road fills, some road cuts, drainage ditches, borrow pits, the road surface, and other working areas should receive erosion control treatment. It is more cost effective and efficient to prevent erosion than to repair the damage or remove sediment from streams, lakes or groundwater. Elements of an Erosion Control and Revegetation Plan include project location and climate; soil types; type of erosion control measures; timing of implementation of the vegetative erosion control measures; source of seeds and plants; planting methods; etc. The table below presents the many aspects of planning, implementation, and care involved in an erosion control plan for roads projects.

Key Elements of an Erosion Control and Revegetation Plan for Road Projects

A. <u>Description of Project</u>

1. Project Objectives
2. Project Location
3. Description of Local Environment

B. <u>Planning</u>

1. Site Analysis
   a. Climate and Microclimate
   b. Vegetation Options
   c. Soils and Fertility
2. Developing the Revegetation Plan
   a. Suitable Plant Species
   b. Soil and Site Preparation
   c. Aesthetics vs Erosion Control Needs
   d. Use of Local “Native” Species

C. <u>Implementation</u>

1. Planting Methods—<u>Cuttings and Transplants</u>
   a. Tools and Materials
   b. Planting Holes and Methods
2. Planting Methods—<u>Seeding and Mulching</u>
   a. Hand Broadcasting or Hydroseeding
   b. Range Drills
   c. Type / Quantity of Seed
   d. Type / Quantity of Mulch and Fertilizer
   e. Holding Mulch with Tackifiers or Netting
3. Plant Protection
   a. Wire Caging around Plants
   b. Fencing Around the Entire Site
4. Maintenance and Care After Planting
   a. Irrigation
   b. Weed Control
   c. Fertilization
5. Biotechnical Planting Methods
   a. Wattling
   b. Brush Layering or Brush Matting
   c. Live Stakes

D. **Obtaining Plants and Handling of Plant Materials**

1. Timing and Planning
   a. Fall versus Spring Planting
   b. Summer Plantings
2. Types of Plant Materials
   a. Cuttings
   b. Tublings
   c. Other Container Plants
3. Hardening-off and Holding Plants (Acclimatizing)
4. Handling Live Plants and Cuttings

Good soil preparation is key to the long term success of vegetative treatments. The quality and fertility of the soil directly affects its productivity and ability to grow vegetation. Compacted soils should be loosened with scarification or subsoiling, and the addition of organic material. Sterile soils may need amendments to promote growth. Other chemicals or minerals in soil may retard growth and need mitigation. The Erosion Control Plan should consider the soil condition and often a chemical analysis of the soil is desirable.

Vegetative treatments need to be designed and installed to provide protection immediately, in the short term, and in the long term! Often physical methods are used to initially protect seeds promote long-term revegetation. Thus a phased and/or mixed application of vegetation is needed, typically with a variety of plants. Ideally vegetation should be selected for good growth properties, hardiness, dense ground cover, and deep roots for slope stabilization. Local native species having these properties are preferable and should be considered first**.** When natives are not practical, select non-native plants with non-invasive characteristics. Some shrubs such as willows (Salix family) have been used extensively in the Western United States, particularly in wet sites, because of their strong, deep roots, adaptability, and ability to resprout. **Refer to local forest botanists and native plant guides and policies before prescribing vegetative treatments.**

Native species should be used whenever possible for the best adaptation to the site and to achieve the best growth. Non-native species annual grasses may initially be needed to protect disturbed areas against surface erosion for the first few years. For difficult sites, such as arid environments, test plots should be set up to determine what species and methods achieve the best results. Consider setting up on-site nurseries to harden and adapt plants to the local project area. In some cases completed projects can be utilized as sources for live cut stock to be used on a new project. Try to select native vegetation that does not require watering or fertilizers.

The type and source of vegetation should be carefully chosen to best accomplish the specific purpose in mind. Project planning (the Erosion Control Plan) should first assess the problem and then determine the effective solution. Information such as location, aspect, climate and microclimate, soil type, fertility, time of planting, and subsequent land use are critical factors in making the final design determination. The **advantage of vegetation with deep root systems** is that they are both more resistant to drought conditions and the deep roots provide slope stabilization as well as ground cover. Many grasses provide excellent dense ground cover but have shallow roots that do little to deter shallow mass failures on slopes when they become saturated.

Road Maintenance

Forest roads must be maintained during active use, after periodic operations have been completed, and after major storm events, to insure that the drainage structures are functioning properly. Heavy rainstorms will cause cut slope failures that block ditches, cause water flow on the road surface, and erode the surface and fill slope. Debris moves down natural channels during heavy rains and blocks drainage structures, causing water to overtop the road and erode the fill. Ruts, washboards and potholes in the road surface will pond water, weaken the roadway structural section, accelerate surface damage, and make driving difficult. Routine maintenance is needed on any road to keep the road serviceable and its drainage system working properly. A well-maintained road will reduce road user costs, prevent road damage, and minimize sediment production.

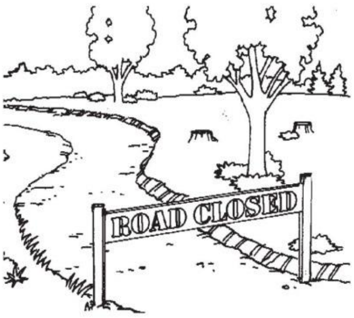
How road maintenance will be accomplished should be resolved before the road is built or reconstructed. Maintenance work can be accomplished either by state or local agency personnel, by contractors, or by local community groups. Funding for maintenance may be directly from allocated agency funds, from local or gas taxes, from road user fees, or from donated local labor by interested road users.

Key road maintenance items that should be performed routinely include:

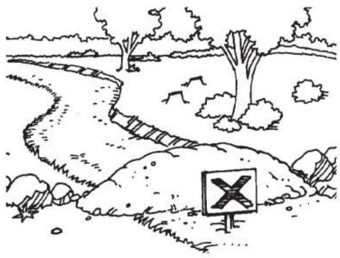
- Grading and shaping the roadway surface to maintain a distinct insloped, outsloped, or crown shape to move water rapidly off the road surface.
- Compacting the graded roadway surface to keep a hard driving surface and prevent the loss of fines. Replace surfacing material when needed. Keep the road surface moist!
- Removing ruts through rolling dips and water bars. Reshape the structures to function properly.
- Cleaning ditches and reshaping them when necessary to have adequate flow capacity. Do not grade ditches that do not need it!
- Removing debris from the entrance of culverts to prevent plugging and overtopping. Check for damage and signs of piping or scour.
- Replacing/repairing rock armor, concrete, or vegetation used for slope protection, scour protection, or energy dissipation.
- Trimming roadside vegetation (brushing) for sight distance and traffic safety.
- Replacing missing or damaged road information, safety, and regulatory signs.

Road Closure

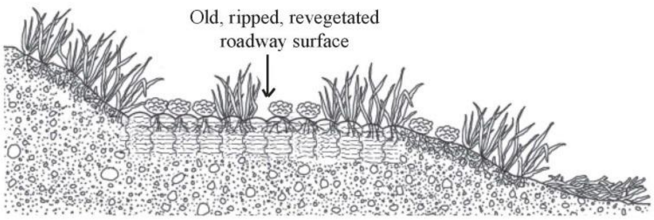
A road may be closed because it is no longer needed**,** such as if a resource is depleted or if a community has moved, if it will not be used for some period of time, or if the road is causing unacceptably high maintenance costs or environmental damage. Road closure often involves input from the public and other affected road users. Basic road closure options include the following: **Temporary closure** or blockage with gates, barricades or berms on a seasonal basis, or **road storage** where the road will not be used for many years, yet it will be reused in the future.; **Permanent closure (decommissioning)** where the road surface is stabilized and drainage structures are removed, yet the road template is left on the terrain; or **Road obliteration** where the roadway and drainage features are totally removed and the area is reshaped to its natural, pre-road condition. The figure below shows the range of options commonly considered in road closure.



a. Gate Closure (Temporary or Seasonal)



b. Earth Mound or Berm Closure (Storage)

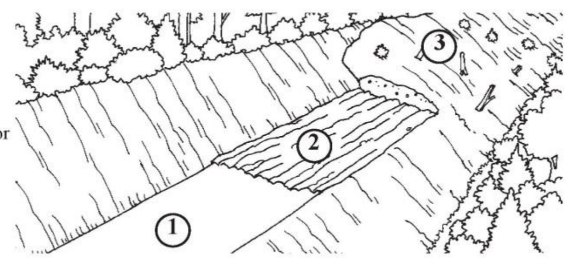


c. Decommissioning - Permanent Road Closure with Surface Ripping or Subsoiling and Seeding for Revegetation, but Keeping Most of Road Template (Shape).

(1) Road template before obliteration.

(2) During obliteration, old road is scarified and refilled by pulling back the fillslope or importing fill material.

(3) Final obliteration, with filling and recontouring to the original natural topography, followed by revegetation.



d. Road Obliteration

The range of options typically used to close a road, either permanently or temporarily.

If interim road use has been completed, such as after logging or mining operations, roads should be temporarily closed, put in storage, or decommissioned in order to protect them from erosion during the period that they are not being used. **Temporarily closed roads** should be blocked with a gate, barricade or berm to keep traffic off the road but drainage crossing structures should be maintained. The road surface should be reshaped for good drainage and stabilized with water bars and possibly scarified, seeded and mulched. Permanent drainage structures such as culverts and ditches will require periodic cleaning. Use of road closure and storage techniques and routine maintenance after operations are completed will protect the road investment until it is needed in the future.

Permanent road closure (decommissioning) involves blocking the road, removing all drainage crossing structures and fill material, and stabilizing the road surface. This is commonly accomplished by breaking up the road surface (scarification), then seeding and mulching, so that the road will naturally be revegetated over time. Cost of this work is relatively inexpensive, most environmental damage from the road is eliminated, and the basic roadbed shape is still in place in case the road is ever reconstructed in the future.

Road closure by **obliteration** is where the roadbed is totally eliminated and the ground is restored to its natural terrain shape. All drainage crossing materials are removed, the ground is reshaped, natural drainage patterns are restored, ideally including subsurface groundwater flow patterns, and the area is revegetated. It is particularly important to remove all fill material that has been placed into drainages, such as the culvert backfill material. These relatively expensive measures are ideally used in sensitive areas such as parks or reserves, near recreation areas, or near streams and lakes. These measures are very effective to remove all traces of a road and eventually restore the area to a pre-road natural condition. However, because of high cost, simple road decommissioning is most cost-effective for road closure, and thus is most commonly used.