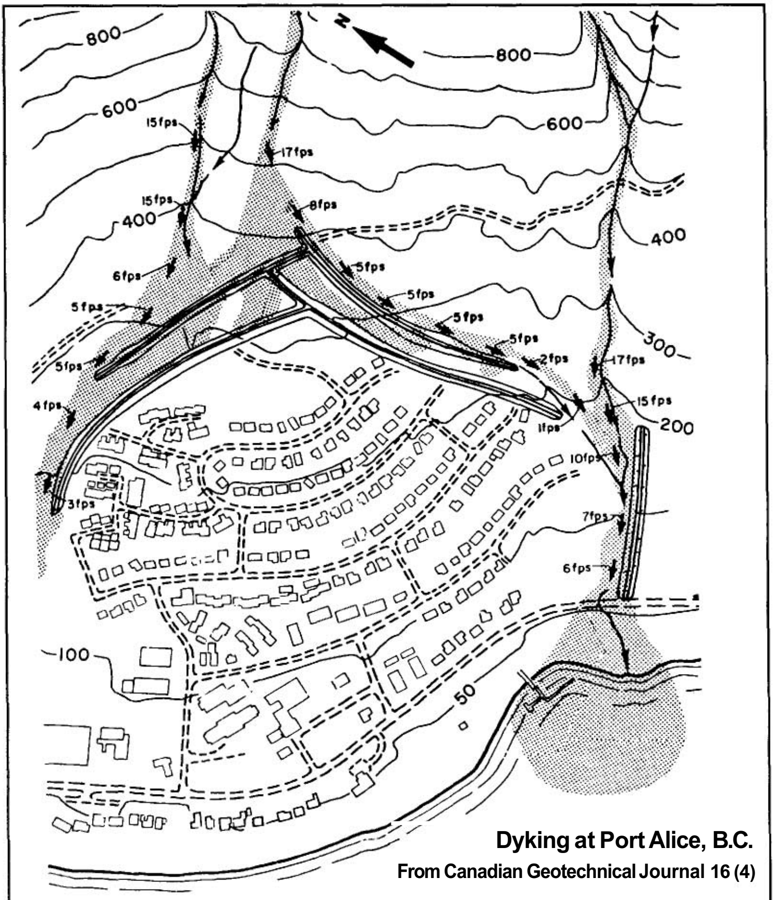
be placed beyond the mouth of the gully where flow becomes unconfined on at least one side. The reduced velocity flow should then be guided by earthfill dykes. Earthfill dykes are linear ridges of gravel used to redirect, but not stop, the debris flow. An example of a dyke protection scheme is that developed for the town of Port Alice, B.C. A double system of dykes was used, with the outside set 3 m high and the inside set 1.5 m high to catch any overtopping



Dyking at Port Alice, B.C.

From Canadian Geotechnical Journal 16 (4)

Two parallel systems of dykes deflect debris torrents around the town water or mud. The dyke system was also designed to control flooding, as streams are often diverted from their channel following a debris flow. The tail of the dyke should terminate in a natural drainageway. A layer of riprap along the toe of the dyke will protect against stream bank erosion.

Dyke protection need not be expensive. Material in the fans of former debris torrents make excellent dyke-building material. Plugged channels can be excavated and the material bulldozed up to form dykes.

Channel excavation

Channel excavation is a means of moving the depositional zone further downslope. In the depositional zone, debris flows can blanket a wide area as well as cause flooding, so maintaining the flow around a camp so that the point of deposition is farther downslope can be beneficial.

Deposition of debris flows occurs when the channel becomes unconfined and the gradient drops below about 15 degrees. An excavated channel can therefore maintain confined flow if the channel meets the following requirements:

ITS WIDTH TO DEPTH RATIO is less than approximately 5 for all flows.
IT TAPERS towards the base to allow confinement of smaller flows. Semi-elliptical cross sections are common.
ITS SIDEWALLS are not vertical.
ITS WIDTH IS SUFFICIENT to allow logs to pass without jamming.

ITS SLOPE IS UNIFORM, without sharp bends or sudden changes in cross-section shape.
IT IS LINED with a material such as grouted riprap, or possibly even loose, large size riprap.

Catch basins

A catch basin is a large excavated basin into which a debris flow runs or is directed, and where it quickly dissipates its energy and deposits its load. Abandoned gravel pits or rock quarries can sometimes be used to advantage.

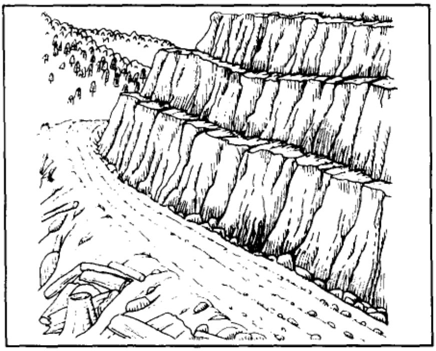
Channel excavation

3.4.2 Rock Slopes

Benches

Horizontal benches excavated into a rock face are the most effective protection from rockfall. Benches not only intercept rockfall, but by reducing tensional forces in the surface rock and reducing surface erosion rates, they also reduce the rate of occurrence of rockfall. However, they have little or no effect on potential deep-seated rock failure.

Individual bench faces can be constructed considerably steeper than the overall slope angle, as any rocks that do fall will remain on the benches. Avoid vertical bench face angles, however, as tension cracks, overhangs and excessive rockfall can result. Bench faces should be terminated at the base of weaker rock layers, fractured rock zones, or water-bearing zones. A minimum width of 4 m is recommended for the benches. All benches should have drainage ditches to divert water away from the rock slope.



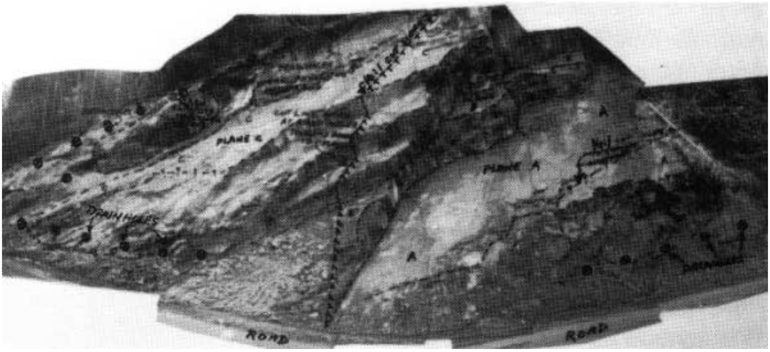
Rock benches

Scaling and trimming

Loose or overhanging blocks of rock, which may endanger passing traffic, can be removed by scaling or trimming. Scaling is the removal of loose blocks by the use of hand pry bars and small explosive charges. Trimming involves drilling and light blasting, followed by scaling, to remove larger areas of overhanging or potentially dangerous rock. The necessity of scaling and trimming can be greatly reduced with the use of controlled blasting.

The adjacent photo shows a typical scaling and trimming plan for a hazardous rock face above a mainline road. Overhanging rock is either removed or trimmed back to a stable face. Note also the large number of drainage drill holes.

Scaling operations are usually carried out by workers on ropes, using pry bars, jacks, and explosives. These operations can be time consuming and expensive (up to $200/m^3), and on active



A typical scaling and trimming plan for a hazardous rock face

slopes may need to be repeated every few years. For most forest road cuts, a hydraulic boom crane can be used for access to the rock slope, greatly speeding the rate of progress and increasing safety.

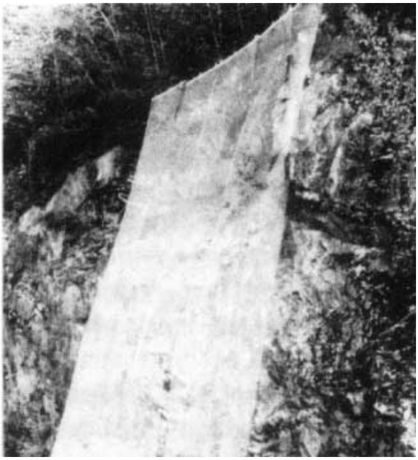
Scaling is dangerous, highly skilled work. Scaling crews should be trained and permanent employees on the road crew, not just casual labourers.

Cable and mesh

Cable lashing and wire nets are simple, economical methods of protecting a road from rockfall.

For large unstable blocks, strands of cable are wrapped around the blocks and anchored to the slope. Where the rock is too fractured to be restrained by individual cables, cable nets or steel ribs can be used to spread the points of contact.

Wire mesh is used to prevent smaller rocks, less than 0.75 m in size, from falling. The standard mesh is double-twisted gabion wire mesh or a heavy gauge chain link. The mesh is either loosely draped over a uniform rock face or bolted where the cliff face is irregular and the mesh can not make close contact with the rock. Bolting the mesh to the rock face often prevents rock from becoming dislodged in the first place, and adds to the overall stability of the slope. Wire mesh is also useful on steep bouldery soil cuts, especially beneath talus slopes.



Mesh over an unstable slope

Catch nets made of cable and wire mesh can be built to catch falling rock at the bottom of gullies and slopes. Suspended from an anchored cable, the mesh forms a flexible barrier to dissipate the energy of the falling rock, and will stop boulders up to 1 m in diameter. Catch nets can also be used in conjunction with roadside catch ditches.

Shotcrete and gunite

Shotcrete and gunite are types of concrete that are applied by air jet directly onto the surface of an unstable rock face. This is a rapid and relatively uncomplicated method commonly used to provide surface reinforcement between blocks of rock and also to reduce weathering and surface scaling. Shotcrete contains aggregate up to 2 cm in size, and is more commonly used than gunite which has smaller aggregate. Both materials can be applied rapidly by air jet, so that large areas can be covered in a short time.

The shotcrete layer bonds with the underlying rock to interlock adjacent loose blocks. The shotcrete envelope itself also has a certain tensile and shear strength, which also reinforces the rock surface. Shotcrete by itself provides no load support, however, so it is not effective against deep-seated rock instability. Structural support can be provided when shotcrete is used in conjunction with rock bolts or wire mesh. It is also useful for providing a more uniform contact surface behind steel straps or anchor beams.

Surface preparation by scaling of all loose rock and cleaning of mud from joints is necessary before the shotcrete is applied. Ideally, the surface should be relatively dry before application, although some mixtures are effective even with wet rock. Shotcrete is usually applied in two layers of 7-10 cm each. The force of the airjet compacts the concrete in place.

Weep holes must be installed at the base of the shotcrete surface to prevent buildup of water pressure in the rock. The holes can be simply drilled after setting, or short sections of plastic pipe can be inserted.

Anchors, bolts, and dowels

Anchors, bolts, and dowels are steel rods or cables that reinforce and tie together a rock face to improve its stability. Anchors are post-tensioned members used to support large blocks of rock, while bolts are shorter and support surface rock. Dowels are similar to bolts but are not post-tensioned.

Reinforcing a rock slope with steel requires specialist knowledge of rock stability analysis, of grouting techniques, and of testing procedures. Determining the orientation of the potential failure surfaces is critical to a successful anchor system. This requires a considerable degree of engineering experience.

Anchors are long pieces of steel rod or cable, grouted into a drilled hole and then tensioned. The reinforcement is therefore from both compressional force on the failure plane, which increases the frictional resistance, and shear force, which resists the downslope movement of the failing block. Anchors are usually used to support an already unstable block of rock, rather than to try to reinforce a slope to prevent instability. Anchors can also be used to reinforce retaining walls, or in some situations, even replace a retaining wall.

Bolts are short pieces of steel, approximately 1 m long, grouted into drilled holes and tensioned. They are used to reinforce the surface rock of an excavated slope. Surface rock failure is usually a result of rock rebound after excavation, or of frost action. By applying a compressive force, bolts stabilize the rock face. The head of the bolt is positioned on either a wide steel plate or a concrete pad. If weathering around the bolt head is a potential problem, then a piece of heavy wire mesh is positioned under the head. Bolts are most effective when installed immediately after excavation, before rebound starts.

Rock bolts on a rock face

Dowels are steel bars that are cemented into bore holes throughout their length. Unlike bolts, they are not post tensioned, and so only the shear resistance is increased across a potential failure plane. Also, dowels reinforce a rock slope only when the slope begins to move. They are most useful on inclined sedimentary beds where interbed sliding may occur. A useful form of dowel, especially in fractured rock, is the perfo-bolt. Perfo-bolts are steel rods encased within a perforated sheet metal liner. The liner is inserted into the hole and, pumped with grout, and then the steel rod is inserted to displace the grout through the perforations, forcing a bond with the rock.

Installation of any steel reinforcement requires good anchorage of the steel beyond the potential failure surface. The steel must have a good bond with the grout and the grout with the rock. The grout pressure must not be so high as to fracture surrounding rock, and probably should not ever exceed 15 pounds per square inch (psi).

Control over the amount of grout spreading is necessary so that it does not impede the natural drainage of the rock slope, particularly along the base of the slope. Adequate anchorage of the steel can be tested during tensioning, but it should also be inspected after installation.

Catch ditches

Falling rock from steep cliffs can endanger passing traffic and block roads. Rock will fall, bounce, or roll down the cliff, depending on the height and shape of the cliff.

Wide catch ditches are effective in containing rockfall, but must be designed in accordance with the cliff geometry. The chart on the next page details the minimum ditch dimensions for various cliff heights and angles.

Rock slope angle	Height (m)	Ditch width (m)	Ditch depth (m)
Near vertical	5-10 10-20 20	3.7 4.6 6.1	1.0 1.2 1.2
0.25 or 0.3:1.0	5-10 10-20 20-30 30	3.7 4.6 6.1 7.6	1.0 1.2 1.8 1.8
0.5:1.0	5-10 10-20 20-30 30	3.7 4.6 6.1 7.6	1.2 1.8 1.8 2.7
0.75:1.0	0-10 10-20 20	3.7 4.6 4.6	1.0 1.2 1.8
1.0:1.0	0-10 10-20 20	3.7 3.7 4.6	1.0 1.5 1.8

Minimum catch ditch dimensions

The bottom of the ditch should be covered with loose earth to prevent falling rock from bouncing or shattering. If there is insufficient space to construct as wide a ditch as is specified, then a combination of a smaller ditch with a gabion or rock wall can be used.

Catch ditch with gabion catch wall

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CHAPTER 4

EROSION CONTROL: PLANNING, FOREST ROAD DEACTIVATION AND HILLSLOPE REVEGETATION

by

J.W. Schwab
B.C. Ministry of Forests
Forest Sciences Section
Smithers, British Columbia

4.1 EROSION AND SEDIMENT CONTROL PLANNING

Erosion and sediment control problems associated with forest roads and harvesting can often be alleviated or prevented through planning and implementation of an erosion and sediment control plan. Such a plan must be an integral part of forest resource management. There must be a commitment to move erosion and sediment control from a "band-aid" treatment to an active, cost-effective mitigation program.

The time required to prepare an erosion and sediment control plan will depend on the project size, complexity of management concerns and the number of erosion problem sites. A project could cover a short section of road or a complete watershed. Regardless of project size, a plan should include eight components:

Objectives
Inventory of Active and Potential Problem Sites
Priority Assignment
Prescribing Treatment
Cost Estimate and Work Schedule
Training Staff and Operators
Implementing Plan
Monitoring Results

4.1.1 Objectives

Objectives are required prior to embarking on a rehabilitation program. Timber and non-timber resources must be considered. This may require consultation with all interested parties. Some factors to consider are: the risk to human life and property, forest development and management plan for an area, road access requirements, fish habitat protection, water quality concerns, potential slope stability and erosion problems, the integrity and capability of drainage structures, long-term road maintenance requirements, visual impacts and aesthetics, present and future recreational use, and other factors.

4.1.2 Inventory of Active and Potential Problem Sites

An inventory is conducted with the use of air photos and on-site field inspections. All active erosion and potential problem sites are identified, measured, located on a map (1:5000) and catalogued. The source or cause of the erosion problem is located (e.g., water diverted down a road). Also, sediment delivery routes are noted. The information collected during the inventory will help to assign priority ratings and treatment options.

4.1.3 Priority Assignment

A set of criteria should be used to assign priority to sites requiring rehabilitation/mitigative actions. The prioritization criteria must reflect the overall plan objectives, and also the magnitude and immediacy of the problem. Some questions that could be asked to determine high, medium and low priority sites:

- Is an event preventable?
- What is at stake (Consequence): human life, private property, fish habitat, water quality, forest site?
- What is the erosion hazard (High, Moderate, Low)?
- What is the risk (Hazard times Consequences)?
- What is the sediment delivery potential (Sediment Routes, Direct or indirect, Distance)?
- What is the magnitude and potential impact?
- What is the stage of the erosion (Early, Active, Advanced, Revegetated, Stabilized)?

4.1.4 PrescribingTreatment

Some methods and techniques for rehabilitation are presented in sections of Chapter 4. They could be thought of as falling into four categories:

Prevention
Temporary Sediment and Erosion Control
Permanent Sediment and Erosion Control
Biotechnical Slope Protection

Prevention of accelerated erosion in managed watersheds is achieved through the active management of water along forest roads. This is best realized through a planned maintenance program. Intensive maintenance is required before long shutdowns and expected peak flows (i.e., the fall storm season). This will involve road ditch and culvert cleaning and installing of new cross drains on active roads. Roads no longer required for regular use or not maintained will require deactivation (section 4.2). This may involve the removal of bridges and culverts, the construction of fords over seasonal and continuously flowing streams, the placement of water bars and cross ditches, the removal of berms and the re-sloping of the road surface.

Temporary sediment control techniques are used immediately after disturbance to reduce surface erosion and sediment production until permanent control measures are put in place. Temporary techniques often used are silt fences, straw bale barriers, settling ponds, mulches and fast-growing, short-lived cover crops.

Permanent treatments provide long-term sediment and erosion control. Primary consideration is to control surface water flow, create mechanically stable slopes, control surface erosion through the use of grass/legume seeding and promote recolonization of native vegetation. Cover is established through dry seeding or hydroseeding (section 4.3.3). In some situations, re-vegetation mats and netting are used where costs and conditions warrant.

Biotechnical slope stabilization uses woody vegetation and engineering structural support to improve the stability (section 4.3.10). These systems may be simple or complex in design. Experienced personnel are required to design and implement complex systems.

4.1.5 Cost Estimate and Work Schedule

Devising budgets, assigning responsibility and preparing a work schedule is necessary. Some treatment options may routinely be done "in house" whereas other options may require "outside" specialized contractor services. Scheduling will depend on equipment and contractor availability, environmental conditions, treatment options, sequence of treatments and access limitations, operational constraints and budget limitations.

4.1.6 Training Staff and Operators

Training of staff and operators is a must for the successful implementationof a rehabilitation program. Do not leave the implementation of the plan up to untrained staff and equipment operators. Disasters may result in a triggered landslide or ineffective rehabilitation work.

4.1.7 Implementing Plan

Implement the plan as set by project objectives, site priority assignment and work schedule. Flexibility in scheduling must be maintained to ensure optimum conditions at the time of treatment. Clearly indicate to contractors and equipment operators what is required. Provide a sketch of site-specific measures. Mark locations on the ground for rehabilitation works with spray paint or flagging tape. Work site inspections are necessary to ensure that rehabilitation requirements are understood and work specifications met.

4.1.8 Monitoring Results

Monitor the results of a project to ensures success. Determine whether the project has achieved the desired objectives. Check for renewed erosion or instability. Inspect the progress of revegetation. Experience is invaluable for determining what works and what does not work. A successful erosion and sediment control program build on past successes.

4.2 FOREST ROAD DEACTIVATION

Erosion occurs on roads not often used or maintained as a result of water accumulation and diversion onto sensitive slopes. (These roads are referred to as "orphan roads" in Washington State.) A person has only to walk a few inactive roads to discover that culverts and ditches do not maintain themselves. Adequate water dispersal structures designed and constructed when roads are deactivated reduce erosion and prevent the need for large expenditures of funds to rebuild roads for future management use. Water is the critical concern in the design of road drainage structures for active haul roads and in the protection of a deactivated road from surface erosion or mass wasting. Forest engineers must know their areas. The most direct approach is to walk inactive roads assessing erosion and drainage structure adequacy relative to the natural drainage requirements of the watershed. Local experience is invaluable.

4.2.1 Estimating Water Source Area

Knowledge of the water source area (drainage basin) and how roads modify water movement is essential for the design and placement of drainage structures. A drainage basin is a topographically defined area of land draining to a critical point, the basin outlet, which in most cases is a culvert or bridge site. Movement of this critical point up or downstream changes the size of the drainage basin, and hence enlarges or reduces the area draining to the basin outlet. The drainage basin could thus be a few square meters in size, draining to a gully headwall or, farther down the stream channel, it could be a large land area draining many square kilometers.

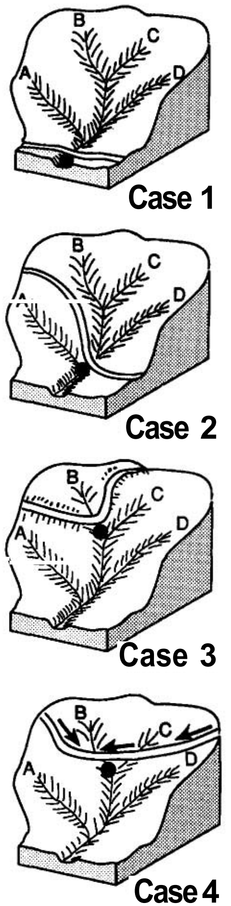
A large drainage basin in mountainous terrain is easily defined topographically, whereas the many small basins 1 ha or less in size may only be identified by an ephemeral stream channel, dips and swales, poorly defined spoon shaped micro-topographic basins, or vegetation changes in ground cover. A road constructed on a hillside intersects many of these poorly defined micro-topographic basins. If cross-drains are not provided, a major redirection of surface and subsurface water runoff down a road to a new critical point could result. This connecting together of many small drainage basins in effect expands the drainage area defined by a single cross-drain. For example, the drainage area to a gully headwall of 0.5 ha in size could be increased to 10 ha by an interconnecting road ditch — a 20-fold increase in drainage basin size.

Calculating the amount of water passing through a single culvert is based on the sum discharges of individual drainage basin areas within the discharge area of the basin outlet.

EXAMPLE:

BASIN	DISCHARGE AREA	DISCHARGE
1.	A+B+C+D	10 m^3
2.	B+C+D	7 m^3
3.	B	2m^3
4.	B+0.7C+0.3D	4.3 m^3

When roads intersect micro-drainages and concentrate discharge into a different drainage, as in Case 4, flow can exceed the normal discharge of the channel and lead to slope failure.



Estimating water source area

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