5.0 Land Disturbance

This section describes the natural causes and consequences of erosion, and how exploration activities can accelerate erosion processes. It then details the steps to take to control erosion during exploration activities. In addition, it explores the unique vulnerabilities of special terrains to erosion.

Erosion is the wearing away of the land surface in response to natural forces such as wind and rain. These forces cause the materials of the earth's surface to loosen, dissolve, or wear away, then to be transported from one place to another by natural agents. The result is a change in the shape, and often the usefulness, of the land surface.

Erosion is accelerated by exploration activities. Understanding the causes and consequences of erosion makes it possible to better evaluate and select methods to mitigate and control the impact of exploration.

5.1 Causes of Erosion

The natural forces of wind, water, ice and mass wasting (gravity) cause soil and rock particles to erode. Exploration activities can exacerbate the natural processes of erosion, because disturbance of the vegetation, soil, bedrock, and permafrost can alter surface drainage patterns. Climate, topography, soil type, vegetation, size of area, and length of time exposed to eroding forces, all affect the rate and degree of erosion.

In particular, regions characterized by arid climate, high rainfall, steep slopes, fine impervious soils, low vegetative cover, or those receiving rapid melt from snow pack, are susceptible to high rates of erosion.

The following sections identify the various causes of erosion, and describe their effects upon the land surface.

Wind

Wind is a powerful agent of erosion. Winds with low velocities of 13-15 km/h at ground level can remove soil particles from a dry surface. Removal of the vegetative cover can result in the complete loss of topsoil layers due to wind erosion.

Wind can also entrain (carry along) soil particles, forming nuisance dusts, which cause health problems and unwanted accumulation of sediment. Erosion due to wind is greater in arid regions. When working in regions highly susceptible to wind erosion, it is vital to preserve the vegetation.

Water and Ice

Water erodes the Earth's surface in several ways. These include:

- Wave action
- Rainfall impact
- Snow and ice buildup
- Surface runoff

Direct precipitation (such as heavy rainfall) breaks apart rock particles and loosens soil, as a result of the forces of impact.

The buildup of snow and ice contributes to erosion in three ways:

- Water that seeps into cracks of rocks can break rock when it freezes and expands
- Glaciers (large bodies of ice), while slowly moving over the land surface, scrape off both soil and rock
- Melting ice and snow produce large volumes of moving water (runoff) during the spring thaw

There are four forms of erosion that result from surface runoff:

- Sheet erosion is due to sheet flow of water across a uniform surface and removal of thin layers of soil.
- Rill erosion is caused by concentrated or repeated runoff that results in the formation of small channels, typically 2.5-3 m below the top of fill slopes.
- Gully erosion results in the formation of deep channels and is caused by concentrated or high-velocity runoff.
- Catastrophic erosion is caused by mudslides or landslides, which are in turn due to water building up in the soil and subsoil. This can be a health and safety risk as well as an environmental issue causing, for example, the catastrophic failure of a drill site.

Each of these can result in changes to the pre-existing drainage pattern.

The sediment that is carried from the land surface into waterways by runoff can degrade the downstream water quality, affecting the aquatic ecosystems. Suspended sediment can inhibit photosynthesis and plant growth, due to decreased light penetration. It can also clog fish gills. Excessive sedimentation changes the stream substratum, leading to channel infill and damage of spawning grounds.

In addition to sediment, the runoff can carry away pesticides, petrochemicals, heavy metals, road salts, and other pollutants. Not only are these pollutants toxic to humans and fauna, they negatively affect soil fertility and plant water uptake.

Exploration activities can affect the intensity of erosion resulting from rainfall and surface runoff. Concentrated runoff on denuded areas or areas of unstable soils causes the most severe erosion as a result of water movement. It is therefore very important to ensure that the minimum area of vegetation and topsoil is disturbed during an exploration program, so that the existing protective cover is maintained as far as possible. This is particularly important in areas of high rainfall.

Gravity

Mass wasting occurs when gravitational forces overcome the natural resistance of a mass of soil or rocks, without the aid of a flowing medium such as air at normal pressure, water, or glacier ice. A landslide is an example of mass wasting.

Vegetation Clearance

Vegetation inhibits erosion. Plant roots hold the topsoil in place, while leaves protect the surface against the erosive action of rainfall and act as barriers to the wind. Topsoil contains valuable nutrients, micro-organisms, minerals, seeds, and rootstocks - important elements for successful site rehabilitation after exploration activities are completed.

When soil is moved or loosened it:

- Washes away with the runoff
- Creates sediment in streams
- Loses its nutrients after a period of time

Erosion frequently starts with the cutting, clearing or removal of vegetation. Once the vegetative cover is gone, erosion is accelerated. The longer the exposed area is subject to erosive forces, the more severe the effect. Reestablishment of the native flora will be more difficult if the vegetation has been completely removed, and this may result in further degradation of habitat.

Soil Disturbance

Soil characteristics can affect the rate of erosion. Fine-textured soils are prone to wind and water erosion, once exposed by removal of surface organic layers. Fine-textured and wet soils are more susceptible to rutting than drier, medium, or coarse soils. Disturbed or compacted soils may interrupt soil moisture movement, and this can inhibit successful remediation activities.

Bedrock Disturbance

Disturbance of the bedrock changes drainage and runoff patterns, which may increase the rate of erosion. Trenching is the exploration activity that most disturbs bedrock.

5.2 Consequences of Erosion

Erosion can result in

- Degradation of surface waters with eroded sediment.
- Altered patterns of surface water flow and drainage.
- Increased stream flow velocity or channelling flow (channelization).
- Loss of valuable and productive topsoil.
- Generation of non-point source pollution (mainly sediment, but also spilled fuels).
- Destruction of natural habitat (on land and in aquatic ecosystems).
- Compaction of soil, which reduces the capacity of water to infiltrate soil resulting in higher runoff volumes.

5.3 Methods of Erosion Control

Line cutting and other exploration activities disturb the landscape and can accelerate the erosion of unstable soils. It is essential to introduce appropriate erosion and sediment control structures and procedures into activities, even as early as the survey stage.

The goal should be to expose the smallest practical area of land, for the shortest possible time, to eroding forces. Reaching this goal requires planned exploration activities, anticipating the needs of the exploration program. Careful planning facilitates the eventual rehabilitation process. As a general rule, minimize vegetation, soil, and bedrock disturbance and exposure to wind and water.

There are many different erosion and sediment control structures available to you which, if properly designed, installed and maintained, will effectively reduce the transport of sediments,

minimize the degradation of water resources and reduce negative impacts to natural resources. It is very important that you do not discharge sediment-laden water into streams or lakes.
Control structures protect the watershed and natural resources in a number of ways. For example, they

- Prevent the formation of, or the advancement of, rills and gullies.
- Reduce the flow velocity in watercourses or provide structures capable of withstanding high flow velocity.
- Stabilize the grade and control head cutting in natural or artificial channels.
- Convey water from one elevation to another.
- Divert water away from unstable slopes.
- Filter and retain sediment.

You should use erosion control structures where there is potential for a sediment control or an erosion problem. This could happen when

- Flow velocity of runoff is high enough to cause erosion.
- Excessive grade or overfill conditions occur (where the existing drainage system is at its maximum capacity.)
- Water needs to be moved from higher to lower elevations.
- Critical slopes have sheet erosion problems.
- Vegetative cover is being established.
- Concentrated runoff from unstabilized areas can be diverted onto stabilized areas.

The steps that you can take to reduce and control erosion caused by natural forces and exploration activities include

- Minimizing vegetation, soil and bedrock disturbance and exposure to wind and water,
- Collecting and managing (dispersing) runoff and drainage, and
- Collecting and removing sediment.

5.4 Minimizing Disturbances

Make every effort to minimize vegetation removal and soil and bedrock disturbances. The disturbance caused by vehicle and mobile equipment use can be minimized through proper equipment selection.

Further discussion on minimizing disturbances is presented in the following sections:

- Clearing of Vegetation
- Soil Conservation
- Trenches and Pits.
- Managing Soil on Slopes.
- Soil Stabilization.
- Vehicle and Equipment Use

5.4.1 Clearing of Vegetation

There are important issues to consider when clearing trees or vegetation for surveys.

- Do not clear land of vegetation more than 6 months in advance of when it is required
- Avoid clear cutting and bulldozer blading
- Where possible, drive over flattened vegetation, to preserve rootstock and prevent soil erosion
- Limit the amount of clearing with heavy machinery.
- Wherever possible, preserve the organic mat
- Avoid cutting commercial plant species (presume someone is cultivating them)
- Cut and remove unstable or snagged trees where they pose a danger to workers or could fall across the roadway.
- Not leave trees leaning into marginal timber.
- Leave large trees standing, if possible.
- When constructing access roads or other facilities, weave roads around trees or relocate facilities to help reduce the visual impact of vegetation clearance.
- Avoid removing vegetation adjacent to lakes, rivers and streams. Leave a buffer zone of undisturbed vegetation at least 10 metres wide on either side of the stream or waterway.

Cutting Vegetation

Each jurisdiction will have local guidelines and permit requirements for cutting and removal of trees. Learn the regulations and ensure that all authorizations or permits have been granted before commencement of any work.

As a general guideline, in the survey stage of the exploration process:

- Cut vegetation close to ground level for safety reasons, to avoid dangerous “spikes” of stumps protruding.
- Buck cut trees. The boles of trees should be cut from the stump at the root crown.
- Saw felled trees into manageable lengths.
- Trim overhanging vegetation to reduce the hazard of protruding branches.
- Do not fell live saplings of any species over 150 mm in diameter unless absolutely necessary.
- Ensure cutters are trained to recognize and avoid cutting any native species that are subject to local regulations.
- Minimize cutting in sensitive (e.g. alpine) areas.
- Remove all introduced debris (e.g. bottles, cans, paper).

When using power equipment:

- When changing oil, collect waste oil and take it to an appropriate disposal area.
- Do not dump used oil in the bush.
- Ensure that appropriate fire hazard control materials are on-site. Keep a knapsack filled with not less than 10 L of water, or a powder-type extinguisher of not less than 1 kg capacity, within reach on all worksites where chainsaws, power augers, and other gasoline-driven machinery are used.
- Be aware of any fire bans.
- When using a portable generator, keep the exhaust area clear of leaves and twigs.

Line Cutting and Surveys

When establishing a grid and conducting ground surveys, ensure that:

- Cut lines or walking tracks do not exceed 1 m in width.
- Access to cut lines is discreet, in order to reduce the possibility of subsequent misuse by unauthorized users (for environmental as well as safety reasons).
- Cut lines are established using hand tools only (e.g., machete, fern hook, axe, chainsaw).
- Biodegradable tape is used in preference to ordinary plastic type. This tape will last at least 2 years, but will eventually disintegrate.
- Only small lengths of tape should be used. “Streamer” type markers of several metres of tape are not necessary.
- Wherever possible, grids in sensitive areas are only pegged and flagged with tape.

On completion of the program, ensure that:

- All equipment, including wires, is removed from the grid.
- Hipchain cotton is removed from grid lines, as birds can become entangled in this line.
- Wherever possible, conspicuous markers such as pegs and tape are removed, especially from the beginning of grid lines. Special attention should be given to this in sensitive areas.
- All pickets are removed from ice on water courses prior to break-up.

Managing Removed Vegetation

Vegetation cut during the establishment of lines can be used in a number of ways, including the acceleration of the process of revegetation disturbed areas. Consider the following procedures in this regard:

- Store removed vegetation so that it can be later used as a seed source, moisture retention aid, and shade for new growth during reclamation.
- Incorporate some of the cut timber and slash into a road sub grade and dispose of the remainder of the slash by scattering, piling and burning, or burying.
- Use some of the vegetation that was removed as mulch.
- Lop or limb cut bulldozed trees and scatter the branches and limbs
- Use some of the removed vegetation as mulch.
- Cut slashed vegetation (slash) into less than 4 m lengths, cover with at least 1 m of soil, reseed, and fertilize.
- Dispose of slash such that it does not degrade aquatic habitats or pose a fire hazard.
- Determine if slash burning is permitted. Never burn during dry periods or when there is a high fire hazard. Scatter or bury residues from burning.

5.4.2 Soil Conservation

In order to protect and support vegetation that inhibits surface erosion, it is critical to conserve topsoil in disturbed areas. Topsoil contains valuable nutrients, micro-organisms, minerals, seeds, and root stocks, which are important for reclamation. Of particular importance is the seed resource of native species contained in topsoil. This seed resource is essential to restoring the diversity of plant species within the disturbed area.

Plan all activities that disturb the ground surface in such a way that the amount of topsoil that is moved is minimal.

Stockpiling Topsoil

Stockpile topsoil separately from subsoil and protect it for future use in reclamation.
Consider the following factors before disturbing topsoil:

- If there is a heavy mulch of decaying vegetation overlying the soil layer, it should be removed first and stockpiled separately.
- Topsoil usually constitutes the top 10-20 cm of soil, but in some areas may be very shallow.
- Excavated soil should be stockpiled for reapplication to disturbed areas.
- Topsoil and the subsoil should be stored in separate piles no higher than 1-2 m. This ensures proper aeration for soil fauna. (Good practice for topsoil storage height from various sources ranges between 0.6 m and 3 m. The 1-2 m height has been chosen here as a reasonable midpoint within this range.)
- Soil should be covered with permanent or temporary vegetation to prevent erosion.
- Subsoil needs to be reapplied before the topsoil.

5.4.2.1 Trenches and Pits

Ideally, locate trenches (or "costeans") and pits to avoid large trees (>150 mm in diameter). Where this is not possible, pre-cut these trees and move them to one side for salvage.

Always strip topsoil (including scrubby vegetation and the organic mat) and move it to one side of the trench into long, narrow piles, no more than 1-2 m high. If topsoil is piled into larger heaps, oxygen cannot reach the centre of the pile, and useful soil organisms die. The soil then becomes sterile and loses nutrients. It is important to store soil properly, wherever possible.

Ensure that there is proper drainage through the topsoil piles, especially if they have to lie for several months before rehabilitation work commences. Topsoil is easily erodible, and must be protected from needless erosion loss by installing drainage, if required, and covering its surface to protect from wind erosion. On a slope, use a table drain or ditch uphill from the trench, to prevent the trench from filling up with water. On sloping sites provide drainage above trench and soil storage.

Before designing and building trenches and pits, take into account the local conditions. The key steps in the construction and rehabilitation of trenches are illustrated below.

Place subsoil and any excavated rock in separate piles, not on top of the topsoil. One easy method for small trenches is to place the topsoil on one side of the trench and subsoil on the other. If there is not enough room on one side of the trench for all of the subsoil, pile both the topsoil and subsoil on each side of the trench, but in separate piles.

With small trenches, which are filled in on the same day or within a few days of being dug, there is no need to strip the topsoil from the area used to store the subsoil. As noted above, however, if the trench is large and will be left open for weeks or months, strip and store the topsoil from the subsoil storage area.

For the safety of workers, bench the sides of large or deep trenches (>1 m deep) and consider the addition of shoring in unstable ground. The design of trenches is regulated in many jurisdictions and may require engineering advice.

Never use bulldozers to dig trenches. Excavators and backhoes can do a far neater job. However, when a shallow scrape is needed to expose rock for examination, then a bulldozer may be the most suitable machine for the job. Replace scraped-off soil (if any) when the shallow "scrape" trench is no longer required.
When refilling the trench, replace the rock and subsoil first, then cover it with the topsoil/vegetation mixture. Fill in trenches as soon as possible after the program has finished.

Place all acid-producing waste rock back in the excavation or pit, and backfill it as soon as practical. Backfill all trenches and pits containing acid-producing waste rock with benign, low-permeability material topped with a compacted capping layer at least 1 m thick.

Encourage new vegetation growth with the application of fertilizer and seeds. If topsoil is stored for longer than 3 months, the nutrients become depleted, and fertilizing will be needed to aid revegetation. If topsoil is stored longer than 6 months, seeding is beneficial.

Figure 10: Large trenches such as this one in West Africa can be hazards to both wildlife and people unless reclaimed. © Iamgold.

Figure 11: Trenching can leave a major scar on the landscape unless reclaimed. The muck pile from this trench in Argentina will be used as backfill upon completion of work. © Iamgold.

5.4.2.2 Managing Soil on Slopes

On sloping sites, provide drainage above trench and soil storage.

Soils on slopes are susceptible to erosion. The rate of erosion increases as the angle and length of slope increases, due to higher flow velocities and a greater chance that channels will develop. Soil texture is also a factor to be considered in assessing susceptibility to erosion. The following table sets out some of the criteria that can help determine this assessment.

Table 2: The Rate of Erosion

Soil Texture	Degree of Slope				
	$0 – 3^o$ 0 – 5%	$3 – 5^o$ 5 – 9%	$5 – 17^o$ 9 – 30%	$17 – 31^o$ 30 – 60%	$>31^o$ >60%
Fine	Moderate	High	High	High	High
Fine to Medium	Moderate	Moderate	High	High	High
Medium	Low	Low	Moderate	High	High
Medium to Coarse	Low	Low	Moderate	Moderate	High
Coarse	Low	Low	Low	Moderate	High

In order to reduce the velocity of the runoff, contour a long (>30 m) or steep slope and incorporate benches, terraces, or breaks in the slope. Careful selection of trail, track, and road location along slope contours is important to reduce the potential for erosion and its impacts.

Activities on slopes should be conducted so as to maintain the vegetative cover as much as possible.

Re-establish disturbed vegetation cover as soon as possible. In steep areas with slopes greater than 3:1, techniques other than revegetation may be required to stabilize the slope and prevent erosion.

When constructing a trench on a slope:

- Construct the trench along the slope contour, and include a ditch or drain at the ends to outlet flow to a level area or other stabilized discharge area
- Place excavated materials on the sides of the trench, keeping topsoil and subsoil piles separated and protected from erosion
- Install a drain on the upslope side of the trench to prevent runoff from eroding stockpiled topsoil and subsoil and flowing into the trench
- If the trench is to be left open for a period of time, stabilize and revegetate the trench, slope, and the surrounding disturbance area as soon as practical
- Reclaim trenches by filling with subsoil and topsoil and revegetation, as appropriate, at the end of the program

5.4.2.3 Soil Stabilization

Soil stabilization by re-establishing vegetation cover is the most cost-effective, long-term surface erosion control method, because it controls sediment at the source. Revegetate soil exposed during construction, and installation of a stream crossing following construction. Revegetation of approach ditches, cut slopes, and other disturbed areas reduces the possibility of stream sedimentation. Undertake revegetation immediately following completion of the work.

Standard revegetation techniques include hand-broadcast or hydraulic seeding, and mulching using regionally adapted seed and mulch mixes. Select seed mixes that are less palatable to livestock, to minimize livestock activity at crossing sites.

The timing of seed application is determined largely by the completion time of the construction or stream crossing installation. Seed all exposed soils in the vicinity of the stream crossing installation immediately following completion of construction, and reseed the site as necessary. Hydroseeding is the most efficient means for seeding steeper slopes.

Mulching accelerates seedling development, and reduces the chance of seed being washed away by rainfall and runoff. When combined with hand-broadcast seeding, straw is a fast and cost-effective mulch substitute for dealing with smaller exposed areas near stream crossings. Apply seed and mulch by hand, independent of the seeding schedule, or by the method established for the rest of the road system. This practice can accelerate revegetation at higher-risk locations.

Fibre-bonding agents are slurries of wood fibres and tackifiers (binding agents) that conform to the ground and dry to form a durable, continuous erosion control blanket that stays in place until vegetation is established. The fibre mats created are biodegradable and decompose slowly as vegetation is re-established. Like other forms of mulching, bonded fibre matrices hold seed and fertilizer in place, yet allow sunlight and plants to penetrate. Compared to conventional erosion control blankets, they require no manual labour to install, and are not subject to under-rilling or tenting, as can occur with erosion control matting and netting.

Erosion control revegetation matting and seed overlaid with a biodegradable netting material such as jute (woven fibres) are other effective methods to use for speeding germination and plant growth, and holding materials in place. Fix the matting or netting in place with stakes, and it can be made to overlie most slope angles adjacent to stream crossings. Jute netting may also be used to hold mulch and other materials in place, although it provides little if any soil protection.

Keep soil in disturbed areas covered as much as possible through the use of slash, mulches, mats, and temporary vegetation. Mulches, mats and nets are particularly effective at reducing wind erosion. Revegetate as soon as possible.

5.4.3 Vehicle and Equipment Use

Figure 12: Any spills on access routes must be carefully cleaned. © Noranda/Falconbridge

Mobile equipment and vehicles can damage vegetation and disturb topsoil, which accelerates erosion. Plan activities to minimize disturbances, such as rutting and soil compaction.

Consider the following:

- Perform work during the season in which the least amount of disturbance is likely to occur (e.g., winter or dry season).
- Limit the number of routes and volume of traffic.
- Locate routes to minimize disturbance. Use frozen waterways, natural clearings, and avoid slopes.
- Use the lightest equipment and vehicles possible (e.g., use ATVs in place of trucks).
- Transport heavy survey support equipment on multi-axle trailers.
- Use dedicated roads for heavy machinery and dedicated snow paths for snowmobiles where possible.

5.5 Managing Drainage and Runoff

Runoff is water that flows over land into the natural drainage system of the streams, rivers, and lakes in a region. Runoff contributes to erosion and the transport of soil into waterways.

Exploration activities can disturb natural runoff and drainage patterns. Altering of drainage patterns through blockage or diversion can result in major changes to affected areas, such as the ponding of water, or the deprivation of water to other areas. Since drainage in arid regions usually occurs as sheet flow, it is important to ensure that any land and water disturbances do not result in channelization of surface runoff.

Anticipate the consequences of all exploration activities, and take actions to control flow velocity, water volume, and resulting erosional effects. Bear in mind that it is generally better to spread out water than to make it concentrated.
It may be necessary to divert uncontrolled surface water runoff around disturbed areas in order to minimize erosion (e.g., sheet wash, gullying). Construct drainage diversions before the start of road building or stripping and trenching activities.

Pay particular attention to:

- Road and track design and construction
- Location of bridges and crossings
- Use of culverts, ditches, and berms
- Presence and steepness of slopes

5.5.1 Road and Track Design

Most jurisdictions have regulations governing road and track construction, and it is important to abide by them. There are also many practical and reasonable issues to consider when designing and building a track or road.

Permits may be required for stream crossings, for example. To avoid project delays, take into account the time required for approval of all permits.

The first step in planning access by road or track is to ascertain whether or not it is essential. Always use an existing road or track in preference to constructing a new one. This will prevent duplication, avoid unnecessary environmental interference, and reduce maintenance costs for the track.

A well-planned road or track will cost less than one that is poorly placed and requires frequent maintenance. In designing a track, for instance, consider the anticipated volume and type of traffic.

It is important to:

- Avoid long uninterrupted slopes
- Create crowned road surfaces
- Select sites that will help prevent water from collecting and flowing along the road

The following sections explore many aspects of planning, design and construction of roads and tracks to take into consideration.

5.5.1.1 Planning

If no suitable access exists and a track must be constructed (as opposed to using helicopters for access), consider the following issues:

- Volume and type of traffic
- Frequency of use of the track
- How long the access will be required
- The seasons during which access is required

Also consider how future developments might affect the track use. At some time the volume of traffic or type of equipment using the track may change. Keep in mind possible future events (e.g., a discovery) that might result in the track being upgraded or extended.

Other factors that influence track design include the possible need for a drill rig to be sledded along its surface, and the requirement for access for heavy, wheeled trucks.

Figure 13: Where appropriate, consider access using helicopters or fixed-wing aircraft to avoid road construction. © Miramar

Figure 14: Mobilizing the drill to a high altitude site in Peru. Access roads can be minimized using lightweight, modular drill rigs. © Kluane Drilling

Figure 15: If well-designed, access roads can be constructed with minimal land disturbance as in this example from Argentina. © Noranda/Falconbridge

5.5.1.2 Location

Take steps to select the location of a track carefully. Find possible routes for the track or road, first by using available maps and air photos, then by field inspection. Be careful to investigate the various possibilities or alternative sites for different parts of the proposed track, and walk the whole length of the proposed route, not just the beginning.

In track planning:

- Assess the potential visibility impact of different routes, not only from roadways, but also from local residential sites and vantage points in the neighbourhood.
- Take visual impact into account in planning. Colour contrasts between soil and the underlying material can produce a high visual impact, which is not evident when the soil and underlying material are of the same colour.
- Learn to recognize and avoid rare or valued tree species.
- Establish control points first (e.g. creek crossings, saddles) to assist in the location of the track, then decide on the required gradient between the control points.
- Where removal of trees is unavoidable, consider routes that minimize tree clearing. Try and mark both sides of the track by tying a "corridor" of tapes along the proposed route. This will greatly assist the earthmoving contractors in putting the track in neatly.

Avoid poor or difficult ground, such as:

- Rock outcrops
- Soaks (a natural depression holding rainwater)
- Swamps

Generally, the best track locations are found on ridge tops or on bottom slopes just above the valley floor. It is better to keep off valley floors, as drainage is generally a problem in these locations. Recognize wet areas, which may not be wet at the time of inspection, by the type of vegetation present. Examples of vegetation found in wet areas include:

- Peat
- Buttongrass (Australia)
- Bullrushes

In laying out a track:

- Minimize the number of stream crossings.
- Fit the track to the topography so that the earthworks disturbance is minimized.
- Try to position tracks along the contours, and avoid sudden changes in gradient. Steep sections of tracks are prone to severe erosion - incurring high maintenance costs - and must have drainage systems (ditches and/or cross drains) put in during construction. Avoid building dead-level tracks, as water will pool on these flat sections and not drain properly.
- Where topography permits, locate roads on old benches (provided they are not backslopes of old landslides), ridge tops and flatter slopes. Ideally, build tracks to a grade of not less than 1% (so water will run off), but not more than 5%, especially if constructed in erodible soils or clay areas where traction may be a problem in the wet.

When developing a new track off an existing roadway:

- Ensure that the junction is discreet, but is also safe.
- Ensure that traffic has a clear view at junctions.
- Avoid junctions located just over the brow of a hill, or round a sharp bend on a main road.
- Ensure that the entry angle between track and road is large and that the track includes a "dogleg" in the bush, close to the road, to reduce visibility where possible.

- Ensure that tracks constructed parallel to a major watercourse are some distance from the watercourse (check local regulations). The general rule is the larger the watercourse, the larger the margin of undisturbed vegetation to be left on the banks.

Protect watercourses in a manner consistent with regulatory and legislative guidelines.

It is also important to:

- Prevent heavy machinery from entering streamside reserves, except to cross the streams at defined crossing points. These streamside reserves are recognized as necessary for the protection of water quality.
- Keep interference with the natural drainage to a minimum.
- Build stream crossings at right angles to the stream.

5.5.1.3 Construction

When constructing a track:

- As a general rule, pre-cut all fallen logs and saplings greater than 150 mm in diameter before pushing aside with dozer or excavator. Any commercial timber should be set aside for salvage.
- Remove topsoil and vegetation and store in a long windrow, no higher than 1-2 m alongside the track.
- Make sure the topsoil stockpile is out of the way of traffic. Ensure that drains are constructed through the stockpiled soil to allow runoff to escape; otherwise, valuable topsoil may be eroded.
- Store subsoil (spoil) in a windrow (i.e. a long, low ridge) alongside the track, but do not pile this on top of the topsoil. Clear topsoil from the spoil storage area.

In many cases, pushing over trees in line with the proposed track may be preferable to cutting. Revegetation on roadsides (where a fallen log, with roots partly intact forms the roadside verge) is frequently improved by re sprouting from the tree trunk. The reason for pre-cutting is to avoid damage to peripheral vegetation from uncontrolled falling of large trees. On occasions, however, careful felling of trees can assist in stabilizing the road verge. This is mostly applicable in the construction of narrow tracks on moderate slopes.

In general:

- Do not make the track any wider than necessary.
- Choose the smallest machine suitable for the job to restrict the width, or use an excavator.
- Recognize that tracks made with excavators frequently are neater and require less rehabilitation work, although there are situations where a bulldozer is the more appropriate machine to use. Use excavators wherever possible, in conjunction with a bulldozer if necessary.
- Observe that on steep slopes (>30°), some benching will probably be necessary.

In addition:

- Limit vegetation clearance to the extraction site, and remove trees with the same precautions as for the track.
- Do not needlessly remove vegetation from either side of a roadway.

- Ensure service areas are limited in size and number. Where possible, ensure construction service areas, fuel, equipment, vehicle depots, and campsites are confined to the future road alignment.
- Do not use creek floors as tracks.

Fill and Road-Building Materials

Always use fill from cuts wisely - do not push it over a bank and waste it. Try to compact the fill as much as possible, to minimize water penetration and to prevent the fill from washing away.

When a demand for road building material is anticipated, locate a few good source sites, and develop these systematically. Do not poach fill and surfacing from along the road verges.

Fill material can be obtained by slightly widening the track, and on some occasions this may be preferable to opening up a borrow pit next to the track. Always design road material pits to be compact, and inconspicuous from the roadway and from neighbouring vantage points, by judicious site selection, utilizing local landforms, leaving natural screens of vegetation, constructing mounds capped with topsoil, and revegetation.

5.5.1.4 Drainage

Water can quickly damage roads and tracks. To protect against this damage:

- Repair drainage on existing roads
- Install proper drainage systems on all tracks

This last point cannot be emphasized enough. A little money spent on adequate drainage in the beginning will save much time and money later on in repairing water damage.

Table Drains and Cross Drains

This section discusses the use and construction of table drains (ditches) which parallel the road or track, and cross drains that interrupt water flow on the track and/or channel water from table drains onto level, stable areas for dispersion. The aim of these is to prevent direct flow from roads or tracks into waterways. Table drains should be "dish-shaped", at least 30 cm (0.3m) deep and at least 60 cm (0.6m) wide. Dig them on the inside edge of the curve, or the uphill side of the track, and connect them to a properly constructed cross drain. Table drains should channel water into cross drains.

Place cross drains at frequent intervals. On moderately steep slopes, construct cross drains every 30 m (or even closer). Of all the faults seen in poorly constructed tracks, the lack of cross drains is the most common.

When installing drains:

- Construct cross drains at approximately right angles across the track. They should be dish-shaped, about 0.6 m wide and 0.3 m deep. These drains are often damaged by the regular passage of traffic and need to be kept in a good state of repair.
- Locate the cross drain at an angle to best intercept water from the table drain, and on a slight grade (1-3%) to pass the water from one side of the track to the other.
- Ensure that table drains and cross drains are not "square in cross section", as can easily happen when drains are constructed with a backhoe or excavator. The preferred shape is that of a shallow dish, as it erodes much less easily.

Mounds (Waterbars)

Use "mounds" (also known as waterbars) to divert water off a track. These are made during track construction by piling up any available material - gravel, crushed rock, even soil - into a long "hump" across the track, rather like a "speed hump" used to force cars to slow down.

The hump works by directing water flowing down the track off to one side, into a table drain or stabilized drainage area. Carefully maintain these mounds. The material to make the mound may be obtained by making a long spoon-shaped scrape 1-2 m in front of the mound during construction of the track.

Waterbars should be constructed on all access roads to minimize rills and gullies.

Water Flow

Ensure that the dimensions of cross drains and table drains are adequate to cope with the volume of runoff. In easily eroded soils, water velocity in the drains should not exceed 0.5 m/sec. In more resistant soils, the velocity should not exceed 1.0 m/sec. When constructing drains, try to stick to the same gradients as used in track construction - between 1-5% slope wherever possible.

Where substantial water flow is expected:

- Line the drains with broken rock, half-pipes or concrete interlocking channels where they cannot cope with the volume of water.
- Construct large cross drains and culverts in conjunction with a sediment trap or a pond into which the drainage water can collect, allowing sediment to settle out before flowing on, following the natural drainage channels where excessive silt loads are anticipated, or where water quality is an issue.
- Locate culverts and cross drains where the runoff either filters through undisturbed forest soil or into natural drainage channels. If this is not possible, direct the discharge onto solid ground, not fill.
- Remember to check drains and culverts frequently and unblock where necessary. A blocked culvert can cause massive washouts.

Culverts

Where culverts are necessary:

- Lay culvert pipes on a very slight grade, not too flat or too steep. This is to minimize silting up of the pipes, which will occur if the pipes are too flat, and to control "scouring" of the culvert outlet, which will happen if the water flow is concentrated by a pipe.
- Place broken rock in the discharge area to prevent erosion.
- Place pipe on a solid base.

The most convenient spot for a culvert is often on the side of a gully. The most important factor in choosing a pipe’s location is to ensure that the pipe will not move. Lay culvert pipes straight and on a good foundation, to prevent movement of pipes after laying. Where pipes are joined, take care to have them laid straight. Use rubber ring joints or external bands where movement is anticipated.

The minimum recommended soil cover over pipes is 60 cm.

5.5.1.5 Creek Crossings

Be aware of, and abide by, any regulations concerning water crossings. There are a number of issues to consider when designing a track or road that will cross a creek or stream. These depend primarily on the size of the creek to be crossed.

Small Creeks

Some smaller creeks may be crossed by fording. This is generally only suitable when crossings are infrequent. A ford may be made more permanent by concreting the width of the roadway across the creek, but only do this where creeks have a low summer flow and where few crossings are envisaged.

Even small creek crossings usually require the installation of a culvert to allow the water to run under the road. Small crossings can be made by using a "nest" of logs, by placing logs parallel to each other in the creek, so that the water can flow between the logs. Gravel and fill are usually placed over the collection of logs to complete the road surface.

Large Creeks

Larger creeks require something more substantial, such as a piped culvert or a log culvert. Each of these is discussed below.

The size of the culvert will depend on the size of the creek to be crossed. Anticipate water flows and install culverts that will cope with the maximum expected water flow. Evaluate the size of the catchment area - do not put in a culvert only just capable of taking the seasonal low flow, as this will almost certainly wash out.

Piped Culverts

As the name implies, piped culverts involve the installation of a pipe to facilitate stream flow under the track. Round pipes are installed to a depth equivalent to 40% of their diameter and the streambed conditions replicated inside the pipe. The pipe is then covered with gravel and soil to form the surface of the track.

Log Culverts

Construct log culverts by placing two "abutment" logs on each bank of the creek, parallel with the creek direction, then place logs (stringers) across the creek, with their ends resting on the abutment logs. Cover the logs with a seepage barrier, then gravel or soil. These are much more substantial structures than "nests" of logs or piped culverts, and are usually only required in exploration where rivers have to be crossed.

During the last 50 metres before a road crosses a watercourse, you should divert road drainage into the surrounding vegetation or sediment traps, and not allow it to continue to the stream unchecked. Where necessary, you should install a culvert to pass drainage from the top side of the road to the lower side, and then divert it into the surrounding vegetation.
Other important considerations to take into account include the following:

- If access is only required for one season or so, consider installing a temporary bridge that can be lifted into place and taken away again after use
- On major creek crossings or minor creeks important for use by spawning fish, use a log culvert or a temporary bridge

5.5.1.6 Track Use

To reduce the daily wear of tracks:

- Respect existing roads and tracks. Do not aggravate deterioration by use of excessive speed, oversized or overloaded vehicles, or by use in extreme weather conditions.
- Do not use tracked vehicles on unsuitable surfaces (e.g., bitumen).
- Try, wherever possible, to confine the use of temporary tracks to the drier months.

To maximize the useful life of tracks:

- Have a spade in the vehicle to unblock cross drains as required. Keeping water off the surface of tracks will greatly reduce the expenditure required for maintenance.
- Perform maintenance work before tracks fail - do not wait.
- Plan the daily and weekly workloads, or crew changes, so that these are accomplished with the fewest number of journeys. Trips are frequently duplicated unnecessarily. Planning time well and choosing a suitable vehicle will minimize both expense and environmental impact on the track.

Recognize that the track may be subject to some flooding and plan accordingly. Build tracks that are required to withstand some flooding for a number of years. Traditional road building incorporates a "flood interval" component in the design, taking into account that there will be a bigger than annual flood every 10 years, a fairly big flood every 50 years, and a huge flood every 100 years.

When reopening a former track, take the following steps to prepare it for use:

- Cut overhanging vegetation; do not push it out of the way with either an excavator or bulldozer.
- Cut logs that are lying across the track; do not simply push them out of the way.
- Reopen old drainages and be sure to install additional drainage wherever necessary.

5.5.2 Ditches and Drains

Drainage control is critical to the successful retention of sediments both during and after site and road construction - consider it in relation to the existing drainage pattern on the site. A site sketch plan is the best tool to work with when developing a drainage control plan. The two most effective steps to take in reducing water-related problems are:

- Reducing the volume of water that enters ditches
- Preventing ditch water from draining directly into a stream

Place cross drains and/or cross drain culverts in the track or road at the location that allows as much of the water to be diverted away from the stream crossing as possible. This minimizes:

- The length of the approach ditch (portion of ditch between cross drain and stream) that contains water
- The amount of ditch open to erosion

It is important to ensure that ditch blocks are:

- Installed to divert water into the cross drain or tail out ditch
- Constructed of material sufficient to withstand the erosive forces of the anticipated amount of water carried by the ditch

Tail out ditches drain water from the ditch or table drain into the surrounding vegetation or a constructed sump, away from the road or track. To improve drainage, breach or flatten any berms or other impediment to the flow of water. Also avoid draining ditch water directly into a stream. Drain as much ditch water as possible out of the ditch and into constructed sumps or onto vegetated areas, which should allow ditch sediments to deposit out before the water reaches the stream.

Develop a system of ditches and cross drain culverts on permanent or heavily used roads. On temporary roads, use mounds (waterbars) and "dips" to divert water. In both cases, install them at frequent intervals to prevent concentrating runoff. Angle waterbars and dips to direct water into the downhill drainage structures. Waterbars and dips should not be perpendicular to the water flow direction, because this will create dams or channelized flow.

5.5.3 Bridges and Crossings

The practices described below apply to all fish stream installations. Variations to those presented may be agreed to by the appropriate fisheries agency. When installing a stream crossing, simulate conditions that existed before the structure in question was installed.

Environmental objectives associated with the construction, installation, and use of stream crossings include:

- Protecting fish and fish habitat
- Providing for fish passage
- Preventing impacts on fish eggs and alevin (hatchlings) that are present in the gravel, or on adult and juvenile fish that are migrating or developing
- Reducing the risk of release of sediment and other deleterious substances during work at stream crossings

To achieve those objectives, take the following fish stream protection measures:

- Complete the work during the appropriate in-stream work window (the seasonal period of minimum water flow in the stream bed)
- Eliminate or reduce sediment-related problems during installation
- Prevent deleterious substances from entering streams
- Minimize or avoid disturbing fish habitat above and below the area required for actual construction of the stream crossing
- Ensure that the design specifications for safe fish passage are achieved
- Revegetate and stabilize the site to prevent post-construction erosion
- Minimize vegetation clearing at the crossing site and retain streamside vegetation within the stream crossing right-of-way wherever possible, recognizing operational requirements

5.5.3.1 Vegetation Management

It is important to retain as much understory vegetation as possible within the riparian management area (where land and water meet) of any stream crossing, to prevent erosion and minimize disturbance to fish habitat. To do this:

- Remove only the vegetation required to meet operational and safety concerns for the crossing structure and the approaches

- Consider salvaging rooted shrubs during crossing construction to assist in post-construction site stabilization
- Make every effort to minimize impacts to the riparian fish habitat on both the upstream and downstream sides of the crossing site

Felling and yarding of trees at stream crossings can result in unnecessary stream damage. Ensure that felling is away from the stream whenever possible, and design the method of felling, tree removal, and stream cleaning to minimize potential damage. For example:

- When construction work poses a risk of erosion and bank damage, consider directional felling and machine-free zones
- Where there are leaning trees, consider using directional felling techniques
- If it is necessary that trees be felled across the stream for safety and operational reasons, lift rather than drag them out of the stream to minimize disturbance and siltation

Grubbing and stripping includes the removal of:

- Stumps
- Roots
- Downed (non-merchantable) or buried logs

Do not do this removal in any area of the riparian management area not required for:

- Road construction
- Ditches
- Installation of the crossing structure

Remove all slash and debris that enters the stream from felling and yarding as soon as possible. Place this material where it cannot be reintroduced into the stream by subsequent flood events. On most streams, this location is above the elevation of the active floodplain. Any stream cleaning carried out should not result in the removal of any hydraulically stable, natural debris.

It is important to carry out the following activities outside the riparian management area of a stream:

- Burying
- Trenching
- Scattering
- Burning of debris

Where this is not possible, locate debris piles where they cannot enter the stream (e.g., not in the active floodplain, nor on steep slopes adjacent to the stream).

5.5.3.2 Types of Crossings

Aim to keep stream crossings to a minimum and ensure that they are at locations where natural conditions provide for minimal disturbance to the streambed and bank. If it is necessary to cross the water frequently, construct a proper structure to minimize erosion.

This section discusses the design considerations and installation practice recommended for various types of stream crossing structures. Fish stream crossing structures should retain the preinstallation stream conditions to the extent possible. The objective is to ensure that the crossing does not restrict the cross-sectional area, or change the stream gradient, and that the streambed characteristics are retained or replicated.

The choice and design of fish stream crossing structures are determined by a number of factors, including: sensitivity of fish habitats; engineering requirements; cost and availability of materials; and cost of inspection, maintenance, and deactivation. Not all options are appropriate on all sites.

The types of structures to consider include:

- Open bottom structures (bridges and culverts)
- Closed bottom structures (corrugated pipes)
- Other structures (ice bridges and snowfills)

This list does not preclude the use of other structures, or a combination of structures, provided they meet the requirements of regulation and legislation. Be aware that special design considerations are required for roads and crossing structures in alluvial fans, where streams are in active floodplains, or where streams are meandering or braided.

Figure 16: Bridges can be constructed from local materials and need not be major structures if equipment can be moved by hand as in this example from Central America. © Energold

Open Bottom Structures

There are two types of open bottom structures to consider for any stream crossings required by an exploration program. These are:

- Bridges
- Open bottom culverts

The information below describes these choices and ways to install them with minimal environmental impact.

Bridges

When designed and constructed with abutments that do not constrict the stream channel, bridges have the least impact on fish passage and fish habitat. When constructing bridges, get appropriate engineering input to ensure the least impact.

Figure 17: A well-constructed bridge can minimize stream disturbance, carry heavy equipment and need not have high cost. © Golden Band.

Bridges can be designed for permanent, temporary, or seasonal installation. They range from log stringer bridges (with gravel or timber decks) to steel girder bridges (with timber or precast concrete decks).

Bridges can be supported by various means, including:

- Log cribs
- Steel pipes
- Steel bin walls
- Cast-in-place concrete
- Precast lock block walls
- Timber
- Piers

Where practicable, avoid in-stream piers, because these can collect debris during flood events, resulting in scouring of bridge foundations. In-stream piers can also result in hydrologic changes, such as bedload scour or deposition, which may adversely affect fish habitat. It is likely that fisheries agencies may only approve bridges with support piers after all other options (e.g., clear span) are considered.

The decision to use a bridge rather than a culvert can be driven by:

- Economics
- Engineering requirements
- Site parameters
- Environmental or hydraulic concerns

- Bedload and debris transport factors

Three examples of bridges are:

- Steel girder bridge
- Log stringer bridge
- Concrete slab bridge

It should be noted that a well-designed and constructed log stringer bridge can carry most of the heavy loads required for exploration programs, and costs considerably less than a steel girder or concrete slab bridge.

Figure 18: Good example of a steel girder bridge with wooden deck and stone-filled cribs. Locking gate can be used in this case to control access.© Noranda/Falconbridge

Open Bottom Culverts

Open bottom culverts are similar to bridge structures, generally spanning the entire streambed and minimizing impacts to the natural stream channel. They are differentiated from bridges in that the fill placed over these structures is an integral structural element.

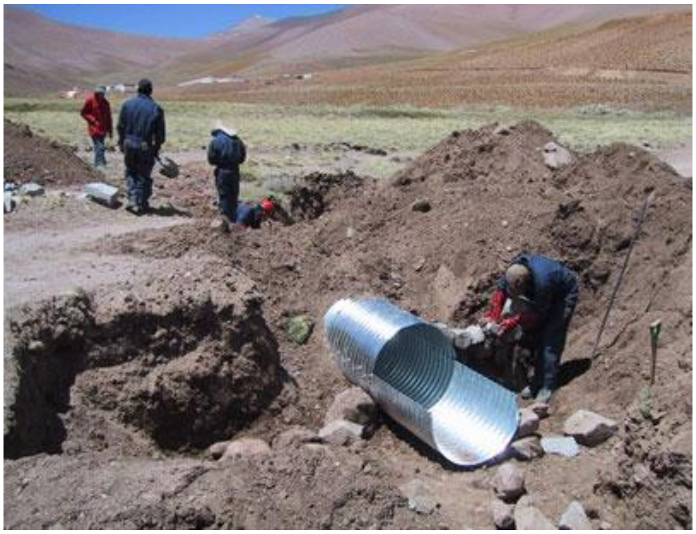

Figure 19: Placing a culvert in the high Andes of South America.
© Noranda/Falconbridge

Log Culverts

The most common type of open bottom culvert is the log culvert. It is widely used in areas where the availability of suitable logs makes it an economical alternative to steel or concrete. Log culverts are readily adapted to meet flood requirements and generally do not pose a risk to fish passage when sill logs are placed to maintain the stream channel width.

Design the bottomless culvert to span the stream channel width and so avoid impacts on fish habitat and fish passage. Depending on the stream profile, there may be a need for large sill logs or log cribbing with log culverts to achieve adequate flow capacity. Alternatively, small sill logs may be used, with the span increased, to get sill logs well above and outside the scour zone of the stream.

Arches

Other types of open bottom culverts include arches constructed of:

- Steel
- Plastic
- Other materials

Arches come in various shapes, ranging from low to high profiles and are typically installed on concrete or steel foundations.

It is important to differentiate small, arch-type open bottom structures requiring excavation and reconstruction of the streambed, from larger arches that are constructed without disturbance to the streambed. Install small bottomless arches with the same considerations afforded closed bottom structures. Engineer these carefully to ensure that the footings of these small arches are secure and not subject to undercutting.

Installation of Open Bottom Structures

The steps below outline the general installation procedures to follow for open bottom structures as they apply to fish streams. Ensure that excavation and backfilling for footings does not encroach on the stream channel width.

Vibrations during Construction

Carry out practices such as pile driving and blasting, that result in vibrations potentially harmful to fish or fish eggs during the in-stream work windows. Fish salvage may be required to remove the fish from harm.

Sediment Control at Worksite

Where feasible:

- Operate all equipment from the top of the stream bank
- Isolate the work area from water sources
- Contain sediments within the worksite
- Pump out sediment-laden water to a settling site during construction and installation

Drainage

Do not allow road ditches to drain directly into the stream. Instead, divert ditch water into a constructed sump or, where possible, onto stable forested vegetation that can filter sediments before reaching the stream.

Ensure that adequate cross drainage is in place before the bridge approach, to minimize water volume directed into approach ditches at bridge sites. To divert runoff from the road surface, consider:

- Crowning the surface
- Using rolling grades
- Employing other practices (e.g., mounds/waterbars)

Where cross ditches are used, ensure that they are properly armoured with broken rock at the outlet and along the base.

Constricting the Stream

Do not allow activities, including the placement of broken rock, to cause any constriction of the stream channel width.

Deleterious Materials

To prevent deleterious substances from entering streams, use precautionary measures with materials such as:

- New concrete
- Grout
- Paint
- Ditch sediment
- Fuel

- Preservatives

If using wood preservatives that are toxic to fish, use them in accordance with local guidelines.

Seepage Barriers

Geotextiles can be used to prevent loss of fines and gravel through seepage along the edges of structures (e.g., abutments, side walls of arches). The fabric, prefabricated seepage barriers, or other cut-off measures (e.g., sandbagging), installed along the edges of the structure near the inlet, are intended to prevent most of the fines and gravel seepage and mitigate potential support fill erosion that can occur here.

Geotextiles

For gravel-decked bridges or log culverts, use a geotextile filter fabric to fully cover the stringers, or some other measure to prevent road material from entering the stream.

Turnouts

Construct turnouts at a sufficient distance from the bridge to prevent road material from entering the stream, and to minimize impacts on riparian vegetation.

Closed Bottom Structures

Closed bottom structures for fish stream crossings are corrugated pipes (metal or plastic) which, embedded to retain stream substrate, provide fish habitat and fish passage. Closed bottom structures are not allowed in critical fish habitat, but are an option for use in small streams with a stream channel width of 2.5 m or less, and at an average stream gradient of 6% or less.

Stream Simulation

Experience has shown that closed bottom structures can be successfully installed when paying careful consideration to site conditions and structure design parameters. The stream simulation (also known as embedment methodology) requires the selection of a culvert (pipe) of adequate opening to encompass the stream channel width and to emulate the streambed within the culvert, by lining the bottom with representative streambed substrate. Supplement the natural substrate materials with additional larger material to help retain the substrate within the culvert and assist fish passage. By emulating the streambed and stream channel width, the culvert's stream flow characteristics can reflect the natural stream flow characteristics.

The use of closed bottom structures in fish streams requires careful design and layout, paying particular attention to fish passage and fish habitat over the lifespan of the structure.

Stream Profile

Construct a detailed profile of the existing streambed for an extended distance upstream and downstream of the proposed crossing (approximately 50 m each way), and establish benchmarks for elevation and construction control. The objective is to accurately model the streambed profile, to determine the culvert slope, streambed elevations, and streambed conditions. Streams that have bedrock outcrops or little variation in bed elevation generally require shorter profiles.

Culvert Installation

Design and install a closed bottom culvert at the same slope as the stream, retaining the same stream substrate characteristics within it. For migrating fish, this will impose no changes or stress, nor induce any delays at the crossing structure in upstream migration. Substrate transport should move through the culvert naturally, and there should be no sediment buildup upstream or deprivation downstream.

The vertical placement of the culvert in relation to the overall stream longitudinal profile is extremely important. The longitudinal profile of the streambed should be used to ensure that the culvert is located at a low point along the streambed. Remember that the culvert is to follow the slope of the streambed. Make special note of any other non-permanent anomalies (e.g., large debris-holding areas), as they may not provide a suitable location for culvert installation.

Where practicable, retain the natural meander pattern of a stream. Do not place a closed bottom structure in the bend of a stream, as this leads to bank erosion and debris problems. When this cannot be achieved, relocate the crossing structure or choose another type of crossing structure, such as an open bottom structure.

Pipe Size

The stream channel width should determine the required culvert diameter or width. Ensure that the width of the replicated or simulated streambed within the culvert is equal to or greater than the stream channel width, to emulate the natural stream and to prevent deposition, scouring, or other damage at the outlet. Factors that help determine appropriate stream channel width are included below.

Size a closed bottom structure to accommodate the 100-year return period peak flow after embedment. Carry out this flow determination, and enlarge the pipe if it cannot pass the 100-year peak flow design.

Factors in determining the appropriate culvert width include:

- Depth of fill
- Skew angle of the culvert to the road
- Gradient of the culvert
- Required road width

Design the closed bottom structure properly to avoid letting side slope and backfill material enter the culvert or flow channel. Use broken rock to provide scour protection for materials potentially exposed to erosion.

Embedment

For circular culverts, the embedment should make up at least 40% of the culvert diameter, or 0.6 m, whichever is greater. For pipe arch or box culverts, embedment depth should be at least 20% of the vertical rise of the arch.

To allow for proper embedment, the streambed requires sufficient layers of unconsolidated gravel, sand, cobble, and other sediment lying over the top of the bedrock to allow for proper embedment. If little streambed is available to be excavated, culvert sinking and embedding strategies become impractical.

Substrate Placement Within the Pipe

For successful substrate placement, it is critical to know the type of material found in the natural streambed, and to have a specification for replicating this material. As a general rule, the sizing of material within the culvert should be similar to the size of material in the adjacent natural stream channel. The hydraulic roughness of the culvert bottom is related to the size of bed material. Hydraulic roughness in turn is related to water velocities and water depth inside the culvert.

Based on a design specification for gradation, fill the closed bottom structure with substrate material to the natural streambed level, using clean, well-graded material and supplemental material that is equal to, or greater than, the stream channel particle size. Use a heterogeneous mixture of various substrate sizes that contains enough fine material to seal the streambed. Where the streambed is not sealed, subsurface flow may result, creating a barrier to fish passage. It may be necessary to supplement the substrate by washing in sand and gravel to seal the bed. Wash the simulated streambed and intercept the sediment at the outlet of the pipe before it enters the stream.

When closed bottom structures are installed in streams with gradients between 3-6%, the physical placement of supplemental larger material (D90+) is even more important. (Note: D90 is defined as the largest size class of streambed substrate that can be moved by flowing water. Approximately 90% of the streambed substrate will be smaller than this size class.) Oversized material may be problematic, creating increased hydraulic roughness and flushing out fines through the poor gradation of the embedment materials.

At these gradients, ensure the pipe is large enough to allow for the physical placement and orientation of these larger elements. This should assist in retaining substrate and preventing scour in the culvert. The design should note the dimensions and quantity of the additional larger material. Establish a thalweg (low-flow channel) through the culvert to enable fish passage at low flow.

Closed bottom structures for fish stream crossings are corrugated pipes (metal or plastic) which, embedded to retain stream substrate, provide fish habitat and fish passage. Closed bottom structures are not allowed in critical fish habitat, but are an option to use in small streams with a stream channel width of 2.5 m or less, and at an average stream gradient of 6% or less.

Stream Simulation

Experience has shown that closed bottom structures can be successfully installed when paying careful consideration to site conditions and structure design parameters. The stream simulation (also known as embedment methodology) requires the selection of a culvert (pipe) of adequate opening to encompass the stream channel width, and emulate the streambed within the culvert by lining the bottom with representative streambed substrate. Supplement the natural substrate materials with additional larger material to help retain the substrate within the culvert and assist fish passage. By emulating the streambed and stream channel width, the culvert's stream flow characteristics can reflect the natural stream flow characteristics.

The use of closed bottom structures in fish streams requires careful design and layout, paying particular attention to fish passage and fish habitat over the lifespan of the structure.

Stream Profile

Construct a detailed profile of the existing streambed for an extended distance upstream and downstream of the proposed crossing (approximately 50 m each way), and establish benchmarks for elevation and construction control. The objective is to accurately model the streambed profile, to determine the culvert slope, streambed elevations, and streambed conditions. Streams that have bedrock outcrops or little variation in bed elevation generally require shorter profiles.

Culvert Installation

Design and install a closed bottom culvert at the same slope as the stream, retaining the same stream substrate characteristics within it. For migrating fish, this will impose no changes or stress, nor induce any delays at the crossing structure in upstream migration. Substrate transport should move through the culvert naturally, and there should be no sediment buildup upstream or deprivation downstream.

The vertical placement of the culvert in relation to the overall stream longitudinal profile is extremely important. The longitudinal profile of the streambed should be used to ensure the culvert is located at a low point along the streambed. Remember that the culvert is to follow the slope of the streambed. Make special note of any other non-permanent anomalies (e.g., large debris-holding areas), as they may not provide a suitable location for culvert installation.

Where practicable, retain the natural meander pattern of a stream. Do not place a closed bottom structure in the bend of a stream, as this leads to bank erosion and debris problems. When this cannot be achieved, relocate the crossing structure or choose another type of crossing structure, such as an open bottom structure.

Installation of Closed Bottom Structures

The steps below outline the general procedures to follow for the installation of closed bottom structures in fish streams.

Planning

Deliver all required materials and mobilize equipment in advance, so the installation can proceed without delay on a dry bed, within the timing window. Employ appropriate worksite isolation techniques during the closed bottom structure installation.

Survey

Lay out the worksite with precise instruments, including establishing the horizontal and vertical field references, to accurately establish the culvert embedment elevation and slope during construction.

Bed Preparation

Prepare and grade the culvert bed to conform to the design elevation and slope, using benchmarks and precise instruments. Ensure the barrel of the closed bottom structure is set to the appropriate depth below the streambed, and at the same natural stream gradient as shown by the longitudinal profile survey. Ensure that the culvert foundation, trench walls, and backfill are free of logs, stumps, limbs or rocks that could damage or weaken the pipe.

Seepage Barriers

Consider using geotextiles to prevent loss of fines and gravel through seepage along the culvert wall. The fabric, or other cut-off measure (e.g., sandbagging, prefabricated seepage barriers), placed along the culvert near the inlet, is intended to cut off most seepage and mitigate potential support fill erosion that can occur along the pipe.

Drainage

Do not allow side ditches to drain directly into the stream. Instead, divert ditchwater into a constructed sump or, where possible, onto stable forested vegetation that can filter sediments before the water reaches the stream. Ensure that adequate cross drainage is in place before the culvert approach, to minimize the water volume directed into approach ditches at culvert sites. Consider the use of mounds (waterbars) to divert road surface runoff. Where cross ditches are used, ensure that they are properly armoured with broken rock at the outlet and along the base.

Constricting the Stream

Do not allow any activities, including the placement of broken rock, to cause any constriction of the stream channel width.

Erosion Protection

Begin erosion-proofing all exposed mineral soil as soon as possible after disturbance.

Downstream Weir

Establish an in-stream weir within 1.5 to 2 channel widths downstream of the culvert outlet, particularly for streams greater than 3% gradient, to retain substrate within the culvert and to prevent the formation of a plunge pool. The residual pool depth formed by this downstream weir should be less than 0.3 m.

Backfill

Your backfill practices should conform to those specified by the culvert manufacturer, or otherwise specified by an engineer, and incorporate mechanical vibratory compaction immediately adjacent to the culvert.

Slopes >3% grade

For culverts installed at slopes greater than 3%, you should mix larger material (D90 or greater) into the substrate to help retain the substrate in the pipe. You should place the larger material so that it projects from the streambed. This should create velocity shadows to enhance fish passage, retain substrate, and simulate conditions in the natural stream.

Ice Bridges

Ice bridges are effective stream-crossing structures in cold climates for larger streams and rivers, where the water depth and stream flow under the ice are sufficient to prevent the structure from coming in contact with the stream bottom (grounding), and where there are no concerns regarding spring ice jams. Grounding can block stream flow and fish passage and cause scouring of the stream channel.

Design of Ice Bridges

Consider the following when planning the design of ice bridges:

- Depth of water
- Minimum winter daily stream flow
- Substrate
- Crossing location

- Maximum load strength
- Time of use
- Thickness of ice required
- Approach construction
- Maintenance and monitoring
- Decommissioning

Installation of Ice Bridges

The steps below outline the general installation procedures for ice bridges as they apply to fish streams:

- Determine whether using logs as reinforcing material could cause problems. There is a possibility that logs, if left in place through spring break-up, could contribute to debris jams and increase the risk of flooding, river channel alteration, erosion, and habitat loss. If this is an unacceptable risk, do not use logs. In most cases, log removal from a deteriorating ice bridge is an unsafe practice. In these situations, removing all but the lowest logs from the ice bridge may be acceptable.

- Measure and record ice thickness and stream depth routinely. Evidence of grounding, or an increased risk of the ice base grounding with the streambed, may require that the bridge be temporarily or permanently decommissioned.

- Locate ice bridges where cutting into the stream bank would be minimized during construction of the approaches. Remove all debris and dirt and place this at a stable location above the high-water mark of the stream.

- Construct approaches of clean compacted snow and ice to an adequate thickness to protect stream banks and riparian vegetation. Construction should begin from the ice surface. Where limited snow is available, gravel (if available locally and from approved pits) can be used to build up approaches. Remove this gravel when the ice bridge is deactivated.

When it is time for deactivation, remove all ice bridge approaches. Recontour and revegetate stream banks where the soil has been exposed, using all appropriate measures to stabilize the site and facilitate its return to a vegetated state.

Snowfills

Snowfills are options to consider for seasonal use, depending on the site, time of year, and other environmental constraints that may apply. Construct and deactivate snowfills such that they do not affect fish or fish habitat at break-up. Deactivation is difficult and often results in channel disturbance as frozen material clings to logs.

Construct snowfills by filling the channel with compacted clean snow (e.g., free of dirt and debris). Consider their use only if the stream is dry or the water is frozen to the stream bottom. Log bundles or culverts can accommodate unanticipated stream flow due to unseasonal thaws. To avoid adverse impact on the stream, remove the log bundles, culverts, and snow prior to spring thaw.

Figure 20: Winter stream crossing. Note use of snow fencing for guidance, warning signs and silt fencing. © Noranda/Falconbridge

The steps below outline the general installation procedures for snowfills as they apply to fish streams:

- Construct snowfill of dirt-free snow, only when there are sufficient quantities available for construction. Begin construction after the stream has frozen solid to the bottom, after the stream has ceased to flow, or when there is sufficient ice over the stream to prevent snow-loading from damming any free water beneath the ice. Where possible, place snow into the stream channel with an excavator. Crawler tractors can be used to push snow into the stream channel, but only if they can push snow unaccompanied by dirt and debris.

- Place a pipe culvert, heavy steel pipe or bundles of clean, limbed, and topped logs within the stream channel to allow for water movement beneath where stream flow is anticipated during periodic winter thaws. It is not acceptable to use logs on streams where winter fish migration may be required. Heavy steel pipe is easier to salvage and has less chance of crushing under load and during removal.

- Do not cap snowfill with soil. There is risk that soil placed within the stream channels could make its way into the stream during winter thaws.

- Remove any snowfill that may cause damage to the stream because of warmer weather, and reconstruct a new snowfill when colder weather returns.

- Remove all snowfills and materials before the spring melt, and place materials above the normal high-water mark of the stream, to prevent them from causing sediment and erosion. When deactivating, include the use of all appropriate measures to stabilize the site and facilitate its return to a vegetated state.

Fords

Fords, constructed as crossing structures, can result in habitat degradation through sedimentation, channel compaction, and the creation of barriers to fish passage. For these reasons, authorizing agencies do not encourage the construction of fords on fish streams. If considering a ford, check with the appropriate fisheries agency.

The fording of fish streams is generally limited to one location and one crossing (over and back) for each piece of equipment required for construction on the opposite side. Where additional movements of equipment may be required, obtain approval from the appropriate fisheries agency, regardless of habitat type.

Use a temporary crossing, or other practices, to protect the streambed and banks, if the streambed and stream banks are highly erodible (e.g., dominated by organic materials, silts, silt loams), and significant erosion and stream sedimentation or bank or stream channel degradation may result from heavy equipment crossings.

5.6 Controlling Sediment

It is important to contain sediment-laden runoff so that soil particles can be removed using filtering or settling methods.

Control sediment at the source, as much as possible. Once entrained in water, it is more difficult to control. To effectively control sediment during excavation or construction, use the following, singularly or in combination:

- Sediment traps and basins
- Silt fences
- Straw bale dikes and basins
- Geotextiles

Sediment traps and basins can be either simple, small pits or large, complex, engineered structures designed to impound large quantities of sediment. Silt fences and straw bales, in contrast, are designed primarily to intercept and filter small volumes of sheet-flowing, sediment-laden runoff, before it reaches the watercourse. These are more likely to be applicable to exploration programs.

Do not use silt fences as filters within a watercourse, as they have limited capacity to pass water. On completion of the exploration activity, remove these temporary control structures and stabilize the sediment.

It is important to control runoff and remove sediment from diverted drainages. The variety of methods that can be used include:

- Barriers
- Traps
- Settling ponds

These methods slow the flow of water and allow the suspended sediment to settle or be trapped in filters. The type of barrier to choose depends on the:

- Materials available

- Drainage configuration
- Particle size of suspended sediment
- Velocity of runoff
- Site layout

Types of barriers include:

- Straw bales and sandbags, incorporating geotextile filter cloth
- Silt fences
- Brush barriers
- Diversions and dams
- Sediment traps or basins

These barriers and/or traps can temporarily control sediment at sites with low volumes of water and sediment. Barriers can be placed across ditches or drainages at periodic intervals, on the perimeter of a disturbed area and at storm drain inlets. Traps and basins also can filter out sediment effectively.

5.6.1 Straw Bales and Sandbags

Straw bales and sandbags are best suited where temporary, relatively minor erosion control is needed, while more permanent solutions are being devised. However, do not use sandbags as filters within a watercourse, as they have limited capacity to pass water.

When used properly, straw bales can be effective in intercepting sheet flow runoff at the base of a slope, or in acting as a check-dam in the ditchline of a road. Do not stack straw bales on top of each other. Take care to ensure that noxious weeds and non-native grasses are not spread as a result of using straw bales. In particular, hay bales generally contain the edible portion of grasses and more seeds than straw bales.

Straw bales and sandbags require routine inspections, maintenance and frequent repair, particularly after precipitation. In order to extend their effective service life when installing these barriers:

- Use straw bales bound with wire or nylon line (less susceptible to rot).
- Excavate a trench the width of the bales and to a depth of 15 cm.
- Lay the straw bales on their sides and stake in place. At a minimum, drive 2 metal stakes through each bale, and extend into the ground at least 30 cm. Angle the first stake toward the previously placed bale, and drive through both the first and second bale.
- Tamp and smooth any excavated soil along the upstream portion of the barrier.

Incorporate geotextile fabric with straw bale barriers, or use them in conjunction with a silt fence, to improve their effectiveness. In some circumstances, straw bales can be used to help anchor silt fencing

To ensure that straw bale or sandbag barriers remain effective:

- Remove deposited sediment routinely and dispose off-site
- Replace damaged or rotten bales or sandbags

Figure 21: Used together, silt fencing and hay bales can be very effective in some circumstances. © Noranda/Falconbridge.

5.6.2 Silt Fences

Filter or silt fences are designed to intercept surface runoff on slopes of varying degree. They retain soil on the site and reduce runoff velocity across areas below the fence. Silt fences are effective, and can be used to intercept soil from disturbed slopes and ditchlines, and to isolate work areas from a stream. They are intended to prevent sediment from entering channelized flows.

Construct these barriers in series, depending on the size of the contributing drainage area. A rule of thumb is approximately 30 m of fence for every 0.1 ha of drainage area. Fences require regular maintenance to maintain functionality, so access is necessary.

Construction of filter or silt fences involves attaching filter fabric to wood stakes. Depending upon the specifics of the site, place the stakes on 1-2 m centres. Construct a trench along the base of the silt fence and ensure that approximately 20 cm of the filter fabric (a suitable permeable geotextile) is buried both vertically and horizontally, to hold the fabric in place. After securely attaching the filter fabric on the uphill side of the wood stakes, backfill the trench and compact the soil against the filter fabric. The average usable life of filter or silt fences is 6 months to 1 year.

Thoroughly inspect the filter or silt fence after each precipitation or storm event, and immediately repair it if required. Remove sediment regularly to keep the barrier functional, and do not allow sediment to reach one-half the height of the fence. Properly dispose of excavated material off-site and never place it downslope. The effectiveness of filter or silt fences is excellent if they are installed properly and maintained regularly.

After work is completed, carefully remove silt fence structures, to prevent the sediment retained from entering the watercourse or being remobilized during the next precipitation or storm event.

Figure 22: Silt fence in place on stream crossing in northern Canada. © Noranda/Falconbridge.

5.6.3 Brush Barriers

Brush barriers are perimeter sediment control structures that you can use to prevent soil in storm water runoff from leaving a construction site. Brush barriers are constructed of material such as small tree branches, root mats, stone, or other debris left over from site clearing and grubbing. In some configurations, you can cover brush barriers with a filter cloth to stabilize the structure and improve barrier efficiency.

Generally, the drainage slope leading down to a brush barrier should be no greater than 2:1 and no longer than 30 metres. You should recognize that brush barriers have limited usefulness because they are constructed of materials that decompose.

You should construct a brush barrier using only material cleared from a site, and you can cover the mound of material with a filter fabric barrier to hold the material in place and increase sediment barrier efficiency. Whether a filter fabric cover is used or not, the barrier mound should be at least 1 metre high and 1.5 metres wide at its base. You should not use material with a diameter larger than 15 centimetres, as it may be too bulky and create void spaces where sediment and runoff will flow through the barrier.

You should bury the edge of the filter fabric cover in a trench 10 centimetres deep and 15 centimetres wide on the drainage side of the barrier in order to secure the fabric and create a barrier to sediment while allowing storm water to pass through the water-permeable filter fabric. The filter fabric should be extended just over the peak of the brush mound and secured on the down-slope edge of the fabric by fastening it to twine or small-diameter rope that is staked securely.

Brush barriers are an effective storm water runoff control only when the contributing flow has a slow velocity and are therefore not appropriate for high-velocity flow areas. A large amount of material is needed to construct a useful brush barrier. For sites with little material from clearing, you may find that alternative perimeter controls such as a fabric silt fence may be more appropriate. Although brush barriers provide temporary storage for large amounts of cleared material from a site, you will have to remove this material from the site after construction activities have ceased and the area reaches final stabilization.

You should inspect brush barriers after each significant rainfall event to ensure continued effectiveness. If channels form through void spaces in the barrier, you should reconstruct the barrier to eliminate the channels. You should remove accumulated sediment from the uphill side of the barrier when sediment height reaches between 1/3 and 1/2 the height of the barrier. When the entire site has reached final stabilization, you should remove the brush barrier and dispose of it properly.

5.6.4 Diversions and Dams

Sediment delivered to stream channels can harm fish and fish habitat. Most sedimentation occurs in the first year, when soils are exposed during and immediately following road construction or stripping. The amount of sediment generated at a stream crossing or from a construction or excavation site is directly related to the:

- Sensitivity of the soil to erosion
- Amount of area exposed to runoff or stream flow
- Disturbance caused by the camp or road construction

Diversions and dams redirect water away from disturbed sites or create "dry" work areas in streams, thereby minimizing the erosional effects of flowing water.

It is essential to prevent sedimentation by minimizing disturbance to stream banks and retaining riparian vegetation. Many small streams and adjacent worksites are dry during the dry season, allowing construction or excavation without special measures for erosion and sediment control. When water is present, most erosion and sediment problems can be avoided through the use of a variety of methods that control sediment at the source, and prevent it from becoming entrained in the flowing water.

The key is to isolate flowing water from the worksite. During periods of heavy or persistent rainfall:

- Suspend work activities, as they could result in sediment delivery to the stream and adversely affect aquatic resources
- Implement measures to minimize the risk of sediment delivery to the stream

The subsections which follow present details of

- Diversions
- Cofferdams

Diversions

It may be necessary for you to divert uncontrolled surface water runoff from around disturbed surfaces in order to minimize erosion (such as sheet wash and gullying). Where necessary, you should construct storm water runoff drainage systems and adapt them to the general terrain of the area.

Before the start of construction, excavation or road building activities you should construct drainage diversions to

- Intercept water, and

- Divert it away from work areas.

To provide adequate drainage and slope gradient to control the volume and velocity of runoff you can use

- Sloping,
- Ditching, and
- Berming.

It is generally better for you to spread out water than to concentrate it.

In order to collect and divert runoff, you should

- Locate cleared areas on the most level ground available.
- Avoid areas subject to flooding.
- Design construction or stripping so as to avoid creating long uninterrupted slopes.
- Create sloping or crowning road surfaces to prevent water from collecting and flowing along the road.

You should also

- Develop a system of ditches and culverts for permanent or heavily used roads. On temporary roads, you can use waterbars (mounds) and dips (narrow, shallow trenches) to divert water, and these should be installed at frequent intervals to prevent concentrating runoff (see figure below). You should construct waterbars at an angle across the road to permit downhill drainage of water across the road or track.
- Control any discharge of diverted water.
- Plan roads, grids, and trenching with as low a grade as possible. Maximum grades of 8 to 10 percent are desirable, although short distances of 15 percent can be accepted if necessary.

You should place rip-rap, as needed, in locations where the soil is easily erodible. You can provide sediment control structures such as silt fences or rip-rap in camp runoff gullies before their intersection with natural systems. You should place rip-rap or a shot rock pad at the outlet of all cross drains where ditch water is being diverted from an approach ditchline and discharged onto erodible soils or fills.

You will find that ditches lined with rip-rap, shot rock, or large gravel are an effective method for reducing erosion at approaches to stream crossings. Rip-rap slows the velocity of ditch water and armours erodible ditch bed materials.

All rip-rap or rock that you use should be free of

- Silt.
- Overburden.
- Debris.
- Other substances deleterious to fish.

The material should be durable and sized to resist movement by streamflow. Where rip-rap is not available, you can use fabric linings temporarily at approaches and culvert spillways.

On small streams or where flows are very low, pipes or erosion-proofed ditches may be adequate to divert flow around the construction site. To minimize sediment loss at these sites from and along the diversion, you should install sediment traps, combined with the use of geotextiles.

You should always excavate temporary stream diversions in isolation from streamflow, starting from the bottom end of the diversion channel and working upstream to minimize sediment production. To prevent loss of sediment, you should leave the bottom end of the diversion channel intact until the diversion trench is almost complete and you should not open it until all measures have been taken to reduce surface erosion resulting from water flowing in the new channel. After your exploration activity has been completed, you should close the diversion from the upstream end first and re-establish the pre-diversion conditions, stabilize and revegetate the site.

Where practical, you can also pump water across the work site and discharge it into the stream channel below the site. This technique requires that you dam the stream above the exploration site. This eliminates the need for a diversion channel, and thus greatly reduces the problems of sediment production associated with digging and operating a newly created stream channel. You should screen pump intakes to prevent entrainment of juvenile fish. Backup pumps on site are highly recommended in all pumping situations.

Cofferdams

You may require cofferdams to isolate work from the streamflow. Cofferdams are temporary enclosures that are built in the stream bed to keep water out during the construction activity. When building these structures you should not reduce the stream channel width by an amount that could lead to erosion of the opposite banks or of upstream and downstream areas. You can construct cofferdams in various ways. For example, sandbags lined with geotextiles or rubber aqua dams can be used.

You should remove all materials after your exploration activity is completed, and discharge all water pumped from contained work areas within cofferdams to a forested site to allow sediment to settle before the water re-enters the stream.

Dams can experience the buildup of sediment. You should be aware that

- Water retention or siltation ponds (or sediment ponds) collect runoff and allow the suspended sediment to naturally settle to the bottom of the pond.
- Dams and embankments can be constructed and shaped to reduce the runoff velocities.
- Sedimentary basins may be required to control the discharge of suspended solids which will settle out of the water when it is left standing in the basin for a period of time.

5.6.5 Sediment Traps or Basins

Sediment traps or basins are excavated pits that capture coarse sediments from ditchlines before they can enter a stream. For these to be effective, clean all sediment traps and basins frequently while they are in place. At the site of a stream crossing, direct ditch water into the sediment trap or basin.

If a large amount of ground water is encountered, or anticipated, during drilling or trenching operations, construct a sediment basin (mud pit). Constructed properly, sediment basins reduce or abate water pollution, by providing basins for deposition and storage of silt, sand, gravel, stone, drill cuttings, and other debris.

Sediment basins can be utilized in conjunction with erosion control measures installed at the source of the sediment, or where a sediment basin offers the most practical solution to the problem. Straw bales and filter fences work effectively with sediment basins.

5.7 Special Terrains

Some terrains may have unique ecologies that are particularly sensitive to land disturbance. It is important to recognize the vulnerabilities of these terrains, and to operate around them to minimize any impact. The following sections discuss specific terrains, and the measures that are applicable to them.

5.7.1 Arctic and Alpine Terrains

Arctic and alpine terrains are typically very fragile and highly sensitive to change. These regions have very slow growth rates and any disturbance can be very long lasting. If at all possible, avoid road construction in such areas. Tracks are difficult to construct and nearly impossible to restore. It is preferable to use tracked, low ground pressure vehicles when there is adequate snow cover, or helicopters.

To minimize loss of topsoil in alpine terrains, preserve the vegetation cover as far as possible. If a road must be constructed for transport of equipment and supplies in arctic terrains, use a winter road. Use only clean snow and ice as fill material, minimizing the damage to the fragile arctic environment, as the ground will be frozen. Make sure that the route is marked, confining traffic to the selected route and preventing vehicles from becoming lost during whiteout conditions.

Arctic Terrain

For purposes of EES Plus, the Arctic is considered that portion of the northern hemisphere generally above the tree line. As such, the Arctic includes portions of North America, Asia and Europe. The region is characterized by long winters with short daylight periods and short but dynamic summer periods. Permafrost is ubiquitous. Precipitation is low and much of the Arctic is a true desert despite the presence in portions of the region of almost continuous snow and ice cover. Parts of the Arctic encompass alpine terrain, coastal terrain, wetlands and riparian terrain. Population is generally sparse and dominantly made up of indigenous peoples. Vegetation and wildlife are unique, in largest part due to the climate and but also due to lack of human activity in the area. The low precipitation and generally low temperatures create conditions where material left in the field can last for generations and damage to soils/vegetation can take many years to heal. This unique and valuable environment requires special respect and attention during exploration programs.

Exploration in the Arctic requires special planning to avoid unnecessary environmental impact. Wherever possible, plan programs during the winter season to avoid impact on fragile vegetation and soil cover. (Clearly, this is not possible for prospecting and mapping programs but these activities are much less disruptive.) Avoid all activities that might disrupt the migratory pattern of animal life (information on migration patterns and periods is usually available from local wildlife officials.) Respect cultural and archaeological sites (see separate EES Plus section.) Ensure that only native species are used for reclamation purposes.

Almost all Arctic exploration involves fuel handling and containment to one degree or another. Fuel caches are usually required because of the long distances from supply centres to the project. All the precautions described elsewhere on this website apply but it should be especially noted that fuel leaks often go unnoticed with snow cover since the fuel will travel beneath the snow. Cleanup of such leaks is difficult and messy. The best solution is prevention of all leaks.

Permafrost conditions are unique to the Arctic and certain alpine terrain. Special care is needed when working in such conditions to avoid uncontrolled thawing of the permafrost. Exposure of the permafrost during warmer seasons will create melt which becomes self-perpetuating, i.e. the meltwater itself causes thawing of more and more permafrost. Especially in areas of slope, this melting will create gullys and unsightly erosional scars on the landscape.

Figure 23: Drilling in the Arctic may require special techniques to deal with permafrost (and the long hours without sunlight). © BHPBilliton.

Wherever possible, use helicopter (or fixed wing) access and servicing for all programs in Arctic terrain. (In most cases, this will be the most effective means of access for other reasons as well.) If other forms of access are required, use lightweight, low ground pressure vehicles and, wherever possible, restrict their use to snow and ice covered areas. Avoid disturbance of permafrost, vegetation and soil.

Objects and landscape scars are visible for many kilometres in the Arctic both from the air and on land. Because of climatic conditions, decay of these objects and healing of the scars are extremely slow. As explorationists we must act responsibly to avoid such situations. We will become (with justification) more obvious targets for activist groups if we are the cause of such problems.

Trenching and pitting in the Arctic should be reclaimed as soon as possible, especially in permafrost areas. Particularly if on a slope, the trench will become an unsightly point source of erosion by rain and meltwater. Organic soil should be carefully preserved for use during reclamation.

Trenches and pits in permafrost for placer gold exploration require special mention. Side slopes in ice-rich overburden ("black muck") may be left near-vertical to thaw and stabilize naturally. Ideally, these slopes should be undercut so that the top vegetated mat falls over and covers the exposed ice-rich slope. As in all trenching or pitting programs, special care should be taken to ensure trenches and open cuts for placer exploration do not become self-perpetuating growing gullies.

Alpine Terrain

Definition

Alpine terrain is steep-sloped landscape occurring above the tree line in mountainous country, covered with grass, scree/talus, and rock.

Although the word “alpine” (derived from the Alps of Europe) is used in this section, in South America a more appropriate word would be “andean” (derived from the Andes Range). Some of the descriptions also apply to tundra terrain, although differences in sunlight intensity, variation between daytime and nighttime temperatures and other factors lead to important distinctions between alpine and tundra conditions. Tundra is mainly restricted to circum-Arctic regions, largely in the northernmost parts of North America and Eurasia, together with the coast of Greenland and a number of Arctic islands.

For the sake of brevity, this section will use only the word “alpine”.

Alpine terrain occurs at all latitudes – even at the equator – as the tree line occurs at any elevation that fails to have 60 days with temperatures of more than 15°C. At altitudes with these conditions, there is no sustained tree growth, so there is no continuous cover of deciduous and/or coniferous trees.

Alpine terrain is found throughout an extremely wide range of climatic zones, descending from elevations of 4,000-5,000 m.a.s.l. in the warm and cool temperature mountainous regions, through to sea level in the sub-Artic/sub-Antarctic regions.

Examples of these wide-ranging climatic zones include:

- **Hot/wet**: the Andes (Brazilian slope), Central America, Ruwenzori (Congo/Uganda), Himalayas, Irian Jaya (Indonesia), Philippines, Borneo, Papua New Guinea.
- **Hot/dry**: Interior Andes, Iran, Pakistan, south-central Asia.
- **Temperate/wet**: Tasmania, New Zealand, northern Europe, coastal British Columbia, northwest United States, Japan.
- **Temperate/dry**: Nevada, Colorado, California, central interior British Columbia, central Argentina.
- **Cold/wet**: Northern coastal British Columbia, coastal Alaska, south-central Chile, Patagonia, northern coastal Scandinavia.
- **Cold/dry**: Interior Yukon, Greenland, Spitsbergen, Argentinean Patagonia, sub-Antarctica, interior Alaska, Urals, Siberia, north-central Asia.

Alpine terrains have a high percentage of rock exposure, and give prospectors the ability to locate distinctive colour anomalies due to alteration and gossans. Alpine terrains also make it possible, with relative ease, to carry out heavy mineral, silt, soil, and rock geochemistry, and to relate any geochemical anomalies to a specific location. However, the terrain that provides these positive attributes is one of the most fragile and highly vulnerable to any disturbance caused by mineral exploration activity.

Potential Impacts on Alpine Terrains

In the low temperature environment of the alpine terrain there is little biological activity of any kind, with little possibility of biological regrowth to mitigate any disturbance. This terrain records every intrusion that is made on it and the visual reminders of these intrusions can last for hundreds of years. As tracings of exploration activity often have a striking linearity (e.g., geochemical and geophysical survey lines), they are immediately and jarringly obvious to the eye against the natural harmonious background.

Without tree cover, every object is extremely visible, often from tens of kilometers and even in areas which experience torrential rain, mass wasting, soil creep, cryoturbation.[1] For example, an orange peel might be very visible throughout the many years it takes to decay. This is also true for any man-made addition to the alpine landscape, from toilet paper, cans, wooden pickets, nylon measuring thread, and other objects used when laying out survey lines. Coloured flagging tape will last for decades, but the intense ultraviolet radiation is likely to turn all colours to white and marker pen numbers can begin to deteriorate within one or two summers.

Exploration programs in alpine terrains have the potential to have an impact on more than just the surface. In permafrost areas, a different set of impacts can have serious consequences. This is especially the case on polar-facing slopes, where permafrost is often at surface or within centimeters of the surface. Any disruption of the surface will lead to almost immediate melting of the permafrost, with quite extreme consequences. Firstly, erosion "gullying" will begin on side hills; this gullying becomes self-perpetuating. Secondly, some of these permafrost areas, particularly in the high Arctic, are effectively "cold deserts"; the unique supply of surface water from the exposed permafrost can cause greatly enhanced biological activity. This results in, for example, a path/road becoming a vivid linear array of alder bush against the local subdued grass/willow scrub.

Much of northern Scandinavia, Siberia, Alaska, Yukon, mountainous Northwest Territories, Nunavut, northern Quebec and southernmost Chile and Argentina lies within the semi-permanent/permanent permafrost zone.

On equator-facing slopes where the permafrost lies at greater depth (+/- 1 m), there is not the same degree of gullying or biological stimulation when the surface is broken; instead, a linear brown scar can remain for literally hundreds of years.

Also, as there is always some water (rain/snow/permafrost) available, erosion of a disturbed site can continue indefinitely. In fact, a surface disturbance becomes the locus for a new drainage system which usually intersects existing drainages, making these hydraulically unstable, unsightly and highly visible.

Best Practice Guidelines – Above the Tree Line

The best solution to any of the above problems is prevention rather than remediation.Mineral exploration in alpine terrain has to be carried out with the absolute minimum degree of physical impact, even at the earliest stages, including:

- Reconnaissance exploration (e.g., staking, widespread regional sampling, or ground geophysics)
- Establishing grid lines
- Soil/stream sampling with station positions
- Hand-dug pits

If possible, there should be no roads to campsites and drill sites. Instead, helicopters should be used to transport people and equipment, using the smallest sized helicopter pads, or float/ski planes should be employed on lakes or snow whenever possible.

[1] For a list of terminology see http://nsidc.org/fgdc/glossary/english.html#C

The following considerations are critical when working in alpine terrains:

1. Campsites
   When selecting a campsite location, ask the following pertinent questions[2]:
   - Will it be on level ground and well drained?
   - Will it be situated where it will have the least impact, for example on non-vegetated rock or moraine sites?
   - What is the source of water for camp use?
   - What is the plan for grey water/effluent containment?
   - What is the plan for any spills – aviation gas, oil, etc.?
   - Will the camp be at least 200 m away from any stream, river, or lake, to avoid contamination overflow?

   When selecting and establishing a campsite one should take into account the impact on safety of the following[3]:
   - Mass flow of slopes
   - Rock flow
   - Scree/talus
   - Snow, ice, crevasses, avalanches, cornice failure
   - Ice-dammed rivers/lakes (ice dam may fail)
   - High rainfall
   - Heavy snowfall
   - High winds
   - Fog
   - Cloud level below the elevation of the camp, causing difficulty with communications, line-of-sight, etc.

2. Survey Lines
   - Consider whether survey work can be completed using non-intrusive GPS technology
   - Do not blaze the few small trees that may exist. These could be hundreds of years old, and may be barely surviving
   - If using nylon thread for survey lines, have the survey party return and collect them; otherwise, they will last indefinitely, even with the high ultraviolet radiation
   - If using wooden pickets, collect after use as they will last indefinitely; also, the pickets will become totally bleached and any marker pen numbers will vanish due to the high ultraviolet radiation, usually within one or two summers
   - Flagging tape colours and markings can deteriorate very quickly due to the high ultraviolet radiation; a better alternative is to use aluminum tags
   - The best solution for a long-life survey station is to build a rock cairn with an aluminum tag placed inside

   Note that in most alpine terrains, the local rodent population (e.g., ground squirrels, marmots, pikas) "collect" flagging tape, aluminum foil, etc., as do the few hawk and raven species of birds.

3. Sample Pits

[2] Please also refer to "Site Management" section of e3Plus
[3] See Health and Safety in Exploration Toolkit of e3Plus

It is best to fill in sample pits as soon as possible, particularly if they are on a slope. Otherwise, empty sample pits will become a point where rain/snow/melted permafrost forms a continually enlarging erosion gully.

4. Backhoe Trench
   Use a helicopter to transport a unitized, small size backhoe (this has been very successfully done in the Yukon). Use the backhoe to fill in the trench after use, and to smooth the surface after infill. Make sure the trench is not the source of erosion gullying on a side hill.

5. Drill Site
   If necessary, use a backhoe and blasting to build the drill site. Often, however, one can manually organize talus on a side hill and then use a helicopter to bring in enough cut timber to make a drill platform. After drill hole completion, the helicopter can then carry away the wooden drill platform, as well as the drill itself. Once this is achieved, move the talus blocks back and try to prevent the creation of any local depression, which would then form a point source for erosion gullying on a side hill.

6. Road Building
   If possible, delay any major road building until a “Go/No Go” decision is made on the pre-feasibility study. Then, try to design the road plan for the advanced drilling program, with the eventual mine/mill/infrastructure plan in mind. For example, design the road plan so that drill roads will end up in the pit, or are part of the access to the decline/head frame. This will help ensure that there are very few unnecessary roads, and those that have to be constructed will be part of the eventual “permanent” mine/mill road infrastructure.

7. Remediation
   Wherever possible, use indigenous plants in revegetation programs. Also, wherever possible, roll away any vegetation layer when setting up the site; later, this layer can be rolled back into place when the site is no longer active. Try to contour the exploration area to blend in as much as possible with its surroundings.

Figure 24: Treeplanter planting into steep-sloped landscape. © TRCR 2009

For further information about remediation of mining areas in alpine terrains, visit the Technical and Research Committee on Reclamation of British Columbia .[4]

Best Practice Guidelines – Below the Tree Line on Steep Slopes

There is a fairly comprehensive coverage of “common sense practices” as described in the Government of B.C. Mines Act R.S.B.C. 1996, c 293, updated to July 2002, Programs and Services Mine Code. The B.C. Ministry of Energy and Mines undertook a review of the entire practice of access/exploitation of resources on both steep slopes and in the alpine terrain .

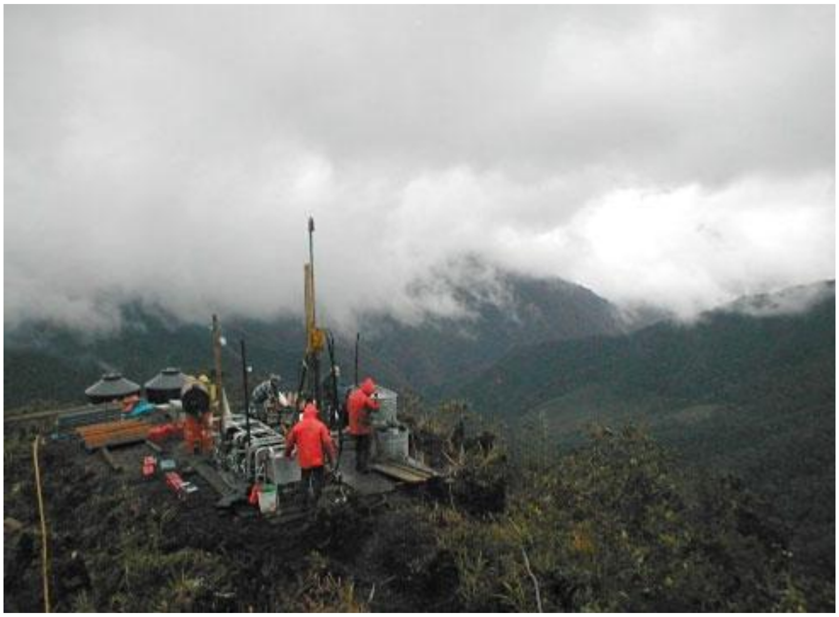

Figure 24: Drilling in high altitude, alpine Andean terrain of Peru (+/-4,000 m). Note small footprint of the operation. © Kluane Drilling.

5.7.2 Arid and Tropical Terrains

Arid and tropical terrains are particularly susceptible to erosion. In arid terrains, wind may be the most important agent of erosion. Aim to preserve as much of the original vegetative cover as possible, to minimize loss of topsoil.
Tropical terrains are susceptible to erosion due to the high volumes of rainfall, and drainage control is very important to minimize loss of topsoil because, typically, the topsoil layer is very shallow. It may be necessary to minimize work during the wet season.

Arid and tropical terrains are considered together because they occur in equatorial areas often in close proximity to each other. It should be noted however that arid terrain can occur in areas of higher latitude and rain forest can occur at various latitudes, particularly around the Pacific rim.

Both arid and tropical terrains are highly vulnerable to erosion. In arid terrain, wind can be a very important agent of erosion because of lack of vegetation and the deep weathering profile with very little organic soil development. Seasonal rains can be torrential causing severe erosion and

[4] http://www.trcr.bc.ca/index.htm

man-made disturbances can increase this severity. Regeneration can be very slow because of the low annual rainfall and often hot temperatures. You should therefore aim to preserve as much of the original vegetative cover as possible during exploration activity.

In both arid and tropical terrain, seasonal rains may also cause damage especially if compounded by man-made disturbances. While not desert-like, much of the brush or savannah country of the tropics is characterized by the same poorly developed organic layer and a deeply weathered soil profile. Areas of rain forest may regenerate quickly due to high rainfall but the second growth forests are much less attractive. Activities in rain forest areas are often monitored by groups with a special interest in preserving these important ecosystems. Local expertise should be consulted to determine if a rain forest area contains endangered or protected species of vegetation.

Even in rain forest, regeneration can be extremely slow if the land is underlain by laterite. Organic soil will be limited to absent and any disturbance may take generations to recover, regardless of rainfall. Vegetation on laterites has taken many years to develop and must be carefully protected. There are virtually no reasonable means of reclamation after significant disturbance during exploration programs.

Exploration programs in both arid and tropical terrain must be designed to preserve as much of the vegetative cover as possible to avoid erosion of the usually thin topsoil. In many areas, it may be necessary to avoid or minimize work during the rainy season both for safety reasons and to minimize the erosion during these seasons.

In both arid and tropical terrain, avoid cutting as much vegetation as possible during preparation of access roads and trails. Stream crossings are critical and should avoid any disturbance that will compound erosion during the rainy season. Wherever possible, use existing roads, tracks and pathways. It should be noted that some jurisdictions have regulations specifying the dimensions and amount of access roads permissible.

Arid Climates

Definition of Arid Climates

It is common to consider that the only places that are “arid” are deserts and that the only deserts are land covered in sand dunes. However, as dry lands cover about 47% of the Earth’s land surface, it can be concluded that mineral exploration will frequently take place in such climates and explorers should be well prepared for the special environmental conditions required for exploration and reclamation.

The words “dryland areas” or “arid climates” will be used interchangeably in this text to refer to all climates ranging through hyperarid, arid, semi-arid, Mediterranean and grasslands.

The Convention of Biological Diversity divides aridity[5] into three categories:

- Hyperarid
- Arid
- Semi-arid

The categories are determined using theoretical calculations of evaporation, plant transpiration and precipitation. For example, in the hyperarid areas, the theoretical potential loss of water from the land can be around 20 times more than the precipitation, and for arid and semi-arid it can be more than double the precipitation.

[5] See website (www.biodiv.org)

Examples of hyperarid climates would be the Sahara and Atacama deserts. The hyperarid climatic region is estimated to cover 10 million square kilometers (7% of all land on Earth). Arid regions are estimated to cover 16 million square kilometers (11% of all land on Earth) and semi-arid an additional 35 million square kilometers (23% of all land on Earth). Thus, all arid regions cover about 40% of Earth's land surface.

Further classifications of dryland areas, as well as the above arid areas, include grassland ecosystems (5% of all land) and Mediterranean ecosystems such as those found in California and southern Australia (1 to 2% of all land) . Grassland/savanna ecosystems transition into forest ecosystems.

Note also that many areas not discussed here, especially the cold areas of the planet, are also arid areas. They are discussed in section 5.7.1 of *e3 Plus* Excellence in Environmental Stewardship toolkit.

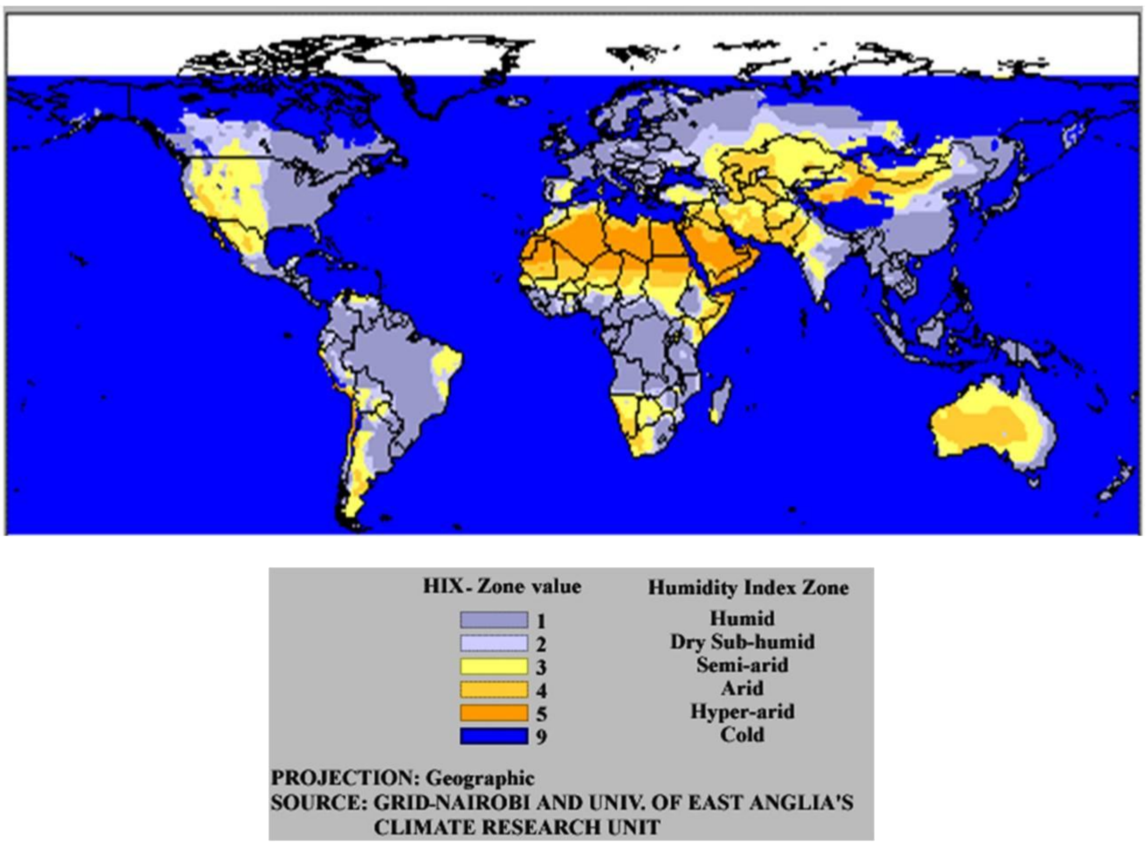

Figure 26: Humidity index zones in regions around the world.

The Nature of Arid Climates

Understanding the climatic patterns in arid regions is essential to environmental remediation during and after mineral exploration activities.

A number of climatic patterns occur in dryland areas. While some hyperarid zones have virtually no rainfall, a number of climatic patterns occur in dryland areas. For example, in the Atacama Desert there are infrequent rains that occur during a period known as "Bolivian winter," which is from December to March. The rains, however, can be torrential and cause considerable damage due to mudflows. They represent significant risks to exploration activities and communities.

Arid and semi-arid climates often have alternating wet and dry seasons. The Mediterranean climate has cool wet winters and hot dry summers. In grassland and Mediterranean areas there are periodic droughts when vegetation is susceptible to fire, another significant risk to exploration and communities.

The Nature of Arid Soils

Soil is the unconsolidated material at the surface of the Earth that serves as the growth medium for plants. It is largely the roots of plants, both large and small, that hold the soil in place and slows the effects of climate on erosion of the surface. Soils are complex bodies including both inorganic and organic constituents. The organic constituents comprise the obvious plants that are visible at surface, but also many micro-organisms that are often in symbiotic relationship with the roots of visible plants.

The primary direct effect of intrusive mineral exploration activities is on soil and vegetation. If road building and other intrusive activities are not done carefully, they can increase erosion both directly and indirectly by damaging the surface crusts and by removing or killing vegetation, thus creating channel ways for water.

Soil usually forms as a result of the effects of climate (largely temperature and water) and micro- and macro-organisms which break down the constituents of the underlying rock. Soils in dry climates are generally poorly developed in terms of fertility as a direct or indirect result of the lack of water. The lack of water inhibits chemical reactions that break rock down into smaller particles. The lack of water also means less vegetation, leading to less biological effect on soil formation. Because of the lack of fertility, the lack of water and the sparse vegetation, desert soils and vegetation are exceedingly sensitive to disturbance. Once the vegetation, especially the root mass, is disturbed, the area is vulnerable to erosion and this can prevent vegetation from re-establishing itself.

In hyperarid climates, the ground has virtually no soil development as there is little or no surface water and often no vegetation. In this type of climate, the main causes of the formation of soil-like material at the Earth's surface are wind and temperature. Ground water may also have some effect. Wind blows sand and dust sized particles that scour and erode rock faces and boulders and also damages vegetation.

Although it might seem that desert soil in hyperarid regions should be loose and sand-like with little or no organic activity, neither of these assessments is totally true. Despite the fact that they are deserts, most hyperarid areas are not covered in sand.

The soil surface in the driest deserts is often held together partly by material that gives many desert areas the various hues of red, brown and black. In North America, this material is referred to as "desert varnish". Desert varnish is largely made of clay that cements particles of manganese and iron oxides to exposed rock surfaces. The varnish layer, often only 0.01mm thick, is created by colonies of bacteria. It is suggested that the varnish can take up to 10,000 years to form a complete coating.

Figure 27: Drill roads and on upper left, old trench, Atacama Desert, Chile. Illustrates very slow recovery of old trenches in very arid environment. Also clear is the very visual and permanent effect of roads in this environment. (Photo courtesy Noranda 2004)

A second type of material that holds deserts soils together is “caliche”, sometimes called “hardpan”.

Figure 28: Gravelly arkosic channel sand overlying dense array of caliche nodules (light grey) developed in mud overbank deposit. In: http://www.geo.sunysb.edu/lig/Field_Trips/hartford-basin/

Caliche forms when soil pore water or ground water bearing magnesium and calcium carbonates evaporates at the soil surface, leaving behind a hard layer of carbonate, either at the soil surface or often just below the surface. Caliche has negative effects on plant life, for three reasons:

1. Most plants' roots cannot physically penetrate the hard layer. Consequently, the plants have shallow roots and are more susceptible to drought or disturbance (natural, such as wind, or man-made such as bulldozing) than plants where there is no caliche layer.
2. The caliche causes high pH making iron and other micronutrients less available or unavailable to plants.
3. Water drainage is poor in caliche areas. Rather than water soaking into the soil to be available to plants for slow absorption, water rapidly runs off the surface leaving little behind.

In some cases, the roots of larger older trees penetrate the caliche to reach the underlying water table. These trees, in effect, pull water from below the caliche to the surface and create a local micro-ecosystem where other plants can flourish.

Operating in Arid Climates

Introduction

Due to the poor soil development and lack of vegetation, any disturbance of arid land tends to be visually and ecologically apparent for very long periods. This is illustrated, for example, by studies and documentation of military operations in the western USA (see Table 1 below). It is also apparent in historic archaeological remains that show man's impact on the landscape from thousands of years ago. Native American trails in the western USA that were used only for foot travel are still visible hundreds of years later. In South America the "Camino del Inca," a foot trail used for communications by the Incas, is still clearly visible in Chile and Peru and is a tourist attraction.

The most important principle to apply when exploring in arid climates is to reduce initial impact and to eliminate, as much as possible, the need for reclamation as it may be impossible or extremely difficult to achieve. In addition, similar to alpine areas, aesthetic effects on landscape are extremely important as they are so long lasting.

Table 3: Estimated natural recovery times in years for California desert plant communities subjected to various anthropogenic impacts (selected from Lovich and Bainbridge, 1999).

Impact	**Location**	**$T_{recovery}$ (Years)**
Tank tracks	Eastern Mojave	65, 76
Tent areas	Eastern Mojave	45, 58
Dirt roadways	Eastern Mojave	112, 212
Tent sites	Eastern Mojave	8-112
Tent roads	Eastern Mojave	57-440
Parking lots	Eastern Mojave	35-440
Main roads	Eastern Mojave	100-infinity
Military operations	Eastern Mojave	1500-3000
Fire	Western Colorado Desert	5
Off-road vehicle use	Western Mojave	probably centuries
Pipeline (berm and trench)	Mojave Desert	100

$T_{recovery}$ = estimated time in years to natural recovery

Table 4: Adverse impacts on California desert, their relative intensity and historical occurrence (selected from Lovich and Bainbridge, 1999).

Impact	**Intensity**	**Current/Historic**
Grazing	Moderate	Primarily historic
Invasive plants	Moderate/severe	Historic/current
Highways	Severe	Current
Urbanization	Severe	Current
Off-road vehicles	Severe	Current
Agriculture	Severe	Both
Military operations	Severe	Both
Mining	Locally severe	Both
Linear corridors	Locally severe	Current

Studies reported by Lovich and Bainbridge on military camps show that, in terms of environmental degradation, tent camps had the least effect on the environment, tank tracks were intermediate and roads had the most effect. Exploration camps may have greater effect on the environment than 20th Century military camps, but tank tracks are comparable to drill access and the roads analogous to the more permanent roads that an exploration company may construct. If these research results are in fact applicable to exploration, then roads and drill pads are likely to be the cause of the most damaging impact in terms of area covered and intensity of effect.

The basic principle to apply in arid regions is to:

MINIMIZE INTENSITY, FREQUENCY AND AREA OF DISTURBANCE.

Water Use

Water can be one of the most contentious issues in an exploration project. This includes both the use of water supplies and concern for the potential to contaminate water supplies. This might be especially true in arid climates where water resources are scarce.

It is critical that water use be reduced as much as possible in camp and drilling activities and that extraordinary lengths be taken to avoid contamination of the few water sources that are present. Water contamination may result from camp activity such as waste management or sewage disposal, from road building or use, or from drilling.

In many cases, discharged water must be kept away from natural water sources. It is important to understand the nature of the discharged water in relationship to the body of water into which it is to be discharged. An important question to consider would be: Is the water from a small camp, purified to a significant degree, using a properly designed sanitation system and going into a relatively large body of water, or is it of questionable quality and potentially discharging into a small body or stream that contains fish?

Advanced exploration might also have to consider such issues as water discharge from exploration adits.

The water level in scarce surface water bodies should not be lowered significantly as the local ecology and local inhabitants and their livestock are likely dependent upon it. All access to local water should be discussed and negotiated with the community (see the Community Engagement, and Land Management Sections under *e3 Plus* Social Responsibility Toolkit).

Road Building and Use

Road building is the most important environmental issue for arid climate exploration as it is the largest surface disturbance, it creates significant lasting visual scarring of the landscape, and it can also stress the area by inviting in more vehicles which creates added ecological stress.

Impacts include:

- More camps from off-road tourists and hunters.
- Invasive or foreign plant species attached to vehicles.
- As the road becomes more rutted, it concentrates water flow during seasonal torrential rains, resulting in even more severe water erosion.
- It also may change the local drainage patterns and affect groundwater.
- Disturbance of desert crusts also increases soil susceptibility to wind erosion.

Vehicles can often travel easily in the flatter deserts without having to create roads; however this results in tracks that may end up causing more problems than building a road. Roads can be engineered to minimize their impact, but tracks usually deteriorate far more quickly. The end result of tracks is that drivers are tempted to drive parallel to the existing track. The wheels of an off-road vehicle have been shown to impact half a hectare per 6 kilometers traveled. Multiple parallel passes by vehicles can increase that considerably. The problem is that, in many cases, the vehicle use breaks up the desert varnish thus creating conditions for wind erosion and, in others, the vehicles compact the already hard ground or duricrust, making it even more difficult for plants to maintain, or regain, a hold. Consequently the track size increases, and becomes more susceptible to water and wind erosion.

Numerous studies have been completed, especially in western USA, of off-road vehicle impacts. The impacts can be summarized as follows:

- The primary damage is caused by compaction of the soil.
- The degree of compaction increases with the frequency of vehicle use.
- Most susceptible to compaction are loamy sands and coarse gravelly soils.
- Wet soils are more susceptible than dry.
- Clay soils are least susceptible.

Figure 29: Photograph demonstrates depth of erosion due to cut and soil loss on off road vehicle trail. Tape has been strung horizontally to depict the unaffected ground surface. Last Chance Canyon, California (picture courtesy of San Diego Office, California State Parks)

Mitigating the Effects of Roads

In order to minimize the impact of access trails or roads, the following issues should be considered in arid areas:

- Can you walk instead of driving?
- Use as few access routes as possible.
- To the extent feasible, limit road access to other users.
- Be aware of what the road is for and how long it will be used (for example, the main access route may be used for many exploration seasons whereas the road to a drill site might be only used for a matter of days).
- It may be better to build roads rather than just drive through the desert if the route is to be used more than a few times.
- If the road is to be used for a number of seasons, design the road construction to strengthen the bed so that it will not deteriorate rapidly.
- If the road is to be used for only one season, do not over-engineer it. Afterwards, scarify the land to undo the compaction caused by the weight of vehicles.
- Route access roads through gently sloping areas to minimize erosion.
- When a hillside road is crossing a stream it should not continue at the same angle to the slope, as it will create a drainage route that will compete with the streambed, altering the drainage pattern. At the stream location a depression filled with rocks will ensure that the water will continue in the same bed.
- In some cases, route the road through areas of colonizing vegetation, as it will tend to naturally reclaim the ground but consider the caveats below.
- When preparing a trail using a bulldozer, avoid blading the soil aside; instead minimize moving of soil and overburden and leave plant root systems intact as much as possible. The vegetation will recover far faster.
- Do not route through vegetation used as grazing or other purposes by communities.
- Avoid disturbing plants that are nitrogen fixers (for example paloverde trees, acacia and mesquite).
- Go around and do not disturb large plants or trees. An example is the saguaro cactus of northern Mexico and the USA which takes hundreds of years to grow. Large plants have deep root systems that are critical to the ecosystem.
- When exploration is finished, soil loosening techniques will reduce the effects of compaction.

The on-site project manager should be responsible for ensuring that staff, such as bulldozer operators, drillers, geologists or others do not take short cuts off road, in effect creating multiple new routes.

Figure 30: Picture illustrates deep dust formation due to repeated vehicle passes over same area, exposing location to potential soil removal due to wind or rain (picture courtesy of San Diego Office, California State Parks)

Stream Crossing

Although stream crossings may seem unimportant, especially in areas where the streams are all dry, some arid climates can have considerable rain in short periods of time. Because of the critical nature of water in this type of climate, stream crossings must be given the same serious consideration as in wet climates. Planning of the optimum approach to the stream bed or flowing stream crossings should aim to achieve the least disturbance and eliminate as far as practical the chance of water contamination.

When planning stream crossings, the following should be taken into account:

- How long and often is the access to be used and in which season?
- Is water flowing during the access period? If so, then a culvert or other system is probably optimum.
- Is the stream small and can it be bridged by a simple structure that keeps vehicles out of the water but allows water to continue to flow unimpeded?
- Is the stream bed dry? Is it likely to stay dry during the exploration season? If the stream starts flowing can you avoid using the crossing during the period? If the answer to these questions is yes, then it is possible that a "ford type crossing"[6] may cause least disturbance.
- How resistant will the structure be to a sudden torrential rain storm and a flash flood? How quickly could it be removed if necessary?
- Are all camp areas, equipment and fuel storage locations well away from potential flash flood areas?
- Are adequate emergency response plans and communications capability in place in areas susceptible to flash floods?

[6] www.gbcma.vic.gov.au

Figure 31: Mountain streams in arid climates often have vegetation adjacent that is susceptible to disturbance. Southern Andes of Chile. Photograph: Bill Mercer

Drilling

All considerations listed for roads above apply to the construction of access and drill pads for any form of drilling in arid climates. A key factor is the length of time the access route will be used, and whether it will be reused in the future.

Reverse circulation drilling, and other similar methods such as percussion, as well as the access issues, also produce significant dust that requires control. This is an issue for environmental, health and safety and aesthetic reasons. In addition, the rigs are often very large, which increases the area required for the drill to stand.

Diamond drilling, in addition to the issues noted above, also requires large volumes of water, resulting in the following considerations:

- Is sufficient water available without negatively impacting ecology or people in the area?
- Is access to the water possible without risking contamination?
- If ground waters are used, will the pumping of them negatively impact springs, or other water courses nearby that people or the ecology are dependent upon?
- Are the ground waters saline or poisonous such that they could have a negative impact on the environment? What if a drill hole makes water and the water is high in heavy metals – do you have a plan in place?
- Does the drill company have a system in place to handle the water after drilling to ensure that there is no contamination of surface or ground waters?

Water supply is critical to mine development in arid areas. Considerable detailed information can be obtained during the drill program related to aquifer size, ground water table and flows, ground water quality and other parameters that will be critical to future environmental impact assessments and project design. Consideration for the collection of this data should be included in the drilling program to reduce delays and reduce costs in the event that the program leads to mine development. Living organisms have been found in ground water sources, and identification of them at early stages can minimize impact and ensure adequate management.

Of course, with some forethought, the drilling may be positive for a local community if it creates access to groundwater that was previously in short supply.

Trenching

Trenches have often been dug in arid climates and not reclaimed, perhaps because people viewed them as no different to natural gulleys. However, trenches are aesthetically unpleasing eyesores that damage the reputation of the industry and should be reclaimed for this reason alone. The difference between a trench and a natural gulley can be seen in the colours of the rock where the trench is a scar because it exposes unweathered material. Apart from aesthetic concerns, trenches, depending on the size and shape, can also be a safety hazard to animals and people.

When trenching in arid climates the same considerations apply as in other situations (see Sections 6.10 and 14.2 of *e3 Plus: Excellence in Environmental Stewardship*) The topsoil should be separated from any rock dug out of the trench so that the material can be returned in the order it came out of the trench. Although desert soils may appear relatively structureless, usually there is still a structure present. If the climate is suitable for vegetation to grow, then the surface of the trench, once reclaimed, should be planted (see reclamation below).

Figure 32: Picture illustrates slow recovery of desert. Erosion gulleys still clearly visible 25 years after off road vehicles were fenced out. Tuttle Ridge, Red Rock Canyon State Park, California. Taken 2005 (picture courtesy of San Diego Office, California State Parks)

It may appear that in arid environments acid rock drainage is not important. In fact, due to the scarcity of water, it is still an important issue. As a result the disposal of sulphide bearing rock must take this into account and precautions taken to reduce the risk.

Other Activities

Many normal exploration activities such as geological mapping, geochemical sampling and geophysics, have very minimal impact in many environments where there is abundant vegetation. However, in arid climates seemingly innocuous work can have long lasting effects. The most common problem is the use of vehicles off-road in order to ease geophysical surveys and the carrying of geochemical samples. Sometimes geologists will be tempted to drive to every outcrop instead of walking. This should clearly be discouraged.

Reclamation

Key to reclamation is planning.[7] In areas that are particularly ecologically sensitive or with high aesthetic or cultural value, reclamation plans should be researched and tested in advance.

Due to the nature of arid lands, revegetation with native species requires access to native plants from nurseries and/or seed, both of which might not be readily available on short notice. If seed collection is required for a nursery to grow plants, allow at least 6 months for growth of the seedlings. Seed collection should be done by experienced people who can recognize mature seeds. Examine the possibility of saving plants that are to be disturbed and using them later in revegetation. Also, where it is difficult to obtain or grow from seed, division of existing plants may be possible, such as “coiron,” a grass that grows in tufts in Chile. In some cases, there should be consideration of utilization of faster growing, commercially available nurse crops to aid early soil formation, reduce wind and water erosion, protect slower growing native plants and to encourage water infiltration. However, these must be carefully considered to ensure that new species are not introduced at the expense of native species.
There must be a contingency plan in place in case seed or plants are not available, or planting is unsuccessful. Apply a few solutions (scarifying, seeding, planting, water enhancement, etc.) rather than depending on the success of one. Reclamation is also an excellent opportunity to use local labour, thus increasing the positive input to the community and enhancing community relations. Local farmers or ranchers may also understand the ecology, knowing what grows easily and what does not, having lived with it for long periods, if not generations.

In areas where snow is a significant proportion of the precipitation, vegetation may trap snow in branches. When planting a tree or shrub, it may be possible to create a small artificial trap for snow by created a depression around the trunk, thus increasing the moisture content of the soil.

As soon as work stops and an area is to be reclaimed, measures should be taken to ensure that the area does not deteriorate further. This may include restricting access to unauthorized people as far as possible.

[7] see D. Bainbridge, 1995: A Beginners Guide to Desert Restoration

Figure 33: Reclaimed drill site using scarifying with bulldozer to encourage retention of rainwater, assist vegetation growth and reduction of erosion, Queensland, Australia, Photograph: Bill Mercer

First Steps in Reclamation

Reclamation can be considered in two categories. Firstly, in hyperarid regions that basically have little or no water, reclamation will be mainly restricted to removing all exploration materials (camps, equipment, etc.), restoring the surface contours of the ground and minimizing the chances of erosion during infrequent wet periods.

In areas that have seasonal or periodic precipitation such as rainfall or snow, reclamation should be undertaken to utilize the optimum period assisting any plant growth. Surface restoration would be similar to that noted above for hyperarid regions, focused on returning any excavated material in the order in which it came out of the trench or drill pad, and contouring to reduce erosion possibilities.

Once the surface contours have been restored, then further reclamation can be undertaken. As soil has many components, and given the complex nature of arid soils (see Arid Soil above) recovery can be aided by “inoculating” an area with sections of soil taken from other undisturbed areas. Obviously considerable thought is required for this to avoid doing this at the expense of the undisturbed areas.

Figure 34: Scarifying by bulldozer of old drill site to assist in rain retention and encourage plant growth. South Australia. Photograph from Mithril Resources Ltd.

Revegetation

The next stage in reclamation would be revegetation. In some areas, if vegetation is clearly still present and rooted in the soil, scarifying the access routes, drill pads, trenches and other areas of disturbance prior to the rainy season, may be sufficient to encourage plant growth and additional planting is not required. Depending on the degree of soil compaction, ripping may involve the use of hand rakes. However, if the situation is a road used by vehicles and drill pads, then a large bulldozer equipped with a ripper is required in order to effectively break up the surface. Ripping in these circumstances should be to 75cm or 1m. Machinery such as tractor mounted equipment should be considered for situations between these two extremes or a power auger to plant trees and bushes.

If planting is required, it is critical that the plants are native to the region. This is not primarily for aesthetic reasons but the fact that native plants are not only more likely to survive but are also critical to other parts of the ecosystem (birds, reptiles, mammals). Also, an attempt should be taken to use species that exhibit rapid growth and are visually dominant.

Revegetation in arid regions is difficult due to:

- High temperatures
- Strong sunlight
- Limited moisture
- Herbivorous animals
- Low soil fertility.

Larger plants have been successfully raised in nurseries and transplanted. A hand power auger is useful in order to efficiently create holes deep enough for larger plants. It is important that the plants are protected as far as possible from future disturbance. This means that larger species such as trees or shrubs should have collars and/or wire mesh to protect them from grazing species – either small or large (rodents, deer, and cattle).

Figure 35: Revegetation activities in Brazil (photo courtesy Falconbridge)

Where this is impractical, rocks or brush can be placed around plants. A hand power auger is useful in order to efficiently create holes deep enough for larger plants.

Once the plant is in the ground and a protective collar applied, the plant should be irrigated at least once. Again, it is critical to plant just prior to, or during, the wet period. In addition, mulch within the plant collar can assist in maintaining the soil moisture content. It has been documented that mulch comprising larger fragments (for example, bark or chunks of wood) is more successful than fine material as it decomposes more slowly and is less likely to be blown away. Fertilizer is generally not recommended as it has been shown that it does not increase plant survival rate, and in fact can decrease it.

Smaller plants can be seeded mechanically or by hand, however, it should be born in mind that desert plants are difficult to grow from seed in the wild. In light of this, in any difficult environment, it is suggested that expert local advice be obtained prior to considering a program of seeding.

Finally, it is important to document the reclamation procedures followed both in writing and with digital photographs. The purpose is to monitor the success of the program over the long term (at least one year) and to disseminate the lessons learned, at least within your company and preferably to industry as a whole. If the program is unsuccessful, a contingency plan should be in place for an alternative method.

Community Relations

When conducting exploration in arid environments, the concerns of communities are especially important due to the scarcity of water and the requirement of sufficient clean water for human survival. Exploration programs must take into account the requirements of the inhabitants of such sensitive regions and ensure that there are no adverse effects on the water that they depend on or the sparse vegetation that they or their livestock depend upon. In some cases, the people may not be empowered politically to defend their needs and the company must be mindful of the impacts and make allowances for this (See the Community Engagement/Development section in *e3 Plus* Social Responsibility toolkit).

Figure 36: Deep trenches are often required in tropical to semi-tropical terrain to assess saprolitic deposits. If used, project managers must seriously address issues of safety for the workers. © Iamgold.

With deep weathering in both arid and tropical terrain, pitting and trenching are important tools for mineral exploration in these regions. The pits and trenches, often several metres deep, allow a geologist to penetrate the saprolite layer and have a means of determining underlying rock type. In many cases, a trench also provides a means of sampling mineralized saprolite to determine grade. Trenches and pits in saprolite are surprisingly stable when dry but excavation and entry should not be attempted during the rainy season. Trenches should be filled in after mapping and sampling, carefully ensuring that the segregated topsoil is added at the end of back-fill to allow rapid revegetation. It is worth noting that deep trenches in saprolite should always be checked before entering to ensure there are no dangerous animals present such as snakes, scorpions or spiders. It should also be noted that some jurisdictions have regulations limiting the amount of trenching and pitting that is allowed within a given area (hectares or square kilometres) of arid or tropical terrain.

All the usual procedures and precautions apply during drilling programs in arid and tropical terrain although there may be unique logistical and technical problems to be resolved beyond the scope of this discussion. It should be noted that some jurisdictions have regulations limiting the number of drill sites per hectare, the size of drill pads and the use of drilling additives. Cementing of drill hole collars may be required upon completion of the program. Great care must be taken, especially in arid to semi-arid areas, to ensure that the water table is not lowered and that water quality is not compromised in any way.

Figure 37: Drilling in arid terrain can present logistical and environmental challenges. © Iamgold

Figure 38: Lightweight, modular drill rigs can mitigate environmental disturbance in tropical terrain. © Kluane Drilling

5.7.3 Riparian Areas

The area where land and water meet is called the riparian zone. It is a transition zone, containing elements of both upland and aquatic ecosystems. Because of this, it is the most productive environment in the forest.

Unless otherwise authorized, maintain a minimum 90 m buffer of undisturbed vegetation between all trenching, stripping, and drilling operations and any lakes, rivers or major streams. Leave a 30 m buffer of undisturbed vegetation between any water body and campsite, unless otherwise approved.

5.7.4 Wetlands

The term "wetlands", for the purpose of this e-toolkit, encompasses all poorly drained areas, for example:

- Muskeg
- Buttongrass plains (Australia)
- Moors
- Marshes
- Page zones
- Swamps
- Mangroves
- Bogs.

Wetlands occur in a variety of locations from the High Andean Plateau (La Puna) to the high Arctic.

"Riparian Terrain" is a form of wetland, transitional between permanently saturated wetlands and upland terrain. Lands adjacent to flowing rivers, glacial potholes, and the shores of lakes are typical riparian areas. These areas have vegetation and physical characteristics reflective of permanent surface or subsurface water influence. As with wetlands, riparian terrain occurs in most regions across the world.

Both wetlands and riparian terrain are highly sensitive to environmental impact and generally take a long time to recover. Wherever possible, work in such areas should be avoided but, if essential, plan the work to minimize any disturbance. Schedule the program during low water season or, in colder climates, when the ground is frozen. These areas are often used by migratory birds as significant feeding and resting sites so avoid the annual migration season.

All equipment brought across or into these areas should be cleaned of any residual soil and plant material from previous work to avoid introduction of non-native species of vegetation.

These areas are highly sensitive to environmental impact and generally take a long time to recover. Avoid these areas wherever possible when locating roads/tracks. If it is necessary to cross these areas, try to do so during the seasonal period when the least amount of impact will be incurred (e.g., dry season, frozen, snow covered) and use low ground pressure vehicles. Tracks through wetlands usually result in highly visible scarring which lasts for many seasons.

Any drilling activity in these areas must be conducted with extreme care. The drill site should be contained by a silt fence/oil boom/berm system to prevent release of any contaminants into the area. Drilling water should be re-circulated to avoid significant drawdown of the local water table. Where there is a possibility of holes 'making water', holes should be plugged upon completion of the program. Any disturbance of soil-binding vegetation should be minimized. As soon as work is completed, the area should be reclaimed as necessary by replanting and seeding with local vegetation while controlling sediment movement with silt fencing until the new vegetation matures.

5.7.5 Beaches and Coastal Sand Dunes

Vegetated sand ridges called dunes, built up by dry beach sand blown inland and trapped by plants and other obstructions, back most beaches. As sand accumulates, the dunes become higher and wider. Stable sand dunes play an important part in protecting the coastline. They act as a buffer against wave damage during storms, protecting the land behind from saltwater intrusion. This sand barrier allows the development of more complex plant communities in areas protected from saltwater inundation, sea spray, and strong winds. The dunes also act as a reservoir of sand, to replenish and maintain the beach at times of erosion.

Vegetation on beaches and on sand dunes tends to occur in zones, according to the degree of exposure to harsh coastal conditions.

Closest to the sea is the pioneer zone, extending landward from the debris line at the top of the beach to the crest of the foredune, or frontal dune. Only specialized pioneer plants can colonize the seaward slope and crest of the foredune, as these areas are exposed to:

- Salt spray
- Sand blast
- Strong winds
- Flooding by the sea

These plants are often protected by waxy or hairy coverings on stems and leaves, and grow low to the ground, offering little resistance to the wind. They have strong root systems and spread rapidly, creating a mesh of creeping stems, so if one part is buried in shifting sand or uprooted, another part can continue growing. They thus serve to stabilize the sand, forming and building dunes.

Frontal sand dunes are vulnerable. The vegetation can be destroyed by natural causes, such as:

- Storms
- Cyclones
- Droughts or fires

The same effects can result from human interference, such as:

- Clearing
- Grazing
- Vehicles
- Excessive foot traffic

If the vegetation cover is damaged, strong winds may cause "blowouts" or gaps in the dune ridge. Unless repaired, these blowouts increase in size, and the whole dune system sometimes migrates inland, covering everything in its path. Meanwhile, with a diminished reservoir of sand, erosion of the beach may lead to coastal recession.

Sand dunes are prone to erosion by wind. Always strive to retain the full vegetation cover when working in dune country. Stabilization of sand dunes is often dependent upon their precise shape and their fragile vegetation cover. Minor cuttings or limited alteration of dune form can, in time, provoke blowouts.

For these reasons, do not make tracks in areas of dune development unless they are absolutely essential.

Ensure that grids are pegged, not cut, wherever possible. Dunes, with their covering of grasses and other plants, are so fragile that even footsteps can damage or kill the plants and weaken the dunes. Wherever possible, avoid driving vehicles on dunes, as the tires destroy dune vegetation, increasing the chance of dune destruction. It is therefore of vital importance to take whatever measures are necessary to protect the vegetation in areas of coastal sand dune development.

Behind the frontal dunes, in areas protected from windy and salty conditions, vegetation depends on local circumstances (e.g., freshwater swamps, well-drained ridges). These zones are not fixed. As plants grow taller and humus (e.g., dropped leaves) accumulates, exposure to sun and soil conditions change. The soil becomes richer and holds more water. This enables scrub and woodland plants to move in, and the type of vegetation changes through a process called succession.

There are other items to consider when operating in coastal areas. The hostile salt-water environment can play havoc with a camp, a program and, ultimately, a budget. Camps must be carefully planned so that electrical systems do not cause safety hazards. You must ensure that there is no possibility that sewage systems will contaminate the coastal waters or estuaries.

Because of increased corrosion possibilities, greater care is necessary to avoid compromising fuel containment. Empty and partially used fuel drums should always be removed from camps and storage sites but this is particularly important in coastal areas where salt-laden mist will rapidly corrode steel and aluminum fittings.

It is also worth noting that some jurisdictions define coastal areas by elevation above sea level. There are situations where elevations remain low for many kilometres inland from the ocean. Coastal regulations may apply in such areas even if apparently inappropriate.