

Large-scale Erosion and Flooding after Wildfires

Understanding the Soil Conditions

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Ministry of Forests and Range
Forest Science Program

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Mike Curran, Bill Chapman, Graeme Hope,
and Dave Scott



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TABLE OF CONTENTS

Acknowledgements	iii
Introduction	1
Purpose and Scope	1
Wildfire Effects on Soil	1
Predicting Sensitive Areas.	3
Water-repellent Soils	4
Soil Pore Clogging, Crusting, and Breakdown of Surface Soil Structure	6
Loss of Forest Floor	6
Catchment Area and Slope Gradient	6
Effects on Natural Revegetation Processes	8
Seasonal Timing and Duration of the Risk of Catastrophic Erosion and Flooding	9
The Potential for Repeated Erosion.	9
Management Considerations and Mitigative Measures	10
Natural Context	10
Measures during fire suppression efforts	10
Measures during rehabilitation planning and operations	11
Erosion timing	11
Erosion control seeding	11
Use of soil mulches.	12
Use of physical remediation	12
Salvage logging	13
Recognition of geotechnical risk.	13
Evaluation and prediction of erosion risk	13
Summary	14
Recommendations	15
Further Reading	15
APPENDICES	
1 Information and operational trial gaps related to large-scale soil erosion after wildfire	17
2 Descriptions of fire and burn severity	18
TABLES	
A2.1 Descriptions of fire and burn severity	18
A2.2 Burn severity classification based on post-fire appearances of litter and soil and soil temperature profiles	18

FIGURES

1	Debris flow deposit on fan of Kuskanook Creek	2
2	Water drop test for repellency	5
3	“Dusty footprints in the mud”	5
4	Evidence of overland flow on water-repellent soil, Kuskanook Fire, August 2004	7
5	Evidence of concentration of overland flow on water-repellent soils at Kuskanook, August 2004	8
6	Log across slope in Kuskanook Fire after August erosion event	12

INTRODUCTION

Large-scale erosion and flooding after severe wildfires are common, normal occurrences in mountainous or hilly terrain. These events include debris flows, mudflows, mudslides, gully erosion, landslides, and debris floods. When such phenomena occur away from human activity, they go largely unnoticed, even when they may be locally significant. However, in interface locations, these events attract media attention because they can be catastrophic, destroying infrastructure such as roads and water supply systems, property, and lives. In some parts of the Southern Interior, these events seemed more pronounced after the 2003 wildfires. By the end of 2004, at least five major soil erosion and/or flooding events related to the 2003 fires had occurred. Recent research in the Interior has shown that, since glaciation, similar large-scale erosion and flooding have repeatedly occurred after wildfires. These events significantly shape the post-glacial Interior landscape, with one result being large deposits on alluvial and colluvial fans.

PURPOSE AND SCOPE

This report discusses soil-related properties and processes determining large-scale soil erosion and associated runoff. Soil characteristics related to these properties and processes should be assessed and considered in evaluating wildfire effects. The information presented is based largely on scientific principles, literature from other locations, and local experience. To better quantify or predict the importance of the various contributing factors described below, more local experience and research are needed. Some of these information gaps are listed in Appendix 1.

At the end of the document, we discuss mitigative actions that should be considered during and after wildfires. The greatest risk from these large-scale events is to people and structures that are on alluvial or colluvial fans. These fans are the run-out areas for deposition of debris from large-scale erosion in the catchment above them. In mountainous areas, houses and other infrastructure are often located on these gently sloping landforms.

WILDFIRE EFFECTS ON SOIL

In a natural forest environment, vegetation and forest floor (litter and duff) protect the surface soil, preventing surface soil erosion or reducing it to negligible levels. If the vegetation or forest floor is removed and/or the soil is disturbed, soil erosion may occur.

In a wildfire, the forest canopy and the forest floor are completely or partially consumed within a mosaic of burn severities (burn severity classes are defined in Appendix 2). In areas of high burn severity, the interception of precipitation is reduced while the protective layer overlying the soil surface decreases. This change increases the likelihood of surface soil eroding after heavy rain or rapid snowmelt. Heating the soil during the fire may alter the soil structure or reduce the organic matter content of the soil, thereby

increasing soil erodibility. Combustion of surface fuels and the forest floor vaporizes hydrophobic organic substances, which may move downward and condense on cooler underlying soil layers, creating water-repellent soils. Such soils are more prevalent on severely burned areas of a wildfire.

All of these factors contribute to a natural consequence of fires: relatively more precipitation reaches an altered soil surface that may have reduced water infiltration capacity. The final result is both increased overland flow of water (or surface runoff) and erosion. Overland flow, which also contains eroded soil, can then be concentrated in channels, gullies, and eventually streams. At the same time, the sediment-laden water will erode more channel material. The concentration of flow also occurs more rapidly than on an unburned watershed. As a result, channels, gullies, and streams after wildfire carry more water; the water can be more sediment-rich and is delivered to alluvial fans faster than if the watershed was unburned.

Most often the erosion, overland flow, and concentrated flow go unnoticed. Occasionally factors come together such that concentrated flows trigger large-scale erosion or flooding in the form of debris floods or flows. These events will affect, and may even devastate, anything in their path. A recent example of this occurred in August 2004, downstream of the Kuskanook Fire, north of Creston (Figure 1).



FIGURE 1 *Debris flow deposit on fan of Kuskanook Creek.*

Three factors can lead to large-scale erosion.

1. Fire effects on the soil
 - large areas of severely burned forest floor or mineral soil exposed on slopes that are associated with:
 - loss of protective ground cover (mainly the forest floor, also referred to as the litter and duff layers),
 - a high frequency of water-repellent soil conditions that reduce water infiltration, and/or
 - soils that have reduced cohesion and higher erodibility
2. Physiographic characteristics
 - catchment areas that can collect or concentrate large volumes of water
 - generally, but not necessarily, steep slopes
 - soil that is susceptible to erosion
3. Precipitation events
 - high intensities of rainfall, or in some cases snowmelt

Large-scale erosion and flooding, and the formation of water-repellent soils following wildfires, have been reported for many years in the literature from much of the western United States, including California, Oregon, Washington, Idaho, and Montana. However, this phenomenon was not widely recognized in British Columbia before 2003, partly because of fewer interface wildfires in the past and because little post-fire flooding and erosion have occurred in interface areas. The 2003 wildfire season may have been different, since a much larger area burned at the interface, and soils and fuels were drier than average. These conditions led to a more severe heating of the soil, and created conditions that were more sensitive to high-intensity rainfall. Also, more post-wildfire, high-intensity precipitation events may have occurred in some areas.

PREDICTING SENSITIVE AREAS

The usual variables that are used to predict soil erosion hazard also apply after a fire. The likelihood of surface soil erosion is a function of the probability of high-intensity storm occurrence or rapid snowmelt, the surface soil conditions regulating infiltration and drainage of water, the energy of the resultant surface overland flow and runoff, and the inherent erodibility of the soil. The erodibility of the soil is primarily influenced by soil properties (texture, cohesion, and structure). The energy of the overland flow and runoff depends on topographic features such as slope length and gradient within the hillslope catchment area, and the size and characteristics of the catchment area. Surface cover, presence of water-repellent soil layers, and inherent soil properties affect infiltration and hydraulic conductivity. High coarse fragment content in the soil, and any dense root mats that remain after fires can reduce erodibility. Using a standard technical approach, soil scientists experienced with erosion can assess erosion hazard by considering these factors. Some of this work, except for the evaluation of water repellency and surface cover changes, could be done before or while a fire occurs, so that suppression crews could be alerted to higher-sensitivity areas.

Severe burns seem to be particularly prone to large-scale erosion because of the physical effects associated with fires. For this reason, predicting sensitivity to large-scale erosion after fire requires the participation of individuals familiar with fire effects on soil. Some of the particular considerations for predicting susceptibility to large-scale soil erosion after forest fire are discussed below.

WATER-REPELLENT SOILS

Water repellency is a natural phenomenon that can occur in forest and range soils when they dry. Water-repellent organic substances, such as waxes and lipids, naturally occur in the forest floor and mineral soil. These substances come directly from plant litter and roots; indirectly during decomposition of these materials and from fungal hyphae. In summer, it is not uncommon for these materials to impart some water-repellent properties to the surface soil. However, this type of repellency is usually not hydrologically significant because it is not as well developed; it does not affect a large, continuous part of the forest soil; or the ground cover of woody debris, litter, and duff offer protection and water storage capacity.

During wildfire, the forest floor can be partially or totally consumed. During and immediately before combustion, the waxes, lipids, and other compounds vaporize and diffuse both into the atmosphere above the ground and into the soil profile.¹ In the soil, these compounds will condense when they reach a lower temperature, coating mineral soil particles. This often occurs > 1 cm below the surface. Photos 2a and 2b show water beading in small trenches used to expose the soil to test for water repellency. Photo 3 demonstrates the typically wet surface soil that can stick to your boots, creating “dusty footprints” in the underlying water-repellent soil. For a fairly continuous coating of water-repellent compounds on the soil particle surfaces, the following conditions need to be present:

- a source of organic compounds (e.g., forest floor),
- enough heating of the soil to vaporize these organic compounds and move them down into the soil profile,
- soil that was dry enough to allow the gaseous vapours to penetrate and coat soil particles, and
- enough of these vapours to adequately coat soil particles at the depth of condensation.

Sandy soils, which have the lowest specific surface area, are more susceptible to water repellency following wildfire, although these layers can form on a range of soil textures. Large rocks and stones at the soil surface appear to reduce the formation and continuity of the water-repellent layers.

¹ At the same time, any water-repellent substances at the soil surface are denatured, leaving the surface soil completely wettable.

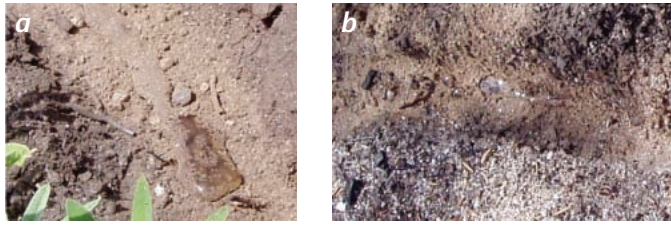


FIGURE 2 *Water drop test for repellency. a) Dust covers some of the water, which is common during these tests. b) Water drops accumulating in small trenches used to test water repellency of soil in Kuskanook Fire, August 2004.*



FIGURE 3 *“Dusty footprints in the mud.” A dusty footprint in underlying water-repellent soil is formed from saturated surface soil sticking to boots.*

A water-repellent “layer”² in the soil will significantly reduce infiltration of water into the soil during intense rainfall events, resulting in increased overland flow and erosion. The effects of the layer are most pronounced after prolonged dry periods, or shortly after a fire, when the upper soil profile is dry. If soils are water repellent, the first major rainfalls after a fire can cause significant erosion. Water repellency persists for 2–6 years, with more strongly repellent areas remaining for the longest periods. The repellency decreases as the water-soluble hydrophobic substances break down, sites revegetate, and the forest floor builds up.

As soils moisten, the water repellency weakens. The wetting process may take considerable time, although a long, low-intensity rain will normally sufficiently soak the soil profile. The resultant wetting of the soil is often variable across a hillside, because the reduction of repellency requires higher soil moisture contents as burn severity increases. For example, on the Kuskanook Fire, about half of the severely burned areas were observed to still be strongly water repellent after several weeks of rainy weather. Eventually, the water “fingers through” wetted, less repellent channels and zones such that under these wetted conditions, water appears to infiltrate at normal or near normal rates. For this reason, water repellency of soil is usually not a concern during snowmelt or in the spring, although erosion can still be a concern if spring runoff creates overland flow.

The importance of water repellency varies from year to year. Sustained periods or even repeated years of hot, dry weather are more conducive to the maintenance of water-repellent conditions. Recent erosion investigations in

² The term “layer” is used without trying to give the impression that repellency produces a complete waterproof horizon in the burned soils: the repellency is neither continuous nor at a uniform depth—there are always wettable channels and zones (such as burned-out roots) in the soil. However, in strongly water-repellent soils, the result is an overwhelming amount of runoff during intense rainfall, making it appear as if there was a continuous layer.

the Southern Interior indicate that water-repellent soils were one of the major contributing factors to several large-scale erosion events that occurred during the fall of 2003 and summer of 2004 on areas burned during 2003. These fires included Kuskanook (Figure 1), Cedar Hills near Falkland, Okanagan Mountain near Kelowna, and Lamb Creek near Cranbrook.

While formation of water-repellent soil conditions has been commonly observed in the past, it appears to have been more common during the 2003 wildfires. Formation of wildfire-induced water-repellent layers is known to be more likely when soils are very dry, a condition that was widespread during the mid-summer wildfires of 2003.

SOIL PORE CLOGGING, CRUSTING, AND BREAKDOWN OF SURFACE SOIL STRUCTURE

When forest floor burns, a significant amount of ash is created that has the properties of very fine soil particles. Ash can form a crust of its own or plug the pores of the remaining duff and the surface mineral soil. The mineral soil may also lose its structure when exposed to intense heat. Finer-textured soils with strong structure might normally have good infiltration properties but when fire degrades this structure, infiltration of water can be greatly reduced. A thick ash coating can exacerbate this phenomenon. Intense rainfall, which causes splash erosion, may also reduce infiltration by creating a surface coating of eroded material. Thick ash deposits, crusting, puddling, and plugging of surface soil following a fire are all indicators of increased susceptibility to overland flow and erosion.

LOSS OF FOREST FLOOR

The forest floor (the organic litter and duff covering the mineral soil) lessens the risk of erosion in many ways. It prevents raindrops from hitting the mineral soil and breaking down the surface structure. The fibres of the forest floor act as miniature dams to reduce the kinetic energy of overland flow, reducing the ability to dislodge any soil particles. The forest floor has very high porosity and water-holding capacity and if not saturated can absorb sudden water inputs and then release the water slowly, allowing steady infiltration into the mineral soil. In addition, soils that develop under thick forest floor layers tend to be different from those that develop without the protection of this overlying, protective layer. Thus, soils with thick forest floor layers before burning will generally be more susceptible to erosion after this layer is fully consumed than soils with no or very thin layers. Severe burns that completely consume the duff (FH layers) make an area much more susceptible to erosion than less severe fires that only partially consume the duff layer. In addition, during less severe burns, the remaining forest floor insulates the underlying soil from heating effects and protects the soil surface after the fire; and the post-wildfire litterfall from dead or dying trees forms a litter-mulch that protects the soil from large-scale erosion.

CATCHMENT AREA AND SLOPE GRADIENT

Areas that experience crown fires lose the normal rainfall interception and evaporation that occurs in forested ecosystems, resulting in more precipitation and higher rainfall energy at the soil surface. In addition, burned soils may lose almost all of their capacity to absorb this extra water, and it takes a surprisingly small catchment area to produce significant erosion. Managers should be aware that, under the right conditions, even very small fires or catchment areas of 1 or 2 ha with shallow slopes can have very significant erosion or runoff events. The amount, location, and distribution of burn severities within a watershed determine the probability of significant damage downslope or downstream. While many areas may benefit from a fire, the right combination of factors can result in large-scale erosion even when only 10% of a watershed is severely burned. Runoff from such burned areas can be 10 or more times higher than may normally be expected. For example, less than 10% of the Kuskanook catchment was severely burned, yet an intense summer rainstorm on the resulting water-repellent soils in one catchment area created a 1-in-100-year debris flow on the fan at the base of the entire watershed.

Initial soil erosion (sheet and rill) or increased overland flow (Figure 4) may concentrate runoff (Figure 5), which may then lead to large-scale erosion and flooding. Although the initial process of concentration can occur on gentle slopes, the problem and consequences are more pronounced on steeper slopes or where topography like small gullies and concave depressions facilitates the concentration and speed of overland flow.



FIGURE 4 *Evidence of overland flow on water-repellent (hydrophobic) soil, Kuskanook Creek, August 2004. Lighter areas below trowel and auger are from overland flow; note the low slope gradient and the small burned catchment area in this example.*



FIGURE 5 *Evidence of concentration of overland flow on water-repellent soils at Kuskanook, August 2004.*

EFFECTS ON NATURAL REVEGETATION PROCESSES

Re-establishment of plant cover is essential for long-term erosion control. Vegetation protects the soil surface from raindrop impact, and develops a surface mulch and below-ground root system that increases water infiltration and holds soil in place.

Wildfire is a natural disturbance agent in the Southern Interior, and natural revegetation of burned areas may occur rapidly after fire because various species are ecologically adapted to wildfire. Such adaptations include seed-banking in the partially consumed forest floor, basal meristems in grasses and related species, rhizomatous root mats, and fire-stimulated seeds. Generally, revegetation will be achieved more quickly, and with greater abundance, by native plants that are self-establishing after fire than by domestic grass seeding. However, this may be altered by the season of the fire and by burn severity, as seen on some still-revegetating upper slopes on 2003 fires. Native riparian vegetation often appears to recover more quickly than hillslope vegetation, and burn severity is often lower in riparian areas.

On less severely burned areas, little damage may occur to roots, even those of dead trees. Such roots and their associated soil organisms and organic compounds help to stabilize the soil and prevent erosion during the most susceptible post-wildfire periods.

Natural revegetation can be slow in areas that had little understorey vegetation before the fire or in severely burned areas. Numerous areas like this have been observed in the 2003 wildfires, although not all severely burned areas have poor revegetation. Further study of natural revegetation after wildfire is required before more definitive statements can be made.

A knowledge of the plant community before fire, and an understanding of burn severity effects on plant recovery can help in determining erosion risk and evaluating the need for any erosion control measures such as mulching, seeding, or physical barriers to erosion.

SEASONAL TIMING AND DURATION OF THE RISK OF CATASTROPHIC EROSION AND FLOODING

Large-scale erosion and flooding are most likely during intense summer or fall (thunder)storms the year of a fire, or during intense summer storms that follow a drought in subsequent summers. Prediction of these precipitation events that often control post-wildfire erosion is difficult because they are infrequent, vary widely in severity, and are generally localized.

Water repellency is greatest when soils are dry, as after prolonged dry periods, and becomes less pronounced as soils become moister. Loss of forest and vegetation cover on the burns may also result in surface soils drying faster as well. Vegetation re-establishment is also lowest in the first year after fire. Therefore, during the first year, intense rainfall can lead to large-scale erosion, especially if preceded by a dry period. The hazard remains in subsequent years but is mitigated over time by natural revegetation and the gradual weakening of the hydrophobic coatings.

Water-repellent behaviour will initially exist each summer until the affected soils are gradually wetted again, normally in the fall rains or under the snowpack. This cycle of behaviour generally lasts only a few years, but has been noted to exist for up to 6 years in other areas and will have to be studied under our climatic and soil conditions.

THE POTENTIAL FOR REPEATED EROSION

Once areas have eroded, it is likely that they will erode again if a combination of contributing factors occurs before revegetation. This is because large-scale erosion removes residual vegetation and soil structure that help to prevent erosion. Hillslope erosion depends on the balance between natural self-armouring of the soil by roots and coarse fragments, and on erosional forces. Considerable erosion of fertile topsoil may occur while self-armouring develops in rills and gullies. In uniform materials with low coarse fragment content (e.g., glacio-lacustrine deposits), subsequent erosion can be worse than the initial event.

Repeated erosion is common in stream channels, as the over-steepened or undercut sidewalls and new deposits stabilize. These subsequent channel events are not usually as large as the first event because the channel has already been scoured and the remaining, larger bedload material protects most areas where water runs. The consequences downstream from the hillslope erosion depend on the capacity for storage and transport in the previously scoured channel, and the presence of remaining debris left to be transported. After the large erosion event off the Kuskanook Fire in August 2004, another smaller erosion event occurred in September. At that time a peak in runoff resulted in localized sidewall sloughing and mobilization of some remaining

deposits adjacent to the lower reaches of the creek. No new hillslope erosion was observed in this subsequent event.

Even if initial erosion is avoided, the possibility that slope failure risk may increase several years after a fire should be considered. The roots of the dead trees help to stabilize slopes; as those roots reach a certain stage of decay, the likelihood of slope failure may increase. While this process has clearly been studied and demonstrated for clearcutting of steep, potentially unstable slopes under coastal conditions, it needs further study under interior conditions. This possible hazard may be mitigated on sites where revegetation includes deep-rooted species.

MANAGEMENT CONSIDERATIONS AND MITIGATIVE MEASURES

Natural Context

As with all natural phenomena, erosion in its own environment is neither good nor bad, but simply a part of the natural world. Within a catchment area, the sites that have received the largest impacts from large-scale erosion (e.g., loss of topsoil and/or exposure or deposit of subsoil) will have reduced productivity for a very long time. On the other hand, productivity will increase in areas receiving the eroded topsoil. Eroded material transported into lakes and rivers may adversely affect spawning areas but it may also increase nutrient levels, which can increase productivity in oligotrophic lakes and streams (both are common in the Southern Interior).

Large-scale erosion may significantly affect infrastructure, private property, and human safety and welfare. In addition, provincial government agencies such as the Provincial Emergency Program, infrastructure owners, and municipal or regional governments all have potential roles and responsibilities after an event. Currently, however, there is no agency responsible for, or taking a lead role in, assessing the hazards and risks after wildfires, and mitigation options are limited and without funding. The following considerations and measures are listed as a guide for the Ministry of Forests and Range in identifying or mitigating potential hazards. To support these considerations, a Standard Operating Procedure and related technical support materials are being developed in the Southern Interior Forest Region. Further work is being undertaken by the Ministry of Forests and Range and the Provincial Emergency Program to develop a provincial policy regarding assessment of hazards, risk consideration, risk control, and stakeholder roles and responsibilities. In the interim, more information on a number of these topics and practices is available in the Further Reading section listed at the end of this report.

We realize that many of the following considerations and measures are already in place but have included a comprehensive list for completeness.

Measures during fire suppression efforts

- Consider initiating an erosion assessment if high-severity burning is occurring in sensitive watersheds or on steep slopes above developments.
- Plan for rehabilitation measures during fireguard construction by using techniques like windrowing the topsoil for respreading during rehabilitation.
- Wherever possible, fireguards should be scraped only to the surface of the mineral soil so that the existing root systems of the plant community are left intact. A surface soil full of roots will be less prone to erosion than

deeper subsoil. Plants may also resprout from roots that are left intact in the surface mineral soil of a fireguard.

- Consider not burning off residual trees/fuels in high-hazard catchment areas where downslope or downstream areas may be sensitive to erosion and flooding.
- Where possible, plan suppression trails and fireguards with consideration of future harvest or salvage opportunities, thereby minimizing overall soil disturbance on the landscape.

Measures during rehabilitation planning and operation

- Soils compacted by machine traffic should be de-compacted before pull-back or recontouring of fill materials.³
- In addition to standard pullback and recontouring in high-hazard gulley areas, consider using excavators to reach off fireguards to place physical barriers like logs across the slope. Logs need to be cribbed in to form sediment traps and barriers to water movement.
- All fireguards and other access trails should have some minimal level of waterbarring and/or cross ditching to prevent contributing to any runoff concentration.
- Where erosion potential is high, control measures may be required. Such measures may include hillslope placement of woody debris, sediment traps, and/or revegetation, as appropriate, given the specific downslope/downstream values at risk.

Erosion timing

- Erosion is most likely to occur with the first significant rainfall after the fire, then subsequently in dry, summer conditions followed by intense rainfall. On strongly water-repellent soils, the hazard may linger for at least a few weeks of rainy weather, until the soils wet up enough to permit infiltration. We have no local observations or research indicating how long this cycle may occur. However, on similar sites in the northwestern United States, it lasts from 2 to 6 years.
- On steeper, potentially unstable slopes, the initial potential for surface soil erosion can be followed or overlapped by another increased risk of slope failure after the first few years, when tree roots begin to decay (typically 6–10 years for root decay).

Erosion control seeding

- If vegetation is to effectively control initial erosion after wildfire, a ground cover should be established as soon as possible after the fire. Erosion control seeding alone may not achieve this objective because an effective plant cover may not be established during the first critical year after wildfire and its effectiveness may be no greater than native vegetation that regrows during the subsequent growing seasons.
- Observations in the Southern Interior and some studies in the United States suggest that grass seeding does not assure increased plant cover and that grass establishment is often best on the areas where it is needed least, such as on gentle slopes and in riparian areas. Joint evaluations by ecologists and soil scientists will help to determine the appropriate mitigative techniques needed for downslope/downstream values at risk.

³ In addition to the soil rehabilitation info-flip in Bulmer et al. (2002), a video and field card on trail rehabilitation are available from the senior author.

- In the interim, any seeding should include large-seed grasses like rye grain, which tend to establish themselves better in a poor seedbed. Fall rye grain should be considered in all mixes to provide some initial, temporary cover that can form in the fall.
- Studies are needed to investigate the value of previous grass seeding and the effectiveness of new mixes.

Use of soil mulches

- Soil mulches, which are now used in other jurisdictions to augment erosion control seeding in sensitive catchments, should be considered.
- In sensitive catchment areas where the expense is warranted, using mulches like (weed-free) rye straw or hydrosprayed cellulose mulches should be considered. Mulches alone can protect against erosion and may help establish seeded grass in a poor seedbed.

Use of physical remediation

- In very sensitive areas, physical remediation techniques should be considered. Such techniques include cribbing of logs into the ground (contour logs; Figure 6), construction of straw bale or wattle dams, on-site mulching of some trees, and spreading of debris such as branches and tops on the ground to provide mulch. These types of physical barriers can reduce large-scale erosion effects in the interim before vegetation re-establishes. Areas treated in this way may also be planted if there is little probability that vegetation will naturally establish in the short term. Such techniques can also be used on deeply bladed fireguards.



FIGURE 6 *Log across slope in Kuskanook Fire after August erosion event. Note trapped sediment and possible protection from deeper erosion (which has occurred in non-protected area in the foreground).*

- Existing road systems should be reviewed to ensure maximum stability, which may require pulling or re-sizing culverts for anticipated increased runoff, installing drain dips, clearing ditches, etc.
- In the literature, successful efforts to mitigate wildfire effects on erosion and flooding are normally intensive operations on key catchment areas. These operations are costly, but may be comparable to the historic costs associated with broadcast seeding and reforestation of entire burn areas. Such operations should be tested in British Columbia.

Salvage logging

- Literature from elsewhere suggests that salvage logging can increase the risk of large-scale erosion, especially that associated with roads and trails. While the authors are not aware of this being assessed in British Columbia, the routine terrain stability assessments for wildfire salvage areas should be augmented with a “large-scale soil erosion assessment” before approving salvage logging in sensitive catchment areas.
- The removal of burned trees also removes their potential to stabilize slopes and to begin the rebuilding of the forest floor when they fall to the ground. Retention of these trees may also present the opportunity to protect the site from large-scale erosion and runoff. The following practices may mitigate the effects of removing burned trees (although local studies are needed):
 - maximize slash coverage of the soil to provide mulching and sediment trapping,
 - before road and trail networks or cable-yarding corridors are deactivated, use them as access for any necessary slope rehabilitation measures, and
 - promptly reforest to ensure restoration of root strength to the area.

Recognition of geotechnical risk

- In areas of extensive or high-severity fire where there are significant values at risk downslope or downstream, the appropriate authorities should assess the geotechnical or engineering risk. The assessments should recommend how the risk from flooding or erosion, including landslides, can be mitigated. Examples include installing temporary barriers that might be considered to divert debris floods or debris flows around valuable infrastructure or property (protection), strengthening the element at risk, or removing the element at risk from the hazardous area (avoidance). The appropriate authorities may also wish to consider a monitoring and warning system wherein high-risk areas would be closely monitored during high rainfall or runoff (some examples exist in the United States).

Evaluation and prediction of erosion risk

- Every severe or extensive wildfire that has high-value downslope or downstream elements at risk, whether rural or urban, should have some form of detailed risk assessment for the possibility of large-scale soil erosion. Although not every fire will be followed by large-scale soil erosion and flooding, there is a high potential for serious consequences when this type of erosion happens.
- While scientists and engineers can help identify risk, it is up to other authorities to take appropriate measures to mitigate or reduce the risk to life and property. An integrated approach is required in areas of overlapping authority. Government agencies will need to co-operate in erosion assessments that involve or are above land outside the Provincial Forest.

- Future wildfire and post-wildfire response would benefit from an “integrated approach” of science and engineering expertise combined with adaptive management to formally capture practical experience and monitoring and trial data for the benefit of future activities. A Standard Operating Procedure for an integrated approach is being developed in the Southern Interior Forest Region.
- Remote sensing or airphotos should be evaluated for use in overview assessments, perhaps following models developed in the United States.
- Maintenance and preferably expansion of current climate monitoring networks would help in interpreting large-scale erosion events. Because of the unpredictability of weather, delineation of areas prone to large-scale erosion is not the same as predicting when and exactly where the erosion will occur.
- Field assessments and predictive computer models have been developed and calibrated for areas in the neighbouring United States. With the likelihood of more dry summers and wildfire seasons similar to those of 2003, there is a need to investigate the applicability of these tools in British Columbia, the underlying soil science, and effective mitigative techniques. These and other soil erosion, overland flow, and runoff assessment techniques should be tested for use or adaptation in British Columbia.

SUMMARY

- Large-scale soil erosion is most commonly associated with wildfires that have severely burned areas.
- Severely burned areas generally have altered soil properties, including fire-induced water repellency.
- The altered soil properties greatly increase the risk of large-scale erosion and flooding, which deposit on alluvial fans at the base of steep mountain slopes.
- Most events occur without warning.
- Only a small proportion of a watershed needs to be severely burned to result in catastrophic soil erosion and/or a flood.
- Water repellency in the soil can last for several years, and the more water-repellent areas take longer to degrade.
- A technical team can identify areas most susceptible to large-scale erosion. At a minimum, this approach should be considered for all wildfires that may affect interface areas.

RECOMMENDATIONS

Whenever there are interface or other high-consequence wildfires, the potential for large-scale erosion must be considered through some assessment of the resulting soil conditions in the wildfire area. The following should be considered:

1. A standard procedure, similar to the USDA Forest Service Burn Area Emergency Response technical team approach, should be developed and used in British Columbia.
2. Where large-scale erosion presents a risk to life, property, or infrastructure, relevant agencies need to co-ordinate, determine, develop, and implement appropriate mitigative (or avoidance) measures.
3. Agencies dealing with large-scale erosion following wildfires should consider the information gaps (technical information, tools, trials, research) and climate monitoring needs discussed in this document.

FURTHER READING

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APPENDIX 1 Information and operational trial gaps related to large-scale soil erosion after wildfire

Information gaps are summarized for general soil erosion, fire-induced water repellency, and climate influences on erosion. Research and operational trials on these subjects will support better understanding and prediction of the contributing factors discussed in this document.

General soil erosion information gaps

1. Testing of assessment techniques for predicting soil erosion, overland flow, and runoff potential under British Columbia site conditions.
2. Influence of other site conditions (slope, micro-topography, drainage system) on the observed erosion events.*
3. Spatial variability of burn severity and water repellency, and the influence of variability on erosion and overland flow.
4. Effect of fire on other soil properties, particularly erodibility, and the other physical characteristics such as surface crusting/sealing.*
5. Effectiveness of erosion control methods (seeding, mulching, etc.).*
6. Effectiveness of physical remediation measures.*
7. Natural vegetation recovery after fire and the interaction with season of fire, biogeoclimatic zone and site series, and species and plant community.
8. Long-term slope stability implications of wildfires in relation to salvage logging or as a function of root strength decay.*

Water-repellency information gaps

1. Formation of repellency as a function of soil, forest, and fuel types; moisture content; and resulting fire and burn severity.*
2. Influence of soil moisture content at time of fire on severity and repellency, and to what extent repellency is actually neutralized by elevated water content.
3. Persistence of repellency, both seasonally and long term.*
4. Influence of soil characteristics, vegetation type, and lithology on the formation and duration of repellency.*

Climatic information gaps

1. Rainfall amount and intensity necessary for catastrophic soil erosion and flooding to occur under specific conditions.*
2. Thresholds that apply to the particular site—a combination of factors such as wettability, surface storage (wettability depth and micro-topography), slope, forest floor.
3. Assessment of climate monitoring needs to assist in predicting erosion events.

* Topics that are currently being studied to varying degrees by U.S. researchers.

APPENDIX 2 Descriptions of fire and burn severity

Two terms can be used in assessing fire impacts on hillslopes: fire severity and burn severity (Table A2.1). Fire severity refers to fire effects on the overstorey and understorey vegetation. Burn severity relates to the severity of the effects of the fire on soil hydrologic function (Table A2.2), and is a collation of the terms described in more detail in this document.

TABLE A2.1 *Descriptions of fire and burn severity*

Fire severity	A general term describing the combined effects of flaming and smouldering. It is inferred after the fact from fire impacts on a range of attributes, predominantly overstorey and understorey. Three suggested classes are used.	<p>Low: canopy unburned, trunks partially burned, understorey lightly or patchily burned.</p> <p>Medium: trees burned and dead, scorched needles remain, understorey burned.</p> <p>High: trees blackened and dead, needles consumed, understorey burned.</p>
Burn severity	A relative measure describing the effects of the fire on soil hydrologic function. Classes of burn severity are generally high, moderate, low, and unburned.	<p>Low: litter scorched or consumed, FH layers intact, mineral soil unchanged.</p> <p>Moderate: litter consumed, FH layers consumed or deeply charred, mineral soil unchanged.</p> <p>High: forest floor consumed, ash often thick, mineral soil has altered structure, porosity, etc.</p>

Note: These definitions have been adapted from Canadian Interagency Forest Fire Centre (2000); U.S. definitions are slightly different.

TABLE A2.2 *Burn severity classification based on post-fire appearances of litter and soil and soil temperature profiles (adapted from Robichaud et al. 2000, based on DeBano et al. 1998)*

Soil and litter parameters	Burn severity		
	Low	Moderate	High
Litter	Scorched, charred, consumed	Consumed	Consumed
Duff (FH layers)	Intact, surface char	Deep char, consumed	Consumed in most locations
Woody debris – Small	Partly consumed, charred	Consumed	Consumed
Woody debris – Logs	Charred	Charred	Many consumed, others deeply charred
Ash colour (if still present)	Black	Light coloured	Fine, white
Mineral soil exposure (may still be covered with loose ash or charcoal)	Little	< 40%	> 40%
Mineral soil	Not changed	Not changed; water repellency is slight or patchy	Altered structure, porosity, etc. Often reddish, and often strongly water-repellent
Depth to live roots or rhizomes (in mineral soil)	0 mm	0–5 mm	> 5 mm
Soil temp. at 10 mm ^a	(< 50°C)	(100–200°C)	(> 250°C)

^a Usually assessed by indirect methods.