FPInnovations

Erosion and sediment control practices
for forest roads and stream crossings

A practical operations guide

Advantage Vol. 9 No. 5

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Erosion and sediment control practices for forest roads and stream crossings

A practical operations guide

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Keywords

Erosion, Sediment control, Forest roads, Water crossings, Stream management, Riparian zone management.

Foreword

What this handbook is

This handbook is a compilation of erosion and sediment control practices aimed at aiding the forest industry, and includes background information to support such practices. These practices are often termed Best Management Practices (BMPs). The handbook will offer guidance for erosion prevention and sediment containment along forest roads where the driving forces are rain and moving water; erosion from wind and mass wasting processes will not be covered.

What this handbook is not

The handbook will not cover the installation details of the erosion and sediment control techniques presented. Installation techniques can be found in various publications listed in the *Suggested reading* and *References* sections. This handbook is not a substitute for keeping current with relevant provincial and/or federal legislation or municipal by-laws.

Who the handbook is for

The handbook is aimed at forest road construction crews and their supervisors. Environmental monitors may also find the handbook useful, as well as planners who incorporate erosion and sediment control into their planned activities.

The issue

The focus of this handbook is on soils that have been exposed due to forest road building activities, while the main issue is preventing exposed soils from eroding at unacceptable levels, as well as containing sediment to help prevent it from reaching streams and water bodies.

The problem

When sediment enters a stream it can degrade the water and habitat quality of the stream. Erosion along ditchlines can jeopardize road stability and hinder the function of culverts and cross drains. Erosion of the soil around abutments at bridge crossings, or the fill at the inlet or outlet of a culvert, can cause these structures to fail.

Solutions and best management practices

The handbook will guide the user to solutions through the implementation of best management practices. The overriding statement will always be "*address erosion before it becomes a source of sediment.*" The primary objectives are to maintain existing ground cover where possible, replace ground cover where soils are exposed, and contain sediment from eroded sites.

How the handbook is organized

Section 1: Introduction, planning, and riparian area management introduces background information, and discusses erosion and sediment control plans and riparian area management. *Section 2: Principles and practices for erosion and sediment control* discusses the fundamental issues and techniques for erosion and sediment control. *Section 3: Practical applications for forest roads and water crossings* discusses how specific practices can be applied to the construction of forest roads and water crossings. The *Glossary, Suggested reading,* and *References* sections provide additional information and resources.

Section 1. Introduction, planning, and riparian area management

Introduction

This section provides background information which will introduce the basis for concepts discussed in other sections.

What is erosion and sediment?

Erosion is caused by rain, moving water, wind, or gravity displacing soil, loose rock, or dissolved portions of rock. Sediment is the fine particles of eroded soil and rock that have been moved and deposited away from their original location. Erosion is a natural process but the accelerated erosion caused by human activities may reach unacceptable levels. Five common types of water-caused erosion are identified in Figure 1.

The magnitude of raindrop erosion is highly under-estimated.

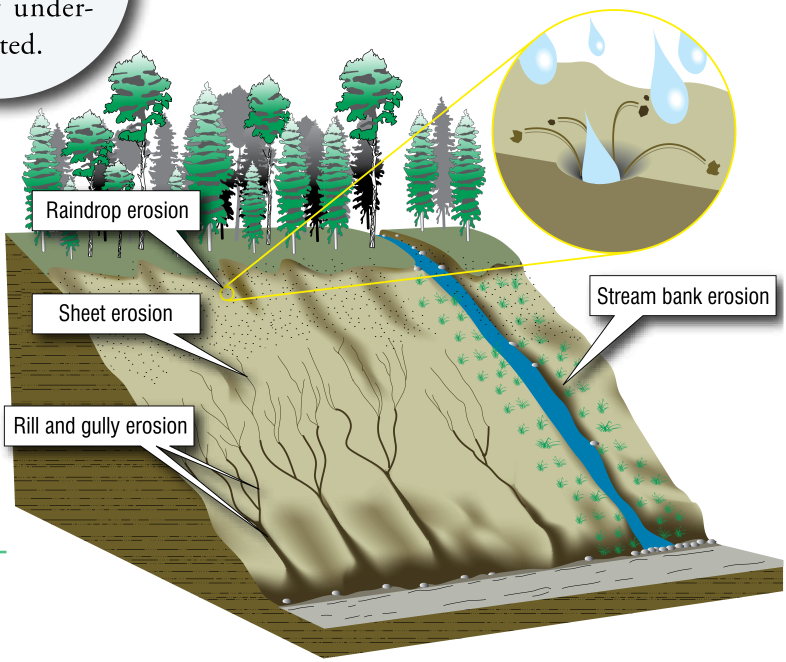
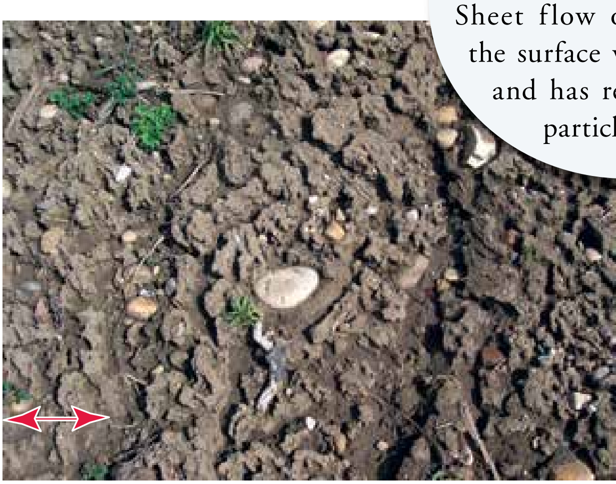


Figure 1. Types of erosion along a cutslope and a stream channel.

- **Rain splash/raindrop erosion:** Soil particles are dislodged and moved by the force of raindrops. The amount of this erosion depends on the duration and intensity of the rain, the transfer of the raindrop's kinetic energy to the soil, and the structure of the soil itself. As soil particles become dislodged, they are vulnerable to movement in a process called sheet erosion.
- **Sheet erosion:** The overland and uniform flow of water transports soil particles that have been dislodged by raindrops or by saturated surface flow. See Figure 2 for an example of raindrop and sheet erosion.
- **Rill erosion:** Runoff from sheet erosion merges into a single flow path, and starts to cut into the soil to form a rill. Rills are typically orientated straight up and down a slope (Figure 3). If left unchecked, rills will continue to widen and deepen.
- **Gully erosion:** Gullies form where rills merge together or where a single flow path has grown into a gully (Figure 4). Action should be taken once rills are formed because gullies can be challenging to repair.
- **Stream channel erosion:** Occurs along the stream bed during bedload movement, and along the stream banks due to undercutting and re-directed flows.



The energy and impact of raindrops has dislodged soil particles. Sheet flow occurred once the surface was saturated, and has removed soil particles.

Figure 2. View of soil surface eroded by raindrops. Arrow indicates a distance of approximately 2.5 cm.

The poor germination and growth of the reclamation seed mix results in lack of cover and eventual rilling. The rills abruptly disappear as they reach the fibrous matting along the ditch. This site should be aggressively seeded with an appropriate reclamation seed mix for the area; mulches, fibrous matting, fertilizer, or logging slash can all aid in the establishment of the seed.

Figure 3. Rills formed along a fillslope showing orientation predominantly straight downslope.

This gully has formed near a curve along a forest road. The cobbles lining the bottom of the gully have been exposed during the erosion. The gully will continue cutting into the soil until it reaches a resistant layer or until the natural cobbles lining the bottom prevent further erosion. Preventing concentrated flows from entering the gully will help stop it from growing larger. Early response to rill formation and attention to concentrated flows can help prevent gullies from forming.

Figure 4. Gullies are deeper and wider than rills.

Know the law

Knowing the laws governing and/or affecting your work is imperative, as is having a good understanding of how these laws are enforced and which agencies enforce them. Each province and municipality has its own set of laws. The *Fisheries Act, Navigable Waters Protection Act,* and *Species at Risk Act* all contain federal legislation and regulations that may be applicable to your worksite.

Identifying soils

Identifying the soil texture at your worksite and knowing its erodibility risks will allow you to prepare an appropriate erosion control plan. The soil particle size will dictate the feasibility of sediment control through containment systems; for example, clays require a longer time in detention to settle than silts or sands and constructing an appropriate system may not be possible at some sites. Table 1 gives practical examples of soil particle sizes for coarse fragments and fine earth. Typically very few erosion control issues occur with boulder and cobble-sized material; the fine earth particles pose an erosion hazard and require attention.

Table 1. Size range of coarse fragment and fine earth particles

Soil category	Common name	Example of size[a]
Coarse fragment	Boulders	Larger than bowling ball
	Cobbles	Grapefruit
	Gravels - coarse	Orange or lemon
	- medium	Grape or pea
	- fine	Rock salt
	Sands - coarse	Sugar
	- medium	Table salt
	- fine	Icing sugar
Fine earth	Silts Clays	Not visible. Use “feel” test to distinguish between silts and clays.

[a] Examples taken from B.C. Ministry of Forests (2002).

Table 2 expands the fine earth component and shows the increased risk of erosion by soil texture.

The two smallest grain particles in the fine earth category, silts and clays, require a "feel" test to distinguish between them. Some common field tests (Table 3) can be performed to determine the textural class of a soil.

Measuring slopes

Table 4 illustrates the three common terms used to describe slopes. Slope length and steepness have a direct effect on the erosion potential on a site.

Table 2. Relative soil erodibility for fine earth portion of soil[a]

Surface soil texture	Risk of water-caused erosion
Very fine sand	
Loamy very fine sand Silt loam Very fine sandy loam Silty clay loam	Higher ↑
Clay loam Loam Silty clay Clay Sandy clay loam	
Heavy clay Sandy loam Loamy fine sand Fine sand Coarse sandy loam	Lower
Loamy sand Sand	

[a] Adapted from Wall et al. (2002).

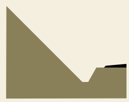
Table 3. Field test to help determine soil textural classes[a]

Criterion	Sand	Sandy loam	Loam[b]	Silty loam	Clay loam	Clay
Individual grain visible to eye	Yes	Yes	Some	Few	No	No
Stability of dry clods	Do not form	Do not form	Easily broken	Moderately easily broken	Hard and stable	Very hard and stable
Stability of wet clods	Unstable	Slightly stable	Moderately stable	Stable	Very stable	Very stable
Stability of ribbon when wet soil rubbed between thumb and fingers	Does not form	Does not form	Does not form	Broken appearance	Thin, will break	Very long, flexible

[a] From Brady (1990).

[b] The soil textural class of loam is comprised predominantly of silt.

Table 4. Common expressions of slope

Percent	Slope ratio[a]	Degree[b]	
100%	1:1	45°	
50%	2:1	27°	
33%	3:1	18°	
25%	4:1	14°	
10%	10:1	6°	

[a] Defined as run (horizontal distance) over rise (vertical lift).

[b] Rounded to whole number.

Predicting soil loss

The Revised Universal Soil Loss Equation for Application in Canada (RUSLEFAC) generates the predicted soil loss due to water erosion from a disturbed area of land, and is most applicable to croplands. For forest roads, the equation is useful when comparing different treatments to predicted soil loss. The equation identifies several conditions that can affect erosion, including climate (rainfall), soil (erodibility), topography (slope length and steepness), vegetation or crop (soil cover, rooting, and stalk influence), and land use practices. See Wall (2002) for a complete description of RUSLEFAC.

Predicting erosion hazards

Table 5 presents the level of erosion hazard based on soil properties and slope. This table is useful when preparing an erosion and sediment control plan and deciding which areas require attention. Downslope or downstream values (aquatic habitat, community water intake, etc.) should be weighted appropriately when considering the overall risk in an area.

Roads are a sediment source

The primary sediment source in the forest environment is forest roads, either from events originating from a road, or from erosion of exposed soils within the road prism. The road prism is the width of soil exposed, including the cutslope, road surface, ditches, and fillslope. Road drainage is critical and structures need to be properly designed, located, and maintained to prevent extensive erosion. Three different levels of erosion and the management implications are shown in Table 6. Thompson (2001) suggests that threshold erosion levels of 4 m^3/km and 10 m^3/km are significant. These levels would correspond with the division between low to medium, and medium to high in Table 6. Eroded volume can be estimated by the width, depth, and length of a rill or gully.

Table 5. Detailed erosion hazards (low, moderate, severe) by soil type and slope[a]

		Slope (%)														
Texture	**Material**	**0–5**	**5–10**	**10–15**	**15–20**	**20–25**	**25–30**	**30–35**	**35–40**	**40–45**	**45–50**	**50–55**	**55–60**	**60–65**	**65–70**	**70–75**
Coarse	Sandy gravels	L	L	L	L	L	L	L	M	M	M	M	M	S	S	S
	Gravelly sands															
	Gravels															
Moderately coarse	Sand	L	L	L	L	L	L	M	M	M	S	S	S	S	S	S
	Loamy sand															
	Sandy loam															
	Fine sandy loam															
	Gravelly sandy loam															
	Gravelly loamy sand															
Moderately fine	Loam	L	M	M	M	S	S	S	S	S	S	S	S	S	S	S
	Silt loam															
	Silt															
	Sandy clay loam															
	Clay loam															
	Silty clay loam															
Fine	Sandy clay	L	L	M	M	M	S	S	S	S	S	S	S	S	S	S
	Clay															
	Silty clay															
	Heavy clay															

[a] From Carr (1982).

Table 6. Appearance and management implications of erosion levels[a]

Erosion level	Management implications	Visual representation
Low: barely visible	• None, routine maintenance	
Medium: minor rilling	• Will require corrective action	
High: severe rilling and/or obvious ditch erosion	• Will require immediate corrective action • May cause trafficability problems • Accumulated sediment may cause malfunction of drainage structures	

[a] Text adapted from Thompson (2001).

Planning

Planning for erosion and sediment control during road building activities should be part of all phases from field layout to phasing and scheduling of machinery. Walking a proposed road location with the machine operators will help ensure that plans are fully understood (New Brunswick Department of Forest Management 2004).

Control vs. repair

It is less costly to plan ahead and identify techniques to control erosion than to conduct repairs once the erosion has started. This is particularly true at watercourse crossings, when riparian vegetation is disturbed and removed. Including an erosion and sediment control plan can save time and effort in the long run.

Temporary vs. permanent roads

An erosion and sediment control plan should be in place regardless of road class or length of use. The risk of erosion and sediment movement is common to both temporary and permanent roads. Temporary winter roads predominantly made of snow also have erosion and sediment control issues, especially at watercourse crossings.

Field identification

During field layout of a proposed road and associated crossings, personnel should document areas with a high likelihood of erosion in their field notes. Proposed road placement can then be weighed against the hazards present. Areas at risk should be identified on field maps and plans should be made to control erosion from these sites. Streams and lakes, in particular, will need to be marked and buffered. Long continuous side slopes without benches or breaks pose a high erosion hazard once the right-of-way is felled.

Key areas to identify during field layout include:

- watercourse crossings including dry stream beds; note if fish were observed
- lakes, marshes, seepage, spring sites, etc.
- known plant species as field indicators of wet sites including horsetails, skunk cabbage, cow-parsnip, devil's club, etc.
- beaver activity
- gully crossings or deep draws
- also note predominant surface soil texture, obvious outcrops, or pockets of soil type

Erosion and sediment control plan

The complexity of an erosion and sediment control plan will depend on the size of the activity and the known hazards within the area. It may be as basic as following standard operating procedures or as complex as incorporating an overlay on a crossing design. A plan prepared before right-of-way felling may need to be modified if felling shows previously unknown erosion concerns. Where site plans, detailed designs, and planning or location maps are produced to aid in road construction, an erosion and sediment control plan can be shown as an overlay (Figure 5). Where a written plan is not required, a hand-sketched plan is a good technique for communicating and implementing the appropriate actions during construction. Once a plan is in place, the areas identified for erosion or sediment control may need to be marked in the field. Monitoring and maintenance of erosion and sediment control practices allow for continuous improvements (Saskatchewan Highways and Transportation 2007).

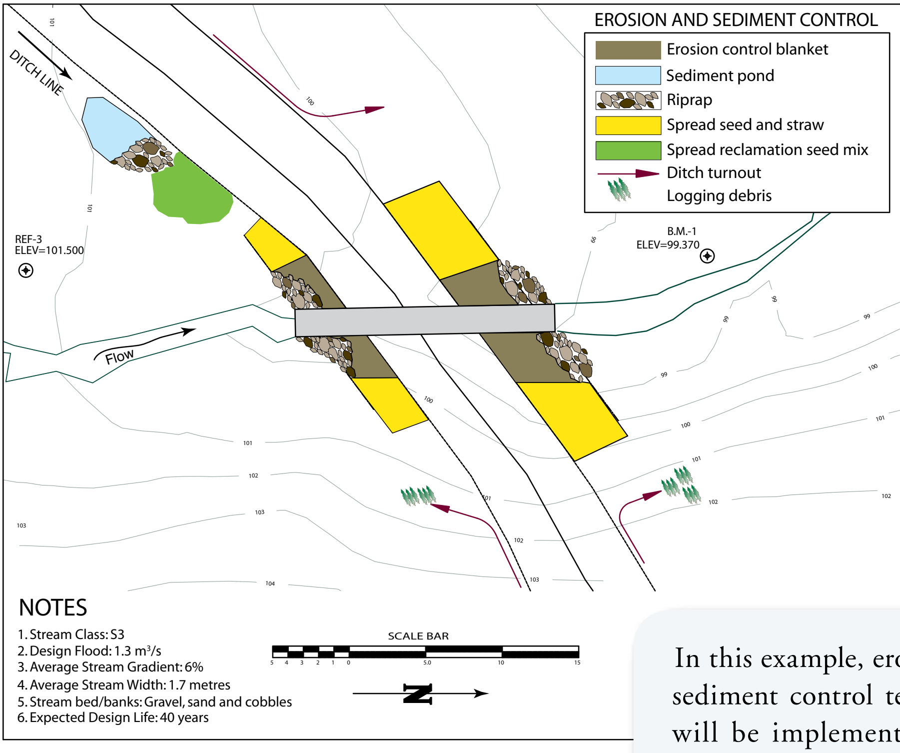


Figure 5. Example of incorporating aspects of an erosion and sediment control plan within a site plan for a culvert installation.

> In this example, erosion and sediment control techniques will be implemented along the fillslope above the inlet and outlet of the culvert, and along the four ditchlines entering the crossing location (these are typically six areas of concern at culvert crossings). Straw mulch, reclamation seed mix, turned out ditches, sediment trap/basin, and riprap are all incorporated into this plan.

When large areas of soil are expected to be exposed, they should be identified as erosion hazards during planning. Figure 6 shows a felled and cleared right-of-way along a newly built road. This area poses a high potential hazard while road work is on-going, primarily because of the fine soils and amount of exposed area without cover protection. The use of wet-weather shutdowns is an excellent management practice included in many standard operating procedures.

During this phase of the operation the planner should expect this level of exposed soil, and deem it to be a high hazard until the running surface has been capped and the cutslopes have been protected with a cover. Prolonged wet weather would cause high erosion from the exposed soils, and a wet weather shut-down may be appropriate. Later, this road should look like that in Figure 7, with good cover along the sides and a running surface that is less susceptible to erosion (capped with gravel).

Figure 6. Newly built road showing exposed soil and a cutbank and running surface vulnerable to erosion.

Straw bales have been placed in this ditchline to lessen ditchline erosion. The reclamation seed mix contained a clover species that fixes nitrogen in the soil. It appears the clover is slowly giving way to the ingress of native vegetation. Regardless of reclamation seed mix, the high erosion potential at this site when it was first constructed (similar to Figure 6) has been successfully addressed.

Figure 7. Well covered ditchline and cutslope along older road.

Phasing

After the vegetation has been disturbed during road construction, erosion can be reduced if the various phases of construction are conducted as closely as safety and machine availability allows. For example, apply a surface to a newly built road as soon as possible. An aggregate surfacing material helps to lessen the erosive forces acting on the road surface, and therefore also helps to keep material in place (Figures 8, 9, and 10). Phasing construction operations is a cost-effective erosion and sediment control practice.

Surfacing material for the running surface of the road should be delivered and applied as soon as possible to prevent erosion. While felled trees remain on-site, the erosion potential is lower due to ample cover over the soil (far side of draw). Once the trees have been removed and road building activities begin (near side of draw), the erosion hazard increases.

Figure 8. View of a newly built road showing right-of-way felling on far side of the wetland/stream crossing.

After delivering and placing this first lift of surfacing material, the trucks and heavy equipment travel on a protected running surface. This first lift also offers some erosive protection against rainfall impact and surface sheet flow.

Figure 9. Newly built road with initial surfacing aggregate to satisfy immediate erosion hazards during construction.

This is an excellent example of multiple phasing. Two surfacing lifts were conducted over the construction period. The first provided immediate protection during construction, and the second gave longer-term protection. The road building crew delivered and placed the slightly more angular aggregate in the first lift in an attempt to keep the material from "sinking" too rapidly. The material in the second lift was slightly rounder in form. Note that the banks have been hydroseeded for erosion control.

Figure 10. Same section of road as Figure 9 after second application of surfacing aggregate to further reduce erosion hazard and prepare surface for more traffic.

Communication

Communicating with the regulatory agencies early in the process will ensure valuable feedback and approval in a timely manner. Communicating the erosion and sediment hazards and control techniques to the field crew early in the process will help to ensure the intended precautions are understood and implemented. Regularly scheduled meetings, such as tailgate sessions, between the supervisor and crew are an excellent means to address issues during a construction project. Mistakes made during construction with respect to exposed and disturbed soils are time consuming and costly to repair.

Riparian areas

Riparian areas are the last line of defense against sediment entering a watercourse; when intact, they help protect water quality by maintaining stream bank and stream channel stability, and offer a filtering function for sediment-laden water arriving from upland areas. Riparian areas are among the most diverse areas found within the forest ecosystem.

Buffers

Establishing buffers: Forest management activities, including road building near streams, lakes, marshes, and other water holding areas should promote water quality and preservation of riparian vegetation. This is best accomplished by establishing a buffer of intact vegetation and riparian terrain characteristics (downed woody debris, remnant overflow channels, terraced floodplains, etc.). The vegetation and terrain characteristics together filter sediment and protect against erosion at the interface between the water body and its banks (Figure 11).

The buffer must be wide enough to support many attributes including those to promote the slowing of overland flows and the subsequent deposition of sediment. The vegetation acts as a filtering agent as does downed woody debris. Hand-placed logging slash can increase the roughness within the buffer, essentially increasing its filtering capabilities. Buffers also give numerous aquatic and habitat benefits.

Figure 11. Riparian area around small remote lake showing timber harvesting activities in the background.

Buffers at stream crossings: It is good practice to narrow the width of the right-of-way felling when approaching a stream crossing (Figure 12). This allows the riparian vegetation to be left adjacent to a greater length of the stream than when the clearing width is maintained through the crossing location. The remaining riparian vegetation will lessen sediment delivery to the stream at the crossing.

No buffers: Where forest roads parallel a water body and are devoid of riparian vegetation, the erosive forces acting at the interface of the road and water body should be addressed. The practice of building roads immediately adjacent to streams or lakes is no longer common, but can be encountered along older roads. Figure 13 shows aggressive use of aggregate (rip rap) to help prevent erosion within what would have been the riparian area.

By narrowing the right-of-way clearing and leaving more intact riparian area adjacent to the stream, the erosion along the stream bank and sediment delivery to the streams will be reduced. Depending on the road class and required sight-lines for safety, the type and amount of riparian vegetation remaining will vary.

Figure 12. The riparian vegetation along the stream has been left immediately adjacent to the log-stringer bridge.

This short section of an older road required aggressive armouring to ensure that the stream did not continue to erode the road fill. New roads should not be built adjacent to streams like this. Removing the riparian vegetation adjacent to the stream also removed the living roots which would have given strength to the original stream bank.

Figure 13. Aggressive aggregate armouring of older road adjacent to river with no riparian area remaining.

Habitat and habitat quality indicators

The location for a road to cross a watercourse and the potential disturbance to the stream, stream banks, and vegetation must be assessed when planning and locating the road. The potential for sediment to enter a stream during construction of a watercourse crossing can be high due to land-clearing activities and the close proximity of equipment to the stream. Sediment can have a negative effect on fish depending on the amount and duration of exposure (Ward 1992). Crossing locations need to take into account the fish, required habitat, and quality of the habitat at the crossing site. Crossings over highly sensitive sites with a high potential for negative impacts should be avoided. A risk management framework has been developed by the Department of Fisheries and Oceans to offer guidance for assessing risk (NRIA-DFO 2006). At all crossing locations, erosion and sediment control measures should be planned in advance and communicated to all those involved with implementation. An environmental monitor can be used to ensure erosion and sediment controls are in place and functioning.

Section 2. Principles and practices for erosion and sediment control

Preventing erosion: ground preparation and cover

One of the key strategies for preventing erosion is to keep the amount of exposed soil to a minimum and to maintain the ground cover where possible. If soils are exposed, a cover should be established quickly to reduce the effects of rainfall and flowing water. Where cover is not feasible, a roughly textured surface will help keep soil in place.

Machine operating techniques

Tracked machines can be driven up and down exposed slopes to create small terraces by the grouser imprints (Figure 14), which in turn help reduce the erosive energy of flowing water. The bottom of these terraces helps trap and hold native or applied seed. They also remain moist longer than adjacent micro-sites during dry periods, thus benefiting germinating plants.

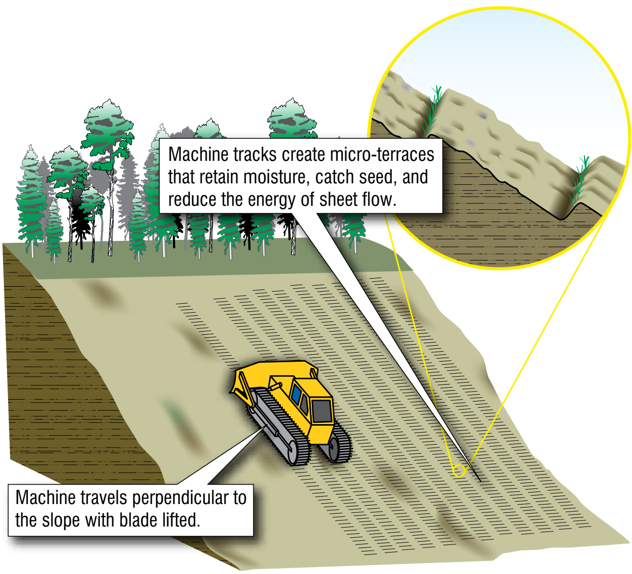


Figure 14. Tracked machinery can be driven up and down a slope to create a micro-terracing effect.

Where tracked machines are not used or where tracking along the slope is not prescribed, prescriptions and/or techniques should promote rough and irregular surfaces on exposed areas. Table 7 shows the potential impact of these practices on erosion.

Table 7. Effectiveness of construction techniques

Soil-surface condition	Relative impact on erosion
Compacted and smooth	30% greater erosion
Rough and irregular	10% less erosion
Machine tracked along contour	20% greater erosion
Machine tracked up and down slope	10% less erosion

[a] Source: Fifield (2004).

Maintaining existing vegetation

In areas with high erosion risk as identified on plans or marked in the field, equipment operators should disturb the ground cover as little as possible (Figures 15 and 16). Maintaining vegetation by reducing disturbance is the most cost-effective method of preventing erosion and controlling sediment.

Construction techniques during bridge installations should maintain the natural state of the stream banks and the associated riparian vegetation. Locating the abutments above and beyond the high water mark and sizing the structure appropriately will reduce disturbance to the site.

Figure 15. View below a recently installed bridge showing intact riparian vegetation and woody debris.

Figure 16. Undisturbed riparian vegetation below recently installed bridge. Note the use of aggregate and a geotextile fence for erosion and sediment control.

The riparian vegetation adjacent to the stream has been well protected. The geotextile fence will prevent fine soil particles from migrating downslope and entering the stream, and will function as a boundary marker to indicate soil disturbance limits to the road building crew.

Establishing live cover for exposed soils

When establishing seed or plant growth, the appropriate level of moisture and nutrients must be available. Reclamation seed mixtures are available for various geographical areas and can be modified for the target sites. For bioengineering projects, the live plant material must be harvested and stored appropriately to ensure re-growth. Adding compost to a site can increase the nutrients available for plant growth and retain moisture. Fertilizers can also be added to promote vigorous and continuous root and shoot growth. A technique known as "lop-and-scatter" where portions of non-merchantable stems are placed against the slope to provide cover, micro-terracing, and a favourable environment for seed growth can also be used to lessen erosion and promote seed germination (Figure 17). Critical sites may need to be watered during dry periods to prevent desiccation of plant material.

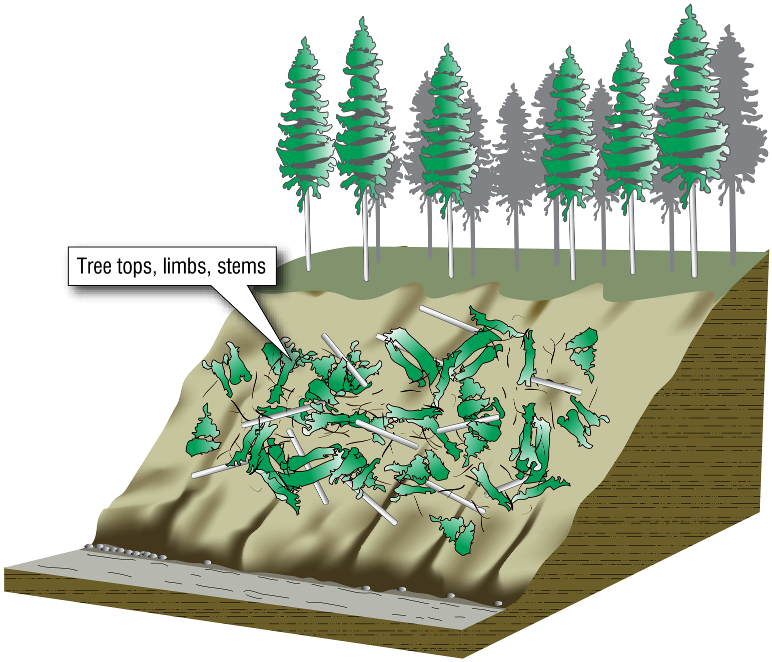


Figure 17. Schematic showing a lop-and-scatter technique.

Dry seeding: A common method of dry seeding is to apply seed, fertilizer, or other granular products using a hand-held broadcast seed spreader or a powered spreader mounted on an ATV. Unpowered two-wheeled spreaders are less common. The ATV-mounted spreader works well for large and lineal areas because they can deliver a fast and uniform application. Hand-held spreaders are better suited for small areas (Figure 18) or sensitive sites where powered vehicles are not appropriate. On very small areas, field personnel can apply a handful of seed to an exposed area. On very steep and continuous slopes (Figure 19), a tackifier should be added to the seed mixture to help hold the seed in place until seed germination.

An example of dry seeding with cereal rye, a drought-tolerant and aggressively rooting biennial which can reach over 1 m in height. This crop can be established quickly and used to help control erosion. Over winter, the crop flattens and creates an organic mat over the soil, providing further protection from erosion.

Figure 18. Dry broadcast seeding using a hand-held spreader produced a continuous cover of cereal rye.

The dry seed applied to this steep slope did not germinate successfully and much of the seed ravelled to the bottom of the slope. A tackifier can help temporarily keep the reclamation seed mixture in place on the slope. This site may be too steep to apply the lop-and-scatter technique.

Figure 19. Steep continuous slope showing poor germination after dry-seeding.

Hydroseeding and hydromulching: The principle of a hydro-application is to mix water and a fibrous material in a portable tank and pressure spray the slurry onto a target area. Hydroseeding (also known as hydraulic planting) is the application of a seed mixture to a site. Tackifiers can be added to hold the slurry in place, and fertilizers will help promote plant establishment. Hydromulches are applied to give immediate protection against erosion and to improve the seeding environment. The mulch itself may be composed of wood fibres, ground newsprint or cardboard, or a combination of these. When mulch is added to water and seed, and possibly a tackifier, the mixture can be propelled farther than seed and water alone. Exposed soils completely covered with a slurry are protected in a manner similar to an erosion control blanket (see description under *Use of inert material* on page 32). Common terms for fibrous slurries are bonded fibre matrix and stabilized fibre matrix.

Because delivery tanks are typically mounted on trucks, hydroseeding and hydromulching are predominantly roadside practices (Figure 20). Delivery hoses allow off-road applications at a distance dictated by the length of the hose and/or pressure required (Figure 21). Stand-alone or non-mounted tanks are not as common but they may be used for aerial applications in conjunction with a delivery bucket (Figure 22). A dye is often added to the slurry to ensure complete coverage without overlap.

Figure 20. Hydromulching from roadside with a truck-mounted unit (photo courtesy Canadian Forest Products Ltd.)

Figure 21. Hydroseeding with a trailer-mounted unit using a delivery hose. The hose allows the forest worker to work on or off the road and away from the trailer during application (photo courtesy Canadian Forest Products Ltd.).

Figure 22. Helicopter hydromulching can treat a large area in a short period of time. In this example, the application rates for the slurry mix were 60 kg/ha of seed mix, 300 kg/ha of slow release fertilizer, 25 kg/ha of tackifier, and 50 kg/ha of mulch.

Compost application: Compost can be applied to a site in several forms. Commonly, specialized pumps on trucks blow dry compost through a hose directly onto a site to produce a "compost blanket" over exposed soils. This type of pneumatic application can reach up to 90 m from the truck. In another form, compost "socks" are prepared by blowing compost into net tubes of various lengths and diameters. The socks can be sited to promote deposition, or skewed across slopes to divert and control the flow of upland water (Figure 23). A compost berm (Figure 24) is made by blowing compost through a hose and berm-forming apparatus (Figure 25).

Figure 23. Compost "socks" (see inset) are easily prepared and positioned on-site (photos courtesy of Top Spray, a division of Spray Lake Sawmills [1980] Ltd.).

Figure 24. A compost berm is a barrier to sediment movement, and functions like a geotextile fence to control sheet flows and promote deposition of fine soil particles (photo courtesy of Top Spray, a division of Spray Lake Sawmills [1980] Ltd.).

Figure 25. An example of the apparatus used to build a compost berm. Inset shows apparatus without the use of guide wheels (photos courtesy of Top Spray, a division of Spray Lake Sawmills [1980] Ltd.).

The compost berm has similar attributes to a geotextile fence and can be used in a similar manner. However, the compost berm, sometimes described as a "green" solution on the landscape, has several advantages compared to the geotextile alternative. Trenches or stakes are not needed, the berm does not need to be removed at the end of its usefulness, and the compost can act as a soil amendment if left in place. The microbial activity, organic material, and nutrient-retaining properties of compost make it an excellent medium for plant growth. Additives such as seed or tackifiers are easily incorporated into the delivered compost to provide an all-in-one application. Composts also hold moisture and have moderate heat fluctuations.

Live plant material: Soil bioengineering uses live plant material to prevent erosion, enhance soil stability, and capture sediment. The plant material not only has a structural function, but also sprouts and grows. The growing plants protect the soil from rainfall, help stabilize soil as roots develop, and provide leaf litter and shade to improve overall soil and growing conditions.

The plant material is often preferred as "cuttings." Cuttings are prepared for use by trimming plant stock to appropriate lengths, kept moist, protected from physical damage, and used when dormant. Willow (*Salix* spp.) is the most common species used; balsam poplar/cottonwood (*Populus* spp.) and red-osier dogwood (*Cornus sericea*) are also used. All three are pioneer species and well adapted to recently disturbed sites.

Common bioengineering structures are terraces or benches along exposed slopes. The terracing helps to reduce surface ravelling, and gives natural vegetation and seed an opportunity to become established. Wattle fences (Figure 26), modified brush layers (Figure 27), or combinations of techniques all help to reduce erosion (Figure 28).

Figure 26. A wattle fence (also known as live fascines) made with willow cuttings and rebar gives a terraced effect along a slope and shows new shoot growth.

Figure 27. Modified brush layer made of willow cuttings, wooden boards, and rebar. Non-modified brush layers, another technique, are constructed without boards, logs, or fibrous rolls to prop up the cuttings.

Bioengineering techniques can be combined to meet a project's objectives. This scar was treated with brush layers, wattle fences, live stakes, a live pole drain, tree seedlings, and grass seed. Trees at the top of the scar were felled (lop-and-scatter) to reduce erosion or failures associated with potential windfall or the pivoting motion of the trees. These trees were felled across the slope to create a terracing effect.

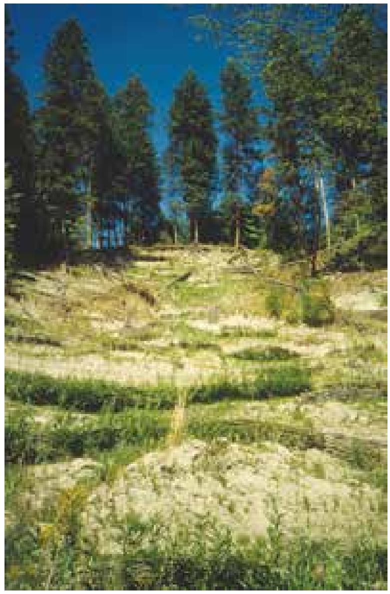


Figure 28. A ravelling scar treated with bioengineering structures.

Use of inert material

Inert materials can cover exposed soil surfaces and reduce the risk of erosion.

Rolled erosion control blankets/mats are used to cover exposed soils, usually on cutslopes and fillslopes (Figure 29), culvert embankments, and ditchlines including cross-ditches. Numerous products are available, ranging from all-natural (organic) products such as straw, wood, coconut or jute fibres, to similar compositions with polypropylene or nylon (inorganic) material incorporated within the blanket to provide additional strength. These reinforced mats are often called turf reinforcement mats.

Figure 29. An erosion control blanket placed on a fillslope.

These blankets are typically secured to the surface by pins placed at a prescribed spacing. Some products have coloured marks to indicate the required pin spacing. The soil surface should be prepared by smoothing any areas that would cause "tenting" of the mat.

Straw and crop stalks bundled in bales can be opened and the straw spread over a site as an immediate ground cover (Figure 30). This is an excellent method of providing protection against rainfall impacts, as well as providing shade and moisture retention to promote vegetation establishment. Bales are easily transported in a pickup truck and stored on-site. In case of unexpected heavy rains, stockpiled bales can be used as an emergency measure to cover exposed areas, including soil stockpiles, quickly and easily.

Logging debris and reclaimed topsoil can be spread (Figure 31) over exposed soils to create a rough and irregular surface. Branches, stems, and other woody debris are usually plentiful along recently felled road right-of-ways or harvested areas. Figure 32 shows a cutslope where debris has been spread along the upper portion but not the lower portion.

Figure 30. Forest worker spreading straw over exposed soil as an erosion control measure.

Spreading woody debris and reclaimed topsoil over exposed soils, leaving the surface rough and irregular, is an effective means of containing sediment and preventing it from migrating downslope.

Figure 31. Crawler-tractor spreading logging debris and reclaimed topsoil over an exposed slope.

The upper slope, where soil was covered with logging debris (see arrow), shows a distinct lack of rilling, and better seed germination and growth compared to the lower slope. The higher moisture content and nutrient availability provided by the debris and topsoil likely contribute to the improved seed germination and growth. The lower area with its severe rilling, smooth surface, and absence of debris may not be as favourable for seed germination due to continued soil movement, exposure to rainfall, and lack of nutrients.

Figure 32. Cutslope showing logging debris and reclaimed topsoil spread over the upper portion and severe rilling along the untreated lower slope.

Aggregate (rock) is a useful and versatile construction material, and may be used as a long-term solution to control erosion and trap sediment. Smaller aggregate can be applied to road surfaces (Figure 33) and ditchlines (Figure 34), while larger aggregate, known as rip rap, can be placed to protect stream banks and bridge abutments. Aggregate is especially cost-effective when the source (gravel pit or rock quarry) is nearby. Aggregate purchased from more distant commercial operations is more expensive, yet it remains the preferred material for erosion control at many sites. Some maintenance or re-application may be required to ensure continued effectiveness.

Where aggregate is scarce, it should be targeted for high priority sites, such as at stream crossings to prevent sediment delivery into the water course. Figure 35 shows placement of scarce aggregate above a culvert and along the approaches to a stream crossing along a newly built road. This targeted armouring technique is an example of a practice that can be shown on an erosion and sediment control plan.

Although it is common practice to place aggregate as final surfacing during road construction, the technique also doubles as a method of erosion control. The subgrade material is easily erodible, and aggregate gives protection from erosion and promotes the deposition of fine soil particles due to the increased roughness of the surface.

Figure 33. Crushed aggregate placed along a newly built road.

Aggregate was aggressively placed over a short section of road and ditchline to prevent erosion and subsequent sediment delivery to a fish-bearing stream 75 m downhill. Other erosion and sediment control measures implemented at this site include a sediment pond, cross-drain, and French drain.

Figure 34. A ditch lined with a continuous blanket of angular aggregate to prevent erosion and control sediment.

Along this newly constructed forest road, aggregate was used at each stream crossing to provide initial protection against erosion and sediment delivery into fish streams. Although the entire length of the road may eventually receive an aggregate lift, this is an example of prioritizing the use of aggregate, as well as phasing of the construction activities. Identifying high hazard areas for immediate protection is an excellent management practice and should be prescribed within an erosion and sediment control plan.

Figure 35. New road construction showing aggregate placed along the approaches and embankments of a fish-stream crossing (embedded culvert).

Chemical soil stabilization, which uses products known as soil binders or hydraulic soil stabilizers, is gaining acceptance as a method of erosion control. Polyacrylamide (PAM) is a common chemical treatment to prevent precipitation-induced erosion and enhance infiltration. The compound is mixed with water and applied to the surface of the soil. The dissolved polyacrylamide binds to surface soil particles, and promotes coagulation of finer particles. Because these larger particles are not as easily transported by water, the soil's erosion potential is reduced. Infiltration of water into the soil is also improved because more micro-pore spaces are created.

The effects of polyacrylamide on soil are temporary and repeat applications are required for longer term protection. Polyacrylamide may also be combined with treatments such as hydroseeding or hydromulching.

Containing and collecting sediment

Typically, the strategies for containing sediment promote deposition. Slowing the movement of sediment-laden water allows suspended particles to fall out of suspension and deposit on the bottom of the containment system. Settling rates for various particle sizes are shown in Figure 36. Particles that can stay suspended for a long time, such as clay, can travel a great distance from their point of origin.

When planning to manage sediment within a containment system, knowing the soil texture will help the designer determine the length of time required for sediment to fall or settle out. For sands and silts, gravity may be enough to achieve deposition within a reasonable length of time, but for clays a flocculent may be required to accelerate deposition. A flocculent added to sediment-laden water attracts fine particles to each other to form a larger particle, which then falls more quickly out of suspension.

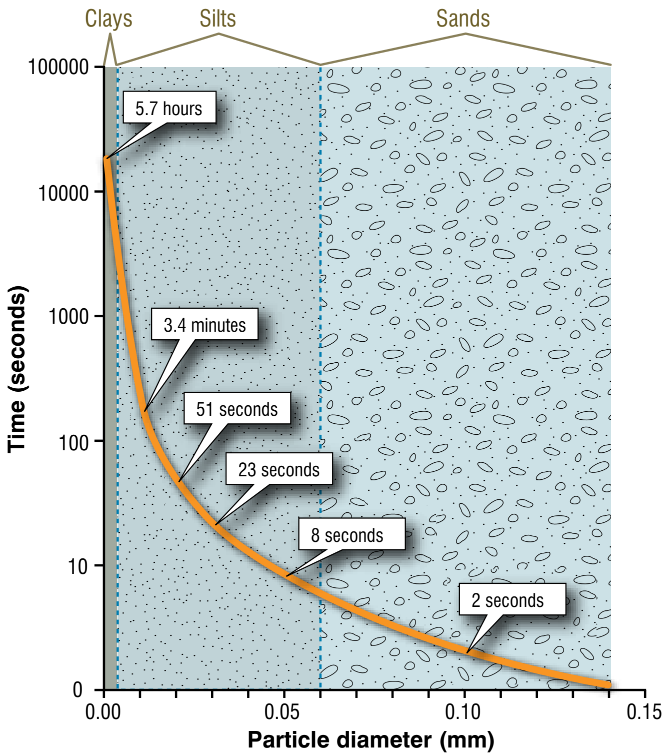


Figure 36. Logarithmic graph showing time for suspended particles to fall one centimetre through water at 0°C. The time required for mid-sized sands and silts ranges from seconds to a few minutes, whereas clays take hours. Source: Fifield (2004).

Geotextile fences

Geotextile fences, also known as silt fences, slow overland water flow and promote sediment deposition (Figure 37). Although the material used is usually a geotextile, any porous material will perform a similar function (Figure 38). Silt fences retain deposited sediment on the uphill side of the structures, and need to be maintained by removing this material, either with equipment or by hand. If silt fences are not maintained, they are likely to fail, negating any benefits they may have achieved. Silt fences are a temporary technique; once their function is completed, they should be properly removed. They are not appropriate for placement across a flowing stream (Figure 39). Floating silt barriers are better suited for instream sediment and turbidity control (Trow Consulting Engineers Ltd. 1997).

This silt fence is near failure because an excessive amount of material has deposited. Removal of the material and continued maintenance are required. The overly wide spacing between the stakes is contributing to the fence's premature failure, and additional staking should be done.

Figure 37. A silt fence made of geotextile has slowed overland flow resulting in a large amount of deposition on the uphill side.

When fences work properly they create an environment for deposition. Here, deposition was achieved but the material needs to be removed for the fence to continue functioning. The water is spilling over the top of the fence and developing a scour pool. This site needs maintenance to prevent fence failure and re-suspension of accumulated material.

Figure 38. Fence made from burlap and wooden stakes showing deposition of material on the uphill side.

This is not a preferred use for a geotextile fence. Although the water in this example was slow-moving, higher volume flows would overwhelm the fence's capacity to pass water. The base of the fence should be positioned within a prepared trench and backfilled which is not possible to do in a flowing stream. Further, the removal of the deposited material from within the channel would be difficult to do without re-suspending it.

Figure 39. A geotextile fence placed across a slow-flowing channel during a nearby culvert installation.

Geotextile is available as either a woven or non-woven fabric, and in numerous grades within these two categories. Woven fabric is often used for silt fences mainly because of its high strength properties (elongation, burst, tear, and puncture). The fabric needs to be robust to withstand the forces acting on it during and after construction. Other applicable fabric properties are flow rate and apparent opening size of the voids in the fabric. Woven and non-woven fabrics with similar grades and attributes are comparable in price.

Straw bales

Straw bales are often used as check structures along ditchlines to slow water and promote deposition of sediment (Figure 40), but they are not intended to filter sediment-laden water. Proper installation will prevent water from travelling around or under individual bales, and includes aggressive staking (Figure 41). As with any structure that promotes deposition, removal of deposited material is necessary.

Figure 40. Straw bales positioned to form a check structure and promote deposition of fines. The twine or wire used to package the bales should be left intact. The arrow points to a vulnerable location in this structure where the bales are not aligned. Loose straw should be pushed into the gap.

Figure 41. Straw bales staked to the ground as well as loose straw spread over an exposed area.

Because straw bales contain portions of a harvested crop, they may also contain residue from non-native or invasive plants. Invasive plant material, also referred to as alien plants or noxious weeds, are prohibited in many forest environments. Potential users of straw bales should consult pertinent federal and provincial legislation dealing with the transport of noxious weeds and obtain certified weed-free bales whenever possible.

Sediment pond/basin

Sediment ponds are built to allow fine soil particles to settle out from sediment-laden water, and cleaner water to exit or infiltrate into the ground (Figure 42). These ponds are also known as settlement ponds or basins. Given that soil particles settle at different rates depending on their size, ponds should be built to accommodate the length of time needed for settlement of the predominant soils in an area. Additional detention time can be accomplished by building a meandering path for water flow (Figure 43). Sediment ponds require periodic maintenance and cleaning.

Figure 42. Sediment pond partially filled with sediment-laden water built to receive flow from a rock-lined ditch. The exit to this pond has been planted with willow species; the protruding stems, root system, and leaf litter provide additional protection and increased surface roughness to the exit route.

Figure 43. A meandering flow path (see arrows) has been built within this pond using straw bales to provide a longer detention time for the sediment-laden water. Sheets of plywood could also be used to guide the water.

Ponds are often built where the local terrain does not permit a ditch turnout for delivery of sediment-laden water onto the forest floor—usually a preferred practice because minimal maintenance is required for ditch turnouts (see *Ditch turnout* on page 51). A common location for these ponds is in-line with ditches as they approach a stream crossing.

Flocculents

A flocculent is used to accelerate the deposition rate of particles suspended in a liquid. When a flocculating agent is added to silt-laden water, fine particles combine to form larger particles, which fall more quickly to the bottom of a containment system such as a sediment pond. Flocculents are available in gel or liquid form. The gel is typically packaged in a porous sack or belt and dissolves slowly when immersed in water. A sack or belt can also be positioned so that silt-laden water passes over it before entering a sediment pond, such as channeling sediment-laden water through a culvert with a flocculent bag secured within it. The sediment particles exposed to a flocculent settle out more quickly than those in untreated water. In its liquid form, a flocculent is usually sprayed onto the surface of a containment area.

Natural flocculents are made from chitosan, a product derived from shellfish. Polyacrylamide can also function as a flocculent.

Diverting flows and seepage: upland water management

Flow or seepage can cause severe rills and gullies on exposed soils, jeopardizing the integrity of forest roads. It is important to have a plan to manage these sites when they are identified in the field. Wetland and spring areas producing flows or seepage need to be marked on a map and a strategy should be identified for erosion prevention. This strategy becomes part of an erosion and sediment control plan and identifies to the road building crew the technique to manage the seepage areas during construction. Seepage water should be kept as clean as possible while preventing it from eroding exposed soils.

Building a diversion channel or berm to collect and redirect flows around vulnerable areas is less expensive than building below-ground drainage structures, such as French drains (discussed in *Subsurface water management* on page 76). Above-ground trenches should be lined or armoured (Figure 44 and 45) to prevent erosion along the flow path. Unlined trenches (Figure 46) are vulnerable to erosion and sediment transport. Berms can be built with a variety of materials, including rolled products made from straw (Figure 47), fibrous material, compost, commercial products such as Triangular Silt Dike™, or logs. Berms should be built at a slight skew across an exposed slope to direct flows to a designated exit route or path.

Collecting seepage and channelling surface flows to a single path around an exposed cutslope is a proven method for preventing erosion. The diversion channel accumulates and delivers seepage to a designated path which exits the slope along an aggregate apron. During field layout, the black spruce stand along the top of the cutbank was identified as a wet site with a high water table. Because of this, best management practices were specified in an erosion and sediment control plan (i.e., build upland water diversion) which prepared the road crew for this work.

Figure 44. Diversion channel lined with fibrous matting and aggregate check dams.

Ample amounts of aggregate are needed to build an apron thick enough to resist the forces from the anticipated flows. A short section near the top is showing signs of downcutting (see circle), and additional aggregate was placed in this area. If the downcutting were left unattended, it would rapidly develop into a deep gully. This slope has also been hydroseeded; green dye mixed with the slurry helps crews see where the slurry has been applied in order to achieve uniform coverage.

Figure 45. Same diversion channel as Figure 44 after a rainfall event showing water flowing down and through the aggregate apron.

The seepage at this site comes from impermeable clay layers intersected by the newly exposed cutbank. A diversion channel was constructed to collect seepage and protect the steep cutbank from sheet erosion. The channel should be armoured to prevent downcutting.

Figure 46. Diversion channel built to address upland seepage flows.

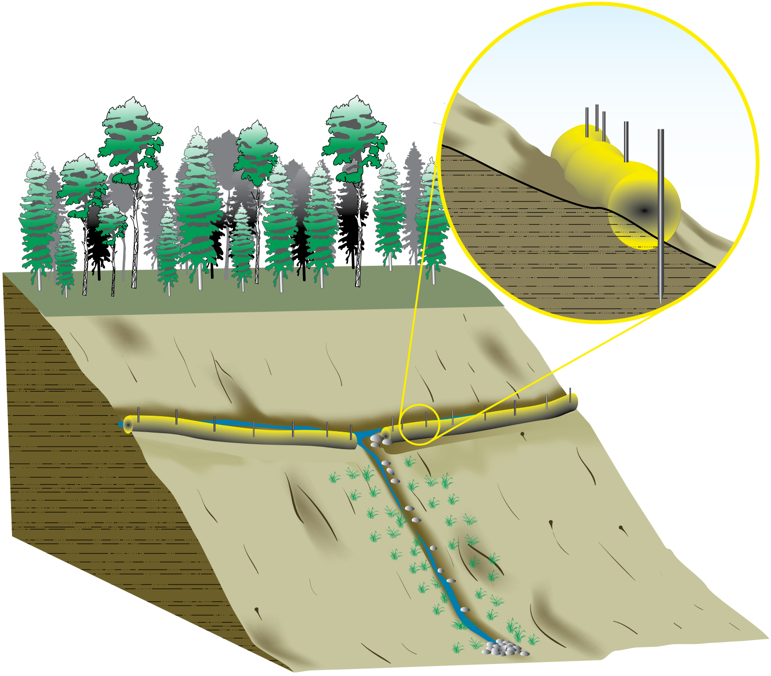


Figure 47. Schematic showing an above-ground berm built across a slope to redirect surface flows. The berm in this illustration is made from a straw roll, one of several types of above-ground structures that can be used to divert such flows.

Section 3. Practical applications for forest roads and water crossings

This section contains practical examples of erosion control and sediment containment techniques using six broad categories: ditches, road surface, cutslopes and fillslopes, culverts, clear-span bridges, and subsurface water management. Many of the techniques discussed apply the principles and practices described in Section 2.

Ditches

Ditches collect and carry road surface water, and springs or seepage from banks, to designated discharge locations. Because flows are concentrated, ditches may be downcut and degraded, and erosion and sediment movement may follow (Figure 48).

Figure 48. Ditch showing signs of downcutting and poorly functioning geotextile.

Ditch armouring

Ditches can be armoured to resist erosion and downcutting. Common armouring methods and products include reinforced matting (Figure 49), aggregate (Figure 34), and mulch/straw (Figure 50). The most aggressive armour is a permanent high-density polyethylene ditch liner. When using matting, the appropriate product must be selected for the expected flows and the length of time protection is needed. Ditches or portions of ditches may eventually become vegetated and therefore ditch armouring is most beneficial until vegetation is established.

Matting and aggregate were placed in a continuous pattern along the flow path, with additional aggregate placed as wider check structures. Aggregate of this size and shape (angular compared to round) was not available on-site and was purchased and hauled. This additional cost and effort was appropriate for this site when considering the hazards and risk associated with sediment delivery to a nearby stream.

Figure 49. New road construction showing ditch lined with fibrous matting and aggregate.

Figure 50. Straw spread along the ditch gives protection from rainfall and helps with germination of applied seed.

Check structures

Ditch check structures are used to slow the flow within a ditch, promote deposition of suspended soil particles, and reduce erosion within the ditch. The edges of the structure should extend up the bank far enough to prevent water from flowing around the structure. The middle of the structure should be low enough to allow water to flow over it, and wide enough to prevent concentrated flows. Spacing of check structures is determined by the gradient of the ditch and the height of the structure. For highly erodable soils or where there is knowledge of problematic ditches, the suggested spacing will allow the spill over area to be backwatered by the next lower check structure thereby preventing scour. Where armouring is placed in the spill-over area or where the constructed ditch is not considered problematic, check structures can be spaced farther apart. Spacing for check structures can be calculated as shown in Equation 1, or as shown in Figure 51.

Equation 1: Spacing length in cm (L) = $100 \times (H/S)$

Where H is the height of the structure in cm, and S is the slope of the ditch in %.

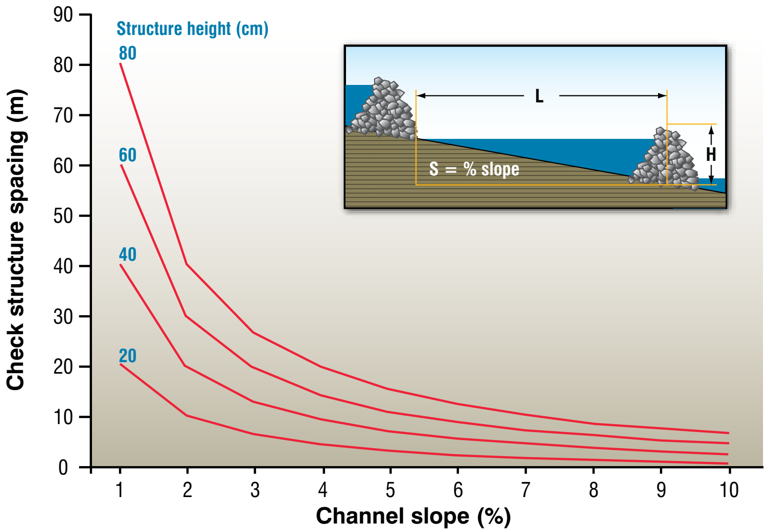


Figure 51. Graph and schematic showing suggested spacing of check structures.

Check structures can be constructed from various materials, including aggregate (Figure 52), geotextile (Figure 53), logging debris (Figure 54), or numerous commercial products (Figure 55).

Figure 52. Check structures built of aggregate placed on top of fibrous matting. Inset shows a "rock-line" built as a check structure across a ditch.

The check structures are spaced closely as an added measure to prevent sediment from reaching a stream located just past the last check structure (arrow indicates guardrail on bridge). This ditch could not be turned into the forest due to a steep and continuous bank. The steep bank has been hydroseeded and is showing good growth with continuous coverage.

Figure 53. Ditch check structures built from aggregate wrapped with geotextile.

Ditch turnout

Ditch turnouts, also known as off-take ditches, deliver sediment-laden water onto the forest floor. These are economical but the terrain will often dictate where turnout areas can be located. Where possible, ditch turnouts should be built at approaches to a stream crossing to reduce direct sediment delivery to the stream (Figure 56). Some ditches cannot be turned into the forest (as seen in Figures 53 and 57) and other techniques should be employed. Riparian areas are not a preferred location for a ditch turnout due to the close proximity to a watercourse or waterbody.

Figure 54. A ditch showing established vegetation and check structure built from logging debris (photo courtesy of Hinton Wood Products – a division of West Fraser Mills Ltd.).

Figure 55. A recently installed ditch check structure using a Triangular Silt Dike™. The foam inside the geotextile wrapping conforms well to irregular surfaces.

Figure 56. The photo shows a ditch that has been turned to direct flows into the forest, which prevents direct delivery of sediment to the stream at the bottom of the slope (see dashed line). The schematic shows a ditch turned into the forest with aggregate placed in the flow path to prevent erosion and to promote deposition of sediment.

Figure 57. A steel pipe is used to bypass ditch water (see arrow) over a stream (photo courtesy of Island Timberlands Limited Partnership).

Ditch bypass

A ditch bypass can be used where the options are limited, typically due to terrain or space limitations. The bypass allows the ditch water to cross over the stream and continue into the ditch on the opposite side (Figure 57).

Double ditching

Where clean water is seeping or flowing from a bank, a double ditch may be used to keep this water from mixing with dirtier ditch water (Figure 58). In this example, the shallower ditch with the dirty water may function well when transporting small flows, but dirty water may spill into the deeper ditch during high rainfall events. If it keeps the water sources separated most of the time, then this method can be effective for protecting water quality.

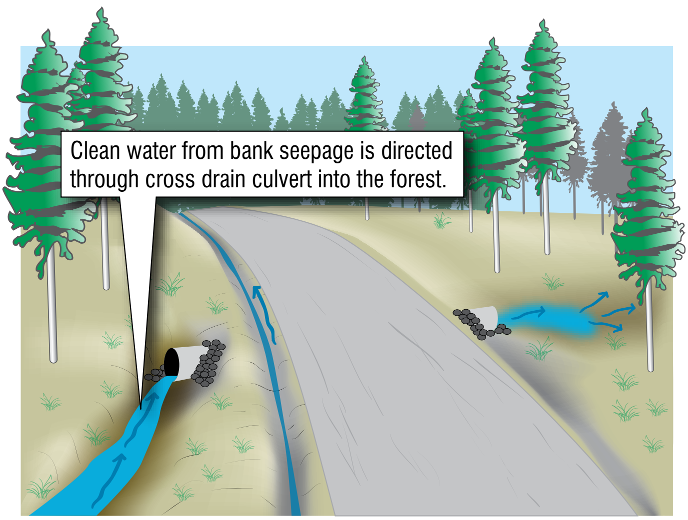


Figure 58. The use of a double ditch allows clean spring or seepage water to flow in a ditch separate from the dirty road surface water.

Ditch cross-drain culvert

A cross-drain culvert directs ditch water to the opposite side of a road (Figure 58). It is installed through a road where the ditch water can be directed into a preferred or natural flow path, or where the ditch water needs to be dispersed before descending towards a stream. The culvert should be skewed at an angle ranging from 25 to 45 degrees through the road to allow ditch water to easily flow into it. A ditch block is constructed to prevent the water from travelling further along the ditch and forces the flow into the culvert. The culvert should have a minimum gradient of 2% to ensure continuous water flow, and its length should allow the outlet to be at the natural ground level. Where shorter culverts are used and the outlet is positioned along a fillslope, aggressive armouring should be used at the outlet to prevent erosion.

Cross ditch

A cross ditch diverts ditch water to the opposite side of the road through an open-top ditch; being open also allows road surface water to enter (Figure 59).

The cross ditch needs to be excavated to a depth, angle, and gradient that allows the water in the roadside ditch to easily flow into and through the cross ditch. A ditch block is constructed to force the flow from the roadside ditch into the cross ditch. The outflow area should be armoured to protect against erosion. Cross ditches are suitable for infrequently used roads, not for main haul roads.

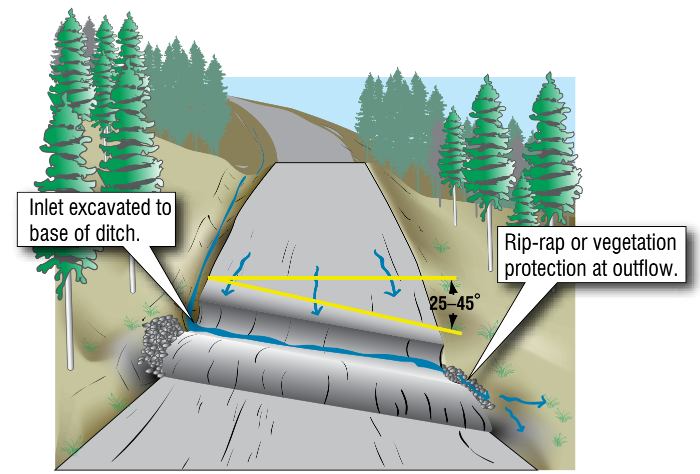


Figure 59. Schematic of a typical cross ditch showing ditch block at inlet and armouring at outlet. Signage may be required to indicate where cross ditches are used, as vehicles need to slow when passing over them.

Road surface

Erosion from forest road surfaces can be minimized with proper road building and maintenance practices. Road surfaces can be armoured against erosion using aggregate or other surfacing agents. The running surface should be compacted and shaped to shed water and keep it from accumulating in any one area; standing water will weaken the subgrade and promote the deterioration of the road. Water can accumulate in potholes and ruts and these should be repaired. Identifying and maintaining natural drainage patterns, avoiding wet and marshy areas, designing for frequent surface and ditch drainage, and using adequately sized and designed watercourse crossing structures all contribute to reducing erosion.

Rolling grade

Rolling grades, also known as broad-based dips or swales, can be constructed to direct road surface water to the low areas (Figure 60). An insloped or outsloped road surface then directs the water to a ditch or dispersal point. This practice has little effect on vehicle traffic when constructed in a gradual and shallow manner. To prevent erosion from road surface water, the approaches and lowest section of a rolling dip should be armoured with aggregate. As well, the low sections of a rolling grade, where water will exit the road, should be planned and constructed away from water crossings and riparian areas. Figure 61 shows suggested spacing for rolling grades for two broad categories of soil types.

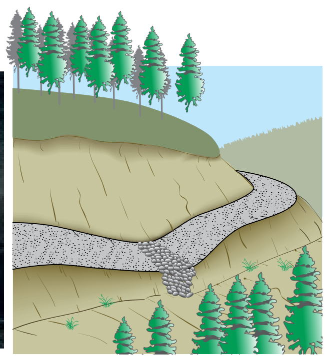


Figure 60. Rolling grades will accumulate road surface water at the lowest point, and in combination with an outsloped or insloped road surface, will shed water at that location. The road in the photo is entirely capped with aggregate rather than only through the approaches and low section of the rolling grade.

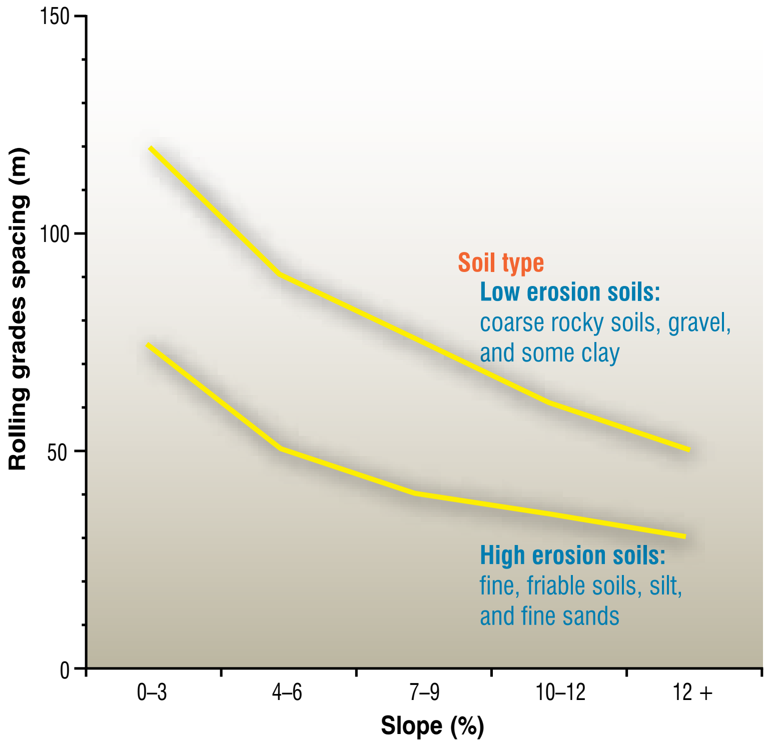


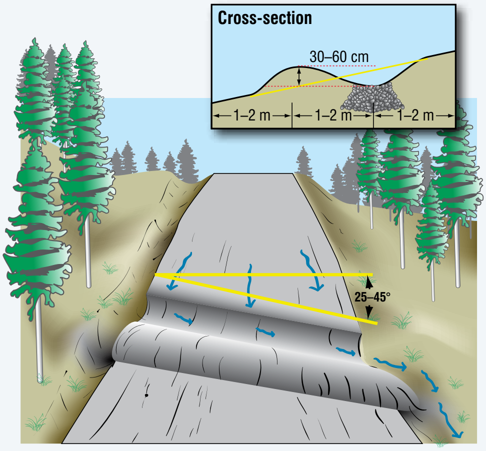
Figure 61. Suggested spacing between rolling dips. Adapted from Keller and Sherar (2003).

Waterbar

A waterbar is a shallow excavation constructed across a road at an angle to collect road surface water (Figure 62) and divert it off the road. Road surface erosion is reduced because surface flows do not travel long distances along the road. Waterbars are not suitable for main haul roads but are for low use roads. Waterbars should be skewed, typically at a 30 degree angle to the road's travel direction. Unlike cross drains, waterbars are not constructed to intercept and transfer ditch water across a road.

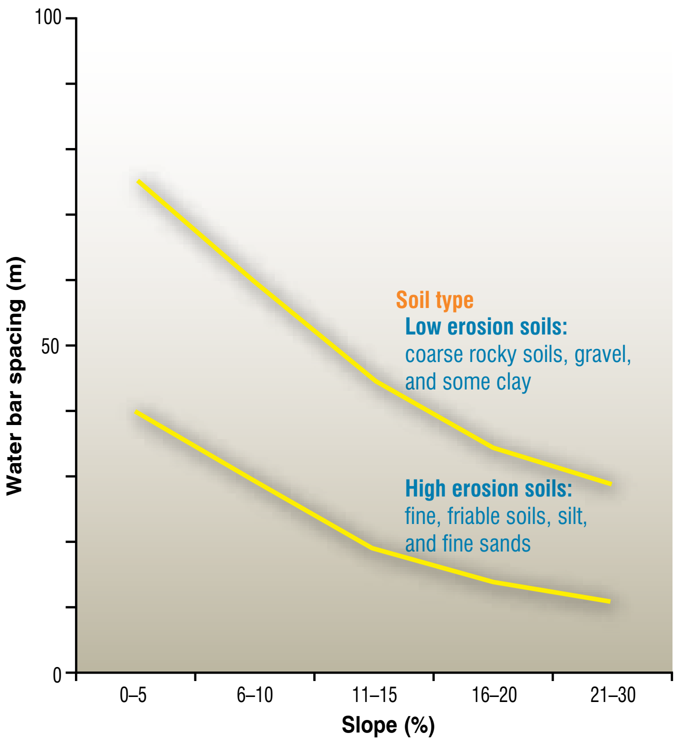
Figure 63 shows an example of waterbar spacing for low and high erosion soils. The exact location of any road surface or ditch drainage structure will be dictated by the topography of the adjacent land and the ability of these areas to receive drainage water.

Figure 62. Photo and schematic of typical waterbar.



Waterbars need to be constructed to allow vehicles to pass through them at a slow speed. Signage may be required. Often, waterbars will be armoured along their length to prevent downcutting. In the photo, armouring material was scarce so two rock lines were constructed to slow flows and prevent erosion.

Figure 63. Suggested spacing between waterbars. Adapted from Keller and Sherar (2003).



Open-top surface drains

Open-top surface drains are placed through a road to collect and direct surface flows off the road (Figure 64). These drains can be made from dimensional lumber, small logs, or any material that can be laid parallel to one another and able to accept vehicle traffic. The drains can also function as a cross-ditch drain if the inlet is designed (proper elevation and ditch block required) to receive ditch water and transfer it to the other side of the road.

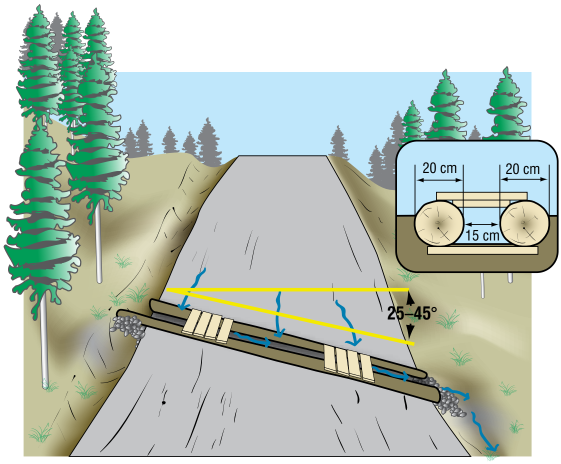


Figure 64. Open-top surface drains are placed through the road. The top section of the drain in the photo can be removed to allow for cleaning and removal of sediment. The schematic shows a typical log structure.

Deflectors

Above-ground deflectors placed across a road can prevent water from travelling along the road surface for long distances by intercepting and diverting surface flows. Deflectors need to allow vehicle traffic and be well marked to prevent the road grading crew from damaging them. Deflectors made from recycled rubber conveyor belts (Figure 65) have been used and documented (Kosicki, Gillies, and Sutherland 1997).

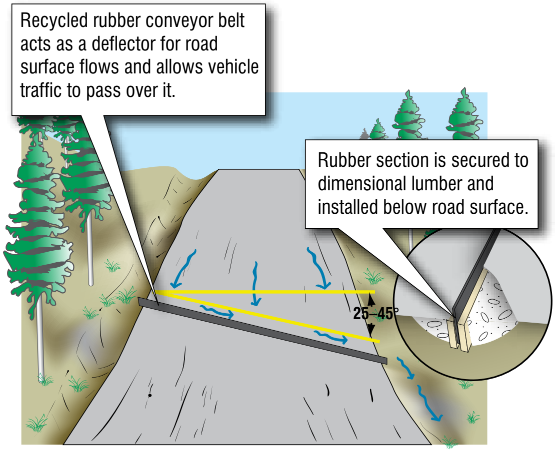


Figure 65. Recycled rubber conveyor belts used as deflectors.

Outslope, inslope, and crowned surfaces

Water that runs any distance along a road surface has the potential to cause erosion. However, the shape of a road can shed water and prevent it from accumulating and travelling along the road surface. The common road geometries to accomplish this are outsloped, insloped, and crowned surfaces. Figure 66 shows an insloped road that creates positive drainage towards the ditch, and the general view of a crowned surface. To ensure positive water flow off a road surface, the angle should be 3–5%.

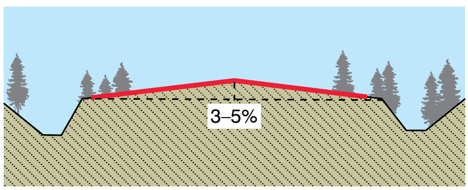


Figure 66. The photo shows an insloped road, built to direct flows towards the ditch (see direction of arrow) and away from the fillslope. The schematic shows a general view of a crowned road surface.

Roadside berms

Figure 67. A temporary grader berm is built during the grading of this road. Although this berm was pulled back onto the road, it should not be left in place for long periods of time.

Grader berms are associated with poor grading practices and are typically avoided (Figure 67). Long continuous berms along a road edge will contain water on the road, resulting in a greater potential for erosion and damage or weakening of the subgrade. Grader berms need to be breached periodically to allow water to exit. This also applies to winter roads containing snow berms or where a road is cut below the natural ground on both sides.

Roadside berms can purposefully contain water and sediment on the road surface to protect a resource from sediment delivery, such as a fish-bearing stream or community water intake. Figure 68 shows a section of road with built-up berms travelling downhill towards and past a watercourse crossing. This technique requires an erosion-resistant road surface and berm (i.e., well compacted). Berms should eventually be breached to allow water and sediment to exit the road at a preferred location.

Figure 68. Roadside berms (see arrows) used to contain water and sediment on the road surface to protect and minimize sediment delivery to a watercourse crossing (see dashed line). A controlled breach of the berm is located away from the watercourse crossing.

Cutslopes and fillslopes

Cutslopes and fillslopes are vulnerable to erosion because they are composed of loose material and often steeper than the surrounding area. A cover over the exposed soil can be established by seeding with a reclamation mix, using erosion control blankets, spreading compost or straw, or bioengineering (see *Preventing erosion: ground preparation and cover* on page 23 for a description of these methods). Numerous bioengineering examples can be found in FPInnovations' *Compendium of Watershed Restoration Activities, Techniques and Trials in Western Canada* (Kosicki, Gillies, and Sutherland 1997).

Slope drain, downdrain, or open-top flume

When water is directed onto a long continuous roadside slope where concentrated water previously did not flow, a high risk of erosion can be created. A dedicated drain pipe or flume can be used where armouring the entire flow path is not practical. The specific flow path and outflow location can then be chosen. Figure 69 shows a length of plastic pipe used to carry road source water down a steep continuous slope.

Figure 69. A flexible plastic pipe is used to carry water down a fillslope to prevent erosion along the long continuous slope.

Use of logs/terracing

Logs can be placed along a fillslope to form terraces to slow sheet flows and capture sediment. Rothwell (1983) found that logging debris placed parallel to the contour on road shoulders, ditches, and cutslopes near stream crossings reduced sediment reaching the streams. Figure 70 shows non-merchantable logs placed in this manner along a fillslope near a stream.

Figure 70. Non-merchantable logs placed parallel to each other across the contour create a terracing effect to capture sediment. The slope was successfully seeded and riparian vegetation was protected adjacent to the nearby stream (see arrow).

Culverts

When installing culverts along a newly built road, or when replacing existing structures with culverts, precautionary measures keep erosion to a minimum and sediment from entering the stream.

Armouring

Aggregate is the preferred material for armouring the inlet and outlet of a culvert, the immediate fillslope (Figures 71 and 72), and any portion of a reconstructed stream channel or bank (Figures 73 and 74).

Figure 71. Aggregate armouring placed around the inlet of an arch culvert. The larger sized material is placed to direct high flows through the culvert and protect against scour, whereas the smaller sized material is placed further upslope mainly to control erosion.

It is preferable to armour the fillslope completely to the road surface regardless of deep fills or length of slope. Where armouring material is scarce, use it wisely; in this case, the more critical areas next to the stream and around the culvert were well armoured with aggregate and the upper fillslope is without aggregate. This area will eventually be seeded and erosion control blankets will cover the exposed soil.

Figure 72. Outlet of 3-m-diameter culvert showing rounded rock used for armouring the fillslope, and a geotextile fence to prevent the migration of sediment towards the stream.

Figure 73. Inlet of culvert showing a section of newly constructed stream channel armoured with aggregate. The construction site is dewatered and the stream flow has not been re-introduced to the new channel.

Figure 74. Outlet of newly installed culvert showing aggressively armoured stream bank and a geotextile fence to prevent sediment from migrating towards the stream. The arrow indicates rot-wad structures installed for aquatic habitat diversity.

Figure 75. Smaller aggregate placed inside wire-mesh gabions.

Figure 76. Wire-mesh gabions filled with aggregate used to armour a stream bank at the inlet of a culvert.

Alternatives to aggregate armouring

There are many alternatives to aggregate armouring; a few specific to culverts follow, while others are discussed in Section 2. When the size of aggregate is smaller than desired, it can be placed inside a gabion basket and then act as a much larger armouring unit (Figures 75 and 76). Used concrete has also been utilized successfully to armour stream banks (Figure 77) and culvert outlets. Fibrous matting combined with a reclamation seed mix will protect against rainfall and sheet flows along embankments (Figure 78). A high performance turf reinforcement mat can be placed adjacent to or within a stream channel to protect against stream flows and channel erosion.

Figure 77. Used concrete keyed together to armour against stream bank erosion below a bridge abutment.

One year later the vegetation along the embankment is established and the risk of sediment delivery to the stream has been greatly reduced. Any small bare areas can be re-seeded by hand. The aggregate initially armoured the stream bank which is the most vulnerable to erosion. Eventually, through a phased approach, additional aggregate was placed above the culvert as well.

Figure 78. Before-and-after photos of an embankment above a culvert showing the use of a fibrous mat and reclamation seed mix (photo courtesy of Hinton Wood Products – a division of West Fraser Mills Ltd.).

Ditch considerations at stream crossing sites

Ditches should not deliver ditch water directly into the aquatic environment. Instead, they should be turned out to disperse sediment-laden water onto the forest floor, preferably before the riparian area. For flat and gradual road approaches, the ditch can be turned out well before the riparian area (Figure 79). Steep approaches are more challenging and a turned-out ditch may need to be armoured (Figures 80 and 81). Ditches that deliver water towards a stream will also direct sediment to the same area (Figure 82).

Figure 79. A ditch is turned out (see arrow) where the surrounding terrain allowed, rather than uphill from this location where the terrain would not accommodate it. The dashed line indicates a culvert position.

Figure 80. A steep and turned out ditchline approaching a stream was protected from erosion with geotextile and aggregate armouring.

Figure 81. Fibrous matting is used to armour a turned-out ditch against erosion, and geotextile fences were built to promote deposition of sediment. The maintenance required for the fences (removal of deposited sediment) may damage the fibrous matting.

Figure 82. A ditch that was not turned into the forest before entering the riparian area has delivered ditch water and sediment to a stream (see arrow).

Vertical alignment of road

The elevation of the road surface directly above a culvert should be higher than the approaches (Figure 83). Road surface water will then flow away from the crossing to the lower area of the road and eventually off the road, rather than be channelled directly towards a stream crossing.

Where local knowledge indicates that high flow events or freshets can overtop the road, the low area of the vertical alignment should be armoured to accommodate and withstand the overtopping. This armouring will protect the road against severe damage or a complete washout, either of which would result in massive transport of sediment.

Figure 83. The vertical alignment of the road over the culvert results in the road surface water flowing away from the crossing and stream channel.

Dewatering

During culvert installation, the construction site needs to be dewatered by diverting the stream flow. This will minimize the amount of suspended sediment leaving the site, and help to obtain the desired compaction levels for the foundation and backfill. The two most common methods for diverting a stream are forced diversions using a pump and hose system (Figure 84), and gravity-fed diversions. Gravity-fed diversions force the flow either through a flexible pipe (Figures 85, 86, and 87) or into an excavated and open trench (Figure 88). Sumps should also be prepared to collect and contain seepage from within an excavation during construction (Figure 89). Even if a stream is not flowing during the start of construction, it can still produce ample seepage once the excavation has started.

Figure 84. Outlet area along an excavation during a culvert installation showing pumped stream water re-entering the stream. A sump is used to collect sediment-laden seepage and prevent it from leaving the construction site and entering the stream.

To maintain gravity-fed flow through the diversion pipe, a trench was excavated with attention to matching the inlet elevation with the natural stream bed elevation. The elevation difference along the length of the pipe should promote flow through the pipe to the outlet. After the pipe was located in the trench, a dam made of sandbags and plastic sheeting was built to force the water into the diversion pipe.

Figure 85. Preparing to divert stream flow through a flexible pipe during the replacement of a temporary concrete slab crossing.

Figure 86. Outlet of a large diameter diversion pipe (left) showing stream flow re-entering the channel during preparation for the replacement of the perched culvert (right).

Figure 87. A Water-Gate™ dam and its diverter tunnel were used to direct stream flow around a culvert replacement construction site. A sump was still required (see arrow) to collect seepage flow from in front of the dam, typical with saturated soils below a natural stream channel.

Figure 88. An open trench diversion is used to dewater a stream channel. The plastic lining will prevent erosion of the trench itself.

Although there was no surface flow within the stream during the construction of an embedded culvert, seepage was present once the excavation penetrated below the natural stream channel. A sump was prepared at the downstream end to collect the sediment-laden water. The sump was pumped free of water as needed; the intake of the hose was placed within a bucket to help prevent pumping loose soil with the water. Sediment-laden water was delivered onto the forest floor away from the stream channel. A sump can also be prepared at the inlet if required.

Figure 89. View of seepage along an excavation during the installation of a culvert and a prepared sump at the outlet (see arrow).

Stockpile management

Often with culvert installations, excavated material is stockpiled until it is reused during the backfilling operation. This material needs to be protected from erosion because it is loose and close to a watercourse. Moderate protection techniques include building a peaked stockpile to rapidly shed rainfall (Figure 90), or placing a sediment containment structure, such as a straw roll, around the base of the pile. When severe weather events are expected, the pile should be aggressively protected against rainfall impact and sheet flows. Techniques include covering the pile with a plastic sheet or tarp, covering with an erosion control blanket, spreading straw over the surface (avoid in heavy winds), or placing logging slash over the surface.

The stockpile is well peaked for its size and has been handled twice by an excavator to move it farther from the stream and to allow room for heavy equipment to work. Operations shut down during heavy rains, and silt fences were erected to contain sediment movement. A wet weather shut-down is commonly incorporated into standard operating procedures.

Figure 90. Stockpiled material (see arrow) during a culvert installation.

Protection against beaver damming

When culverts are blocked by beaver dams (Figure 91), the greater water height can erode fillslopes or force a stream to overtop a road, both resulting in erosion and massive sediment delivery into the aquatic environment. Areas with high beaver activity should be identified and plans made to ensure proper culvert function. There are many culvert design strategies which can be used to lessen the beaver's ability to dam a culvert (B.C. Ministry of Water, Lands and Air Protection 2004). Culverts can be protected by using various types of extensions (Figure 92), grates (Figure 93), and add-ons. Two examples of commercially available products are the Beaver Proof Add On (Figure 94) that attaches to the end of culverts and the Beaverstop® which is an extension for culverts (Partington 2002).

Figure 91. Recent beaver activity at the inlet of a culvert (photo courtesy of Hinton Wood Products – a division of West Fraser Mills Ltd.).

Figure 92. An extension attached to the inlet of a culvert is intended to prevent blockage of stream flow due to beaver activity.

Figure 93. A grate attached to the inlet of a culvert is intended to prevent blockage due to beaver activity.

Figure 94. A Beaver Proof Add On attached to the inlet of a culvert has grated openings at the top and bottom of the vertical section, and is designed to prevent blockage due to beaver activity. The bottom portion of the vertical section needs to be placed into an area with sufficient depth to accommodate its length.

Clear-span bridges

During the installation of a clear-span bridge, instream work is typically not required. However, land-clearing activities associated with bridge installations raise the concern of sediment delivery into the watercourse.

Bridge deck

Sediment can enter a stream by falling through spaces or gaps in a bridge surface or by ravelling over the edge. Bridges with obvious spacing between running boards should be cleaned routinely or retrofitted with a non-gapped surface. Bridges with openings below the guardrail should also be cleaned routinely or these openings should be blocked to prevent sediment from depositing into the stream below (Figure 95). Sediment can also accumulate along the top of guardrails (Figure 96) by being projected upwards by moving vehicles. Bridge decks can be cleaned by sweeping and removing the sediment by hand (Figure 97) or by using purpose-built sweeping trucks.

Figure 95. Two bridges with similar guardrails, but one has been left open while the other has been retrofitted with steel plates to block the openings and prevent the deposit of sediment into the stream below.

Figure 96. A bridge showing sediment on the deck and on top of the concrete curb. If sand is applied during the winter, cleaning should be planned for the following spring and summer to remove this material from the deck and prevent its delivery into the aquatic environment.

Figure 97. A bridge deck being hand-cleaned with a broom, shovel, and wheelbarrow. Workers must wear high-visibility safety gear and be aware of road use during cleaning activities to avoid working on the bridge during a busy haul period.

Abutments and wing walls

Bridge abutments should be planned and placed where they are not affected by high flow events. The area below the abutments may require armouring to prevent erosion and undermining (Figure 98). Wing walls help retain road fill material and prevent material from ravelling towards the stream crossing. Some wing walls are built to protrude at a 90-degree angle to the road (Figure 99), while others are turned back towards the road at a 45-degree angle (Figure 100). The wing wall–road surface interface is vulnerable to erosion and should be monitored and well-maintained (Figure 101).

Figure 98. Riprap armouring below the abutment will prevent erosion and undermining in this area.

Figure 99. Concrete wing walls positioned at 90-degree angles to the road help to contain material.

Figure 100. This steel-pile-reinforced wooden wing wall is built at a 45-degree angle to the road.

Figure 101. Erosion can occur where abutments or wing walls end (see arrow), especially where the embankment is steep as it approaches the stream.

Vertical alignment of bridge deck and approaches

As with culverts, the vertical alignment of the road approaches to a bridge, both permanent and temporary structures, should be planned so that the highest section of road is the bridge deck (Figure 102). This will ensure that road surface water will flow away from the stream crossing. Where an existing bridge or road location does not allow the raising of the bridge deck, other road surface water control techniques need to be employed (Figure 103).

Figure 102. A permanent bridge showing the road approach at an elevation lower (see arrow) than the surface of the deck.

Figure 103. Where older existing bridge decks are located at a low elevation along the road alignment, water interception techniques should be used to divert road surface flows from reaching the deck and entering the stream. The arrow indicates the position of the open-top surface drain seen in Figure 64.

Subsurface water management

Where subsurface flows or seepage areas pose a hazard to a road (Figure 104), commonly a drain is built to direct water away from the source area. Water will tend to flow along the path of least resistance, and man-made voids and openings offer a flow path of lower resistance. Drains can be built from a variety of materials; two common materials are perforated plastic pipe (Figure 105) and aggregate (Figure 106). Either material needs to be wrapped with a geotextile to prevent fine soil from migrating and filling the voids of the flow path. Subsurface drains built in this manner are often termed French drains. Any material that will promote a lineal path for water flow can be used, including used and damaged culverts (Figure 107).

Figure 104. Road edge failure due to saturated soils from seepage and subsurface flows below the road has resulted in sediment delivery towards a nearby stream.

Pockets of stagnant surface water in a black spruce stand nearby indicated that a layer of impervious material at a shallow soil depth may be hindering water movement into the soil.

Figure 105. Construction of a subsurface drain made of perforated plastic pipe wrapped with a geotextile.

This French drain will be backfilled and completely subsurface. Subsurface seepage and flows in this area will move towards the drain (path of least resistance) and continue along the dedicated downhill path (see arrow), relieving the source area of water.

Figure 106. Same site as Figure 104 showing the construction of a subsurface drain made of aggregate wrapped with a geotextile.

Figure 107. A used and deformed culvert is wrapped with a geotextile to act as a drainage path, offering voids for water flow, similar to the use of geotextile-wrapped aggregate. This drain will be subsurface once construction is completed.

A stand pipe (Figure 108) is another type of drain, used to prevent subsurface seepage from weakening or eroding a road. The stand pipe acts as a vertical receptor for seepage and directs it to a horizontal drain to move the water away from the source area. The need for a stand pipe can often be determined once the right-of-way is felled and the soil is easily viewed for visible springs or aggressive seepage.

During right-of-way felling, this site was identified as a heavy seepage area with large pockets of clay soils along a sloped section of road. The geotextile wrapped around the perforated stand pipe allows water but not fine soil material to enter. The road fill will reach the top of the stand pipe and seepage will enter through the perforations and exit through the elbow. The elbow will be positioned to direct water (see arrow) into a French drain. The French drain exits into an open diversion channel (Figure 109) which directs the water into the forest. This technique was used on both sides of the road at this site.

Figure 108. *(above)* A stand pipe with protruding elbow is wrapped with geotextile and placed directly over a seepage site amongst an outcrop of heavy clay during road construction. *(left)* The prepared perforations along the inside of the pipe (photo courtesy of Millar Western Forest Products Ltd.).

Figure 109. Exit area of French drain showing diversion channel directing water away from the road and into the forest. The dashed line indicates the location of a fish bearing stream.

Glossary

Abutment – a structure that supports the end of a bridge.

Aggregate – granular material such as crushed rock, gravel, or sand.

Aquatic habitat – area associated with water that provides food, cover, and other critical elements for an organism's life cycle; such areas include wetlands, rivers, riparian areas, and streams.

Best management practice – a proven and recommended technique that has been recognized to be an effective means of preserving or protecting the environment, or limiting harmful impacts to it. This includes any program, technology, process, operating method, measure, or device that controls, prevents, removes, or reduces a negative outcome.

Bioengineering – the use of live plant material to perform a biological and engineering function as a result of the growth of a plant or the performance of a built structure.

Check dam – a dam constructed in a gully, ditch, or similar small watercourse to reduce scour erosion and promote sediment deposition through reduced flow velocities and increased roughness.

Coir – Coconut fibre; often used for the fibre content of erosion control blankets, mats, and rolls.

Cross drain culvert – a ditch relief culvert placed through the road to remove water from a ditch to the other side of the road.

Culvert – a conduit used for the passage of water and everything that can be found or lives in water; typically placed under a road and covered with backfill material.

Deposition – the ability of suspended sediment to drop, deposit, or accumulate at a resting place due to mechanical, chemical, or gravitational forces.

Dewatering – to remove water from an area, such as the temporary removal of a stream through a culvert installation site.

Diversion dam – a barrier built within a stream to divert the water through a different flow path.

Erodibility – the susceptibility to erosion.

Erosion – a natural or human-induced process of sediment movement where soil particles have become detached and are transported from their original location.

Fines – or fine earth, representing the silt and clay portion of a soil.

Gabion – a woven galvanized wire basket typically filled with rocks and used as an erosion-resistant structure.

Geotextile – a permeable fabric or textile made from a synthetic material, with the primary functions of layer separation, aggregate confinement, and load distribution.

Grade – the slope, often represented in percent, of a road, channel, or natural ground.

Logging debris – forest residue left behind after logging, pruning, or other forest operations; includes tree tops, branches, bark, and stumps. Also called slash.

Lop – to cut or saw branches, tops, or small trees.

Lop-and-scatter – same as lop but the debris is spread on the ground afterwards.

Riparian area – an area located next to banks of streams, lakes, and wetlands; includes areas dominated by continuous high soil moisture and any adjacent upland vegetation that influences the moister area.

Rip rap – aggregate/rock placed on soil for protection against flowing water or rainfall-induced erosion, and for increased stability against gravity-induced sloughing or ravelling.

Road prism – the area of exposed soil within the right-of-way; typically includes the entire width across the cutslope, road, ditches, and fillslope. Does not include areas within the right-of-way with intact forest soil.

Sediment – eroded material.

Sedimentation – the deposition of the eroded material.

Silt – fine soil particles associated with sediment; smaller than sand but larger than clay.

Silt fence – a structure commonly built using a geotextile material supported between stakes to slow and contain surface flow, and promote deposition of sediment within the containment area.

Tackifier – a binder for mulch; often used during hydraulic applications.

Waterbar – a combination of a ditch and berm built across a forest road to collect and direct surface flows off the road; not intended to direct ditch flows across the road.

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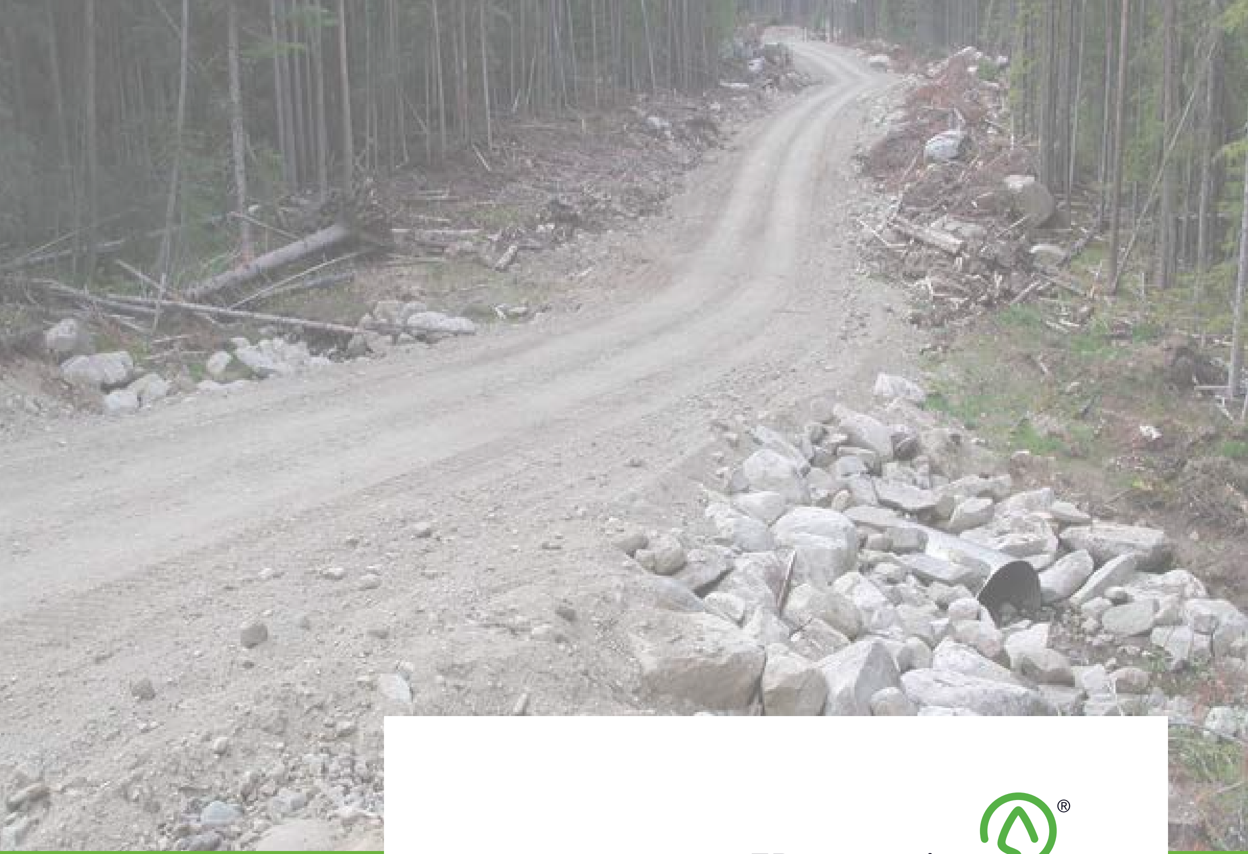

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