Clarke Geoscience Ltd.

POST-WILDFIRE NATURAL HAZARD RISK ASSESSMENT OF THE WHITE ROCK LAKE FIRE

Dated:	January 14, 2022
Presented To:	Ministry of Forests, Lands and Natural Resource Operations and Rural Development (MFLNRORD) – BC Wildfire Service
Attention:	Mr. Trevor Bohay
CGL Project #	21-0111

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Executive Summary

This assessment has determined that the 2021 White Rock Lake Fire has led to conditions posing a high level of risk to public safety, property, and infrastructure. While this initial work identifies and raises awareness to the potential hazards that may be experienced, it is now critically important to prepare for their potential occurrence.

Introduction and Study Objectives

Clarke Geoscience Ltd. (CGL) was retained by the Ministry of Forests, Lands and Natural Resource Operations and Rural Development (MFLNRORD) to complete a detailed Post-Wildfire Natural Hazard Risk Assessment (PWNHRA) for priority areas within the Okanagan Basin that were affected by the White Rock Lake Wildfire (Fire K61884). The areas included in this assessment lies within the jurisdictions of the Okanagan Indian Band (IR #1), Regional District of the North Okanagan, and Regional District of the Central Okanagan, and include:

- Newport, Bradley and Irish Creek watersheds and the areas (Face Units) in between.
- Equesis Creek watershed and the fan area.
- Naswhito Creek watershed and the fan area.
- Whiteman Creek watershed and the fan area.
- Drainages in the Killiney Beach area, including the Morden Creek, Norris Creek and Fisbee Creek watersheds and the areas (Face Units) in between.

The primary objective of this assessment is to identify and evaluate post-wildfire natural hazard risk to residences, occupied structures, roads, and/or infrastructure and to provide conceptual-level recommendations for mitigative work required to reduce or eliminate risk. The intended use of the report will be to inform owners, agencies and stakeholders of high-risk sites that may require immediate mitigative action to address risks, or where more detailed assessments may be required.

Study Approach

The assessment approach generally follows that which is outlined in Land Management Handbook (LMH) No. 69 – *Post-Wildfire Natural Hazards Risk Analysis in British Columbia* (2015). The assessment builds upon and confirms results of a reconnaissance-level post-wildfire natural hazards risk assessment. The study approach included a helicopter overview flight and ground-based field work to characterize the post-wildfire conditions in the study area.

It was anticipated that the predicted level of impact would be proportional to the area burned and specifically the proportion burned at a high vegetation burn severity. It was assumed, and confirmed with limited field testing, that vegetation burn severity corresponds to an equivalent soil burn severity (i.e., a high vegetation burn severity equals a high soil burn severity). High soil burn severity is associated with a higher level of post-wildfire impact due to the loss of vegetation and the effect on soils, often resulting in the development of soil-water repellency.

Post-Wildfire Natural Hazards

Post-wildfire natural hazards are associated with hydrogeomorphologic processes including:

> **Hydrologic Hazards** - Flooding, debris floods, and sediment-laden floods are hydrologic processes associated with the loss of vegetation due to wildfire within the contributing upslope catchment area. Sediment-bulking on streams occurs with increasing sediment inputs from tributaries, side slopes or within-channel mobilization.
>
> **Geomorphic Hazards** - Landslides, rockfall, debris flows, and soil erosion are geomorphic (hillslope stability) processes associated with the loss of vegetation due to wildfire along slopes within the study area.

The above-listed hazards are governed by climate, which is variable and difficult to predict. For the fire-affected slopes in the study area, short-term effects on hydrology and slope stability are typically associated with short-duration high-intensity rainfall events. These effects will be the greatest from the first year, to about 5 years post-fire. Longer-term hydrologic effects at a watershed scale are typically associated with changes to the spring snowmelt hydrograph (i.e., snow accumulation, snow melt, rain on snow events, etc.). These long-term effects are expected to persist beyond 5 years, decreasing until vegetation in the watershed approaches a state of recovery, which could be more than 20 years post-fire.

Summary of Natural Hazard Risk Assessment Results

The Natural Hazard Risk Assessment results are detailed for each watershed, face unit, and for each fan area on Maps, Report Cards, and Photographs provided in Appendices D1 to D5. The Watershed Report Card estimates natural hazard levels that would be anticipated based on the watershed conditions. This includes the type of hydrogeomorphic process that is likely to occur, the potential for hydrologic (peak flow) hazard, and the potential for sediment bulking associated with terrain and riparian conditions.

Within each watershed and for the associated fan, Elements at Risk are identified. These include residences, occupied structures, roads, and/or infrastructure such as bridges or vulnerable culverts, domestic water supply infrastructure, hydrometric station, as well as Elements identified by the Okanagan Indian Band.

The results, summarized in Section 7, Table 7.1, indicate that all six watersheds/areas were impacted to some degree, and that twenty downslope fan areas were found to have a high to very high risk of impact from the identified hazards. On the larger watersheds (Whiteman, Naswhito and Equesis), there is a moderate to high hazard level associated with elevated peak flows (flooding) and sediment bulking (debris flood). Depending on the location, some Elements at Risk on the fan areas are subject a very high level of risk.

On the smaller catchments, such as Newport, Irish and Bradley Creek there is a high hazard level associated with sediment-laden flooding and debris flows. There is a similar high hazard level associated with sediment-laden flooding and small-scale debris flows for small, gullied face units in the Newport Creek area, south of Naswhito Creek, and for the Killiney Beach area. Geomorphic hazards, such as landslide and rockfall were identified within the larger watershed areas where instability along the valley side slopes and within steep tributary catchments was observed or is anticipated because of wildfire effects.

Recommendations for Risk Mitigation

Recommendations for risk mitigation are provided in Section 6 and are summarized in Section 7, Tables 7.2 to 7.5. To summarize, mitigation measures on the large alluvial fans focus on the peak flow and flood-related hazards. Mitigation measures on smaller catchments and within face unit areas focus on sediment-laden flooding and debris flows.

To help direct efforts, recommended measures to reduce the natural hazard risk are described as "Urgent and Important", or as "Important but not Urgent". These are defined as follows:

- **Urgent and Important** – short-term efforts to reduce risk
    - Identifies measures to increase hazard awareness and to manage the potential crisis.
    - Measures should be implemented prior to the 2022 spring freshet.
    - Includes measures such as: public awareness, emergency protection of high value assets, monitoring, and emergency response planning.
    - Recognizing the critical importance for access, this includes specific measures to protect Westside Road at the major stream crossings.
- **Important but not Urgent** – longer-term planning efforts to reduce risk
    - Identifies measures to better characterize the hazard for more efficient and effective risk mitigation
    - Planning initiatives are recommended to reduce the time spent managing the crisis.
    - Includes measures such as: instrumentation, modelling, engineering assessment and design, and land use planning.
    - Identifying risk mitigation measures within the larger watersheds will require additional planning and may eventually lead to specific activities associated with stream channel restoration and/or landslide rehabilitation.

Territorial Acknowledgement

The project study area is located on unceded territory of the sqilxʷ/syilx (Okanagan) peoples.

The following information, obtained from the Okanagan Indian Band website (www.okib.ca), summarizes the ancestral and cultural history of the sqilxʷ/syilx (Okanagan) peoples in the study area:

> KʷU KʷLIẆT L̓ NQMAPLQS | WE LIVE AT HEAD OF THE LAKE
>
> The north end of Okanagan Lake is the largest of six reserves of the Okanagan Indian Band (OKIB). OKIB members live in various historical villages along Okanagan Lake and these settlement areas are still highly valued and are occupied by current generations.
>
> While the main reserve is often associated with nqmaplqs, many of the tributaries and sites of significance along the lake hold place names each associated with ancestral and contemporary use. Each place name holds the significance of the area often associated with activities, specific species, landforms, or seasonal settlements. While the Okanagan Indian Band is located in the North Okanagan valley, the territory of the sqilxʷ/syilx Okanagan People extends beyond the reserve boundaries.

Many creek names referenced in this report have an associated local reference name. The following creek names were provided by OKIB:

Whiteman Creek - Bouleau Creek	**nq´ʷɬínəm**	"In the Birch Trees", or "Birch Creek"
Naswhito Creek (formerly Siwash Cr) -	**nʕastkʷítaʕkʷ**	"Little Spring coming out of large Cedar trees, Cedar Creek"
Six Mile Creek (Equesis Cr) -	**snƛ̓´xʷxʷtan**	**"**Where many were killed"
Bradley Creek (Dry Creek) -	**nsəsulaʕxʷ**	"Dry Creek or Intermittent Creek"
Newport Creek -	**nyxʷu̓t**	"Deep Creek or Gully"
Irish Creek -	**nq'aplqs**	"Wide brush at the bottom"

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Appendices

1. Introduction

Clarke Geoscience Ltd. (CGL) was retained by the Ministry of Forests, Lands and Natural Resource Operations and Rural Development (MFLNRORD) to complete detailed watershed reviews for priority areas within the Okanagan Basin that were affected by the White Rock Lake Wildfire. The assessment constitutes a Post-Wildfire Natural Hazard Risk Assessment (PWNHRA).

The scope of work was defined in a letter proposal to MFLNRORD (dated October 25, 2021). Work was authorized by MFLNRORD, BC Wildfire Service, and is defined in Consulting and General Services Contract #10005-40/RH22483-004. The services provided by Clarke Geoscience Ltd. are subject to the General Conditions and Limitations included in Appendix A.

1.1 Project Background and Objectives

The White Rock Lake Wildfire (Fire K61884) was first reported on July13, 2021. Between mid-July to mid-September, when the fire was finally deemed under control, the Wildfire of Note burned a total area of 83,342 ha (833 km^2). The fire affected areas within the Salmon River watershed to the west, the Monte Lake area to the north, and the Killiney Beach area to the south, all the way down to Okanagan Lake. The wildfire perimeter, shown in relation to the study area boundary, is shown on Figure 1.1.

Within the study area, at least 85 structures were lost within four different jurisdictions, including:

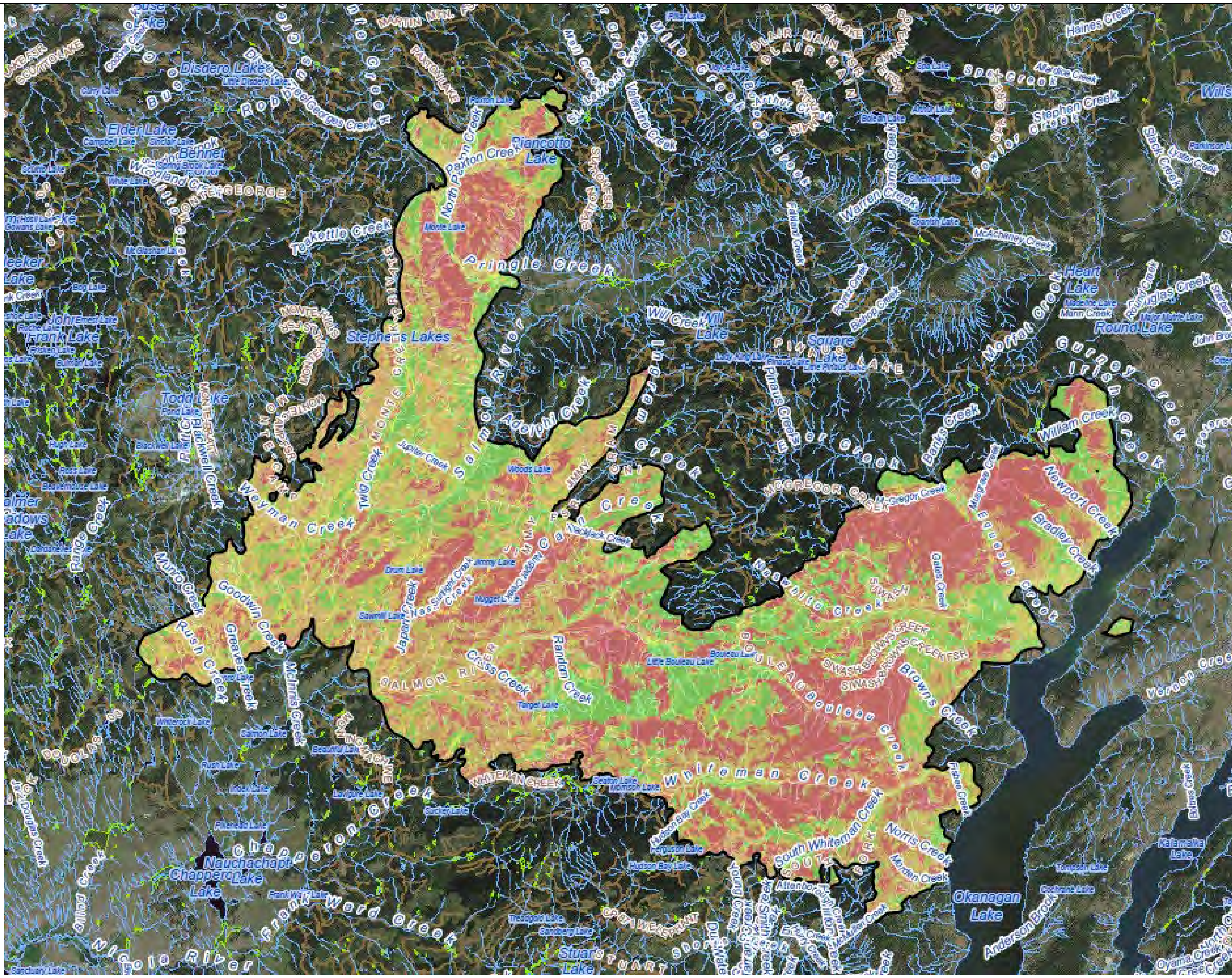
- Okanagan Indian Band, Reserve No. 1 (OKIB) – 10 homes and one commercial business
- Regional District of the Central Okanagan (RDCO) – 75 impacted properties where one or more structures destroyed
- Regional District of the North Okanagan (RDNO)
- Provincial Crown Land

An overview-level Post-Wildfire Natural Hazard Risk Assessment – Reconnaissance Report was prepared by Westrek Geotechnical Services Ltd. (dated October 14, 2021) (included as Appendix B). The reconnaissance assessment recommended watershed reviews and fan hazard assessments, to confirm hazard and risk ratings for the identified areas.

The primary objective of this detailed PWNHRA is to identify and evaluate post-wildfire natural hazard risk to residences, occupied structures, roads, and/or infrastructure and to provide conceptual-level recommendations for mitigative work required to reduce or eliminate risk.

1.2 Scope of Work

The scope of work for this assignment is to refine the results of the overview-level assessment and to complete post-wildfire natural hazard risk assessments for the following five (5) priority watershed and face unit areas which drain into Okanagan Lake and are shown in Figure 1.2:



Source: British Columbia Ministry of Forests, Lands, Natural Resource Operations and Rural Development (dated 10-26-21)

White Rock Lake Wildfire (K61884) Fire Perimeter and Burn Severity Mapping

Date: Jan. 13, 2022

Figure No.: 1.1

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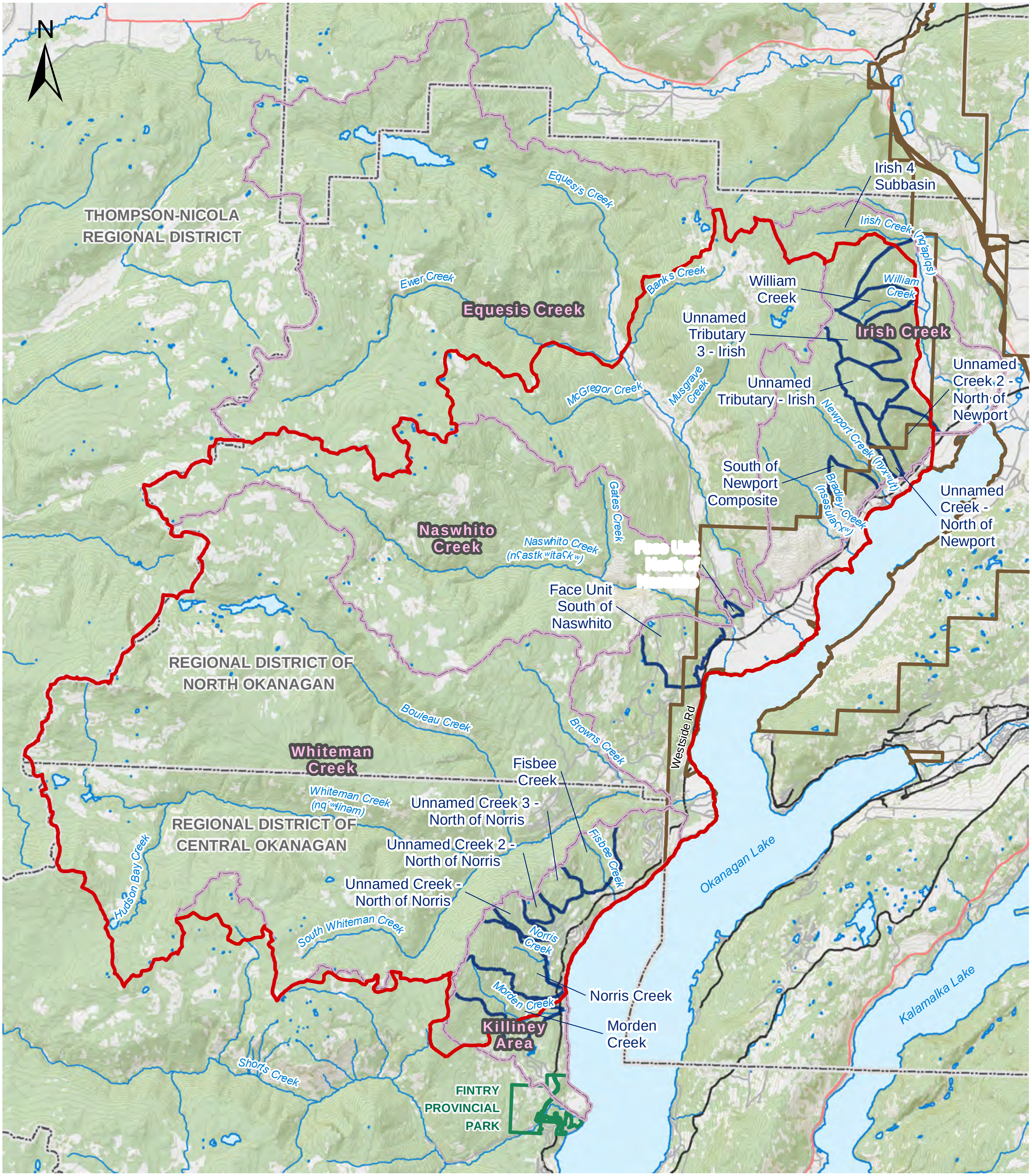


LEGEND

- Study Area Boundary
- Regional District Boundary
- Okanagan Indian Band (OKIB) Reserve Lands Boundary
- Watershed Boundary
- Catchment Area

Client: **MFLNRORD**

Project: **POST WILDFIRE NATURAL HAZARD RISK ASSESSMENT - WHITE ROCK LAKE FIRE (OKANAGAN BASIN)**

Title: **STUDY AREA, WATERSHEDS, AND CATCHMENT AREAS**

1,750 875 0 1,750 3,500
metres

Scale: 1:175,000 NAD 1983 UTM Zone 11 U

Project No: 21-0111 Date: January 13, 2022

Figure No. 1.2

Clarke Geoscience Ltd.

- **Newport, Bradley and Irish Creek** watersheds. Review will provide an understanding of the potential impacts to the Newport and Bradley Creek fluvial fans of the increase in streamflow and sedimentation from the upper watersheds. A review of the west-facing tributary creek in the Irish Creek watershed should determine the potential impact of increased streamflow and sedimentation to the properties in the upper Irish Creek watershed.
- **Whiteman (and Bouleau Creek sub-basin) Creek** watershed and the fluvial fan. Review will provide an understanding of the potential impacts to the creeks of the increase in streamflow and sedimentation from the upper watershed down to Okanagan Lake.
- **Equesis and Naswhito Creek** watersheds and their coalescent fans. watershed and the fluvial fan. Review will provide an understanding of the potential impacts to the creeks of the increase in streamflow and sedimentation from the upper watershed down to Okanagan Lake.
- **Drainages in the Killiney Beach area**, including the area upslope to the height of land from Morden Creek in the south to the start of the Sugar Loaf Forest Service Road in the north.

Post-wildfire natural hazard risks are associated with the hydrologic effects such as faster runoff, lower infiltration, higher peak flows, and geomorphic effects such as increased soil erosion, landslides and debris flow, and sediment transport. In larger catchments, the risk scenario is dominated by hydrologic effects, while smaller, steeper catchments are more likely to be affected by geomorphic effects. Properties located on fan areas may be subject to risk where there is a potential for upstream flow diversion or avulsion.

2. Study Methods

The assessment approach generally follows that which is outlined in *Land Management Handbook (LMH) No. 69 – Post-Wildfire Natural Hazards Risk Analysis in British Columbia* (2015). The proposed work will build upon the reconnaissance report to provide a more detailed evaluation of risks. The intended use of the report will be to inform owners, agencies and stakeholders of high-risk sites that may require immediate mitigative action to address risks, or where more detailed assessments may be required.

Our method of assessment is based on our understanding of MFLNRORD requirements, and our understanding of what information is required for post-wildfire damage assessments. Our assessment approach is comprised of the following tasks:

Task 1: Preparation for site work, including background information review and base map preparation. In advance of completing the field work we gathered and reviewed pertinent background information. Publicly available information was reviewed to characterize area topography, terrain, bedrock, and hydrology.

Task 2: Develop list of contacts. A list of contacts, agency representatives and persons to be contacted if a high-risk emergency situation is identified and provided in Appendix E.

Task 3: Conduct a helicopter overview of the watershed areas. An overview helicopter flight was completed on November 1, 2021 to review current conditions in the upper watershed and to identify upslope risks. A member from the OKIB Territorial Stewardship field crew also attended the flight.

Task 4: Visual ground-based assessment of the slopes, creek banks, and fan areas within the identified project areas. A field assessment was completed on November 8, 10, 12 and 17, 2021 by J. Clarke, of Clarke Geoscience Ltd. accompanied by a member from the OKIB Territorial Stewardship field crew. Photos and field notes were collected using a tablet on georeferenced maps using the Avenza app.

Task 5: Conduct a hazard and risk analysis. Assign a qualitative level of risk to the identified issues and identify sites/areas requiring immediate response/repair and distinguish from sites that can be addressed at a later time. The risk assessment procedure is described as a partial risk analysis, as outlined in the LMH #69. Partial risk analysis does not quantify the degree of impact (i.e., vulnerability). Rather it is an expression of relative negative impact assuming that an event (i.e., flood or debris flow) reaches a specific Element at Risk.

Task 6: Develop concept-level mitigative strategies and costs to address high risk sites. Measures to reduce or eliminate risk are identified for the three large fan areas, for the smaller face unit areas, and for the upstream watersheds. Recommended measures are identified as being “Urgent and Important”, meaning that measures should be implemented prior to the 2022 spring freshet, or “Important but not Urgent”, meaning that measures should be completed, over the longer term. Order of magnitude level cost estimates are provided for planning purposes where possible.

Task 7: Prepare a Report. A summary report will accompany Watershed and Fan Report Cards that document post-wildfire natural hazard conditions and the results of the risk assessment for each catchment within the study area. The Report Cards are provided in Appendix G, along with mapping and selected photographs.

Upon completion of a draft report, we recommend a **review of high and very high-risk sites with stakeholders**. We recommend scheduling time to review high to very high-risk sites identified during the field assessment. The review would allow for all interested parties and stakeholders to review site conditions and discuss possible mitigation strategies.

3. Post-Wildfire Natural Hazards

The following sections describe the post-wildfire natural hazards, define terminology used to describe the associated processes, and provides comment on the anticipated duration of post-wildfire effects.

3.1 Wildfire Effects on Hydrology and Geomorphology

Wildfire has the potential to affect hydrologic and geomorphologic processes in a watershed. In watersheds that have been subject to high burn severity wildfire, particularly those with steep terrain, peak flows can be flashier and orders of magnitude higher (Neary, et al, 2011).

Wildfire consumes the forest canopy and associated organic duff layer mantling the mineral soil surface. Normally, these intercept precipitation, moderate infiltration, and protect mineral soils from erosion. With burning, there is a decrease in evapotranspiration and infiltration, and exposed mineral soils are subject to erosion. These effects may also be exacerbated by fire-induced soil-water repellency.

Soil-water repellency is a characteristic that develops more strongly on moderate to high burn severity. The development of repellency is a function of antecedent soil moisture (dry soils more likely to develop repellent character) and thickness of the forest floor duff layer (thicker organic layers provide insulation against heat from the wildfire) (De Bana, 1981).

The presence of water repellent soils causes irregular wetting, preferential flow paths in the soil matrix, reduces rainfall infiltration rates, and leads to enhanced overland flow (Doerr and Moody, 2004).

3.2 Post-Wildfire Natural Hazards Background

Post-wildfire natural hazards considered for this assessment are the hydrogeomorphologic processes that are most affected by the effects of wildfire. These processes are listed below, and technical definitions of the terms used, are provided in Section 3.3:

Hydrologic Hazards - Flooding, debris floods, and sediment-laden floods are hydrologic processes associated with the loss of vegetation due to wildfire within the contributing upslope catchment area. Effects include:

- faster runoff and greater volume of runoff due to the loss of interception and transpiration by vegetation, by the reduced infiltration into fire-affected soils.
- Sediment-bulking of a stream occurs with increasing sediment inputs from tributaries, side slopes or within-channel mobilization.
- In snow-dominated watersheds, wildfire results in greater snow accumulation, earlier onset of snow melt, and increased rates of snow melt.
- Peak flows may be orders of magnitude higher (US studies report increased peak flow of 1.4 times to 870 times the pre-fire peak flows).
- Post-fire hydrologic response will be greater in smaller catchment areas due to the short time of runoff concentration and synchronization of runoff. While hydrologic changes in larger watersheds may be reduced by the desynchronization of runoff from diverse aspects, elevations, and slope types.

Geomorphic Hazards - Landslides, rockfall, debris flows, and soil erosion are geomorphic (hillslope stability) processes associated with the loss of vegetation due to wildfire along slopes within the study area. Effects include:

- Accelerated soil erosion due to exposed mineral soils.
- Thermal expansion of rocks due to intense heating may destabilize exposed bedrock or may destabilize rock retaining walls.
- In the study area there, stability impacts will be most apparent on steep (>60%) slopes and along steep debris-flow prone gullies. Trigger mechanisms for debris flow in fire-affected areas is likely to be related to increased peak flow (Jordan, 2016).
- Burned trees that remain standing are a potential safety hazard, and when the trees fall, they may destabilize the slope and expose soils to erosion.

The current assessment provides a qualitative assessment of likelihood of occurrence. To estimate event frequency and magnitude, detailed investigations are required and considered outside the scope of work for this assessment.

Snow avalanches are not considered for this study. However, we would like to bring awareness to the increased likelihood for snow avalanche associated with the loss of forest cover by wildfire. Loss of trees and the associated understory, reduces the anchoring and surface roughness effect for the snowpack, which can result in avalanches occurring with greater likelihood[1]. Loss of trees can also alter the local snow climate, increasing the likelihood for sensitive snow layers (i.e., sun or wind crusts) to develop in areas where they previously did not occur.

Danger tree assessment associated with burned trees is not considered for this study.

3.3 Terminology and Definitions

The following definitions are provided for the natural hazards considered for this assessment. Additional information regarding natural hazards terminology is provided from Hungr et al. (2005), Hungr et al. (2013) and other technical literature.

Flood - Flooding is a hydrologic process associated with elevated clear-water discharge on a stream. From a natural hazard perspective, a flood is a condition in which a watercourse or body of water overtops its natural or artificial confines and covers land not normally under water (EGBC, 2017). Flood, as a hazard type, is when a flood becomes a source of potential harm to humans, property, infrastructure, the environment, and other assets.

Debris Flood – A debris flood is a hydrologic process characterized as a very rapid flow of water, heavily charged with debris in which the entire streambed becomes mobile (Church and Jakob, 2020). Debris floods can mobilize large volumes of material and have significant potential for damage. Peak discharge of a debris flood can be up to 2 times the clearwater flood peak discharge for the same stream, due to the amount of woody debris and sediment that is entrained.

For the purposes of this assessment, flood and debris flood hazards are combined. This is relevant for the large fan areas where is becomes difficult to distinguish between the two processes.

Sediment-Laden Flood – Sediment-laden floods are hydrologic processes that are common following wildfire. Defined here, sediment-laden floods are considered to be a smaller-scale runoff process, occurring on gullied face units or ephemeral channels in response to post-wildfire runoff. Sediment-laden flooding is a flood event that mobilizes ash, fine-grained soils and woody debris down fire-affected slopes and gullied terrain. Although these processes tend to be smaller in scale, often occurring within normally dry gullies and channels, they can transition to debris flow events capable of mobilizing larger material and are potentially destructive.

Debris Flow – A debris flow is classified as a landslide characterized as a fast-moving flow of saturated non-plastic debris in a steep channel. Debris flows are most common on small, steep creeks that have abundant sources of debris.

[1] https://avalanche.ca/blogs/wildfire-avalanches

Debris flows are triggered within a steep, confined channel and transport material down to a fan area. Once the channel loses confinement, sediment is deposited. Debris flows can have a high destructive potential due to the extremely large, spontaneous discharge, and the corresponding capacity to transport large boulders and woody debris.

Landslide / Rockfall – Landslides and rockfalls are discrete geologic processes that predominantly occur on steeper terrain. Landslides are the slow to rapid downslope movement of soils. They can be shallow or deep and can runout to areas downslope, usually terminating where slopes are less steep. Rockfall is a process that can be accelerated by the thermal expansion of rock affected by wildfire. Intense heat can fracture rock, making it more susceptible to downslope transport.

Landslides and rockfall processes can surcharge channels and gullies, making the channels more susceptible to debris flow.

3.4 Persistence of Water Repellent Soils and Expected Duration of Post-Wildfire Effects

Research on the persistence of fire-induced water repellent soils indicates that it is a phenomenon that decreases with depth and is spatially highly variable. The persistence is site specific, dependent upon the strength and extent of hydrophobic chemicals in the soil and the physical and biological factors affecting the breakdown of these chemicals. MacDonald and Huffman (2004) showed rapid deterioration of soil-water repellency after 1 year, while others found that conditions may persist for up to 6 years (DeBano, 1981).

Repellency tends to decrease when soils have prolonged contract with moisture. As such, this characteristic will become reduced with prolonged rain and spring snowmelt. Once wet, water repellant soils are not repellent again until they dry out. Once dry, they can reoccur in subsequent dry seasons for several years (Curran, et al. 2006).

The effects of wildfire on hydrology and geomorphology depend largely on the extent of high severity burn, damage to soils, slopes and stream channels and on the nature of subsequent rainstorms, snow accumulation, and melt rates. Recovery is also dependent upon the rates of forest (both overstory and understory) recovery. Hope et al. (2015) indicate that post-fire effects on hydrology increase in the first two to three years following fire, and then decrease in time after that. Hydrologic effects can persist for many years, perhaps at least 20 years, until the structure of the new forest approaches a pre-fire condition (Hope et al, 2015) (Jordan, 2015).

For the fire-affected slopes in the study area, short-term effects on hydrology and slope stability, are typically triggered by short-duration high-intensity rainfall events. These effects will be the greatest from the first year to about 5 years post-fire. Longer-term hydrologic effects at a watershed scale are typically associated with changes to the spring snowmelt hydrograph (i.e., snow accumulation, snow melt, rain on snow events, etc.). These effects are expected to persist beyond 5 years until vegetation in the watershed approaches a state of recovery, which could be more than 20 years post fire.

4. Study Area Characteristics

The project study area is located on the west side of Okanagan Lake and extends from just north of Fintry Provincial Park, all the way to the north end of the Lake. Within the study area there are three large watersheds; Whiteman Creek, Naswhito Creek and Equesis Creek. The study area also includes face unit[2] areas in between that drain into Okanagan Lake (see Figure 1.2).

Study area characteristics that are relevant to the post-wildfire natural hazard risk assessment are provided at an overview level for each of the watershed areas. The characteristics most relevant include:

- **Physiography**, which includes catchment area, relief, slopes, morphometric relations that help characterize the dominant hydrogeomorphologic processes occurring in the watershed.
- **Climate**, provides information on seasonal temperatures and precipitation (rain and snow), including information on the timing of the spring snow melt (help characterize the timing and magnitude of freshet). Characteristics rainfall intensity and duration and frequency to characterize precipitation intensities that may trigger hazardous events. Forest cover and soils expressed as the biogeoclimatic zone reflects the forest cover and soil response to the local climate character (changes with aspect and elevation)
- **Hydrology**, provides a sense of the seasonal timing of peak flows, characteristics peak flows, and past flood events.
- **Geomorphology**, provides information on bedrock geology, soils, terrain stability and geomorphological processes occurring in the watershed. These indicators provide key information with regards to natural hazard types and processes occurring with the study area.
- **Natural disturbance and logging history.** Understanding the development history and the hydrologic and geomorphic response to disturbance will help predict future response due to wildfire.
- **Vegetation and Soil Burn Severity.** Vegetation burn severity refers to the effects of fire on the forest canopy and the understory and provides an indication of the likelihood and distribution of hydrologic and geomorphologic impacts. For this study vegetation burn severity is considered equivalent to soil burn severity. Areas with a moderate to high burn severity are more likely to have associated soil hydrophobicity, or water repellency. This condition increases the likelihood of overland runoff during rain events, which contributes to increased hazard conditions.

4.1 Physiography

The study area includes three large watersheds and the face unit areas in between. These include:

- Whiteman Creek Watershed;

[2] A face unit is described as an open slope located between two catchments and draining into a broad area.

- Naswhito Creek Watershed;
- Equesis Creek Watershed;
- Smaller named catchments including Irish Creek, Newport Creek, Bradley Creek, Norris Creek and Morden Creek; and,
- Small unnamed catchments and face units that drain into Okanagan Lake.

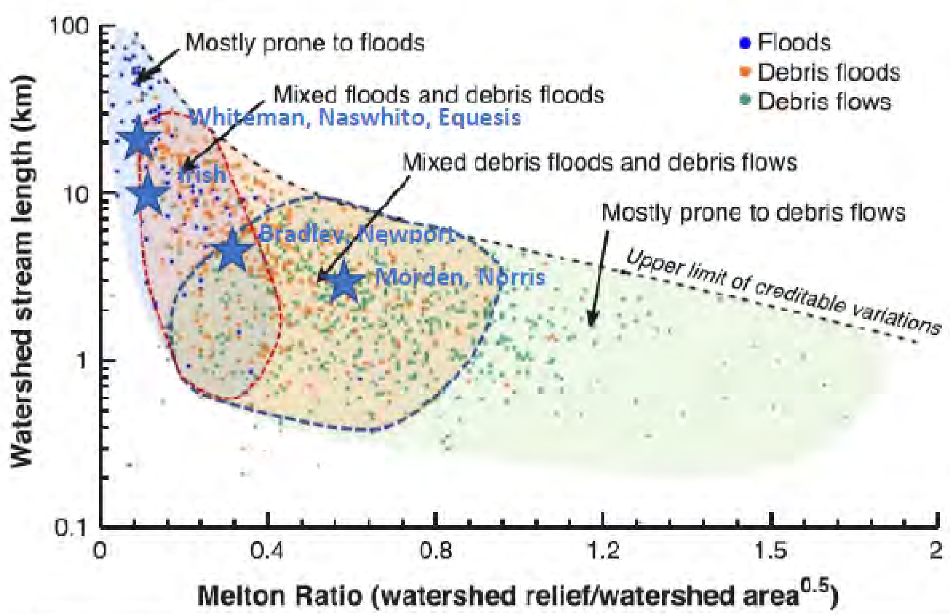
The study area streams originate on the rolling topography of the Thompson Plateau, flowing eastward into Okanagan Lake. The streams become more incised within confined valleys, flowing through narrow bedrock-controlled canyons, before opening onto large alluvial fans. While Whiteman Creek and Naswhito Creek remain tightly connected to valley side slopes, Equesis Creek has a broad floodplain area above the canyon reach. All three watersheds have a dendritic drainage pattern, with contributing sub-basin areas.

The smaller named catchment areas within the study area are generally steeper. Irish Creek has several steep contributing sub-catchments above a broad valley west of Okanagan Lake. Newport Creek has a catchment area characterized by very steep, potentially unstable side slopes. Face unit drainage areas a moderately-steep to steep areas that are characterized as till-mantled bedrock slopes that drain onto valley fill deposits. Drainage areas within the Killiney Beach area are strongly influenced by bedrock lineaments and the streams within the area become less distinct as they encounter a moderately slope terrace comprised of ice-contact sands and gravel deposits.

Table 4.1 provides a physiographic summary and Melton Ratio classification of study area watersheds. The morphometric parameters that are used to derive the Melton Ratio provide insight to the dominant geologic/hydrologic process occurring within each area. Melton Ratio is plotted against watershed stream length and superimposed on data from Church and Jakob (2020) in Figure 4.1. The classification indicates that the larger watersheds are mostly prone to floods, while the smaller, steeper catchments are prone to a mixture of flood, debris flood and debris flow processes, indicating increasing potential for damages due to sediment/debris bulking. Depending on sediment transport availability and transport potential, the subbasin catchments within the larger catchments, or small catchments located within face unit areas are subject to debris flow and/or sediment-laden flooding. Morphometric data for the sub-catchments is provided in the Watershed Report Card summaries for each area (see Appendix D).

Table 4-1: Physiographic Summary of Study Area Watersheds

Watershed	Area (sq km)	Relief (m)	Watershed Stream Length (km)	Melton Ratio (Relief/Area$^{0.5}$)	Dominant Process
Whiteman Creek	202	1670	21.9	0.12	Flood
Naswhito Creek	86	1670	18.0	0.18	Flood
Equesis Creek	203	1410	23.4	0.10	Flood
Bradley Creek	6.5	930	4.6	0.36	Debris Flood and Debris Flow
Newport Creek	9.5	980	5.6	0.32	Debris Flood and Debris Flow
Irish Creek	64	980	10.8	0.12	Flood and Debris Flood
Morden Creek	4.1	1160	3.9	0.57	Debris Flood and Debris Flow
Norris Creek	3.8	1010	2.7	0.52	Debris Flood and Debris Flow



Melton Ratio and Watershed Stream Length for Study Area Watersheds superimposed on plot from Church and Jakob (2020). Plot shows steep creek processes derived for fans in Alberta and British Columbia. Process boundaries are approximate and overlap, which reflects hybrid watersheds where floods, debris floods and debris flows may occur at different frequencies and magnitudes.

Figure 4-1: Melton Ratio Classification for Study Area Watersheds

4.2 Climate

4.2.1 Precipitation

The closest climate stations measuring precipitation (rain/snow) are located near Vernon, ranging between 15 to 30 km to the east-southeast of the study area (see Figure 4.2). These are:

- Vernon North (ECCC Stn. 1128583)
- Vernon Bella Vista (ECCC Stn. 1128553)
- Vernon Auto (ECCC Stn. 1128582)
- Vernon Silver Star Lodge (ECCC Stn. 1128584)
- Silver Star Mtn Automatic Snow Pillow (Stn. 2F10P)

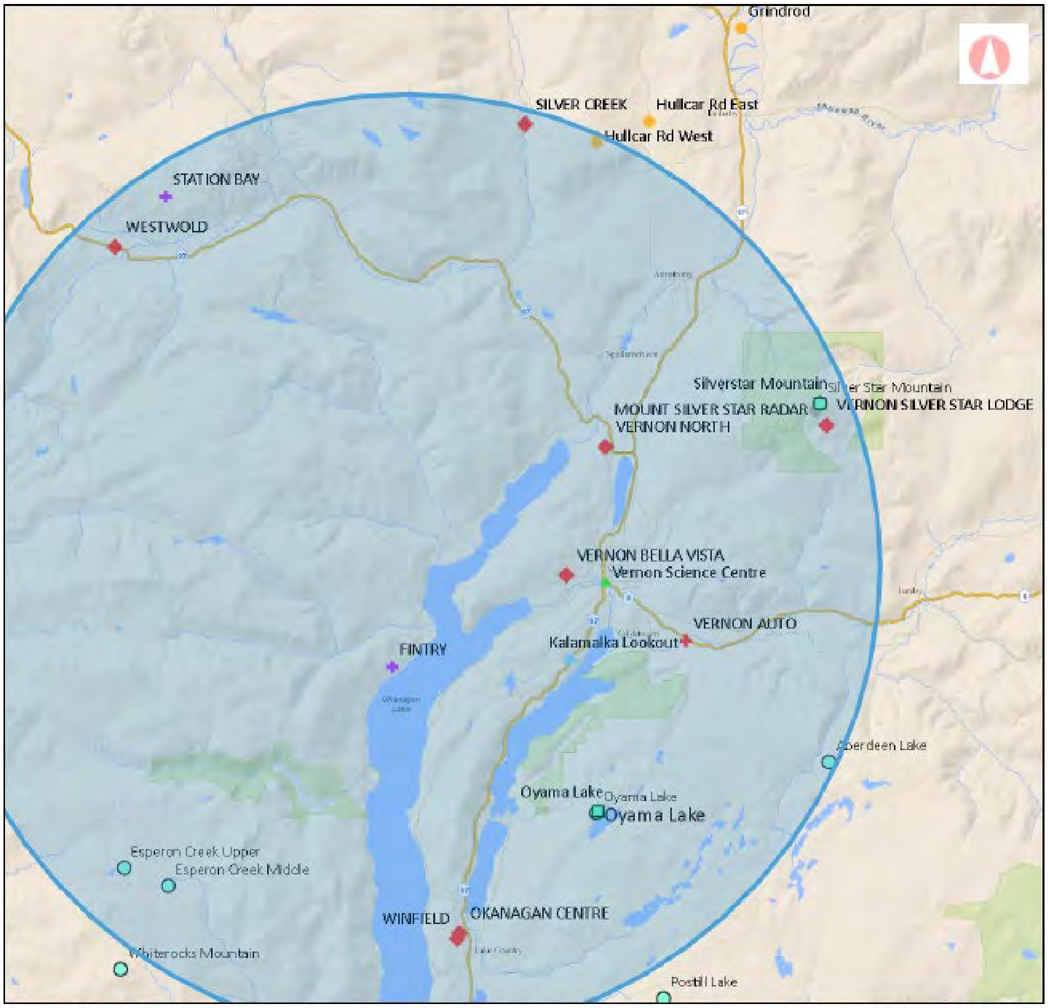


Figure 4-2: Meteorological Stations near the Study Area

Climate Normals, available for Vernon North (Stn. 1128583), indicate that the total annual precipitation is 487mm (see Figure 4.3). Precipitation is highest in the spring months, falling as rain in May-June, and during the winter months, falling as snow between November and January. Over the period of record at the Vernon North station, the largest extreme daily rainfall was 35.1mm, recorded on November 13, 1995.

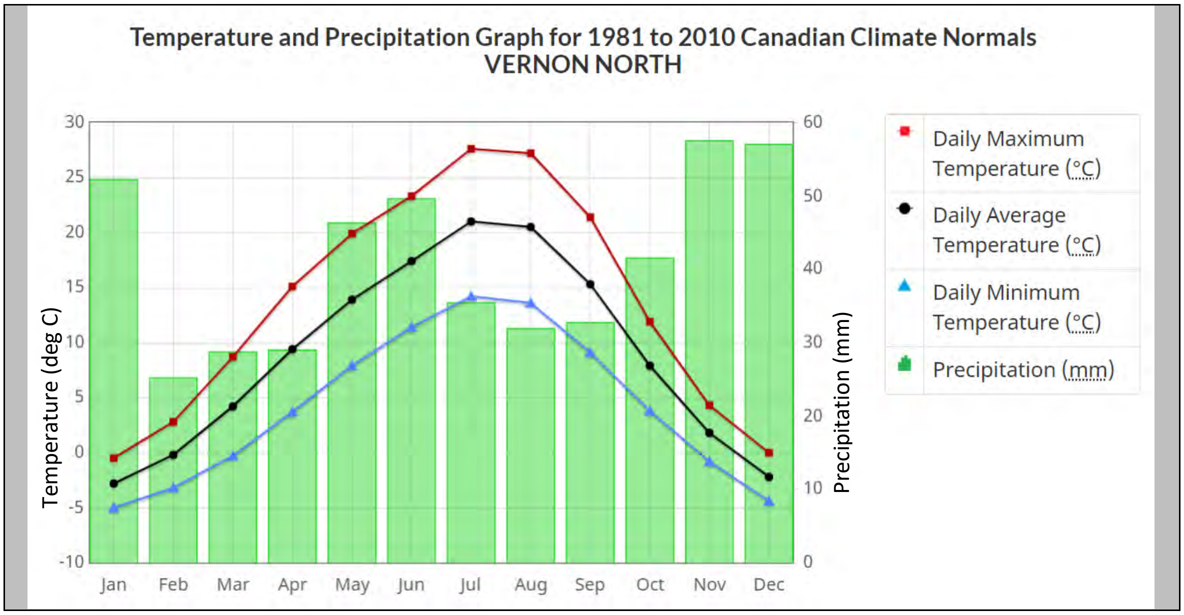


Figure 4-3: Temperature and Precipitation Normals (1981-2010) for Vernon North Station

It is noted in Hope et al. (2015) that precipitation amounts, intensities, durations and recurrence intervals all influence the hydrologic and geomorphic response type in a watershed. Therefore, the data derived from the local (i.e., Vernon) IDF curve (Table 4.2), correlates with the process types as follows (Moody et al., 2013):

- Soil erosion – 10 min rainfall intensity
- Debris flow – 15 min rainfall intensity
- Peak flows – 30 min rainfall intensity

Table 4-2: Rainfall Intensities (mm/hr) for Various Return Periods at Vernon (Stn. 1128551)

	Rainfall Duration				
Return Period (years)	5 min	10 min	15 min	30 min	1 hour
2	39.8	27.7	21.2	12.9	7.7
5	56.0	42.5	33.1	19.5	10.9
10	66.8	52.2	40.9	23.9	13.1
25	80.4	64.6	50.9	29.4	15.7
50	90.5	73.7	58.2	33.5	17.7
100	100.5	82.8	65.6	37.6	19.7

Although the Vernon meteorologic stations lie within 30km of the study area fans, climate parameters are not necessarily representative of the entire study area and cannot be relied upon to capture high intensity convective storm events. More reliable precipitation and precipitation intensity data for the study area can be obtained from the Silver Star radar station. Figure 4.4 illustrates historical radar imagery from November 15, 2021. The image illustrates how radar captured an intense rain event that triggered several sediment-laden floods and small debris flows on burned slopes south of Newport Creek. On that same day, only 9.9 mm of rain was recorded at the Vernon Auto station (the only station in the area measuring hourly rainfall) and 19.5 mm of rain was recorded the day before on November 14, 2021.

The review indicates that radar data from Silver Star Mtn is a much better data source for the localized, intense rainfall events.

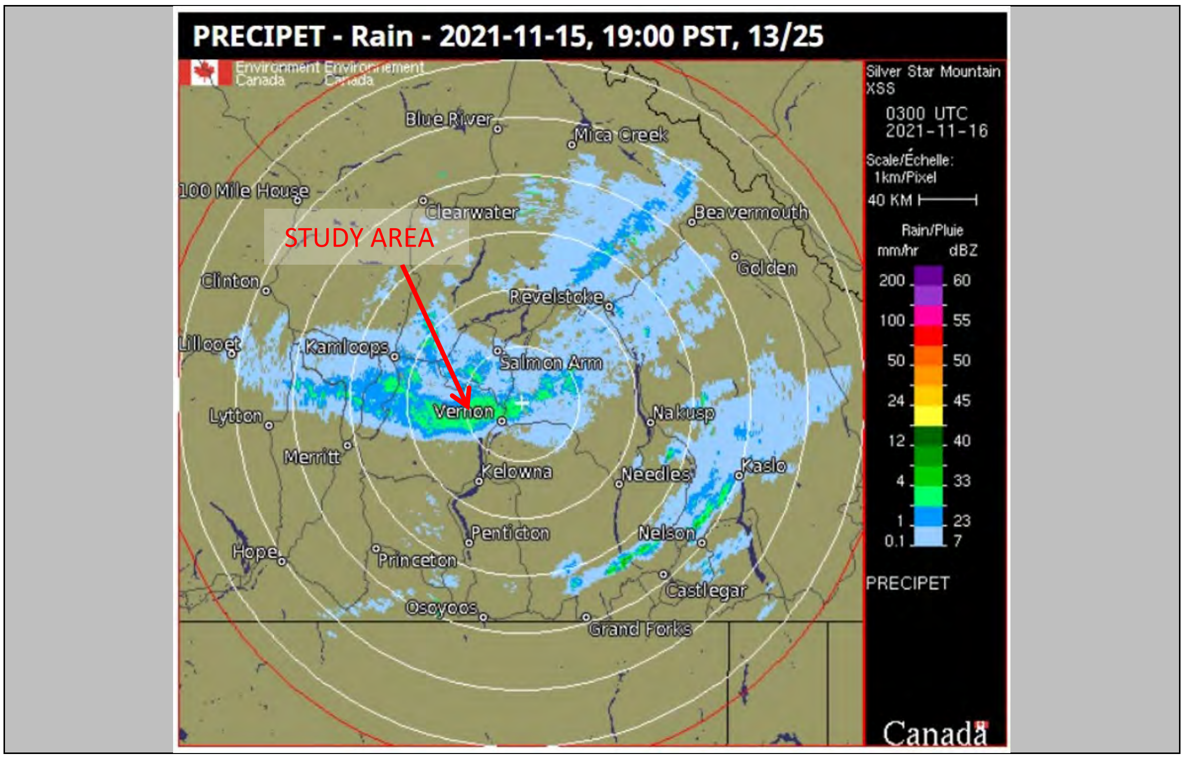


Figure 4-4: Historical Radar Imagery of November 15, 2021 Storm Event (at Silver Star Mtn Station)

4.2.2 Biogeoclimatic Zones in the Study Area

Biogeoclimatic zones in the study area vary by aspect and elevation and are summarized in Table 4.3. At elevations below ~1300m the area is characterized by a dry Interior Douglas Fir forest. Above ~1300m elevation, the study area transitions to a Interior Cedar-Hemlock and, at the highest elevations, to a Montane Spruce forest. These higher elevation biogeoclimatic zones reflect the influence of a seasonal snowpack. The 1300m elevation approximately defines the uppermost 60% of the watershed area that is responsible for the peak flows generated by snowmelt. As a result, the wildfire effects on hydrology are greater within the snow accumulation zone, above ~1300m elevation.

Table 4-3: Biogeoclimatic Zones in the Study Area

Biogeoclimatic Zone/Subzone		Elevation Range	Study Area Occurrence
Interior Douglas Fir, very dry hot subzone	IDFxh1	Okanagan Lake to ~1000m	All low elevation slopes in the study area
Interior Douglas Fir, dry cool	IDFdk2	~1000m to ~1300m	North side of Equesis Ck, Irish Ck, and Upper elevation slopes in Newport Ck
Interior Douglas Fir, moist warm	IDFmw1	~1000m to ~1300m	Areas south of Equesis Ck.
Interior Cedar Hemlock, moist cool	ICHmk2	~1300m to ~1500m	All upper elevation slopes in study area
Montane Spruce, dry mild	MSdm2	>1500m	Scattered areas on high elevation plateau, largely unburned by White Rock Lake Wildfire

Source: Biogeoclimatic Subzone Variant Mapping (Ver. 2, 2018)

4.3 Hydrology

There is an active Water Survey of Canada hydrometric station on Whiteman Creek[3] upstream of Bouleau Creek. The station provides 52 years of data (1970-2021) and operates real-time, recording flows in the upper watershed.

Additional hydrometric stations were installed on area creeks (Whiteman, Equesis and Naswhito) by the Okanagan Nation Alliance (ONA) as part of the Environmental Flow Needs assessment work completed in collaboration with MFLNRORD and the Okanagan Basin Water Board[4]. It is unclear whether the monitoring is still underway and whether the data is available for review. Follow up is recommended.

Based on a review of flow data from the Whiteman Creek hydrometric station, the following hydrologic characteristics considered representative of the three large watersheds in the study area are summarized:

- Peaks stream flows occur between mid-May and mid-June, as a result of snow melt;
- Stream flows start increasing by the end of April (mid- to late-April); and,

[3] ECCC Station #08NM174, Whiteman Creek above Bouleau Creek (114 km^2, 52 year record from 1970-2021 (active))
[4] A methods for determining Environmental Flow Needs, or "target flows", and Critical Flows, or "minimum flows" were developed in 2016 (Associated Environmental, 2016)..Follow up is required to determine the current status of the project.

- Low flows occur between early August through the fall and winter month until spring (mid-March).

Stantec Consulting Ltd. prepared post-flood channel assessments on Whiteman, Equesis and Naswhito Creeks in 2018, focusing on OKIB Reserve Lands across the fan areas. Two consecutive years of higher-than-average peak flows occurred in 2017 and 2018. In an analysis of peak flows from the Whiteman Creek hydrometric Station, Stantec concluded that:

- The 2017 peak instantaneous flow on **Whiteman Creek was 38.2 m^3/s** and was attributed to a rain on snow event. Flows exceeded that average peak instantaneous flow of 9.8 m^3/s for **~21 days**.
- The 2018 peak instantaneous flow on **Whiteman Creek was 28.2 m^3/s** and was attributed to melting of a higher-than-average snow pack. These flows exceeded the average peak instantaneous flow for **~14.5 days**.
- The 2018 peak flow was estimated to have a return period of **~50 years**.
- The 2017 and 2018 events resulted in **aggradation, bank erosion, and localized inundation** along the fan reaches and at the stream mouths.

The peak flows and peak flow duration measured on Whiteman Creek can be extrapolated to nearby Equesis Creek and Naswhito Creek. Although flow data is not available for these creeks, similar flood processes and effects were experienced. This recent flood information provides useful information relating to flood planning and/or expectations for the large fan areas.

The three large fan areas located within the study area are traversed by Westside Road. These major crossings are maintained by the MOTI roads contractor (AIM) and are listed in Table 4.4. Based on anecdotal information from OKIB, the crossings must be carefully monitoring during the spring freshet to ensure there is no debris blockage. It is likely that the major crossings are the primary constraining feature on the large fans. However, there are also other, smaller, usually privately owned crossings of the major creeks. Further hydrotechnical analysis is required to determine the capacity of the crossings.

With respect to emergency egress, the smaller private crossings are not easily accessed and cannot be relied upon. Thus, the major crossings on Westside Road constitute critical infrastructure.

Table 4-4: Major Stream Crossings on Westside Road

Major Stream Crossing	Dimensions	Historic Problems (anecdotal)
Whiteman Creek	~10m wide concrete bridge with centre pier (circa 1984 stamp). Recent (2021) wooden deck replacement.	Noted issues with debris build up.
Naswhito Creek	~4 m wide corrugated steel arch culvert	Some noted issues with debris blockage, flow generally stays in culvert
Equesis Creek	~4 m wide corrugated steel arch culvert	Problematic, historic avulsion above and below Westside Road.

Major Stream Crossing	Dimensions	Historic Problems (anecdotal)
		Sedimentation issues, ~200 truckloads of sediment removed in 2018
Newport Creek	950 mm corrugated steel culvert	Seasonally dry stream channel but sedimentation issues experienced in 2018. Near washout of Westside Road and considerable volume of sediment removed at culvert in 2018.

4.4 Bedrock Geology

Bedrock geology varies across the study area, see Figure 4.4. At the south end of the study area, in the Killiney area and within the Whiteman Creek watershed, bedrock is generally granodiorite, with some syenitic to monzonitic intrusive volcanic rock of the Penticton Group (iMap BC). These tend to be coarse-grained rocks that weather to sand. When competent, these rocks tend to be more stable. However, the coarse-grained rocks can also be brittle and fracture easily. This brittle nature was particularly apparent along the steep valley sideslopes in the Whiteman Creek watershed, where fire-affected rocks slopes appeared highly fractured and unstable.

Bedrock at the north end of the study area and within the Naswhito and Equesis Creek watersheds, is predominantly fine clastic sedimentary rocks of the Harper Ranch and Nicola Groups (iMap BC). These rocks are comprised of mudstone, siltstone, and shale. These are fine-grained rocks that weather to angular colluvium and degrade to sand and silt. Colluvium, derived from rockfall and downslope ravelling, mantles the lower slopes at the north end of the study area.

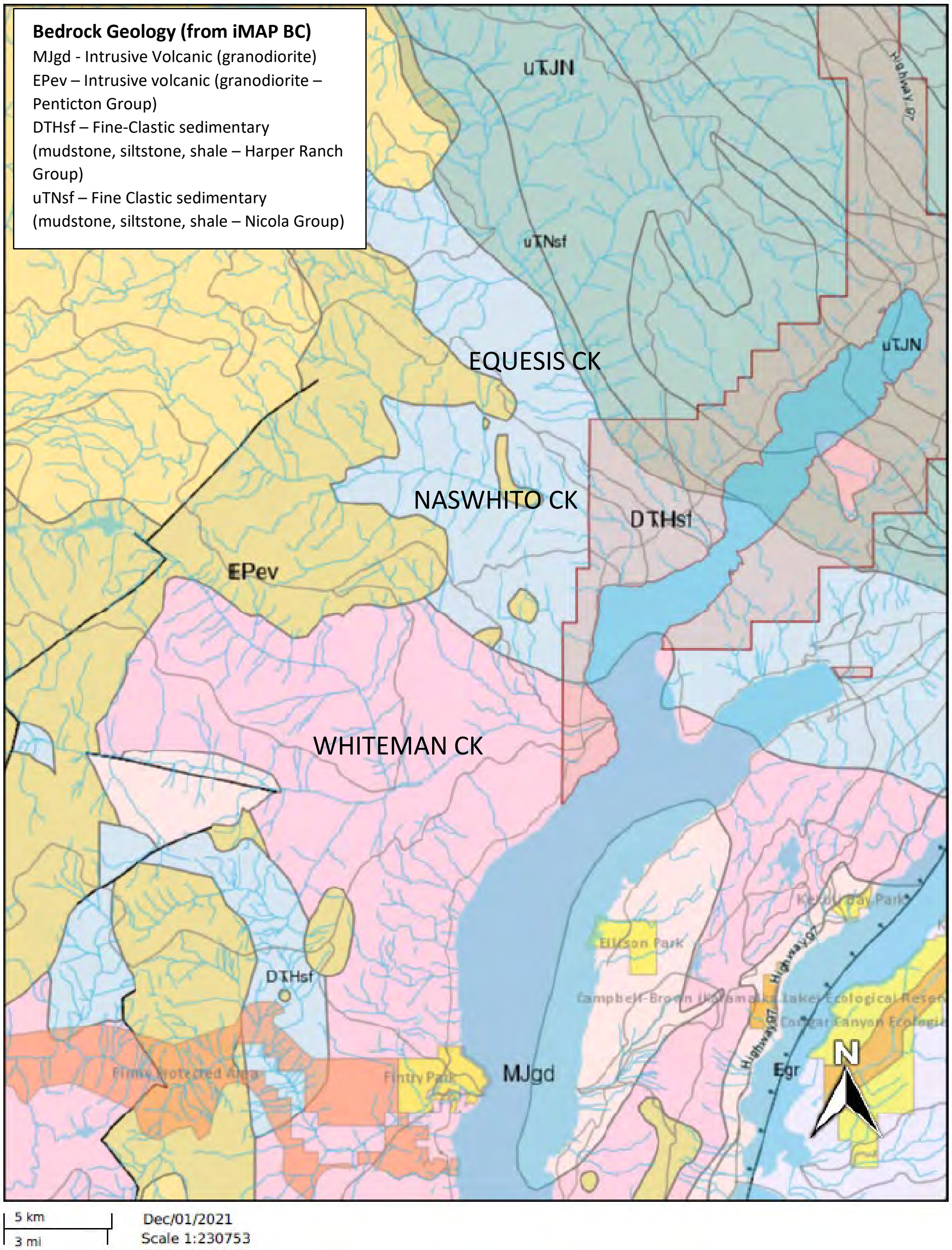


Figure 4-5: Bedrock Geology within the Study Area (from iMAP BC)

4.5 Surficial Geology and Soils

The surficial geology in the study area is reflective of the last glaciation and post-glacial history. After the last glaciation, ice retreated upwards towards the plateau, leaving behind till mantled bedrock. At the time, a stagnant valley glacier occupied the Okanagan Valley. Meltwaters draining the plateau deposited sediments along the margin of the valley glacier, forming raised fans and outwash terraces at the mouths of the major watershed and along the valley side slopes. Fine-textured silts and clay sediments deposited in ice-margin lakes, and later in the large post-glacial lake referred to as Glacial Lake Penticton. The study area was deglaciated between 8,000 to 10,000 years ago.

Soils in the study area are generally gravelly silty sand or gravelly sandy silt. ((There are few observed occurrences of glaciolacustrine silts and/or clays but they are most likely to be present along lower elevation slopes in the face unit areas. Soils within the large fan areas are more contemporary alluvial sands and gravel sediments deposited by the creeks.

Information on terrain stability was available from the BC Data Catalogue (iMAP BC) for the Whiteman Creek watershed, the Naswhito Creek watershed and for RDCO lands in the Killiney Beach area. For these three areas, Class IV (potentially unstable terrain) and Class V (unstable) terrain is mapped. For all other areas within the study area the 1:20 000 scale mapping was used to derive slope class and an assumed corresponding level of stability. Slopes were classified into 0-40% (i.e., stable), 40-60% (i.e., potentially unstable) and >60% (i.e., unstable).

4.6 Forest Harvesting and Past Watershed Disturbance

There is historical forest harvest activity throughout the study area, including the three largest watersheds. Watershed Assessments have been completed for the Whiteman and Naswhito Creek watersheds (Dobson Engineering Ltd., 1994). It is unknown whether more recent hydrologic assessment of the watersheds has been completed.

Natural disturbances from the recent 2017/2018 flood events were documented for Whiteman, Naswhito and Equesis Creek fan areas located on OKIB Reserve lands (Stantec Consulting Ltd.).

Information pertaining to historic harvesting or natural disturbance for areas other than these was interpreted from Google Earth imagery, field observations, and/or anecdotal sources, and is considered approximate.

Table 4-5: Natural Disturbance and/or Forest Harvesting in Study Area Watersheds

Watershed/Face Unit	Natural Disturbance and/or Forest Harvesting
Whiteman Creek	In 1994, the overall Equivalent Clearcut Area (ECA) was 14% and the ECA for the area above 1320m elevation (classified as the snow-accumulation zone) was 16% (Dobson Engineering Ltd., 1994). The potential for hydrologic impacts associated with harvesting (at the time) was assessed to be "low". The watershed assessment identified 239 stream crossings on 273 km of road (road density 1.23 km/km^2).
Naswhito Creek	In 1994, the overall Equivalent Clearcut Area (ECA) was 23% and the ECA for the area above 1320m elevation (classified as the snow-accumulation zone) was 30% (Dobson Engineering Ltd., 1994). The potential for hydrologic impacts associated with harvesting (at the time) was assessed to be "high". Harvesting generally occurred on gently rolling terrain on the upper plateau, avoiding the steep valley side slopes. Many roads are no longer active but are not yet deactivated.

Watershed/Face Unit	Natural Disturbance and/or Forest Harvesting
	The watershed assessment identified 122 stream crossings on 144 km of road (road density 1.78 km/km^2)
Equesis Creek	No watershed assessment information available. There is forest harvest activity in the MacGregor Creek subbasin. At the time of the assessment, salvage logging was taking place on private lands on the slopes above Musgrave Creek.
Killiney Face Unit	Slopes above the Killiney Beach area were selectively logged historically but not by more recent industrial methods. Slopes are hot and dry, with slow regeneration. Soils are shallow to rock, making reforestation efforts more challenging.
Bradley Creek	Lower elevation slopes are grassland areas used for livestock range use. Creek is largely contained within an incised gully. There is some historic forest harvesting in the upper watershed.
Newport Creek	Historic forest harvesting in upper elevation plateau area. Anecdotal sources indicate that the area had been extensively burned approximately 40-50 year ago.
Irish Creek	Relatively undeveloped subbasins above the valley bottom (south side of the watershed). Valley bottom areas, including fan areas, are cultivated.

1 – ECA = Equivalent Clearcut Area

4.7 Vegetation and Soil Burn Severity

4.7.1 Vegetation Burn Severity

Vegetation burn severity is based on the Burned Area Reflectance Classification (BARC) mapping of the White Rock Lake Wildfire was completed by the Province of BC and shown in Figure 1.1 and on each of the enclosed Watershed Maps (Appendix D). Vegetation burn severity refers to the effects of fire on the forest canopy and the understory and the mapping provides an indication of where the hydrologic and geomorphologic impacts are likely to occur.

Burn severity is mapped and classified as follows (after Curran et al., 2006):

- High (red areas) – trees are blackened and dead, needles consumed and understory consumed;
- Moderate (orange areas) – trees are burned and dead, needles remain and understory mostly burned;
- Low (yellow areas) – canopy and trunks partially burned, understory lightly or patchily burned.

Distribution of burned areas within the watershed influences effect on hydrology. For example, burn areas within the snow accumulation zone (~above 1300 m elevation) will have a greater relative impact on hydrology since burned areas in the snow accumulation zone will experience a greater relative increase in snow accumulation, rainfall interception, and a greater effect on melt rates. Loss of forest cover by wildfire has similar hydrologic effect as harvesting, with the exception that wildfire also has an impact on soils.

4.7.2 Soil Burn Severity

Soil burn severity is a relative measure describing the wildfire effect on soil conditions, namely the hydrologic function, or character, of soils. Soil burn severity is not always proportional to vegetation burn severity. For example, soils may experience a higher severity where a smoldering ground fire persisted (Hope, et al, 2015). Intense, fast-moving fires can have a high burn severity but not always a high soil burn severity.

A classification scheme that is similar to vegetation burn severity is developed to differentiate the relative effects on soils (Curran et al, 2006) as follows:

- High – forest floor is consumed; mineral soil has altered porosity and structure. Soils are highly likely to develop hydrophobicity (water repellency);
- Moderate – litter is consumed, duff is consumed or charred, mineral soil unaltered. Soils may be prone to development of hydrophobicity (water repellency);
- Low – litter is scorched or consumed, duff and mineral soil is unaltered.

Soils that have a moderate or high soil burn severity are more likely to have associated hydrophobicity, or water repellency. This is a characteristic of burned soils that increases the likelihood of overland runoff during rain events.

Extensive soil sampling was not completed for this project. Soils testing for water repellency was completed at a small number of sites within each major catchment area. Because of the large study area affected, it was considered impractical to sample many sites. In addition, because of the time elapsed since the fire (~8-10 weeks) and the occurrence of rain, snow and freezing weather, the ground was already saturated in many cases, making soils testing inaccurate.

Results from the field testing are summarized in Table 4.4. The limited amount of testing suggests that water repellency appears to be correlated with the moderate and high vegetation burn severity mapping and is likely to be pervasive throughout these areas. For the purposes of this assessment, we use vegetation burn severity as a surrogate for soil burn severity.

Table 4-6: Soil Burn Severity Testing at Sites within the Study Area

Site # - Watershed	Elevation	Vegetation Burn Severity	Water Repellency Class (based on water droplet test)
Site 1 - Equesis Creek, MacGregor Creek sub-basin (logged area)	895m	High	Weak
Site 2 – Whiteman Creek, Bouleau Creek subbasin	762m	High	Strong

Site # - Watershed	Elevation	Vegetation Burn Severity	Water Repellency Class (based on water droplet test)
Site 3 – Whiteman Creek, near confluence with Bouleau Creek	884m	Moderate to High	Strong
Stop 4 – Killiney Area, along Beachwood Rd.	380m	Low to Moderate	Weak (check)
Stop 5 – Slopes South of Newport Creek	450m	Moderate	Strong

5. Post-Wildfire Natural Hazard Risk Assessment

5.1 Hazard and Partial Risk Assessment Approach

Post-wildfire hazards identified during the field assessment are defined as "a potentially hazardous situation or event that has the potential to affect an Element at Risk". The post-wildfire risk assessment approach, outlined in Land Management Handbook 69 and adopted for this project, is a qualitative partial risk assessment. The results provide a means to identify and prioritize sites for mitigative measures.

A detailed description of the risk assessment methodology is provided in Appendix C.

In summary, partial risk is defined as the probability of a specific hazardous event affecting an element at risk, and it can be expressed as:

$$P(HA) = P(H) \times P(S{:}H)$$

where:

$P(HA)$ is the partial risk

$P(H)$ is the likelihood of a hazardous event occurring

$P(S{:}H)$ is the spatial likelihood that the hazardous event will reach the element at risk.

Qualitative ratings (i.e., low, moderate, and high) are used to describe hazard levels and the spatial likelihood level. These ratings, and the criteria used to assign each rating, are defined in Appendix A (Tables A1 and A2). The hazard and spatial likelihood ratings are combined in a matrix (see Table 5.1 below) to determine partial risk.

Table 5-1: Qualitative Partial Risk Assessment Matrix

Partial Risk P(HA): the probability that a specific hazard will occur and the probability of it impacting a site occupied by a specific Element at Risk (ie., P(HA) = P(H) x P(S:H)		**P(S:H) – the probability (likelihood) that the specific hazard will reach or otherwise affect the site occupied by an Element at Risk, assuming the event occurs.**		
		High	Moderate	Low
P(H) – the annual probability (likelihood) of occurrence of a specific hazard (i.e. landslide, debris flow, sediment-laden flood)	High	Very High	High	Moderate
	Moderate	High	Moderate	Low
	Low	Moderate	Low	Very Low

The outcome of the partial risk evaluation, above, is an assigned risk level. Five possible outcomes, or risk levels, are described in Table 5.2. These risk levels broadly assume a threshold level of acceptability or tolerance. This is completely dependent upon regulatory requirements or perspective of the end user. Assigned risk levels provide a relative risk rating, which can be used to prioritize sites and each level has associated management implications for risk mitigation that are described.

Table 5-2: Risk Levels Defined

Risk Level	Description	Management Implications
Very High	Risk is unacceptable within the short-term (before next flood season).	Risk reduction is required. A plan to reduce risk should be developed as soon as feasible and implemented prior to the next flood season.
High	Risk is unacceptable within the short to medium-term (3-5 years).	A plan to reduce risk should be developed as soon as feasible and implemented within a reasonable time frame.
Moderate	Risk may be tolerable. More detailed review may be required.	Reduce to low where reasonably practicable
Low	Risk is acceptable and tolerable but there is a remote possibility of effects.	Monitor for changing conditions, as resources permit.
Very Low	Risk is acceptable and tolerable.	No further assessment or risk reduction is required

5.2 Elements at Risk

Elements at Risk are defined as the population, building or engineering works, utilities, infrastructure in the area potentially affected by the hazards being assessed (Wise et al., 2004). Environmental features, such as fish and fish habitat and water quality are not considered for this study.

OKIB provided georeferenced data identifying Elements at Risk on the OKIB Reserve Lands. These features, and other identified "structures" within the study area, include:

- Residences, structures, dwellings on public property, private property or on OKIB Reserve Lands;
- Community (OKIB) buildings such as fire hall, school, administrative or government offices;
- Infrastructure, utilities, engineering works, such as domestic water supply infrastructure (i.e., intakes, distribution lines, pump stations or reservoirs). This includes the community water supply infrastructure for the Killiney Community (RDCO) and the Estamont Community Water Supply (private system);
- Transportation routes and infrastructure required for access (i.e., Westside Road) and associated major stream crossings (i.e., bridges/culverts) that are under the jurisdiction and responsibility of the BC Ministry of Transportation and Infrastructure (MOTI); and,
- Other features, such as a hydrometric station.

The list of Elements at Risk within the watershed is not considered exhaustive. Rather, observed features are noted and the level of risk may be extended to other features as they become known. The Elements at Risk are mapped on the Fan Maps (Appendix D), which present the results of the risk assessment.

5.3 Risk Assessment Results

The Natural Hazard Risk Assessment results are summarized for each watershed, face unit, and for each fan area on the Report Cards provided in Appendix D. The Watershed Report Cards incorporate field observations and summarize the following:

- General watershed/subbasin conditions, including the percentage of the basin that was burned and burned at high severity. Watershed physiography is also characterized.
- Terrain conditions, including the percentage of potentially unstable and unstable terrain that was burned at moderate and high severity.
- Mainstem stream channel and riparian conditions, include the length of channel that was burned at moderate to high burn severity.
- Post-Wildfire Natural Hazards that would be anticipated based on the watershed conditions and level of burn. This includes the type of process that is likely to occur, the potential for hydrologic (peak flow) hazard, and the potential for sediment bulking associated with terrain and riparian conditions.

Associated with each Watershed and with many of the identified Face Units is a fan area. Fan Report Cards summarize the results of the risk assessment for identified Elements at Risk. On each fan area, the following are summarized:

- General fan conditions, including physiographic character, development, and other notable physical features.
- Impacts from the 2017 and 2018 flood events. During the 2017 and 2018 flood events, the large fan areas experienced aggradation, bank erosion and inundation in certain areas. Understanding past impacts will help predict future impacts and help focus efforts to mitigate risks.
- Risk levels are assigned identified Elements at Risk on the fan area. These include: Elements identified by OKIB, Westside Road, and road infrastructure including major stream crossings.

For each watershed and fan area, photographs are provided, and map(s) are referenced.

5.3.1 Irish (nq'aplqs) Creek, Newport (nyxʷủt) Creek and Bradley (nsəsulaʕxʷ) Creek and Associated Face Unit Areas

The study area includes the fire-affected areas within Irish Creek, Newport Creek, Bradley Creek, and the face unit areas in between these three small watersheds.

The portion of **Irish Creek watershed** affected by the White Rock Lake wildfire includes the moderately-sloped northeast-facing slopes. These slopes include several gullied catchments with >50% of the catchment area burned. Based on an overview-level of assessment (helicopter overview flight and orthoimage interpretation), the gullies and slopes do not appear to be active or currently unstable. However, the gully catchments have a physiography that suggests that a mixture of debris flood and debris flow processes are likely, if conditions are suitable. Based on the extent of wildfire, there is a post-wildfire debris flow hazard on the four gullied tributaries above Irish Creek and a potential for hydrologic (peak flow) hazards on the mainstem Irish Creek, downstream of the fire-impacted areas. Rural agricultural properties within the jurisdiction of the North Okanagan Regional District occupy the fan slopes at the outlet of these gullies and downstream reaches of Irish Creek flow through the Okanagan Indian Band Reserve Lands and cross Westside Road. There is a potential for elevated peak flows reaching the culvert crossing on Westside Road.

There is a small face unit area located between Irish Creek and Newport Creek **("Face Unit North of Newport Creek")** that was extensively burned (98%). There is a potential for sediment-laden flows and small debris flows along these slopes. Structures located on fan areas downslope of this face unit are at high risk of impact and warrant further review to develop appropriate risk mitigation measures.

The **Newport Creek watershed** is a small (9.5 sq km) steep watershed that was extensively burned by the White Rock Lake Wildfire. Approximately 90% of the catchment area burned, and 60% of the catchment burned at a high burn severity, which represents a catastrophic loss of forest cover. The physiography of the Newport Creek watershed suggests that dominant hydrogeomorphic processes in the watershed are a mixture of debris flood and debris flow. Based on field observations there is clear historical evidence of large-scale sediment transport, including boulders over 1m in diameter just downstream of the fan apex.

The gullied face unit area between Newport Creek and Bradley Creek (**“Face Unit South of Newport Creek”**) experienced immediate post-wildfire natural hazard impacts during late fall rain events in November 2021. This small area was almost completely burned (98%) with ~40% at high burn severity. Sediment-laden flooding and small debris flows occurred along the gullied slopes, impacting several properties located on the fan area upslope of Westside Road. A technical memo documenting site conditions and providing interim mitigation measures to reduce immediate risk to the properties was prepared (enclosed in Appendix x?). Ongoing monitoring and more detailed assessment to prepare long term mitigation measures is warranted.

The **Bradley Creek watershed** is a small (6.5 sq km) watershed located in a grassy open-range stand type (biogeoclimatic zone IDF-xh1). Although the percentage of the watershed burned is high (71%; 33% high burn severity) the riparian forest along the incised channel experienced a low burn severity. The physiography of the Bradley Creek watershed suggests that dominant hydrogeomorphic processes in the watershed are a mixture of debris flood and debris flow. There is an elevated peak flow hazard with the potential to impact stream crossings along the mainstem channel. There is one property located on the fan area upslope of Westside Road. There is a potential risk of channel avulsion and peak flow impacts to the trail and nearby structures on the fan.

5.3.2 Equesis (aka Six Mile Creek) (snƛ̓´xʷxʷtan) Creek

The Equesis Creek watershed is a large (~203 sq km) watershed that was only partly burned by the White Rock Lake Wildfire. The wildfire perimeter affected the lower half of the watershed, representing only 20% of the total watershed area. The upper elevation plateau areas, or the snow accumulation zone, was not burned.

Despite this lower level of large-scale impact, a large proportion of the lower watershed was burned at a high severity, including some of the contributing subbasins. The McGregor Creek subbasin was extensively burned (74%) with 65% at high burn severity.

Equesis Creek watershed has a wide mid-watershed floodplain area that is occupied and developed for agriculture. The floodplain area is not well connected to the burned valley sideslopes. Further downstream the creek becomes incised and tightly constrained within a canyon reach before exiting onto a large alluvial fan and into Okanagan Lake.

A considerable length of the Equesis Creek mainstem channel (~4.6 km) and almost the entire length of McGregor Creek stream channel was burned at moderate or high burn severity.

Based on the area affected by wildfire, and the lack of wildfire impact in the headwater areas, the peak flow hazard on Equesis Creek is rated Moderate. Due to a lack of connectivity between burned valley side slopes and the mainstem channel the potential for sediment bulking is also rated Moderate. Bulking will most likely arise from tributary subbasin(s) and channel sediment sources (bed and bank erosion). The McGregor Creek subbasin has high potential for peak flow increases and sedimentation.

Equesis Creek occupies a narrow canyon reach before reaching the fan. Within the narrow reach above the fan there are several homes and the OKIB groundwater wells, providing domestic water supply to the community. These Elements are at risk of impact by elevated peak flows and bank erosion.

The Equesis Creek alluvial fan area is large and flat (<5% slope) and the channel is fairly well confined above Westside Road, which traverses across the upper third of the fan. The channel becomes unconfined and more sinuous and meandering downstream of Westside Road. Here the floodplain bank materials are loose, unconsolidated and easily eroded. The fan area is highly developed with ~265 identified structures, including sensitive and critical OKIB buildings and infrastructure.

Based on the level of wildfire disturbance within the watershed, areas adjacent to the channel are assessed as being high risk of impact by elevated peak flows, bank erosion, and inundation. Measures to reduce the level of risk to critical OKIB infrastructure and sensitive structures are warranted.

5.3.3 Naswhito (nʕastkʷítaʕkʷ) Creek

The reconnaissance post-fire assessment (Westrek Geotechnical Consultants Ltd., 2021) indicates a moderate risk of flooding on Naswhito Creek because the burned areas are well distributed throughout the watershed, including plateau areas, and along the mainstem channel.

The Naswhito Creek watershed has an area of ~85 sq km, of which more than half was burned (~58%) during the White Rock Lake Wildfire. Over 40% of the watershed burned at moderate to high burn severity. Based on the total area burned and the percentage of moderate to high burn severity, combined with the high connectivity of steep valley side slopes to the mainstem channel, the detailed assessment has assessed a high potential for peak flow and sedimentation impact. Because of the distribution of burn severities, there is a degree of uncertainty associated with this assessment.

The Gates Creek tributary subbasin was heavily burned (94% burned, with 58% of catchment at high burn severity). The Gates Creek subbasin also has a history of a large chronic landslide and hydrologic impacts at several road crossings. Therefore, there is a potential for continued instability at these sites.

The Naswhito Creek fan area is a large (1.72 sq km) alluvial fan that is coalescent with the alluvial fan of Equesis Creek. Naswhito Creek is a single meandering channel that exits a bedrock canyon at the fan apex and flows across the broad fan to Okanagan Lake. Downstream of Westside Road the channel is confined within relatively high (~1-3m high) banks and has a well-vegetated riparian fringe, which offers some streambank stability. Land development on the fan is primarily open range/agricultural land, except for the densely occupied lakeshore. There are approximately 130 structures identified on the fan, concentrated mostly along the lakeshore.

Based on the level of watershed disturbance and the potential for elevated peak flows on Naswhito Creek, areas adjacent to the stream channel across the fan are mapped as having a very high risk. Risk mitigation measures are recommended for properties situated with the high to very high-risk area, including several homes located upstream of Westside Road at the fan apex. Risk mitigation is also recommended for Westside Road and the arch culvert stream crossing, and for properties and infrastructure located within the areas adjacent to the stream channel.

5.3.4 Face Unit South of Naswhito

This face unit is located south of Naswhito Creek and contains several small unnamed ephemeral (seasonal) water courses. The water courses become incised as they down cut unconsolidated glaciofluvial sand and gravel deposits. There is an unpaved road/trail with no drainage structures traversing the top of the terrace slope. The catchment area above these slopes was extensively burned (68%), with a high proportion (26%) burned at high severity.

The terrace scarp slopes above Westside Road are steep, gullied slopes with observed recent and historic instability. Shallow landslides have occurred along the scarp slope with the runout upslope of Westside Road. Recent (November 2021) sediment-laden flooding was observed to have filled the roadside ditch and along the edge of Westside Road.

Based on proportion of the area burned there is a high likelihood for post-wildfire sediment-laden runoff and small scale debris flow activity from the face unit slopes. Elevated surface and groundwater runoff may increase the likelihood for landslides along the scarp slopes above Westside Road.

5.3.5 Whiteman (nq´ʷɬínəm) Creek

Whiteman Creek watershed is a large watershed (202 sq km) that was extensively burned by the White Rock Lake wildfire. The Bouleau Creek, South Whiteman Creek, and Browns Creek subbasins were also extensively burned. Approximately 68% of the total watershed was burned, and over half (~55%) of the watershed burned at a moderately to high burn severity. A significant proportion of the fire affected area is located within the snow accumulation zone (above 1300m elevation). In addition, fire-affected valley side slopes are directly connected to the mainstem channel. The situation represents an extremely high level of disturbance to the watershed forest cover and soils.

Over 10 km of riparian forest along the mainstem channel, and ~5.4 km of the Bouleau Creek channel, was burned at a moderate or high burn severity. This constitutes a high potential for bank erosion, sediment transport, woody debris input and, therefore, debris jams.

The Whiteman Creek FSR and South Fork FSR roads have a very high risk of landslide and rockfall, and associated bridges and crossings have a high to very high risk of impact by elevated peak flows. Of these, the most vulnerable bridge structure is located at the Maw FSR crossing, near the confluence with Bouleau Creek. Another vulnerable stream crossing is located on the South Fork FSR on South Whiteman Creek, near the confluence with the mainstem. Also at risk within the watershed is the Water Survey of Canada Hydrometric Station located just upstream of the confluence with Bouleau Creek. This station is considered a valuable asset as it provides real-time flow monitoring of the fire-affected watershed within the study area. If protected, this station may serve to monitor the oncoming freshet and provide advance warning of peak flow conditions.

The Whiteman Creek fan is a large (2.3 sq km) alluvial fan located along the shores of Okanagan Lake. There are almost 500 structures located on the Whiteman Creek fan, all within the OKIB Reserve Lands. A large number of residences are located within the Porter Cove subdivision, developed in the early 1990s, or are tightly spaced along the lakeshore. While it appears as though there are historical flood protection berms along sections of the channel, the level of protection they provide is unknown.

In 2017 & 2018, peak flows exacerbated debris jams in the channel upstream of Westside Road, caused rapid and extensive bank erosion along the right bank of the creek on the fan, and caused aggradation of sediment at the mouth of the creek, which cause localized flooding.

Based on the level of watershed disturbance and the potential for elevated peak flows on Whiteman Creek, areas upstream of Westside Road are mapped as having a very high risk. Some degree of flood protection is assumed for the subdivision area, but other areas adjacent to the channel and downstream of Westside Road are considered at very high risk. The piered bridge structure on Westside Road (MOTI) is also considered at very high risk.

While there are few built structures upstream of Westside Road, mitigation measures are recommended for the commercial building (OKIB) above the road, for Westside Road and the major stream crossing, and for properties and infrastructure located within the area mapped as very high risk.

5.3.6 Killiney Beach Area, Including Norris, Morden, and Fisbee Creeks

The White Rock Lake Fire affected a large face unit within the Killiney Beach area. The face unit includes the Norris, Morden, and Fisbee Creek watersheds, as well as three small unnamed catchments in between. Within the area there are more than 300 properties located above and below Westside Road within the jurisdiction of the RDCO.

The White Rock Lake wildfire burned an extensive proportion of the upslope catchments (between 73-99%). Several catchments had a high (>20%) proportion burned at high severity, including Norris Creek (composite), Unnamed Trib3 North of Norris, and the Fisbee Creek catchment. High burn severity wildfire extended down to Okanagan Lake at the south end of Killarney Place and within the Estamont area.

Many streams lose water by infiltration into pervious glaciofluvial sand and gravel deposits at ~600m elevation, situated just upslope of Westside Road and most developed properties. Fan areas delineated on the enclosed maps are interpreted based on landform, topography, and mapped hydrology. Downslope of these delineated fan areas, stream flows are typically small and often ephemeral in nature. This has led to a high degree of development-related diversions and constructed conveyances (ditches and culverts). For example, small streams have been redirected and/or contained in buried culverts by development on private lands.

Within the face unit area, catchment-scale post-wildfire impacts are likely to be associated with changes in hydrology on small tributary streams originating from the slopes above the subdivision. Altered hydrology, including increased groundwater discharge from spring sources, may also lead to localized effects on soil stability.

A site-specific assessment hazardous conditions was completed for specific burned properties within the Killiney Beach and Estamont communities by RDCO. The current assessment provides additional supplemental information for RDCO and area residents.

At the time of the site visit, several high hazard sites were identified. These include:

1. Stream crossings on Norris Creek, upslope of the Killiney Beach subdivision. Rehabilitation is recommended at a fireguard crossing, and on a trail (RDCO) crossing on Norris Creek.
2. Severely burned steep slopes above and below Beachwood Road and along Attenborough Road appeared to have observed small-scale soil slumping. Exposed mineral soils on steep slopes are considered to have a high potential for soil erosion and sediment-laden runoff. There is a high likelihood that runoff would reach downslope properties, and Okanagan Lake.
3. Emergent groundwater in the Buchannan Spring area located in the Estamont subdivision. Flows are contained and diverted along narrow roadside ditches and small, discontinuous lengths of culvert through the developed area and downslope before discharging to Okanagan

Lake. There is the potential for increased runoff and groundwater flows that may require mitigative measures to reduce the potential for impact.

6. Recommendations for Risk Mitigation

Stakeholders within each jurisdiction should consider the results of the Natural Hazard Risk Assessment. Depending on the level of risk tolerance, mitigation measures may be warranted to reduce the level of risk to identified Elements.

Depending on the identified natural hazards, recommended mitigation measures are intended to reduce the hazard level, or the exposure (i.e., spatial likelihood of impact).

For hazards associated with elevated peak flows, mitigation measures should be implemented prior to the spring freshet (i.e., end of April to mid-May). To achieve this, agency consultation and collaboration should begin immediately. Where further detailed engineering assessment and/or design is warranted, this should commence immediately.

6.1 For the Three Large Alluvial Fan Areas (Whiteman, Naswhito, and Equesis)

Prior to and leading into the 2022 spring freshet, recommended short term measures to reduce the risk of flood impact to identified Elements at Risk are identified for the three large fan areas. These **Urgent and Important** measures include:

1. **Monitoring** - Monitor snowpack conditions through the winter months at the Silver Star automated snow weather station or the Esperon manual snow survey station (https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-science-data/water-data-tools/snow-survey-data) and be apprised of developing spring runoff conditions reported through the BC River Forecast Centre (https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/drought-flooding-dikes-dams/river-forecast-centre). If desired, an early warning system for flooding could be developed. Recommendations for protection are based on assumed worst-case scenario and may proceed without an early warning system.

2. **Public awareness** – Ensure that the public is made aware of hazard situation by conducting public information meetings, developing a public information bulletin on recognizing hazard situations and how to respond. Provide emergency response information (egress routes, warnings, evacuation instructions). Install large warning signs on roads and at bridges.

   A list of emergency contacts is provided in Appendix E.

3. **Protect Assets** – Identify Elements at greatest risk and protect or relocate.

4. **Protect major stream crossings at Westside Road** - With any loss of, or disruption to, any major stream crossing on Westside Road, there is the risk that access in and out of the community is also disrupted, as there are no established bypass routes. Closer to the onset of

spring freshet, heavy equipment and operators should be placed on standby, ready to respond with short notice. Debris and accumulated sediment should be removed from the channel at Westside Road to prevent blockages.

5. **Increase frequency of inspection and monitoring along Westside Road** – this recommendation applies to the length of Westside Road through the study area to ensure no loss of use.

6. **Prepare emergency response plans** and assemble resources needed for emergency response. This includes identifying emergency access requirements and evacuation protocols. Materials such as sand/bulk bags, tiger dams, concrete lock blocks, lengths of corrugated steel culvert (to allow passage across flooded areas), gravel, sand, and riprap rock should be stockpiled. In addition, heavy equipment such as excavators and dump trucks should be identified and located near the study area.

Over the longer term, risk mitigation planning and the development of engineered flood protection measures is recommended. These long-term measures are considered **Important but not Urgent** and include the following:

1. **Install a meteorologic station in the Whiteman/Bouleau Creek watershed** – this station would provide valuable climate data for monitoring local precipitation and the timing of the spring freshet.

2. **Flood Inundation Modelling and Mapping** - following the EGBC professional practice guidelines for Floodplain Mapping (EGBC, 2017), flood inundation modelling and mapping should be completed for the three large alluvial fans (Whiteman, Naswhito and Equesis Creeks). Work will include:

    a. Hydrologic analysis and modelling to determine the anticipated effects of wildfire on the peak flow for each watershed. This analysis will provide a design flow.

    b. Hydraulic analysis of the stream channel and associated major crossings to determine the required capacity and design for the crossing upgrades that might be required.

3. **Increase Channel Capacity** - Identify options to widen the stream channel to increase capacity, reduce flow velocities and to encourage infiltration and sediment deposition.

4. **Prepare preliminary designs for crossing replacement at Westside Road** - Based on results of the hydrologic analysis, prepare designs for crossing upgrades if required.

5. **Relocate Assets** - Where possible, relocate sensitive and/or valuable assets that may potentially be impacted by flooding. Focus mitigation efforts on areas mapped as high or very high risk and preferentially target sites that have a history of being impacted by flooding.

6. **Land Use Planning** - Policies for land use can restrict, or place specific flood design requirements, on new building and/or development in high-risk areas on the fan. Geotechnical assessments are recommended prior to rebuilding fire-affected properties located in high-risk areas.

6.2 Newport Creek

Newport Creek is assessed as having a high debris flow hazard and properties located within high and very high-risk areas along the fan are considered vulnerable to debris flow impact and/or inundation by sediment-laden flows. Recommendations for risk mitigation include:

In the Short Term (Urgent and Important): A 2m high, ~100m long concrete lock block retaining wall was installed along the right bank at the fan apex in November 2021. This protective structure is intended to prevent an avulsion along the right channel bank and to contain flows within the channel. Engineering designs with a peak flow discharge were not completed, so it is considered an interim measure until more detailed assessment and analysis can be completed.

In addition to the above, the following recommendations are considered Urgent and Important, to be completed prior to the spring 2022 freshet:

- Public awareness of hazard conditions
- Protect Westside Road stream crossing

In the Long Term (Important but not Urgent): Although difficult to have completed prior to the 2022 spring freshet, a more detailed debris flow hazard assessment is recommended to develop design criteria for an anticipated debris flow event. In the absence of ground-based field work, debris flow modelling may be able to provide information sufficient to better identify hazards and risks associated with debris flow.

The assessment should be detailed enough to determine the potential trigger mechanisms of an event, the nature of a design event, including potential runout distance, volumes, and velocities. Design parameters may be used to determine capacity of the stream channel upstream of Westside Road and downstream of Westside Road and may be used to provide specifications for a crossing upgrade, if required.

Debris flow mitigation measures may include upgrades to the lock block deflection barrier and/or construction of a debris catch basin or debris control structure.

6.3 Face Unit Areas North and South of Newport Creek, South of Naswhito Creek, and Open Slope Areas in the Killiney Beach Area

For open slope areas above identified Elements at Risk where wildfire has led to a high hazard for sediment-laden flood or soil erosion and there is a high to very high risk to property and/or infrastructure, mitigation measures are warranted.

Prior to and leading into the 2022 spring freshet, **Urgent and Important** short-term measures to reduce the risk of impact to identified Elements at Risk include:

1. **Public awareness -** Recommend that property owners prepare for unusually high runoff in the spring. Flows may be higher than normal along existing water courses, and within zones of groundwater emergence (springs and seepages), soils may be wetter than normal.
2. **Inspect and maintain ditches and culverts** - Prior to spring freshet, inspect ditches and culverts to ensure they are clear of sediment and debris. Ensure clear and free passage

through all drainage structures and conveyances. Note that even if structures are clear they may not be adequately sized to accommodate an increased post-wildfire runoff.

3. **Protect assets** - Preparation may include relocating valuable assets or installing temporary protective measures such as sand bags.

Longer term (i.e., **Important but not Urgent**) measures to reduce the risk of impact to identified Elements at Risk include:

1. **Reduce potential for soil erosion on severely burned slopes** - To reduce the potential for surface erosion and to reduce rates of runoff from burned slopes, surface treatment options may be considered. These include:
   a. Weed-free straw mulch – to reduce erosion and runoff from peak flows, and to also reduce soil temperatures and enhance vegetation regrowth.
   b. Wood mulch – reduces erosion and has greater longevity than straw mulch as it is more resistant to wind. Can be derived from local wood sources and is less likely to contain invasive weed species.
   c. Seeding – low cost and easily applied but is a less reliable treatment as it is easily washed away by rainfall.
2. **Reduce potential for sediment transport, or reduce the impact of sediment transport, on high hazard gullies or stream channels.** Measures include:
   a. Check dams or weirs to reduce grade – these will require maintenance as they fill with sediment.
   b. Trash racks or debris catch basins – may be designed to intercept debris and sediment before it reaches downslope Elements at Risk. These structures require periodic clearing to ensure continued function.
   c. Channel clearing – removal of woody debris and sediment will ensure clear passage of flow and will reduce the potential for debris entrainment to Elements at Risk downslope. This is particularly important and easily completed at road crossings.
3. **Further Geotechnical or Hydrotechnical Assessment** - Conduct more detailed geotechnical (slope stability/geohazard) or hydrotechnical (design flow and capacity) assessment to develop engineered mitigation designs, where required. Ground-based traverse of channels upstream of developed areas, and through developed areas, may be required to better characterize hazards.

Mitigation measures for sediment-laden flooding and small debris flow have already been implemented for the high-risk area below the Face Unit South of Newport Creek. In response to immediate post-wildfire hazards, an assessment and emergency mitigation measures were implemented in November 2021 (Clarke Geoscience Ltd., 2021). The interim measures are intended to provide immediate protection, and protection from 2022 spring freshet flows. These included constructed ditches and berms to contain and deflect flows away from homes.

6.4 Large Watershed Areas

Considered beyond the scope of this assessment, detailed post-wildfire natural hazard mitigation plans are recommended for each of the three large watershed areas, upstream of the fan area. The mitigation plans would address identified hazards at vulnerable bridge crossings or along roads in heavily burned sub-basins. In general, it is recommended that backcountry access into the watersheds continues to be restricted due to the presence of hazards and to allow for natural recovery.

Other recommended mitigation measures within the large watershed may include:

- **Stream channel treatments along fire-affected reaches**
  - Remove woody debris from the channel to reduce the potential for entrainment and downstream transport. Unnaturally large accumulations of instream woody debris can lead to debris jams that may cause downstream impact when they eventually fail.
  - Riparian planting along low gradient reaches to accelerate recovery.
  - Stream bank armouring at vulnerable sites to protect infrastructure.
- **Road treatments in high hazard fire-affected areas**
  - Temporarily remove vulnerable culverts and close roads to allow passage of flows until the watershed/subbasin recovers.
  - Clear ditches and culvert inlets to reduce the potential for plugging.
  - Where roads cannot be closed, increase culvert size and/or install rolling dips to serve as backup.

7. Summary of Assessment Results

7.1 Summary of Post-Wildfire Natural Hazard Risk Assessment Results

An assessment of post-wildfire natural hazards was completed for Okanagan catchments affected by the White Rock Lake Wildfire. Post-wildfire natural hazards are associated with hydrologic changes in the watershed and constitute hazards such as flooding, debris floods, debris flow and sediment-laden flooding. Post-wildfire impacts associated with changes in slope stability constitute hazards such as landslide, rock fall, and soil erosion. All associated hazards have the potential to impact property, infrastructure, or the environment.

The natural hazards assessment builds upon and confirms results of the Westrek (2021) reconnaissance-level assessment. The assessment included a helicopter overview flight and ground-based field work to characterize the post-wildfire conditions in the study area. The study results anticipate that the predicted level of impact is proportional to the area burned and specifically the area with a high vegetation burn severity. This assumes that a high vegetation burn severity also has a high soil burn severity. Limited field testing of soil infiltration confirms this assumption.

Assessments were completed for six watersheds and for several face units containing smaller catchments that drain into Okanagan Lake. Results of the hazard assessment are summarized in Table 7.1

The results indicate that all six watersheds were impacted to some degree and that twenty downslope fan areas were found to have a high to very high risk of impact from the identified hazards. On the larger watersheds, such as Whiteman, Naswhito and Equesis, there is a moderate to high hazard level associated with elevated peak flows (flooding) and sediment bulking (debris flood). On the smaller catchments, such as Newport, Irish and Bradley Creek there is a high hazard level associated with sediment-laden flooding and debris flow. A similar high hazard level associated with sediment-laden flooding and small-scale debris flow was identified for small, gullied face units and for the Killiney Beach area. Geomorphic hazards, such as landslide and rockfall were identified within the larger watershed areas where instability along the valley side slopes and within steep tributary subbasin catchments was observed or is anticipated because of wildfire effects.

The partial risk assessment results summarized in Table 7.1. For the large fan areas, the spatial likelihood of impact is interpreted using LiDAR data, field observations, and orthoimage interpretation. Using these data sources, areas of historic flooding, channel avulsion, or periodic inundation are identified to provide a relative level of impact potential. This information is used to subdivide the large fans into zones of low, moderate, high, and very high risk.

The smaller delineated fan areas have an assumed uniform level of hazard exposure (i.e., spatial likelihood), which results in a uniform level of risk. Thus, for a hazard rated as a high likelihood of occurrence, and a high likelihood of reaching the fan area, the risk rating for the entire fan area is “very high”. In reality, the fan areas would have a variable risk level.

Table 7-1: Summary of Post-Wildfire Natural Hazard Assessment Results

Watershed or Face Unit Subbasin / Fan Area	**% Burned**	**Post-Wildfire Natural Hazard Summary**	**Hazard Level**	**Elements at Risk**	**Risk Level (varies depending on location of Element at Risk)**
Irish Creek Watershed	48	There is a post-wildfire debris flood and debris flow hazard on two gullied tributaries above Irish Creek and levels of burn indicate a potential for hydrologic (peak flow) hazards on the mainstem Irish Creek. Downstream reaches of Irish Creek flow through the Okanagan Indian Band Reserve Lands and cross Westside Road.	**High**	• Rural properties (RDNO) • OKIB Band Office • Westside Road	**VH**
Unnamed Trib 1	55		Moderate		**VH**
William Ck	79		**High**		M
Unnamed Trib 3	25		Low		VL
Unnamed Trib 4	16		Low		M
Face Unit N of Newport	-	The post-wildfire peak flow hazard is high for the Unnamed Ck N of Newport catchment area and moderate for the other small catchments. There is moderate to high likelihood of sediment-laden flooding and small-scale debris flow activity along the face unit slopes.	**-**	• OKIB Properties upslope of Westside Road • Westside Road	M to **H**
Unnamed Ck N of Newport	98		**High**		**H**
Unnamed Ck2 N of Newport	59		**Moderate**		M
Newport Creek Watershed	91	Post-wildfire hazards on Newport Creek include peak flow, sediment bulking, debris flood and debris flow. There is a history of large-scale instability within the canyon above the fan and the presence of large (2m) boulders on the fan indicates there is potential for destructive events. Short-term mitigation measures (lock block barrier) were installed in November 2021 to reduce potential for avulsion. Sediment transport in the channel has led to previous blockages at the Westside Road culvert. This crossing is anticipated to have capacity issues for the upcoming freshet.	**High**	• OKIB Properties upslope of Westside Road • Westside Road	**VH**
Face Unit S of Newport	98	There is a high likelihood is ongoing post-wildfire natural hazards within the face unit. Hazards include sediment-laden flooding and small-scale debris flow. The presence of larger boulders along the upper part of the fan area suggests there is potential for large-scale debris flow activity. Short-term mitigation measures (ditches and berms) were installed in November 2021 to reduce potential for impact to properties. More detailed assessment and ongoing monitoring is recommended.	**High**	• OKIB Properties upslope of Westside Road • Westside Road	**VH**
Bradley Creek Watershed	71	Due to the extent of the watershed area burned there is a potential for peak flow increases. There is a potential avulsion hazard at the top of the fan, above Westside Road. Normally the seasonally dry channel would not cause a problem but with potentially higher stream flows, there is a hazard for property on the upper fan area.	**High**	• OKIB Properties upslope of Westside Road • Westside Road	**VH**
Equesis Creek Watershed	20	Moderate peak flow hazard (due to lack of wildfire in headwater areas) and moderate sediment bulking potential. Bulking will most likely arise from tributary subbasin(s) and channel sediment sources (bed and bank erosion). McGregor Creek subbasin has high potential for peak flow increases and sedimentation. Although overall watershed hazards may be moderate, there is a high potential for sediment transport in the canyon reach just upstream of the fan.	Moderate	In watershed: • Private bridges and property (RDNO) • FSR and public roads On fan: • OKIB Community incl. 265 structures and sensitive infrastructure (domestic water supply, fire hall, school, offices) • Westside Road	Varies: M to **H to VH**
Fan Area	-		Moderate to Low		L to **H**
Musgrave Creek	35		**High**		Varies depending on site
McGregor Creek	74		**High**		Varies depending on site

Table 7.1 (cont.): Summary of Post-Wildfire Natural Hazard Assessment Results

Watershed or Face Unit Subbasin / Fan Area	**% Burned**	**Post-Wildfire Natural Hazard Summary**	**Hazard Level**	**Elements at Risk**	**Risk Level (varies depending on location of Element at Risk)**
Naswhito Creek Watershed	59	Within the watershed, the burn severity appears to be evenly distributed. However, the total % burned is high. High peak flow hazard is assessed due to aggregate of burned area, and moderate sediment bulking potential. Bulking will most likely arise from tributary subbasin(s). There is a high potential for post-wildfire landslide and debris flow on the Gates Creek subbasin. Gates Creek subbasin also has a historic large chronic landslide and hydrologic impacts at the road crossings, which increases the potential for continued problems.	**High**	In watershed: • Gates Ck Road & Siwash Ck Road On fan: • OKIB Property upslope of Westside Road • Westside Road • Properties situated along the channel downstream of Westside Road	VL to **VH**
Fan Area	-		**Moderate to High**		M to **VH**
Gates Creek	94		**High**		**VH**
Face Unit S of Naswhito	68	The terrace scarp slopes above Westside Road south of Naswhito Creek are steep, gullied slopes with indications of historic instability. Shallow landslides have occurred along the scarp with the runout upslope of Westside Road. Sediment-laden runoff infilling roadside ditches and reaching Westside Road was noted in November 2021.	**High**	• OKIB Property upslope of Westside Road • Westside Road	**VH**
Whiteman Creek Watershed	69	Steep valley side slopes and riparian areas in the middle watershed area are severely burned and show evidence of post-fire instability. Overall, a large proportion of the watershed has been burned and over 30% at high burn severity. Channel is vulnerable to debris jams and sediment transport. Highly affected tributary catchments include: Bouleau (40% high burn severity and steep slopes) and South Whiteman (20% high burn severity and steep slopes). Whiteman Creek is tightly connected to the valley side slopes until reaching a large alluvial fan at its mouth on Okanagan Lake. There is a high peak flow hazard on Whiteman Creek and on the three largest tributaries and a high potential for sediment bulking due to valley side slope instability and length of burned riparian forest that increases potential for debris jams and within-channel sediment transport	**High**	In watershed: • Whiteman FSR and 5 bridges • WSC hydrometric station • South Fork FSR On fan: • OKIB Community incl. Portside Subdivision (~472 structures) and sensitive infrastructure (community hall, commercial) • Westside Road	**H to VH**
Fan Area	-		**Moderate to High**		**M to VH**
Browns Creek	64		**High**		Varies
Bouleau Creek	65		**High**		Varies
South Whiteman Ck	67		**High**		**VH**
Hudsons Bay Creek	22		Low		VL
Killiney Beach Face Unit	-	This face unit area was burned extensively at varying levels of burn severity. There are several small tributary streams in the area, and many lose water by infiltration into pervious glaciofluvial sand and gravel deposits upslope of Westside Road. There are many historic water diversions associated with land development that influence runoff patterns through the area. Of concern will be the capacity for downstream conveyance and capacity of downstream ditches and culverts. Post-wildfire impacts are likely to be associated with changes in hydrology on small tributary streams.	Varies	• Private property (RDCO) • Infrastructure (domestic water supply reservoirs, water distribution lines, gas lines, etc.) • Westside Rd, Sugar Loaf FSR, and public roads	-
Morden Creek	73		Moderate		**H**
Norris Creek	98		**High**		**VH**
Trib 1 N of Norris	95		Moderate		M
Trib 2 N of Norris	99		Moderate		M
Trib 3 N of Norris	93		**High**		**H**
Fisbee Creek	94		**High**		**VH**

7.2 Summary of Recommendations for Risk Mitigation

To help direct efforts, recommended measures to reduce the natural hazard risk are described as “Urgent and Important”, or as “Important but not Urgent”. These are defined as follows:

- **Urgent and Important** – short-term efforts to reduce risk
    - Identifies measures to increase hazard awareness and to manage the potential crisis.
    - Measures should be implemented prior to the 2022 spring freshet.
    - Includes measures such as: public awareness, emergency protection of high value assets, monitoring, and emergency response planning. A list of emergency contacts is provided in Appendix E.
    - Recognizing the critical importance for access, this includes specific measures to protect Westside Road at the major stream crossings.
- **Important but not Urgent** – longer-term planning efforts to reduce risk
    - Identifies measures to better characterize the hazard for more efficient and effective risk mitigation
    - Planning initiatives are recommended to reduce the time spent managing the crisis.
    - Includes measures such as: instrumentation, modelling, engineering assessment and design, and land use planning.
    - Identifying risk mitigation measures within the larger watersheds will require additional planning and may eventually lead to specific activities associated with stream channel restoration and/or landslide rehabilitation.

For the large alluvial fans, the recommended mitigation measures focus on the peak flow and flood-related hazards. Mitigation measures on smaller catchments and within face unit areas focus on sediment-laden flooding and debris flows. Within the large watersheds there are also identified hazards associated with riparian disturbance, landslide/rockfall, and vulnerable stream crossings. Summary tables describing recommended mitigation measures and providing high-level cost estimates are provided below, in Tables 7.2 to 7.5.

Table 7-2: Summary of Risk Mitigation Recommendations and Estimated Costs for Large Fan Areas

For: Large Fan Areas (Whiteman, Naswhito, Equesis)		
Action (URGENT AND IMPORTANT – prior to 2022 freshet)	**Description**	**Assumptions and Estimated Cost**
Monitor snow and weather conditions and develop an early warning system for flooding	Monitor snowpack at Silver Star Station, precipitation at Vernon Station, and stream flows on Whiteman Creek. Develop a warning system (decision matrix) that comprises criteria for flood alerts (snowpack, spring temperature, rainfall thresholds). This will inform flood response measures.	Assumes use of existing data and reliance on River Forecast Centre forecasting. Est. $10,000 to $15,000.
Public awareness	Conduct public information meetings, develop a public information bulletin on recognizing hazard situations and how to respond. Provide emergency response information (egress routes, warnings, evacuation instructions). Install large warming signs on roads and at bridges.	Internal communication practices and procedures for each jurisdiction – involve the EOC, FNESS for example.
Protect assets	Identify elements at greatest risk and protect or relocate. Emergency (short-term) protective measures include: • Sand bags, Bulk bags, Lock blocks, Ditching and culverts, Stream bank armour (riprap) • Upgrade any existing protective works Identify material sources and stockpile prior to freshet.	Cost depends on what needs to be protected and how it is protected.
Protect major stream crossings at Westside Rd	Have equipment on standby throughout freshet to clear debris and sediment at crossing to ensure no blockage (mid-April to end of June, depending on snowpack and weather conditions).	Excavator on standby rates (responsibility of MOTI roads contractor - AIM).
Increase frequency of inspection and monitoring along Westside Rd	Ensure clear ditches, culverts, and road surfaces through the study area	Responsibility of MOTI roads contractor - AIM
Develop Emergency Response Plan	Prepare response plans if not already done to manage emergency access requirements and evacuation protocols.	Internal procedures for each jurisdiction - involve the EOC, FNESS for example
Action (IMPORTANT BUT NOT URGENT – longer term)	**Description**	**Assumptions and Estimated Cost**
Install meteorologic station in Whiteman/Bouleau Creek watershed	Site has been located and work is underway by OKIB/ONA to install the station.	Assumes station instrumentation is available and ready to deploy.
Flood inundation modelling and floodplain mapping	Complete hydrologic analysis to determine post-fire design flows and hydraulic modelling across fan area to determine flood extent and water depths for the design flow.	Assumes availability of LiDAR survey data for each fan area. Est. $20,000 to $40,000 per fan.
Increase channel capacity	Through results of floodplain modelling, identify channel constrictions, regain capacity at key locations to protect assets. Dredge channel at vulnerable locations identified by historic flooding or avulsion and/or results of modelling.	Cost depends on sites, volumes to be removed, and access. Assumes results of floodplain mapping are available. Otherwise relies on knowledge of past impact sites.
Prepare preliminary designs for crossing replacement at Westside Road	Based on results of the hydrologic analysis, prepare designs for crossing upgrades if required.	Engineering design est. $20,000 to $40,000 per crossing.
Relocate assets	This may not be possible for many assets in the short term. It may be a long-term response depending on the type of asset to be relocated.	Cost depends on what needs to be relocated.
Land use planning	Develop policies within each jurisdiction to identify flood prone lands and provide guidance for new development. Geotechnical assessments should be completed prior to rebuilding in high-risk areas.	Internal costs for each jurisdiction (RDCO, RDNO, OKIB)

Table 7-3: Summary of Risk-Mitigation Recommendations and Estimated Costs - Large Watershed Areas

For: Large Watershed Areas Above Fan Areas (Whiteman, Naswhito, Equesis)		
Action (IMPORTANT BUT NOT URGENT – longer term)	**Description**	**Assumptions and Estimated Cost**
Detailed risk mitigation plans for sites located in watershed	Complete more detailed assessments and risk mitigation plans for high to very high-risk sites (or subbasins) within the watershed. Review access requirements in the watersheds (i.e., salvage logging, research, private lands).	Assessments for each watershed to identify risks and complete more detailed assessments. Est. $30,000 to $50,000.
Stream channel treatments along fire-affected stream reaches.	Implement measures to reduce potential for sediment/debris transport along reaches impacted by wildfire: • Remove woody debris • Riparian planting • Stream bank armouring	Costs depend on site conditions and chosen approach. Sites and approach to be identified in detailed mitigation plan.
Road treatments in fire-affected areas.	Implement measures to mitigate hazards associated with watershed roads: • Identify rockfall and landslide hazards and mitigate through ditches and barriers. • Remove vulnerable culverts and close roads • Clear ditches and culvert inlets • Upgrade culvert capacity or construct rolling dips	Costs depend on site conditions and chosen approach. Sites and approach to be identified in detailed mitigation plan.

Table 7-4: Summary of Risk Mitigation Recommendations and Estimated Costs - For Newport Creek and Other Debris Flow Catchments

For: Newport Creek (and other high-risk catchments subject to debris flow – i.e. Irish Creek Tributaries)		
Action (IMPORTANT AND URGENT– prior to 2022 freshet)	**Description**	**Assumptions and Estimated Cost**
Public awareness	Conduct public information meetings, develop a public information bulletin on recognizing hazard situations and how to respond. Provide emergency response information (egress routes, warnings, evacuation instructions). Install large warming signs on roads and at bridges.	Internal communication practices and procedures for each jurisdiction – involve the EOC, FNESS for example.
Protect Westside Road stream crossings (Irish, Newport and Bradley Creek)	Increase frequency of inspection and monitoring along Westside Road. Have equipment on standby throughout freshet to clear debris and sediment at crossing to ensure no blockage (mid-April to end of June, depending on snowpack and weather conditions).	Excavator on standby rates (responsibility of MOTI roads contractor - AIM)
Action (IMPORTANT BUT NOT URGENT– longer term)	**Description**	**Assumptions and Estimated Cost**
Debris flow assessment	Conduct debris flow assessment including field investigation and to determine potential debris volume, peak discharge, velocity. Assessment will refine risk assessment and obtain design parameters for mitigation.	Est. $20,000 to $40,000 per watershed.
Upgrade debris flow mitigation structures and downstream crossings, incl. Westside Road.	Based on results of the assessment, mitigation measures may need to be upgraded. Based on results of the debris flow assessment, upgrade stream crossing with larger structure and/or debris basin. Preliminary designs for crossing upgrades on other creeks, as warranted.	For Newport Creek, assume use of existing concrete lock blocks. Engineering assessment and construction est. $20,000. Replacement cost at Westside Rd will depend on new crossing design.

Table 7-5: Summary of Risk Mitigation Recommendations and Estimated Costs for High-Risk Face Unit Areas

For: High Risk Areas Subject to Sediment-Laden Flooding and Debris Flow (Face Unit Areas North and South of Newport Creek, South of Naswhito Creek and area within Killiney Beach Area)		
Action (IMPORTANT AND URGENT – prior to 2022 freshet)	**Description**	**Assumptions and Estimated Cost**
Public awareness	Recommend that property owners prepare for unusually high runoff in the spring (along water courses and within zones of groundwater emergence. Conduct public information meetings, develop a public information bulletin on recognizing hazard situations and how to respond. Provide emergency response information (egress routes, warnings, evacuation instructions). Install large warming signs on roads and at bridges.	Communication responsibility for each jurisdiction.
Inspect ditches and culverts to ensure clear passage for increased flows	Prior to spring freshet, inspect ditches and culverts to ensure they are clear of sediment and debris.	Responsibility for property owner on private lands and MOTI (road maintenance contractor) on public roadways.
Protect assets	Identify elements at greatest risk and protect by relocation or physical protection (ditching, berms, barriers). Further assessment may be required. Identify material sources and stockpile prior to freshet.	Cost depends on what needs to be protected and how it is protected.
Action (IMPORTANT BUT NOT URGENT – longer term)	**Description**	**Assumptions and Estimated Cost**
Reduce potential for soil erosion	Implement measures to reduce potential for soil erosion (each have pros and cons): • Straw mulch • Wood mulch • Seeding	Estimated costs per ha (adjusted from Ecological Restoration Institute, 2021): • Straw mulch ($480/ha) • Wood mulch ($720/ha) • Seeding ($50/ha)
Reduce potential for sediment transport on gullies or stream channels	Implement measures to reduce potential for sediment transport (site-specific): • Check dams or weirs • Trash racks or catch basins • Channel clearing	Costs vary depending on treatment and site conditions. Channel clearing is the least expensive option.
Further assessment of upstream channels to refine mapping.	More detailed site assessment included ground-based traverse of stream channels upstream of the developed area to review instability, blockages, etc.	Cost depends on site and extent of study.
Further assessment of stream channels flowing through developed area.	More detailed site assessment to further characterize connectivity with upstream channels and identify opportunities to restore nature drainage patterns.	Cost depends on site and extent of study.

8. Closure and Limitations

This report has been prepared exclusively for the use of MFLNRORD. The assessment has been carried out in accordance with generally accepted practice. Professional judgment has been applied in the interpretations provided in this report. No other warranty is made, either expressed or implied. The report is subject to the CGL General Conditions and Limitations specified in Appendix A.

This report has been Independently Reviewed by Tim Giles, M.Sc., P.Geo., of Westrek Geotechnical Consultants Ltd. as per the *Professional Governance Act* and EGBC Guidelines for Independent Review of High-Risk Professional Activities.

Prepared by:

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References

Associated Environmental. 2016. Collaborative Development of Methods to set Environmental Flow Needs in Okanagan Streams. Prepared for Okanagan Nation Alliance, Ministry of Forests, Lands and Natural Resource Operations, and Okanagan Basin Water Board. Vernon, BC.

Church, M. and M. Jakob. 2020. What is a Debris Flood? Water Resources Research. 56, e2020WR027144. https://doi.org/10.1029/2020WR027144

Clarke Geoscience Ltd. 2021. Completion Inspection of Mitigation Measures – Unstable Gullies south of Newport (aka Lanahoot) Creek. Prepared for the Okanagan Indian Band. EMBC Task #223882. December 8, 2021. Kelowna, BC.

Curran, M.P., Chapman B., Hope G.D., and Scott D. 2006. Large-scale Erosion and Flooding after Wildfires: Understanding the Soil Conditions BC Ministry of Forests and Range, Technical Report 030.

DeBano, L.F. 1981. Water repellent soils: A state-of-the-art. USDA USDA Forest Service. Gen. Tech. Rep. PSW-46. Pacific Southwest Forest and Range Experiment Station, Berkeley, CA.

Dobson Engineering Ltd. 1994. TFL 49 Block A Watershed Assessment for Naswhito, Whiteman and Shorts Creek. Prepared for Riverside Forest Products Ltd. Kelowna, BC.

Doerr, S.H. and J.A. Moody. 2004. Hydrological effects of soil water repellency: On spatial and temporal uncertainties. Hydrological Processes 18. pp 829–832.

EGBC (2017) Flood Mapping in BC, Professional Practice Guidelines, V1.0. Vancouver, BC

Hope, G., P. Jordan, R. Winkler, T. Giles, M. Curran, K. Soneff, and B. Chapman. 20□5. Post-wildfire natural hazards risk analysis in British Columbia. B.C. Ministry of Forests, Research Branch, Land Management Handbook No. 69. Victoria, B.C.

Hungr, O. Leroueil, S. and L. Picarelli. 2013. Varnes Classification of Landslide Types, an Update. Landslides, 11, pp. 167-194.

Hungr, O., S.M. McDougall, and M. Bovis. 2005. Entrainment of Material by Debris Flows. In: M. Jakob and O. Hungr (eds.) Debris-flow Hazards and Related Phenomena. Praxis. Springer Berlin Heidelberg.

Jordan, P. 2016. Post-wildfire debris flows in southern British Columbia, Canada. International Journal of Wildland Fire. 25, pp 322–336.

MacDonald, L.H. and E.L. Huffman. 2004. Post-fire Soil Water Repellency: Persistence and Soil Moisture Thresholds. Soil Sci. Soc. Am. J. 68, pp 1729–1734.

MFLNRORD. 2018. Biogeoclimatic Subzone Variant Mapping (Ver. 2, 2018). Forest Analysis and Inventory Branch, 1:250,000 scale.

Moody, J.A., R.A. Shakesby, P.R. Robichaud, S.H. Cannon, and D.A. Martin. 20□3. Current research issues related to post-wildfire runoff and erosion processes. Earth-Sci. Rev. 22. pp 10‑37.

Neary, D.G., K.A. Keostner, and A. Youberg. 2011. Hydrologic Impacts of High Severity Wildfire: Learning from the Past and Preparing for the Future Rocky Mountain Research Station. USDA Forest Service. Colorado.

Wise, M.P., G.D. Moore, and D.F. Van Dine (editors). 2004. Landslide Risk Case Studies in Forest Development Planning and Operations. B.C. Ministry of Forests, Research Branch, Land Management Handbook No. 56. Victoria, B.C.

Appendix A CGL General Conditions and Limitations

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GENERAL CONDITIONS AND LIMITATIONS OF THE REPORT

1.0 **Standards of Care:**

In the performance of professional services, CGL has used the degree of care and skill ordinarily exercised under similar circumstances by reputable members of its profession practicing in the same or similar localities, based on the current state of practice. Professional judgement has been applied in developing the conclusions and/or recommendations provided in the report. No other warranty, expressed or implied, is provided.

2.0 **Use of Report:**

The information developed for this report is intended for the sole use of the CLIENT. Any use of this information by any third party unless authorized in writing by CGL is at the sole risk of the user. The contents of the report are subject to copyright and shall not be reproduced either wholly or in part without the prior, written permission of CGL.

Reference must be made to the whole of the report to fully understand suggestions, recommendations and opinions expressed herein. We are not responsible for use by any party of portions of the report without reference to the whole report.

The CLIENT shall be responsible for reporting the results of any investigation to the relevant regulatory agency if such reporting is required, and the CLIENT acknowledges that CGL may be required by law to disclose information to regulatory agencies and hereby consents to such disclosure.

3.0 **Site Conditions and Interpretation of the Report:**

Site conditions (e.g., soil, rock, and groundwater) may vary from those encountered at the locations where surface exposures exist or where observed by CGL and that the data, interpretations, and recommendations of CGL are based solely on the information available. Classification and identification of soils, rocks, geological units, and terrain are based on investigations performed in accordance with commonly accepted methods and systems employed in professional geotechnical practice. There is no warranty expressed or implied by CGL, that any investigation can fully delineate all subsurface features and terrain characteristics.

4.0 **Limitations:**

The interpretations and conclusions of this report are based on the observed site conditions at the time of the assessment, and on the basis of information provided. We rely in good faith on the representations, information and instructions provided. Accordingly, we cannot accept responsibility for any deficiency, misstatement or inaccuracy contain in the report as a result of misstatements, omissions, misrepresentations or fraudulent acts of any persons providing such information. CGL accepts no responsibility for the accuracy or reliability of information provided by third parties other than the CLIENT.

The report is not applicable, nor are the results transferrable, to any other sites. It is a condition of this report that CGL be notified of any changes to site conditions and be provided with an opportunity to review or revise the recommendations within this report.

5.0 **Environmental and Regulatory Issues:**

Unless expressly agree to in the Terms of Engagement agreement, CGL is not responsible for identifying, considering, or addressing environmental or regulatory issues associated with the project.

6.0 **Liability:**

CGL carries professional liability insurance, and this coverage applies to the services provided. To the fullest extent permitted by law, the total liability of CGL, its directors, employees, and subconsultants, for any and all injuries, claims, losses, expenses, or damages whatsoever arising out of or in any way relating to the Project, the Site, or this Report from any cause or causes including but not limited to the negligence, errors, omissions, strict liability, breach of contract, or breach of warranty of CGL, its directors, employees, and subconsultants shall not exceed the coverage amount available at the time of the Claim.

The CLIENT will indemnify and hold harmless CGL from third party Claims that exceed the available coverage amount.

Appendix B Reconnaissance-Level Post-Wildfire Natural Hazard Risk Assessment (Westrek Geotechnical Consultants Ltd., 2021)

MINISTRY OF FORESTS, LANDS AND NATURAL RESOURCE OPERATIONS AND RURAL DEVELOPMENT
POST-WILDFIRE NATURAL HAZARD RISK ASSESSMENT

RECONNAISSANCE REPORT

NOTE: The results given on this form are preliminary in nature and are intended to be a warning of potential hazards and risks. It is not a final risk analysis and further work may alter the conclusions.

FIRE: K61884 White Rock Lake	**FIRE YEAR**: 2021	**DATE OF REVIEW**: September 9 and 24, 2021 **DATE OF REPORT**: October 14, 2021

AUTHOR: Tim Giles, MSc, PGeo, Geoscientist, Westrek Geotechnical Services Ltd.

REPORT PREPARED FOR:
BC Ministry of Forests, Lands and Natural Resource Operations and Rural Development ("The Ministry") –
Thompson Okanagan Region, Cascades, and Okanagan Shuswap Natural Resource Districts
BC Wildfire Service – *Kamloops Fire Centre, Merritt, Vernon, and Penticton Fire Zones*

FIRE SIZE, LOCATION, AND LAND STATUS: The fire was approximately 83,342 hectares in size.

The Ministry-produced Natural Hazard Assessment map is attached for reference.

The land status is a mix of private, municipal, First Nations reserves, Provincial Parks and Crown land.

VALUES AT RISK:
Much of the White Rock fire was on the Thompson Plateau, encompassing a large part of the Salmon River watershed as well as reaching watersheds tributary to Okanagan Lake.

It advanced north into the community of Monte Lake and burned several residences. Around the Monte Lake area there are impacted slopes above residences and outbuildings, highways, other roads, and the CN Rail line.

On the western shore of Okanagan Lake, large areas of burned slopes exist above the residential communities of Ewing and Killiney Beach. Several small creeks pass through these communities as they enter Okanagan Lake and there is potential for elevated streamflow impacting the residential areas as well as Westside Road.

The watersheds of Whiteman-Bouleau, Naswhito and Equesis Creeks are all significantly burned and there is potential for elevated streamflow as a result of the wildfire. Large communities on the fluvial fans of these watersheds are potentially at risk from flooding.

WATERSHEDS AFFECTED:
South Thompson River - The White Rock Fire burned across much of the upper Salmon River watershed above Westwold which enters Shuswap Lake and the South Thompson River drainage. Small parts of the Monte and Paxton creek watersheds were also burned.

Nicola River – A small part of the upper Chapperon drainage was burned.

Okanagan Basin - on the east side of the fire, the watersheds of Irish, Newport, Bradley, Equesis, Naswhito and Whiteman-Bouleau Creeks were all extensively burned.

- Whiteman-Bouleau: 56% moderate and high burn severity
- Naswhito: 45% moderate and high burn severity
- Equesis: 21% moderate and high burn severity

BURN SEVERITY (map attached)

A burn severity map was compiled by Westrek Geotechnical Services Ltd. The vegetation burn severity map uses satellite images to estimate the change to vegetation canopy. For the White Rock Fire, the images compared were taken September 9, 2020, and September 24, 2021.

HAZARDS AND POTENTIAL RISKS ASSOCIATED WITH FIRE:	POST-FIRE HAZARD [1]	POST-FIRE RISK [2]
• A small portion of the Paxton Creek watershed burned north of Highway 97. Paxton Creek flows west through a culvert under Highway 97 into the Monte Creek system which flows north into the Thompson River. A mix of unburned, low, moderate, and high burn severities were observed within the watershed and the effects of the fire are expected to be incremental increases in sediment movement and channel degradation. The flow in the creek is expected to increase during spring freshet and after rainfall events. Landslides are not expected and any that do occur should be of limited size and only impact short reaches within the creek channel. Properties and structures along Paxton Creek may be impacted by increased flooding as a result of the fire.	Low for flooding along Paxton Creek Low for landslides within the Paxton Creek watershed	Low for flooding along Paxton Creek Low for landslides within the Paxton Creek watershed
• A small area of the Monte Creek watershed (not Monte Lake) burned south of Highway 97. A mix of unburned, low, moderate, and high burn severities were observed, and effects of the fire are expected to be incremental increases in sediment movement and channel degradation. Landslides are expected on the steeper slopes, but they should be of limited size and only impact short reaches within the creek channels. Properties and structures downstream of the fire on Monte Creek are unlikely to affected by the effects of the fire.	Low for flooding along Monte Creek	Low for flooding along Monte Creek
• The Salmon River watershed was extensively burned upstream from the Highway 97 corridor at Westwold. Numerous smaller watersheds, including, Rush, Goodwin, Cain, Weyman, Random, Ingram and Twig Creeks were heavily impacted. It is anticipated that the effects of the fire might be noticed during the next 2 or 3 spring freshets as snowmelt occurs earlier and freshet flows may be flashier. Increased sedimentation is expected along these creeks which may cause increased degradation of the channels. Landslides are expected but will be limited to steep-sided valley-sidewall events which will impact relatively short reaches within the creek channels. Properties and structures along the lower Salmon River (as far downstream as Westwold) may be impacted by flooding as a result of the fire.	Low for flooding on Salmon River Low for landslides within the Salmon River watershed	Low for flooding on Salmon River Low for landslides within the Salmon River watershed
• Monte Lake drains into the Salmon River watershed west of Westwold. On the south side of the lake are numerous creek draws which were extensively burned at moderate to high burn severities. One small erosional sedimentation event was observed on the south side of Monte Lake during the overview flight. There was no clear initiation landslide and it appeared that the event was primarily sediment-laden streamflow. The majority of sediment was deposited above the CN Rail line, but water did reach the tracks. Drainages on the south side of the lake are expected to see further small erosional sedimentation events. Above Highway 97 on the north side of the lake are numerous small creek draws which were extensively burned at moderate to high burn severities. These creek draws are expected to respond rapidly to rainfall events, and nuisance sedimentation events are expected to impact the highway. Properties and structures on both sides of Monte Lake may be impacted by nuisance sedimentation and overland flows as a result of the fire.	Moderate for flooding around Monte Lake High for landslides around Monte Lake	Moderate for flooding around Monte Lake High for landslides around Monte Lake

• A small portion of the northeastern headwaters of the Chapperon Creek watershed was burned and there was a mix of unburned, low, moderate burn severities. The watershed was extensively harvested prior to the fire. Effects of the fire are expected to be incremental increases in sediment movement and channel degradation. Landslides are not expected and any that do occur should be of limited size and only impact short reaches within the creek channels.	Low for flooding on Chapperon Creek	Low for flooding on Chapperon Creek
• The small watersheds of Newport and Bradley Creeks and the face units beside them were extensively burned. They are expected to have increased streamflow and associated sedimentation. Sediment aggradation may occur in the creek channels on the alluvial fan surfaces. This may cause overbank flooding and potential migration of the channel appears possible across much of the very gently sloped, lower fan surfaces. Numerous residences are present along the shoreline of Okanagan Lake below Newport Creek, some of which could be inundated if the main creek migrated laterally across the lower fan surface.	High for flooding on the Newport and Bradley Creek fans	High for flooding on the Newport and Bradley Creek fans
• Several west-flowing tributary drainages in the Irish Creek watershed were burned. These creek draws are expected to respond to rainfall events with increased streamflow and associated sedimentation. These nuisance sedimentation events may impact properties and structures on the upper floodplain of Irish Creek which has been developed primarily for agricultural use	Moderate for flooding on upper Irish Creek	Moderate for flooding on upper Irish Creek
• Around 32% of the Equesis Creek watershed was burned, but of the areas that burned 65% were moderate or high burn severity. The Equesis Creek fan did not burn during the wildfire. McGregor and Musgrave creeks were both extensively and severely burned and are expected to have increased streamflow and sedimentation. The upstream floodplain of Equesis Creek has been developed for agricultural use with numerous residences present. The increased streamflow and sediment movement along upper Equesis Creek has the potential to cause overbank flooding along the upper creek. Downstream from the wide floodplain reach the creek has a narrower incised channel down to the large coalescent fluvial fan which it shares with Naswhito Creek. From the fan apex down to Westside Road, there are several residential structures adjacent to the creek. The creek is constricted at Westside Road where passes it through an arch culvert onto the lower fan surface. Downstream of the highway, at least two water diversions for agricultural irrigation purposes are visible. Increases in sediment transport from the upper watershed and delivery to the fan is expected. Sediment aggradation in the creek on the fan surface may cause overbank flooding and potential migration of the main channel appears possible across much of the very gently sloped, lower fan surface. Numerous residences are present along the shoreline of Okanagan Lake, some of which could be inundated if the main creek migrated laterally across the lower fan surface.	Moderate for flooding on the Equesis Creek fan Moderate for landslides in the tributary watersheds.	Moderate for flooding on the Equesis Creek fan Moderate for landslides in the tributary watersheds.
• The Naswhito Creek watershed had a mix of unburned, low, moderate, and high burn severity patches (45% moderate and high); the fluvial fan was partially burned during the fire. The creek follows a confined valley down to the apex of the large coalescent fluvial fan	Moderate for flooding on the Naswhito Creek fan	Moderate for flooding on the Naswhito Creek fan

it shares with Equesis Creek. Upstream of the fan apex there is no development along the tight valley floodplain. There are a few residences upstream of Westside Road on the upper fan surface. At Westside Road, the creek passes through an arched culvert and then crosses undeveloped agricultural land before entering Okanagan Lake through a narrow outlet with residences on both sides of the channel. It is expected that there will be a minor increase in streamflow and sediments delivered to the apex of the fan. Minor sediment aggradation in the creek on the fan surface has the potential to cause some overbank flooding.		
• The Whiteman-Bouleau Creek watersheds had high burn severities along the deeply incised, steep-sided valleys leading to the plateau surface (56% moderate and high). The creeks join once they leave the hills and the lower 6 km passes through a confined valley with several private land parcels, some with what appear to be residential structures. The Whiteman-Bouleau fan is a large, low gradient fluvial fan which has been extensively developed for residential and recreational use; the fan was not burned during the wildfire. The creek passes under a bridge on Westside Road in a confined channel. A residential area exists on the north bank of the creek downstream of the highway and numerous residences are present along the shoreline of Okanagan Lake. It is expected that there will be a significant increase in streamflow and sediments delivered to the apex of the fan above the highway. Sediment aggradation in the creek on the fan surface may cause rapid overbank flooding and potentially lateral migration of the creek could occur across much of the gently sloped lower fan surface.	High for flooding on lower Whiteman Creek and on the Whiteman Creek fan High for landslides in the tributary watersheds	High for flooding on lower Whiteman Creek and on the Whiteman Creek fan High for landslides in the tributary watersheds
• The Killiney Beach area (Westside Road between Morden Creek to Sugar Loaf FSR) was extensively burned, and numerous residences were destroyed. Topographic maps indicate that there are several small watersheds which drain through the residential areas. There is an expected increase in surface flows through the creeks leading through the residences and into Okanagan Lake. Properties and structures in the Killiney Beach area may be impacted by nuisance sedimentation and overland flows as a result of the fire.	High for flooding + landslides in the Killiney Beach area	High for flooding + landslides in the Killiney Beach area
1. Hazard = P(H), the probability of occurrence of a hazardous event. It does not address the natural or pre-fire hazard that may already have existed. *2. Risk = Partial risk P(HA) = P(H) × the probability of it reaching or affecting an element at risk*		

FURTHER ACTIONS:

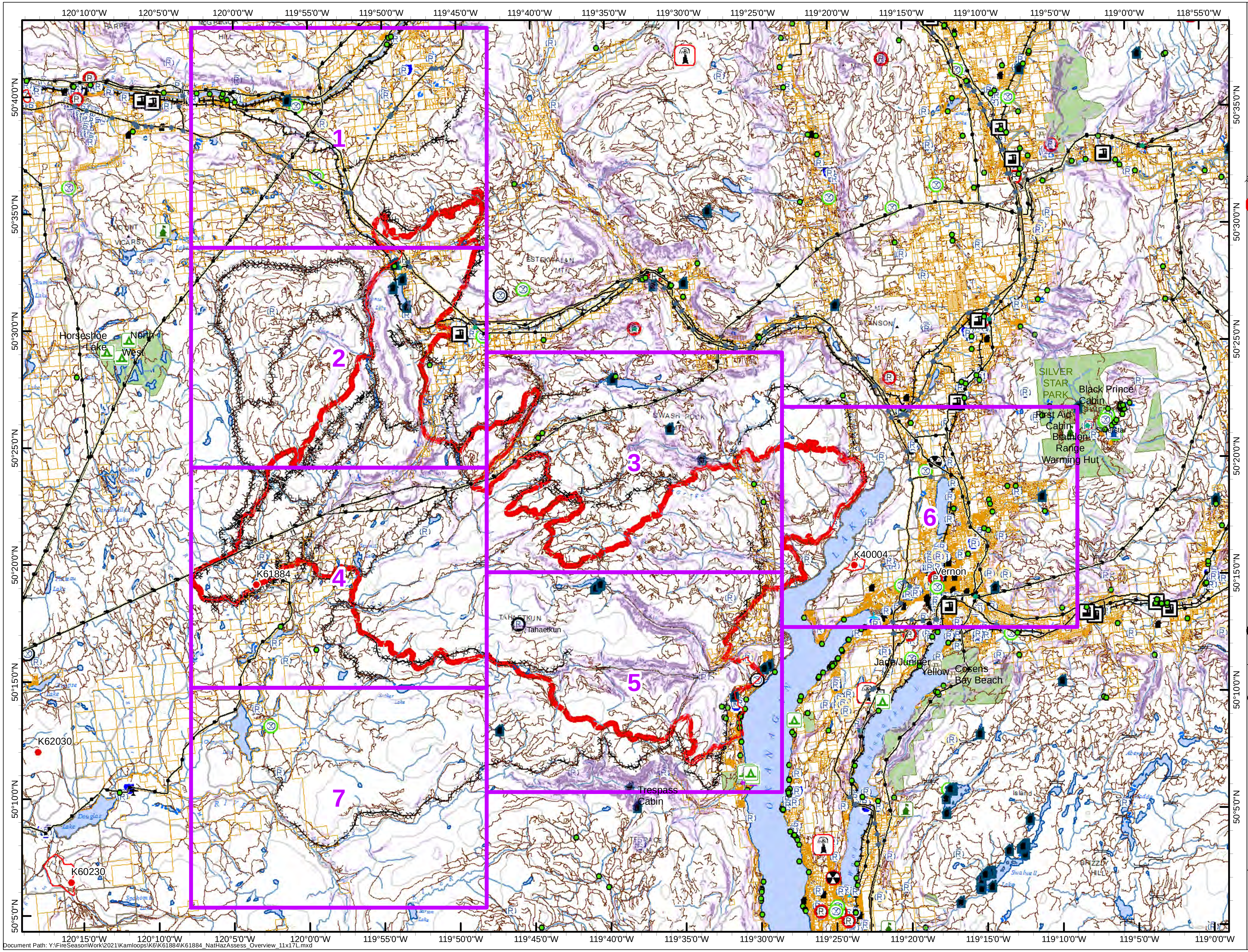
Post-wildfire assessments are recommended for several areas of the White Rock wildfire to assess the potential impacts that the wildfire has had on the natural hazards and to present potential options that the stakeholder can consider for mitigating their risk. Specific sites are:

- Paxton Creek – MOTI are recommended to review their drainage structures along Paxton and North Paxton Creeks upstream from Highway 97.
- Monte Lake – MOTI are recommended to review ditch lines and culverts on Highway 97 between the Paxton Valley Road and the CN Rail track crossing east of Monte Lake. Residents around Monte Lake should also be warned of the increased potential for nuisance sedimentation and overland flows as a result of the fire.
- A watershed review of the Newport, Bradley and Irish Creek watersheds. This review should include an understanding of the potential impacts to the Newport and Bradley Creek fluvial fans of the increase in streamflow and sedimentation from the upper watersheds. A review of the west-facing tributary creeks in

the Irish Creek watershed should determine the potential impact of increased streamflow and sedimentation to the properties in upper Irish Creek watershed.

- A watershed review of the Whiteman (and Bouleau) Creek watersheds and the fluvial fan. This review should include an understanding of the potential impacts to the creeks of the increase in streamflow and sedimentation from the upper watershed down to Okanagan Lake.
- A watershed review of the Equesis and Naswhito Creek watersheds and their coalescent fluvial fan. This review should include an understanding of the potential impacts to the creeks of the increase in streamflow and sedimentation from the upper watershed down to Okanagan Lake.
- A review of the drainages in the Killiney Beach area. This review should include the area upslope to the height of land from Morden Creek in the south to the start of the Sugar Loaf Forest Service Road in the north.
- CN Rail should independently assess all of their infrastructure within the fire perimeter.

SIGNATURE:	**ATTACHMENTS:**
PROFESSIONAL PROVINCE OF T. R. GILES BRITISH COLUMBIA GEOSCIENTIST 2021-10-14 Tim Giles, MSc, PGeo, October 14, 2021 Senior Geoscientist *Westrek Geotechnical Services Ltd.* *Permit to Practice Number: 1002522*	K61884 White Rock Lake Natural Hazard Assessment Map K61884 White Rock Lake Vegetation Burn Severity Map



White Rock Lake

K61884

Natural Hazard Assessment

Map Date: August 27, 2021

Perimeter Date: 2021-08-26

Hectares: 81453.20938695

Overview

Compl... Line
Fire Perim...
Fire Point
Other Fire Perim...
0 - 40%
40 - 60%
> 60%
Priority Water Rights Licenc...
Lodge
Camp...
Day Use
Wildla... Struct...
Cultur... Park Value
Hydro
Comm... Tower
Ski Resort
Lodge
Airport
Weather Station - Active BCWS
O&G Facility
Indust...
O&G Well Site
O&G Facility
BC Hydro Critical Assets
Hydro Facility
Pipeline
Pipeline - Constr... Unkno...
Trans... Lines
Radio Tower - Restri...
Radio Towers - FLNRO
Radio Tower - Cellular
Navaids
Navaids - High Value
RADAR - High Value
Weather Station
Seapl... Facility
Bridge
Rail Line
Ambul... Fire, Police
Attack Base - Primary
Fire Zone Office
Public Building
Dam
Popul... Place
Indian Reserve
Private Land
Road
Contour - 1000m
Contour - 200m
Mount...
BC Parks {O}

1:280,000

0 1.5 3 6 9 12 Km

This map may contain CONFIDENTIAL information: for INTERNAL use only

Disclaimer:
Wildfire perimeters for the current fire season, including both active and inactive fires, are supplied from various sources. The data is refreshed from operational systems nightly to the public map. Wildfire data may not reflect the current fire situation, and therefore should only be used for reference purposes.

Wildfire data from the incident is updated when practicable and the occurrence of individual fire updates will vary . The information is intended for general purposes only and should not be relied on as accurate because fires are dynamic and circumstances may change quickly. The levels of current fire activity within the mapped fire perimeters can vary widely.

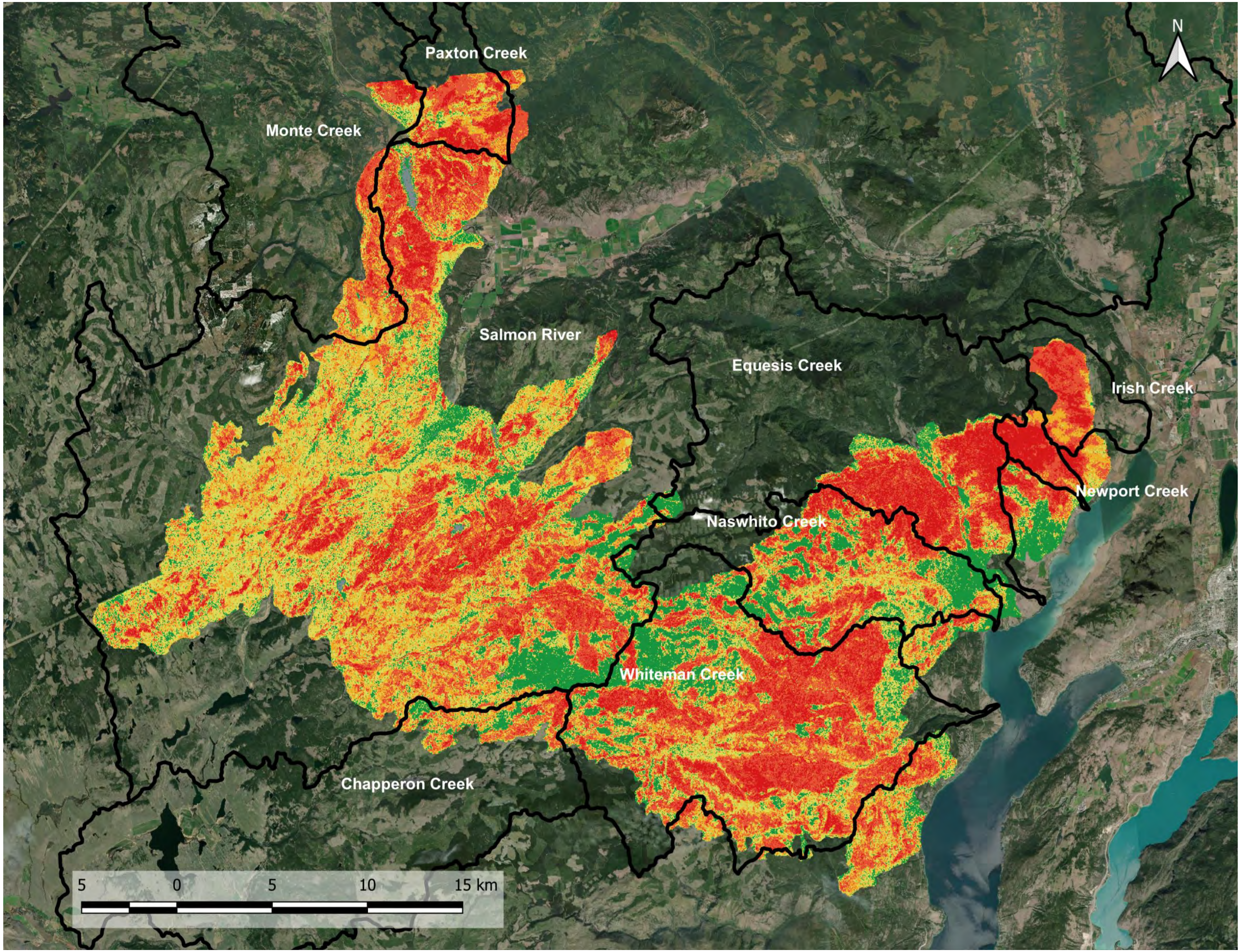
Data Sources and Notes:

N

Projection: NAD 1983 BC Environment Albers
Created by: jdoerkse

BRITISH COLUMBIA
Ministry of Forests, Lands, Natural Resource Operations and Rural Development
BC Wildfire Service

Document Path: Y:\FireSeasonWork\2021\Kamloops\K6\K61884\K61884_NatHazAssess_Overview_11x17L.mxd



WHITE ROCK LAKE
K61884

Burn Severity Map for Natural Hazard Assessments
1 : 180 000

Fire Boundary

Burn Severity 2021
(Year-Over-Year Classification)*

<= -550	UNKNOWN
-550 - 99	UNBURNED
99 - 269	LOW BURN
269 - 439	MOD-LOW BURN
439 - 660	MOD-HIGH BURN
> 660	HIGH BURN

This burn severity mapping is created using a Differenced Normalized Burn Ratio (dNBR) calculation on pre- and post-fire imagery as described by Key and Benson, 2006. The map is classified into five burned area reflectance classification (BARC) categories. Default breakpoints for burn severity classifications are used for all timber types across BC and therefore may not accurately reflect the forest type or field conditions.

IMPORTANT: THIS BURN SEVERITY RUN USES POST-FIRE IMAGERY THAT CAN CONTAIN SMOKE AND/OR CLOUDS WHICH COULD ADVERSELY AFFECT THE BURN SEVERITY ANALYSIS*. THIS MAP IS FOR EMERGENCY NATURAL HAZARD ASSESSMENT ONLY AND SHOULD NOT BE USED FOR ANY OTHER PURPOSES.

*"Year-over-Year classification", means that the burn severity mapping was done using satellite scenes approximately (as close to) a year apart to capture similar vegetation and moisture levels.

Data Sources:
Pre-fire scene: Sept 09, 2020; Modified Copernicus Sentinel data [2021]/Sentinel Hub
Post-fire scene: Sept 24, 2021; Modified Copernicus Sentinel data [2021]/Sentinel Hub

Map produced by: JSchafer, 2021
Coor System: NAD 1983 BC Environment Albers

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Tel: 778-765-9525

Figure 1

Appendix C Risk Assessment Methodology

Appendix C - Partial Risk Assessment Methodology

The following describes the risk assessment methodology and provides definitions of the technical terms used. The approach is adopted from, and described in more detail in, Land Management Handbook No. 56 (Wise et al., 2004) and is the recommended approach for post-wildfire risk assessment described in Land Management Handbook No. 69 (Hope et al., 2015).

The term "partial risk" refers to the probability of a specific hazardous event affecting an element at risk. Partial risk analysis differs from a Total Risk analysis as it does not estimate the damages that may occur because of an impact (i.e., vulnerability). Partial risk assumes that any encounter is undesirable.

Partial risk is expressed as:

$$P(HA) = P(H) \times P(S{:}H) \times P(\mathrm{T{:}S})$$

where:

$P(HA)$ is the partial risk;
$P(H)$ is the likelihood of a hazardous event occurring;
$P(S{:}H)$ is the spatial likelihood that the hazardous event will reach the element at risk;
$P(\mathrm{T{:}S})$ is the temporal likelihood that the element at risk will be at the site if the hazard event occurs.

For fixed or stationary structures such as buildings and roads, the temporal probability [P(T:S)] is equal to 1 and the above equation is reduced to:

$$P(HA) = P(H) \times P(S{:}H)$$

Partial Risk = **Hazard** (likelihood of a hazardous event) x **Spatial Likelihood** (likelihood that event reaches and otherwise affects the Element at Risk)

Each component of risk is defined, and the interpretive assessment criteria are described below.

Hazard P(H) – is defined as a process that has the potential to damage, harm, or cause other adverse effects to human health, property, the environment, or other things of value (CSA, 1997). With respect to the post-wildfire risk assessment work, hazards may include **flooding, debris flood, landslides, soil erosion, debris flow, sediment-laden flood, or other natural geological processes**.

For the large fan areas within the study area (i.e., Whiteman, Naswhito, and Equesis Creeks) the predominant hazard being considered is flood and debris flood. Both processes are combined for the assessment.

Hazard levels that pertain to specific hazardous events associated with post-wildfire effects are expressed in qualitative, or relative, terms and according to the criteria defined in the Table C1 below.

Table C1: Hazard Levels (Likelihood of a Post-Wildfire Hazardous Event) and Criteria Defined

Hazard Level P(H)	Qualitative Description	Hazard Criteria
High	An event is very likely to occur or will occur in the near future (within 5 years).	• A large proportion (>40%) of the upslope catchment area is burned and >20% at high burn severity. • Severe burn extends along long lengths of riparian forest. • There is observable evidence of recent or past instability or impact (i.e., 2017/2018 flood events). • There are geomorphic indicators of instability.
Moderate	An event is not likely but possible in the short term (within 5 years).	• Proportion of upslope catchment area burned is less than 40% but greater than 20%, and less than 20% burned at high burn severity. • Limited degree of burn affecting the riparian forest. • There is potentially unstable terrain, characterized as having moderately steep to steep (45->60%) slopes with no observable instability. • Areas show historic geomorphic indicators of instability but have not been directly impacted by recent flood events.
Low	An event is unlikely to occur within the short term.	• A smaller proportion of the upslope catchment is burned (<20%). • There are no geomorphic indicators of instability or impacts by recent past events. • Terrain is generally stable with no observable instability and moderate slopes (<60%)

Spatial Likelihood P(S:H) – is defined as the likelihood that post-wildfire hazardous event reaches and otherwise affects the Element at Risk. For the partial risk assessment there is no estimate of potential damages, only that an encounter is assumed to be undesirable.

Within the large fan areas within the study area (i.e., Whiteman, Naswhito and Equesis Creeks) spatial likelihood is dependent upon the anticipated flows and their associated flood extents. For this assessment, the spatial likelihood levels are based on judgement and interpretation of field indicators. To obtain a more reliable and precise estimate of potential impact requires a quantitative estimate of flood discharge and detailed topographic mapping. Flood inundation mapping would determine depth and velocities associated with a predicted design flow. This quantitative assessment is outside the scope of this study.

Relative levels of spatial likelihood are expressed in qualitative, or relative, terms. These levels as the associated criteria for assigning these levels at a particular site is defined in the Table C2 below.

Table C2: Spatial Likelihood Levels (Likelihood that a Post-Wildfire Event Reaches an Element at Risk) and Criteria Defined

Spatial Likelihood Level	**Description**	**Criteria**
High	The Element at Risk is likely to be impacted or otherwise affected by the hazard, should the hazard occur.	• The Element at Risk is located within the zone of potential runout or zone of impact of the hazard being evaluated. • For flood/debris flood, the site is situated within an area of previous flood impact, or within an area interpreted to be immediately vulnerable based on interpreted process and field indicators of previous events. • Active fan area.
Moderate	The Element at Risk may potentially be impacted or otherwise affects by the hazard, should be hazard occur.	• The Element at Risk is located outside the zone of impact but within an area of potential impact based on topography and process. • This would include the potentially difficult to predict effects of an avulsion event resulting from a debris jam. • Inactive fan area but within zone of avulsion or erosion.
Low	The Element at Risk is unlikely to be affected by the hazard being evaluated.	• The Element at Risk is located at the distal end of the runout zone or outside the zone of influence of the hazard being evaluated. • Inactive fan area.

Elements at Risk – are defined as the population, building or engineering works, utilities, and infrastructure features in the area potentially affected by the hazards being assessed. Environmental features, such as fish and fish habitat and water quality are not considered for this study.

Elements at risk identified within the study area include:

- Residences, structures, dwellings on private property or on OKIB Reserve Lands;
- Community (OKIB) buildings such as fire hall, school, administrative or government offices;
- Infrastructure, utilities, engineering works;
- Transportation routes necessary for emergency access (i.e., Westside Road) and associated bridges/culverts;

OKIB Risk Elements were provided as a kmz file by the OKIB and added to the map deliverables. RDCO Risk Elements were interpreted. The completeness or accuracy of this data cannot be warranted.

Partial risk P(HA) - is defined as the likelihood of a hazardous event, such as a flood, debris flood, debris flow, or landslide event, reaching or otherwise affecting an element at risk, AND causing an impact to that element. Risk may be evaluated quantitatively using probabilities, or, as in the case for this assessment, qualitatively using relative ratings and a risk matrix (see Table C3).

Partial risk assessments are completed for the study area. However, more detailed mapping is completed only for the three large fan areas.

Table C3: Qualitative Risk Matrix for Partial Risk Assessment

<table>
<tr><td colspan="2" rowspan="2">Partial Risk P(HA): the probability that a specific hazard will occur and the probability of it impacting a site occupied by a specific Element at Risk (i.e., P(HA) = P(H) x P(S:H)</td><td colspan="3">P(S:H) – the probability (likelihood) that the specific hazard will reach or otherwise affect the site occupied by an Element at Risk, assuming the event occurs.</td></tr>
<tr><td>High</td><td>Moderate</td><td>Low</td></tr>
<tr><td rowspan="3">P(H) – the annual probability (likelihood) of occurrence of a specific hazard (i.e. landslide, debris flow, sediment-laden flood)</td><td>High</td><td>Very High</td><td>High</td><td>Moderate</td></tr>
<tr><td>Moderate</td><td>High</td><td>Moderate</td><td>Low</td></tr>
<tr><td>Low</td><td>Moderate</td><td>Low</td><td>Very Low</td></tr>
</table>

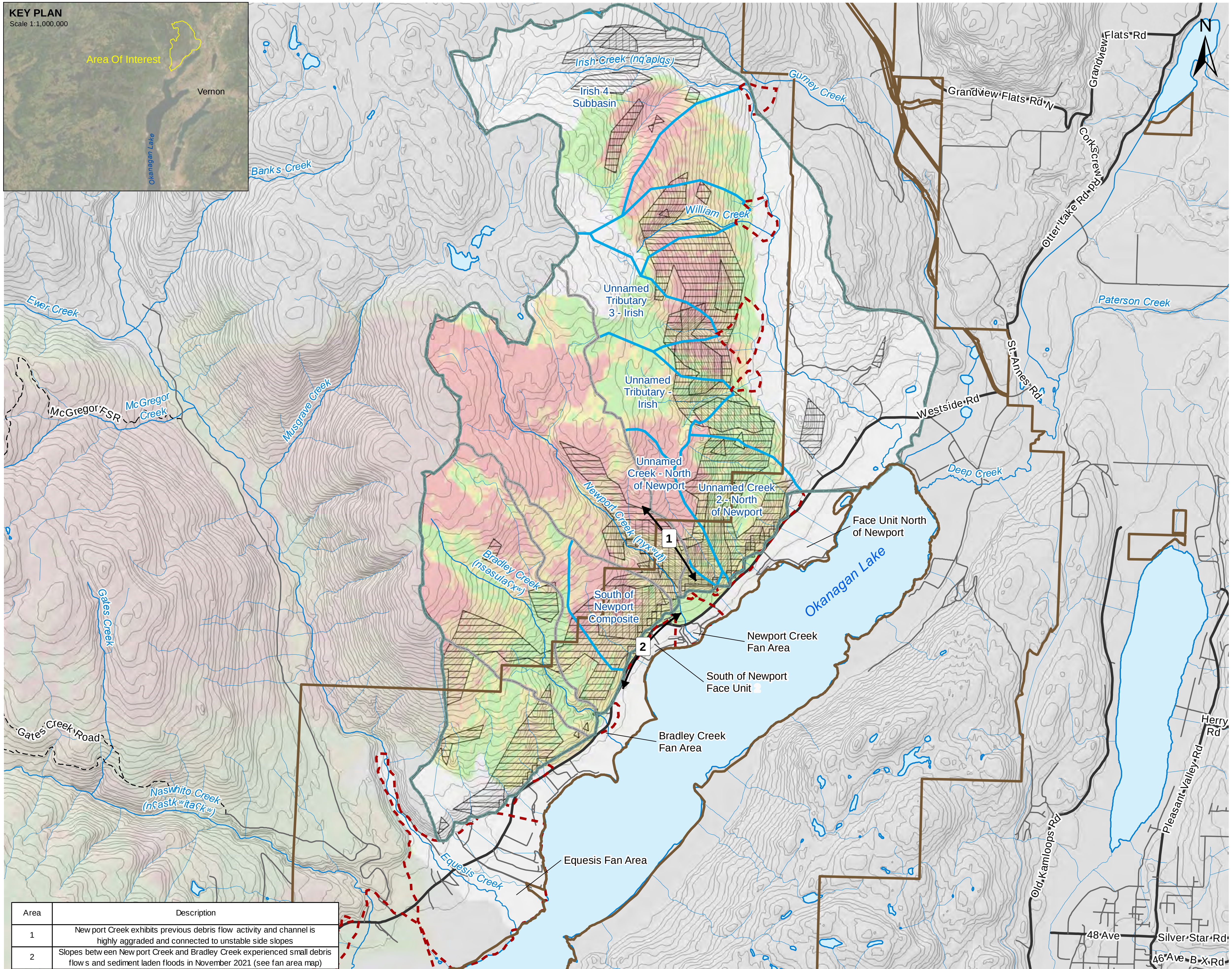
The outcome of the partial risk evaluation, above, is an assigned risk level. Five possible outcomes, or risk levels, are described in Table C4. These risk levels broadly assume some threshold level of acceptability or tolerance. This is completely dependent upon regulatory requirements or the perspective of the end user. Assigned risk levels provide a relative risk rating, which can be used to prioritize sites and each level has associated management implications for risk mitigation that are described in Table A4.

Table C4: Risk Levels Defined

Risk Level	Description	Management Implications
Very High	Risk is unacceptable within the short-term (before next flood season).	Risk reduction is required. A plan to reduce risk should be developed as soon as feasible and implemented prior to the next flood season.
High	Risk is unacceptable within the short to medium-term (3-5 years).	A plan to reduce risk should be developed as soon as feasible and implemented within a reasonable time frame.
Moderate	Risk may be tolerable. More detailed review may be required.	Reduce to low where reasonably practicable
Low	Risk is acceptable and tolerable but there is a remote possibility of effects.	Monitor for changing conditions, as resources permit.
Very Low	Risk is acceptable and tolerable.	No further assessment or risk reduction is required

Appendix D1 to D5 Watershed and Fan Report Cards

Appendix D1 Irish (**nq'aplqs**), Newport (**nyxʷủt**), and Bradley (**nsəsulaʕxʷ**) Creeks (and associated Face Units)



Area	Description
1	Newport Creek exhibits previous debris flow activity and channel is highly aggraded and connected to unstable side slopes
2	Slopes between Newport Creek and Bradley Creek experienced small debris flows and sediment laden floods in November 2021 (see fan area map)

LEGEND

- Watershed Of Interest
- Subbasin Of Interest
- Catchment Area
- Fan Area
- Okanagan Indian Band (OKIB) Reserve Lands Boundary
- Elevation Contour (20m Interval)

Road Type (Source: BC Digital Roads Atlas)

- Arterial
- Local
- Resource

Burn Severity (Source: BC Data Catalogue)

- High
- Medium
- Low
- Unburned
- Unknown

Slope Class (Source: BC Terrain Resource Informaiton Management)

- 0-40%
- 40-60%
- >60%

750 375 0 750 1,500
metres

Client: **MFLNRORD**

Project: **POST WILDFIRE NATURAL HAZARD RISK ASSESSMENT - WHITE ROCK LAKE FIRE (OKANAGAN BASIN)**

Title: **NEWPORT CREEK/BRADLEY CREEK/ IRISH CREEK**

Scale: 1:60,000 NAD 1983 UTM Zone 11 U

Figure No. **D1-1**

Project No: 21-0111 Date: January 13, 2022

Clarke Geoscience Ltd.

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Ministry of Forests Lands and Natural Resource Operations
Post-Wildfire Natural Hazards Risk Assessment

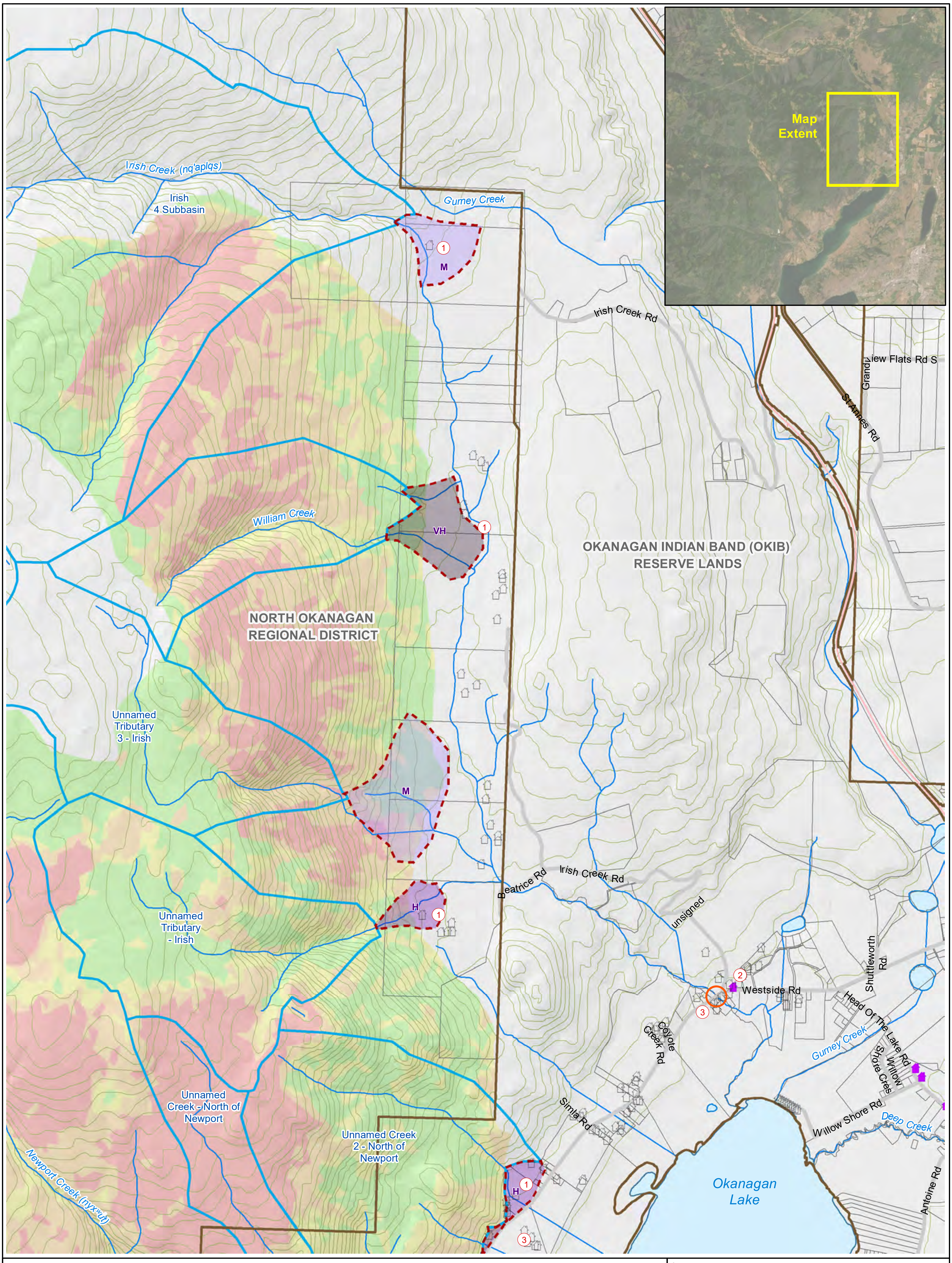
IRISH CREEK WATERSHED REPORT CARD

		% Burned	% High Burn Severity	Peak Flow Hazard	Melton Ratio	Dominant Process
Watershed Area (sq km):	64.3	48	21	High	0.12	Flood
Williams Ck subbasin (sq km):	1.8	79	27	High	0.46	Debris Flood
Unnamed Trib 1 subbasin (sq km):	2.4	55	16	Moderate	0.4	Debris Flood
Unnamed Trib 3 subbasin (sq km)	2.3	25	8	Low	0.38	Debris Flood
Unnamed Trib 4 subbasin (sq km)	8.4	16	10	Low	0.23	Debris Flood

General Watershed /Subbasin Conditions:	The portion of Irish Creek watershed affected by the White Rock Lake wildfire includes the moderately-sloped east-facing slopes. These slopes include several gullied catchments. Rural agricultural properties within the jurisdiction of the North Okanagan Regional District occupy the fan slopes at the outlet of these gullies. The low gradient mainstem stream channel flows through broad valley bottom before reaching OKIB Reserve Lands and Westside Road. The channel is meandering with no developed alluvial fan at Okanagan Lake.
Terrain Conditions:	The gullies and slopes do not appear to be active or unstable but the area was heavily burned - this was apparently the result of a back burn used to control spread of the larger wildfire. The gully catchments have a Melton Ratio 0.3-0.5 indicating that catchments may be subject to a combination of debris flood and debris flow, depending on channel and sediment input conditions.
Mainstem Stream Channel/Riparian Conditions:	Wildfire affected lengths of the tributary streams but not the mainstem channel of Irish Creek. This is likely to be sediment-related impacts on the steeper tributary channels but not on the mainstem channel of Irish Creek.
Post-Wildfire Hazards:	There is a post-wildfire debris flood and debris flow hazard on two gullied tributaries above Irish Creek and levels of burn indicate a potential for hydrologic (peak flow) hazards on the mainstem Irish Creek. Downstream reaches of Irish Creek flow through the Okanagan Indian Band Reserve Lands and cross Westside Road.

	Element at Risk					
	Rural properties on the Unnamed Trib 1 fan area (RDNO)	Rural properties on the Unnamed Trib 3 fan area (RDNO)	Rural properties on the William Ck fan area (RDNO)	Rural properties on the Unnamed Trib 4 fan area (RDNO)	OKIB Band Administration Office	Westside Road Crossing
Map Reference	1	1	1	1	2	3
Hazard	**Hazard Level - Likelihood of Event P(H)**					
Flood / Debris Flood	Moderate	Low	High	Low	Moderate	High
Debris Flow	Moderate	Low	Moderate	Low	Low	Low
	Spatial Likelihood of Impact P(S:H)					
Flood / Debris Flood	High	High	High	High	Moderate	High
Debris Flow	Moderate	Low	Moderate	Low	Low	Low
	Partial Risk P(HA) = P(H) x P(S:H)					
Flood / Debris Flood	H	M	VH	M	M	VH
Debris Flow	M	VL	M	VL	VL	VL

Notes:
Watershed area is measured as the area upstream of the fan apex.



LEGEND

- Fan Area
- Catchment Area
- Okanagan Indian Band (OKIB) Reserve Lands Boundary
- Property Parcel
- Structure
- OKIB Risk Element
- Element at Risk – Map Reference # (refer to Report Cards)
- Major Stream Crossing (Westside Road)

Burn Severity (Source: BC Data Catalogue)

- High
- Medium
- Low
- Unburned
- Unknown

Post-Wildfire Natural Hazard Risk Assessment

- VH Very High
- H High
- M Moderate
- L Low

N

250 125 0 250 500
metres

Client: **MFLNRORD**

Project: **POST WILDFIRE NATURAL HAZARD RISK ASSESSMENT - WHITE ROCK LAKE FIRE (OKANAGAN BASIN)**

Title: **IRISH CREEK SUB-BASINS - FAN AREAS**

Scale: 1:25,000 NAD 1983 UTM Zone 11 U

Figure No. **D1-2**

Project No: 21-0111 Date: January 13, 2022

Clarke Geoscience Ltd.

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Ministry of Forests Lands and Natural Resource Operations
Post-Wildfire Natural Hazards Risk Assessment

FACE UNIT NORTH OF NEWPORT AREA REPORT CARD

		% Burned	% High Burn Severity	Peak Flow Hazard
Unnamed Ck N of Newport (sq km)	1.1	98	68	High
Unnamed Ck2 N of Newport (sq km)	2.8	59	11	Moderate

Melton Ratio	Dominant Process
0.71	Debris Flow
0.37	Debris Flood

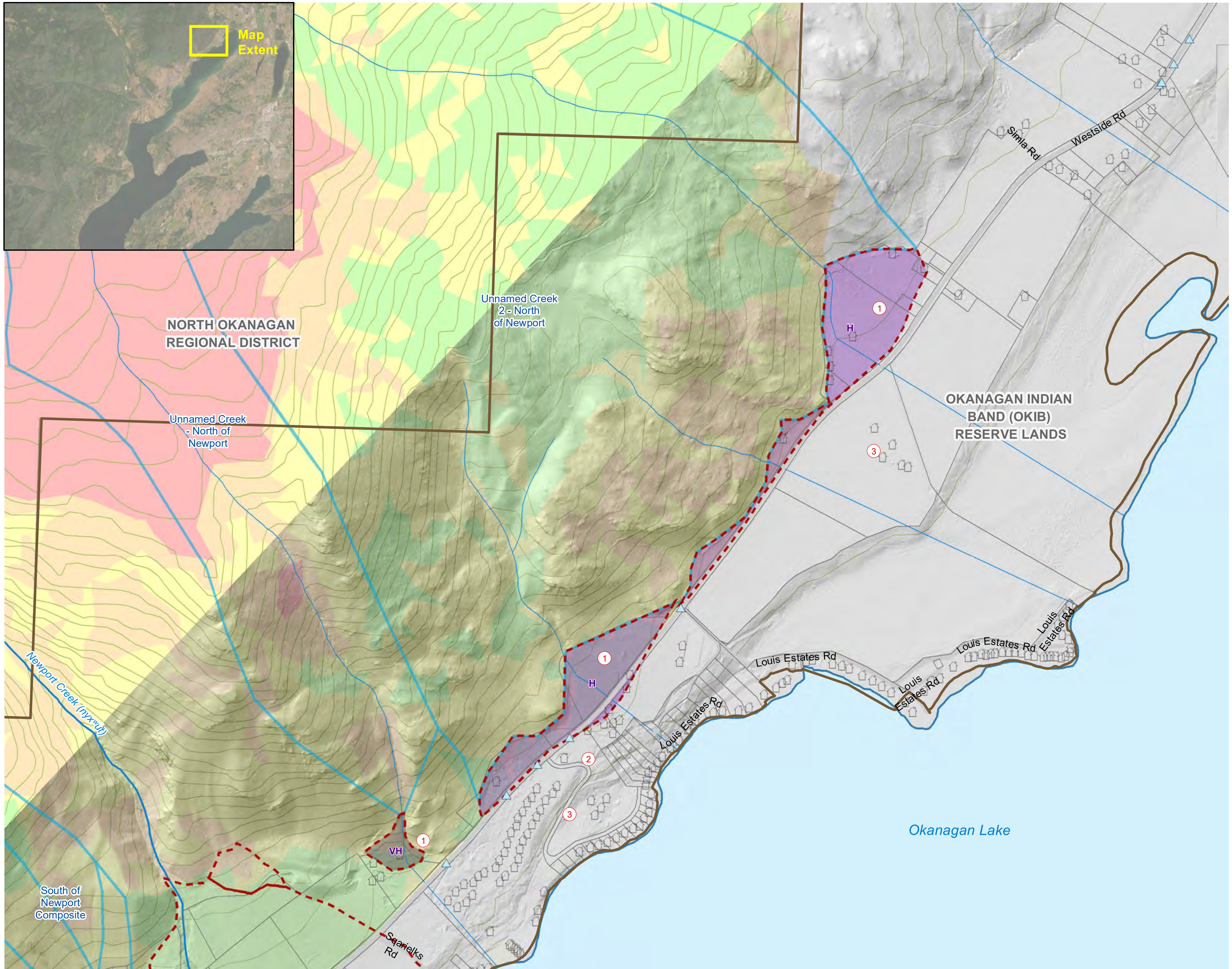
General Watershed /Subbasin Conditions:	This face unit area has several unnamed seasonal water courses and the area has several gullies (two catchment areas are delineated on map). The area was extensively (60-100%) burned, and one of the small subbasin catchments burned at a high burn severity. The downslope fan area is characterized as a colluvial apron spread along the toe of the slope. Field observations at Unnamed Ck N of Newport indicate no recent instability in the gullied channel but there are some boulders on the upper part of the small fan indicating potential for debris flow. This catchment has a Melton Ratio >0.7 indicating potential for debris flow.
Terrain Conditions:	Slopes above the fan area are moderately steep with strong bedrock control. No terrain stability information is available.
Mainstem Stream Channel/Riparian Conditions:	The stream channels within the face unit are seasonal, with poorly-defined channels. Stream channel process is dominated by rockfall and small-scale landslide activity.
Post-Wildfire Hazards:	The post-wildfire peak flow hazard is high for the Unnamed Ck N of Newport catchment area and moderate for the other face unit. There is moderate to high likelihood of sediment-laden flooding and small-scale debris flow activity along the face unit slopes.

	Element at Risk			
	Properties (OKIB) on composite fan of Unnamed Ck 2	Properties (OKIB) on composite fan of Unnamed Ck	Westside Road	Properties (OKIB) downslope of Westside Road
Map Reference	1	1	2	3
Hazard	**Hazard Level -**			
Flood / Debris Flood	Moderate	High	Moderate	Moderate
Debris Flow	Moderate	High	Low	Low
Landslide/Rockfall	Low	Low	Low	Low

	Spatial Likelihood of Impact P(S:H)			
Flood / Debris Flood	High	High	High	Varies
Debris Flow	Moderate	Moderate	Low	Low
Landslide/Rockfall	Low	Low	Low	Low

	Partial Risk P(HA) = P(H) x P(S:H)			
Flood / Debris Flood	H	VH	H	Varies
Debris Flow	H	H	VL	VL
Landslide/Rockfall	VL	VL	VL	VL

Notes:
Watershed area is measured as the area upstream of the fan apex.



LEGEND

- Fan Area
- Catchment Area
- Okanagan Indian Band (OKIB) Reserve Lands Boundary
- Property Parcel
- Structure
- OKIB Risk Element
- Element at Risk – Map Reference # (refer to Report Cards)
- Major Stream Crossing (Westside Road)
- Culvert (MOTI)

Burn Severity (Source: BC Data Catalogue)

- High
- Medium
- Low
- Unburned
- Unknown

Post-Wildfire Natural Hazard Risk Assessment

- VH Very High
- H High
- M Moderate
- L Low

N

100 50 0 100 200 metres

Client: **MFLNRORD**

Project: **POST WILDFIRE NATURAL HAZARD RISK ASSESSMENT - WHITE ROCK LAKE FIRE (OKANAGAN BASIN)**

Title: **NEWPORT CREEK AND AREAS NORTH - FAN AREAS**

Scale: 1:10,000	NAD 1983 UTM Zone 11 U	Figure No. D1-3
Project No: 21-0111	Date: January 13, 2022	

Clarke Geoscience Ltd.

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Ministry of Forests Lands and Natural Resource Operations
Post-Wildfire Natural Hazards Risk Assessment

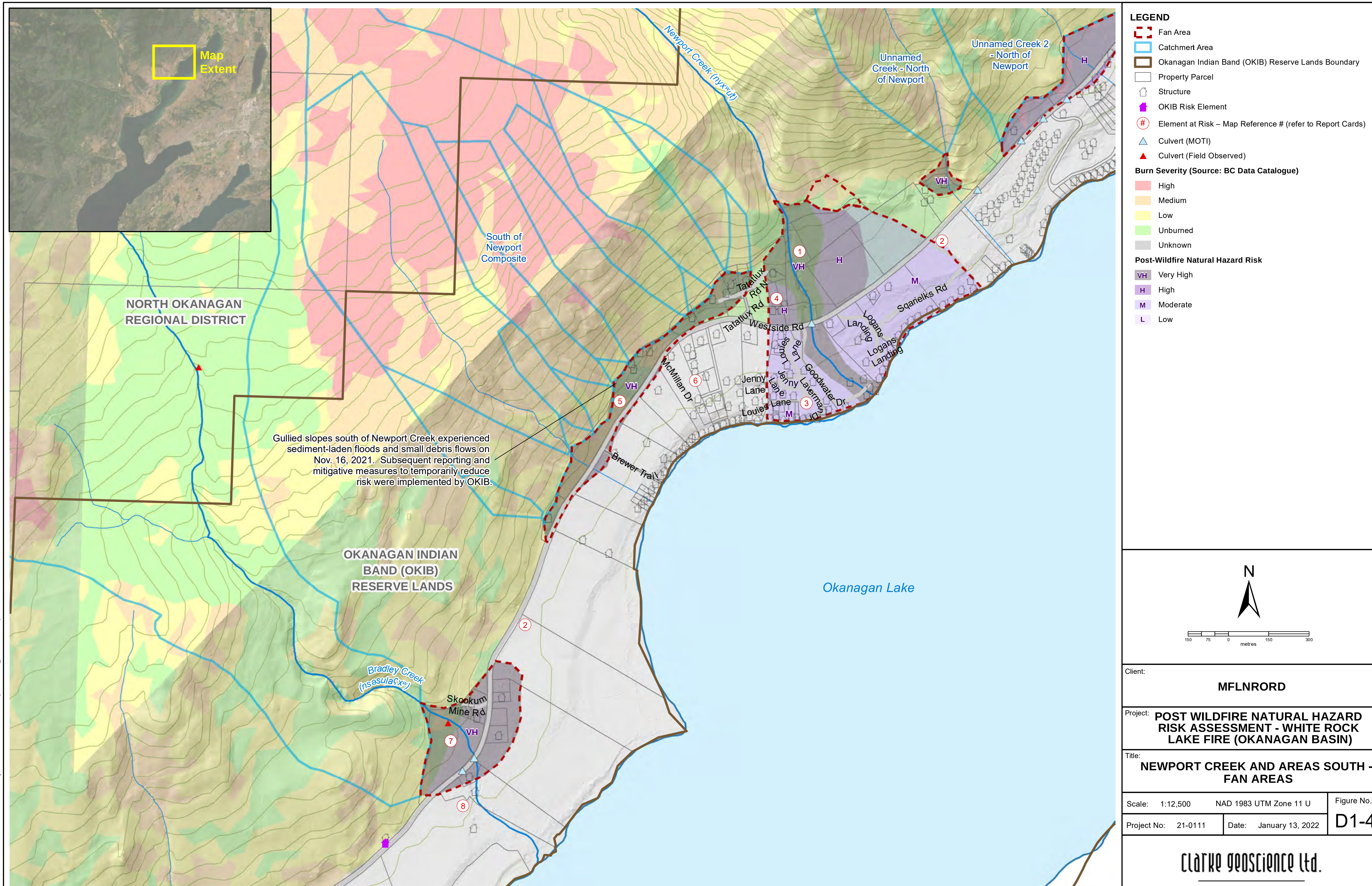
NEWPORT CREEK WATERSHED REPORT CARD

		% Burned	% High Burn Severity	Peak Flow Hazard	Melton Ratio	Dominant Process
Watershed Area (sq km):	9.5	91	60	High	0.32	Debris Flood

General Watershed /Subbasin Conditions:	The upper part of the watershed is located on the plateau but the channel becomes incised within a steep catchment with unstable side slopes. The tightly confined channel is highly aggraded with evidence of large-scale sediment transport activity within the canyon reach. There are water intake structures within the channel that extend down to the fan. The license is active but the structures appear to be in disrepair. The fan apex is traversed by a trail and fireguard and there is a potential for channel avulsion along the right bank.
Terrain Conditions:	The valley sideslopes are steep and classified and potentially unstable and unstable. There is observed instability on slopes that are directly connected to the stream channel and a high volume of sediment (and woody debris) available for downstream transport.
Mainstem Stream Channel/Riparian Conditions:	Downstream of the fan apex the mainstem channel becomes fairly well incised before reaching Westside Road. Heavy aggradation of sediment within the channel results in a seasonally dry channel during most months. However, historic peak flows in 2017-2018 have blocked the arch culvert crossing at Westside Road. Westside Road limits sediment transport to downstream reaches of Newport Creek but elevated peak flows have the potential to impact properties adjacent to the channel.
Post-Wildfire Hazards:	Post-wildfire hazards on Newport Creek include peak flow, sediment bulking, debris flood and debris flow. There is a history of large-scale instability within the canyon above the fan and the presence of large (2 m) boulders on the fan indicates there is potential for destructive events. Short-term mitigation measures (lock block barrier) were installed in November 2021 to reduce potential for avulsion. Sediment transport in the channel has led to previous blockages at the Westside Road culvert. This crossing is anticipated to have capacity issues for the upcoming freshet.

	Element at Risk			
	Property on the fan upslope of Westside Road	Westside Road	Property on the fan downslope of Westside Road	Domestic/Irrigation Water License
Map Reference	1	2	3	4
Hazard	**Hazard Level - Likelihood of Event P(H)**			
Flood / Debris Flood	High	Moderate	High	High
Debris Flow	High	High	Low	High
	Spatial Likelihood of Impact P(S:H)			
Flood / Debris Flood	High	High	Moderate to High	High
Debris Flow	Moderate to High	Moderate	Moderate	High
	Partial Risk P(HA) = P(H) x P(S:H)			
Flood / Debris Flood	VH	H	H to VH	VH
Debris Flow	H to VH	H	M	VH

Notes:
Watershed area is measured as the area upstream of the fan apex.



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Ministry of Forests Lands and Natural Resource Operations
Post-Wildfire Natural Hazards Risk Assessment

FACE UNIT SOUTH OF NEWPORT CREEK AREA REPORT CARD

		% Burned	% High Burn Severity	Peak Flow Hazard
Face Unit Area (sq km):	1.9	98	40	High

General Watershed /Subbasin Conditions:	The face unit is located between Newport Creek and Bradley Creek. Slopes are moderately steep to steep (slope gradients vary from 40 to 70%) and are dissected by several shallow ephemeral gullies developed within till deposits mantling bedrock. Bedrock exposures along the upper slopes are comprised of dark-grey argillite, phyllite, with minor quartzite of the Slocan Group . The rock outcrops have been subject to intense heat and thermal expansion from the recent wildfire, and were observed to be highly fractured and loose. Loose bedrock colluvium has already mobilized along some of the small gullies and remains an abundant source of material for future transport. Soils were observed to be silty sand to sandy silt textured till deposits with abundant coarse fragments. Burned soils within the affected area were observed to have strong water repellent character and loss of structure. An emergency assessment of unstable gullies was completed by Clarke Geoscience Ltd. and by Stantec Consulting Ltd. during the post-wildfire debris flow activity in November 2021 and mitigation measures were implemented to protect properties located within the fan area upslope of Westside Road.
Terrain Conditions:	Potentially unstable and unstable slopes were burned at high severity and water repellent soils were observed. A high degree of post-wildifre instability was observed.
Mainstem Stream Channel/Riparian Conditions:	There are no stream channels within the face unit. The face unit is dissected by shallow gullies that are subject to seasonal runoff.
Post-Wildfire Hazards:	There is a high likelihood is ongoing post-wildfire natural hazards within the face unit. Hazards include sediment-laden flooding and small-scale debris flow. The presence of larger boulders along the upper part of the fan area suggests there is potential for large-scale debris flow activity. Short-term mitigation measures (ditches and berms) were installed in November 2021 to reduce potential for impact to properties.

	Element at Risk		
	Property upslope of Westside Road within the composite fan area	Westside Road	Property downslope of Westside Road
Map Reference	5	2	6
Hazard	**Hazard Level - Likelihood of Event P(H)**		
Flood / Debris Flood	High	Moderate	Moderate
Debris Flow	High	Low	Low
Landslide/Rockfall	Moderate	Low	Low

	Spatial Likelihood of Impact P(S:H)		
Flood / Debris Flood	High	High	Moderate
Debris Flow	Moderate	Low	Low
Landslide/Rockfall	Moderate	Low	Low

	Partial Risk P(HA) = P(H) x P(S:H)		
Flood / Debris Flood	VH	H	M
Debris Flow	H	VL	VL
Landslide/Rockfall	M	VL	VL

Notes:
Watershed area is measured as the area upstream of the fan apex.

Ministry of Forests Lands and Natural Resource Operations
Post-Wildfire Natural Hazards Risk Assessment

BRADLEY CREEK WATERSHED REPORT CARD

		% Burned	% High Burn Severity	Peak Flow Hazard	Melton Ratio	Dominant Process
Watershed Area (sq km):	6.5	71	33	High	0.36	Debris flood

General Watershed /Subbasin Conditions:	This watershed is on a west-facing open slope characterized by open stand forest, dry grassland, with sinous incised stream channels in shallow gullies. Although high percentage is burned, the effect on hydrology will not likely be as high as if the watershed had been completely forested.
Terrain Conditions:	Slopes are relatively stable, characterized as a thin veneer of till over bedrock. Gullies are incised with minor sideslope instability.
Mainstem Stream Channel/Riparian Conditions:	The riparian forest burned at moderate to low severity and mainly affected higher elevation channels. The channel normally has very low flows and does not often reach the culvert at Westside Road.
Post-Wildfire Hazards:	Due to the extent of the watershed area burned there is a potential for peak flow increases. There is a potential avulsion hazard at the top of the fan, above Westside Road. Normally the channel would not cause a problem but with potentially higher streamflows, there is a hazard for property on the upper fan area.

	Element at Risk		
	Property on fan above Westside Road	Westside Road	Property downslope of Westside Road beyond fan
Map Reference	7	2	8
Hazard	Hazard Level - Likelihood of Event P(H)		
Flood / Debris Flood	High	High	High
Debris Flow	Low	Low	Low
Landslide/Rockfall	Low	Low	Low

	Spatial Likelihood of Impact P(S:H)		
Flood / Debris Flood	High	Moderate	Low
Debris Flow	Low	Low	Low
Landslide/Rockfall	Low	Low	Low

	Partial Risk P(HA) = P(H) x P(S:H)		
Flood / Debris Flood	VH	H	M
Debris Flow	VL	VL	VL
Landslide/Rockfall	VL	VL	VL

Notes:
Watershed area is measured as the area upstream of the fan apex.

Summary of Risk Mitigation Recommendations and Estimated Costs - For Newport Creek and Other Debris Flow Catchments

For: Newport Creek (and other high-risk catchments subject to debris flow – i.e. Irish Creek Tributaries)		
Action (IMPORTANT AND URGENT– prior to 2022 freshet)	**Description**	**Assumptions and Estimated Cost**
Public awareness	Conduct public information meetings, develop a public information bulletin on recognizing hazard situations and how to respond. Provide emergency response information (egress routes, warnings, evacuation instructions). Install large warming signs on roads and at bridges.	Internal communication practices and procedures for each jurisdiction – involve the EOC, FNESS for example.
Protect Westside Road stream crossings (Irish, Newport and Bradley Creek)	Increase frequency of inspection and monitoring along Westside Road. Have equipment on standby throughout freshet to clear debris and sediment at crossing to ensure no blockage (mid-April to end of June, depending on snowpack and weather conditions).	Excavator on standby rates (responsibility of MOTI roads contractor - AIM)
Action (IMPORTANT BUT NOT URGENT– longer term)	**Description**	**Assumptions and Estimated Cost**
Debris flow assessment	Conduct debris flow assessment including field investigation and to determine potential debris volume, peak discharge, velocity. Assessment will refine risk assessment and obtain design parameters for mitigation.	Est. $20,000 to $40,000 per watershed.
Upgrade debris flow mitigation structures and downstream crossings, incl. Westside Road.	Based on results of the assessment, mitigation measures may need to be upgraded. Based on results of the debris flow assessment, upgrade stream crossing with larger structure and/or debris basin. Preliminary designs for crossing upgrades on other creeks, as warranted.	For Newport Creek, assume use of existing concrete lock blocks. Engineering assessment and construction est. $20,000. Replacement cost at Westside Rd will depend on new crossing design.

Summary of Risk Mitigation Recommendations and Estimated Costs for High-Risk Face Unit Areas

For: High Risk Areas Subject to Sediment-Laden Flooding and Debris Flow (Face Unit Areas North and South of Newport Creek, South of Naswhito Creek and area within Killiney Beach Area)		
Action (IMPORTANT AND URGENT – prior to 2022 freshet)	**Description**	**Assumptions and Estimated Cost**
Public awareness	Recommend that property owners prepare for unusually high runoff in the spring (along water courses and within zones of groundwater emergence. Conduct public information meetings, develop a public information bulletin on recognizing hazard situations and how to respond. Provide emergency response information (egress routes, warnings, evacuation instructions). Install large warming signs on roads and at bridges.	Communication responsibility for each jurisdiction.
Inspect ditches and culverts to ensure clear passage for increased flows	Prior to spring freshet, inspect ditches and culverts to ensure they are clear of sediment and debris.	Responsibility for property owner on private lands and MOTI (road maintenance contractor) on public roadways.
Protect assets	Identify elements at greatest risk and protect by relocation or physical protection (ditching, berms, barriers). Further assessment may be required. Identify material sources and stockpile prior to freshet.	Cost depends on what needs to be protected and how it is protected.
Action (IMPORTANT BUT NOT URGENT – longer term)	**Description**	**Assumptions and Estimated Cost**
Reduce potential for soil erosion	Implement measures to reduce potential for soil erosion (each have pros and cons): • Straw mulch • Wood mulch • Seeding	Estimated costs per ha (adjusted from Ecological Restoration Institute, 2021): • Straw mulch ($480/ha) • Wood mulch ($720/ha) • Seeding ($50/ha)
Reduce potential for sediment transport on gullies or stream channels	Implement measures to reduce potential for sediment transport (site-specific): • Check dams or weirs • Trash racks or catch basins • Channel clearing	Costs vary depending on treatment and site conditions. Channel clearing is the least expensive option.
Further assessment of upstream channels to refine mapping.	More detailed site assessment included ground-based traverse of stream channels upstream of the developed area to review instability, blockages, etc.	Cost depends on site and extent of study.
Further assessment of stream channels flowing through developed area.	More detailed site assessment to further characterize connectivity with upstream channels and identify opportunities to restore nature drainage patterns.	Cost depends on site and extent of study.

APPENDIX D1 – PHOTOS

Photo 1: Slopes just south of Bradley Creek, note open grassland with gullied slopes

Photo 2: Slopes on Face Unit between Bradley and Newport Creek, unstable gullies

Photo 3: Burned headwater area above South of Newport Creek face unit area with unstable gullies

Photo 5: Newport Creek Fan

Photo 6: Steep middle reaches of Newport Creek

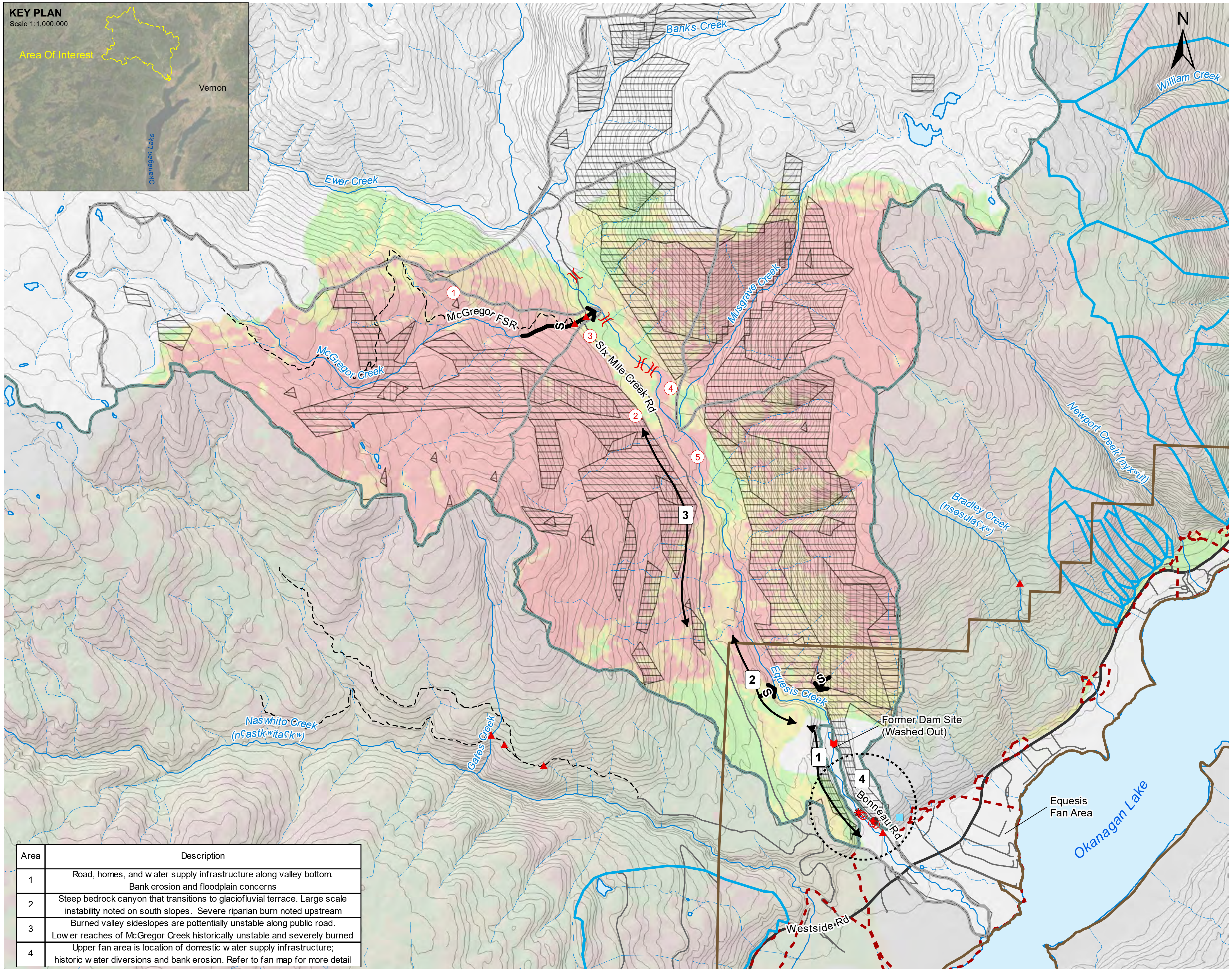
Photo 7: Headwater reaches of Newport Creek

Photo 8: View of burned subbasin side slopes in Irish Creek watershed

Photo 7: Boulders on upper fan of Newport Creek

Photo 8: Newport Creek at Westside Road

Appendix D2 Equesis (**snƛ̓´xʷxʷtan**) (aka Six Mile) Creek Watershed and Fan Area



Area	Description
1	Road, homes, and w ater supply infrastructure along valley bottom. Bank erosion and floodplain concerns
2	Steep bedrock canyon that transitions to glaciofluvial terrace. Large scale instability noted on south slopes. Severe riparian burn noted upstream
3	Burned valley sideslopes are potentially unstable along public road. Low er reaches of McGregor Creek historically unstable and severely burned
4	Upper fan area is location of domestic w ater supply infrastructure; historic w ater diversions and bank erosion. Refer to fan map for more detail

LEGEND

- Watershed of Interest
- Subbasin Of Interest
- Catchment Area
- Fan Area
- Okanagan Indian Band (OKIB) Reserve Lands Boundary
- Elevation Contour (20m Interval)
- Observed Landslide Or Debris Flow Channel
- Element at Risk – Map Reference # (refer to Report Cards)
- Blocked Inlet
- Bridge
- Chlorination Plant
- Culvert
- Dam
- Reservoir
- Well

Road Type (Source: BC Digital Roads Atlas)

- Arterial
- Local
- Resource

Burn Severity (Source: BC Data Catalogue)

- High
- Medium
- Low
- Unburned
- Unknown

Slope Class (Source: BC Terrain Resource Informaiton Management)

- 0-40%
- 40-60%
- >60%

600 300 0 600 1,200
metres

Client:

MFLNRORD

Project: **POST WILDFIRE NATURAL HAZARD RISK ASSESSMENT - WHITE ROCK LAKE FIRE (OKANAGAN BASIN)**

Title:

EQUESIS CREEK WATERSHED

Scale: 1:50,000	NAD 1983 UTM Zone 11 U		Figure No.
Project No: 21-0111	Date: January 13, 2022		D2-1

Clarke Geoscience Ltd.

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Ministry of Forests Lands and Natural Resource Operations
Post-Wildfire Natural Hazards Risk Assessment

EQUESIS (6 MILE) CREEK WATERSHED REPORT CARD

		% Burned
Watershed Area (sq km):	203.5	20.4
Musgrave Ck subbasin (sq km):	19.4	34.9
McGregor Ck subbasin (sq km):	14.6	73.8

High Burn Severity (%)	14.5
Mod & High Burn Severity in Snow Zone (above 1300m elev) (%)	1.7
Moderate Burn Severity (%)	4.2
Low Burn Severity (%)	1.7

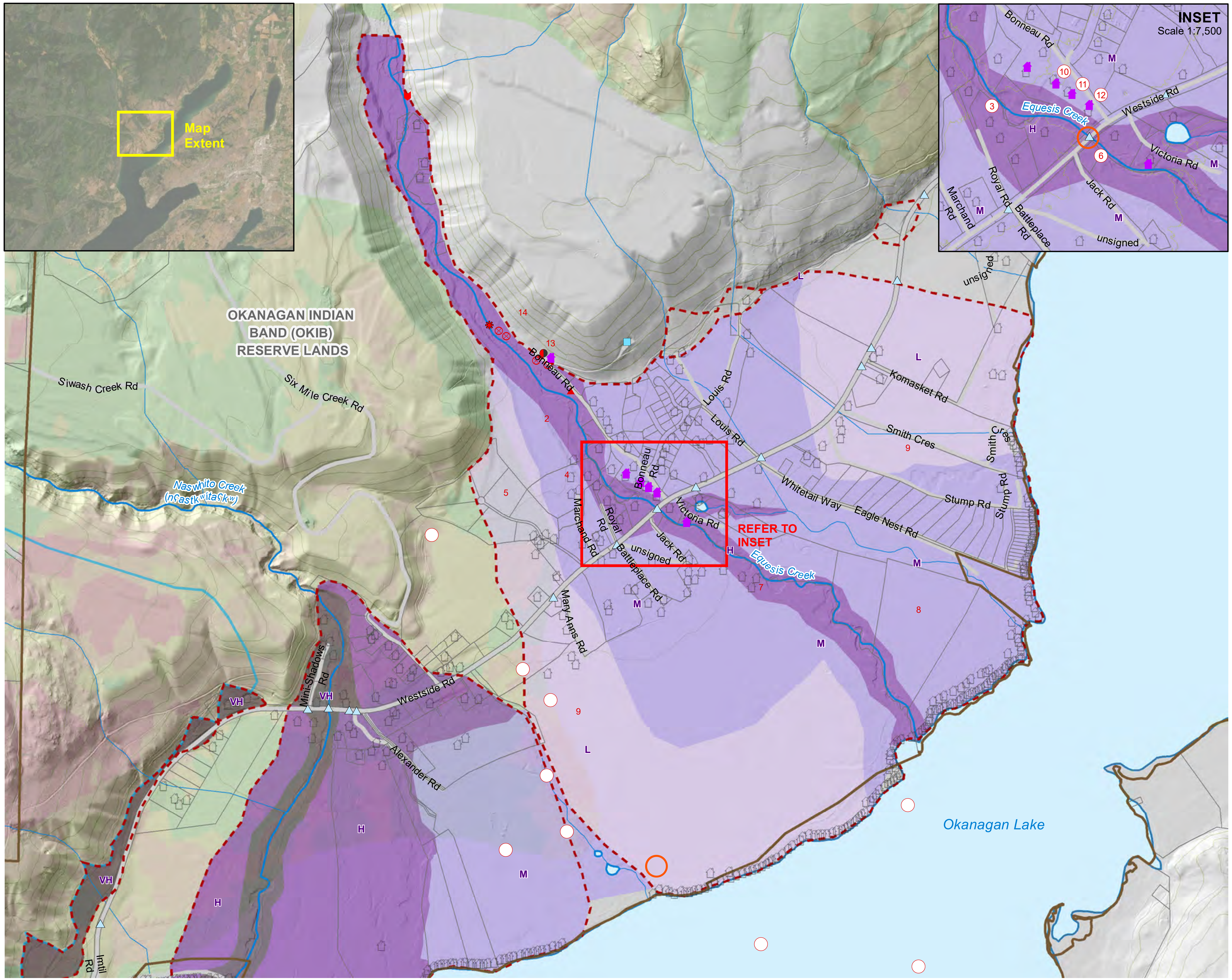
General Watershed /Subbasin Conditions:	Wildfire affected the lower half of the watershed only, resulting in a lower total area affected (20%) and very little of the high elevation watershed was burned. However, of the lower half of the watershed, approximately 60% was burned and 40% at high burn severity. McGregor Creek subbasin was extensively burned (74%) with 65% at high burn severity. Equesis Creek watershed has a wide mid-watershed floodplain area that is not well connected to the valley sideslopes. The creek becomes incised and tightly constrained within a canyon reach before exiting onto a large alluvial fan and into Okanagan Lake.
Terrain Conditions:	Burned areas include steep sideslopes within the tributary subbasins. Mainstem valley sideslopes are not directly connected to the mainstem channel until the lower canyon reach. Approximately 20% of the watershed burned at a moderate to high severity and is also classified as having slopes >40% in gradient (i.e., potentially unstable or unstable) (39 sq km).
Mainstem Stream Channel/Riparian Conditions:	Stream reaches above Ewer Creek (~700m elevation) and the plateau reaches, including Pineus Lake, were not burned. Almost the entire length of McGregor Creek stream channel burned at moderate or high severity. 4.6 km of the mainstem channel located within the broad mid-valley floodplain was burned at moderate or high burn severity. Within the burned area, a large pre-existing landslide was observed within the confined reach above the fan. Through this mid-watershed burned reach there is high potential for sediment transport and debris jams. This creates a potential hazard for the fan area, which is located a short distance downstream.
Post-Wildfire Hazards:	Moderate peak flow hazard (due to lack of wildfire in headwater areas) and moderate sediment bulking potential. Bulking will most likely arise from tributary subbasin(s) and channel sediment sources (bed and bank erosion). McGregor Creek subbasin has high potential for peak flow increases and sedimentation. Although overall watershed hazards may be moderate, there is a high potential for sediment transport in the canyon reach just upstream of the fan.

	Element at Risk				
	McGregor FSR	Six Mile Creek Road	Culvert on McGregor Ck on Six Mile Rd	Private bridges in middle watershed	Private property in mid-valley
Map Reference	1	2	3	4	5
Hazard	Hazard Level - Likelihood of Event P(H)				
Flood / Debris Flood	High	Varies	High	Moderate	Moderate
Debris Flow	Low	Varies	Moderate	Low	Moderate
Landslide/Rockfall	Low	Varies	Low	Low	Low

	Spatial Likelihood of Impact P(S:H)				
Flood / Debris Flood	Varies	Low	High	High	Varies (M-H)
Debris Flow	Low	Varies	High	Low	Varies (L-H)
Landslide/Rockfall	Low	Varies	Low	Low	Low

	Partial Risk P(HA) = P(H) x P(S:H)				
Flood / Debris Flood	Varies	M	VH	H	M to H
Debris Flow	VL	Varies	H	VL	VL to H
Landslide/Rockfall	VL	Varies	VL	VL	VL to H

Notes:
Watershed area is measured as the area upstream of the fan apex.



LEGEND

- Fan Area
- Catchment Area
- Okanagan Indian Band (OKIB) Reserve Lands Boundary
- Property Parcel
- Structure
- OKIB Risk Element
- Element at Risk – Map Reference # (refer to Report Cards)
- Major Stream Crossing (Westside Road)
- Culvert (MOTI)
- Culvert (Field Observed)
- Blocked Inlet
- Chlorination Plant
- Dam
- Reservoir
- Well

Burn Severity (Source: BC Data Catalogue)

- High
- Medium
- Low
- Unburned
- Unknown

Post-Wildfire Natural Hazard Risk Assessment

- VH Very High
- H High
- M Moderate
- L Low

N

150 75 0 150 300 metres

Client: MFLNRORD

Project: POST WILDFIRE NATURAL HAZARD RISK ASSESSMENT - WHITE ROCK LAKE FIRE (OKANAGAN BASIN)

Title: EQUESIS CREEK - FAN AREA

Scale: 1:15,000 NAD 1983 UTM Zone 11 U

Figure No. D2-2

Project No: 21-0111 Date: January 13, 2022

Clarke Geoscience Ltd.

Ministry of Forests Lands and Natural Resource Operations
Post-Wildfire Natural Hazards Risk Assessment

EQUESIS (6 MILE) CREEK FAN REPORT CARD

Upstream watershed area (sq km):	203.5
Fan Area (sq km):	4.1
Fan Gradient (avg %):	2%

Total Area Burned (%):	20.4
High Burn Severity (%)	14.5
Mod & High Burn Severity in Snow Zone (%)	1.7
Moderate Burn Severity (%)	4.2
Low Burn Severity (%)	1.7
Length of Mainstem Channel in Mod & High Burn (km):	4.6

No. of structures (residences) on the fan area:	265
Length of Westside Road on the fan area:	2.13 km
Length of Westside Road at H to VH Risk:	1.06 km

General Fan Conditions:	The Equesis Creek Fan area is large and generally flat (<5% slope). Equesis Creek is a single meandering channel that is fairly well confined above Westside Road, which traverses across the upper third of the fan. The channel becomes unconfined and more sinuous and meandering downstream of Westside Road. Here the floodplain bank materials are loose, unconsolidated and easily eroded. The fan area is highly developed with ~265 identified structures, including sensitive and critical OKIB buildings and infrastructure.
2017/2018 Impacts:	High spring freshet flows impacted areas along the creek in 2017 & 2018. Upstream of the fan area, past impacts included bank erosion (loss of access road and loss of property along left bank) and inundation. A concrete water diversion dam (upstream of Westside Rd) was fully washed out by the end of 2018. Downstream of Westside Road, the channel experienced bank erosion (in one location the bank eroded ~60m), and a build up of alluvial sediment at the mouth led to localized flooding (the mouth area was excavated in 2017 and filled again in 2018) (Stantec, 2018)

	Element at Risk													
	Property (OKIB) in canyon reach upslope of fan apex	Irrigation Diversion Structures (2)	Property (OKIB) upslope of Westside Road and near channel	Property (OKIB) upslope of Westside Rd away from channel	Property (OKIB) upslope of Westside Rd above right bank, away from channel	MOTI Culvert at Westside Road	Property (OKIB) downslope of Westside Road along channel	Property (OKIB) downslope of Westside Rd and away from channel	Property (OKIB) downslope of Westside Road at distal end of fan	Territorial Stewardship Office	OKIB Fire Hall	OKIB School	Water Treatment Facility	Water Wells
Map Reference	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Hazard	Hazard Level - Likelihood of Event P(H)													
Flood/Debris Flood	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
	Spatial Likelihood of Impact P(S:H)													
Flood/Debris Flood	High	High	High	Moderate	Low	High	High	Moderate	Low	Moderate	Moderate	Moderate	High	High
	Partial Risk P(HA) = P(H) x P(S:H)													
Flood/Debris Flood	H	H	H	M	L	H	H	M	L	M	M	M	H	H

Summary of Risk Mitigation Recommendations and Estimated Costs for Large Fan Areas

For: Large Fan Areas (Whiteman, Naswhito, Equesis)		
Action (URGENT AND IMPORTANT – prior to 2022 freshet)	**Description**	**Assumptions and Estimated Cost**
Monitor snow and weather conditions and develop an early warning system for flooding	Monitor snowpack at Silver Star Station, precipitation at Vernon Station, and stream flows on Whiteman Creek. Develop a warning system (decision matrix) that comprises criteria for flood alerts (snowpack, spring temperature, rainfall thresholds). This will inform flood response measures.	Assumes use of existing data and reliance on River Forecast Centre forecasting. Est. $10,000 to $15,000.
Public awareness	Conduct public information meetings, develop a public information bulletin on recognizing hazard situations and how to respond. Provide emergency response information (egress routes, warnings, evacuation instructions). Install large warming signs on roads and at bridges.	Internal communication practices and procedures for each jurisdiction – involve the EOC, FNESS for example.
Protect assets	Identify elements at greatest risk and protect or relocate. Emergency (short-term) protective measures include: • Sand bags, Bulk bags, Lock blocks, Ditching and culverts, Stream bank armour (riprap) • Upgrade any existing protective works Identify material sources and stockpile prior to freshet.	Cost depends on what needs to be protected and how it is protected.
Protect major stream crossings at Westside Rd	Have equipment on standby throughout freshet to clear debris and sediment at crossing to ensure no blockage (mid-April to end of June, depending on snowpack and weather conditions).	Excavator on standby rates (responsibility of MOTI roads contractor - AIM).
Increase frequency of inspection and monitoring along Westside Rd	Ensure clear ditches, culverts, and road surfaces through the study area	Responsibility of MOTI roads contractor - AIM
Develop Emergency Response Plan	Prepare response plans if not already done to manage emergency access requirements and evacuation protocols.	Internal procedures for each jurisdiction - involve the EOC, FNESS for example
Action (IMPORTANT BUT NOT URGENT – longer term)	**Description**	**Assumptions and Estimated Cost**
Install meteorologic station in Whiteman/Bouleau Creek watershed	Site has been located and work is underway by OKIB/ONA to install the station.	Assumes station instrumentation is available and ready to deploy.
Flood inundation modelling and floodplain mapping	Complete hydrologic analysis to determine post-fire design flows and hydraulic modelling across fan area to determine flood extent and water depths for the design flow.	Assumes availability of LiDAR survey data for each fan area. Est. $20,000 to $40,000 per fan.
Increase channel capacity	Through results of floodplain modelling, identify channel constrictions, regain capacity at key locations to protect assets. Dredge channel at vulnerable locations identified by historic flooding or avulsion and/or results of modelling.	Cost depends on sites, volumes to be removed, and access. Assumes results of floodplain mapping are available. Otherwise relies on knowledge of past impact sites.
Prepare preliminary designs for crossing replacement at Westside Road	Based on results of the hydrologic analysis, prepare designs for crossing upgrades if required.	Engineering design est. $20,000 to $40,000 per crossing.
Relocate assets	This may not be possible for many assets in the short term. It may be a long-term response depending on the type of asset to be relocated.	Cost depends on what needs to be relocated.
Land use planning	Develop policies within each jurisdiction to identify flood prone lands and provide guidance for new development. Geotechnical assessments should be completed prior to rebuilding in high-risk areas.	Internal costs for each jurisdiction (RDCO, RDNO, OKIB)

Summary of Risk-Mitigation Recommendations and Estimated Costs - Large Watershed Areas

For: Large Watershed Areas Above Fan Areas (Whiteman, Naswhito, Equesis)		
Action (IMPORTANT BUT NOT URGENT – longer term)	**Description**	**Assumptions and Estimated Cost**
Detailed risk mitigation plans for sites located in watershed	Complete more detailed assessments and risk mitigation plans for high to very high-risk sites (or subbasins) within the watershed. Review access requirements in the watersheds (i.e., salvage logging, research, private lands).	Assessments for each watershed to identify risks and complete more detailed assessments. Est. $30,000 to $50,000.
Stream channel treatments along fire-affected stream reaches.	Implement measures to reduce potential for sediment/debris transport along reaches impacted by wildfire: • Remove woody debris • Riparian planting • Stream bank armouring	Costs depend on site conditions and chosen approach. Sites and approach to be identified in detailed mitigation plan.
Road treatments in fire-affected areas.	Implement measures to mitigate hazards associated with watershed roads: • Identify rockfall and landslide hazards and mitigate through ditches and barriers. • Remove vulnerable culverts and close roads • Clear ditches and culvert inlets • Upgrade culvert capacity or construct rolling dips	Costs depend on site conditions and chosen approach. Sites and approach to be identified in detailed mitigation plan.

APPENDIX D2 – PHOTOS

Photo 1: Lower Equesis Creek at top of canyon reach. Large landslide location noted with arrow.

Photo 2: Equesis Creek mid-reaches with broad floodplain and significant riparian forest burn.

Photo 3: Broad floodplain along middle reaches of Equesis Creek, view downstream from McGregor Creek

Photo 4: View of McGregor Creek sub-basin (in Equesis Creek watershed)

Photo 5: Burned forest in mid-Equesis Creek (at McGregor Creek subbasin)

Photo 6: Mouth of Equesis Creek at Okanagan Lake

Photo 7: McGregor Creek concrete box culvert at Six Mile Creek Road crossing, ~250m upstream from Equesis Creek

Photo 8: McGregor Creek culvert at FSR Crossing, view downstream

Photo 9: McGregor Creek, view upstream from FSR crossing

Photo 10: Upper McGregor Creek subbasin, view of road and burned slopes.

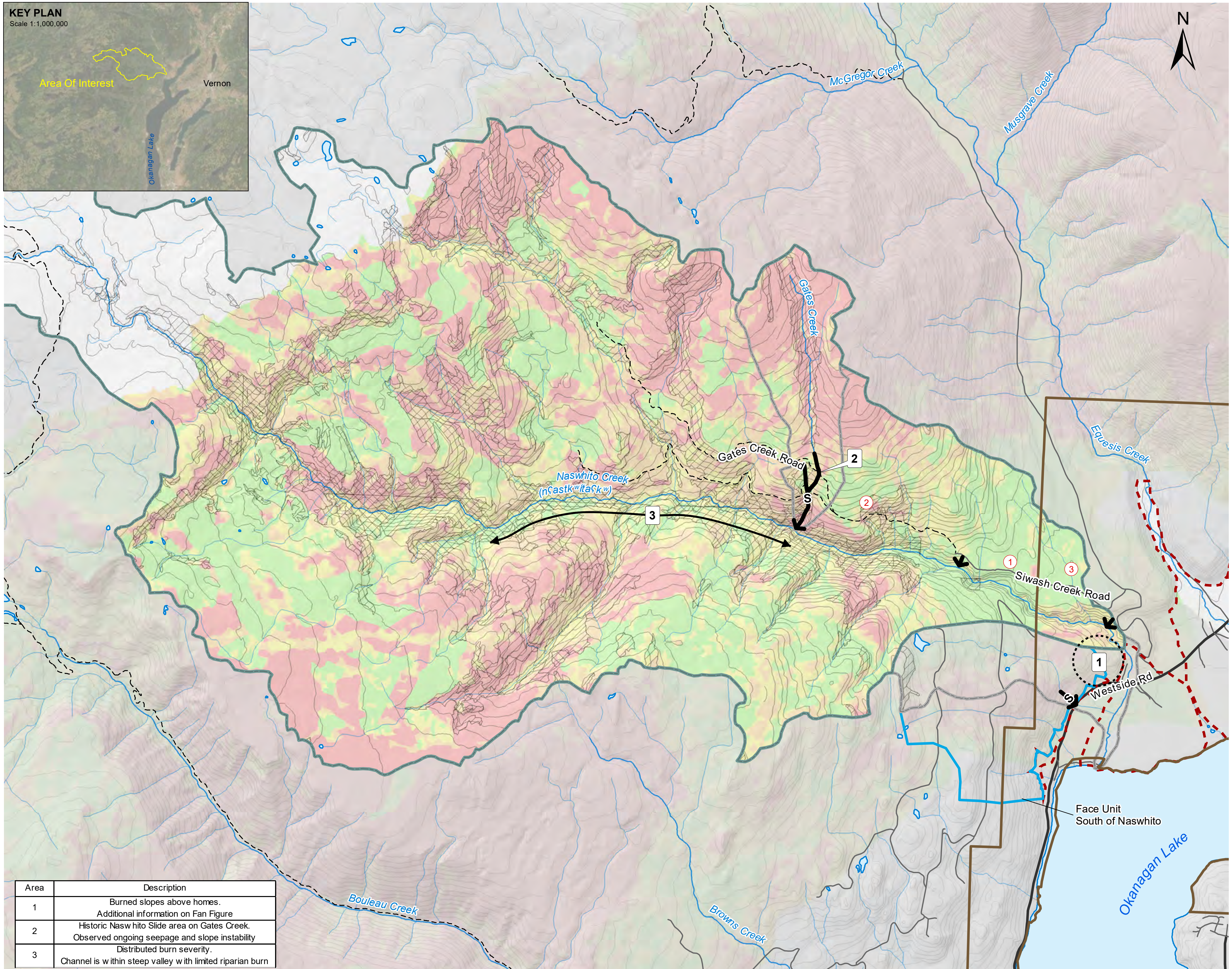
Photo 11: Lower Equesis Creek riprap armour along left bank, view upstream.

Photo 12: Lower Equesis Creek, seasonally blocked inlet to irrigation ditch on left bank, view upstream

Photo 13: Lower Equesis Creek and adjacent OKIB community development

Photo 14: Equesis Creek arch culvert at Westside Road, view downstream

Appendix D3 Naswhito (**nʕastkʷítaʕkʷ**) Creek Watershed and Fan Area



Area	Description
1	Burned slopes above homes. Additional information on Fan Figure
2	Historic Naswhito Slide area on Gates Creek. Observed ongoing seepage and slope instability
3	Distributed burn severity. Channel is within steep valley with limited riparian burn

LEGEND

- Watershed of Interest
- Subbasin Of Interest
- Catchment Area
- Fan Area
- Okanagan Indian Band (OKIB) Reserve Lands Boundary
- Elevation Contour (20m Interval)
- Observed Landslide Or Debris Flow Channel
- Element at Risk – Map Reference # (refer to Report Cards)

Road Type (Source: BC Digital Roads Atlas)

- Arterial
- Local
- Resource

Burn Severity (Source: BC Data Catalogue)

- High
- Medium
- Low
- Unburned
- Unknown

Terrain Stability Class (Source: BC Terrain Stability Mapping TSM)

- IV - Potentially Unstable
- V - Unstable

600 300 0 600 1,200
metres

Client: **MFLNRORD**

Project: **POST WILDFIRE NATURAL HAZARD RISK ASSESSMENT - WHITE ROCK LAKE FIRE (OKANAGAN BASIN)**

Title: **NASWHITO CREEK WATERSHED**

Scale: 1:50,000	NAD 1983 UTM Zone 11 U	Figure No. D3-1
Project No: 21-0111	Date: January 13, 2022	

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Ministry of Forests Lands and Natural Resource Operations
Post-Wildfire Natural Hazards Risk Assessment

NASWHITO CREEK WATERSHED REPORT CARD

		% Burned
Watershed Area (sq km):	86.5	58.5
Gates Ck Subbasin (sq km):	3.3	94.2

High Burn Severity (%)	23.5
Mod and High Burn Severity in Snow Zone (above 1300m elev) (%)	16
Moderate Burn Severity (%)	19.6
Low Burn Severity (%)	15.4

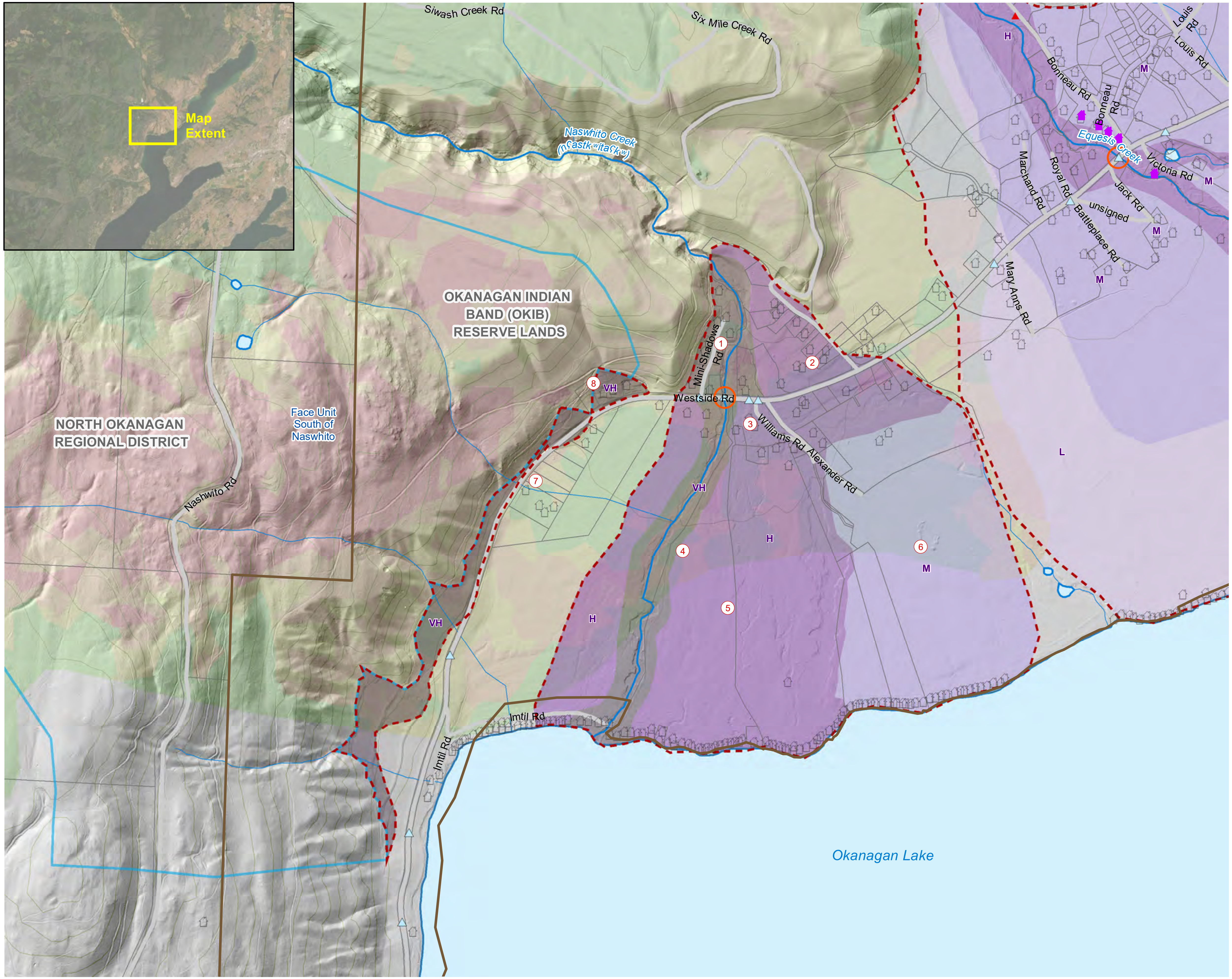
General Watershed /Subbasin Conditions:	Within the watershed, the burn severity appears to be evenly distributed. However, the total % burned is high at 58%. The small Gates Creek subbasin is 94% burned and 64% burned at high burn severity, which indicates a high potential for peak flow and sedimentation impact. Gates Creek subbasin also has a historic large chronic landslide and hydrologic impacts at the road crossings, which increases the potential for continued problems.
Terrain Conditions:	Burned areas include steep mainstem valley sideslopes that are directly connected to the mainstem channel. Approximately 16% of the watershed burned at a moderate to high severity and is also classified as being potentially unstable or unstable (~11 sq km).
Mainstem Stream Channel/Riparian Conditions:	Short sections of mainstem channel are burned at moderate and high severity (total length is 5.7 km) while most of length is burned at low severity. Headwater reaches on tributaries on the north side of the watershed (towards Equesis Creek watershed) are burned at high severity.
Post-Wildfire Hazards:	High peak flow hazard (due to aggregate of burned area) and moderate sediment bulking potential. Bulking will most likely arise from tributary subbasin(s). There is a high potential for post-wildfire landslide and debris flow on the Gates Creek subbasin.

	Element at Risk		
	Siwash Creek Road	Gates Creek Road	Agricultural (orchard) Land on terrace above creek
Map Reference	1	2	3
Hazard	**Hazard Level - Likelihood of Event P(H)**		
Flood / Debris Flood	Low	Low	Low
Debris Flow	Varies	Varies	Low
Landslide/Rockfall	High	High	Low

	Spatial Likelihood of Impact P(S:H)		
Flood / Debris Flood	Low	Low	Low
Debris Flow	Varies	Varies	Low
Landslide/Rockfall	High	High	Low

	Partial Risk P(HA) = P(H) x P(S:H)		
Flood / Debris Flood	VL	VL	VL
Debris Flow	Varies	Varies	VL
Landslide/Rockfall	VH	VH	VL

Notes:
Watershed area is measured as the area upstream of the fan apex.



LEGEND

- Fan Area
- Catchment Area
- Okanagan Indian Band (OKIB) Reserve Lands Boundary
- Property Parcel
- Structure
- OKIB Risk Element
- Element at Risk – Map Reference # (refer to Report Cards)
- Culvert (MOTI)
- Culvert (Field Observed)
- Major Stream Crossing (Westside Road)

Burn Severity (Source: BC Data Catalogue)

- High
- Medium
- Low
- Unburned
- Unknown

Post-Wildfire Natural Hazard Risk Assessment

- VH Very High
- H High
- M Moderate
- L Low

N

150 75 0 150 300
metres

Client: **MFLNRORD**

Project: **POST WILDFIRE NATURAL HAZARD RISK ASSESSMENT - WHITE ROCK LAKE FIRE (OKANAGAN BASIN)**

Title: **NASHWITO CREEK AND FACE UNIT SOUTH OF NASWHITO - FAN AREA**

Scale: 1:12,500	NAD 1983 UTM Zone 11 U	Figure No.
Project No: 21-0111	Date: January 13, 2022	D3-2

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Ministry of Forests Lands and Natural Resource Operations
Post-Wildfire Natural Hazards Risk Assessment

NASWHITO CREEK FAN REPORT CARD

Upstream watershed area (sq km):	86.5
Fan Area (sq km):	1.72
Fan Gradient (avg %):	3%

Total Area Burned (%):	58.5
High Burn Severity (%)	23.5
Mod & High Burn Severity in Snow Zone (%)	16
Moderate Burn Severity (%)	19.6
Low Burn Severity (%)	15.4
Length of Mainstem Channel in Mod & High Burn (km)	5.71

No. of structures (residences) on the fan area:	130
Length of Westside Road on the fan area:	726 m
Length of Westside Road at H to VH Risk:	726 m

General Fan Conditions:	The Naswhito Creek Fan area is large and generally flat (<5% slope). Naswhito Creek is a single meandering channel that exits a bedrock canyon at the fan apex and flows across the broad fan to Okanagan Lake. Westside Road traverses across the upper third of the fan. Downstream of Westside Road, the channel is confined within relatively high (~1-3m high) banks and has a well-vegetated riparian fringe, which offers some stability. The Fan area is not highly developed and is primarily open range/agricultural land, with the exception of the densely occupied lakeshore. There is a landslide from Six Mile Creek Road into the canyon reach above the fan.
2017/2018 Impacts:	High spring freshet flows of 2017 & 2018 impacted Naswhito Creek. Downstream of Westside Road, the channel experienced areas of bank erosion (in one location the bank eroded ~30m), debris jams, and a build up of alluvial sediment at the mouth (excavation was completed at the mouth after 2017 and filled again in 2018) (Stantec Consulting, 2018)

	Element at Risk					
	Property (OKIB) upslope of Westside Road and near channel	Property (OKIB) upslope of Westside Rd away from channel	MOTI Culvert at Westside Road	Property (OKIB) downslope of Westside Road along channel	Property (OKIB) downslope of Westside Rd and away from channel	Property (OKIB) downslope of Westside Road at distal end of fan
Map Reference	1	2	3	4	5	6
Hazard	**Hazard Level - Likelihood of Event P(H)**					
Flood/Debris Flood	High	High	High	High	High	High
	Spatial Likelihood of Impact P(S:H)					
Flood/Debris Flood	High	Moderate	High	High	Moderate	Low
	Partial Risk P(HA) = P(H) x P(S:H)					
Flood/Debris Flood	VH	H	VH	VH	H	M

Summary of Risk Mitigation Recommendations and Estimated Costs for Large Fan Areas

For: Large Fan Areas (Whiteman, Naswhito, Equesis)		
Action (URGENT AND IMPORTANT – prior to 2022 freshet)	**Description**	**Assumptions and Estimated Cost**
Monitor snow and weather conditions and develop an early warning system for flooding	Monitor snowpack at Silver Star Station, precipitation at Vernon Station, and stream flows on Whiteman Creek. Develop a warning system (decision matrix) that comprises criteria for flood alerts (snowpack, spring temperature, rainfall thresholds). This will inform flood response measures.	Assumes use of existing data and reliance on River Forecast Centre forecasting. Est. $10,000 to $15,000.
Public awareness	Conduct public information meetings, develop a public information bulletin on recognizing hazard situations and how to respond. Provide emergency response information (egress routes, warnings, evacuation instructions). Install large warming signs on roads and at bridges.	Internal communication practices and procedures for each jurisdiction – involve the EOC, FNESS for example.
Protect assets	Identify elements at greatest risk and protect or relocate. Emergency (short-term) protective measures include: • Sand bags, Bulk bags, Lock blocks, Ditching and culverts, Stream bank armour (riprap) • Upgrade any existing protective works Identify material sources and stockpile prior to freshet.	Cost depends on what needs to be protected and how it is protected.
Protect major stream crossings at Westside Rd	Have equipment on standby throughout freshet to clear debris and sediment at crossing to ensure no blockage (mid-April to end of June, depending on snowpack and weather conditions).	Excavator on standby rates (responsibility of MOTI roads contractor - AIM).
Increase frequency of inspection and monitoring along Westside Rd	Ensure clear ditches, culverts, and road surfaces through the study area	Responsibility of MOTI roads contractor - AIM
Develop Emergency Response Plan	Prepare response plans if not already done to manage emergency access requirements and evacuation protocols.	Internal procedures for each jurisdiction - involve the EOC, FNESS for example
Action (IMPORTANT BUT NOT URGENT – longer term)	**Description**	**Assumptions and Estimated Cost**
Install meteorologic station in Whiteman/Bouleau Creek watershed	Site has been located and work is underway by OKIB/ONA to install the station.	Assumes station instrumentation is available and ready to deploy.
Flood inundation modelling and floodplain mapping	Complete hydrologic analysis to determine post-fire design flows and hydraulic modelling across fan area to determine flood extent and water depths for the design flow.	Assumes availability of LiDAR survey data for each fan area. Est. $20,000 to $40,000 per fan.
Increase channel capacity	Through results of floodplain modelling, identify channel constrictions, regain capacity at key locations to protect assets. Dredge channel at vulnerable locations identified by historic flooding or avulsion and/or results of modelling.	Cost depends on sites, volumes to be removed, and access. Assumes results of floodplain mapping are available. Otherwise relies on knowledge of past impact sites.
Prepare preliminary designs for crossing replacement at Westside Road	Based on results of the hydrologic analysis, prepare designs for crossing upgrades if required.	Engineering design est. $20,000 to $40,000 per crossing.
Relocate assets	This may not be possible for many assets in the short term. It may be a long-term response depending on the type of asset to be relocated.	Cost depends on what needs to be relocated.
Land use planning	Develop policies within each jurisdiction to identify flood prone lands and provide guidance for new development. Geotechnical assessments should be completed prior to rebuilding in high-risk areas.	Internal costs for each jurisdiction (RDCO, RDNO, OKIB)

Summary of Risk-Mitigation Recommendations and Estimated Costs - Large Watershed Areas

For: Large Watershed Areas Above Fan Areas (Whiteman, Naswhito, Equesis)		
Action (IMPORTANT BUT NOT URGENT – longer term)	**Description**	**Assumptions and Estimated Cost**
Detailed risk mitigation plans for sites located in watershed	Complete more detailed assessments and risk mitigation plans for high to very high-risk sites (or subbasins) within the watershed. Review access requirements in the watersheds (i.e., salvage logging, research, private lands).	Assessments for each watershed to identify risks and complete more detailed assessments. Est. $30,000 to $50,000.
Stream channel treatments along fire-affected stream reaches.	Implement measures to reduce potential for sediment/debris transport along reaches impacted by wildfire: • Remove woody debris • Riparian planting • Stream bank armouring	Costs depend on site conditions and chosen approach. Sites and approach to be identified in detailed mitigation plan.
Road treatments in fire-affected areas.	Implement measures to mitigate hazards associated with watershed roads: • Identify rockfall and landslide hazards and mitigate through ditches and barriers. • Remove vulnerable culverts and close roads • Clear ditches and culvert inlets • Upgrade culvert capacity or construct rolling dips	Costs depend on site conditions and chosen approach. Sites and approach to be identified in detailed mitigation plan.

Summary of Risk Mitigation Recommendations and Estimated Costs for High-Risk Face Unit Areas

For: High Risk Areas Subject to Sediment-Laden Flooding and Debris Flow (Face Unit Areas North and South of Newport Creek, South of Naswhito Creek and area within Killiney Beach Area)		
Action (IMPORTANT AND URGENT – prior to 2022 freshet)	**Description**	**Assumptions and Estimated Cost**
Public awareness	Recommend that property owners prepare for unusually high runoff in the spring (along water courses and within zones of groundwater emergence. Conduct public information meetings, develop a public information bulletin on recognizing hazard situations and how to respond. Provide emergency response information (egress routes, warnings, evacuation instructions). Install large warming signs on roads and at bridges.	Communication responsibility for each jurisdiction.
Inspect ditches and culverts to ensure clear passage for increased flows	Prior to spring freshet, inspect ditches and culverts to ensure they are clear of sediment and debris.	Responsibility for property owner on private lands and MOTI (road maintenance contractor) on public roadways.
Protect assets	Identify elements at greatest risk and protect by relocation or physical protection (ditching, berms, barriers). Further assessment may be required. Identify material sources and stockpile prior to freshet.	Cost depends on what needs to be protected and how it is protected.
Action (IMPORTANT BUT NOT URGENT – longer term)	**Description**	**Assumptions and Estimated Cost**
Reduce potential for soil erosion	Implement measures to reduce potential for soil erosion (each have pros and cons): • Straw mulch • Wood mulch • Seeding	Estimated costs per ha (adjusted from Ecological Restoration Institute, 2021): • Straw mulch ($480/ha) • Wood mulch ($720/ha) • Seeding ($50/ha)
Reduce potential for sediment transport on gullies or stream channels	Implement measures to reduce potential for sediment transport (site-specific): • Check dams or weirs • Trash racks or catch basins • Channel clearing	Costs vary depending on treatment and site conditions. Channel clearing is the least expensive option.
Further assessment of upstream channels to refine mapping.	More detailed site assessment included ground-based traverse of stream channels upstream of the developed area to review instability, blockages, etc.	Cost depends on site and extent of study.
Further assessment of stream channels flowing through developed area.	More detailed site assessment to further characterize connectivity with upstream channels and identify opportunities to restore nature drainage patterns.	Cost depends on site and extent of study.

APPENDIX D3 – PHOTOS

Photo 1: Naswhito Creek mainstem lower valley, looking upstream

Photo 2: Naswhito Creek watershed headwaters, looking downstream

Photo 3: Mouth of Naswhito Creek at Okanagan Lake

Photo 4: Failing culvert on Siwash Creek Road

Photo 5: Gates Creek culvert crossing on Siwash Creek Road

Photo 6: Observed slope instability (headscarp and tension cracks) near the Gates Creek crossing on Siwash Creek Road (part of the larger Nashito Slide)

Photo 7: Pre-existing landslide from Six Mile Creek Road down slope to Naswhito Creek

Photo 8: Naswhito Creek arch culvert at Westside Road, view downstream.

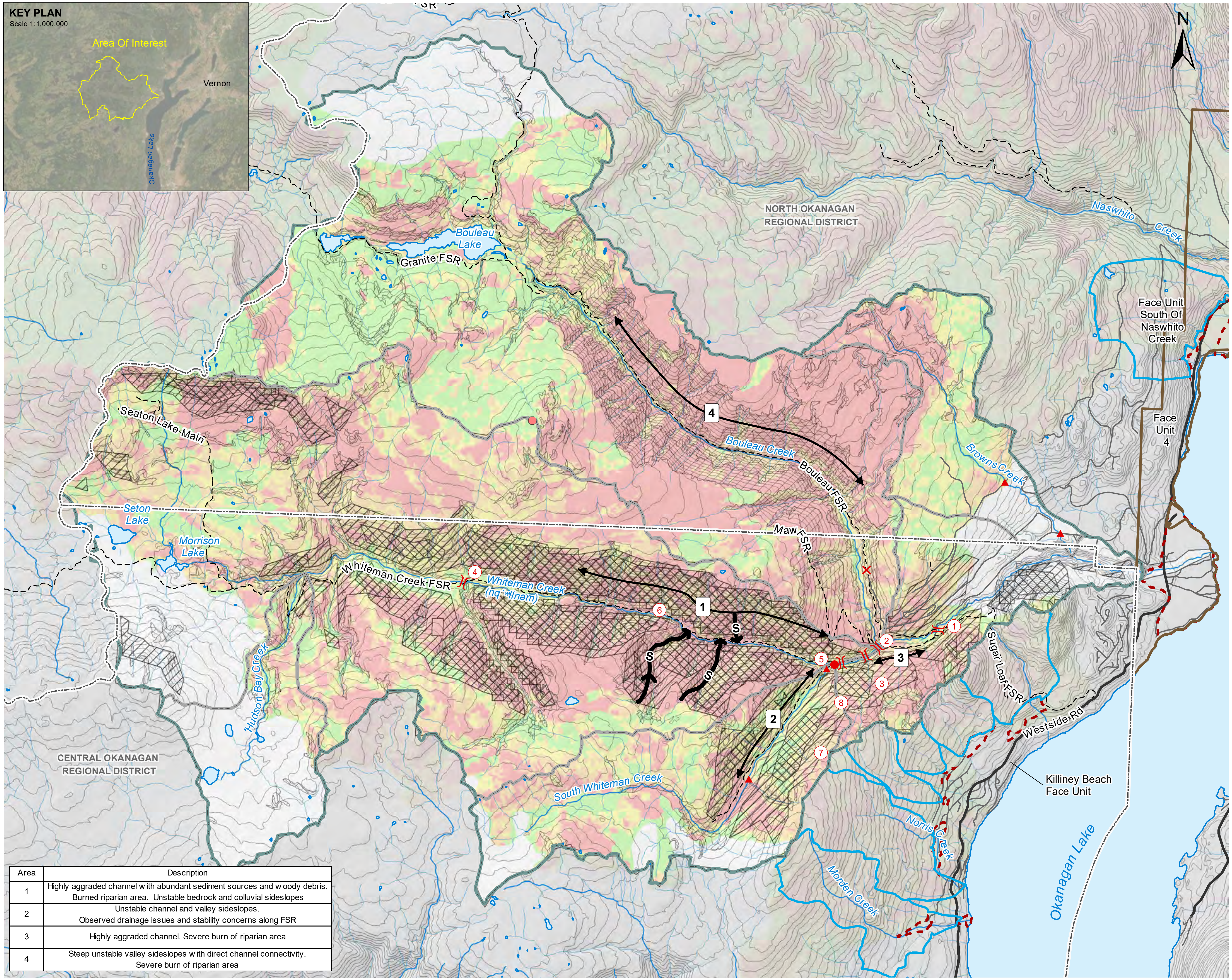
APPENDIX D3 – PHOTOS

Photo 1: Face Unit south of Naswhito Creek, view of burned slopes above access trail

Photo 2: Face Unit south of Naswhito Creek, burned gully below access trail, view downslope towards Westside Rd.

Photo 3: View of unstable slopes and fresh landslide activity on burned slopes below access trail (Face Unit south of Naswhito Creek)

Appendix D4 Whiteman (**nq̓ʷɬínəm**) Creek Watershed and Fan Area



Area	Description
1	Highly aggraded channel with abundant sediment sources and woody debris. Burned riparian area. Unstable bedrock and colluvial sideslopes
2	Unstable channel and valley sideslopes. Observed drainage issues and stability concerns along FSR
3	Highly aggraded channel. Severe burn of riparian area
4	Steep unstable valley sideslopes with direct channel connectivity. Severe burn of riparian area

LEGEND

- Watershed Of Interest
- Subbasin Of Interest
- Regional District Boundary
- Catchment Area
- Fan Area
- Okanagan Indian Band (OKIB) Reserve Lands Boundary
- Elevation Contour (20m Interval)
- Observed Landslide Or Debris Flow Channel
- Element at Risk – Map Reference # (refer to Report Cards)
- Bridge
- Culvert
- Deactivated Road - No Access
- Hydrometric Station
- Proposed Site for Meteorological Station

Road Type (Source: BC Digital Roads Atlas)

- Arterial
- Local
- Resource

Burn Severity (Source: BC Data Catalogue)

- High
- Medium
- Low
- Unburned
- Unknown

Terrain Stability Class (Source: BC Terrain Stability Mapping TSM)

- IV - Potentially Unstable
- V - Unstable

Client: **MFLNRORD**

Project: **POST WILDFIRE NATURAL HAZARD RISK ASSESSMENT - WHITE ROCK LAKE FIRE (OKANAGAN BASIN)**

Title: **WHITEMAN CREEK WATERSHED**

Scale: 1:75,000	NAD 1983 UTM Zone 11 U	Figure No.
Project No: 21-0111	Date: January 13, 2022	D4-1

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Ministry of Forests Lands and Natural Resource Operations
Post-Wildfire Natural Hazards Risk Assessment

WHITEMAN CREEK WATERSHED REPORT CARD

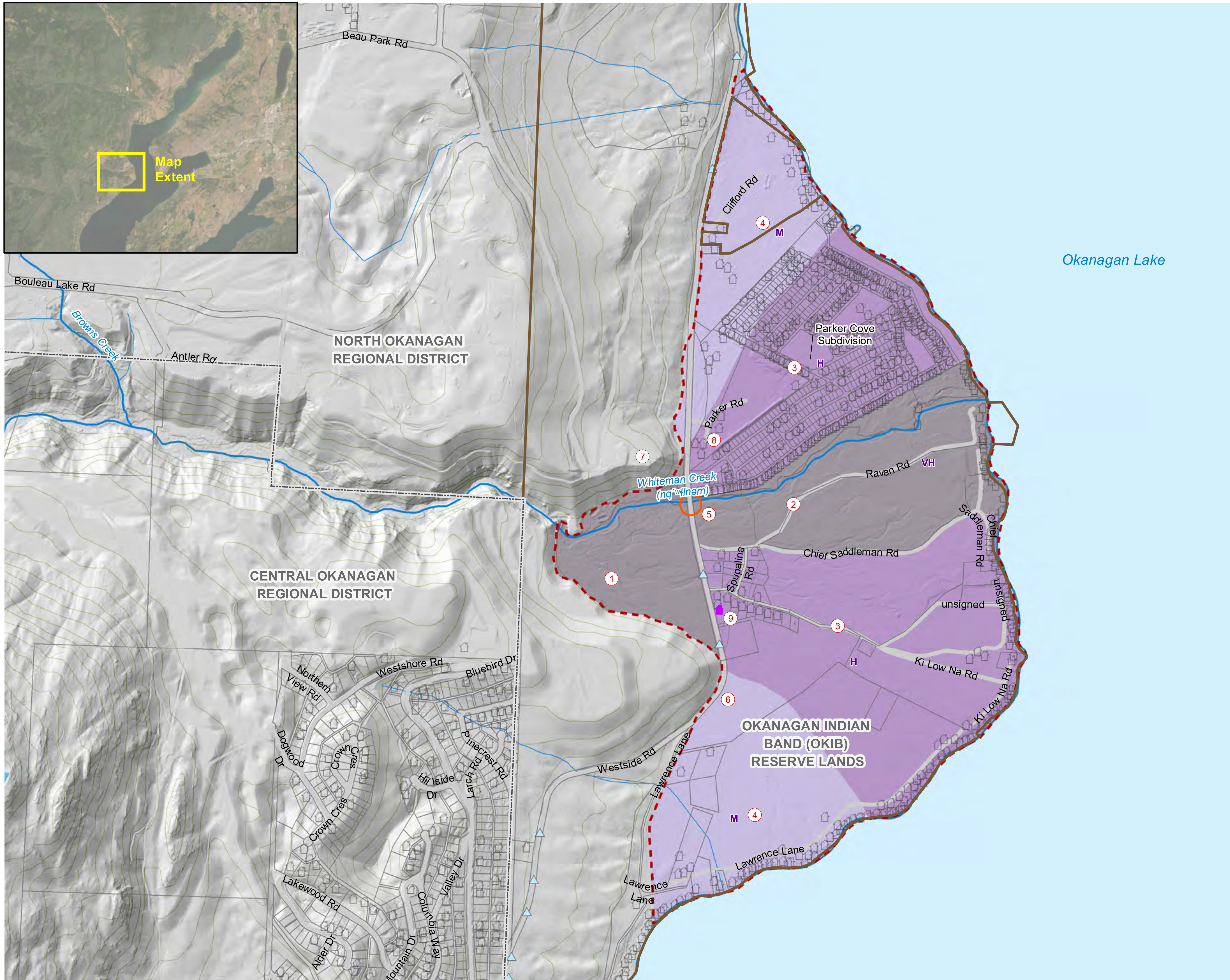
		% Burned
Watershed Area (sq km):	202.3	68.5
Browns Ck Subbasin (sq km):	11.0	64.1
Bouleau Ck Subbasin (sq km):	72.1	64.6
South Whiteman Ck Subbasin (sq km):	18.4	67.1
Hudson Bay Ck Subbasin (sq km):	10.0	21.8

High Burn Severity (%)	33.9
Mod and High Burn Severity in Snow Zone (above 1300m) (%)	30
Moderate Burn Severity (%)	21.4
Low Burn Severity (%)	13.2

General Watershed /Subbasin Conditions:	Steep valley side slopes and riparian areas in the middle watershed area are severely burned and show evidence of post-fire instability. Overall, a large proportion of the watershed has been burned (69%) and over 30% at high burn severity. Channel is vulnerable to debris jams and sediment transport. Highly affected tributary catchments include: Bouleau (40% high burn severity and steep slopes) and South Whiteman (20% high burn severity and steep slopes). Whiteman Creek is tightly connected to the valley side slopes until reaching a large alluvial fan at its mouth on Okanagan Lake.
Terrain Conditions:	Burned areas include steep sideslopes within the Bouleau Creek subbasin and mainstem valley sideslopes that are directly connected to the mainstem channel. Approximately 20% of the watershed burned at a moderate to high severity and is also classified as being potentially unstable or unstable (41 sq km).
Mainstem Stream Channel/Riparian Conditions:	Long lengths (10.2km) of mainstem channel burned at moderate to high burn severity, including headwater reaches in the Morrison and Seaton Lake area and on tributary streams below Tahaetkun Mountain. Bouleau Creek tributary channel (5.4km) also burned at moderate to high severity.
Post-Wildfire Hazards:	High peak flow hazard on Whiteman Creek and on the three largest tributaries due to high % burned and high % burned at high severity. High potential for sediment bulking due to valley side slope instability and length of burned riparian forest that increases potential for debris jams and within-channel sediment transport.

	Element at Risk							
	Bridge at 9k	Bridge on Maw FSR	Bridge at 10k	Bridge at 19k	WSC Hydrometric Station	Whiteman Ck FSR	South Fork Ck FSR	Bridge at South Fork
Map Reference	1	2	3	4	5	6	7	8
Hazard	**Hazard Level - Likelihood of Event P(H)**							
Flood / Debris Flood	High	High	High	High	High	Varies	Varies	High
Debris Flow	Low	Low	Low	Low	Low	Varies	Varies	Low
Landslide/Rockfall	Low	Low	Low	Low	Low	High	High	Low
	Spatial Likelihood of Impact P(S:H)							
Flood / Debris Flood	Moderate	High	High	High	High	Varies	Varies	Moderate
Debris Flow	Low	Low	Low	Low	Low	Varies	Varies	Low
Landslide/Rockfall	Low	Low	Low	Low	Low	High	High	Low
	Partial Risk P(HA) = P(H) x P(S:H)							
Flood / Debris Flood	H	VH	VH	VH	VH	Varies	Varies	H
Debris Flow	VL	VL	VL	VL	VL	Varies	Varies	VL
Landslide/Rockfall	VL	VL	VL	VL	VL	VH	VH	VL

Notes:
Watershed area is measured as the area upstream of the fan apex.



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LEGEND

- Fan Area
- Catchment Area
- Regional District Boundary
- Okanagan Indian Band (OKIB) Reserve Lands Boundary
- Property Parcel
- Structure
- OKIB Risk Element
- # Element at Risk – Map Reference # (refer to Report Cards)
- Major Stream Crossing (Westside Road)
- Culvert (MOTI)

Post-Wildfire Natural Hazard Risk Assessment

- VH Very High
- H High
- M Moderate
- L Low

N

130 65 0 130 260
metres

Client:

MFLNRORD

Project: **POST WILDFIRE NATURAL HAZARD RISK ASSESSMENT - WHITE ROCK LAKE FIRE (OKANAGAN BASIN)**

Title:

WHITEMAN CREEK - FAN AREA

Scale: 1:12,500	NAD 1983 UTM Zone 11 U	Figure No. D4-2
Project No: 21-0111	Date: January 13, 2022	

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Ministry of Forests Lands and Natural Resource Operations
Post-Wildfire Natural Hazards Risk Assessment

WHITEMAN CREEK FAN REPORT CARD

Upstream watershed area (sq km):	202.3
Fan Area (sq km):	2.3
Fan Gradient (avg %):	3.5

Total Watershed Area Burned (%):	68.5
High Burn Severity (%)	33.9
Mod & High Burn Severity in Snow Zone (above 1300m) (%)	30
Moderate Burn Severity (%)	21.4
Low Burn Severity (%)	13.2
Length of Mainstem Channel in Mod & High Burn (km)	10.2

No. of structures (residences) on the fan area:	472
Length of Westside Road on the fan area:	2.15 km
Length of Westside Road at H to VH Risk:	730 m

General Fan Conditions:	There is bedrock control along left bank at the fan apex. The right bank is less confined and there is an inlet to an irrigation channel at the top of the fan (right bank) that may form a potential avulsion risk. There is a berm located along the right bank upstream of Westside Road but there is still a potential for avulsion to the right side of the upper fan (more detailed assessment is required to determine). Below Westside Road, there is a large subdivision (Porter Cove) on the left side of the channel (looking downstream) that was developed in the early ~1990s. It is unclear whether bank protection measures are in place but it is understood that there is some channel containment along the upper part of the channel below Westside Road. The channel is relatively straight for the upper part of the fan and then becomes sinous and braided where it becomes less confined along the lower part of the fan before entering Okanagan Lake.
2017/2018 Flood Impacts:	Flood impacts during the 2017/2018 flood events include debris jams within the channel upstream of Westside Road, bank erosion along the right bank of the lower channel, and aggradation at the stream mouth at Okanagan Lake (Stantec, 2018). Excavation of material at the creek mouth was completed in 2017 by OKIB but infilled again in 2018.

	Element at Risk								
	Property (OKIB) upslope of Westside Road	Property (OKIB) downslope of Westside Road along the channel	Property (OKIB) downslope of Westside Road away from the channel	Property (OKIB) downslope of Westside Road at distal edge of fan	MOTI Bridge at Westside Road	Westside Road	Commerical Property (upstream side of Westside Road)	Parker-Bonneau Memorial Hall (Community Centre) (downstream side of Westside Road)	OKIB Rental Units
Map Reference	1	2	3	4	5	6	7	8	9
Hazard	**Hazard Level - Likelihood of Event P(H)**								
Flood/Debris Flood	High	High	High	Moderate	High	Varies	High	High	High
	Spatial Likelihood of Impact P(S:H)								
Flood/Debris Flood	High	High	Moderate	Moderate	High	Varies	High	Moderate	Moderate
	Partial Risk P(HA) = P(H) x P(S:H)								
Flood/Debris Flood	VH	VH	H	M	VH	Varies	VH	H	H

Summary of Risk Mitigation Recommendations and Estimated Costs for Large Fan Areas

For: Large Fan Areas (Whiteman, Naswhito, Equesis)		
Action (URGENT AND IMPORTANT – prior to 2022 freshet)	**Description**	**Assumptions and Estimated Cost**
Monitor snow and weather conditions and develop an early warning system for flooding	Monitor snowpack at Silver Star Station, precipitation at Vernon Station, and stream flows on Whiteman Creek. Develop a warning system (decision matrix) that comprises criteria for flood alerts (snowpack, spring temperature, rainfall thresholds). This will inform flood response measures.	Assumes use of existing data and reliance on River Forecast Centre forecasting. Est. $10,000 to $15,000.
Public awareness	Conduct public information meetings, develop a public information bulletin on recognizing hazard situations and how to respond. Provide emergency response information (egress routes, warnings, evacuation instructions). Install large warming signs on roads and at bridges.	Internal communication practices and procedures for each jurisdiction – involve the EOC, FNESS for example.
Protect assets	Identify elements at greatest risk and protect or relocate. Emergency (short-term) protective measures include: • Sand bags, Bulk bags, Lock blocks, Ditching and culverts, Stream bank armour (riprap) • Upgrade any existing protective works Identify material sources and stockpile prior to freshet.	Cost depends on what needs to be protected and how it is protected.
Protect major stream crossings at Westside Rd	Have equipment on standby throughout freshet to clear debris and sediment at crossing to ensure no blockage (mid-April to end of June, depending on snowpack and weather conditions).	Excavator on standby rates (responsibility of MOTI roads contractor - AIM).
Increase frequency of inspection and monitoring along Westside Rd	Ensure clear ditches, culverts, and road surfaces through the study area	Responsibility of MOTI roads contractor - AIM
Develop Emergency Response Plan	Prepare response plans if not already done to manage emergency access requirements and evacuation protocols.	Internal procedures for each jurisdiction - involve the EOC, FNESS for example
Action (IMPORTANT BUT NOT URGENT – longer term)	**Description**	**Assumptions and Estimated Cost**
Install meteorologic station in Whiteman/Bouleau Creek watershed	Site has been located and work is underway by OKIB/ONA to install the station.	Assumes station instrumentation is available and ready to deploy.
Flood inundation modelling and floodplain mapping	Complete hydrologic analysis to determine post-fire design flows and hydraulic modelling across fan area to determine flood extent and water depths for the design flow.	Assumes availability of LiDAR survey data for each fan area. Est. $20,000 to $40,000 per fan.
Increase channel capacity	Through results of floodplain modelling, identify channel constrictions, regain capacity at key locations to protect assets. Dredge channel at vulnerable locations identified by historic flooding or avulsion and/or results of modelling.	Cost depends on sites, volumes to be removed, and access. Assumes results of floodplain mapping are available. Otherwise relies on knowledge of past impact sites.
Prepare preliminary designs for crossing replacement at Westside Road	Based on results of the hydrologic analysis, prepare designs for crossing upgrades if required.	Engineering design est. $20,000 to $40,000 per crossing.
Relocate assets	This may not be possible for many assets in the short term. It may be a long-term response depending on the type of asset to be relocated.	Cost depends on what needs to be relocated.
Land use planning	Develop policies within each jurisdiction to identify flood prone lands and provide guidance for new development. Geotechnical assessments should be completed prior to rebuilding in high-risk areas.	Internal costs for each jurisdiction (RDCO, RDNO, OKIB)

Summary of Risk-Mitigation Recommendations and Estimated Costs - Large Watershed Areas

For: Large Watershed Areas Above Fan Areas (Whiteman, Naswhito, Equesis)		
Action (IMPORTANT BUT NOT URGENT – longer term)	**Description**	**Assumptions and Estimated Cost**
Detailed risk mitigation plans for sites located in watershed	Complete more detailed assessments and risk mitigation plans for high to very high-risk sites (or subbasins) within the watershed. Review access requirements in the watersheds (i.e., salvage logging, research, private lands).	Assessments for each watershed to identify risks and complete more detailed assessments. Est. $30,000 to $50,000.
Stream channel treatments along fire-affected stream reaches.	Implement measures to reduce potential for sediment/debris transport along reaches impacted by wildfire: • Remove woody debris • Riparian planting • Stream bank armouring	Costs depend on site conditions and chosen approach. Sites and approach to be identified in detailed mitigation plan.
Road treatments in fire-affected areas.	Implement measures to mitigate hazards associated with watershed roads: • Identify rockfall and landslide hazards and mitigate through ditches and barriers. • Remove vulnerable culverts and close roads • Clear ditches and culvert inlets • Upgrade culvert capacity or construct rolling dips	Costs depend on site conditions and chosen approach. Sites and approach to be identified in detailed mitigation plan.

APPENDIX D4 – PHOTOS

Photo 1: Middle reaches of Whiteman Creek mainstem

Photo 2: Whiteman Creek watershed headwaters

Photo 3: Boulleau Creek sub-basin (in Whiteman Creek watershed), steep burned side slopes

Photo 4: Steep burned side slopes of Boulleau Creek sub-basin (in Whiteman Creek watershed)

Photo 5: Boulleau Creek sub-basin, severe burn through riparian forest

Photo 6: Mouth of Whiteman Creek at Okanagan Lake, arrows indicate bank erosion site from 2017/2018 flood

Photo 7: Whiteman Creek at Westside Road (concrete bridge ~10m span)

Photo 8: Whiteman Creek – Bridge at 9K

Photo 9: Whiteman Creek – Bridge at 10K

Photo 10: Whiteman Creek – Bridge at 19K

Photo 11: Whiteman Creek – Bridge at South Whiteman Creek (South Fork)

Photo 12: Whiteman Creek – Bridge at Maw FSR

Photo 13: Whiteman Creek – burned valley bottom riparian forest

Photo 14: Whiteman Creek - Burned riparian forest and aggraded channel

Photo 15: Confluence of Boulleau Creek and Whiteman Creek, aggraded channel and abundant woody debris

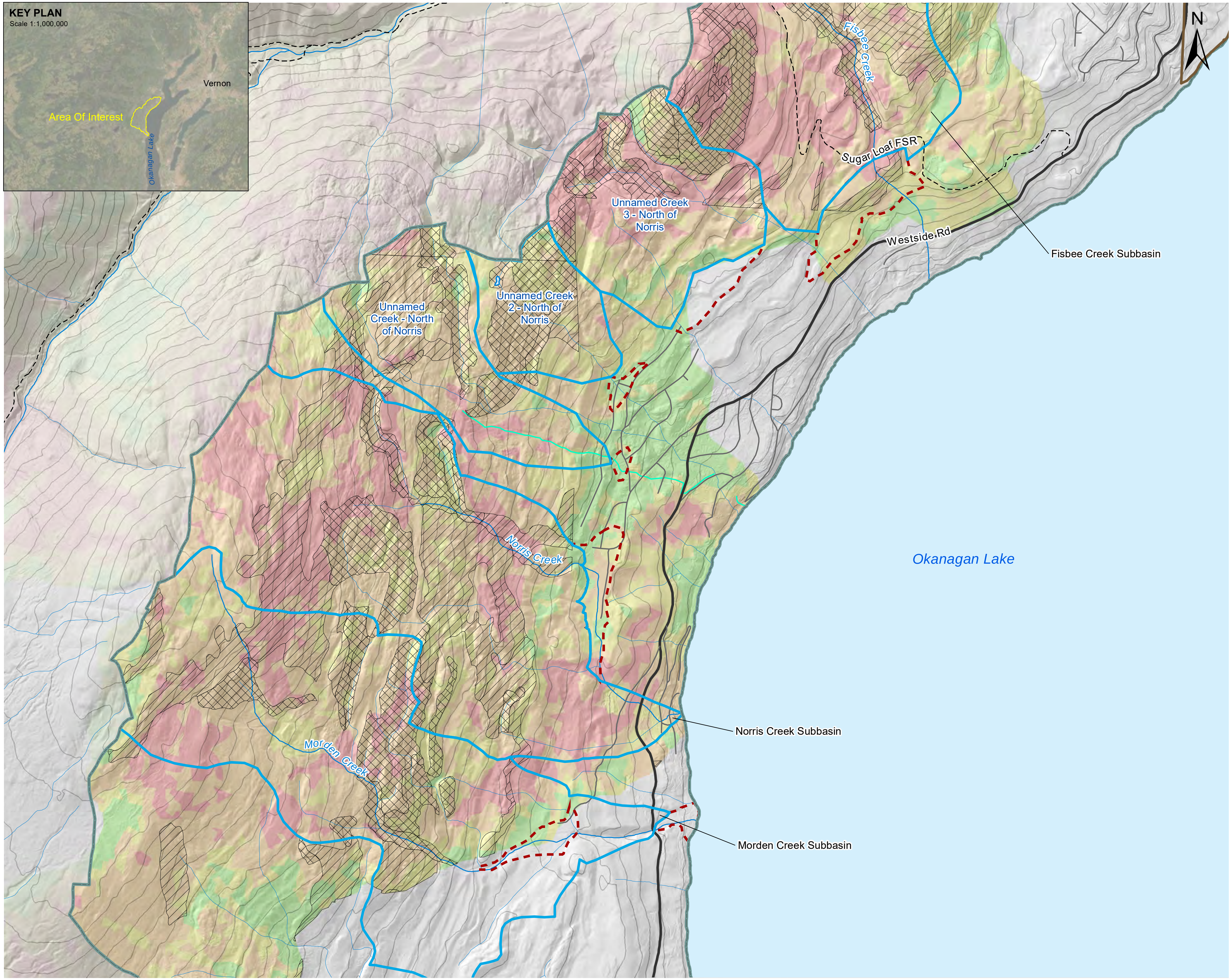
Photo 16: South Whiteman Creek, culvert along South Fork FSR

Photo 17: Example rockfall process along Whiteman Creek FSR

Photo 18: Burned steep debris-flow prone tributary along mainstem Whiteman Creek (Outflow from Martin Lake)

Photo 19: Water Survey of Canada Hydrometric Station "Whiteman Creek about Boulleau Creek", view downstream on Whiteman Creek

Appendix D5 Killiney Beach Face Unit Area (including Morden, Norris, and Fisbee Creek Watersheds)



LEGEND

- Watershed of Interest
- Subbasin Of Interest
- Catchment Area
- Fan Area
- Okanagan Indian Band (OKIB) Reserve Lands Boundary
- Elevation Contour (20m Interval)
- Interpreted Watercourse

Road Type (Source: BC Digital Roads Atlas)

- Arterial
- Local
- Resource

Burn Severity (Source: BC Data Catalogue)

- High
- Medium
- Low
- Unburned
- Unknown

Terrain Stability Class (Source: BC Terrain Stability Mapping TSM)

- IV - Potentially Unstable
- V - Unstable

300 150 0 300 600
metres

Client: **MFLNRORD**

Project: **POST WILDFIRE NATURAL HAZARD RISK ASSESSMENT - WHITE ROCK LAKE FIRE (OKANAGAN BASIN)**

Title: **KILLINEY BEACH AREA**

Scale: 1:25,000	NAD 1983 UTM Zone 11 U	Figure No. D5-1
Project No: 21-0111	Date: January 13, 2022	

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Ministry of Forests Lands and Natural Resource Operations
Post-Wildfire Natural Hazards Risk Assessment

KILLINEY BEACH FACE UNIT AREA REPORT CARD

	Area (sq km)	% Burned	% High Burn Severity	Peak Flow Risk	Melton Ratio	Dominant Process Type
Morden Creek Subbasin	4.3	73	15	Moderate	0.57	Debris flood
Norris Creek Subbasin	4.4	98	31	**High**	0.52	Debris flood
Unnamed Trib N of Norris	1.3	95	10	Moderate	0.41	Debris flood
Unnamed Trib2 N of Norris	0.7	99	1	Moderate	0.47	Debris flood
Unnamed Trib3 N of Norris	1.4	93	38	**High**	0.36	Debris flood
Fisbee Creek Subbasin	2.7	94	36	**High**	0.29	Flood

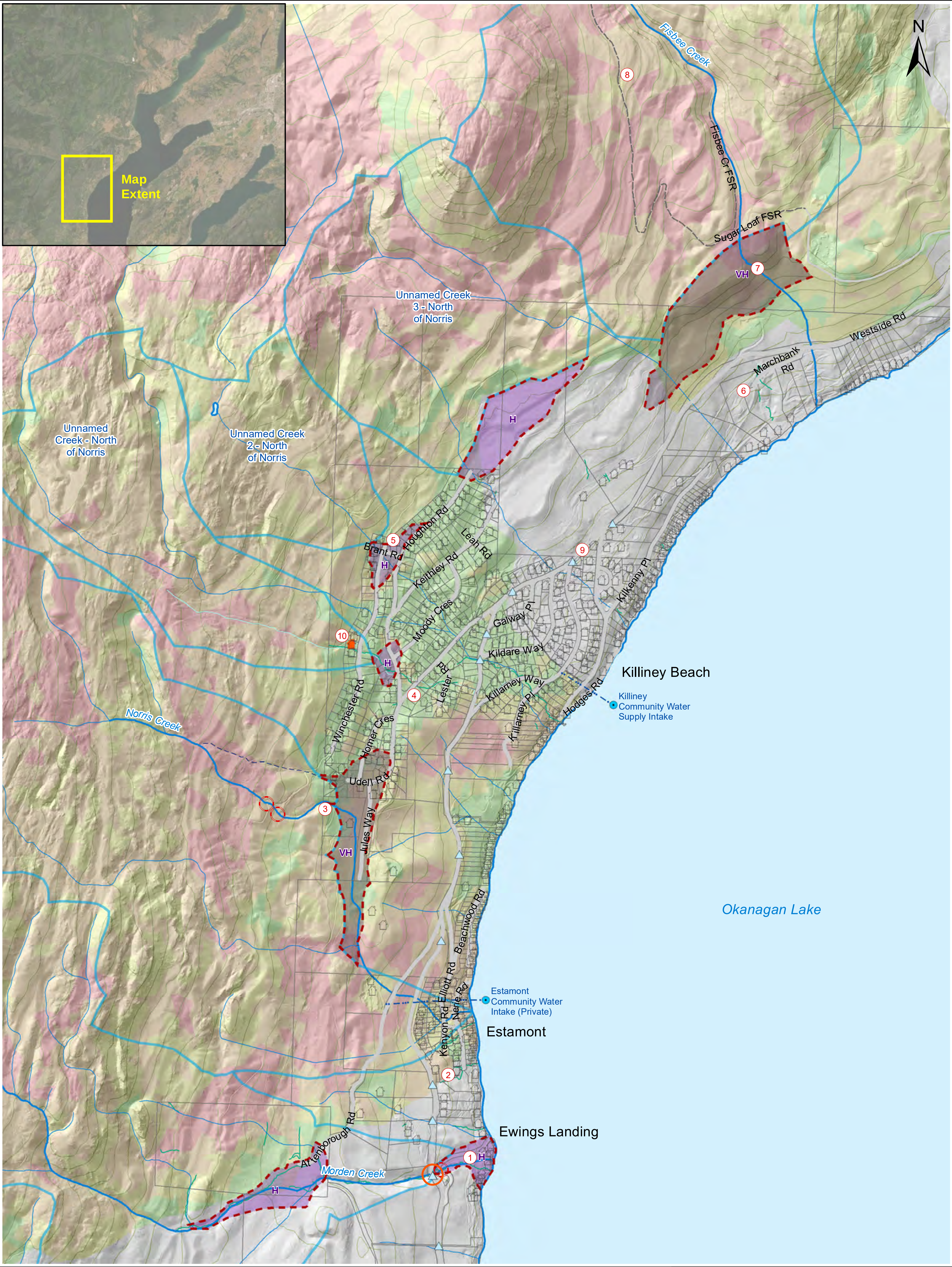
General Conditions:	This face unit area was burned extensively at varying levels of burn severity. There are several small tributary streams in the area and many lose water by infiltration into pervious glaciofluvial sand and gravel deposits at ~600m elevation, above Westside Road and generally above the developed subdivision area. There are many historic water diversions influencing runoff patterns through the area. Of concern will be the capacity for downstream conveyance and capacity of downstream ditches and culverts.
Terrain Conditions:	Slopes within the face unit are generally moderately sloped with steeply sloped bedrock lineaments. Pre-existing instability is predominantly small-scale rockfall activity, with little evidence of debris flow transport along the small stream channels (with the possible exception of Morden Creek). Upper Fisbee Creek is in a steep bedrock canyon that was severely burned. There are indications of instability along the Fisbee FSR, and sensitive exposed soils.
Mainstem Stream Channel/Riparian Conditions:	Streams flowing through the face unit are moderately well-confined at higher elevations but become indistinct. Flows infiltrate soils along the slope and transition to groundwater seepage along lower slopes closer to the lake. Updated SHIM mapping within the RDCO area provides more information on stream channels at lower elevations (below Westside Road).
Post-Wildfire Hazards:	Post-wildfire impacts are more likely to be associated with changes in hydrology on small tributary streams. Two hazard sites, where debris potentially restricts flow in Norris Creek, were identified during the field assessment and are being addressed by Okanagan Shuswap Forest District office. There is a high likelihood for soil erosion and sediment-laden runoff on severely burned steeper slopes in the Attenbrough Road - Beachwood Road/Elliott Road area.

	Element at Risk									
	Morden Creek Channel, incl. Westside Rd crossing and Ewings Landing Rd crossing	Groundwater springs and seeps in the Estamont Area	Norris Creek channel and downslope fan area	Unnamed Creek N of Norris channel and downslope ditches and culverts through subdivision	Unnamed Creek 2 North of Norris channel and downslope ditches	Springs and seeps in the Marchbank Rd area downslope of Fisbee Creek	Fisbee Creek fan area upslope of Westside Rd	Sugar Loaf FSR & Fisbee FSR	Westside Road	Killiney Water Supply pump station (on Winchester Rd)
Map Reference	1	2	3	4	5	6	7	8	9	10
Hazard	**Hazard Level - Likelihood of Event P(H)**									
Flood/Debris Flood	Moderate	Moderate	High	Moderate	Moderate	High	High	Low	Varies	Moderate
Landslide	Moderate	Moderate	Moderate	Low	Low	Unknown	Moderate	High	Low	Low
Sediment-Laden Flood	Moderate	Moderate	High	Moderate	Moderate	High	High	Moderate	Varies	Moderate
	Spatial Likelihood of Impact P(S:H)									
Flood/Debris Flood	High	High	High	High	High	High	High	Varies	Varies	Moderate
Landslide	Moderate	High	High	High	High	Unknown	High	Varies	Low	Moderate
Sediment-Laden Flood	High	High	High	High	High	High	High	Varies	Varies	Moderate
	Partial Risk P(HA) = P(H) x P(S:H)									
Flood/Debris Flood	H	H	VH	H	H	VH	VH	L (Varies)	Varies	M
Landslide	M	H	H	M	M	Unknown	H	H (Varies)	L	M
Sediment-Laden Flood	H	H	VH	H	H	VH	VH	M (Varies)	Varies	M

There is old water distribution infrastructure above the Killiney Beach subdivision (Norris Creek) that appears to be in disrepair. Where there is abandoned equipment, fence material, and pipes within the channel, this forms a potential risk for debris jar

Ditchlines along subdivision roads are undersized and not well maintained and driveway culverts and road culverts require maintenance to ensure adequate capacity.

Fisbee Creek is an indistrinct channel within a steep bedrock canyon. The channel discharges onto a raised fan area, which is likely to become a runout zone. This is a high recreation use area and there is high potential for ongoing soil disturbance and erosion. Recommend limiting access to motorized vehicles (OHV)



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LEGEND

- Fan Area
- Catchment Area
- Okanagan Indian Band (OKIB) Reserve Lands Boundary
- Property Parcel
- Watercourse (Source: BC Fresh Water Atlas)
- Watercourse (Source: RDCO-SHIM)
- Interpreted Stream
- Ephemeral Stream Interpreted
- Water Intake Line (Source: BC Water Resources Atlas)
- Water Rights Licenses - Water Supply Intake (Source: BC Water Resources Atlas) (Community Sources Only)

Burn Severity (Source: BC Data Catalogue)

- High
- Medium
- Low
- Unburned
- Unknown

Post-Wildfire Natural Hazard Risk Assessment

- VH Very High
- H High
- M Moderate
- L Low

- Structure
- RDCO Risk Element
- Culvert (MOTI)
- # Element at Risk – Map Reference # (refer to Report Cards)
- Hazard Identified During Field
- Major Stream Crossing (Westside Road)

metres

Client: **MFLNRORD**

Project: **POST WILDFIRE NATURAL HAZARD RISK ASSESSMENT - WHITE ROCK LAKE FIRE (OKANAGAN BASIN)**

Title: **KILLINEY STUDY AREA - FAN AREAS**

Scale: 1:17,500	NAD 1983 UTM Zone 11 U	Figure No.
Project No: 21-0111	Date: January 13, 2022	D5-2

Clarke Geoscience Ltd.

Summary of Risk Mitigation Recommendations and Estimated Costs for High-Risk Face Unit Areas

<table>
<tr><th colspan="3">For: High Risk Areas Subject to Sediment-Laden Flooding and Debris Flow (Face Unit Areas North and South of Newport Creek, South of Naswhito Creek and area within Killiney Beach Area)</th></tr>
<tr><th>Action
(IMPORTANT AND URGENT – prior to 2022 freshet)</th><th>Description</th><th>Assumptions and Estimated Cost</th></tr>
<tr><td>Public awareness</td><td>Recommend that property owners prepare for unusually high runoff in the spring (along water courses and within zones of groundwater emergence.

Conduct public information meetings, develop a public information bulletin on recognizing hazard situations and how to respond. Provide emergency response information (egress routes, warnings, evacuation instructions). Install large warming signs on roads and at bridges.</td><td>Communication responsibility for each jurisdiction.</td></tr>
<tr><td>Inspect ditches and culverts to ensure clear passage for increased flows</td><td>Prior to spring freshet, inspect ditches and culverts to ensure they are clear of sediment and debris.</td><td>Responsibility for property owner on private lands and MOTI (road maintenance contractor) on public roadways.</td></tr>
<tr><td>Protect assets</td><td>Identify elements at greatest risk and protect by relocation or physical protection (ditching, berms, barriers). Further assessment may be required.

Identify material sources and stockpile prior to freshet.</td><td>Cost depends on what needs to be protected and how it is protected.</td></tr>
<tr><th>Action
(IMPORTANT BUT NOT URGENT – longer term)</th><th>Description</th><th>Assumptions and Estimated Cost</th></tr>
<tr><td>Reduce potential for soil erosion</td><td>Implement measures to reduce potential for soil erosion (each have pros and cons):
• Straw mulch
• Wood mulch
• Seeding</td><td>Estimated costs per ha (adjusted from Ecological Restoration Institute, 2021):
• Straw mulch ($480/ha)
• Wood mulch ($720/ha)
• Seeding ($50/ha)</td></tr>
<tr><td>Reduce potential for sediment transport on gullies or stream channels</td><td>Implement measures to reduce potential for sediment transport (site-specific):
• Check dams or weirs
• Trash racks or catch basins
• Channel clearing</td><td>Costs vary depending on treatment and site conditions. Channel clearing is the least expensive option.</td></tr>
<tr><td>Further assessment of upstream channels to refine mapping.</td><td>More detailed site assessment included ground-based traverse of stream channels upstream of the developed area to review instability, blockages, etc.</td><td>Cost depends on site and extent of study.</td></tr>
<tr><td>Further assessment of stream channels flowing through developed area.</td><td>More detailed site assessment to further characterize connectivity with upstream channels and identify opportunities to restore nature drainage patterns.</td><td>Cost depends on site and extent of study.</td></tr>
</table>

APPENDIX D5 – PHOTOS

Photo 1: Killiney Beach area slopes (Beachwood Rd / Nerie Road)

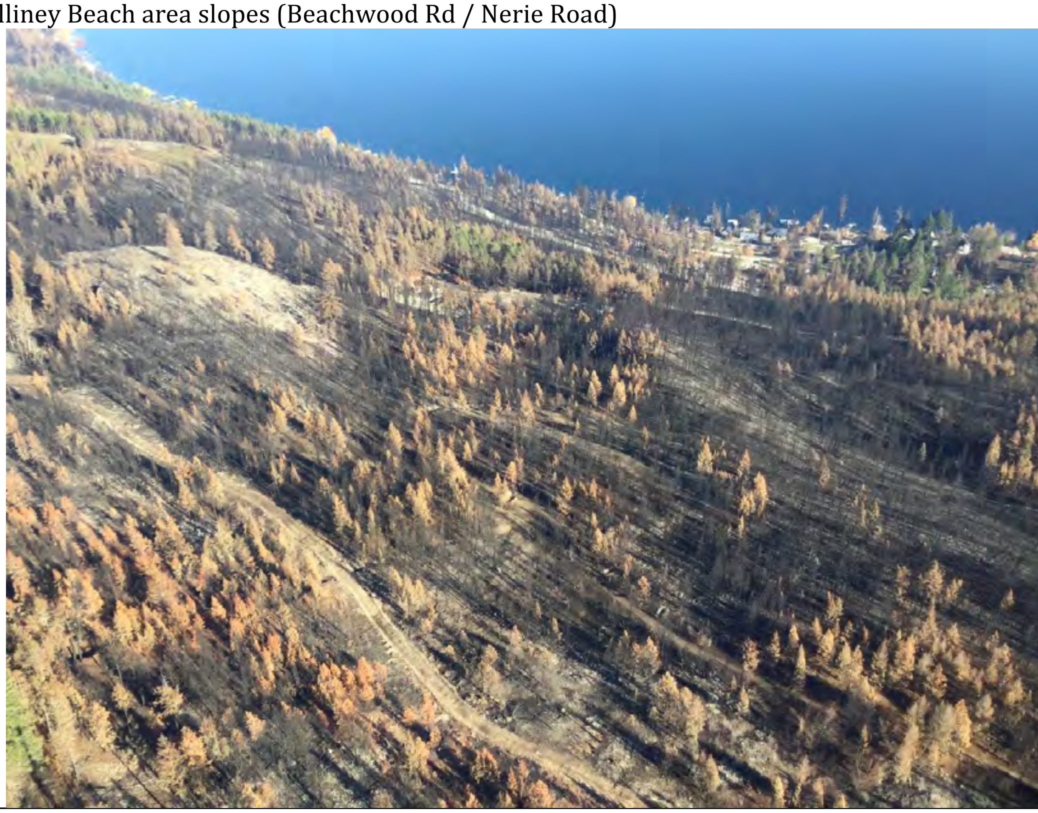

Photo 2: Killiney Beach area slopes, midslope areas high burn severity

Photo 3: Killiney Beach area slopes, view across the slope

Photo 4: General view to the north across the burned residential area above Nerie Road.

Photo 5: Culvert under Nerie Road, with flowing water from spring-fed stream (Buchanan Spring) and with contributing ditch flow.

Photo 6: View of outlet of culvert under Nerie Road, Flow directed into a drain and buried culvert through lot (at 25 Nerie Rd)

Photo 7: Shallow slope failures above upper Beachwood Rd (upper 43 Beachwood lot) (est. volume <10 cubic m)

Photo 8: View downslope from upper Beachwood Rd. towards lakefront properties.

Photo 9: View across top of slope below upper Beachwood Rd. where burned trees were being removed.

Photo 10: View upslope from upper Beachwood Rd. showing burned vegetation and exposed soils on steep slopes.

Appendix E List of Emergency Contacts

Appendix E - Stakeholder Contact List in the Event of an Emergency Condition or Event

On Okanagan Indian Band (OKIB) Reserve Lands:

Director of Territorial Stewardship	Colleen Marchand	250-306-9796
First Nations Emergency Services (FNESS)		

On BC Ministry of Transportation and Infrastructure (MOTI) Roadways

MOTI Okanagan Shuswap District Office (Vernon)	Danny Morris, Operations Manager	778-943-0189
AIM Roads Contractor – Service Area 13		1-866-222-4204

On Crown Lands:

Report landslide / debris flow indicators or event. Emergency Info BC		Tel. 1-800-663-3456, or 911
MFLNRORD	Shaun Reimer, Section Head, Public Safety and Protection	778-622-6826
MFLNRORD – Okanagan Shuswap Forest District	Christian Guay, Acting District Manager	250-558-1700

On Private and Public Lands within the RDCO:

RDCO Chief Administration Officer	Brian Reardon	250-469-6214
Manager of Engineering Services	Travis Kendel	250-469-6214
Director of Engineering	David Komaike	250-469-6214
Central Okanagan Emergency Operations Centre (EOC)		250-469-8490, or 1-877-569-8490

Other:

Downed Powerlines	Fortis BC	Tel. 911, or 1-866-436-7847 (FortisBC)
Natural Gas Leak	Fortis BC	Tel. 911 or 1-866-436-7847 (FortisBC)