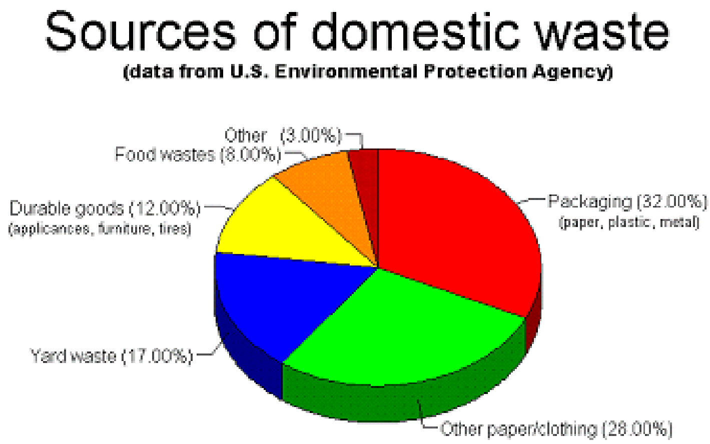
Geological issues in Waste Disposal, Forestry and Engineering

6.1 Waste disposal

From a geological point of view the most important thing about waste disposal is the isolation of the waste, and anything that might leach out of it, from the rest of the environment - particularly from surface and ground waters. The types of waste that we will consider are domestic and industrial wastes (including mine wastes), and wastes from the nuclear energy industry. In all cases we will be concentrating on solid wastes, as opposed to liquid wastes.

Domestic waste

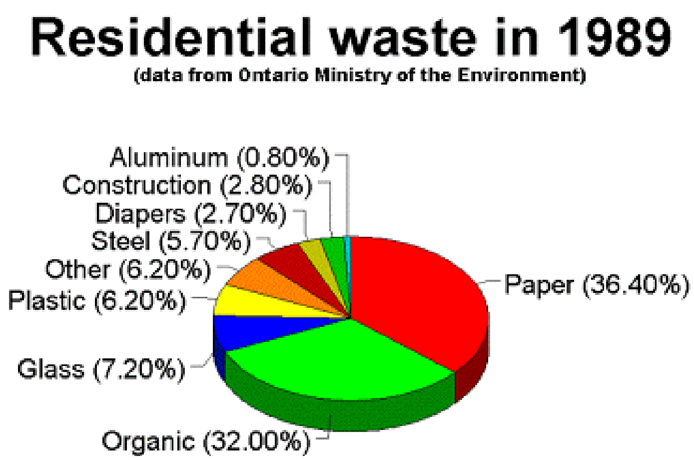
Sources of domestic waste in the United States in 1988



Domestic wastes are what we put in our garbage cans. In Canada each person generates an average of 1.7 kg of household waste per day[1]. This number, which is very similar to that for the US, is roughly twice that of most European countries, and is many times that of most third world countries. In the US the proportions of the sources of domestic waste in 1988 were roughly as shown on the figure above. The proportions in Canada in 1988 were probably very similar.

Composition of domestic waste in Ontario in 1989

A breakdown of the actual materials in domestic waste in Ontario in 1989 is given on the figure below.



In recent years the rates of diversion of some of these materials from waste into recycling programs has increased significantly, and our waste stream now includes a smaller proportion of paper, glass and metal than before.

Anaerobic decomposition

Once it is deposited in a dump or a landfill the waste material starts to break down. Organic material breaks down the most easily - largely through the action of aerobic

[1] In the RDN in 2004 each household generated an average of 30 kg of waste and 12 kg of recycling per month.

bacteria - when the waste is exposed at surface. After the waste is buried anaerobic bacteria continue the process, but the rate is much slower - even for organic matter. Other materials, such as plastic, may decompose at an almost negligible rate when buried.

Metal leaching

Water percolating through wastes will leach out various components, such as heavy metals (arsenic, cadmium, copper, lead, manganese, zinc etc.) nitrate, phosphate and others, and unless this water is recovered (as described below) it could contaminate the groundwater.

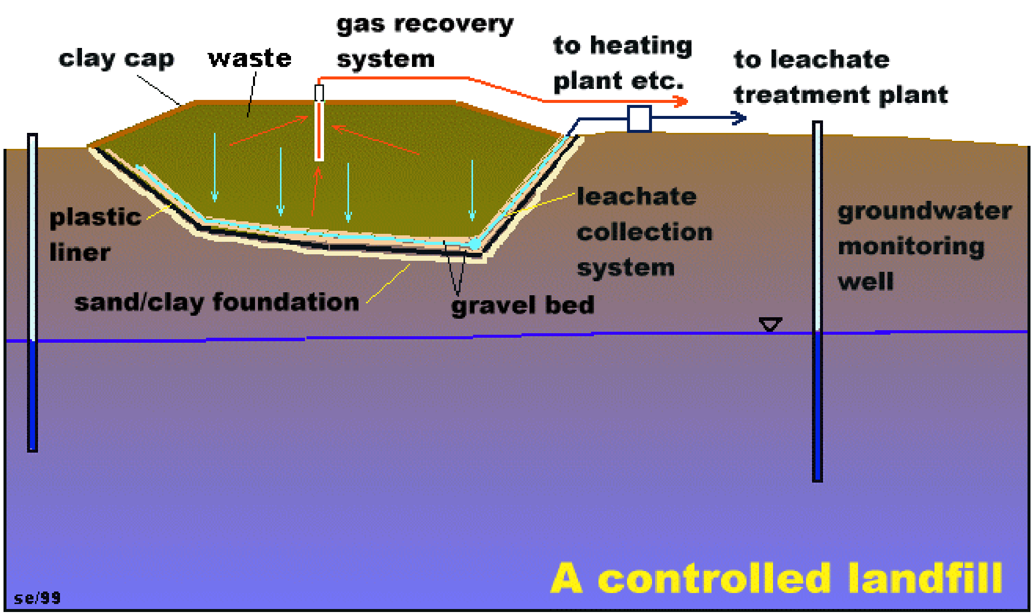
Gases generated

Decomposing waste materials also generate a significant amount of carbon dioxide and sulphur dioxide (from aerobic breakdown) or methane and hydrogen sulphide (from anaerobic breakdown)[2]. Other gases may also be released in small amounts. Again, unless these gases are recovered, they will have an environmental impact - by contributing to the flux of greenhouse gases and to gaseous pollution. The explosive methane can also create a safety problem.

Dumps versus landfills

In the past, municipal wastes were disposed of at dump sites, chosen where there was already a hole in the ground, or where it was easy to dig one. When the dump was full it was covered over and forgotten. Many such dumps are still in use in Canada, but in most parts of the country regulations do not allow new dumps to be constructed (or old dumps to be used for that matter). Instead, wastes must be disposed of in what is known as a controlled landfill.

Schematic view of a controlled landfill



Siting considerations

The primary consideration in the choice of a site for landfill should be the protection of the groundwater supply, but many other factors come into play, such as proximity to the source of the wastes, other uses for the land (agriculture, forestry, wilderness etc.)

[2] Carbon-dioxide and methane each make up nearly 50% of the gases released at the Cedar landfill (personal communication, Ron McCaw, Regional District of Nanaimo)

and proximity to residences and airports[3].

Preference for a dry climate

In a dry area there may be a wide choice of landfill sites because the water table is likely to be tens or hundreds of metres below surface, and any contamination within the leachate is likely to break down or be adsorbed onto clays and other minerals before it actually reaches the groundwater. Furthermore, with low rainfall, the rate of leaching will be low, and the volume of leachate will be small.

Isolation from groundwater

In a wet area it is important to find a site where the drift (overburden) or bedrock has low permeability. If there is a significant amount of drift, the drift should be clay-rich so that any leachate will move very slowly towards the water table, and the contaminants will be adsorbed. If the drift is thin, the bedrock should have low permeability, with no significant faults or fracture systems.

Landfill liner

In some cases, where the natural conditions are very favourable - such as with thick clay-rich drift, low rainfall and a low water table - it may be acceptable to construct a landfill site with no leachate recovery system, but in most cases it is necessary to create an artificial impermeable barrier beneath the waste, and to extract the leachate for treatment.

The impermeable barrier could be a thick layer of clay, but it should also include a synthetic (plastic) liner. At most landfill sites a combination of these is used, with gravel and sand laid down first, followed by clay, then the plastic liner, then more clay, then more sand and gravel. One of the purposes of the sand and gravel is to protect the plastic liner from the waste, the other is to provide a zone of permeability for the leachate to flow into the drainage system.

Leachate extraction system

Before any waste is put in, a system of pipes and pumps needs to be set up so that leachate that collects at the base of the landfill can be removed. This would normally consist of a network of pipes within a layer of gravel, where, as noted above, the gravel acts as a permeable body to allow the leachate to migrate towards the pipes. The leachate should then be treated to separate the contaminants from the water. Leachate from the RDN landfill at Cedar is pumped into Nanaimo's sewage treatment facility.

Gas extraction system

Once a landfill site has been filled and covered - again with an impermeable layer - the gases given off by the wastes should be removed so that they do not accumulate to dangerous levels. At Cedar, as at most other municipal landfills, these gases contain sufficient methane to be flammable. The gases are captured and, at present, are flared off, although there are plans to use the energy potential of the methane to generate electricity. Even though they are not yet being used as an energy source, its better to burn the gas than to just let it escape, because the methane could be dangerous if it was allowed to escape, and because methane is 21 times more potent as a greenhouse gas than the carbon dioxide that is produced when the methane is burned.

Industrial wastes

Industrial wastes

[3] Waste disposal sites are notorious for their bird populations, and the birds can cause significant problems to aircraft - especially jet aircraft if they are sucked into an engine.

Industrial wastes can be a particularly difficult problem because of their high volume and, in some cases, their significant toxicity. In British Columbia, where there is relatively little manufacturing, and only a small chemical industry, most of our industrial wastes come from the forest and mining industries.

Forest industry wastes

Forest industry wastes

The wastes generated by a pulp mill, include both liquids and solids. The liquid wastes are treated and the post-treatment water is pumped into deep ocean water. According to a spokesperson from the Harmac-Pacific pulp mill in Nanaimo, the water from their operation is non-toxic and contains no organo-chlorines (including dioxin)[4].

Ash, lime and wood waste

The solid wastes from pulp mills include ash from the steam-generating boiler (waste wood products are used to heat the boiler), lime waste (CaO from the calcining plant) and wood waste. These materials are typically placed in an on-site land-fill. Because of the significant quantity of lime in the waste the leachate is normally quite alkaline (as compared with the mildly acidic leachate at a typical domestic landfill). There are monitoring wells around the landfill, and Harmac-Pacific is required to test the water several times a year and provide the results to the environment ministry. The Harmac landfillis not lined.

Mining industry wastes

Acidic drainage and metal contamination related to mining

Almost all types of mining, including metal mining and coal mining, and even some quarrying, or rock excavation related to construction, result in the exposure of sulphide minerals (especially **pyrite**) to the oxidizing surface environment. Oxidation of the sulphides leads to the generation of strongly acidic drainage water. Such waters commonly also have high levels of metals.

The following strategies can be used for minimization and treatment of acid drainage.

Predicting acid drainage

> **Prediction**: Prediction of the acid-producing potential of a mining or excavation project is essential in order to be able to design appropriate mitigation facilities and procedures. The sulphide content of the waste rock must be assessed, and the nature of the sulphide minerals, including factors such as mineral type, grain-size, distribution within the rock, should be studied. The content of any alkaline-producing minerals (such as calcite) must also be considered as these can help to reduce the acid problem. Theoretical models may not be adequate in many cases, and experimental studies should be carried out using representative samples of the actual material that will be exposed.

Isolating acid-producing materials

> **Isolation**: In some cases it is possible to isolate the acid-producing materials from the air and/or water of the surficial environment. Oxygen has a very limited solubility in water, and if the wastes can be stored in a stagnant (or very low flow) sub-aqueous environment, the degree of oxidation can be kept to a manageable low level. This can be

[4] Personal communication, Mr. Bart Howie, Harmac Pacific's environmental division, Nanaimo, spring 1998

done at surface within a constructed holding pond[5], within an exhausted open pit, or within mine tunnels and shafts that would then be flooded. The use of flooded mine openings is not necessarily a straightforward solution, especially in high-relief areas, where the flow of oxidizing water is still likely to take place. The advantage of sub-aqueous isolation is that as long as it is well designed the facility should last for an indefinite period, and thus the ongoing costs will not be excessive.

Isolation of mine wastes in a dry environment above the water table - using clay caps - is also a possible solution, but in practice it would be very difficult to ensure complete isolation of the material, especially over a period of many decades.

Treating acidic drainage

Treatment: In most cases it is necessary to use alkaline treatment techniques to neutralize acid drainage and to promote precipitation of heavy metals. Various reagents can be used, depending on the severity of the problem. The simplest and least expensive treatment is with limestone (calcite), however this is only effective for solutions with relatively low acid levels[6]. Hydrated lime (Ca(OH)2) is the most commonly used agent for neutralizing acidic drainage because it is safe to handle and effective with high-strength acidic solutions. Hydrated lime must be produced from limestone ($CaCO_3$), and this represents a significant cost (and also an environmental cost because it involves heating and release of carbon dioxide to the atmosphere). Furthermore, treatment with lime it produces a high volume of very wet sludge, which becomes a disposal problem in itself. Other reagents used for neutralization include sodium carbonate, sodium hydroxide and ammonia. These are relatively high cost solutions, and the reagents are dangerous to work with. In the case of ammonia the downstream environmental effects (nitrification and toxicity to fish) can be significant.

Artificial wetlands

A relatively new concept for the treatment of acid runoff (as distinct from the acid-generating material) is the use of artificially constructed wetlands (ie artificial bogs). In this type of environment natural micro-organisms and plants can neutralize and remove metals from waste solutions. The primary advantage would be that the facility should be capable of operating indefinitely with little maintenance.

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[5] In fact natural swamps, ponds and small isolated lakes would probably be ideal for this type of isolation because they are already full of natural organic reductants and there is a continuing supply from the surrounding environment. It is very unlikely, however, that the environmental community would accept the concept of dumping mine waste into a natural drainage basin.

[6] Acidity is expressed in pH units, but the strength of the acid solutions is also an important factor. A dilute solution of acid (such as acidic rain) can have a low pH, but it would take the addition very little alkaline material to balance that pH. A concentrated solution with a similarly low pH would require much more alkaline material to reach a neutral pH. Solutions with acidities exceeding 50 mg/L cannot be effectively treated using limestone.

Waste treatment at the Myra Falls operation

The Myra Falls mine

Since 1966 a large and profitable copper, lead and zinc mine (volcanogenic massive sulphide deposit) has been operated at Myra Falls, near to the southern end of Buttle Lake, within Strathcona Park, Vancouver Island[7]. The mine is actually within a special part of the park, and has been allowed to continue operation because it was discovered before the park was established.

Disposal of mill tailings into Buttle Lake

From 1967 to 1984 mill tailings were deposited within Buttle Lake beneath 30 m of water, and waste rock was piled up adjacent to the mine. During the late 1970's the provincial environment ministry discovered that lake water in the area of the tailings disposal had zinc levels of over 0.1 mg/l, as compared with the background level of 0.01 mg/l. The company was ordered to stop dumping their waste into the lake and develop an on-land tailings disposal facility, which they did.

Metal contamination from waste rock

It was subsequently discovered that the elevated zinc levels in the lake were not derived from the tailings stored under water, but from the leaching of the waste rock stockpiled near to the mine, 2 to 3 km up Myra Creek from the lake. It was also shown that the conditions around the in-lake tailings were consistently reducing, that the deposited materials were stable, and would probably become more stable as they became covered with additional organic lake sediment.

Underground disposal

At present between 50 and 60% of the mill tailings at Myra Falls is mixed with cement and used to fill mine openings that are no longer needed. The remainder, which is about 50% solids and 50% water, is discharged using spraybars onto a “dry” tailings deposit. The water collects in a pond and is treated. The solids build up in thin (30 to 50 mm) graded layers, and the uppermost fine material provides a nearly impervious barrier to natural precipitation.

Lime treatment of waste water

The waste rock is now stored in an area where its leachate can be recovered, and this liquid, along with the water from the tailings area, is treated with lime to increase the pH and promote precipitation of metals. Some of the treated water is recycled back through the mill, and the rest is released into Myra Creek once it has been ascertained that it meets strict trace-element limits, and passes a bio-assay test. For the bio-assay 10 fingerling Rainbow trout must survive for 96 hours in the undiluted effluent water. The water in Myra Creek, and in the adjacent area of Buttle Lake now has very low levels of zinc and other metals. The mining company monitors lake and stream water chemistry at various locations within the Campbell River drainage system, from adjacent to the mine, to just outside of Campbell River itself.

Once the Myra Falls deposits have been exhausted, as much of the waste rock and tailings as possible will be returned to the underground mine openings. The rest will be sealed over in a dry storage facility, and the area will be re-vegetated[8].

Part of the Myra Falls operation is shown on the figure below. The waste-rock pile is visible in the background, and the tailings pond is situated immediately in front of this.

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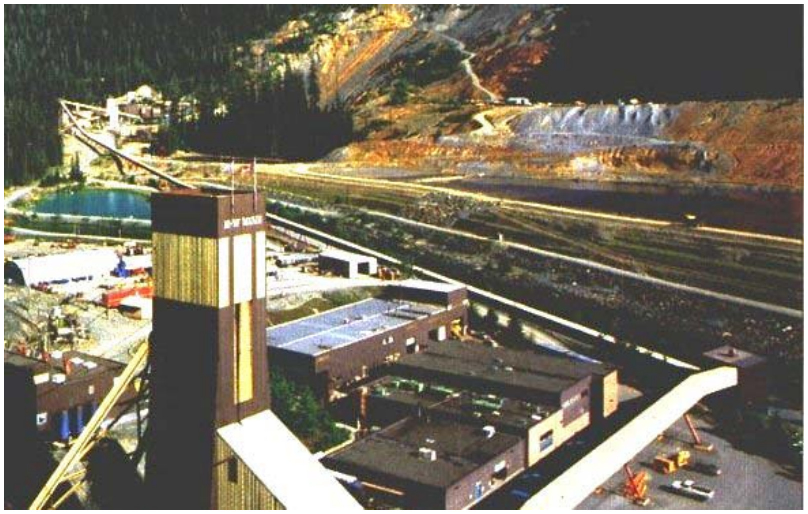
[7] For most of its life the mine was operated by Westmin Resources Ltd. In 1999 Westmin was taken over by the Swedish-Canadian mining company Boliden.

[8] Information on the Myra Falls tailings and waste rock disposal system has been provided by Steven Januszewski, Environmental Engineer for Boliden at Myra Falls



The Myra Falls mining operation in Strathcona Park

(the headframe is the structure that houses the elevator to transport miners, equipment materials, waste rock and ore into and out of the mine)

Note the rusty colouration of much of the rock in the background. Most of this is a product of oxidation of sulphide minerals in the rocks. Myra Creek runs between the tailings pond and the complex in the foreground, which includes the headframe of the mine. The figure below shows the same area from the opposite direction.

Looking across the Myra Falls waste-rock pile (foreground) and tailings pond. Myra Creek runs between the tailings pond and the headframe (back right)

Nuclear wastes

Disposal of waste from nuclear reactors

Wastes from nuclear power plants represent a particularly difficult problem because of their potentially high toxicity and very long life. The actual nature of the wastes is dependant on the type of reactor system in use, but typical components include ^{239}Pu (plutonium), which is highly toxic, and ^{90}Sr (strontium), which can substitute for the calcium in bones and thus can be very dangerous. ^{239}Pu has a half-life of 24,000 years, and if we accept the standard that radioactive wastes should be isolated from the surface environment for at least 10 half lives, then we are faced with the need to store these materials safely for 240,000 years! [9]

[9] After 10 half-lives approximately 0.1% of the original radioactive nuclide remains

Short-term storage of nuclear wastes

At present radioactive wastes are typically stored in large water pools adjacent to nuclear reactors. After several years in one of these pools the wastes are sufficiently "cool" so that they can be stored dry within large concrete containers. These facilities are safe, but it is obvious that this is no long-term solution. While a number of imaginative disposal ideas have been suggested - such as sending the wastes into space, or letting them melt their way down to the base of the Antarctic ice cap, or allowing them to be subducted along with oceanic crust, most people working in this field feel that the most practical solutions involve storage within solid rock deep within the continental crust.

Storage of Canadian nuclear wastes

In Canada the most likely location for nuclear waste disposal would be within the old rocks of the Canadian Shield[10]. The concept is that the waste material should be secured within a system of multiple barriers, as follows:

1. the radioactive material would be immobilized into ceramic or glass composite pellets - materials which are highly resistant to leaching by water,
2. the pellets would be surrounded by absorptive substances (such as bentonite clay) and then enclosed in corrosion-resistant (eg. titanium alloy) canisters,
3. the canisters would be buried within a clay-rich backfill medium in holes drilled into solid rock at a depth of around 1000 m, and
4. eventually the depository would be filled in and sealed.

Deep groundwater flow rates in rocks of the Canadian Shield

The theory behind this concept is that the rocks of the shield are not going to be subject to major tectonic forces for many millions of years, and that groundwater flow rates at depth within such rocks are very slow. In many places deep groundwater has been shown to be in the order of millions of years old (ie. it has been isolated from the atmosphere for millions of years). This is especially true in the low relief parts of the shield where the regional hydraulic gradients are commonly less than 1 metre per kilometre. If the granitic and gneissic rocks of these areas are generally unfractured, their permeability levels will also be very low. See the following box for an estimation of the rate of flow of groundwater deep in the rocks of the shield.

In the Canadian Shield it is not uncommon for the regional slope, and hence the slope (i) of the water table, to be less than1 m per km (<0.001 or 10^{-3}). An unfractured granite may have a permeability (k) of 10^{-8} cm/sec. Using Darcy's law, we can estimate the groundwater flow rate to be:

$$v = ki$$
$$v = 10^{-3} \times 10^{-8} \text{ cm/sec}$$
$$v = 10^{-11} \text{ cm/sec},$$
$$v = 3 \times 10^{-6} \text{ m/year}$$

or 3 metres in one million years.

Nuclear waste demonstration site

The concept of nuclear waste disposal within the shield has been demonstrated at a test site within the Lac du Bonnet granitic pluton at Pinawa, east of Winnipeg, and the next step in the process is to find a suitable and acceptable site within Ontario, where most of Canada's nuclear waste is produced. As in all waste disposal issues, one of the

[10] Atomic Energy of Canada Limited (a federal agency) is responsible for developing nuclear waste disposal in Canada. The work that they are doing is described at their website: http://www.aecl.ca/index.asp?menuid=500&miid=544&layid=3&csid=301

biggest problems is the opposition from people who don't want the facility built near to them.

Geology in the forest industry

Geology in the forest industry

The main geological issues related to logging operations are slope stability and minimization of sedimentation into fish-bearing streams and rivers. Working on steep slopes, removal of vegetation from steep slopes, and building roads on steep slopes all contribute to instability, and to the potential for sedimentation into river systems - one of the major causes of the destruction of fish habitat. In British Columbia the Forest Practices Code and its successor the Forest and Range Practices Act[11] address these issues in some detail, and provide regulations and guidelines that are intended to minimize the impact of logging operations.

The Forest Practices Code and the new Forest and Range Practices Act

The current provincial government has replaced the Forest Practices Code (FPC) with the Forest and Range Practices Act (FRPA). The FPC is rich in regulations and enforcement, and has consumed a great deal of forest-company resources and government bureaucracy. The FRPA is described as "results-based" code that is more focused on letting forest companies take care of protecting the environment themselves, and then reviewing the results and assessing significant penalties where necessary. Under the old system the forest companies could be fairly confident that if they followed the "rules" they would not get into trouble. Under the new system they actually have to be careful that they don't do any harm to the environment. The FRPA places a heavy reliance on professionals to assess environmental risks, and those professional include geologists.

We are currently in a transition period between the FPC and the FRPA. The FRPA came into partial effect in 2003, and will come into full effect in January of 2006. Although the FPC will soon be defunct, many of its regulations and intentions have been incorporated into the FRPA.

By way of example, the FPC includes the following statement regarding the construction of roads:

> Prior to approval of cutting permits or road construction, on-site terrain stability assessments must be conducted by a qualified and licensed terrain specialist in areas identified on a detailed terrain stability map as having moderate or high likelihood of post-logging landslides following harvesting or road building, or areas where field staff have found indicators of instability.
> Terrain assessments are carried out with the primary purpose of identifying areas with a high potential for slope failure prior to the beginning of logging.

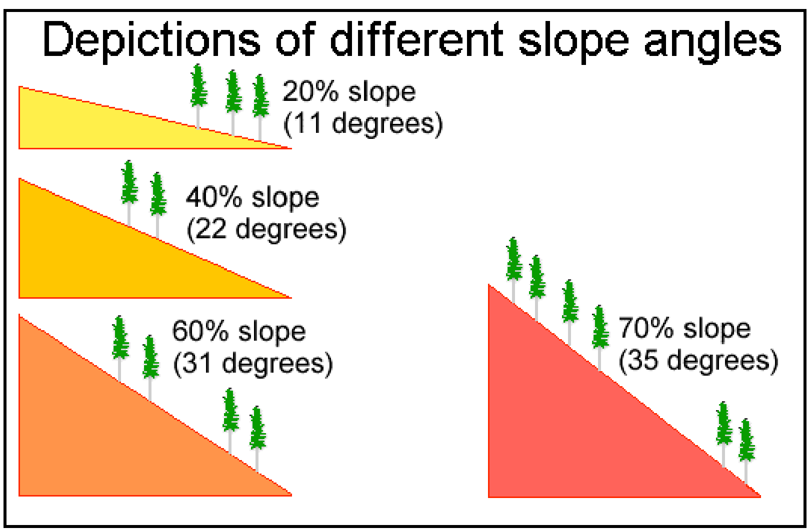
The Forest Practices Code sets out five terrain stability classes, as outlined in the following table.

[11] The Forest and Range Practices Act is described at: http://www.for.gov.bc.ca/code/ Some of the regulations of the Forest Practices Code remain in effect (for now at least) and these can be reviewed at: http://www.for.gov.bc.ca/tasb/legsregs/archive/fpc/fpcaregs/fpcaregs.htm

Forest practices stability classes and their descriptions and interpretations

Stability class	Description*	Interpretation
I (no risk)	Areas with slopes less than 20%. Includes floodplains and level to undulating coastal plains.	No significant stability problems exist.
II (low)	Gently sloping areas (20 to 40%) with poor to moderate drainage, or moderately sloping areas (40 to 60%) with good drainage.	Minor stability problems can develop, but timber harvesting should not significantly reduce stability. Slump-ing may develop along road cuts.
III (minor)	Gently sloping areas (20 to 40%) with lacustrine or marine clays and poor drainage, or moderately sloping areas (40 to 60%) with moderate to poor drainage.	Minor stability problems can develop, but timber harvesting should not significantly reduce stability. Minor slumping may develop along road cuts. A field inspection by a terrain specialist is not normally required.
IV (moderate)	Steeply sloping (> 60%) but well drained areas with deeply gullied surficial deposits. Steeply sloping poorly drained areas. Moderately sloping and poorly drained areas with lacustrine or marine deposits.	Moderate likelihood of landslides following logging or road construction. Wet-season construction will increase slide potential. A field inspection by a terrain specialist is normally required.
V (high)	Any areas where natural land-slides are visible on air photo-graphs. Very steep slopes (>70%) or steep slopes with imperfectly drained deeply gullied deposits.	High likelihood of landslides following logging or road construction. Wet-season construction will increase slide potential. A field inspection by a terrain specialist is required

A graphical impression of the differences between slopes is given on to the right.



Graphical representation of slopes (*gentle slopes* (20 to 40%) *moderate slopes* (40 to 60%), *steep slopes* (>60%) and *very steep slopes* (>70%))

Terrain classes are assigned to internally consistent blocks of ground known as polygons. A preliminary terrain assessment is normally carried out using topographic maps, air photographs and/or satellite images. Subsequent more detailed assessments follow as the harvesting plans become more advanced. The second stage of terrain assessment should involve direct observation from a vehicle or aircraft

A slump in alluvial deposits at Taylor Hill on the south side of the Peace River near to Ft. St. John, B.C.

Evidence for potential slope instability

Some of the indications of unstable or potentially unstable terrain that can be observed from air-photos or on the ground are as follows[12]:

- Vegetation characteristics are useful for identifying soil moisture contents and previous failure. Plants such as skunk cabbage, devils club, deer fern and salmon berry are indicators of saturated soils that may be prone to sliding.
- "Pistol butting", where trees have a pronounced downslope curve in the lower part,
- "Jack-strawed" trees (see figure above) , where the trunks are sloping in various directions, and split trunks, are all indicative of possible slumping.

The need to document previous failures

Evidence of previous landslide activity needs to be mapped carefully. Features that may be indicative of a history of landslides include: linear downslope strips of even-aged trees, landslide debris on lower slopes, mixed or buried soil profiles, tension fractures, step-like terrain, talus deposits, bedrock structures parallel to the slope.

Importance of surficial geology

Understanding surficial geology is particularly important in determining the potential for failure. Both the type of material, and its thickness, are significant factors. Clay-rich materials that do not drain well can be a particular problem.

Terrain maps

Terrain maps are used to plan logging operations. This includes designating which areas can be logged, and which cannot; how different areas can be most safely and efficiently accessed; and where roads can be built without risking slope failure and

[12] after Luxmoore, (1996)

damage to water courses.

Instability caused by tree harvesting

Instability caused by tree cutting

Tree-harvesting activities, particularly yarding (moving logs to a road), can accelerate the natural frequency of slope failure events in the following ways:

- mechanical damage to stumps and root systems during yarding operations,
- uprooting of stumps used for supporting yarding equipment,
- physical disturbance of soil and sub-soil material.

These problems can be minimized through the use of careful yarding practices, and, where necessary, through helicopter logging.

Loss of trees and their roots

Even after a tree has been cut its root system will help to maintain the stability of the slope for some time. Over several years, however, the root will rot, and within an average of 10 to 12 years, the root will no longer provide any support. The loss of the tree canopy will also decrease both interception of precipitation and the rate of evapo-transpiration, and thus can contribute to oversaturation of the soil. In areas prone to high moisture levels these problems can be minimized through rapid revegetation using fast-growing species with high water needs.

Potential for wind damage

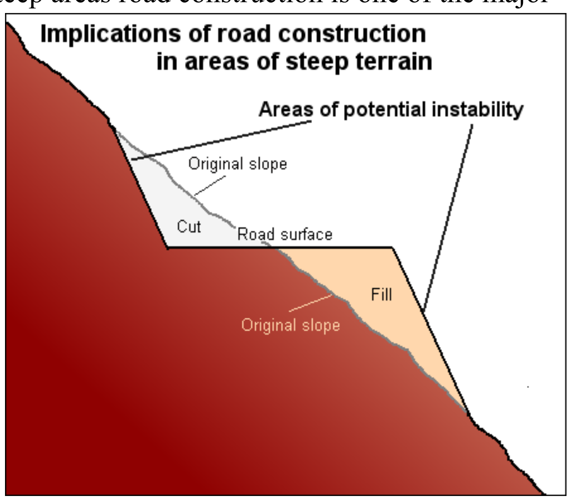
Trees left standing alone, or at the edges of cut blocks, do not have the same resistance to wind damage as those surrounded by other trees. Such trees are susceptible to being uprooted, and this can contribute to slope instability.

Instability caused by road construction

Implications of road construction

In most forestry operations efficient transportation of equipment, and especially of logs, means road construction, and in steep areas road construction is one of the major causes of slope failure. Some of the problems associated with road construction on steep slopes are as follows:

- oversteepening slopes on the fill (downhill) side of a road,
- lack of stability of the fill material,
- undercutting the slope on the cut (uphill) side of the road,
- altering natural drainage patterns, and
- directing road drainage into fill slopes.



Example of road construction by cut and fill

In order to create a relatively flat roadbed it is necessary to make the banks on either side of the road steeper than they were before, in some cases much steeper. These steeper slopes are inevitably less stable than the original slopes, and they can be the starting points for slides that then propagate both up and down the slope. One way to avoid some of the problems associated with road building is to avoid the use of fill in sensitive areas. In other words, a large enough cut would be made to provide sufficient road-bed width, and all of the cut material would be removed and stored somewhere else until decommissioning.

An example of slope failures related to road construction is given on the photo to the right. Several failures are evident. Most appear to originate from just above or just below the roads, but all extend well down the slope.

A logged slope near to Wahleach Lake, B.C. (SW of Hope)

(photo by J. Clague)

Apart from destruction of the environments and ecosystems on the slope, failures of this type can lead to introduction of sediment into streams, and hence to destruction of fish habitat and contamination of water supplies.

Slope failure associated with logging road construction in the Nanaimo area

An example of what can go wrong with a forest road cut is shown on the figure to the right. In this area, near to Nanaimo, it was necessary to make a tight switch-back in the road. The glacial till in the area in between the two parts of the road failed, and this contributed to significant failure below the lower road. Because this area is close to a major fish-bearing river the company was required to spend a lot of money fixing the problem. They built the rock barrier, and they also had to stabilize the slope below the lower road.

Wattling was used to stabilize the slope below the lower road. Green branches (usually willow) are woven around a series of metal stakes along the side of the hill. The branches are meant to take root in order to hold the material together.

Road construction and drainage

All roads disrupt drainage patterns to some extent, and in some cases this can lead to significant oversaturation of surficial materials by water. It is essential for the road designer to have comprehensive information of slopes and drainage patterns, the type and thickness of surficial deposits, as well as existing or potential landslide and slump areas. With this information ditches and culverts can be designed so that water is diverted into natural drainage channels, and away from potential problem areas.

The Forest Practices Code guidebook on Forest Road Engineering provides detailed specifications of many different aspects of forest roads, including route surveys, cut and fill specifications, clearing widths, design of bridges culverts and fords, design of ditches and inspection and maintenance of roads.

FPC requirements for road design

In areas classified as stability classes I to III (see table on p. 10 above) detailed surveys and road design are not required. In areas classified as IV or V, or wherever the slopes are greater than 50% (27 degrees) geometric road design is required. Geometric design involves the following:

- accurate surveying both before and after construction,
- careful design of cut slopes and fill slopes,
- full accounting of cut and fill volumes,
- specification of the locations and diameters of culverts,
- specification of the locations and design of bridges,
- classification of streams, and
- specification of measures for reducing environmental impacts.

Geology in engineering

Geology in engineering

From an engineer's point of view geological materials are classified on the basis of their strength as foundations, their stability in excavations and their usefulness as aggregate. Different types of rocks are grouped according to their engineering properties, as summarized in the table below.[13]

Rock types grouped according to their engineering properties

Group	Representative members
Basalt	basalt, andesite, mafic dyke rocks
Gabbro	gabbro, pyroxenite, dunite (olivine rock), amphibolite
Granite	granite, gneiss, granodiorite, pegmatite
Sandstone	all types of sandstone, conglomerate, breccia
Limestone	limestone, dolostone, marble
Porphyry	all porphyritic rocks, rhyolite, felsite
Schist	schist, phyillite, slate

Isotropic versus anisotropic rock types

In addition to compressive strength, the features which are relevant in assigning rocks to these different groups include properties such as: specific gravity, porosity, degree of cementation, sorting (ie. consistency of grain sizes), grain shape, seismic velocity and chemical reactivity and isotropism. (Isotropism is the directionality of rock texture, where a rock such as basalt or limestone is generally isotropic - or non-directional - while a schist or a thinly bedded siltstone is anisotropic).

The compressive strengths of different types of rocks are as listed and described in the following table.[13]

[13] from McLean and Gribble, 1979

Class	Strength*	Representative rock types
Weak	< 12.5	weakly compacted sedimentary rocks, highly weathered rocks
Moderately strong	12.5 - 50	sedimentary rocks, foliated metamorphic rocks (eg. schist)
Strong	50 - 100	metamorphic rocks, strongly cemented sandstone
Very strong	100 - 200	intrusive igneous rocks, weak quartzite, gneiss
Extremely strong	> 200	fine-grained igneous rocks, strong quartzite, hornfels

Compressive strengths of rocks (in newtons/square mm)

These parameters provide the information necessary to plan footings for buildings, bridges, roads and dams. The foundations for a large building, an airport, a bridge or a dam can certainly not be built on weakly compacted sedimentary rocks or foliated rocks (such as schist) because there is a high probability that these will become either compressed or sheared under the great weight.

Importance of geological structures

With regard to excavations for roads, tunnels, buildings and water-works, one of the most crucial properties of rocks is the type, spacing and orientation of structures that could represent weakness within the rock. The first things to be done by a geological engineer when evaluating a construction site is to carefully study and map the structural features in the rocks. This normally involves surface mapping from outcrops, but in areas where a lot of detail is needed, or where the rocks are not exposed, it could involve diamond drilling and examination of cores. In some cases seismic surveys, and other geophysical techniques can be used to get a picture of the underlying rock structure.

Types of structures

Types of structures to be considered include bedding planes, (which might mean the partings between individual beds or laminations of similar lithologies or the contacts between beds with different lithologies, including sills), metamorphic foliation (such as schistosity or shaly partings), fractures (open or closed), faults (a fault is a fracture with movement) and dykes. A typical classification of spacing characteristics is given in the table below[13].

Description	limits
Very thick (fracture sets or sedimentary beds)	> 2 m
Thick (fracture sets or beds)	60 cm - 2 m
Medium (fracture sets or beds)	20 to 60 cm
Thin (fracture sets or beds)	6 to 20 cm
Very thin (fracture sets or beds)	2 to 6 cm
Narrow (fractures) or thickly laminated (beds)	6 to 20 mm
Very narrow (fractures) or thinly laminated (beds)	< 6 mm

A classification system used for describing thicknesses of sedimentary beds or spacings between fractures

Orientations of strucutres

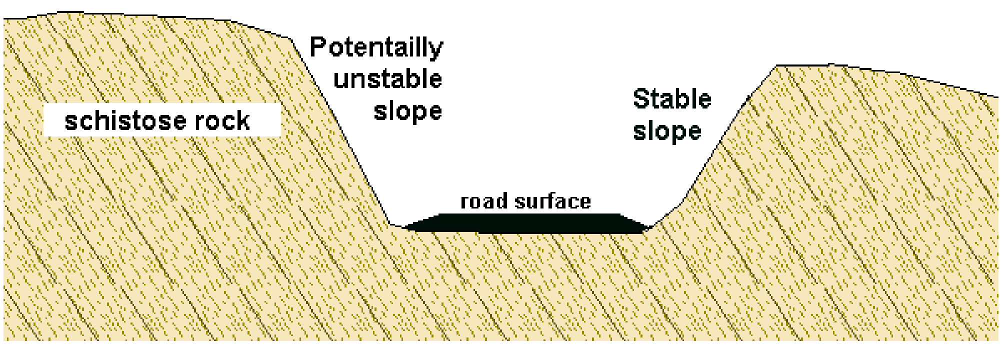
Of even greater significance than the spacings of structural features is their orientations, and of course the relationships between those orientations and that of any planned excavation (see figure below). In some cases it may be sufficient just to know that the body of rock has structures in certain directions. In other cases - especially in areas close to the face of the planned excavation - the locations and orientations of specific faults and fractures must be determined. It is not always necessary to know these things ahead of time, but once the excavation has been cut it is essential to examine the structures near to the face to see if there are any weaknesses that might cause the face to collapse. If so, more blasting must be done to remove any slabs of rock that could be unstable, or else other steps must be taken to stabilize the slope.

Behavior of rock aggregate

In a major construction project, such as a highway or a dam there are usually some areas where the rock has to be cut (drilled and blasted) and other areas where low spots need to be filled. In such cases engineers try to balance the amount of cutting and filling so that the excavated material can be used as fill. It is important, however, to understand the properties of rock when it exists as broken pieces. Some of the parameters of importance include the strength, consistency, chemical reactivity and clay content of the rock in the crushed form.

Shales and mudstones are not useful as aggregate because they are too weak, and also because the clay minerals will be weakened and could even expand when saturated with water. Poorly cemented sandstone and conglomerate and schist or phyllite are generally too weak to be useful as aggregate. Rocks with high sulphide mineral contents should be avoided as fill materials because of the potential for acid rock drainage, and also because as pyrite oxidizes it can cause the surrounding rock to expand[14]. Granite, basalt, strong sandstone (including quartzite) and massive limestone make good aggregate materials.

Implications of slope angle versus foliation angle on rock-cut stability



Aggregate for concrete

Aggregate to be used for concrete must be free from sulphides, clay minerals and organic matter, and should have a rough surface to promote bonding. Although carbonate rocks are acceptable for concrete, the content of carbonate minerals must be known so that the appropriate amount of lime can be added to the mixture.

Implications of water content

Where a highway or a dam involves cutting through unconsolidated materials, or where a large fill-in is created with steep banks, the site must be carefully designed so that the stability of the slopes is not exceeded, even when the material becomes saturated with water. There are many locations along the Island Highway where these types of materials have failed (in rotational slumps). Most such failures are small and do not represent significant hazards. However, if a very large fill, like the one behind the college was to fail in this way the entire road-bed in this area could be compromised.

Groundwater

Groundwater is also an important consideration in construction projects because of the need to avoid building in water-saturated materials, and because of the importance of

[14] In a February of 2000 a number of Montreal-area home-owners complained because their foundations were damaged. The rock fill that had been placed under the foundations contained a significant amount of pyrite, and the oxidation of this material had caused the rock to expand, damaging their basement floors.

not disturbing groundwater resources.

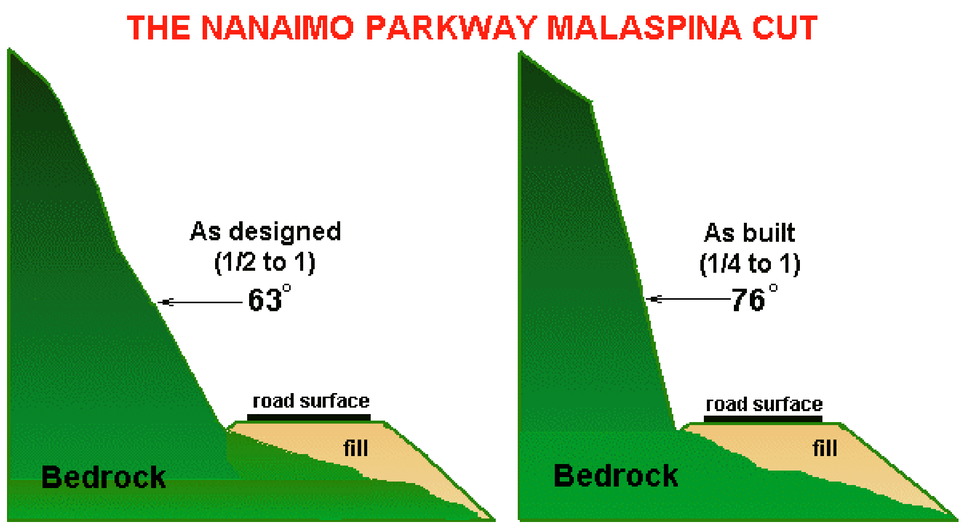
Geotechnical Engineering for the Nanaimo Parkway[15]

Naniamo Parkway

In the early stages of planning a major road such as the Nanaimo Parkway a route survey is undertaken, including examination of topographic maps and air photos, excavation of test pits, and drilling of test holes into bedrock. Overburden and rock samples are classified, and tested for moisture content, plasticity, compressibility and strength. Potential rock cut areas are examined for structure and for the usefulness of the rock as a construction material.

The Malaspina Cut

One of the major challenges of the Nanaimo Parkway was the large cut and fill behind Malaspina University-College. Most of this material is basalt, and in places it is very highly fractured. It is good strong rock, however, and, once crushed, it makes suitable fill. In the original design of this section the recommendation was for a cut with a slope of 63º (1/2 horizontal to 1 vertical). During construction it was decided to make this cut with a slope of 76º (1/4 to 1) (Figure 6.9). This steep rock slope has caused some problems. Scaling was necessary to remove loose rock blocks, and it has also been necessary to cover part of the cut with chain-link mesh in order to control rock falls. This type of problem can also be dealt with by stabilizing the irregular surfaces with cement.



Rock cut angles for the "Malaspina Cut" section of the Nanaimo Parkway

In the area just south of Harewood Mines Road in Nanaimo some old coal mining adits were discovered. Some of these were within 1 m of the surface, and some were about 5 m down. The geotechnical consultant working with the construction company recognized that the workings could collapse under the weight of the highway fill. To prevent subsidence problems the near-surface adits were crushed with a 20 tonne weight repeatedly dropped using a crane. The deeper adits were filled with a runny concrete mixture.

Northfield Marsh

In the area just north of Jinglepot Road the highway crosses the Northfield marsh. It

[15] Information supplied by Bryan Kern (P. Eng.), Geotechnical design coordinator for the Vancouver Island Highway Project, B.C. Ministry of Highways, Victoria.

was anticipated that the road foundation could fail if the marsh was filled in a conventional way. Instead a sinking wedge technique was used, and enough fill was emplaced so that the base of wedge actually rests on the underlying bedrock, rather than "floating" on the organic-rich sediments of the marsh.

Reduction of negative impact

Throughout construction of the Nanaimo Parkway (and other similar roads) the design and construction crews have had to take great care in ensuring that the environmental impacts of the construction, and of the highway itself will be as small as possible. This begins at the design stage, and involves study and analysis of both aquatic and land animal and plant populations. In construction projects of this type the main environmental criterion is that there must be no net negative impact on habitats and migration corridors. In other words, if it is necessary to destroy some habitat, other habitat must be created so that there is no net loss. Of course the concept of no net loss of habitat makes no sense when you are building a highway through a wilderness area. What is really meant is that there will be no net loss of aquatic habitat.

Limiting production of turbid runoff

During highway construction care is taken to minimize the amount of sediments (sand, silt, clay) that can get into drainage systems. Settling ponds are built at various locations along the route so that as little as possible of the large volume of rock and overburden used in the construction process gets into fish-bearing streams.

After construction some of those settling ponds may be converted into constructed wetlands. In biologically sensitive areas the runoff from the road-way will be channeled through the wetlands so that pollutants from the traffic can be trapped by vegetation[16].

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Luxmoore, J., 1996, Terrain stability identification for forest engineers, Univ. of British Columbia, Graduate essay for Bachelor of Forestry, 34 p.

McLean and Gribble, 1979, Geology for Civil Engineers, George, Allen and Unwin, London.

[16] Most of the information on Island Highway environmental issues was supplied by Craig Barlow, environmental consultant to the Ministry of Highways.