Clarke Geoscience Ltd.

POST-WILDFIRE NATURAL HAZARDS RISK ANALYSIS OF THE 2023 MCDOUGALL CREEK WILDFIRE (K52767)

Photo of McDougall Creek Wildfire (from Reddit: r/kelowna, Aug 2023)

Dated:	January 4, 2024
Presented To:	Ministry of Forests – BC Wildfire Service
Attention:	Mr. Gareth Wells, P.Geo.
CGL Project #	23-0106
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Executive Summary

Clarke Geoscience Ltd. (CGL) was retained by the Ministry of Forests – BC Wildfire Service to complete a Post-Wildfire Natural Hazard Risk Analysis (PWNHRA) for areas affected by the 2023 McDougall Creek Wildfire (K52767). The Wildfire of Note burned a total area of approx. 140 km^2, affecting areas within the jurisdictions of the Regional District of the Central Okanagan – Electoral Area West (RDCO), the City of West Kelowna (CWK), the Westbank First Nation (WFN), and provincial Crown Lands.

The study approach generally follows *Land Management Handbook (LMH) No. 69 – Post-Wildfire Natural Hazards Risk Analysis in British Columbia* (Hope et al., 2015). The report intends to assist the Ministry of Forests – BC Wildfire Service in informing owners, other agencies and jurisdictions, and stakeholders of high-risk sites that may require immediate mitigative action to address post-wildfire natural hazard risks, or to direct more detailed assessments where required.

Post-wildfire natural hazards are associated with:

- the hydrologic effects associated with the loss of forest and the development of water repellent soils. These include faster runoff, lower infiltration, and higher peak flows; and
- the geomorphic effects such as increased soil erosion, landslides and debris flow, and sediment transport.

Post-Wildfire Natural Hazards Risk Analysis Results

The study area was divided into seven (7) different areas and catchments within these areas were delineated and assigned post-wildfire hazard ratings. The hazard ratings describe the qualitative likelihood for post-wildfire natural hazards. Each catchment is rated for the dominant hydro-geomorphic process, which is based on a combination of physical characteristics, catchment morphometry, burn severity, and other field indicators.

Risk ratings are assigned to identified Elements at Risk, such as public infrastructure and roads, domestic water intakes, private lands, and other sensitive features. The risk analysis process requires an estimated likelihood of impact to the site/location occupied by the identified Elements at Risk (referred to as “spatial likelihood”). Risk is the hazard rating combined with the likelihood of impact rating. The risk analysis is called a partial risk analysis because it does not include an assessment of vulnerability or exposure to the Element at Risk.

A summary of risk analysis results is presented in the following Table 1. High to very high-risk catchments are identified in the table. Specific sites or road segments identified as high to very high risk are listed in the Watershed Report Cards (Appendix C) and are shown on the following Summary Risk Map.

Recommended mitigation measures are presented in Section 8 of the report and are organized into the following categories:

- Increased awareness of post-wildfire hazards;
- Developing an early warning system for flood and debris flow;
- Mitigating flood impacts for the large watershed areas;
- Mitigating debris flow and debris flood impacts for smaller catchment areas;
- Mitigating small-scale landslide, rockfall, sediment-laden flooding and surface erosion; and,
- Mitigating domestic water quality impacts.

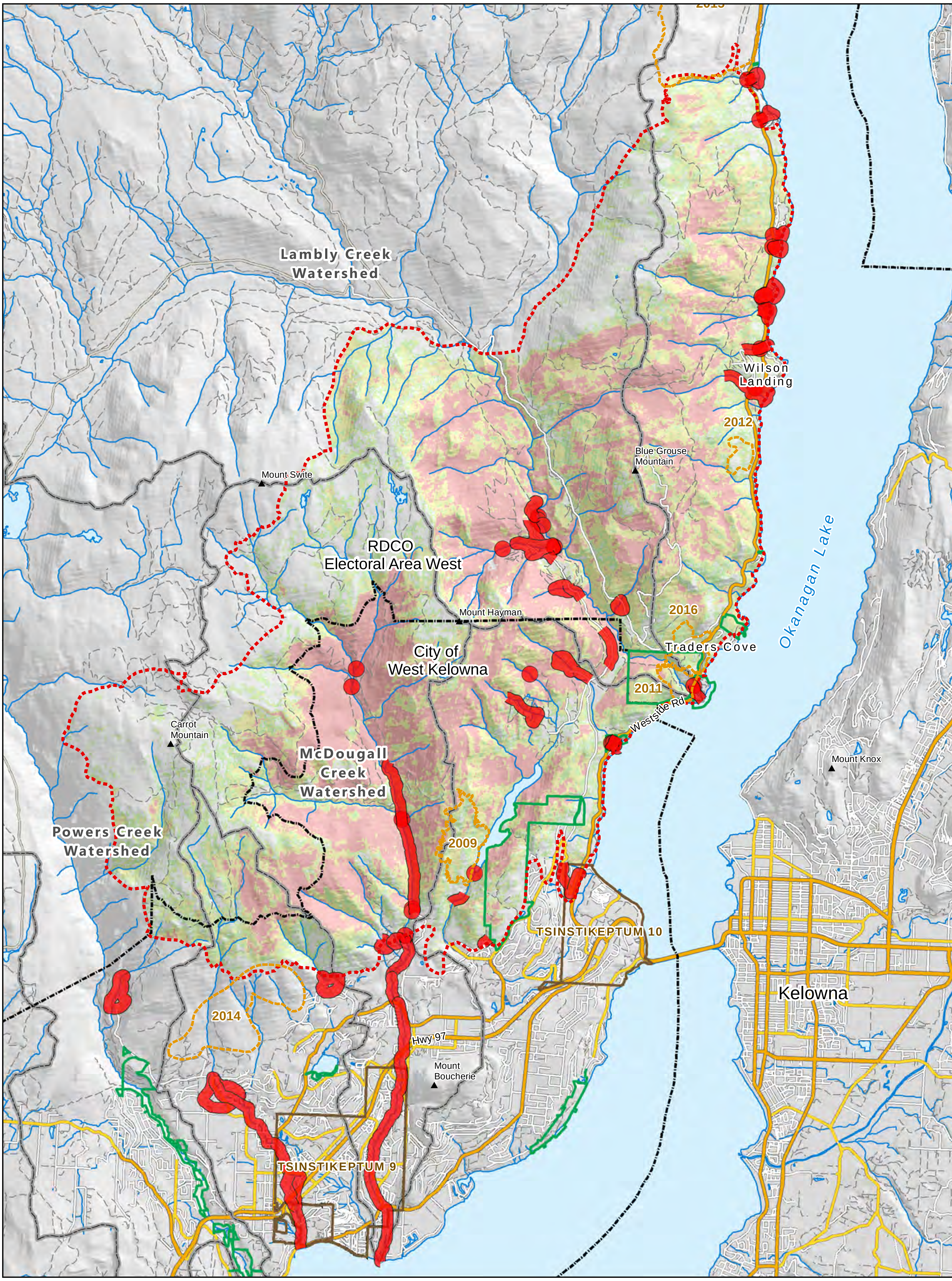
Table 1: Summary of Post-Wildfire Natural Hazard Risk Analysis Results – 2023 McDougall Creek Wildfire

				Spatial Likelihood (P(S:H)) (i.e., likelihood for impact at location)			
Map #	**Watershed / Catchment**	**Dominant Geomorphic Process**	**Post-Wildfire Hazard Level for Dominant Process (P(H))**	**Public Road & Infrastructure**	**Water Intakes & Private Road Crossings**	**Private Property[1]**	**Highest Level of Partial Risk (P(S:H) x P(H))**
Map 002	**Powers Creek Watershed**						
	Powers Creek Tributary 1	Debris Flood	Moderate	n/a	n/a	High	High
	Upper Powers Ck at POI	Flood	Low	n/a	High	n/a	Moderate
	Upland Creeks and Face Units above West Kelowna						
	Smith Creek Tributary	Debris Flood	Low	High	n/a	Moderate	Moderate
	Smith Creek at POI (Copper Ridge Rd)	Debris Flood	High	High	n/a	Moderate	Very High
	Davidson Creek	Debris Flood	High	High	High	High	Very High
	John Moore Creek	Debris Flood	High	High	High	High	Very High
	Unnamed Tributary to Lower McDougall	Debris Flow	High	High	High	High	Very High
	Face Unit near Davidson Creek	Sed Laden Flood and Erosion	High	High	n/a	High	Very High
Map 003	**McDougall Creek Watershed**						
	McDougall Creek Tributary 1	Flood	High	Low	n/a	n/a	Moderate
	McDougall Creek POI at Bartley	Flood	High	High	High	n/a	Very High
Map 004	**Rose Valley Reservoir**						
	Rose Valley Tributary 1	Debris Flow	High	n/a	n/a	n/a	n/a
	Rose Valley Tributary 2	Debris Flow	High	n/a	n/a	High	Very High
	Rose Valley Tributary 3	Debris Flow	Moderate	n/a	Low	n/a	Low
	Rose Valley Reservoir POI at Dam	Surface Erosion	High	Moderate	High	n/a	Very High
	Faulkner Creek, Keefe Creek and Luluwap Creek						
	Upper Faulkner Creek	Localized Erosion & Rockfall	High	High (localized)	n/a	Moderate	Very High
	Keefe Creek (Partial)	Sed-Laden Flood	Moderate	High	n/a	High	High
	Lower Luluwap Creek (at Westside Rd)	Sed-Laden Flood	High	High	High	n/a	Very High
	Upper Luluwap Creek	Debris Flow	High	n/a	n/a	High	Very High
	Face Unit between Keefe Ck and Luluwap Ck	Sed Laden Flood and Erosion	High	High	n/a	High	Very High

Map #	Watershed / Catchment	Dominant Geomorphic Process	Post-Wildfire Hazard Level for Dominant Process (P(H))	Spatial Likelihood (P(S:H)) (i.e., likelihood for impact at location): Public Road & Infrastructure	Spatial Likelihood (P(S:H)): Water Intakes & Private Road Crossings	Spatial Likelihood (P(S:H)): Private Property[1]	Highest Level of Partial Risk (P(S:H) x P(H))
Map 005	**Lambly (Bear) Creek Watershed and Bear Creek Road Area**						
	Lambly - Blue Grouse Ck	Debris Flow	High	High	n/a	n/a	Very High
	Lambly Tributary 2	Debris Flow	High	Moderate	n/a	Moderate	High
	Cedar Creek	Debris Flood	High	High	High	High	Very High
	Cedar Creek Tributary	Debris Flow	High	High	High	High	Very High
	Lambly (Bear) Creek POI at CWK Intake	Flood / Channel Instability	Low / High	Moderate	High	Low	Very High for channel instability
	Lambly (Bear) Creek POI at Mouth	Flood / Channel Instability	Low / High	High	High	Low	Very High for channel instability
Map 006	**Westside Road Tributaries and Face Units**						
	Cinnabar Creek	Debris Flow	Low	High	n/a	High	Moderate
	Dimetri Creek	Debris Flow	High	High	n/a	High	Very High
	Cedar Gulch	Debris Flow	High	High	n/a	Moderate	Very High
	Cedar Gulch-2	Debris Flow	High	High	n/a	Moderate	Very High
	Wilson Creek	Debris Flow	High	Moderate[2]	n/a	Moderate[2]	High
	Oldman Creek	Debris Flow	High	High	n/a	High	Very High
	Jennie Creek	Debris Flow	High	High	n/a	Moderate	Very High
	Unnamed Creek 1	Debris Flow	High	High	n/a	n/a	Very High
	Face Unit Slopes	Sed Laden Flood and Rockfall	High (loc.)	High	n/a	High	Very High
Map 007	Lower Smith Creek, downstream from Copper Ridge Dr.	Flood / Channel Instability	High	High	High	High	Very High
	Lower McDougall Creek, downstream from Bartley Rd.	Flood / Channel Instability	High	High	High	High	Very High

[1] - spatial likelihood for private properties located on the fans is approximate due to uncertainty of event magnitude, unknown capacity of culverts, and event runout characteristics. A refined risk analysis for private properties would require individual site assessments and is beyond the scope of this assessment.

[2] – past mitigation works to be confirmed.



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LEGEND

- High and/or Very High Risk Site
- Fire Perimeter (McDougall Creek Fire K52767) (September 9, 2023)
- Fire Perimiter (Historic) (Year)
- Watershed Boundary
- Municipal Boundary
- First Nations Reserve
- Park / Protected Area

Burn Severity (Source: BC Data Catalogue)

- High
- Medium
- Low

N

1,000 500 0 1,000 2,000
metres

Client: **BC MINISTRY OF FORESTS - WILDFIRE SERVICE**

Project: **POST-WILDFIRE NATURAL HAZARD RISK ANALYSIS - 2023 MCDOUGALL CREEK WILDFIRE (K52767)**

Title: **SUMMARY OF RESULTS**

Scale: 1:75,000	NAD 1983 UTM Zone 11 U	Map No.
Project No: 00-0000	Date: January 04, 2024	000

Clarke Geoscience Ltd.

Territorial Acknowledgement

Westbank First Nation (“Westbank”) are descendants of the original syilx (Okanagan) Peoples of the Okanagan Nation. The Okanagan Nation also includes Okanagan Indian Band, Osoyoos Indian Band, Penticton Indian Band, Upper Nicola Band, Upper and Lower Similkameen and Colville Federation. The trans-boundary Nation is separated by the 49th parallel and spans the Canada-US boundary in Washington state and British Columbia. The syilx territory is roughly the basin of Okanagan Lake, Okanagan River and the Similkameen River to the west of the Okanagan valley and the uppermost valley of the Nicola River.

In 2003, a government-to-government agreement by Canada recognized Westbank as a self- government with the right to make decisions regarding the land, resources on behalf of the community members. Westbank land is comprised of five reserves within West Kelowna and Kelowna area. Tsinstikeptum 9 and Tsinstikeptum 10 were two reserves directly or indirectly impacted by the 2023 McDougall Creek wildfire.

Westbank and its members are part of the syilx Peoples, a historical community of peoples sharing language, customs, traditions, experience, territory, and resources before and including the time of first contact and the Crown’s assertion of sovereignty, and presently, who have occupied and exercised jurisdiction and ownership over syilx territory since time immemorial. The syilx Peoples hold syilx Title and Rights through syilx territory, which are recognized and affirmed by Section 35 of the Constitution Act, 1982, and which have never been ceded, surrendered, or relinquished by syilx Peoples. Further, the syilx people exercise rights recognized by the United Nations Declaration on the Rights of Indigenous Peoples (“UNDRIP”).

Okanagan Place Names (English-Okanagan Translation)

- McDougall Creek - xʷaʔɬmnik
- Mission Creek - nx̌ʷaqʷaʔstn
- Okanagan Lake -kɬusxnitkʷ

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1. Introduction

Clarke Geoscience Ltd. (CGL) was retained by the Ministry of Forests – BC Wildfire Service to complete a Post-Wildfire Natural Hazard Risk Analysis (PWNHRA) for areas affected by the 2023 McDougall Creek Wildfire (K52767).

Work was authorized by the Ministry of Forests - BC Wildfire Service and is defined in the Consulting and General Services Contract #GS24WHQ0143. The scope of work is defined in Schedule A – Services of that contract.

The intended use of the report is to provide information to assist the Ministry of Forests – BC Wildfire Service in informing owners, other agencies and jurisdictions, and stakeholders of high-risk sites that may require immediate mitigative action to address risks, or where more detailed assessments may be required. The following report uses terms and language that are technical in nature and are not necessarily intended for a general audience. For assistance, a glossary of technical terms is provided.

1.1 Project Background

The McDougall Creek Wildfire (Fire K52767) was first reported on August 15, 2023. The Wildfire of Note persisted until it was declared "held" on September 20, 2023, and burned a total area of 13,970 ha (~140 km^2). The wildfire affected residents in multiple jurisdictions within the Central Okanagan, including: the Regional District of the Central Okanagan – Electoral Area West (RDCO), the City of West Kelowna (CWK), Tsinstikeptum 9 and Tsinstikeptum 10 of the Westbank First Nation (WFN), and provincial Crown Land. The wildfire perimeter and location north and west of West Kelowna, BC, are shown on Figure 1-1 and on Map 001 (see Appendix B).

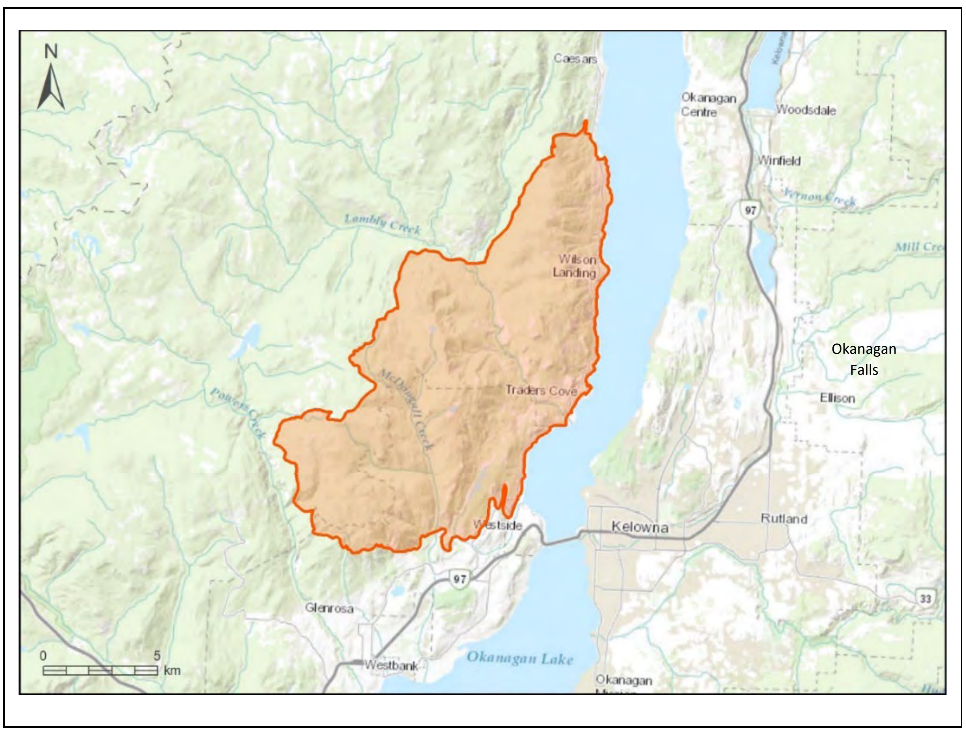


Figure 1-1: Location of Study Area (with 2023 McDougall Creek Wildfire Perimeter)

At the height of the wildfire in late August 2023, approximately 10,000 residents were under evacuation order[1] and the wildfire led to Local and Provincial States of Emergency. In total, approximately 182 structures were lost within each affected jurisdiction as follows:

- City of West Kelowna - sixty-nine (69) structures lost;
- Westbank First Nation - nineteen (19) structures lost; and,
- RDCO - Electoral Area West - ninety-four (94) structures lost, which includes the Lake Okanagan Resort as a single property (approx. 150 units lost)[2].

In addition to the McDougall Creek wildfire, three (3) other wildfires within the Central Okanagan made up what was referred to as the ***Grouse Complex Wildfire***. These other wildfires included the Walroy Lake Wildfire within the City of Kelowna (733 ha; 4 homes lost), the Clarke Creek Wildfire within the District of Lake Country (373 ha; 3 homes lost), and the Glen Lake Wildfire near Peachland (1116 ha; no homes lost). The current PWNHRA is being completed only for the McDougall Creek Wildfire. Additional geohazard assessment work was completed on behalf of the Central Okanagan Emergency Operations Centre by Ecora Engineering & Resource Group Ltd. (2023).

1.2 Project Objectives and Scope of Work

Post-wildfire natural hazard risks are associated with ***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.

The primary objective of this detailed PWNHRA is to identify the Elements at Risk from potential post-wildfire hazards, elaborate on the hazards and risks, identify the need for risk mitigation, and provide conceptual risk mitigation options, if required, with rough costs.

The specific project objectives include the following:

1. Compile an inventory of the Elements at Risk from potential post-wildfire natural hazards including residences on private property, public transportation infrastructure, domestic and community water intakes and infrastructure, recreational sites, and other pertinent values.
2. Identify potential post-wildfire natural hazards which may affect the identified Elements at Risk. These hazards include hydro-geomorphic hazards such as debris flows, debris floods, sediment-laden floods, and clear water flooding, and geomorphic hazards such as landslides, rockfall and soil erosion.
3. Conduct a partial risk analysis for each hazard type, and for each Element at Risk.
4. Identify the need for risk mitigation and provide conceptual risk mitigation options.

[1] City of West Kelowna Website URL: https://www.westkelownacity.ca/en/our-community/mcdougall-creek-wildfire-information.aspx
[2] Central Okanagan Emergency Operations Website URL: https://www.cordemergency.ca/updates/evacuation-order-state-local-emergency-rescinded-mcdougall-creek-wildfire-thu-09282023-1530

2. Study Tasks & Risk Analysis Approach

The approach generally follows that which is outlined in *Land Management Handbook (LMH) No. 69 – Post-Wildfire Natural Hazards Risk Analysis in British Columbia* (Hope, et al., 2015). The work approach provides a detailed evaluation of risks.

2.1 Study Tasks

The 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 pertinent background information was gathered and reviewed. Publicly available information was reviewed to characterize area topography, terrain, bedrock, and hydrology.

Task 2: Complete a Geohazard Screening Assessment and Collect GIS-Derived Watershed Parameters for the Hazard Assessment. This task is a desktop GIS-based screening assessment of the sub-basin areas to determine the dominant hydro-geomorphic process and to direct field efforts to high hazard areas. Catchments were first delineated using high-resolution LiDAR Digital Elevation and Hillshade Model data.

Task 3: Aerial reconnaissance and ground-based field assessment of the slopes, creek banks, and fan areas within the areas potentially affected by the effects of wildfire. A helicopter overview flight documenting conditions at higher elevations was completed on September 19, 2023 by J. Clarke, P.Geo., of Clarke Geoscience Ltd., accompanied by T. Robertson, P.Geo., P.L.Eng. of Sitkum Consulting Ltd. Ground-based field assessment was completed between Sept. 19 and Nov. 7, 2023 by J. Clarke, P.Geo., accompanied various personnel. Photos and field notes were collected using a tablet on georeferenced maps using the Avenza app.

Task 4: Conduct a hazard and partial risk analysis. This task assigns a qualitative level of risk to the identified hazards. It identifies high priority sites/areas which may require response/repair and distinguishes them from lower priority sites that can be addressed at a later time. The risk 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 a combination of the likelihood of an event occurring, and the likelihood of that event reaching or otherwise affecting a specified Element at Risk.

Task 5: Develop concept-level mitigative strategies and approximate costs to address high risk sites. Recommended measures to reduce or eliminate risk are identified and order of magnitude level cost estimates are provided for planning purposes.

Task 6: Prepare a Report. This report accompanies maps (Appendix B) and Report Cards along with select photographs (Appendix C) that document post-wildfire natural hazard conditions and the results of the risk analysis for each catchment within the study area.

2.2 Partial Risk Analysis 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 analysis approach, outlined in LMH #69 and adopted for this project, is a qualitative partial risk analysis. The approach and definitions of technical terminology are provided in LMH #56 (Wise, et al., 2004). The results provide a means to identify and prioritize sites for mitigative measures.

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

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 1 and 2). The hazard and spatial likelihood ratings are combined in a matrix (see Table 2-1 below) to determine partial risk.

Table 2-1: Qualitative Partial Risk Analysis Matrix (adapted from Wise et al., 2004)

<table>
<tr><th 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)</th><th 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.</th></tr>
<tr><th>High</th><th>Moderate</th><th>Low</th></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 analysis, above, is an assigned risk level. Five possible outcomes, or risk levels, range from very low to very high. 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.

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

High vegetation burn severity wildfire consumes the forest canopy and underlying soils. Normally, these function to intercept precipitation, moderate infiltration, and protect mineral soils from erosion. With wildfire, there is an immediate decrease in evapotranspiration and infiltration, and exposed mineral soils become subject to surface erosion. These effects may also be exacerbated by wildfire-induced soil-water repellency[3].

Soil-water repellency occurs at, or just below, the soil surface and is caused when intense heat from wildfire burns plant material that releases waxy substances that coat soil particles. It is a characteristic that develops more strongly on areas burned at moderate to high vegetation burn severity. The development of repellency is also 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) (DeBano, 1981). Soil texture also influences the development of soil-water repellency. Very coarse-textured angular sediments such as colluvium are less likely to become water repellent after severe wildfire.

The hydro-geomorphic processes that are most affected by the effects of wildfire are listed below:

Hydrologic Hazards - Flooding, debris floods, and sediment-laden floods are hydrologic processes associated with the loss of vegetation and soil by wildfire, and by the development of soil-water repellency due to high burn severity wildfire. Effects include:

- Faster runoff and greater volume of runoff due to the loss of interception and transpiration by vegetation, and by the reduced infiltration into wildfire-affected soils. 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).
- Sediment-bulking of a stream occurs with increasing sediment inputs from tributaries, side slopes or within-channel mobilization. With increasing sediment, the hydrologic process will transition to a geomorphic process (i.e., debris flow).
- In snow-dominated watersheds, wildfire results in greater snow accumulation, earlier onset of snow melt, and increased rates of snow melt. Thus, in a transitional watershed that occupies a wide range of elevations, wildfire at higher elevations has a more pronounced effect on snowmelt generated peak flows.
- The effect on peak flows is proportional to the area burned at moderate to high burn severity.

[3] Soil-water repellency, also referred to as hydrophobicity, describes soils that repel water.

- Post-wildfire hydrologic response will be greater in smaller catchment areas due to the short time of runoff concentration and synchronization of runoff during intense convective rain events. While hydrologic changes in larger watersheds may be reduced by the desynchronization of widespread regional rainfall events and snowmelt 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 and soil runoff effects due to wildfire and water repellent soils along slopes within the study area. Effects include:

- Increased likelihood of open slope landslides (slumps, debris slides, debris avalanches) and channelized landslides (debris flows).
- Accelerated soil erosion due to exposed mineral soils.
- Thermal expansion of rocks due to intense heating that may destabilize exposed bedrock.
- Stability impacts will be most apparent on steep (>60%) slopes and along steep debris-flow prone gullies.
- 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.

While snow avalanches are not specifically considered for this study, there is an increased likelihood for snow avalanches associated with the loss of forest cover by wildfire. These effects are more likely to occur in areas that already experience snow avalanche activity. The 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[4]. 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.

The presence of danger trees associated with burned areas is not considered for this study but is an important public safety factor.

3.2 Post-Wildfire Debris Flow Trigger Mechanisms

Post-wildfire debris flow trigger mechanisms for catchments located in the BC Southern Interior were identified after the 2003 Okanagan Mountain Fire and other wildfires in 2007 and 2009 (Jordan and Covert, 2009) (Jordan, 2016).

In Jordan (2016) post-wildfire debris flow events were found to have been triggered by spring snowmelt, by short-duration high-intensity rainstorms in the summer, and by low-intensity fall rainstorms. The specific initiation mechanisms are described as:

- Runoff-Triggered Debris Flows - the most common debris flow initiation mechanism is by runoff, caused by erosion of channel bed and banks, and progressive bulking of sediment within the channel, caused by a critically high discharge; and,

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

- Landslide-Triggered Debris Flows – these types of debris flows are caused when a landslide enters a steep channel. This was found to be the most common debris flow trigger mechanism in unburned forested landscapes in the Southern Interior.

Much of the post-wildfire natural hazard research comes from the Pacific Northwest of the US, and California, where post-wildfire debris flow events are more common. In the Southern Interior of BC there are fewer documented events. This may be attributed to lower rainfall intensities, and lower soil burn severity attributed to thicker, moister forest floors, and wetter climates. More recently, it is widely accepted that BC is experiencing higher precipitation intensities more frequently due to climate change, and normally moist soils are now drier due to prolonged periods of drought. Drier soils and forests contribute to higher burn severities, which also affects debris flow likelihood.

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

Research on the persistence of wildfire-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 repellent 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).

Hope et al. (2015) indicate that post-wildfire effects on hydrology increase in the first two to three years following wildfire, and then decrease in time after that. Degraff et al. (2015) indicate that the great majority of post-wildfire debris flows in the western US region occur within the first 12 to 18 months. Longer-term hydrologic effects at a watershed scale are typically associated with changes to the spring snowmelt hydrograph (i.e., greater snow accumulation, faster 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, or when the structure of the new forest approaches a pre-wildfire condition, which could be several decades post wildfire (Hope et al, 2015; Jordan, 2015).

For the wildfire-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-wildfire.

4. Study Area Characteristics

The project study area is located within the Central Okanagan on the west side of Okanagan Lake immediately west and north of the City of West Kelowna, BC. The McDougall Creek wildfire affected small catchments draining the slopes above Westside Road, the lower portion of the Lambly (Bear) Creek watershed, the Rose Valley Reservoir watershed, a large portion of the McDougall Creek watershed, and smaller catchments to the south, including the upper part of the Smith Creek watershed. Only a small area within the Powers Creek watershed was burned.

The study area is sub-divided into larger watersheds (such as McDougall Creek and Lambly Creek) and smaller catchments. Open slope areas located between the catchments are called "face units". The watersheds and catchments are shown on Maps 002 to 007 in Appendix B. For the purposes of this assessment, Points of Interest (POI) for catchment areas are located at the top of their corresponding fan. For the larger watersheds, POIs are identified at key locations, such as the CWK Diversion Intake on Lambly Creek, or the base of the canyon on McDougall Creek, upstream of Bartley Road.

Study area characteristics that are relevant to the study are provided at an overview level and focus on the pre-wildfire conditions. These include:

- **Physiography**, which includes catchment area, relief, slopes, morphometric relations that help characterize the dominant hydro-geomorphic processes.
- **Climate**, provides information on seasonal temperatures and precipitation (rain and snow), including information on the timing of the spring snow melt (helps 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**, characterizes the (pre-wildfire) seasonal timing of peak flows, characteristics peak flows, and past flood events.
- **Geomorphology & Pre-Existing Natural Hazards**, provides information on bedrock geology, soils, terrain stability and geomorphical processes occurring in the watershed. These indicators provide key information with regards to natural hazard types and processes occurring with the study area.
- **Past Wildfire and Logging History.** Understanding the natural disturbance history and the hydrologic and geomorphic response to past disturbance will help predict future response.
- **Vegetation and Soil Burn Severity.** Vegetation burn severity refers to the effects of wildfire on the forest canopy and the understory and provides an indication of the likelihood and distribution of hydrologic and geomorphic impacts. Field work was conducted to determine whether vegetation burn severity is equivalent to soil burn severity. Areas with a moderate to high soil burn severity are more likely to have associated soil 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 lies within the Southern Interior Plateau physiographic area, characterized by a broad upland area of subdued topography separated by steep-sided u-shaped valleys (Church and Ryder, 2010).

The downslope boundary of the study area is at Okanagan Lake (elev. 353 m), or at the top of the fan for individual catchments, within the Okanagan Valley. The wildfire extended upslope into the headwaters of

McDougall Creek (elev. ~1500 m) to the west, and to the height of land along the areas along Westside Road (elev. ~1200 m). The total relief ranges from ~800 m along Westside Road to ~1000 m on the west side of the study area.

Table 4-1 provides a physiographic summary and Melton Ratio[5] classification of study area catchments. The Melton Ratio and the morphometric parameters that are used to derive the Melton Ratio provide insight to the dominant hydro-geomorphic process occurring within each area (Wilford, et al, 2004) (Church and Jakob, 2020). Melton Ratio is plotted against watershed stream length in Figure 4-1. The classification is used as a screening tool during initial stages of the assessment. Generally, the classification indicates that larger watersheds are mostly prone to floods, while smaller, steeper catchments are prone to a mixture of debris flood and debris flow processes, indicating increasing potential for damages due to sediment/debris bulking. Depending on sediment supply and sediment transport potential, subbasin catchments within the larger catchments, or small catchments located within face unit areas are potentially subject to debris flow and/or sediment-laden flooding. For catchments with plateau (more gently sloped) headwater areas, the Melton Ratio can underestimate debris flow potential.

The physiographic characterization of each catchment provides a sense of pre-wildfire condition. The dominant hydro-geomorphic process would apply regardless of wildfire.

Table 4-1: Physiographic Summary of Study Area Catchments

Catchment/Watershed	Area (ha)	Relief (m)	Length of Catchment (km)	Melton Ratio (calc.)	Dominant Hydro-Geomorphic Process
Powers Creek Watershed					
Powers Creek Tributary 1	206	557	2.1	0.39	Debris Flood
Upper Powers Ck at POI	12,538	1,236	18.5	0.11	Flood
Upland Creeks in West Kelowna					
Smith Creek Tributary	108	573	1.8	0.55	Debris Flood/Debris Flow
Smith Creek at POI (Copper Ridge Rd)	501	896	5.8	0.40	Debris Flood
Davidson Creek	166	698	2.4	0.54	Debris Flood/Debris Flow
John Moore Creek	203	760	3.0	0.53	Debris Flood/Debris Flow
Unnamed Tributary to Lower McDougall	124	724	2.4	0.65	Debris Flood/Debris Flow
McDougall Creek Watershed					
McDougall Creek Tributary 1	869	826	4.7	0.28	Flood/Debris Flood
McDougall Creek POI at Bartley	3,919	996	9.6	0.16	Flood
Rose Valley Reservoir					
Rose Valley Tributary 1	27	470	0.9	0.91	Debris Flow
Rose Valley Tributary 2	102	729	1.9	0.72	Debris Flow
Rose Valley Tributary 3	141	680	2.0	0.57	Debris Flood/Debris Flow
Rose Valley Reservoir POI at Dam	1,070	844	n/a	0.25	n/a

[5] The Melton Ratio is a measure of watershed "ruggedness" and is calculated as the watershed relief (m) divided by the square root of watershed area (m^2) (Melton, 1957; Wilford et al., 2004).

Catchment/Watershed	Area (ha)	Relief (m)	Length of Catchment (km)	Melton Ratio (calc.)	Dominant Hydro-Geomorphic Process
Faulkner, Keefe and Luluwap Creek					
Upper Faulkner Creek	160	517	n/a	n/a	n/a
Keefe Creek (Partial)	231	436	n/a	n/a	n/a
Lower Luluwap Creek (at Westside Rd)	91	327	1.2	0.34	Debris Flood
Upper Luluwap Creek	65	593	1.3	0.74	Debris Flow
Lambly (Bear) Creek Watershed and Bear Creek Road Area					
Lambly - Blue Grouse Ck	113	853	2.4	0.80	Debris Flow
Lambly Tributary 2	42	597	1.1	0.92	Debris Flow
Cedar Creek	306	757	1.9	0.43	Debris Flood
Cedar Creek Tributary	41	582	1.2	0.91	Debris Flow
Lambly (Bear) Creek POI at CWK Intake	23,178	1,273	21.1	0.08	Flood
Lambly (Bear) Creek POI at Mouth	24,363	1,527	25.6	0.10	Flood
Westside Road Tributaries					
Cinnabar Creek	143	822	2.4	0.69	Debris Flow
Dimetri Creek	114	840	2.3	0.79	Debris Flow
Cedar Gulch	56	863	2.3	1.14	Debris Flow
Cedar Gulch-2	43	600	1.4	0.91	Debris Flow
Wilson Creek	126	882	2.8	0.79	Debris Flow
Oldman Creek	142	902	2.6	0.76	Debris Flow
Jennie Creek	157	742	2.6	0.59	Debris Flow
Unnamed Creek 1	86	885	2.3	0.95	Debris Flow

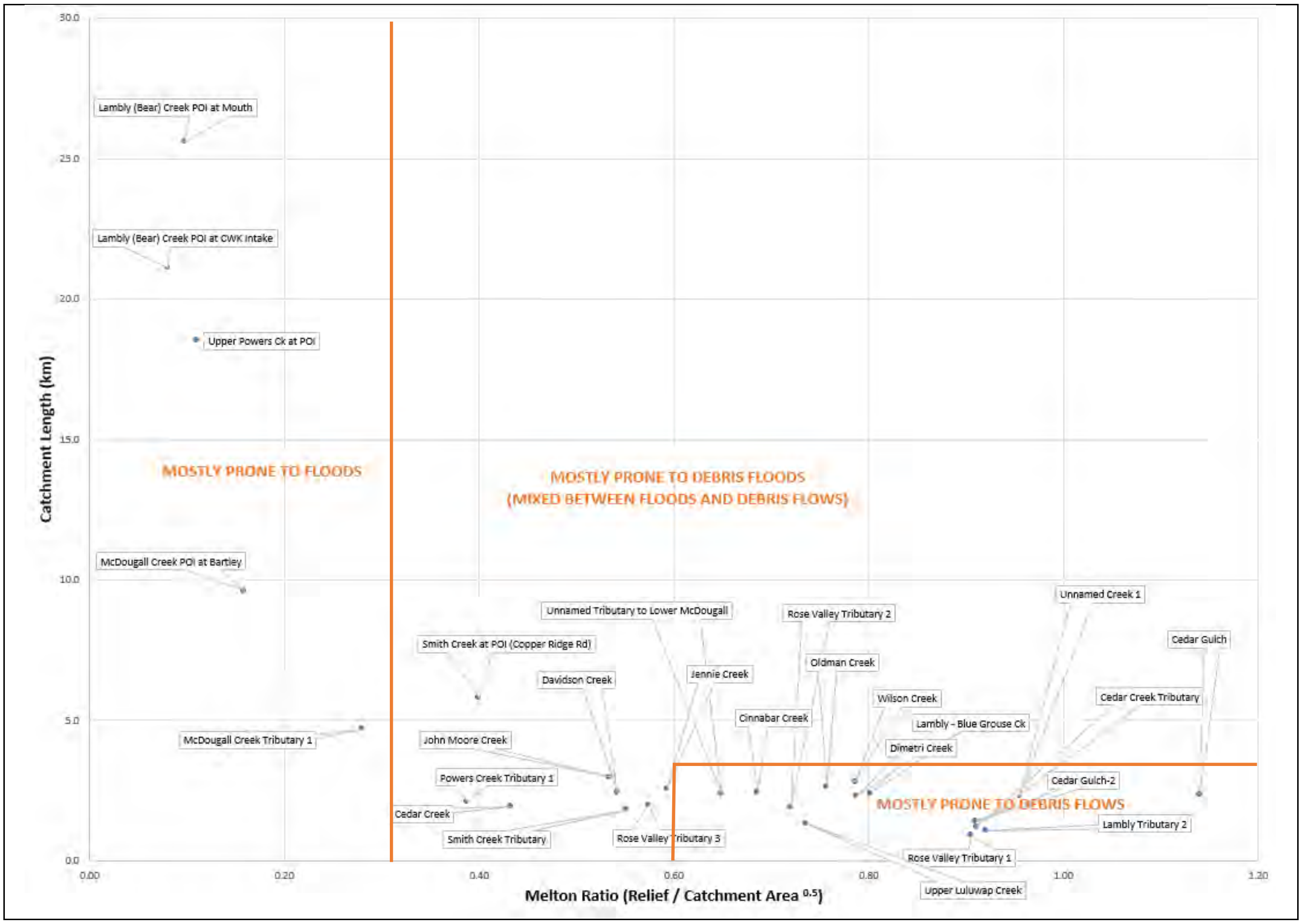
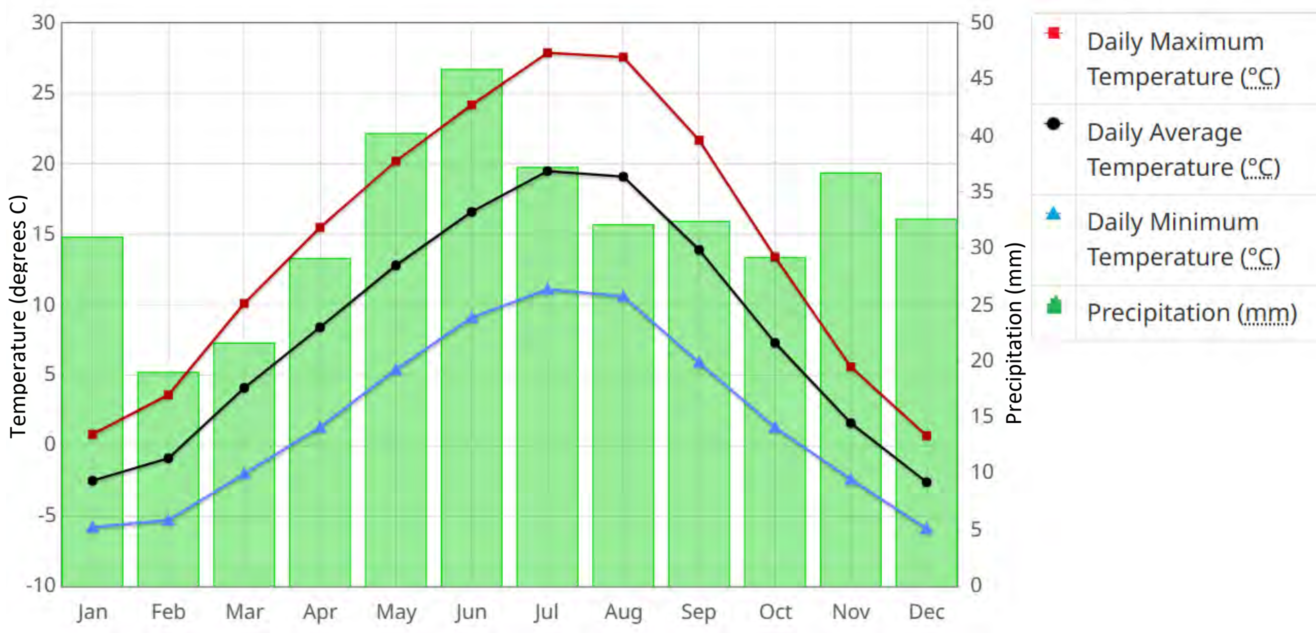


Figure 4-1: Melton Ratio Classification for Study Area Sub-Basins (following approach by Wilford, et al., 2004)

4.2 Climate (Precipitation and Biogeoclimatic Zones)

4.2.1 Temperature and Precipitation

The closest real-time climate station to the study area is located at Kelowna Airport (Stn 1123939) at 433 m elevation (period of record 2009-2023). Long term climate data from the Kelowna A (Stn. 1123970) are provided in the Climate Normals for 1981-2010 (see Figure 4-2). Average annual total precipitation is 386.9 mm, of which 311.3 mm is rain and 89 cm is snow. The data record indicates that the highest extreme daily precipitation of 33.8 mm occurred on July 21, 1997.



Source: Environment Canada[6] data for Kelowna A Station (#1123970)

Figure 4-2: Temperature and Precipitation Climate Normals (1981-2010) for Kelowna A, BC

The closest high elevation automated snow weather station to the study area is Whiterocks Mountain station (#2F09P). The station, located at 1795 m elevation in the headwaters of Lambly Creek, is approximately 20 km northwest of West Kelowna. The data at this station are available in near-real-time. Snow data, reported as snow water equivalent (mm) for the 2022-2023 year, is shown in Figure 4-3. The data indicate that peak snow accumulation occurs in late April, with a rapid period of melt occurring in May. Other nearby manual snow survey stations include: Islaht Lake (#2F24) within the upper Powers Creek watershed, and Esperon Creek Middle (#2F14) in the upper Lambly Creek watershed. For flood forecasting purposes, the May 1 2024 Snow Survey and Water Supply Bulletin from the BC River Forecast Centre[7] will provide valuable spring snow data.

It is understood that local climate and snowpack monitoring is monitored by the City of West Kelowna within the Powers Creek and Lambly Creek Community Watersheds. More information on what data is being collected and whether it can be used to forecast flooding in the area is needed.

[6] https://climate.weather.gc.ca/climate_normals/

[7] https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/drought-flooding-dikes-dams/river-forecast-centre/snow-survey-water-supply-bulletin

Data Source: BC Snow Survey Stations Interactive Map [URL: https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-science-data/water-data-tools/snow-survey-data]

Note: Period of record is not long enough for this station to provide averages and other statistics

Figure 4-3: Historical Snow Water Equivalent (mm) at Whiterocks Mountain (Stn. 2F09P)

Precipitation intensity-duration-frequency (IDF) data is available for the Kelowna A Station based on data for the period 1969-2004. Research from the USGS[8] indicates that the 2 to 5-year, 15 -minute storm is the storm most likely to generate debris flows. For the Kelowna A Station, this storm has an intensity of 25-38 mm/hr.

Real-time precipitation data is useful for monitoring and can be used to develop warning systems for rainfall-triggered debris flow and flooding events. Currently, the only real-time monitoring is available from the following sources:

- Weather forecasts for the southwest interior of BC from Environment Canada: Forecasts for the southwest interior of British Columbia - Environment Canada (weather.gc.ca).
- Severe weather warnings, advisories, and alerts are broadcast through the “Weatheradio” receiver (frequency 162.550 MHz for Kelowna).

4.2.2 Biogeoclimatic Zones in the Study Area

Biogeoclimatic zones are a regional climate-based ecosystem classification that defined as “a geographic area having similar patterns of energy flow, vegetation and soils as a result of a broadly homogeneous climate” (BC Ministry of Forests). Biogeoclimatic zones within the study area are mapped by the BC Ministry of Forests (2021) and are shown in Figure 4-4.

[8] United States Geological Survey, Emergency Assessment of Post-Wildfire Debris-Flow Hazards (URL: https://www.usgs.gov/programs/landslide-hazards/science/emergency-assessment-post-fire-debris-flow-hazards)

Valley bottom areas within the City of West Kelowna and below Westside Road, extending upslope to ~600 m elevation, are characterized by the Okanagan variant of the very dry hot Ponderosa Pine (PPxh1) biogeoclimatic zone. Lower slope areas, extending into the lower McDougall Creek watershed, into the lower Lambly Creek watershed, and upslope of Westside Road to ~1000 m elevation, are within the Okanagan variant of the dry cool Interior Douglas Fir (IDF dk1) biogeoclimatic zone. Upper slopes along the Westside Road area and mid-slope elevations within the larger watershed and upslope areas of the Smith Creek watershed are within the IDFdk2 biogeoclimatic zone.

The highest elevations of the study area are within the Okanagan variant of the (MSdm2) biogeoclimatic zone. The downslope elevation of the MSdm2 biogeoclimatic zone is approx. ~1300 m. Above this approximate elevation, there is an increased role of a seasonal snowpack on hydrology.

The 2023 McDougall Creek wildfire predominantly affected forests located within the IDFdk1 and IDFdk2 biogeoclimatic zone, which generally lies below ~1400-1500 m elevation. This biogeoclimatic zone is described as an ecosystem with frequent stand-maintaining wildfire (i.e., Natural Disturbance Type 4). For these stand types, there is value in maintaining frequent low intensity wildfires rather than suppressing wildfire to the point of experiencing more infrequent high intensity wildfire events.

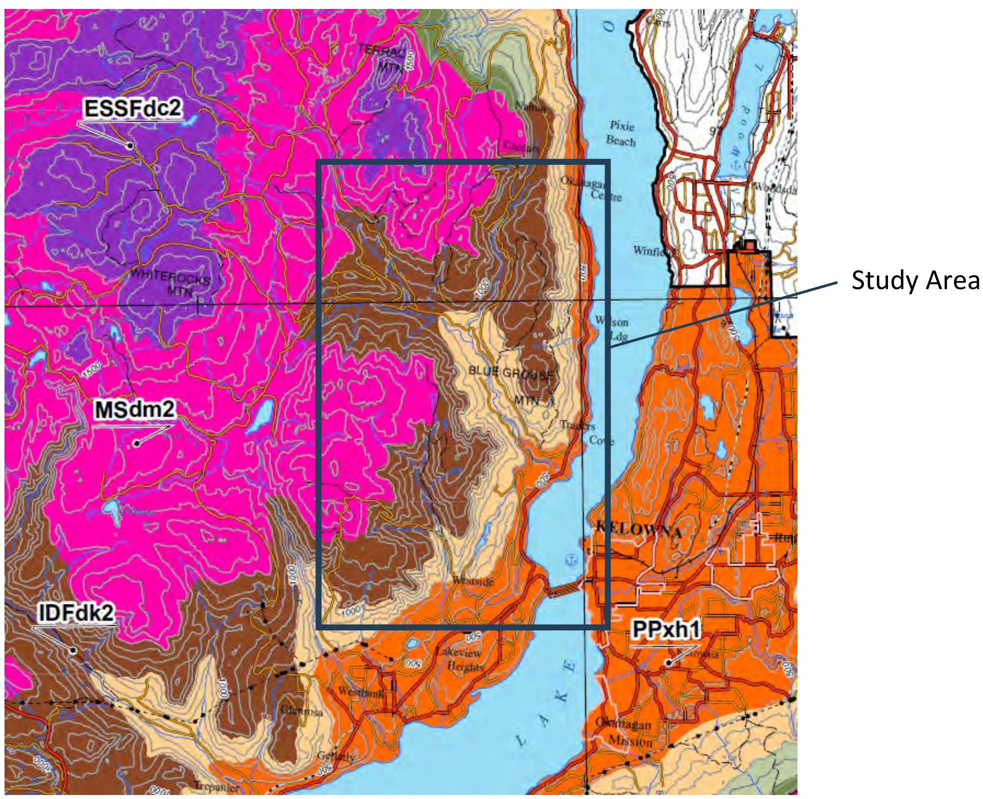


Figure 4-4: Biogeoclimatic Zones within the Study Area (MOF, 2021)

4.3 Hydrology

Characterizing hydrology for the larger streams in the study area, such as McDougall Creek and Lambly Creek, helps to understand what factors influence peak flows and the timing of peak flows. The most relevant hydrologic data is available for Lambly Creek from the Water Survey of Canada hydrometric station "Lambly Creek Above Terrace Creek" (Station #08NM165; Period of record 1970-1996). This station is located approx. 2 km upstream from the CWK Diversion of domestic water from Lambly Creek to the Rose Valley Reservoir. A longer period of record (1971-2019) and real-time monitoring is available for Whiteman Creek (WSC Station 08NM174), located approximately 25 km north of the Lambly Creek station.

Historical flow data for Lambly Creek Above Terrace Creek (see Figure 4-5) indicate that, on average, peak flows typically occur in mid- to late-May and are attributed to snowmelt. Maximum peak flows occur between late-May and late-June, with smaller peaks apparent in the summer that are attributed to rainstorms.

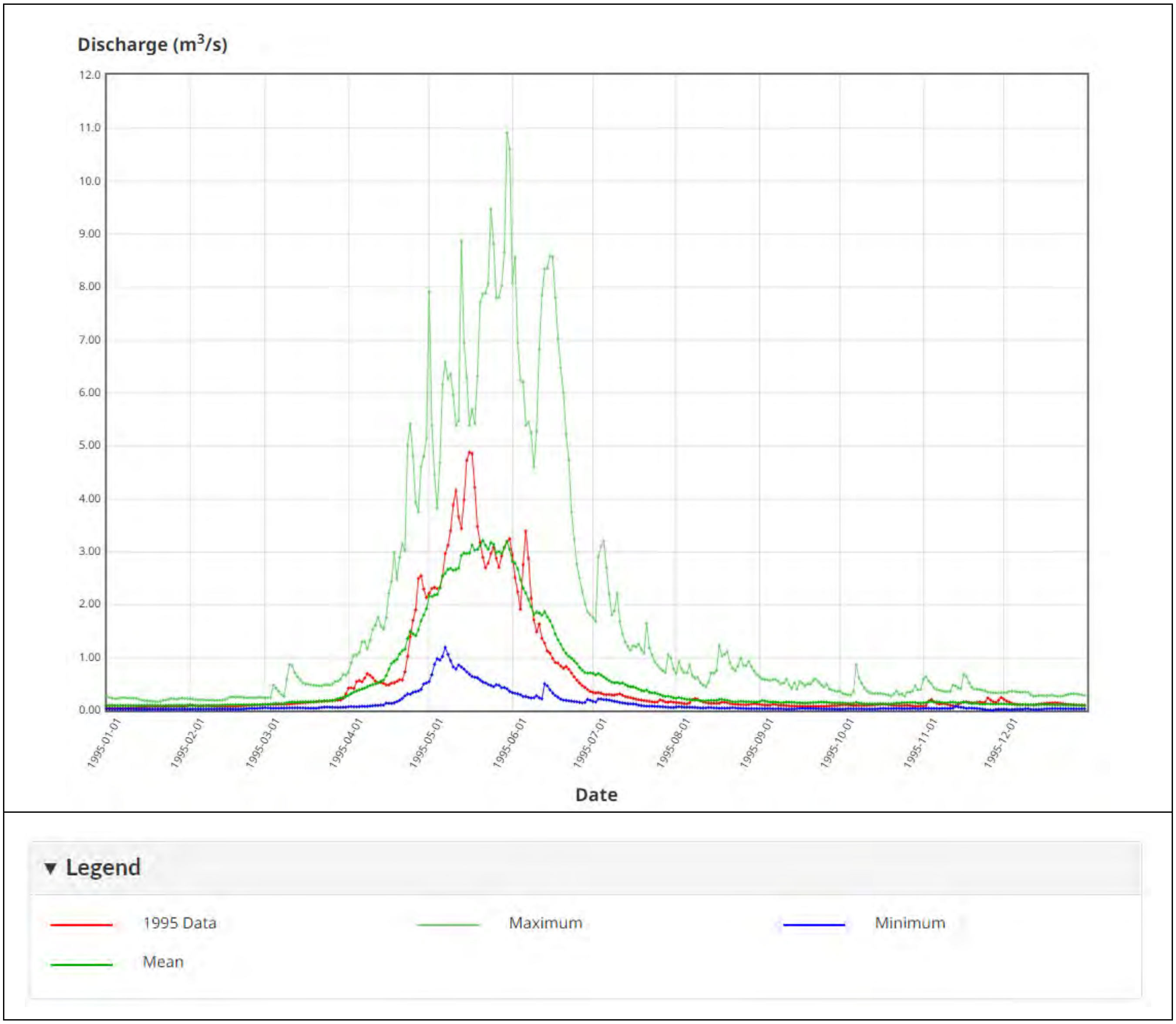


Figure 4-5: Streamflow at Lambly Creek Above Terrace Creek (WSC #08NM165) (Period 1970-1996)

The McDougall Creek wildfire extended into the higher elevation areas (i.e. snow accumulation zone) of the McDougall Creek watershed. Loss of forest within the snow accumulation zone is more likely to result in increased snow accumulation (i.e. higher water yield) and faster snow melt resulting in an earlier peak flow and a higher peak flow in the spring. Other burned areas were at a lower elevation, including areas within the Lambly Creek watershed, the Smith Creek watershed, and the smaller catchments above Westside Road. There are no stream gauges on the smaller catchments in the study area. The small catchments are situated at a lower elevation and the processes that shape the mean annual hydrograph may still be dominated by a spring snow melt, but the peak would occur earlier and may be driven by temperature or rain-on-snow. At any time of the year, the hydrograph responds to rainfall events, so it tends to be flashier, with sharp peaks.

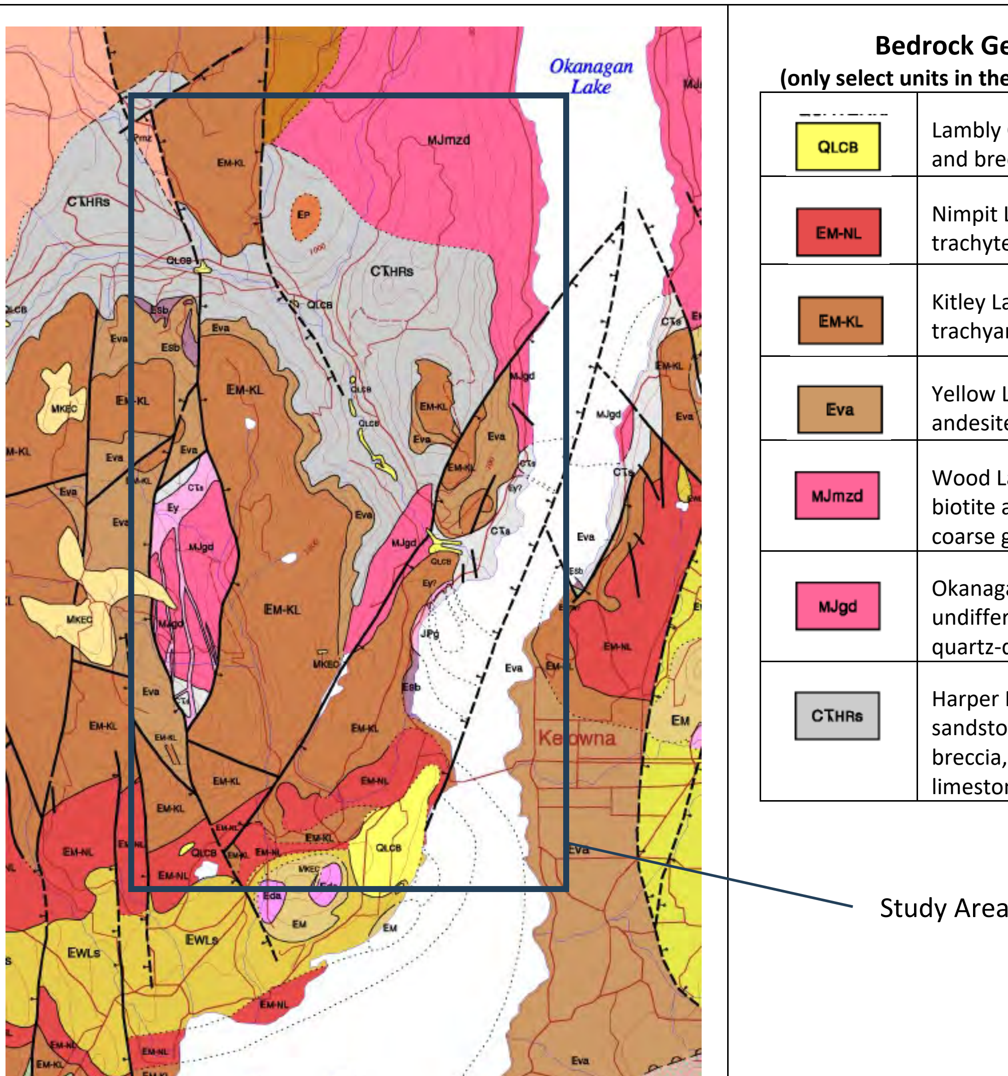
A Flood Mapping Project was completed by Associated Engineering Ltd. (2023) on behalf of the City of West Kelowna. The project provides flood inundation mapping and flood hazard mapping for six (6) watersheds including: Powers, Smith, McDougall, Keefe, Faulkner, and Lambly Creeks. The report includes a hydrologic analysis to determine instantaneous peak flows at various return periods, and hydraulic modelling was completed to develop flood inundation maps. The hydrology data from the Associated Engineering report was used for the post-wildfire hydrology analysis (Section 6.3) and the hydraulic modelling was used to identify areas and structures at risk from potential post-wildfire flood hazards.

Potential post-wildfire flood hazards are anticipated in areas that have experienced past flooding. Damaging flood events have occurred within the study area during the spring freshets of 2017 and 2018 as a result of high snowpack conditions and a rapid spring melt. Sites identified as being impacted by past flooding are reported by Associated Engineering (2023) and include:

- Powers Creek – Sediment deposition in the reservoir at the Water Treatment Plant
- Smith Creek - Flood issues along the entire length of Smith Creek, from Copper Ridge Drive to the mouth at Okanagan Lake.
- McDougall Creek - Flood issues on lower reaches of McDougall Creek, including downstream of Shannon Lake Road and a private driveway crossing on Hitchner Road.
- Faulkner and Keefe Creeks – Erosion issues downstream of Caledonia Way, and past flooding issues on WFN Tsinstikeptum 9 near Westside Road.

4.4 Bedrock Geology & Surficial Geology

Bedrock geology mapping within the study area is compiled by the Geological Survey of Canada (Okulitch, 2013) and is shown in Figure 4-6. At the north end of the study area, the slopes above Westside Road are underlain by intrusive monzonite of the Wood Lake Pluton, a coarse-grained rock that weathers to sandy material.



Bedrock Geology Legend
(only select units in the study area are described)

QLCB	Lambly Creek Basalt – basalt, lava and breccia; minor interflow till
EM-NL	Nimpit Lake Member – lava, trachyte, trachyandesite
EM-KL	Kitley Lake Member – lava, trachyandesite
Eva	Yellow Lake Member - lava, andesite
MJmzd	Wood Lake Pluton – monzonite, biotite and/or hornblende (med to coarse grained)
MJgd	Okanagan Plutonics – undifferentiated granodiorite, quartz-diorite (coarse grained)
CTHRs	Harper Ranch Group – siltstone, sandstone, argillite, conglomerate, breccia, phyllite, quartzite, limestone (fine-grained)

Figure 4-6: Bedrock Geology within the Study Area (Okulitch, 2013)

Bedrock within the Lambly (Bear) Creek watershed is characterized by much older sedimentary rocks of the Harper Ranch Group, which includes siltstone, sandstone, argillite, conglomerate, breccia, and others. These fine-grained rocks have been highly folded and fractured; they tend to weather easily and form fine-textured surficial sediments that are highly erodible. The older sedimentary rocks are overlain by more recent lava flows of the Lambly Creek Valley Basalt, which form blocky near-vertical columns along exposures. There is reported evidence of interflow till deposits between the flow sequences (Roed and Greenough, 2014). The lower reaches of Lambly (Bear) Creek are tightly confined in bedrock that was downcut when streamflow that was previously diverted south to Rose Valley, was later re-established to what is now the creek mouth at Okanagan Lake. The bedrock sequence visible in the lower canyon is described by Roed and Greenough (2014) and a representative example is shown in Figure 4-7.

The southern half of the study area, including the upslope areas within the McDougall Creek and Smith Creek watersheds, is underlain by undivided Tertiary volcanic rocks of the Penticton Group. These rocks are formed by volcanic flows and are relatively resistant but weather to fine-textured sediments. Slopes on either side of the

Rose Valley Reservoir are comprised of volcanic rock and the valley itself is oriented along a bedrock fault. Steep bedrock ridges oriented parallel to the Okanagan Valley characterize the slopes above the reservoir and the McDougall Rim forms the height of land on the west side of the reservoir.

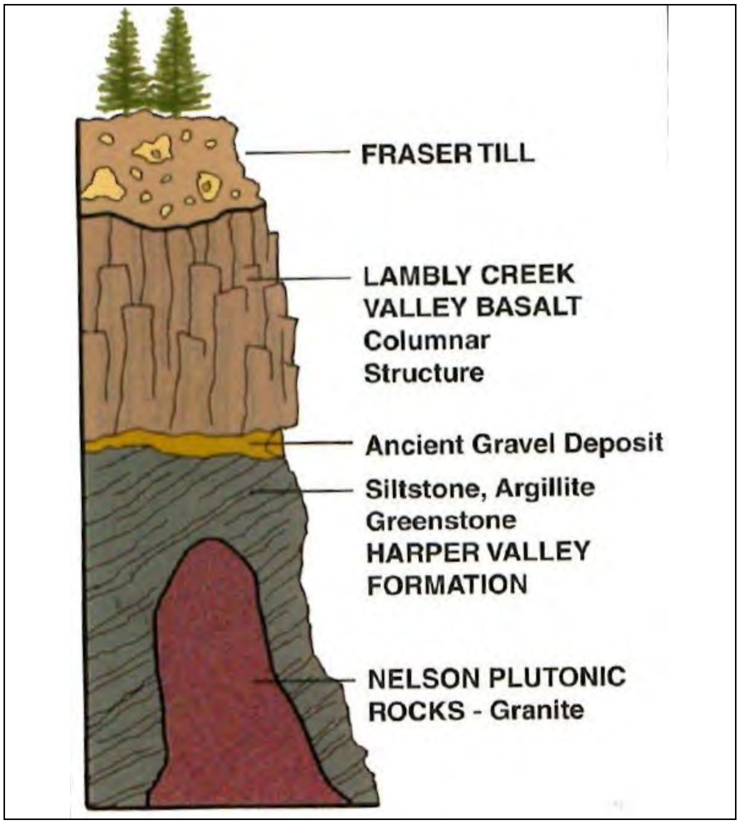


Figure 4-7: Example Bedrock Geologic Sequence Exposed along Lower Lambly (Bear) Creek Canyon (from Roed and Greenough, 2014).

Surficial materials within the study area reflect the processes associated with the most recent glaciation, which ended approximately 10,000 years ago. The glacial history of the study area is described in Nasmith (1962) and the distribution and character of surficial materials is mapped by the Geological Survey of Canada (Paradis, 2009). A map of surficial materials adapted for the study area is provided as Figure 4-8.

At the height of the last glaciation, the upland plateau areas were covered with ice and this ice retreated downwards from the plateau, leaving behind a mantle of heterogenous sediments (i.e., till) over bedrock[9], varying in thickness (see Figure 4-8). During deglaciation, glacial meltwater flowed down into the ice-filled Okanagan Valley. It is speculated that the generally steep slopes and thin mantle of overburden materials across the study area suggests that meltwater flowed on the ice surface resulting in few meltwater channels being carved into the western Okanagan Valley side slopes (Nasmith, 1962). Within the project study area, meltwater channels oriented parallel to the Okanagan Valley are located along Bald Range Creek (a tributary stream in the Lambly Creek watershed), and between Lambly Creek into the Rose Valley Reservoir area. These meltwater (and diverted stream flow) channels are characterized by deeper glaciofluvial deposits (see Figure 4-8). From

[9] The composition and texture of till generally reflects that of the underlying bedrock.

the Rose Valley area, sediments carried by meltwater were deposited into a series of kame terraces along the valley slopes. Shannon Lake is an example of a large kettle formed by a ice block melting into the surrounding kame sediments. As a result, the glaciofluvial sediments deposited along the valley slopes between Rose Valley and Powers Creek are coarse-textured pervious sediments that drain rapidly. It is because of this that many of the creeks draining from the slopes above West Kelowna are seasonally dry, with smaller stream flows than would be expected for the size of the upslope catchment area. For a period, meltwaters were ponded on the west side of Mount Boucherie, and this resulted in the formation of a small-sized glacial lake (Lake Boucherie), which eventually merged with the larger glacial Lake Penticton at ~ 457 m elevation. Glaciolacustrine silt sediments associated with the two lakes may be found in the West Kelowna area (see Figure 4-8).

More contemporary fluvial sediments, comprised of sand and gravel surficial material, associated with alluvial fans are identified where tributary streams enter the valley (see Figure 4-8). Fluvial sediments are identified at the base of John Moore Creek and the lower McDougall Creek Tributary, the lower reaches of Keefe Creek in Tsinstikeptum 10, the base of Rose Valley Tributaries, the mouth of Lambly (Bear) Creek upon which the Bear Creek Provincial Park campground is located, and the Cinnabar Creek and Wilson Creek drainages along Westside Road.

Where steep valley side slopes flank the valley, surficial materials are characterized as unsorted colluvium along talus slopes or talus aprons (where multiple talus fans converge along the toe of a slope).

LEGEND

Fire Perimeter (McDougall Creek Fire K52767) (September 9, 2023)

Surficial Geology (Source: Geological Survey of Canada, Open File

Fluvial sediments: sediments deposited along modern fluvial systems and during their incision into earlier Quaternary deposits (incl. Ap/At/Af)

Glaciofluvial sediments: stratified sediments deposited by meltwater in contact or in proximity of the glacier (incl. Gt/Gb/Go/Gx)

Glaciolacustrine sediments: sediments deposited and/or reworked in proglacial Lake Penticton (or Glacial Lake Boucherie in study area) (incl. Lv/Lb/La/Ld)

Glacial Sediments (Till): diamicton comprised of sediments deposited directly by the glacier, consists of a heterogeneous mixture of particle size and composition. Composition is generally reflected by the underlying bedrock. For this map only thicker (> 1m) deposits are mapped to highlight increased vulnerability to erosion compared to thin deposits (incl. Tb)

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Client: **BC MINISTRY OF FORESTS - WILDFIRE SERVICE**

Project: **McDOUGALL CREEK WILDFIRE**

Title: **SURFICIAL GEOLOGY OF THE McDOUGALL CREEK WILDFIRE STUDY AREA**

Scale: 1:75,000	NAD 1983 UTM Zone 11 U	Map No.
Project No: 00-0000	Date: November 15, 2023	00-0

Clarke Geoscience Ltd.

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4.5 Geomorphology & Pre-Existing Natural Hazards

Terrain stability mapping is available for some of the Crown Land portions of the study area. Provincial map layers, derived from a compilation of different projects dating back to the mid-1990s, were viewed on iMAPBC. In general, potentially-unstable and unstable terrain includes steep valley side slopes along mainstem channels, and steep gullied catchments of some of the small tributaries. Bedrock scarp slopes make up some of these areas. Areas identified as being potentially unstable or unstable generally have a higher likelihood of post-wildfire instability, particularly in areas of high burn severity, due to the loss of forest cover and exposure of mineral soils.

In the absence of continuous and consistent terrain stability mapping across the study area, for the purpose of this assessment, slope classification was completed by GIS using the Digital Elevation Model data. Areas containing slopes >40% gradient that were burned at moderate to high severity were considered for the post-wildfire hazard analysis. These values are provided on the Catchment Report Cards (Appendix C). Catchments with >50% of the area burned at moderate to high burn severity and are moderately-steep (>40% gradient slopes) include:

- Upper Luluwap Creek (above Petterson Road)
- Rose Valley Tributary 1
- Lambly - Cedar Creek
- Lambly - Cedar Creek Tributary
- Lambly – Tributary 2
- Wilson Creek (along Westside Road)
- Cedar Gulch (along Westside Road)

A review of historic air photographs available from the RDCO[10] was completed for this assessment to identify areas of previous slope or stream channel instability. The years of coverage include 1959 (partial), 1973 (shoreline only), 1976, 1995, 2009, and 2018-2019. Additional imagery from Google Earth (dating 2002/2003, 2008/2009, 2012, 2020, and 2022) was also reviewed. It is understood that RDCO has obtained post-wildfire orthoimagery for the burned areas but was not yet available to review at the time of this report.

A 2003 debris flow hazard assessment was completed for Wilson Creek, one of the Westside Road Tributaries impacted by the McDougall Creek Wildfire (Terratech Consulting Ltd., 2003). The report documents a moderate-sized debris flow event dating back to approx. ~1977, that originated in the upper reaches of Wilson Creek and reached as far as the 2003 Fire Hall location at Westside Road. Evidence of two other debris flows, one of which dates back another 70 years (~1930s), was also documented. The report concluded that there is a high likelihood of moderate-sized debris flows impacting the fire hall site and recommended mitigation measures. Measures included relocation of the fire hall to the south side of the fan, construction of berms, and maintenance of the channel. No further confirmation of what measures have been completed was available.

Geotechnical conditions within the Smith Creek drainage, above Copper Ridge Dr. were reported on in the Smith Creek Comprehensive Development Plan (Protech Consulting, 2020). The report, which was completed after the 2014 wildfire, indicated “no obvious signs of landslide, slumps, or other instability features”. Identified potential hazards include rockfall hazards from exposed bedrock scarps and steep slopes above portions of the proposed development.

[10] https://www.arcgis.com/apps/ImageryViewer/index.html?appid=b8b05a87dedd4ca3a7c2e794724b5754

Debris flow frequency within the study area is low but not absent. Post-wildfire debris flows, and road washouts were observed following the 2003 Okanagan Mountain Wildfire in the South Kelowna area (Rembler Creek and small drainages along Lakeshore Road) (Jordan, 2015). Other known geohazard events within (or near) the study area include:

- Spring 2023 landslide in upper part of Powers Creek Tributary 1 caused by diverted drainage on an old trail (discussed in Section 7.1);
- Spring 2018 landslide along Westside Road, north of Fintry;
- Fall 2021 a series of small post-wildfire debris flows along slopes above Westside Road (on OKIB Lands in the North Okanagan);
- Spring 2023 post-wildfire flooding on the fan area of Whiteman Creek (at Parker Cove subdivision on OKIB Lands in the North Okanagan).

4.6 Past Wildfire and Logging History

Historic (i.e., post-1930) wildfires are mapped within the study area by the Province (GeoData BC) and perimeters of more recent wildfires (post-2003) are shown on the attached study maps (Maps 002-007; Appendix B).

Past wildfires appear to have limited the extent and/or reduced burn severity of the 2023 McDougall Creek wildfire. For example, a 2014 wildfire limited progression downslope into lower Smith Creek, a 2009 wildfire limited wildfire severity at the south end of the Rose Valley Reservoir, and a 2015 wildfire limited progression to the north along Westside Road.

Areas burned in the McDougall Creek wildfire were not extensively logged. Forest development (i.e., cutblocks and resource roads) is present at higher elevations on the plateau. The WFN Community Forest is located within the upper McDougall Creek watershed. It is managed by Ntityix Resources LP, which is operated by WFN corporate division. Harvesting activities in the Community Forest in the McDougall Creek watershed have only taken place on the plateau, and most of the watershed is in the Old Forest Zone with little previous harvest (D. Gill, Ntityix, *personal communication*, 2023). There are numerous older (>50 yr) roads and trails in the watershed associated with historic logging activity, many of which are accessed off the end of Bartley Road. These are legacy roads that are no longer being used for forestry purposes and are now heavily used by recreation by Off-Highway Vehicles (OHVs), dirt bikes, and other vehicles. Based on the results of this assessment there is concern that there could be further stability issues along the legacy roads associated with wildfire effects on runoff and stability. Efforts to deactivate and rehabilitate roads may be useful in mitigating further instability (see mitigation recommendations in Section 8.3).

Crown Forests within the mid- and upper-watershed areas of Powers Creek and Lambly (Bear) Creek are managed under Tree Farm License (TFL) 49 by Tolko Industries Ltd. Watershed Assessments have been completed for Powers Creek and Lambly Creek on behalf of Tolko and the City of West Kelowna has completed Community Source Assessments and Protection Plans for Powers Creek and Lambly Creek Watersheds. Since the two large watersheds were not extensively burned, no further reporting on past forestry effects is provided here.

Watershed Risk Mapping was completed by Larratt Aquatic Consulting Ltd. on behalf of the City of West Kelowna (Self, 2021). Assessed areas included the Powers Creek Intake Area, the Rose Valley Reservoir Area, and the Lambly (Bear) Creek Intake Area. The results indicated that high to very high risk sites are located close to major CWK infrastructure such as dams and intakes. The prepared maps may be used to direct post-wildfire restoration activities, such that high to very high-risk areas may be prioritized.

4.7 Vegetation Burn Severity (and Soil Burn Severity)

Vegetation burn severity was mapped by the BC Wildfire Service using the Burned Area Reflectance Classification (BARC) method using pre- and post-wildfire satellite imagery (Hope et al., 2015). Soil burn severity is similarly classified, but relies on field observations to determine the extent of consumption of the forest soils and ground fuels, and the extent and condition of exposed mineral soil.

Definitions for vegetation and corresponding soil burn severity categories are from Hope et al (2015) and Parsons et al. (2010) and are described in Table 4-2.

Table 4-2: Vegetation and Soil Burn Severity Class Descriptions

Burn Severity Class	Vegetation Burn Severity Class Description	Soil Burn Severity Class Description
High (red on map)	Trees are dead (black), needles, twigs, understory is completely burned.	Forest floor and near-surface roots consumed, mineral soil structure altered. Higher likelihood for water repellency effect on soil.
Moderate (yellow on map)	Trees are dead (orange) but scorched needles remain on trees, understory is burned.	Litter is consumed, duff partly consumed or charred, mineral soil unaltered.
Low (green on map)	Canopy is mostly unburned, understory is lightly burned.	Litter is scorched or partly consumed, often with patchy forest floor burn.

Mapped vegetation burn severity for the 2023 McDougall Creek wildfire (see Map 001; Appendix B) indicates that there were expansive areas that burned at high severity. Areas mapped as high burn severity tended to have areas of dense forest cover, including north-facing slopes at mid-elevation, within sheltered valleys or in areas with deeper soils. In the Central Okanagan, these areas are generally cooler and moister. However, drought conditions at the time of the wildfire may have contributed to drier soil conditions and a stressed forest, leading to the higher burn severity in these areas with abundant fuels. Burn severity was lower where forests were less dense due to shallow bedrock, steep ground, natural grasslands, or thinning.

Mapped vegetation burn severity was compared with observed soil conditions to determine correlation with soil burn severity[11]. Soil burn severity assessments were conducted throughout the study area during the field assessment. The results indicate that vegetation burn severity is judged to be fairly well-correlated and representative of the soil burn severity.

[11] Soil burn severity refers to the relative measure of wildfire effects on soil properties that affect hydrologic function, such as loss of organic matter, root loss, altered mineral structure, ash depth, and reduced infiltration. Factors that influence soil burn severity include pre-fire forest floor properties and moisture content.

Table 4-3 summarizes the area (%) burned and the proportion of high severity burn within each of the defined catchment areas within the study area. Many catchment areas experienced 40 to 100% burn and several catchments experienced >50% burn at high severity. These include: John Moore Creek and Unnamed Tributary to Lower McDougall Creek, Tributaries to the Rose Valley Reservoir, Upper Luluwap Creek, burned Tributaries above Bear Creek Road in the Lambly (Bear) Creek watershed, and a few burned tributaries above Westside Road. Based on these numbers alone, these areas would be considered at greater risk of post-wildfire effects on hydrology and/or slope stability.

Table 4-3: Area (%) Burned and Area (%) of High Burn Severity within each Catchment Area

Catchment/Watershed	Area (ha)	Area Burned (%)	Area High Burn Severity (%)
Powers Creek Watershed			
Powers Creek Tributary 1	206	40.1	2.4
Upper Powers Ck at POI	12,538	2.3	0.1
Upland Creeks in West Kelowna			
Smith Creek Tributary	108	18.0	2.5
Smith Creek at POI (Copper Ridge Rd)	501	49.7	8.4
Davidson Creek	166	79.1	27.3
John Moore Creek	203	95.3	55.9
Unnamed Tributary to Lower McDougall	124	87.4	51.0
McDougall Creek Watershed			
McDougall Creek Tributary 1	869	76.3	32.6
McDougall Creek POI at Bartley	3,919	63.4	31.1
Rose Valley Reservoir			
Rose Valley Tributary 1	27	100.0	56.4
Rose Valley Tributary 2	102	98.6	60.4
Rose Valley Tributary 3	141	97.5	59.2
Rose Valley Reservoir POI at Dam	1,070	94.3	50.9
Faulkner, Keefe and Luluwap Creek			
Upper Faulkner Creek	160	76.4	5.7
Keefe Creek (Partial)	231	24.6	1.9
Lower Luluwap Creek (at Westside Rd)	91	74.3	24.1
Upper Luluwap Creek	65	99.9	50.8
Lambly (Bear) Creek Watershed and Bear Creek Road Area			
Lambly - Blue Grouse Ck	113	97.9	53.1
Lambly - Tributary 2	42	99.3	76.7
Cedar Creek	306	91.5	60.8
Cedar Creek Tributary	41	89.0	71.4
Lambly (Bear) Creek POI at CWK Intake	23,178	8.2	3.5
Lambly (Bear) Creek POI at Mouth	24,363	12.2	5.6

Catchment/Watershed	Area (ha)	Area Burned (%)	Area High Burn Severity (%)
Westside Road Tributaries			
Cinnabar Creek	143	26.9	6.6
Dimetri Creek	114	62.3	10.4
Cedar Gulch	57	74.2	37.9
Cedar Gulch-2	43	98.4	48.2
Wilson Creek	126	74.7	25.8
Oldman Creek	142	90.1	42.0
Jennie Creek	157	98.4	75.6
Unnamed Creek 1	86	98.3	56.7

The field assessments also reviewed soil conditions for the development of water repellant (i.e., hydrophobic) soils. The results showed moderate to strong water repellency at shallow soil depths within most areas mapped as high vegetation burn severity. However, weaker soil-water repellency was noted where soils were thin over rock and in areas with coarse-textured colluvial sediments.

5. Elements at Risk

Considered 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). Other elements, such as fish and fish habitat and water quality are not specifically considered for this study.

Elements at Risk that are identified within the study area, and shown on accompanying Maps, include:

- Residences, structures, dwellings on public or private property – the study area includes urban residential areas within the City of West Kelowna, Westbank First Nation, and the Regional District of Central Okanagan. Development density varies and in some areas is sparsely populated rural areas and may also include seasonal dwellings/cabins. Where “private property” is referenced in the report, it is only residences and structures that are risk rated. Risk ratings for private properties have a great deal of associated uncertainty regarding event magnitude, ability for drainage structures to handle events, and the runout characteristics of a design event. For many cases within the study area, risk ratings are broadly assigned to a fan area.
- Surface water licenses were identified and mapped. However, details regarding water supply infrastructure (i.e., water distribution lines and/or reservoirs) and water quality were not investigated for each licence.
- Public transportation routes and associated major stream crossings (i.e., bridges and culverts) that are under the jurisdiction and responsibility of the BC Ministry of Transportation and Infrastructure (MOTI).

Further engagement with WFN is required to identify cultural/archaeological sites of significance. Natural hazards along stream segments and slopes within the Tsinstikeptum 9 and Tsinstikeptum 10 are identified.

The Associated Engineering (2023) flood inundation mapping, combined with stormwater infrastructure mapping available online (CWK and RDCO), formed the basis of an inventory of at-risk stream crossings along Smith Creek and McDougall Creek. These crossings are listed in Table 5-1 and are shown on Map 007.

No further confirmation on the condition of these crossings was completed, nor was any investigation conducted to identify additional (i.e., private) crossings. Based on the results of this assessment, the level of post-wildfire flood risk may be extended to other features as they become known. The Elements at Risk are mapped on the Risk Maps (Appendix B) and listed in the Report Cards (Appendix C) for each area of interest.

Table 5-1: List of Stream Crossings on Lower McDougall Creek and Smith Creek (from upstream to downstream)

Crossing Number	Creek Name	Jurisdiction	Street Location	Structure Details	Date Installed	Reference in Associated Engineering Report (2023)
M1	McDougall Creek	CWK	Shannon Lake Rd	Bridge		
M2	McDougall Creek	MOTI	Highway 97	3 x Bridge		
M3	McDougall Creek	WFN	Daimler Rd	3250 mm CSP	1990	
M4	McDougall Creek	WFN	Elk Rd	2200 mm CSP	2000	
M5	McDougall Creek	WFN	Ridge Estates Dr. and Boucherie Rd	900 mm CSP	2000	
M6	McDougall Creek	CWK	Old Boucherie Rd	Bridge		improvements needed
M7	McDougall Creek	Private	3974 Hitchner Rd	Bridge		capacity concerns
M8	McDougall Creek	CWK	Jennens Rd	Bridge		improvements needed
S1	Smith Creek	CWK	Copper Ridge Dr	600 mm CSP		
S2	Smith Creek	CWK	Wild Horse Dr	900 mm CSP* (TBC)	1992	
S3	Smith Creek	Private				upgrade needed
S4	Smith Creek	CWK	Rainbow Rd	600 mm CSP		upgrade needed
S5	Smith Creek	CWK	Rubicon Rd	trash rack + 600 mm CSP		upgrade needed
S6	Smith Creek	Private				upgrade needed
S7	Smith Creek	CWK	Broadview Rd	600 mm CSP	1991	upgrade needed
S8	Smith Creek	CWK	Reece Rd	900 mm CSP	1995	upgrade needed
S9	Smith Creek	CWK	Old Okanagan Hwy	2 x 900 mm CSP	1990	upgrade needed
S10	Smith Creek	WFN	Butt Rd	900 mm CSP	1990	
S11	Smith Creek	WFN	Louie Dr	ditchline		
S12	Smith Creek	MOTI	Highway 97	1200 mm CSP	2000	
S13	Smith Creek	WFN	Bering Rd	1600 mm CSP	2000	
S14	Smith Creek	WFN	Carrington Rd	1600 mm CSP	2000	
S15	Smith Creek	CWK	Witt Rd	1600 mm CSP	1986	upgrade needed
S16	Smith Creek	CWK	Gellatly Rd	ditchline		O & M Plan for debris blockage needed
S17	Smith Creek	CWK	Boucherie Rd	1600 mm CSP	1986	upgrade needed

6. Post-Wildfire Natural Hazard Screening and Hydrology

6.1 Natural Hazard Screening Approach

The post-wildfire natural hazard risk analysis for the McDougall Creek wildfire is a phased approach (see Figure 6-1). First, an overview-level screening assessment was completed using GIS by combining information on vegetation burn severity with watershed morphometric characteristics. The screening level assessment identified catchments with a higher likelihood for debris flow/debris flood activity and for elevated peak flows. The results then directed field work to sites identified as moderate and high hazard. Based on field verification, the assessment results are collated to develop conclusions and recommendations.

Step 1: Post-Wildfire Natural Hazard Screening Assessment & Hydrology Analysis
- identify priority areas with high likelihood for debris flow or elevated peak flow

↓

Step 2: Field Verification of High and Moderate Likelihood of Post-Wildfire Natural Hazards
- where there is a potential for interaction with Elements at Risk

↓

Step 3: Finalize Risk Analysis and provide Recommendations for Risk Mitigation

Figure 6-1: Post-Wildfire Natural Hazard Risk Analysis Approach

The natural hazard screening level assessment was completed for the study area catchments using criteria that were developed with reference to post-wildfire hazard research. The hazard screening criteria are provided in Figure 6-2. The screening assessment identified catchments with a moderate to high likelihood for post-wildfire debris flow / debris flood and/or post-wildfire peak flow effects. The screening criteria were not strictly applied, allowing for an element of professional judgement that was later confirmed in the field.

The USGS (2022) utilizes a similar screening approach for emergency assessments of post-wildfire debris flow hazards[12]. The USGS study approach uses catchment morphometrics, burn severity, soil properties, and rainfall characteristics to estimate the probability and volume of debris flows that may occur in response to a design storm event. Using Kelowna IDF data, an attempt to use this approach was made and found generally good correlation with the results.

Post-Wildfire Debris Flow Hazard Screening Criteria

Criteria	High Hazard	Moderate Hazard
Melton Ratio	> 0.6	0.3 - 0.6
Catchment Length	< 3 km	< 5 km
% Total Area Burned	> 50%	> 30%
% High Burn Severity	> 20%	> 10%
% Mod Burn Severity	> 50%	> 30%

Post-Wildfire Peak Flow Hazard Screening Criteria

Criteria	High Hazard	Moderate Hazard
Melton Ratio	< 0.6	< 0.6
% Total Area Burned	> 50%	> 30%
High Elevation (>1300 m) Burn	Extensive	Not Extensive

Figure 6-2: Hazard Screening Criteria Utilized for the McDougall Creek PWNHRA

6.2 Screening Level Assessment Results

The results of the screening level assessment are provided in Table 6-1. To summarize:

In general, catchment areas flagged as having a **high** likelihood for post-wildfire **debris flow/debris flood-dominated** effects include:

- Upland creeks above West Kelowna (incl. Davidson Creek, John Moore Creek and an Unnamed Tributary to lower McDougall Creek);
- Small Tributaries at the north end of the Rose Valley Reservoir;
- Upper Luluwap Creek;
- Tributaries to lower Lambly Creek (Blue Grouse Creek), including tributary catchments above Bear Creek Road (incl. Cedar Creek and Lambly Tributary 2); and,
- Tributary catchments upslope of Westside Road.

[12] https://landslides.usgs.gov/hazards/postfire_debrisflow/

Catchment areas flagged as having a **high** likelihood for post-wildfire **peak flow-dominated** effects include:

- Upland creeks above West Kelowna (incl. Smith Creek (above Copper Ridge Rd) and John Moore Creek;
- McDougall Creek (above Bartley Rd);
- Lower Luluwap Creek (at Westside Rd); and
- Cedar Creek (within Lambly Creek watershed).

Table 6-1: Post-Wildfire Natural Hazard Screening Assessment Summary

Catchment/Watershed	Area (ha)	Percentage Burned (%)	% Area Mod Burn Severity	% Area High Burn Severity	Length of Catchment (km)	Melton Ratio (calc.)	Post-Wildfire Debris Flow Screening Hazard Level	Post-Wildfire Peak Flow Screening Hazard Level
Powers Creek								
Powers Creek Tributary 1	206	40.1	18.6	2.4	2.1	0.39	Low to Mod	Moderate
Upper Powers Ck at POI	12,538	2.3	0.9	0.1	18.5	0.11	-	Low
Upland Creeks and Slopes in West Kelowna								
Smith Creek Tributary	108	18.0	7.6	2.5	1.8	0.55	Low	Low
Smith Creek at POI (Copper Ridge Rd)	501	49.7	22.2	8.4	5.8	0.40	Moderate	**Mod to High**
Davidson Creek	166	79.1	30.1	27.3	2.4	0.54	**High**	Moderate
John Moore Creek	203	95.3	28.9	55.9	3.0	0.53	**Mod to High**	**Mod to High**
Unnamed Tributary to Lower McDougall	124	87.4	26.1	51.0	2.4	0.65	**High**	-
McDougall Creek Watershed								
McDougall Creek Tributary 1	869	76.3	26.3	32.6	4.7	0.28	-	**High**
McDougall Creek POI at Bartley	3,919	63.4	19.3	31.1	9.6	0.16	-	**High**
Rose Valley Reservoir Watershed								
Rose Valley Tributary 1	27	100.0	39.9	56.4	0.9	0.91	**High**	-
Rose Valley Tributary 2	102	98.6	31.8	60.4	1.9	0.72	**High**	-
Rose Valley Tributary 3	141	97.5	31.3	59.2	2.0	0.57	**Mod to High**	-
Rose Valley Reservoir POI at Dam	1,070	94.3	33.8	50.9	-	0.25	-	Low (due to attenuation)
Faulkner Creek, Keefe Creek and Luluwap Creek								
Upper Faulkner Creek	160	76.4	40.1	5.7		0.41	-	Moderate
Keefe Creek (Partial)	231	24.6	8.9	1.9		0.29	-	Low
Lower Luluwap Creek (at Westside Rd)	91	74.3	26.5	24.1	1.2	0.34	-	**High**
Upper Luluwap Creek	65	99.9	46.8	50.8	1.3	0.74	**High**	-
Lambly (Bear) Creek Watershed and Bear Creek Road Area								
Lambly - Blue Grouse Ck	113	97.9	37.9	53.1	2.4	0.80	**Mod to High**	-

Catchment/Watershed	Area (ha)	Percentage Burned (%)	% Area Mod Burn Severity	% Area High Burn Severity	Length of Catchment (km)	Melton Ratio (calc.)	Post-Wildfire Debris Flow Screening Hazard Level	Post-Wildfire Peak Flow Screening Hazard Level
Lambly Tributary 2	42	99.3	19.7	76.7	1.1	0.92	**High**	-
Cedar Creek	306	91.5	23.6	60.8	1.9	0.43	**High (Debris Flood)**	**High**
Cedar Creek Tributary	41	89.0	14.4	71.4	1.2	0.91	**High**	-
Lambly (Bear) Creek POI at CWK Intake	23,178	8.2	3.2	3.5	21.1	0.08	-	Low
Lambly (Bear) Creek POI at Mouth	24,363	12.2	4.6	5.6	25.6	0.10	-	Low
Westside Road Tributaries								
Cinnabar Creek	143	26.9	19.0	6.6	2.4	0.69	Low	-
Dimetri Creek	114	62.3	29.2	10.4	2.3	0.79	**Mod to High**	-
Cedar Gulch	57	74.2	22.7	37.9	2.3	1.14	**High**	-
Cedar Gulch-2	43	98.4	43.9	48.2	1.4	0.91	**High**	-
Wilson Creek	126	74.7	34.9	25.8	2.8	0.79	**High**	-
Oldman Creek	142	90.1	36.2	42.0	2.6	0.76	**High**	-
Jennie Creek	157	98.4	20.7	75.6	2.6	0.59	**High**	-
Unnamed Creek 1	86	98.3	33.8	56.7	2.3	0.95	**High**	-

n/a – not applicable to the specific catchment

6.3 Post-Wildfire Hydrology Analysis

A preliminary post-wildfire hydrology analysis was completed for two areas; the Smith Creek catchment upslope of Copper Ridge Road, and the McDougall Creek watershed, upslope of Bartley Road. These two areas screened as having a high likelihood for post-wildfire peak flow effects and both catchments have downstream reaches that flow through urbanized areas.

Using the USGS regression analysis approach[13], which is one of many used by the Burned Area Emergency Response (BAER) team, peak flow changes due to wildfire can be estimated. For this study, pre-wildfire peak flows (without an adjustment for climate change) were obtained from Table 4.9 in the Flood Mitigation Study by Associated Engineering (2023).

The estimated post-wildfire peak flows at different return periods for the two catchment areas considered is provided in Table 6-2. Based on the USGS regression analysis approach, the year 1 results assume that 1/3 of the high severity burn area is water repellent, with a 10x increase in peak flow from those areas. The year 5 results assume that 1/6 of the high severity burn area is water repellent, which corresponds with a diminished effect on burned soils in the 3 to 5 years following wildfire. The approach may underestimate wildfire effects on hydrology since the only runoff effects are related to the soil-water repellency, not forest recovery.

The hydrologic analysis results suggest that post-wildfire peak-flows in the first year following the wildfire may be 73% higher for McDougall Creek and 19% higher for Smith Creek. The anticipated decrease in soil-water repellency in subsequent years has a corresponding reduction in estimate peak flow increase.

Due to the model limitations, these peak-flow estimates are considered preliminary and should not be used to inform future infrastructure decisions. Note that the results do not consider debris (sediment and woody debris) as part of the flow calculation increase.

Table 6-2: Estimated % Change between Pre-Wildfire and Post-Wildfire Peak Flows on Smith Creek and McDougall Creek

Peak Flow (cms) Return Period	McDougall Creek at POI (Bartley Road)			Smith Creek at POI (Copper Ridge Road)		
	Pre-Wildfire without Climate Change[1]	Post-Wildfire (Yr 1)	Post-Wildfire (Yr 5)	Pre-Wildfire without Climate Change[1]	Post-Wildfire (Yr 1)	Post-Wildfire (Yr 5)
Q2	3.31	5.72	4.00	0.72	0.86	0.76
Q20	6.64	11.46	8.01	1.62	1.93	1.71
Q50	7.4	12.77	8.93	1.90	2.27	2.01
Q100	7.92	13.67	9.56	2.12	2.53	2.24
Q200	8.88	15.33	10.72	2.47	2.95	2.61
% Increase		**73%**	**21%**		**19%**	**0.1%**

[1] – Pre-wildfire mean instantaneous peak flows without climate change peak flows obtained from Table 4.9 in Associated Engineering (2023)

[13] USDA Forest Service – Burned Area Emergency Response Tools [https://forest.moscowfsl.wsu.edu/BAERTOOLS/ROADTRT/Peakflow/USGS/]

6.4 Field Assessment

Ground-based field observations were obtained throughout the study area. Foot and vehicle traverses were completed along valley side slopes, along the road corridors, at sites along the mainstem channel of McDougall Creek and Lambly Creek, and at targeted tributary channel crossings along Westside Road.

Aerial reconnaissance of the study area was also completed to examine upper elevation areas within the study catchments (helicopter flight path is shown on Map 001; Appendix B). Field and aerial observations were also used to confirm and correlate vegetation burn severity and soil burn severity ratings.

Field site waypoints are mapped on the enclosed Maps (Maps 002 to 007; Appendix B) and selected photographs are included in Appendix C. Field observations are incorporated into the written summaries for each project area. The field observations are considered in context with other background information to assess the likelihood of post-wildfire natural hazards, and to further identify the spatial likelihood of impact to identified Elements at Risk.

6.5 Preliminary Results of Priority Sites

At the completion of the field assessment, on September 27, 2023, a memo was provided to the BC Ministry of Forests to provide preliminary results (Clarke Geoscience Ltd., 2023). The memo identified priority sites with a high likelihood for post-wildfire natural hazards.

Locations identified as having a high to very high level of partial risk associated with post-wildfire natural hazards include slopes and gullies upslope and downslope of Bear Creek Road North, areas downstream along McDougall Creek, slopes adjacent to the Rose Valley Reservoir, and select slopes and gullies along Westside Road.

At the time, short-duration intense rainstorms were considered most relevant to high hazard scenarios. Thus, interim recommendations to increase awareness, monitoring, and emergency preparedness activities were provided.

7. Post-Wildfire Natural Hazard Risk Analysis Results

The Natural Hazard Risk Analysis results are summarized for each catchment area. Catchment Report Cards (provided in Appendix C) contain summary information and include select photographs that are referenced in the text below. Field sites (Waypoints) are shown on the accompanying Maps 002-007 (Appendix B) and are also referenced in the text below.

The risk analysis results summarized for each area incorporate field observations and summarize the following:

- **General watershed/subbasin conditions**, including the percentage of the total basin area that was burned, and what percentage burned at different levels of burn severity (low, moderate, and high). Watershed physiography is also characterized.
- **Terrain conditions**, including the presence of potentially unstable and unstable terrain in areas that were burned at moderate and high severity. Interpretations regarding pre-existing geohazard conditions are reported.

- **Mainstem stream channel and riparian conditions**, including existing channel stability indicators, and the extent of burn along the channel.
- **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.
- **Risk levels** are assigned for each identified Elements at Risk. These include: public roads including Westside Road, domestic water intakes, and private property. It is noted that water quality effects are not specifically rated. Rather, the risk analysis identifies the likelihood for effects and the potential spatial effect at the license location.

7.1 Powers Creek (Tributary 1)

Only a very small portion of the Powers Creek watershed, upstream of the Water Treatment Plant (WTP), was burned (2.3% upstream of the POI) and it was mostly limited to an upper elevation area within a tributary catchment, referred to as Powers Creek Tributary 1 (see Map 002). This small steep catchment is of interest because there is private property at the lower reach of the tributary (2750 Smith Creek Road), and because the tributary confluence is immediately upstream of the Powers Creek WTP.

In the spring (2023) a landslide initiated along the upper reaches of the tributary (Waypoint Powers-Trib-1). The slide was inspected by MOF and was attributed to flow diversion at a non-status trail crossing (G. Wells, MOF, *personal communication*, 2023). Photos of the slide are presented in the Appendix C-1 (see Photos 1 and 2). During wildfire fighting operations, a resource road accessed off the end of Smith Creek Road was used to access upper elevation areas. In the process of reactivating the road, thick deposits of highly erodible fine-textured silty soils were disturbed (Photo 3). Where the trail crosses the creek (Waypoint Powers-Trib-2), exposed soils may be easily transported by flowing water downstream to private property, and potentially to Powers Creek. Although there is evidence of past debris flood activity on the lower reach (Photo 5; Powers-Trib-3), it is likely that the lower gradient reach, and a constructed pond on the creek, may mitigate sedimentation to Powers Creek downstream.

The MOF has since rehabilitated the access road and trail crossing and have undertaken efforts to stabilize the silty soils (B. DeBoice, MOF, *personal communication*, 2023). Further work may be warranted to ensure long term stability and restoration of the roadbed and to ensure that natural drainage patterns at all stream crossings have been restored.

7.2 Upland Creeks and Face Unit Slopes in West Kelowna

Wildfire-affected areas above the City of West Kelowna are grouped together due to their similar physiography. The catchments are small, steeply sloped upland areas and urban residential development is situated along the toe of the slope, where the steep bedrock-controlled slopes meet the thick glaciofluvial sand and gravel deposits characteristic of Okanagan Valley fill sediments. The Point of Interest (POI) for each stream is located at this transition. This area of interest is shown on Map 002 (Appendix B) and area characteristics are summarized in the Report Card and photographs provided in Appendix C-2).

7.2.1 Smith Creek and Smith Creek Tributary

Upslope of the valley and upslope of urban development, Smith Creek is a larger watershed that is sub-divided into tributary basins. Each are considered separately, but eventually combine downstream into a single channel that flows through the CWK and WFN Tsinstikeptum 9. The Smith Creek Watershed above Copper Ridge Drive was extensively burned (49.7%) and the effects of wildfire are compounded by another wildfire that occurred in 2014 (+11% burned). The Smith Creek Tributary is a small catchment that was not extensively burned in 2023 (18%) but was much more affected by the 2014 wildfire (+57.5% burned). The cumulative effects on the hydrology of the small catchments are considered.

Only 8.5% of the Smith Creek catchment (above Copper Ridge Drive) burned at high severity, and only 3.5% of the areas that burned at moderate to high severity are on steep (>40%) slopes. The headwater reaches are lower gradient, which can lower the likelihood of hydrologic and geomorphic effects on the channel. Steeper, mid-slope reaches that are more tightly confined by valley side slopes are more likely to become loaded with sediment, which can increase the volume of sediment available for transport downstream.

There is little evidence of past debris flow or debris flood activity on the upland portion of Smith Creek, despite the effects of the 2014 wildfire. Thus, the likelihood for post-wildfire debris flow or debris flood activity is moderate. Based on the overall area burned, there is potential for a 15-25% increase in peak flow magnitude on Smith Creek. For this reason, the peak flow hazard level is rated high.

Smith Creek and the Smith Creek Tributary flow into an urban residential area. Downstream, the hydrology of the streams is largely influenced by stormwater runoff. No further analysis on hydrology is completed for this assessment. Potential risks associated with elevated flows and/or bank erosion along the downstream reaches are discussed in Section 7.3.1.

7.2.2 Davidson Creek, John Moore Creek, and Unnamed McDougall Creek Tributary

Other upland tributary basins that were extensively burned in 2023 include Davidson Creek, John Moore Creek, and an unnamed tributary to McDougall Creek. Areas burned at high burn severity are in the upper part of the catchments (generally above 900 m) but are still below the snow-sensitive elevation for the area. Stream flows in the tributaries are seasonal, responding to intense rainfall events rather than a prolonged spring snowmelt runoff period.

The Melton Ratios for the upland catchments indicates that debris flood is the dominant hydro-geomorphic process (characteristics between a flood and a debris flow). It is noted, however, that the Melton Ratio can underestimate debris flow potential in watersheds with a gently sloping upland area above the main channel. The catchments are steep and large enough to generate flows that can easily exceed a peak clear-water flow. Greater than 20% of the catchment areas that burned at moderate to high severity are steep (>40%) indicating an increased likelihood for hillslope erosion processes and instability. Sediment from the steep side slopes that are directly connected to the channel can bulk the peak flows, which can lead to mobilization of sediment and debris to the reaches downstream.

Due to the percentage of >40% gradient sloping terrain that burned at moderate to high severity there is an elevated risk of erosion, sediment-laden flooding, and shallow landslide activity.

It is noted that once the small streams meet the Okanagan Valley, where stream gradient quickly decreases, the streams become ephemeral; only flowing during extended periods of wet weather or during intense rainstorms. Thus, the hazard level does not extend very far beyond the POI for each stream.

There are numerous Elements at Risk located downstream of the POI of each stream. The streams themselves have associated alluvial/colluvial fans. Davidson Creek flows into private property upstream of Shannon Heights Drive (2280 Paramount Dr.) and there is also a water reservoir and channel structures upstream that may be exposed to high peak flow and debris flow hazards. City of West Kelowna storm drain infrastructure mapping indicates that there is a flow diversion upstream of the developed properties. Further investigation and assessment are warranted (see Section 8.4).

At the toe of John Moore Creek and the Unnamed McDougall Creek Tributary there is one large rural property (2202 Bartley Road). Field observations indicate that events on the creeks would runout onto the pasture lands. Potential impacts are likely for the domestic water intakes on the creeks and for the lands located downstream.

7.2.3 Face Unit Slopes above West Kelowna

Within this area of interest, the only Face Unit with significant area burned is between Davidson Creek and John Moore Creek. The fire-affected slopes above developed areas on Shannon Hills Place may experience soil erosion, ravelling sediment, and small sediment-laden flows where runoff becomes concentrated.

Google earth imagery shows a rockfall protection berm behind homes at the end of Shannon Hills Place. It is recommended that the Engineer of Record who designed the berm, review the current state of the berm and it’s ability to handle any potential increases in rockfall activity.

7.3 McDougall Creek Watershed

McDougall Creek watershed is located upslope of the CWK and WFN Tsinstikeptum 9 (see Map 003; Appendix B). Area characteristics are summarized in the Report Card and photographs provided in Appendix C-3. The watershed headwaters are located on the plateau, between Lambly Creek and Powers Creek. The mainstem channel flows south before reaching thick Okanagan Valley fill deposits at the upslope end of Bartley Road. These deposits are comprised of sand and gravel paleofan and glaciolacustrine deposits, which are actively mined for gravel in the area.

For this study, the McDougall Creek watershed area is delineated above Bartley Road (39.2 km^2) (see Map 003). Photo 1 (Appendix C) shows localized disturbance associated with a fire guard crossing on McDougall Creek at the POI. Immediately upstream, McDougall Creek is contained within a bedrock and till canyon, which is a source of sediment and debris to the channel (Waypoint McDougall-1; Photo 2 & 3). The watershed area upstream is distinguished from the lower gradient urbanized reaches downstream.

Above the canyon the McDougall Creek mainstem channel is 7-10% gradient, with a cobble-boulder substrate and an aggraded character indicative of elevated peak flows and sediment transport. There are several domestic water licenses at the lower end of McDougall Creek, accessed off the end of Bartley Road (Photo 4) and the McDougall Creek FSR parallels the channel for ~3 km, before climbing up onto the adjacent slopes. The riparian forest along the middle reaches of McDougall Creek has experienced moderate to high severity burn, with steep (45-60%) side slopes that burned at high severity with exposed mineral soils that have observed water repellency (Waypoint McDougall-2; Photo 5). Over 20% of the overall McDougall Creek watershed that burned at a moderate to high severity is also situated on slopes >40% gradient. The connectivity of burned steep slopes to McDougall Creek constitutes a high potential for sediment delivery to the channel.

Burn severity along the mainstem channel varies. The total length of the mainstem and large tributary channels burned at high severity is ~5 km. Riparian vegetation, particularly along lower reaches, is a mixed deciduous and coniferous forest type. Deciduous trees are less flammable and less susceptible to wildfire than coniferous trees. However, overall impacts indicate an increased vulnerability to windfall and loss of riparian function along the mainstem channel. This increases the risk of channel destabilization, debris jams, sediment loading, and water quality impacts due to loss of shade. A large sediment wedge (200-300 m^3 of sediment) was observed in the channel, which is more likely to be mobilized by elevated peak flows (McDougall-3; Photo 6).

The upslope watershed was extensively burned (over 60%) and over half of this was burned at a moderate to high vegetation burn severity. Moderate burn severity forest along McDougall Creek is shown in Photo 8 at Waypoint McDougall-5 and high burn severity forest is shown in Photo 9 at Waypoint McDougall-6. Areas of high vegetation burn severity in the McDougall Creek watershed were also ground truthed to generally have high soil burn severity, with no surface organics, no rootlets, variable to high soil-water repellency, and a thick ash layer.

Approximately 18% of the total area burned in the McDougall Creek watershed is located above 1300 m elevation (13% at moderate burn severity and 4% at high burn severity), which defines the snow-sensitive elevation. The overall low level of burn severity, combined with the higher elevation losses, represents only a moderate loss of hydrologic function (described in Section 4.3 of this report).

Burned areas in the McDougall Creek watershed also include tributary catchments that are directly connected to the mainstem channel. Highly burned tributaries have a greater potential for flood and debris flood, and an increased likelihood for sediment delivery into McDougall Creek. The most highly affected tributary, Tributary 1, was over 75% burned, with almost 60% of that burned at moderate to high severity. It appears that much of the deciduous riparian forest was not severely burned and the road crossing on Tributary 1 (Waypoint McDougall-7) has been decommissioned, which reduces the potential for sediment transport and washout impacts at this location (see Photo 10).

Preliminary hydrological analysis of post-wildfire peak flows (Section 6.3) estimates a 73% increase in flows within the first year. While peak flow increases in subsequent years is reduced to ~20%, assuming recovery of soil impacts. These estimates support the conclusions of a high post-wildfire peak flow hazard.

Based on the aggregate area burned and the percentage of burned steep, connected tributaries and slopes, there is a high post-wildfire peak flow hazard and high sediment bulking potential. Sediment and debris bulking will most likely arise from valley side slope instability, stream channel and bank erosion along the mainstem, and from instability along tributary subbasins. There is a high potential for post-wildfire peak flow and debris flood along the larger tributaries to McDougall Creek and a high potential for landslide and debris flow from small steep tributaries that are directly connected to the mainstem channel.

With respect to partial risk, there is a very high partial risk for the resource and recreation road that parallels McDougall Creek along the valley bottom, a very high risk to the resource road bridges along McDougall Creek, and very high risk to the domestic water intakes on McDougall Creek.

7.3.1 Lower Reaches of McDougall Creek and Smith Creek

The lower reaches of McDougall Creek (downstream from Bartley Road) and the lower reaches of Smith Creek (downstream of Copper Ridge Drive) flow through an urbanized area made up of two jurisdictions (CWK and WFN) (see Map 007; Appendix B). The hydrology along the lower reaches is influenced by stormwater drainage from adjacent residential and commercial development. Design peak stream flows were determined and then used in hydraulic models to determine flood inundation extents by Associated Engineering (2023).

For both McDougall Creek and Smith Creek, potential changes in hydrology associated with the effects of wildfire are anticipated. Based on the extent and severity of wildfire, potential natural hazards include: elevated peak flows and increased sediment delivery and transport. Cobble and boulder sized alluvial material will likely settle relatively quickly as stream gradient decreases, while gravel, sand, and silt materials will remain in suspension and be transported much further downstream. Wildfire impacts to the riparian forest along the mainstem channel are likely to generate debris jams, which can later fail, causing instability and releasing sediment to the downstream channel. The effects of elevated peak flows, channel instability, and elevated sediment and debris loads will increase the likelihood of flooding and erosion downstream.

As discussed in Section 5.0, the downstream Elements at Risk identified as stream crossing locations were derived from GIS mapping and listed by Associated Engineering (2023). There are sixteen (16) culverts identified along lower Smith Creek, downstream from the POI for this study (see Table 5-1). McDougall Creek, downstream from the POI at Bartely Road, has much fewer crossings and flows within a wider riparian area that is less developed. There are six (6) bridge crossings, including three (3) that are located in the Highway 97 area, and three (3) other culvert crossings before the creek enters Okanagan Lake.

Stream crossing locations and areas of past flooding or erosion issues are considered at continued risk of impact by elevated post-wildfire peak flows. High and very high risk sites along lower McDougall Creek and lower Smith Creek are shown on Map 007 (Appendix B).

7.4 Rose Valley Reservoir

The Rose Valley Reservoir watershed (10.7 km^2) includes the catchment area upstream and upslope of the reservoir dam (see Photo 1; Waypoint RV Dam POI) and includes three (3) small sub-basins delineated at the north end of the reservoir. This area of interest is shown on Map 004 (Appendix B) and area characteristics are summarized in the Report Card and photographs provided in Appendix C-4.

Slopes above the reservoir are moderately-steep to steep bedrock-controlled slopes that are sparsely forested and thinly mantled with till and colluvium sediments. There are no well-defined (perennial) water courses other than the inflow channel at the north end. Inflows include water that is diverted from Lambly Creek for the purposes of drinking water supply. It is noted that inflows are monitored and controlled at the Lambly Creek intake such that when water quality is poor, inflows are bypassed.

The Rose Valley Reservoir watershed and sub-basin areas were extensively burned (overall 95%), most at moderate to high burn severity, and mostly at the north end of the catchment. A relatively high percentage (~40%) of the watershed is steep (>40% gradient) terrain and burned at moderate to high burn severity. Due to the coarse-textured surficial materials it is anticipated that water repellency may not be pervasive. However, where thicker sediments occur, particularly along the reservoir shoreline, there is a higher potential for water repellant soils[14] and a higher potential for surface erosion, ravelling, rockfall, and shallow landslide activity. Photos 2 and 3 shows the steep rock slopes above the Rose Valley Dam and reservoir.

The small tributary basins at the north end of the watershed have a Melton Ratio indicative of a debris flow dominant process and each catchment has a corresponding downslope alluvial or debris flow fan. Debris flow and debris flood processes are anticipated. However, these catchments are not well-connected by surface water to the reservoir, but they do potentially affect domestic water intakes and downslope private property.

The dominant post-wildfire hydro-geomorphic processes affecting the Rose Valley Reservoir are surface erosion, sediment-laden runoff, ravelling, rockfall, and shallow landslides. Thin soils and lack of surface drainages reduces the likelihood for hydrologic processes, such as flooding or debris flow. If not already considered in a dam safety review, further work to determine the reservoir's ability to attenuate peak flows, and the dam structure's ability to manage this, may be required.

With respect to partial risk, the Elements at Risk include the Rose Valley Dam physical infrastructure, domestic water quality in the reservoir, and recreation trails within the Rose Valley Regional Park and on Crown Land. The partial risk to these elements is high with respect to the flood, debris flood and landslide hazard varies depending on exposure. By far, the highest partial risk rating is assigned to domestic water quality in the Rose Valley Reservoir. The very high level of partial risk is associated with smaller-scale surface erosion processes along slopes that are directly connected to the reservoir. Additional work to characterize drinking water risks is being undertaken by Larratt Aquatic on behalf of the City of West Kelowna (H. Larratt, *personal communication*, 2023).

There is a very high partial risk of post-wildfire debris flow to private property (530 Rose Valley Road) along Rose Valley (RV) Tributary 2 located at the north end of the Reservoir catchment. Partial risk to a single surface water license on RV Tributary 1 is rated very high, but there are no other visible Elements at Risk along the downstream reaches of this tributary.

7.5 Upper Faulkner Creek, Keefe Creek and Luluwap Creek (Valley Creeks and Face Units)

The valley creeks and face units included in this part of the study area are located within the urban residential area of the CWK, and within a portion of WFN Tsinstikeptum 10. This area of interest is shown on Map 004 (Appendix B) and area characteristics are summarized in the Report Card and photographs provided in Appendix C-5.

7.5.1 Upper Faulkner Creek and Face Unit Above Rosewood Dr.

Upper Faulkner Creek flows from the outlet of the Rose Valley Reservoir and is paralleled by the Rose Valley Dam Access Road. Along a section of slope on the west side of the road there are pre-existing rockfall hazards (Photo 1; Waypoint Faulkner-1). Along a ~250 m long section on the east side of the access road, moderate to high burn severity on steep colluvial slopes constitutes an elevated rockfall and shallow landslide hazard (est.

[14] Personnel from Larratt Aquatic found water repellent soils along the shoreline (H. Larratt, *personal communication*, 2023)

size <100 m^3) (Photo 2; Waypoint Faulkner-2). Surface erosion and soil disturbance by windfall may loosen cobble to small-boulder-sized fragments that could roll down the slope, posing a risk to road and trail users.

Moderately burned face unit slopes above Rosewood Drive and Rosalee Lane constitute a low hazard. However, there is a shallow swale feature that burned at moderate severity that extends upslope and that may potentially direct sediment-laden runoff towards the rear of residential properties (strata development at 2040 Rosalee Lane) (see Photo 3; Waypoint Faulkner-3). The CWK storm drainage network indicates there is a 600 mm pipe behind the properties, directing flow from the swale to the south.

Stream flows on Faulkner Creek are regulated by the Rose Valley dam. Downstream reaches are rock-lined, with concrete culverts (Photo 4; Waypoint Faulkner-4). Faulkner Creek flows downstream through residential areas into Keefe Creek, a larger catchment area that includes the burned portions of Rose Valley Regional Park, and burned areas of West Kelowna Estates. Keefe Creek flows through WFN Tsinstikeptum 10 and across Westside Road before reaching Okanagan Lake.

7.5.2 Keefe Creek (Partial)

Although the overall likelihood of post-wildfire natural hazards within Keefe Creek is considered low, several locations are identified where blocked drainages or shallow ditchlines may pose a minor maintenance and nuisance hazard during rainfall runoff events. An example of this is shown in Photo 5 along Bear Creek Road (Waypoint Keefe-1). Steeper slopes along Bear Creek Road and above Westside Road in this area are also subject to sediment-laden runoff. A burned gully above Bear Creek Road shows evidence of small-scale sediment-laden flow and associated sediment deposition adjacent to the road (Photo 6; Waypoint Keefe-2). Further sediment transport from this gully may reach the road, block ditches, and disrupt access. Downstream from this at the intersection with Westside Road, there are several culverts (250 mm and 400 mm) that are damaged and at least partly blocked (Photo 7 & 8; Waypoint Keefe-3). Ditchline drainage is severely limited and requires immediate maintenance to avoid sediment deposition on the road (see mitigation recommendations in Section 8.5).

7.5.3 Face Unit Between Keefe Creek and Luluwap Creek

The face unit between Keefe Creek and Luluwap Creek was extensively burned. Upslope areas are steep, bedrock-controlled slopes. There are scattered areas that burned at high burn severity. However, areas closest to developed residential areas (West Kelowna Estates) and Bear Creek Road burned at low severity. In areas that burned at low to moderate severity, field observations noted that soils and organic litter remain and there was a lack of evidence of instability. For these areas, elevated rates of surface water runoff may be expected, and nuisance-level sedimentation and ravelling erosion may occur. Where pre-existing rockfall hazards are present, these would continue to occur. Maintaining associated drainage structures through the sub-division areas is important to reduce the risk to private property.

While there are no well-defined tributary streams within the face unit, the lower slopes (generally downslope of Bear Creek Road) have several deeply incised gullies that may direct sediment-laden flows to Westside Road, and potentially to private properties located along Westside Road. Road users should be aware of potential hazards, particularly during rainy periods.

7.5.4 Luluwap Creek (Upper and Lower)

Luluwap Creek is a discontinuous stream, originating from the steep, bedrock slopes above Rose Valley Road (upper Luluwap Creek catchment), becoming subsurface where thick glaciofluvial sediments are encountered (Middle Luluwap Creek - in the vicinity of the Petterson Rd and Bear Ck Rd intersection), before daylighting again where flows are concentrated in an incised gully upslope of Westside Road and then downstream through Raymer Bay Regional Park, before entering Okanagan Lake (Lower Luluwap Creek). The two catchments, Upper and Lower Luluwap Creek, are assessed separately but it is recognized that Lower Luluwap Creek receives considerable flow from groundwater sources.

There is a surface water (and spring-fed) domestic intake on Lower Luluwap Creek, located just upslope of Westside Road (Photo 9; Waypoint Lower Luluwap-1). The channel is within a wildfire-impacted steep-sided bedrock-controlled gully with abundant sediment sources, colluvium, and debris that are potentially impacting water quality. During the field assessment a bear carcass observed near the water intake structure. The 600 mm culvert under Westside Road is partly blocked (Photo 10; Waypoint Lower Luluwap-1). Based on the degree of burn within the catchment and along the gully sideslopes above Westside Road, combined with observed site conditions, there is a very high partial risk to the domestic water intake, Westside Road and to the downstream Raymer Bay Regional Park.

Upper Luluwap Creek has a Melton Ratio that indicates potential for debris flow (0.74) and based on the degree of burn (100% burn and 50% at high severity) the potential debris flow hazard rating is high. Properties located at the end of Petterson Road (744 and 752 Petterson Road) are located at the base of the catchment (Photo 11; Upper Luluwap-1). There are thick sand and gravel glaciofluvial outwash sediments within the valley and the drainage channel is indistinct and likely subsurface. It is not known whether there is potential for overland flow that may potentially impact those properties and further investigation may be warranted.

The partial risk rating for a section of the Rose Valley Access Road along Upper Faulkner Creek is rated very high for rockfall and shallow landslide, and moderate to high for sediment-laden runoff to residential properties in the Rosalee Lane area. The partial risk rating for burned areas within West Keefe Creek is rated moderate to high for small-scale sediment-laden flooding and very high for the culverts located at the intersection of Bear Creek Road and Westside Road. For Lower Luluwap Creek the partial risk rating for the Westside Road culvert and for Raymer Bay Regional Park is rated very high for sediment-laden flooding and very high for surface erosion and ravelling. For Upper Luluwap Creek the post-wildfire partial risk rating for debris flow, sediment-laden flood and terrain instability is rated very high for private property along upper Petterson Road (744 and 752 Petterson Road).

7.6 Lambly (Bear) Creek Watershed, including Bear Creek Road Area

This area of interest is shown on Map 005 (Appendix B) and area characteristics are summarized in the Report Card and photographs provided in Appendix C-6.

7.6.1 Lambly (Bear) Creek Mainstem Channel and Fan

Within the Lambly (Bear) Creek watershed, the wildfire burned both sides of the valley, including the riparian corridor, downstream of Terrace Creek to Westside Road. Areas to the north and upstream of the wildfire were previously burned in the 2009 Terrace Mountain wildfire, and small areas just upslope of Westside Road were burned in 2011 and in 2016.

For the Lambly Creek watershed as a whole, the anticipated effect on peak flows from the 2023 wildfire is rated low due to the small overall area burned (12.2% of entire watershed). However, wildfire effects on terrain stability and riparian function may still influence natural hazards along the mainstem channel, on the adjacent slopes, and within some of the small, steep tributary catchments.

Areas of interest along Lambly Creek are identified below, and the observed wildfire effects are summarized. Waypoints are identified on Map 005 included in Appendix B and select photographs are provided in Appendix C-6:

Bear Creek Provincial Park Campground and Westside Road Bridge:

- The Bear Creek Provincial Park Campground bridge (Photo 1; Waypoint Lambly-1) and the Westside Road bridge (Photo 2; Waypoint Lambly-2) appear to have good clearance for elevated flow and debris.
- Channel stability on the fan area of Lambly Creek within the campground near the mouth is a pre-existing concern. Bank erosion was observed following the spring freshet floods and high lake levels of 2017, and during the spring freshet floods of 2018, so any further peak flows and/or elevated sediment load may exacerbate the instability.
- There is high likelihood for increased rockfall and soil ravelling activity along the steep bedrock and colluvial slopes within the canyon reach of Lambly Creek, upstream from Westside Road (Photo 3; Waypoint Lambly-3).

Bear Lake Main FSR and Upper North Face Unit Slopes in Watershed:

- Bear Lake Main FSR is a well-travelled busy resource and recreation road, used to access areas within the north side of Lambly Creek watershed. Road grading activities and erosion of exposed sandy soils has already led to some infilling of ditch lines and blockages of culverts. There is evidence of post-wildfire sediment-laden runoff along the slopes below the road and, because of the wildfire, there is no vegetation on the slope to mitigate sediment transport downslope. An example of this sedimentation at a small unnamed drainage crossing is shown in Photo 4 (Waypoint Lambly-4).
- The upper face unit slopes on the north side of the watershed have had previous timber harvesting and the area is also criss-crossed with OHV recreation trails. Vegetation burn severity is moderate to high and this is reflected on the ground by the degree of exposed mineral soil, the presence/absence of rootlets, and small branches on the ground surface (see Photo 5 and 6; Waypoint Lambly-5). Hazards to recreation trail use include windfall (danger trees), burn holes in the ground, loose sediment, and hazards such as surface erosion and shallow landslide activity on steeper (>40%) slopes. The initial stages of vegetative recovery were noted in moderately burned areas at the time of the field assessment (see Photo 6).
- Wildfire severity appeared to be higher on the south side of the watershed. High vegetation and soil burn severity near a harvested area (Waypoint Lambly-9) showed blackened timber, lack of organic soils or woody debris on the ground surface, exposed mineral soils, and observed soil-water repellency (see Photo 7).

Tributary 1 (aka Blue Grouse Creek):

- Blue Grouse Creek crosses the Bear Lake Main FSR (Photo 8 & 9; Waypoint Blue Grouse-1). The culvert at this crossing is partly blocked. There is a very high risk to the FSR associated with debris flood impact on this small, sparsely vegetated, steep catchment.

CWK Diversion and Intake Structure:

- A concrete weir and intake structure is located on Lambly Creek approximately ~6.5 km upstream from the mouth of the creek (Photos 10 & 11; Waypoint Lambly-6 – POI at Intake). Water destined for domestic consumption is diverted from Lambly Creek and piped to the Rose Valley Reservoir. Based on a review of site conditions, approximately ~4 km of riparian forest upstream of the intake site and steep valley side slopes were burned at high severity. Stream channel conditions upstream of the intake (Photo 11) indicate a high gravel-cobble bedload that is relatively mobile. Rock placement in front of the intake pond provides minimal protection from high flows and sedimentation (see Photos 12). Based on the loss of riparian forest upstream of the intake (see Photo 13; Waypoint Lambly-7), there is a very high risk to the intake from increased channel instability, sediment and debris loading. Loss of riparian forest and a resulting increase in stream bank erosion and channel instability continues downstream from the intake (see Photo 14; Waypoint Lambly-8) with the potential for impacts further downstream.
- Access to the intake is along a steep, narrow road accessed from Bear Creek Road. Due to the effects of wildfire, there is a high likelihood of shallow landslide activity (or smaller-scale ravelling) which may potentially impact the access road. Because of the high partial risk of impact from landslide or ravelling to this critical infrastructure, a higher level of inspection and maintenance may be required.

CWK Diversion Pipeline:

- Water destined for domestic consumption is diverted from Lambly Creek to the Rose Valley Reservoir via buried pipeline. The pipeline traverses steep glaciofluvial (and glaciolacustrine) terrace scarp slopes (see Photo 15 and 16; Waypoints Bear Ck Rd-1 and Bear Ck Rd-2). The terrace scarp slopes are actively unstable in some areas, particularly at trail/pipeline cut slopes. The steep slopes above the pipeline, and downslope of Bear Creek Road, were burned at high severity. Post-wildfire effects on slope stability are expected. The pipeline depth needs to be confirmed to understand whether it is at risk of impact by potential increased landslide activity. For localized sections, particularly downstream of the Cedar Creek crossing (discussed in Section 7.6.2 below), the partial risk of landslide activity to the pipeline location may be very high. Specific risk evaluation to the pipeline itself is beyond the scope of work for this study since it requires knowledge regarding burial depth and pipeline strength among other specific factors.

7.6.2 Bear Creek Road Area

The Bear Creek Road area of interest is located beyond (north of) the Petterson Road intersection and traverses steep glaciofluvial terrace side slopes on the south side of Lambly Creek. Upslope of Bear Creek Road there are face unit slopes as well as several small, unnamed catchments, and a few larger catchments (Tributary 2 and Cedar Creek). Post-wildfire hazards identified within the upslope tributary catchments include sediment-laden flooding, debris flow/debris flood occurrence. Post-wildfire hazards occurring downslope of the road include landslides and surface erosion along the wildfire-affected glaciofluvial terrace scarp slopes, where downslope instability may compromise road stability along localized sections. Field observations are noted below, with reference to photos and mapped waypoints:

Bear Creek Road:

- Localized sections of Bear Creek Road are subject to an elevated landslide hazard associated with wildfire-affected fill slopes below the road (Photo 17; Waypoint Bear Ck Rd-1). Natural escarpment slopes below Bear Creek Road are steep (>60% slope gradient) and burned at high vegetation and soil burn severity. Windfall of burned trees may destabilize soils and there is potential for further destabilization (landslide and rockfall) on the slope and along the toe of the slope where it is undercut by the pipeline trail or by Lambly Creek (Photo 18; Waypoint Bear Ck Rd-3).
- In at least one location (at Waypoint Bear Ck Rd-3) there are small, steep burned catchments with colluvial fans that extend down to Bear Creek Road. Photos 19 and 20 show conditions at a small catchment that shows past debris flow activity. This, and other similar catchments upslope of Bear Creek Road, are capable of generating small debris flows with the runout and deposition of sediments and debris at the road.

Cedar Creek and Cedar Creek Tributary:

The Cedar Creek catchment is a small (0.35 km^2) tributary to Lambly Creek. The catchment has steep, bedrock-controlled headwaters that aggregate flow from several small tributaries into a large gully (see Photo 21). The following observations document conditions along Cedar Creek, where post-wildfire hazards are anticipated:

- Cedar Creek flows into Lambly Creek less than 1 kilometer downstream from the CWK water diversion site. The water pipeline crosses Cedar Creek at Waypoint Cedar-1. At this location the pipeline has previously been exposed by high flows. Repair work included installation of two culverts (500 mm and 200 mm) and rock armour (Photos 22 and 23). Log stringers at the crossing have since burned and the anticipated changes in peak flow and sediment transport on Cedar Creek have the potential to exceed the capacity of the cross-drains. This location is rated very high risk and appears vulnerable.
- There is an increased likelihood of peak flow impacts, and high likelihood of landslide activity along the steep slopes adjacent to Cedar Creek, <u>downstream</u> of Bear Creek Road. Slopes along the incised reach are steep and there are observed landslides, surface erosion, and undercutting along the channel banks (see Photo 24; Waypoint Cedar-2). In addition, along this reach, there is a pond on Cedar Creek constructed by a driveway crossing with two culverts (400 mm and 300 mm diameter) passing flow (see Photo 25). If the culverts plug with sediment, then overtopping flows may destabilize the driveway crossing, which may potentially affect private property (875 and 779 Bear Creek Road) and a downstream crossing of the water pipeline.
- There is an increased risk of peak flow impacts to the Cedar Creek crossing on Bear Creek Road (Waypoint Cedar-4). At this location, there is an 800 mm culvert (Photo 26). Upstream of the road, Cedar Creek flows within a ditch along a private driveway (at 944 Bear Creek Rd.) (Photo 27). Although there is no evidence of recent sedimentation along the ditch, there is some scouring by high flows, and there is abundant colluvium associated with past debris flood activity on the downslope side of the road (Photo 28).

- Further upstream on Cedar Creek there is a domestic water license (Photo 29; Waypoint Cedar-5). Anecdotal reports from the owner at 910 Bear Creek Road (L. Jensen, *personal communication*, 2023) indicate that the creek has some sedimentation in the spring and, at the intake site the stream is perennial. The owner reports that there have been no reported washouts on the downstream culverts. The steep slopes along Cedar Creek, and the adjacent Cedar Creek Tributary show evidence of surface erosion, small-scale sediment laden flow (Photo 29 and 30) and there is an overall increased likelihood of debris flood or debris flow activity on Cedar Creek, and on the Cedar Creek Tributary upslope of Bear Creek Road, potentially affecting private property (910 Bear Creek Road).

Lambly-Tributary 2 along Bear Creek Road:

- Lambly-Tributary 2 is a small (0.42 km^2) catchment located upslope of Bear Creek Road. The tributary headwaters are bedrock-controlled slopes lacking indicators of large-scale instability. The small channel is tightly constrained within a steep (40% gradient) colluvium-filled gully until reaching a small fan (slope 20-25%). There are scattered boulders up to 0.5 m diameter on the fan. The stream is ephemeral with no distinct channel across the fan approaching Bear Creek Road (Photo 31 and 32). There is no visible culvert on the downslope Bear Creek Road.
- Private property (524 Bear Creek Road) is located north along the edge of the fan. Domestic water is drawn from a dug well within an incised reach of the channel (Photo 33). The property owner (J. Zeman, *personal communication*, 2023) reports that there have been no reported incidents of debris flow or debris flood activity affecting the fan. Based on the physical characteristics, the catchment is capable of generating a debris flow (Melton Ratio = 0.92) and has been extensively (95%) burned at moderate to high burn severity. Despite a lack of recent large-scale debris flow or debris flood activity, given an appropriately large triggering rainfall event, there is potential to generate a sufficiently large event that could potentially run out to Bear Creek Road and to the adjacent property on the north side of the fan. Debris flow events at this site are infrequent, however, the likelihood is significantly elevated for a few years following a major disturbance such as the recent wildfire.

7.7 Westside Road Tributaries and Face Units

This area includes several small (less than 2 km^2) steep catchments and face units along Westside Road north of Lambly (Bear) Creek within the RDCO. This area of interest is shown on Map 006 (Appendix B) and area characteristics are summarized in the Report Card and photographs provided in Appendix C-7.

The wildfire extended from the height of land downslope to Okanagan Lake, affecting lakeshore development clusters, and scattered rural properties. The high severity burn was situated mostly at an upper mid-slope elevation, with moderate burn severity occurring throughout. Many streams are ephemeral and do not flow year-round. However, past debris flow evidence exists in the form of reforested deposits, and the catchments are capable of producing debris flows if certain conditions and/or events occur.

Slopes within the area generally have moderate gradients with deeply incised gullies. Upper slopes are benchy and bedrock-controlled, with surficial materials increasing in thickness at and below Westside Road. Cut slopes along Westside Road are dominantly bedrock exposures. Based on a review of licenced groundwater well data thick glaciofluvial and glaciolacustrine sediments are present at lower elevations only, typically at or below that of Westside Road. Pre-existing instability is predominantly small-scale rockfall activity, with little evidence of debris flow transport along the small stream channels.

Streams flowing through the area are moderately well-confined until reaching Westside Road. The streams have relatively small, steep fans and Westside Road is roughly located at the fan apex. Culverts on the tributary streams convey flows across Westside Road. Stream flows infiltrate accumulated sediment within the channel and along the fan, and transition to groundwater flows with some apparent seepage along lower slopes closer to the lake.

Post-wildfire impacts may include small-scale landslides along steep gully side slopes and headwalls, resulting in sediment loading into the channel. Depending on stream gradient, these channels have the potential to generate larger-scale debris flows. However, the trigger mechanism is very much dependant upon rainfall (volume and intensity). Past debris flow deposits extending as far downslope as Westside Road were observed at Cinnabar Creek, Wilson Creek, Cedar Gulch, and Jennie Creek. Steep, bedrock-controlled cut slopes along Westside Road may experience increased frequency of rockfall and small sediment-laden runoff through areas burned at high severity.

7.7.1 Field Observations at Delineated Tributary Catchments

Field observations are summarized in Table 7-1 for each of the small tributaries within the study area. Where the observations relate to a post-wildfire hazard, this is indicated. In addition, mapped Waypoints and photographs are referenced.

Table 7-1: Field Observations and Post-Wildfire Hazard Indicators for Westside Road Tributaries

Catchment	Waypoint # (see Map 006)	Observations (Photo # in Appendix C-7)	Hazard Indicator
Cinnabar Creek	Cinnabar-1	Ephemeral stream in gully with past debris flow deposits (levees with up to 1.5 m diam. boulders) (Photo 1). New 900 mm culvert with concrete baffle and armoured ditchlines (Photo 2).	Natural hazard level elevated due to wildfire but not extensive through catchment.
Dimetri Creek	Dimetri-1	Ephemeral stream in gully. New 1200 mm culvert with trash rack and rock lined channel (Photo 3)	Bedrock-controlled channel above Westside Road with limited evidence of scour.
Cedar Gulch	Cedar Gulch-1	Wide gully with high burn severity. Evidence of past debris flow/flood deposition (Photo 5) upslope of Westside Road. A few boulder-sized (>15 cm) clasts were observed. Ephemeral stream (no defined channel, 15% gradient) within steep (65%) sided gully. There are thick sand and gravel deposits at Westside Road but no visible culvert at outlet of gully (Photo 6). Downslope of Westside Road is a steep (dry) gully along south side of Lake Okanagan Resort (Photo 7).	Lacking evidence of large-scale debris flow activity at Westside Road but catchment is capable of producing debris flow events. Lack of drainage structure at road crossing puts Westside Road at risk.
Wilson Creek	Wilson-1	On Wilson Creek at Westside Road there are two culverts with rock armour at the outlet (Wilson-1; Photo 8). At	There is field evidence of past debris flow activity

Catchment	Waypoint # (see Map 006)	Observations (Photo # in Appendix C-7)	Hazard Indicator
Wilson Creek	Wilson-2 Wilson-3 Wilson-4 Wilson-5 Wilson-6 Wilson-7 Wilson-8 Wilson-9	the time of the field assessment there was no flow, and no visible channel, at the culvert outflow. There are abundant sand and gravel deposits in the area, so seasonal flows likely go subsurface upslope of Westside Road. Below the Road there are abundant debris flow and debris flood deposits, including some boulder-sized material (up to 1.5 m diameter) (Photo 9). The fan gradient, approaching Okanagan Lake, is 10-15%. There are gravel and cobble-sized deposits all the way to Lake Okanagan (location of Camp Owaissi) (Wilson-2). The Wilson's Landing Fire Hall is located on the upslope side of Westside Road on the south side of the fan (Photo 10; Wilson-1). Berm and fill material have created a catch basin above Westside Road that would likely be capable of retaining a moderate-sized debris flow event (detailed assessment of capacity was not determined). However, the berm appears discontinuous (Photo 11). The fan starts upslope of Westside Road, where the gully opens up and the gradient decreases (Wilson-3). There is some deposition from past debris flow/debris flood events, including some larger boulder material. Upstream from the fan the channel is steep (40-45%) (Photo 12). However, upslope areas are more moderately sloped and are not well-connected to the channel (Photo 13; Wilson-4) that limit connectivity to the creek. Reaches at ~600 m elevation are tightly confined within a bedrock canyon (Photos 14 & 15; Wilson-5). There are at least two trail crossings that are mostly decommissioned and benchy (12% slope) terrain (Photo 16; Wilson-6). It appears that sediment is stored along low gradient sections but that there appears to be a general lack of sediment storage (small events stop along the channel upslope – and return period for large events is long. The top of the catchment transitions sharply from the low gradient plateau to steep (50-75%) slopes into a large gully. There is an old resource road traversing the top of the catchment, with a clear 400 mm culvert at Wilson-7 (Photo 17). There is abundant windthrow (appears to be related to the strength of the wildfire-generated winds) with lots of exposed soil and observed small-scale landslides (Photo 18; Wilson-8). At Waypoint Wilson-9 there is observed headscarp for a small (50 m^3) landslide that has transitioned to a downstream debris flow. There is evidence of channel scour and deposition in the gully associated with early-stage debris flow initiation.	on Wilson Creek and previous reporting has been completed (Terratech, 2003). The post-wildfire conditions elevate the likelihood of future instability. Future sediment loading of the channel is assured due to the effects of high severity wildfire. Stored sediment will recharge quickly, priming the channel for an appropriate-sized hydrometeorological event to trigger a large debris flow. There have been past efforts to mitigate risk, but the capability of those measures required confirmation.

Catchment	Waypoint # (see Map 006)	Observations (Photo # in Appendix C-7)	Hazard Indicator
		Sediment yield could be 1 to 3 m^3/m (resulting in a predicted debris flow size of ~2300 m^3 to 7000 m^3.	
Oldman Creek	Oldman-1	Oldman Creek is ephemeral and not visible at Westside Road. There is a 500 mm culvert on Westside Road (inlet is blocked) and the upslope gully area is privately developed (Photo 15).	The is a lack of field evidence of past debris flow activity but the steep catchment can produce debris flows, and current post-wildfire conditions are the type of conditions that increase the likelihood. The blocked culvert increases risk to Westside Road.
Jennie Creek	Jennie-1	There is a 1000 mm culvert at Westside Road (inlet mostly plugged with sediment) (Photo 16). Upslope road, channel gradient 20% with boulders (0.7 m diameter) on ground surface and other debris flow deposits apparent (Photo 17). There is evidence of an old trail extending up the channel. No recent large events due to moss on boulders and ~40 year old trees in ravine (but past events likely less than 100 years old). There is direct connectivity of the steep channel and Westside Road (Photo 18). There is no channel visible below road.	Partly blocked culvert increases partial risk of sediment-laden flood or debris flow to Westside Road.

Based on the elevated likelihood for debris flow activity, increased awareness and mitigation measures are warranted. Risk to private properties along the affected streams, and downslope of Westside Road across associated fan areas, is evaluated broadly. An attempt to identify specific properties is made and these are provided on the Catchment Report Card (Appendix C). Mitigation recommendations, including recommendations for further assessment, are presented in Section 8.4.

7.7.2 Westside Road Face Units

The McDougall Creek Wildfire burned slopes above (and below) Westside Road, extending approximately 12 km from Traders Cove (north of Lambly Creek) to Cinnabar Creek (south of Caesars Landing). The face unit slopes are those areas in between the delineated tributary catchments.

Much effort is spent characterizing post-fire natural hazards associated with the delineated tributary catchments. This is largely because of the potential for larger magnitude, and thus, potentially damaging events such as debris flow. The face units between the tributaries are also subject to post-wildfire natural hazards, although the scale of the hazards is likely to be smaller. The risk to Westside Road and to private properties depends on the likelihood for the hazards to reach, and otherwise affect them.

Sediment-laden flows may occur on small gullies or topographic swales where surface runoff is concentrated. An example of this occurs at the north end of the Wilson Landing subdivision, where a small unnamed stream flows to Westside Road, then to Browse Road and Bolton Road, before reaching Okanagan Lake.

Surface erosion and ravelling of soils is anticipated on steep slopes that have burned at moderate to high severity. Sediment reaching the road may potentially block ditches and culverts.

Field observations along Westside Road (Waypoint Westside-1) noted that wide ditches can capture and detain sediment-laden runoff from burned slopes above. An example of this is shown in Photo 4 (Appendix C-7). Sections of Westside Road have upgraded drainage structures, such as the 1200 mm diameter culvert with concrete baffles and rock-lined ditches (at Waypoint Westside-2; Photo 19). These newer structures may be able to accommodate post-wildfire runoff, but not moderate-sized debris flows. A section of Westside Road has been improved, with stabilized rock cuts and installed rockfall mitigation fencing (Westside-3; Photo 20). This structure will reduce the likelihood of rockfall reaching the road.

At Waypoint Westside-4, there is a section of Westside Road that is lacking rockfall protection and based on observations appears to have an elevated hazard level due to wildfire. Increased monitoring, awareness, and mitigation measures may be warranted at this site.

7.8 Climate Change Considerations

Considerations for a changing climate into the long-term future are not considered in this report. It is the recent past climate and immediate (short-term) climate character (which include aspects of a changing climate) that are more relevant. It is the recent past climate conditions, including prolonged drought (lower winter snowpack and low summer precipitation) that may have exacerbated the wildfire conditions in the first place. Post-wildfire effects on hydrology are greatest in the first year following wildfire and are reduced (but not eliminated) in the following 3 to 5 years. While full hydrologic recovery does not occur until the forest recovers, which can take several decades. The preliminary hydrologic modelling results do not account for peak flow changes associated with the predicted effects of climate change.

For long-term consideration, the *Climate Projections for the Okanagan Region* document (RDNO, RDCO, RDOS and Pinna Sustainability, 2020), projected changes for the Central Okanagan for the 2050s (2040-2069) in comparison to a 1961-1990 baseline period. The results indicate the following:

- Total precipitation is expected to increase by 10% to 13% for the spring and autumn seasons, but summer precipitation expected to decrease (-14%).
- Of relevance to this study, the frequency of intense precipitation is expected to increase, as is the associated precipitation amount. Namely, the 1 in 20 wettest day of the year[15] is expected to increase by 18%, from an average of 33 mm to 39 mm.

Thus, provisions for a changing climate should be incorporated into future designs for culverts, drainage structures and road crossings.

[15] 1 in 20 wettest day is an indicator of extreme weather. The likelihood of a single-day rainfall of this magnitude occurring in any given year is 1 in 20, or 5% chance.

7.9 Summary of Risk Analysis Results

A summary of partial risk analysis results for areas affected by the 2023 McDougall Creek Wildfire is presented in Table 7-2. The high to very high-risk sites and segments (road and stream channel) are identified on Maps 002 – 006, and risk sites and segments along lower McDougall Creek and lower Smith Creek, are identified on Map 007 (in Appendix B).

Table 7-2: Summary of Post-Wildfire Natural Hazards Risk Analysis Results (2023 McDougall Creek Wildfire)

				Spatial Likelihood (P(S:H)) (i.e., likelihood for impact at location)			
Map #	**Watershed / Catchment**	**Dominant Geomorphic Process**	**Post-Wildfire Hazard Level for Dominant Process (P(H))**	**Public Road & Infrastructure**	**Water Intakes & Private Road Crossings**	**Private Property[1]**	**Highest Level of Partial Risk (P(S:H) x P(H))**
Map 002	**Powers Creek Watershed**						
	Powers Creek Tributary 1	Debris Flood	Moderate	n/a	n/a	High	High
	Upper Powers Ck at POI	Flood	Low	n/a	High	n/a	Moderate
	Upland Creeks and Face Units above West Kelowna						
	Smith Creek Tributary	Debris Flood	Low	High	n/a	Moderate	Moderate
	Smith Creek at POI (Copper Ridge Rd)	Debris Flood	High	High	n/a	Moderate	Very High
	Davidson Creek	Debris Flood	High	High	High	High	Very High
	John Moore Creek	Debris Flood	High	High	High	High	Very High
	Unnamed Tributary to Lower McDougall	Debris Flow	High	High	High	High	Very High
	Face Unit near Davidson Creek	Sed Laden Flood and Erosion	High	High	n/a	High	Very High
Map 003	**McDougall Creek Watershed**						
	McDougall Creek Tributary 1	Flood	High	Low	n/a	n/a	Moderate
	McDougall Creek POI at Bartley	Flood	High	High	High	n/a	Very High
Map 004	**Rose Valley Reservoir**						
	Rose Valley Tributary 1	Debris Flow	High	n/a	n/a	n/a	n/a
	Rose Valley Tributary 2	Debris Flow	High	n/a	n/a	High	Very High
	Rose Valley Tributary 3	Debris Flow	Moderate	n/a	Low	n/a	Low
	Rose Valley Reservoir POI at Dam	Surface Erosion	High	Moderate	High	n/a	Very High
	Faulkner Creek, Keefe Creek and Luluwap Creek						
	Upper Faulkner Creek	Localized Erosion & Rockfall	High	High (localized)	n/a	Moderate	Very High
	Keefe Creek (Partial)	Sed-Laden Flood	Moderate	High	n/a	High	High
	Lower Luluwap Creek (at Westside Rd)	Sed-Laden Flood	High	High	High	n/a	Very High
	Upper Luluwap Creek	Debris Flow	High	n/a	n/a	High	Very High
	Face Unit between Keefe Ck and Luluwap Ck	Sed Laden Flood and Erosion	High	High	n/a	High	Very High

				Spatial Likelihood (P(S:H)) (i.e., likelihood for impact at location)			
Map #	**Watershed / Catchment**	**Dominant Geomorphic Process**	**Post-Wildfire Hazard Level for Dominant Process (P(H))**	**Public Road & Infrastructure**	**Water Intakes & Private Road Crossings**	**Private Property[1]**	**Highest Level of Partial Risk (P(S:H) x P(H))**
Map 005	**Lambly (Bear) Creek Watershed and Bear Creek Road Area**						
	Lambly - Blue Grouse Ck	Debris Flow	High	High	n/a	n/a	Very High
	Lambly Tributary 2	Debris Flow	High	Moderate	n/a	Moderate	High
	Cedar Creek	Debris Flood	High	High	High	High	Very High
	Cedar Creek Tributary	Debris Flow	High	High	High	High	Very High
	Lambly (Bear) Creek POI at CWK Intake	Flood / Channel Instability	Low / High	Moderate	High	Low	Very High for channel instability
	Lambly (Bear) Creek POI at Mouth	Flood / Channel Instability	Low / High	High	High	Low	Very High for channel instability
Map 006	**Westside Road Tributaries and Face Units**						
	Cinnabar Creek	Debris Flow	Low	High	n/a	High	Moderate
	Dimetri Creek	Debris Flow	High	High	n/a	High	Very High
	Cedar Gulch	Debris Flow	High	High	n/a	Moderate	Very High
	Cedar Gulch-2	Debris Flow	High	High	n/a	Moderate	Very High
	Wilson Creek	Debris Flow	High	Moderate[2]	n/a	Moderate[2]	High
	Oldman Creek	Debris Flow	High	High	n/a	High	Very High
	Jennie Creek	Debris Flow	High	High	n/a	Moderate	Very High
	Unnamed Creek 1	Debris Flow	High	High	n/a	n/a	Very High
	Face Unit Slopes	Sed Laden Flood and Rockfall	High (loc.)	High	n/a	High	Very High
Map 007	Lower Smith Creek, downstream from Copper Ridge Dr.	Flood / Channel Instability	High	High	High	High	Very High
	Lower McDougall Creek, downstream from Bartley Rd.	Flood / Channel Instability	High	High	High	High	Very High

[1] - spatial likelihood for private properties located on the fans is approximate due to uncertainty of event magnitude, unknown capacity of culverts, and event runout characteristics. A refined risk analysis for private properties would require individual site assessments and is beyond the scope of this assessment.

[2] – past mitigation works to be confirmed.

8. Recommendations for Risk Mitigation

Recommendations for risk mitigation are provided for locations and areas assigned a high or very high partial risk. Recommendations are both general and refer to specific sites, where possible. Based on the high-level nature of the post-wildfire risk analysis, not all hazards or risks can be identified for individual properties. However, use of this report can help guide where additional site-specific risk assessment may be warranted.

8.1 Increased Awareness of Post-Wildfire Hazards

In general, for the entire area affected by the McDougall Creek wildfire, increased education and public awareness is recommended. Elevated risks are anticipated during the following periods:

- In the early spring (mid-March to mid-May) when rapid snowmelt from early season warming or rain-on-snow events at lower elevation sites;
- In the late spring (early-May to late-June) during which elevated peak flows in the larger watersheds may be associated with snowmelt from higher elevation sites (due to warm temperatures and/or rain);
- in the summer (July to September), during localized, short-duration high-intensity convective rainstorms; and,
- in the mid- to late fall (mid-October to early December), during rain-on-snow events.

Recommended measures to increase education and hazard awareness include:

- facilitate public access to the Post-Wildfire Natural Hazard Risk Analysis report;
- install signage along public roads, such as Westside Road, alerting residents and visitors of the potential for natural hazards (i.e., hazardous conditions during rain events; rockfall hazards during freeze-thaw periods; no stopping);
- provide public information bulletins on hazard recognition and how to respond (such as BC government info-sheets); and,
- provide emergency response information, including a single central contact number, to be called for all emergencies, or in the event of an observed hazard scenario.

8.2 Develop an Early Warning System for Flood and Debris Flow

Elevated peak flows associated with post-wildfire effects are anticipated on the larger catchments, such as Smith Creek, McDougall Creek, and Cedar Creek (in Lambly Creek watershed), and are generally associated with spring snow melt and/or fall and spring rain-on-snow scenarios. A recommended risk mitigation measure for flood-prone creeks includes monitoring upper elevation snow and weather conditions as follows:

- Monitor snowpack at nearby snow survey sites[16], precipitation at Kelowna[17], and real-time stream flows on Whiteman Creek[18]. Utilize flood warning and advisory notifications provided by the BC River Forecast Centre (http://bcrfc.env.gov.bc.ca/warnings/index.htm) and/or develop a locally-specific warning system (decision matrix) that comprises criteria for flood alerts (snowpack, spring temperature, rainfall thresholds). This will inform flood response measures.

Currently, intense rainfall warnings are provided by Environment Canada[19]. This information is not specifically targeted to the study area and may not be able to provide data that can be relied upon to provide realistic alerts. In absence of a near-real time debris flow warning system based on rainfall thresholds, the provincial storm alerts provide general guidance. It is understood that rain gauges have been installed at sites within the study area and that research is underway (by SFU and UBCO) to better understand rainfall trigger thresholds for debris flow initiation. Further work is recommended to develop a locally-relevant debris flow warning system.

8.3 Recommendations to Mitigate Flood Impacts for Large Watershed Areas

Short-term and long-term mitigation measures for downstream reaches of large watershed areas (Smith Creek, McDougall Creek, and Lambly Creek) that are subject to an elevated likelihood of peak flow-generated flood (and potentially debris flood if sediment-bulking is high) and/or channel instability (see Table 8-1).

[16] See Whiterocks Mountain (2F09) at https://governmentofbc.maps.arcgis.com/apps/webappviewer/index.html?id=c15768bf73494f5da04b1aac6793bd2e

[17] The Kelowna airport climate station located east of the study area is operated by Environment and Climate Change Canada. The next closest station is at Penticton, located south of the study area, and likely reflects a drier climate.

[18] See Water Survey of Canada real-time hydrometric data at Whiteman Creek above Bouleau Creek (08NM174) at https://wateroffice.ec.gc.ca/report/real_time_e.html?stn=08NM174

[19] https://weather.gc.ca/mainmenu/alert_menu_e.html

Table 8-1: Risk Mitigation Recommendations for Large Watershed Areas Subject to Elevated Flood Hazard

For: The mainstem channel of McDougall Creek, Smith Creek, and Lambly Creek, within and downstream of the wildfire-affected area. Many issues along the mainstem channels are pre-existing. However, flood risk in already flood-prone areas may be exacerbated by the effects of the wildfire.		
SHORT-TERM ACTIONS		
Action	**Description**	**Assumptions and Estimated Cost**
Avoidance - Be prepared to protect assets at risk	Identify elements at greatest risk and protect or relocate assets. Short-term protective measures include: • Sandbags • Bulk bags • Lock blocks • Ditching and culverts Identify material sources and stockpile prior to freshet.	Cost depends on what needs to be protected and how it is protected.
Proactively maintain, clear, and upgrade (if possible) drainage structures in high risk areas and increase frequency of inspection along public roads	Ensure clear ditches, culverts, bridges, and road surfaces through the study area. For any high risk bridge sites, emergency preparedness might include staging equipment to maintain clear passage during peak runoff.	Responsibility of private property owners (on private land including driveway culverts on public roads) and MOTI roads contractor – AIM (on public roads).
For: The mainstem channel of **McDougall Creek, Smith Creek,** and **Lambly Creek,** within and downstream of the wildfire-affected area. Many issues along the mainstem channels are pre-existing. However, flood risk in already flood-prone areas may be exacerbated by the effects of the wildfire.		
LONG-TERM ACTIONS		
Action	**Description**	**Assumptions and Estimated Cost**
Plan and implement permanent flood mitigation measures where previously identified.	Develop plans to regain channel capacity where this is found to be lacking. Upgrade culverts and bridges as required.	Cost depends on number of sites, volume of sediment to be removed, and cost of replacement structure.
Update flood inundation modelling and floodplain mapping for lower McDougall Creek and Smith Creek	Update the 2023 hydrologic analysis to determine post-wildfire design flows and hydraulic modelling across fan area to determine flood extent and water depths for the design flow.	Use of watershed-scale hydrologic modelling (i.e., Raven) is recommended. Est. $60,000-$80,000.
Riparian restoration treatments and erosion/sediment control measures along wildfire-affected stream reaches	Implement measures to reduce potential for sediment/debris transport along stream reaches impacted by wildfire: • Riparian planting	Costs depend on site condition and chosen approach.
Deactivate and rehabilitate legacy roads and trails in the watershed	Due to high recreation use, a Comprehensive Access Management Strategy may be required to identify problem sites and determine approaches towards rehabilitation.	Est. $60,000 to $80,000 depending on level of consultation with stakeholders.

8.4 Recommendations to Mitigate Debris Flow and Debris Flood Impacts for Smaller Catchment Areas

Short-term mitigation measures for catchment areas subject to an **elevated likelihood for debris flow and/or debris flood activity**, which may potentially impact public roads and private property (see Table 8-2).

Table 8-2: Risk Mitigation Recommendations - Debris Flow/Debris Flood Catchments

<table>
<tr><td colspan="3">For: High- and Very High-Risk Catchments subject to Debris Flow or Debris Flood.

Includes:
• Powers Creek – Tributary 1
• Upland Creeks above West Kelowna
• Rose Valley Tributary 2
• Upper Luluwap Creek
• Cedar Creek and Lambly – Tributary 2
• Tributaries along Westside Road</td></tr>
<tr><th>Action</th><th>Description</th><th>Assumptions and Estimated Cost</th></tr>
<tr><td>Inspect, Maintain, and Monitor stream crossings sites at and downstream of the high hazard areas</td><td>Proactively maintain and conduct biweekly inspection in advance of the spring freshet and immediately after storm events along public roads including:
• Copper Ridge Road,
• Bear Creek Road, and
• Westside Road.

Do not investigate flow stoppages on foot – avoid/leave the area.</td><td>Responsibility of MOTI roads contractor - AIM</td></tr>
<tr><td>Further debris flow and debris flood assessment</td><td>Conduct a more detailed debris flow assessment including field investigation to determine potential debris volume, peak discharge, velocity, and runout. Assessment will refine risk assessment and obtain design parameters for mitigation.</td><td>Est. $25,000 to $40,000 per watershed.</td></tr>
<tr><td>Construct debris flow mitigation structures to protect private property</td><td>Based on the results of this assessment, mitigation structures may be warranted at high to very high risk sites.

This may include construction of berms at the fan apex to direct potentially damaging flows across the fan area. Details regarding structure type and feasibility could be determined from further detailed assessment.</td><td>Mitigation costs will depend on the results of more detailed debris flow/debris flood assessment and hydrologic analysis.

Protection structures on private land are generally the responsibility of individual land owners.</td></tr>
</table>

Conceptually, slope treatments may be considered in the headwater reaches of high hazard debris flow-prone catchments where there are high to very high downslope risks. Mitigative slope treatments may involve spreading mulch and seeding on high burn severity slopes, while avoiding steep, shallow to bedrock slopes. This treatment was applied on burned slopes after the Springer Creek Wildfire in the West Kootenays (Hope, et al, 2015).

8.5 Recommendations to Mitigate Small-Scale Landslide, Rockfall, Sediment-Laden Flooding and Surface Erosion

Slopes and Face Unit areas affected by small-scale raveling, rockfall, sediment-laden flooding and landslide activity may potentially impact public roads or private property. In general, the public should be made aware of the potential for sediment-laden floods from burned open slope areas along all roads and trails. Sandbags should be made available for emergency response purposes.

Recommendations for risk mitigation are provided for the following high to very high risk sites:

1. Powers Creek – Tributary 1 – Recommend inspection and monitoring of the rehabilitated fire guard, and other non-status roads and trails in the catchment, to ensure long term stability and to ensure that natural drainage patterns have been restored.
2. Upslope of Shannon Hills Place – Recommend that the status and function of a rockfall protection berm located upslope of private properties along Shannon Hills Place be assessed by the Engineer of Record, or another Qualified Professional.
3. Along the Rose Valley Dam Access Road (CWK) - it is recommended that rockfall hazard signage be posted to advise increased caution during stormy weather, and to be aware of the potential for dam access disruption.
4. Along Rosalee Lane (CWK) - Recommend monitoring and maintenance of the storm drain structures along the strata roads and Rosalee Lane.
5. Burned areas within West Kelowna Estates (CWK) and within Tsinstikeptum 10 (WFN) - It is recommended that the storm drainage network be inspected, that culverts are cleared, and that ditches along Bear Creek Road are enhanced to allow for sediment-laden runoff. The series of culverts and associated ditches at the junction of Bear Creek Road and Westside Road is considered very high risk and immediate maintenance is recommended.
6. North Bear Creek Road (Upslope and Downslope) – Signage to notify road users of potential hazards along Bear Creek Road (CWK and RDCO) is recommended. Recommend storm drainage improvements to accommodate changes in surface water runoff and potential sediment-laden runoff from burned slopes above Bear Creek Road. Signage and monitoring stability along the steep side slopes below Bear Creek Road, and along a short section of road cut above the road, along the Cedar Creek gully is recommended. Further work to assess road stability may be required and can be determined based on results from monitoring inspections.

On a smaller scale the following approaches may be used to accelerate recovery in areas with water repellent soils:

- Place logs or woody debris across the slope to slow runoff and intercept sediment;
- On flatter slopes, rake or hoe the upper 3-5 cm of soil to break up water repellent soils and to allow water to infiltrate the ground surface;
- Scatter weed-free straw mulch, wood chips, leaves, grasses, or compost to create and organic barrier to protect soils;
- Seed (choose an annual grass for quick establishment and perennial native grass species), or install check dams or similar barriers to control erosion.

8.6 Recommendations to Mitigate Domestic Water Quality Impacts

Although not specifically referenced by license number, residents with domestic water intakes located on streams within (or downstream from) the wildfire perimeter should be aware of the potential for wildfire effects on water quality. Water quality effects may be induced by changing turbidity, flows, and other contamination (i.e., nutrient loading). Loss of riparian vegetation can also increase stream temperatures, which can impact water quality. Periodic water quality testing is recommended for licenses on catchments rated high hazard for peak flow effects or debris flow/debris flood activity that are identified in this assessment.

Burned Slopes above Rose Valley Reservoir – Mitigation measures are recommended along high severity burned slopes that are directly connected to the Rose Valley Reservoir. Post-wildfire mitigation work within a 15-20 m wide band along the reservoir shoreline has already taken place. Under the direction of Larratt Aquatic, broadcast seeding of a stabilizing grass seed mix (Terralink Rapid Grow Slope Stabilizer mix) was completed for priority areas based on burn severity, soil water repellency, residual vegetation, and other risk factors (Self, J. 2023). Other methods to accelerate vegetation recovery may include shrub planting on dry sites and willow staking on wet sites, placing logs or other coarse woody debris along the contour to limit sediment delivery.

8.7 Mitigation Considerations for Private Lands

Post-wildfire natural hazards were assessed for all areas impacted by the McDougall Creek wildfire, regardless of jurisdiction. At this time, and generally speaking, responsibilities for risk mitigation fall upon the land owner, even though upslope hazards originate on Crown Land.

Risk ratings were broadly assigned to fan areas. For specific properties there is considerable uncertainty associated with the risk rating due to a lack of detailed understanding regarding potential event magnitude, unknown capacity of drainage structures, and event runout characteristics. Further, more detailed analysis would be required to better characterize the risk to human safety on individual properties. This is beyond the scope of work for this assessment. More detailed analysis would also be required to design appropriate mitigation measures, such as barriers or berms, and to provide information on long-term monitoring and maintenance of such mitigation measures.

9. Closure and Limitations

This report has been prepared by Clarke Geoscience Ltd. for the exclusive use of the Ministry of Forests – BC Wildfire Service. Any use of this report by a third-party is the responsibility of such, and no third party shall rely on this document. Use of the information contained within this report shall be at their own risk, and CGL accepts no responsibility for damages, if any, suffered by any third parties as a result of its use, or decisions made, or lack thereof, on this report. No other warranty is made, either expressed or implied.

The assessment has been carried out in accordance with generally accepted professional practices in BC. Professional judgment has been applied in the interpretations provided in this report. The conclusions and recommendations presented in this report are based on available information, limited field investigation, and professional opinion. Inherent variability in local precipitation, runoff, soil and vegetation burn severity, surface and subsurface soil conditions, may create unforeseen situations.

This report is subject to the CGL General Conditions and Terms of Use, presented in Appendix D.

Prepared by:

CLARKE GEOSCIENCE LTD.

PROFESSIONAL PROVINCE OF J.A. CLARKE 25319 BRITISH COLUMBIA GEOSCIENTIST 01/04/23

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In accordance with Professional Practice requirements, this report has been Independently Reviewed by Tim Giles, M.Sc., P.Geo., of Westrek Geotechnical Services Ltd.

References

Associated Engineering. 2023. Flood Mapping Project. Flood inundation Assessment and Mapping and Flood Risk Assessment and Mitigation Plan. Prepared for the City of West Kelowna. Vernon, BC.

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

Church, M. and J.M. Ryder. 2010. Chapter 2: Physiography of British Columbia. In: Pike, R.G., T.E. Redding, R.D. Moore, R.D. Winker and K.D. Bladon (editors). Compendium of forest hydrology and geomorphology in British Columbia. B.C. Ministry of Forests and Range, Forest Science Program, Victoria, B.C. and FORREX Forum for Research and Extension in Natural Resources. Land Management Handbook No. 66. Kamloops, BC. URL: www.for.gov.bc.ca/hfd/pubs/Docs/Lmh/Lmh66.htm

Clarke Geoscience Ltd. 2023. Memorandum: McDougall Creek Post-Wildfire Natural Hazard Risk Analysis – Preliminary Results of Priority Sites. Prepared for the BC Ministry of Forests. Dated: September 27, 2023. Kelowna, BC.

Curran, M.P., W. Chapman, G.D. Hope, and D.F.Scott. 2006. Large-scale erosion and flooding after wildfires: understanding the soil conditions. Technical Report 030. B.C. Ministry of Forests and Range, Victoria, B.C.

DeBano, L.F. 1981. Water Repellent Soils: A state of the art. United States Department of Agriculture, Forest Science. General Technical Report PSW-46. California, USA.

Doerr, S. and J.A. Moody. 2004. Hydrological effects of soil water repellency: on spatial and temporal uncertainties. Hydrological Processes. Vol. 18, No. 4, pp. 829-832. https://doi.org/10.1002/hyp.5518

Degraff, J.V., S.H. Cannon, J.E. Gartner. 2015. The Timing of Susceptibility to Post-Fire Debris Flows in the Western United States. Environmental and Engineering Geoscience. 21 (4) pp. 277-292. https://doi.org/10.2113/gseegeosci.21.4.277

Ecora Engineering and Resource Group Ltd. 2023. Grouse Complex Wildfire Rapid Geotechnical Assessment (Issued for Review). Prepared for the RDCO – Emergency Operation Centre. Kelowna, BC.

Hope, G., P. Jordan, R. Winkler, T. Giles, M. Curran, K. Soneff, and B. Chapman. 2015. Post-wildfire natural hazards risk analysis in British Columbia. Land Management Handbook No. 69. Victoria, B.C. URL: www.for.gov.bc.ca/hfd/pubs/Docs/Lmh/LMH69.htm

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. 2015. Post-wildfire debris flows in southern British Columbia, Canada. International Journal of Wildland Fire. Vol. 25. No. 3, pp. 322-336. https://doi.org/10.1071/WF14070

Jordan, P. and A. Covert. 2009. Debris flows and floods following the 2003 wildfires in southern British Columbia. Environmental and Engineering Geoscience. Vol. 15, pp. 217-234.

MacDonald, L.H. and E.L. Huffman. 2004. Post-fire Soil Water Repellency – Persistence and Soil Moisture Thresholds. Soil Science Society of America Journal. https://doi.org/10.2136/sssaj2004.1729

Ministry of Forests. 2021. Biogeoclimatic Subzone Variant Mapping (Ver. 12, 2021). Forest Analysis and Inventory Branch, 1:250,000 scale.

Nasmith, H. 1962. Late Glacial History and Surficial Deposits of the Okanagan Valley. BC Department of Mines and Petroleum Resources, Bulletin No. 46. Victoria, BC.

Neary, D.G., K.A. Koestner, and A. Youberg. 2011. Hydrologic Impacts of High Severity Wildfire: Learning from the Past and Preparing for the Future. Paper presented at the 24th Annual Symposium of the Arizona Hydrological Society; Watersheds near and far: Response to changes in climate and landscape; September 18-20, 2010; Flagstaff, AZ. 8 p. URL: https://www.fs.usda.gov/research/treesearch/40608

Okulitch, A.V. (comp). 2013. Geology, Okanagan Watershed, British Columbia, Geological Survey of Canada, Open File 6839, scale 1:100,000. Doi:10.4095/292220.

Paradis, S.J. 2009. Surficial Geology, Kelowna, British Columbia. Geological Survey of Canada, Open File 6146, scale 1:50,000.

Parsons, A., P.R. Robichaud, S.A. Lewis, C. Napper, and J.T. Clark. 2010. Field guide for mapping post-fire soil burn severity. U.S. Department of Agriculture, Forest Service, Fort Collins, Colorado. General Technical Report RMRS-GTR-243. URL: www.fs.fed.us/rm/pubs/rmrs_gtr243.pdf

Protech Consulting (2021). 2020. Smith Creek Comprehensive Development Plan. Prepared for the City of West Kelowna.

Roed, M.A. and J.D. Greenough (eds.) 2014. Okanagan Geology, British Columbia. Okanagan Geology Committee. Kelowna, BC.

Self, J. 2021. City of West Kelowna Watershed Risk Mapping Assessment. Prepared for the City of West Kelowna by Larratt Aquatic Consulting Ltd. West Kelowna, BC.

Self, J. 2023. Rose Valley Reservoir Post-Wildfire Progress Update. Prepared for the City of West Kelowna by Larratt Aquatic Consulting Ltd., West Kelowna, BC.

Terratech Consulting Ltd. 2003. Debris Flow Potential, Wilson Landing Firehall. Prepared for the Regional District of Central Okanagan. File 2003-006. Salmon Arm, BC.

USGS. 2022. Emergency Assessment of Post-Fire Debris Flow Hazards. Landslide Hazards Program. URL: https://landslides.usgs.gov/hazards/postfire_debrisflow/

Wilford, D., M.E. Sakals, J.L. Innes, R.C. Sidle, and W.A. Bergerud. 2004. Recognition of debris flow, debris flood and flood hazard through watershed morphometrics. In. Landslides. Springer-Verlag. Vol. 1, pp. 61-66.

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 Partial Risk Analysis Methodology

Partial Risk Analysis Methodology Adopted for Post-Wildfire Natural Hazard Risk Assessment Assignments

The following describes the partial risk analysis methodology adopted for post-wildfire natural hazard risk assessment projects. Definitions of the technical terms used are provided. The approach is adopted from, and is described in more detail in, Land Management Handbook No. 56 (Wise et al., 2004) and is the recommended approach for post-wildfire risk analysis 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 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 analysis work, hazards may include **flooding, debris flood, landslides, soil erosion, debris flow, sediment-laden flood, or other natural hydrogeomorphologic processes**.

For the larger sub-basins, the predominant hazard considered is flood and debris flood. Both processes are combined for the analysis. For smaller, steeper sub-basins and tributary catchments, the predominant hazard considered is debris flow and debris flood.

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 Table 1 below.

Table 1: 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 analysis there is no estimate of potential damages, only that an encounter is assumed to be undesirable.

Within the larger sub-basins, spatial likelihood is dependent upon the anticipated effect on peak flows and their associated flood extents. For this analysis, 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 additional quantitative analysis of flood discharge and detailed topographic mapping. Flood inundation mapping would determine depth and velocities associated with a predicted design flow. This quantitative analysis is outside the scope of this study.

Relative levels of spatial likelihood are expressed in qualitative, or relative, terms. These levels, and the associated criteria for assigning these levels at a particular site, are defined in Table 2 below.

Table 2: 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 affected by the hazard, should the 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;
- Infrastructure, utilities, engineering works;
- Public transportation routes, private driveways required for emergency access to residences, and associated bridges and culverts.

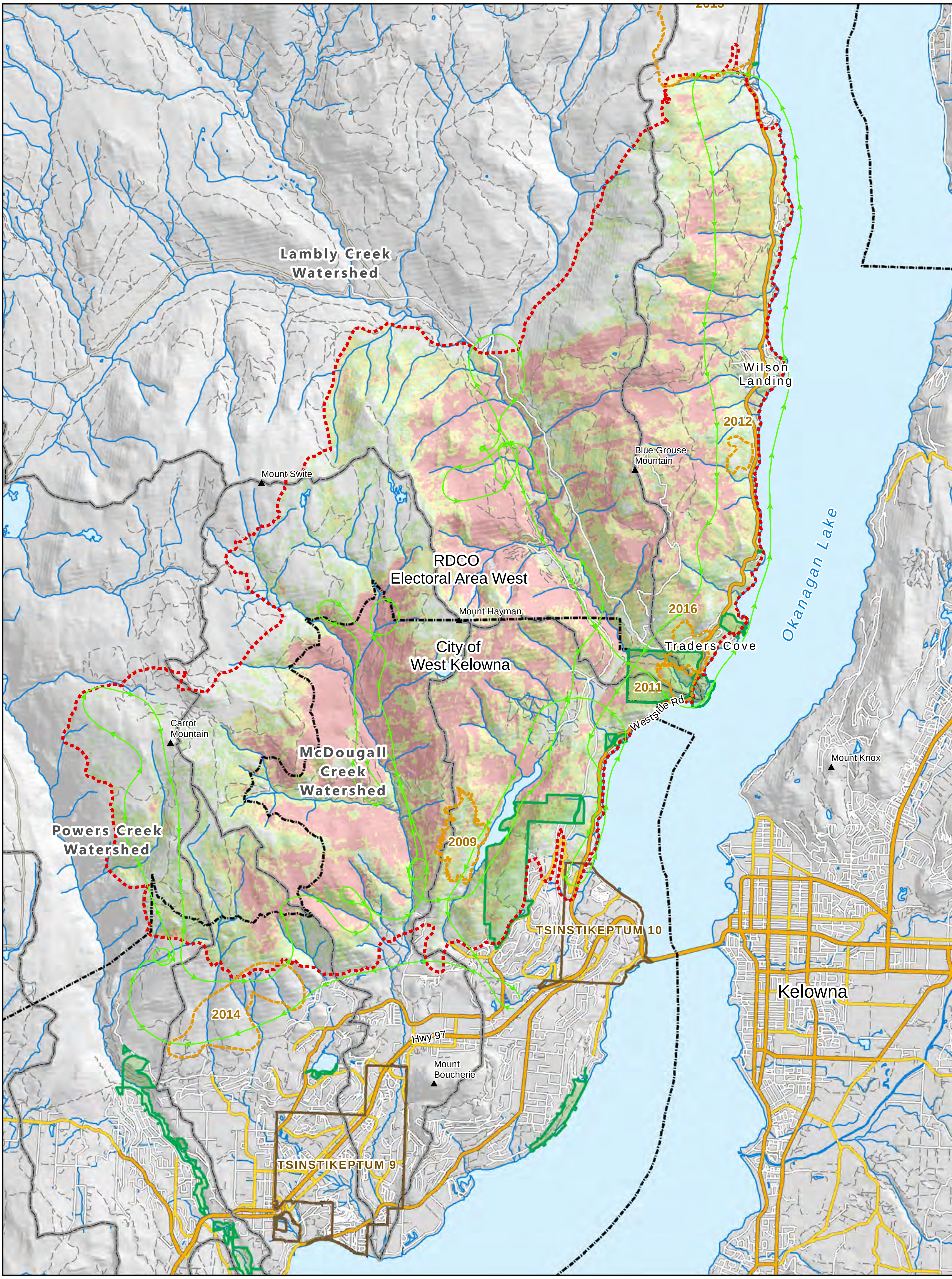
Partial risk P(HA) - is defined as the likelihood of a hazardous event, such as a flood, debris flood, debris flow, or landslide event, reaching or otherwise affecting an element at risk, AND causing an impact to that element. Partial risk may be evaluated quantitatively using probabilities, or, as in the case for this analysis, qualitatively using relative ratings and a risk matrix (see Table 3).

Table 3: Qualitative Partial Risk Analysis 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 (i.e., 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 analysis, above, is an assigned risk level. Five possible outcomes range from Very Low to Very High. 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.

Appendix B Sub-Basin and Risk Maps



LEGEND

- Fire Perimeter (McDougall Creek Fire K52767) (September 9, 2023)
- Fire Perimiter (Historic) (Year)
- Watershed Boundary
- Municipal Boundary
- First Nations Reserve
- Park / Protected Area
- Helicopter Flight Path (September 19, 2023)

Burn Severity (Source: BC Data Catalogue)

- High
- Medium
- Low

N

1,000 500 0 1,000 2,000
metres

Client: **BC MINISTRY OF FORESTS - WILDFIRE SERVICE**

Project: **POST-WILDFIRE NATURAL HAZARD RISK ANALYSIS - 2023 MCDOUGALL CREEK WILDFIRE (K52767)**

Title: **OVERVIEW MAP OF STUDY AREA**

Scale: 1:75,000	NAD 1983 UTM Zone 11 U	Map No.
Project No: 00-0000	Date: January 04, 2024	001

Clarke Geoscience Ltd.

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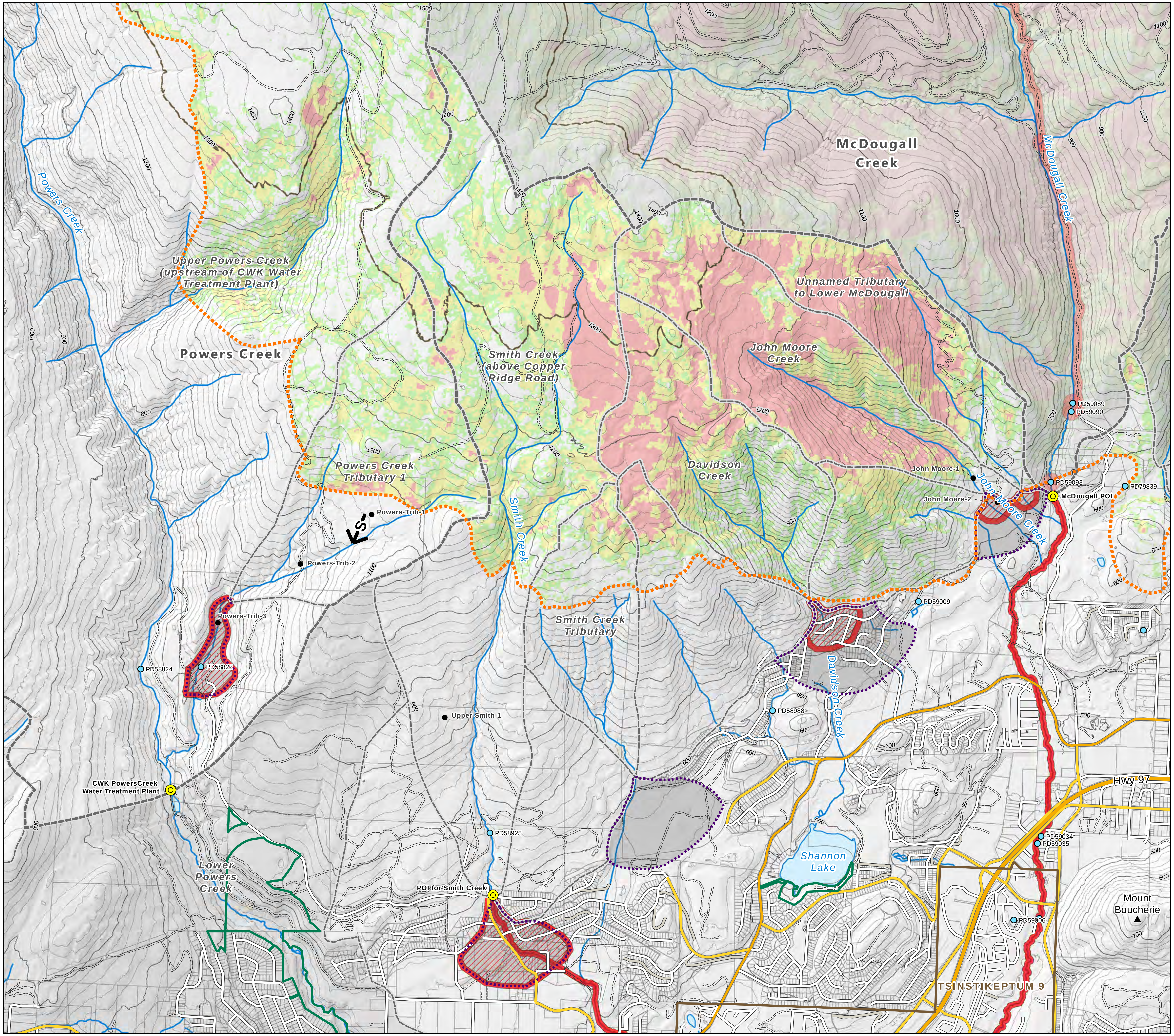


LEGEND

- Fire Perimeter (McDougall Creek Fire K52767)
- Catchment Boundary
- Fan Area
- First Nations Reserve
- Park / Protected Area
- Cadastral Fabric
- Landslide
- Point of Interest (POI)
- Field Waypoint
- Surface Water License (Active) (License Number) (Source: Data BC)

High and/or Very High Risk Site

- Road, Channel Segment, or Fan Area

Elevation Contour

- 20m Interval
- 1300m (Snow-Sensitive Elevation)

Roads (Source: Data BC Digital Roads Atlas)

- Highway / Major Road
- Arterial Road
- Local Road / Street
- Resource Road
- Unclassified Road

Burn Severity (Source: BC Data Catalogue)

- High
- Medium
- Low

KEY PLAN
Scale 1:750,000

N

250 125 0 250 500
metres

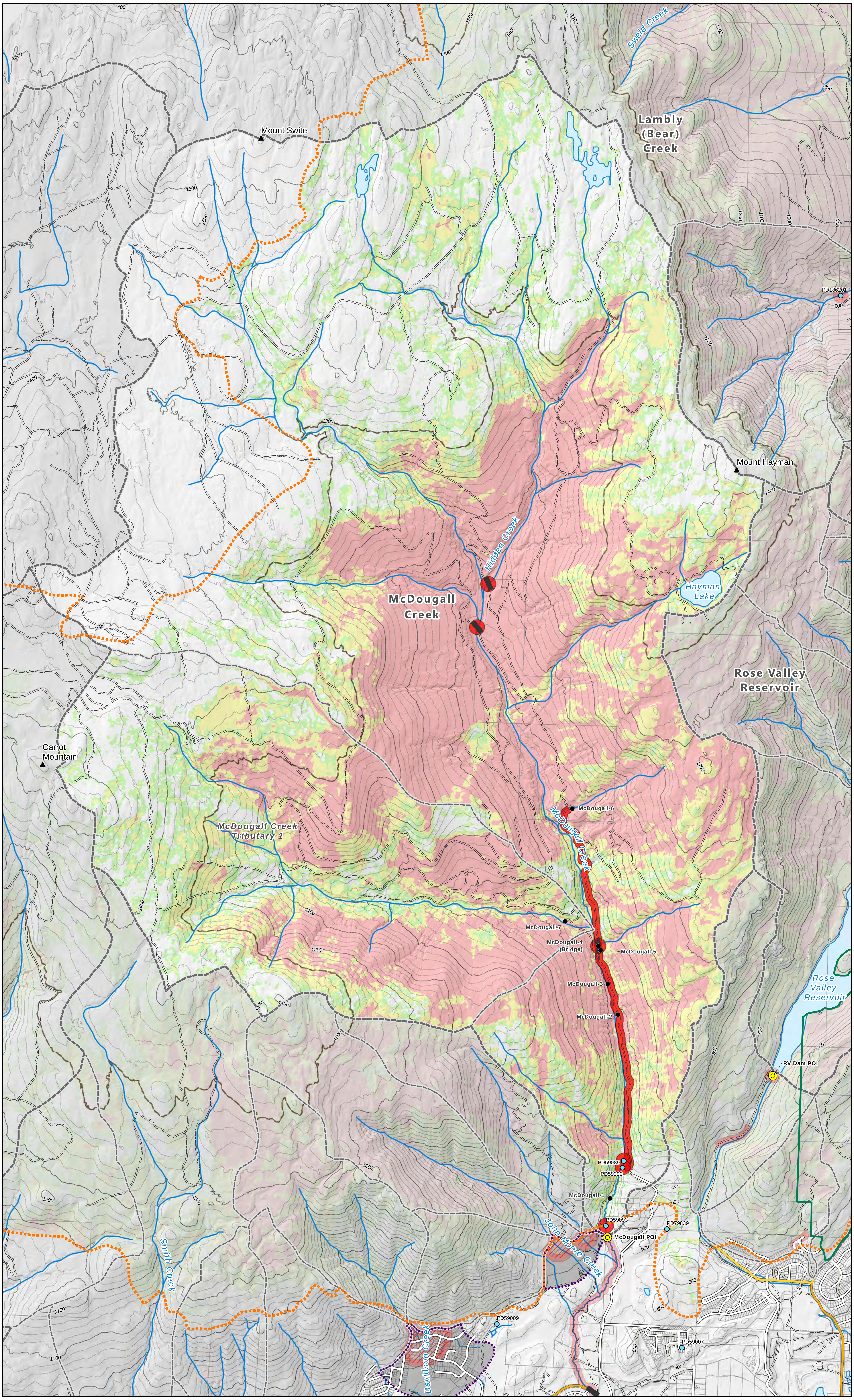
Client: BC MINISTRY OF FORESTS - WILDFIRE SERVICE

Project: POST-WILDFIRE NATURAL HAZARD RISK ANALYSIS - 2023 MCDOUGALL CREEK WILDFIRE (K52767)

Title: POWERS CREEK WATERSHED / UPLAND CREEKS ABOVE WEST KELOWNA

Scale: 1:20,000	NAD 1983 UTM Zone 11 U	Map No. 002
Project No: 23-0106	Date: January 04, 2024	

Clarke Geoscience Ltd.



LEGEND

- Fire Perimeter (McDougall Creek Fire K52767)
- Catchment Boundary
- Fan Area
- Park / Protected Area
- Cadastral Fabric
- Point of Interest (POI)
- Field Waypoint

Elements At Risk

- Surface Water License (Active) (License Number) (Source: Data BC)
- Bridge Crossing

High and/or Very High Risk Site

- Site (Crossing, Water Intake, etc.)
- Road, Channel Segment, or Fan Area

Elevation Contour

- 20m Interval
- 1300m (Snow-Sensitive Elevation)

Roads (Source: Data BC Digital Roads Atlas)

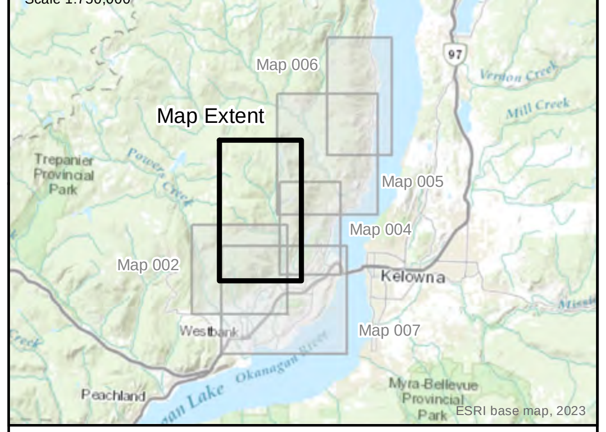
- Highway / Major Road
- Arterial Road
- Local Road / Street
- Resource Road
- Unclassified Road

Burn Severity (Source: BC Data Catalogue)

- High
- Medium
- Low

KEY PLAN

Scale 1:750,000



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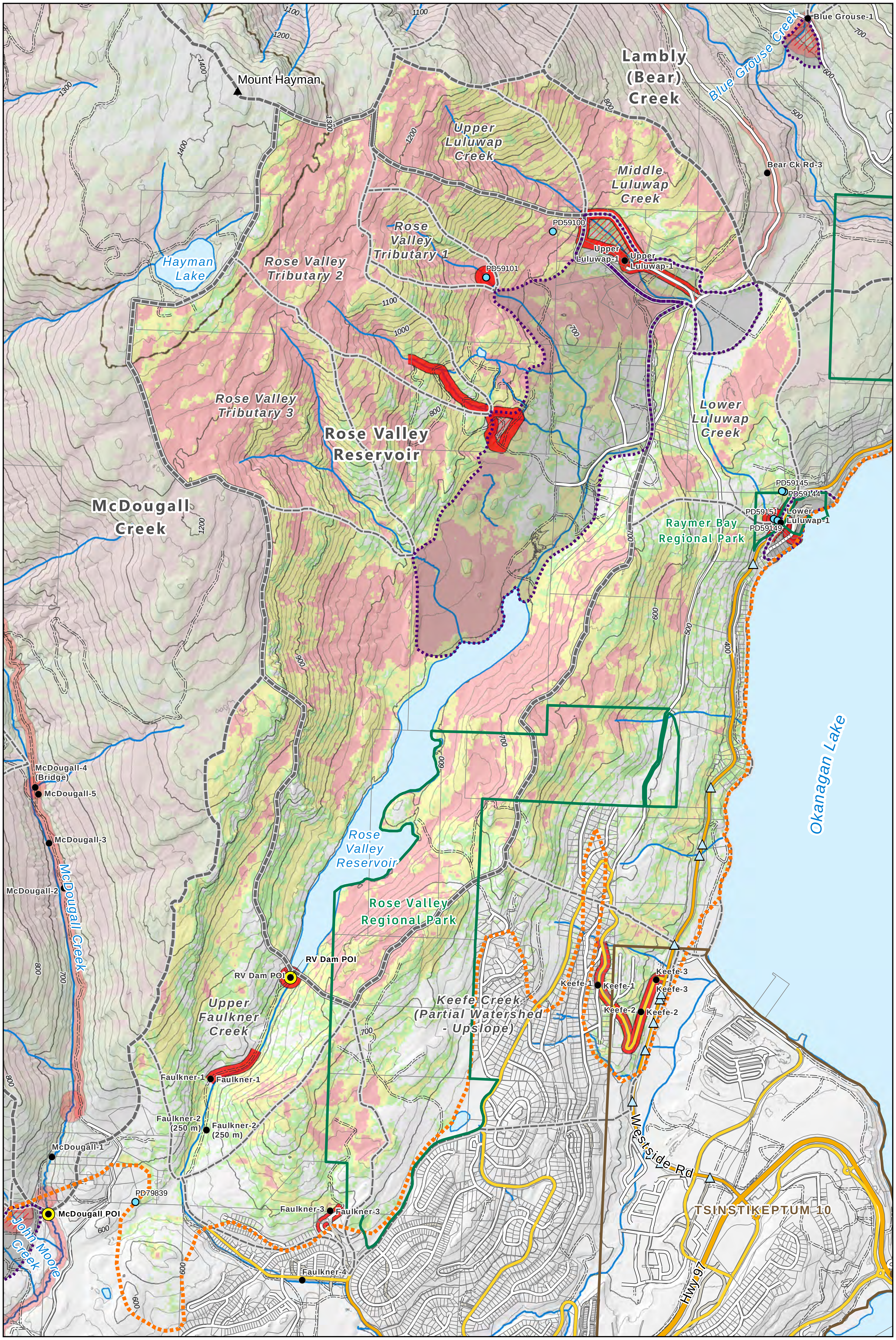
Client: **BC MINISTRY OF FORESTS - WILDFIRE SERVICE**

Project: **POST-WILDFIRE NATURAL HAZARD RISK ANALYSIS - 2023 MCDOUGALL CREEK WILDFIRE (K52767)**

Title: **McDOUGALL CREEK WATERSHED**

Scale: 1:20,000	NAD 1983 UTM Zone 11 U	Map No. 003
Project No: 23-0106	Date: January 04, 2024	

Clarke Geoscience Ltd.



LEGEND

- Fire Perimeter (McDougall Creek Fire K52767)
- Catchment Boundary
- Fan Area
- First Nations Reserve
- Park / Protected Area
- Cadastral Fabric
- Point of Interest (POI)
- Field Waypoint

Elements at Risk

- Culvert (MOTI) for Westside Road Only
- Surface Water License (Active) (License Number) (Source: Data BC)

High and/or Very High Risk Site

- Site (Crossing, Water Intake, etc.)
- Road, Channel Segment, or Fan

Elevation Contour

- 20m Interval
- 1300m (Snow-Sensitive Elevation)

Roads (Source: Data BC Digital Roads Atlas)

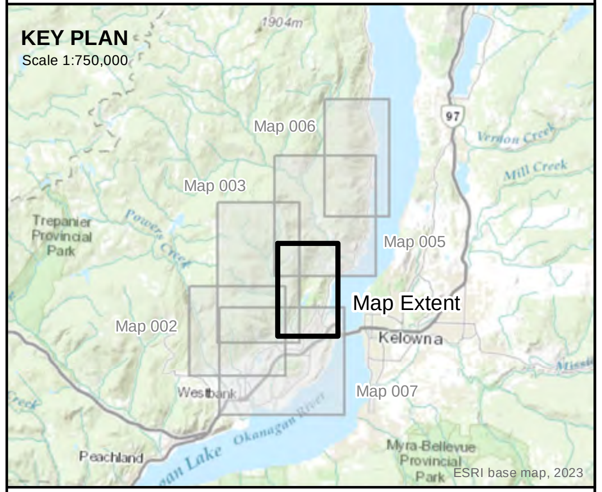
- Highway / Major Road
- Arterial Road
- Local Road / Street
- Resource Road
- Unclassified Road

Burn Severity (Source: BC Data Catalogue)

- High
- Medium
- Low

KEY PLAN

Scale 1:750,000



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metres

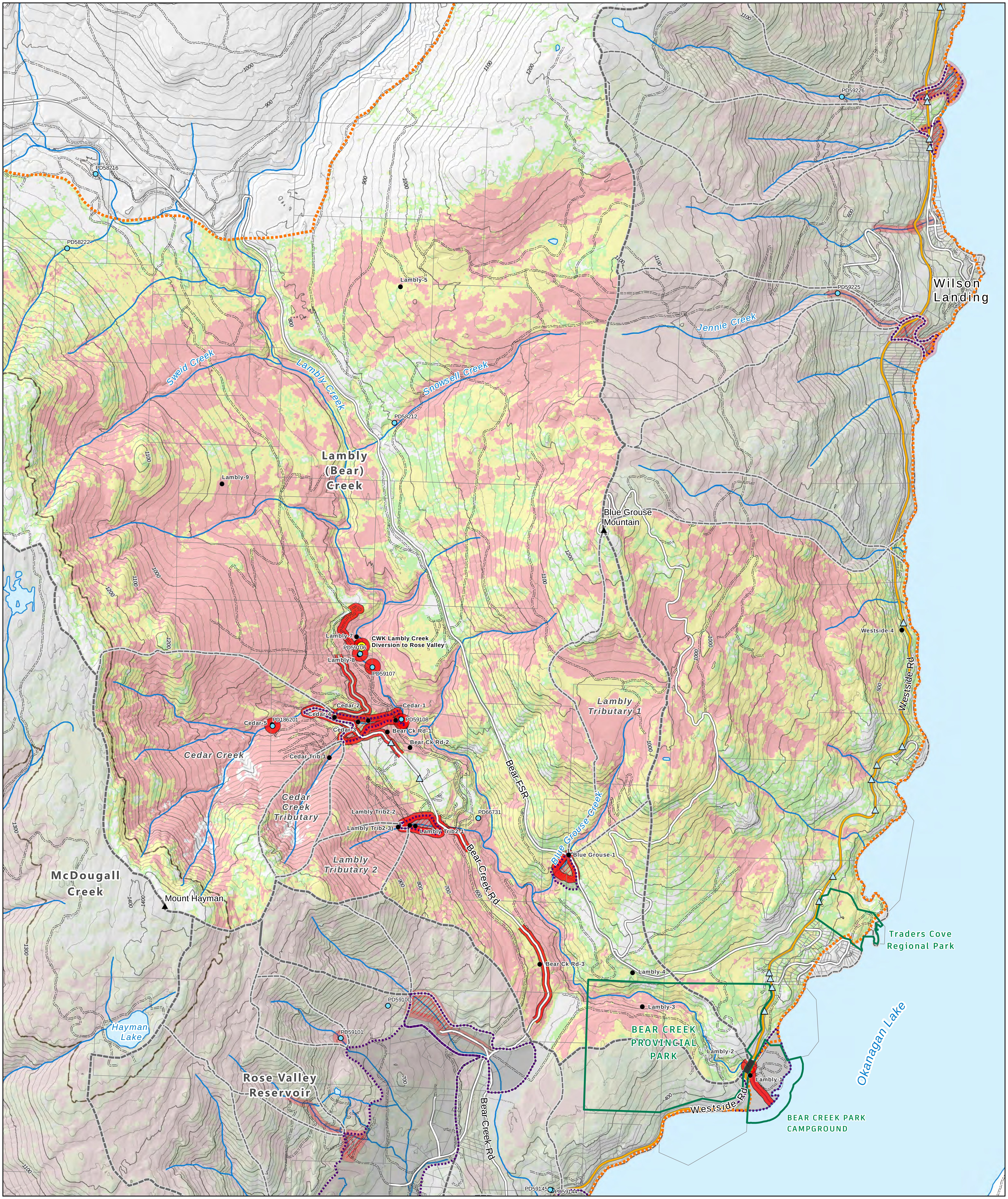
Client: **BC MINISTRY OF FORESTS - WILDFIRE SERVICE**

Project: **POST-WILDFIRE NATURAL HAZARD RISK ANALYSIS - 2023 MCDOUGALL CREEK WILDFIRE (K52767)**

Title: **ROSE VALLEY RESERVOIR, FAULKNER CREEK, KEEFE CREEK, AND LULUWAP CREEK**

Scale: 1:20,000	NAD 1983 UTM Zone 11 U	Map No. 004
Project No: 23-0106	Date: January 04, 2024	

Clarke Geoscience Ltd.



LEGEND

- Fire Perimeter (McDougall Creek Fire K52767)
- Catchment Boundary
- Fan
- Park / Protected Area
- Cadastral Fabric
- Point of Interest (POI)
- Field Waypoint

Elements at Risk

- Culvert (MOTI) for Westside Road Only
- Surface Water License (Active) (License Number) (Source: Data BC)
- Bridge Crossing

High and/or Very High Risk Site

- Site (Crossing, Water Intake, etc.)
- Road, Channel Segment, or Fan

Elevation Contour

- 20m Interval
- 1300m (Snow-Sensitive Elevation)

Roads (Source: Data BC Digital Roads Atlas)

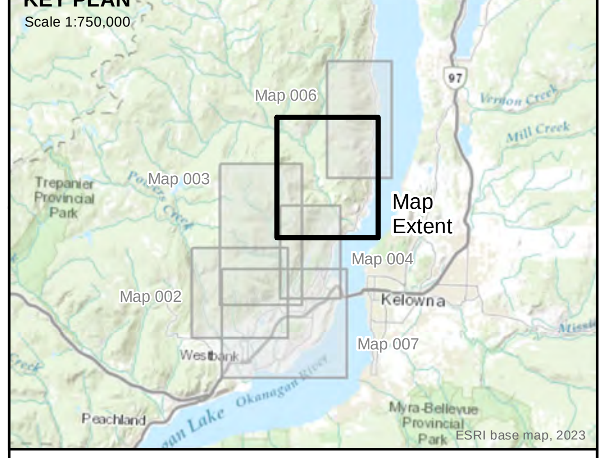
- Highway / Major Road
- Arterial Road
- Local Road / Street
- Resource Road
- Unclassified Road

Burn Severity (Source: BC Data Catalogue)

- High
- Medium
- Low

KEY PLAN

Scale 1:750,000



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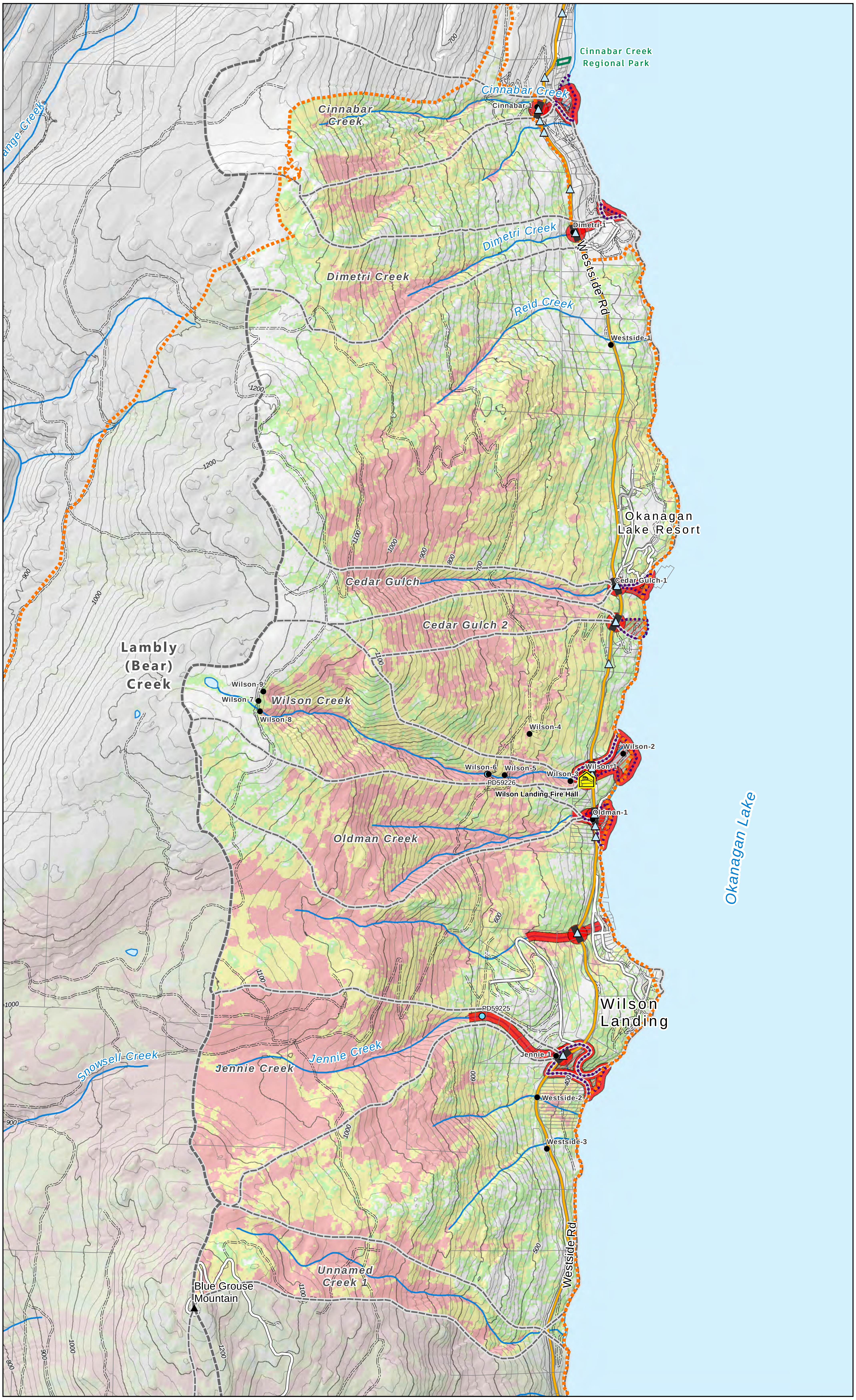
Client: **BC MINISTRY OF FORESTS - WILDFIRE SERVICE**

Project: **POST-WILDFIRE NATURAL HAZARD RISK ANALYSIS - 2023 MCDOUGALL CREEK WILDFIRE (K52767)**

Title: **LAMBLY (BEAR) CREEK WATERSHED AND BEAR CREEK ROAD AREA**

Scale: 1:20,000	NAD 1983 UTM Zone 11 U	Map No.
Project No: 23-0106	Date: January 04, 2024	005

Clarke Geoscience Ltd.



LEGEND

- Fire Perimeter (McDougall Creek Fire K52767)
- Catchment Boundary
- Fan Area
- Park / Protected Area
- Cadastral Fabric
- Field Waypoint

Elements at Risk

- Culvert (MOTI) for Westside Road Only
- Surface Water License (Active) (License Number) (Source: Data BC)
- Bridge Crossing
- Fire Hall

High and/or Very High Risk Site

- Site (Crossing, Water Intake, etc.)
- Road, Channel Segment, or Fan Area

Elevation Contour

- 20m Interval

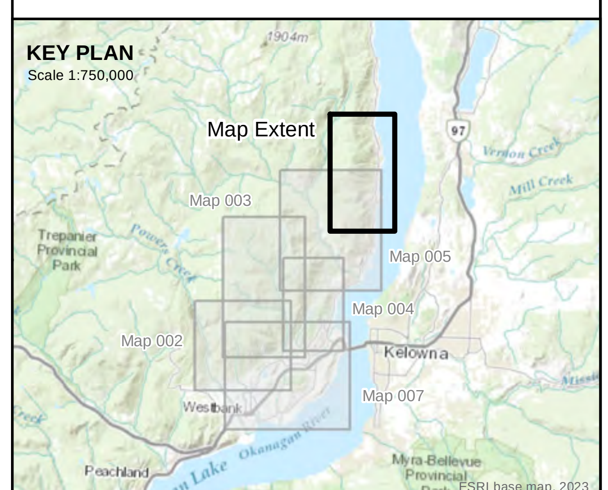
Roads (Source: Data BC Digital Roads Atlas)

- Highway / Major Road
- Arterial Road
- Local Road / Street
- Resource Road
- Unclassified Road

Burn Severity (Source: BC Data Catalogue)

- High
- Medium
- Low

KEY PLAN
Scale 1:750,000



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Client: **BC MINISTRY OF FORESTS - WILDFIRE SERVICE**

Project: **POST-WILDFIRE NATURAL HAZARD RISK ANALYSIS - 2023 MCDOUGALL CREEK WILDFIRE (K52767)**

Title: **WESTSIDE ROAD TRIBUTARIES**

Scale: 1:20,000	NAD 1983 UTM Zone 11 U	Map No.
Project No: 23-0106	Date: January 04, 2024	006

Clarke Geoscience Ltd.

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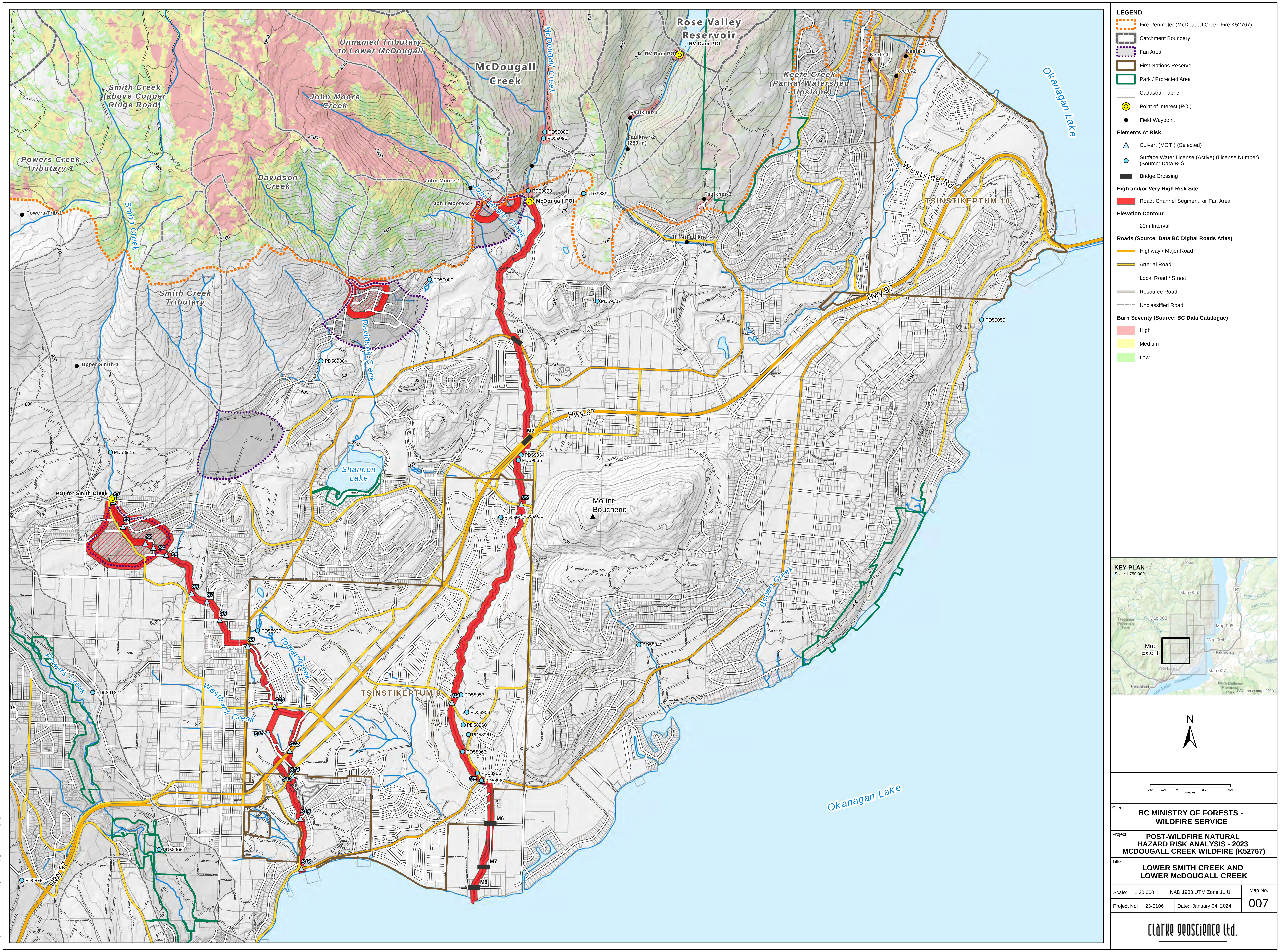
LEGEND
Fire Perimeter (McDougall Creek Fire K52767)
Catchment Boundary
Fan Area
First Nations Reserve
Park / Protected Area
Cadastral Fabric
Point of Interest (POI)
Field Waypoint
Elements At Risk
Culvert (MOTI) (Selected)
Surface Water License (Active) (License Number) (Source: Data BC)
Bridge Crossing
High and/or Very High Risk Site
Road, Channel Segment, or Fan Area
Elevation Contour
20m Interval
Roads (Source: Data BC Digital Roads Atlas)
Highway / Major Road
Arterial Road
Local Road / Street
Resource Road
Unclassified Road
Burn Severity (Source: BC Data Catalogue)
High
Medium
Low
KEY PLAN
Scale 1:750,000
Map Extent
N
250 125 0 250 500
metres
Rose Valley Reservoir
RV Dam POI
McDougall Creek
McDougall POI
Unnamed Tributary to Lower McDougall
John Moore Creek
Smith Creek (above Copper Ridge Road)
Powers Creek Tributary 1
Davidson Creek
Smith Creek Tributary
Keefe Creek (Partial Watershed - Upslope)
Okanagan Lake
Westside Rd
TSINSTIKEPTUM 10
TSINSTIKEPTUM 9
Hwy 97
Shannon Lake
Mount Boucherie
POI for Smith Creek
Powers Creek
Westbank Creek
Tomat Creek
Bowen Creek
Client:
BC MINISTRY OF FORESTS - WILDFIRE SERVICE
Project:
POST-WILDFIRE NATURAL HAZARD RISK ANALYSIS - 2023 MCDOUGALL CREEK WILDFIRE (K52767)
Title:
LOWER SMITH CREEK AND LOWER McDOUGALL CREEK
Scale: 1:20,000
NAD 1983 UTM Zone 11 U
Map No.
007
Project No: 23-0106
Date: January 04, 2024
Clarke Geoscience Ltd.

Appendix C Watershed Report Cards & Photographs

Appendix C1 Watershed Report Cards & Photographs – Powers Creek Tributary 1

Ministry of Forests - BC Wildfire Service
Post-Wildfire Natural Hazards Risk Analysis

POWERS CREEK (Tributary 1 Sub-Basin) REPORT CARD

	Area (sq km)	% Burned	% High Burn Severity	Melton Ratio	% Mod and High Burn Severity on >40% slopes	Dominant Hydro-Geomorphic Process	Post-Wildfire Debris Hazard Level for Dominant Process
Powers Creek Watershed Area (upslope of WTP):	125.4	2.3	0.1	0.11	0.4	Flood	Low
Tributary 1:	2.1	40.1	2.4	0.39	4.0	Debris Flood	Moderate

General Watershed /Subbasin Conditions:	Powers Creek is a large watershed (125 km^2) that flows from the plateau, through Glen Canyon Regional Park, and into Okanagan Lake. The large watershed was only partly burned (2.3%, upstream of the Water Treament Plant) by the 2023 McDougall Creek Wildfire. Only one small tributary sub-basin (Tributary 1) is considered in the post-wildfire natural hazard risk analysis. Although 40% of the Tributary 1 catchment burned, only 2.4% was at high severity. Tributary 1 flows to a private property and enters Powers Creek just upstream of the WTP.
Terrain Conditions:	The Melton Ratio for the tributary catchment indicates that debris flood is the dominant hydro-geomorphic process (characteristics between a flood and a debris flow). The catchment is steep enough and large enough to generate flows that can easily exceed a peak clear-water flow. An example of a landslide-triggered debris flood occured in the spring of 2023 when an old trail in the upper catchment was diverted. The landslide triggered an event that scoured the channel and impacted the private property located at the base of the valley. Field observations along a trail that was reactivated to access the fire exposed and disturbed a ~250 m long section of fine-textured silty soils that are sensitive to erosion.
Mainstem Stream Channel/Riparian Conditions:	Steep, midslope reaches are more tightly confined by valley side slopes are more likely to experience landslides. Sediment loading into the channel can later mobilize at high flows.
Post-Wildfire Hazards:	The pre-existing debris flood hazard on Tributary 1 is elevated based on steep physiography and the spring 2023 slide event. Although 40% of the catchment burned, only a small area was burned at high severity, so the incremental post-fire effect on debris flood and peak flow effects is considered moderate. A fire guard trail reactivated an old road, causing disturbance to fine-textured soils and at a stream crossing location. Although rehabilitaed, there remoans an elevated likelihood for erosion, sediment-laden flooding, and shallow landslide activity.

	Powers Creek	**Powers - Tributary 1**
	Downstream Elements at Risk	
	Water Treatment Plant	Private property (2750 Smith Creek Road)
	Hazard Level - Likelihood of Event P(H)	
Flood / Debris Flood	Low	Moderate
Debris Flow	n/a	Moderate
Landslide/Rockfall	n/a	Low
	Spatial Likelihood of Impact P(S:H)	
Flood / Debris Flood	High	High
Debris Flow	n/a	High
Landslide/Rockfall	n/a	Low
	Partial Risk P(HA) = P(H) x P(S:H)	
Flood / Debris Flood	Moderate	High
Debris Flow	n/a	High
Landslide/Rockfall	n/a	Very Low

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

APPENDIX – PHOTOS (Powers Creek Trib)

 Photo 1: Landslide (spring 2022) in upper reaches of Powers Creek Tributary 1 (Powers-Trib-1)	 Photo 2: Washed out channel of Powers Creek Tributary 1 upstream from road crossing (Powers-Trib-2)
 Photo 3: Road crossing (due to be rehabilitated) on Powers Creek Tributary 1 with abundant sediment and woody debris (Powers-Trib-2)	 Photo 4: Downcutting of fine-textured silty sediments along road used to access the fire (downslope of Powers-Trib-2)

 Photo 5: Lowest reach of Powers Creek Tributary 1 on private land, showing scour and sedimentation from 2022 debris flood event (Powers-Trib-3).	

Appendix C2 Watershed Report Cards & Photographs – Upland Creeks and Face Units in West Kelowna

UPLAND CREEKS & FACE UNITS (SMITH, DAVIDSON, JOHN MOORE, ETC.) REPORT CARD

	Area (sq km)	% Burned	% High Burn Severity	Melton Ratio	% Mod and High Burn Severity on >40% slopes	Dominant Hydro-Geomorphic Process	Post-Wildfire Hazard Level for Dominant Process
Smith Creek Watershed Area (upslope of Copper Ridge Dr):	5.0	49.7 (+10.8% in 2014)	8.4	0.40	3.5	Debris Flood	Moderate to High (+20% increase in peak flow)
Smith Creek Tributary:	1.1	18.0 (+57.5% in 2014)	2.5	0.55	3.2	Debris Flood	Low
Davidson Creek:	1.7	79.1	27.3	0.54	22.1	Debris Flood	High
John Moore Creek:	2.0	95.3	55.9	0.53	42.8	Debris Flood	High
Unnamed McDougall Tributary:	1.2	87.4	51.0	0.65	37.0	Debris Flow	High

General Watershed /Subbasin Conditions:	Smith Creek is a larger watershed that is sub-divided into tributary basins upslope of the Okanagan Valley and upslope of urban development. Each are considered separately but eventually combine downstream into a single channel that flows through the CWK and WFN Tsinstikeptum 9. The Smith Creek Watershed above Copper Ridge Drive was highly burned (49.7%) and the effects of wildfire are compounded by a wildfire that occurred in 2014. Other upland tributary basins that were extensively burned in 2023 include Davidson Creek, John Moore Creek, and an unnamed tributary to McDougall Creek. Areas burned at high burn severity are located in the upper part of the catchments (generally above 900 m), but are still below the snow-sensitive elevation. The tributaries are largely seasonal and are more likely to respond to intense rainfall events, rather than spring snow-melt runoff.
Terrain Conditions:	The Melton Ratios for the upland catchments indicates that the dominant hydro-geomorphic process ranges between debris flood and debris flow. The catchments are steep and large enough to generate flows that can easily exceed a peak clear-water flow. Greater than 20% of the catchment areas that burned at moderate to high severity are steep (>40%) indicating an increased likelihood for hillslope erosion processes and instability. Sediment from the steep side slopes that are directly connected to the channel can bulk the peak flows, which can lead to mobilization of sediment and debris to the reaches downstream.
Mainstem Stream Channel/Riparian Conditions:	The upland stream channels have lower gradient headwater reaches, which can lower the likelihood of hydrologic and geomorphologic effects on the channel. Steeper, midslope reaches that are more tightly confined by valley side slopes are more likely to become loaded with sediment, which can increase the volume of sediment available for transport downstream.
Face Unit Conditions:	The only Face Unit with significant area burned is between Davidson Creek and John Moore Creek. The fire-affected slopes above developed areas on Shannon Hills Place may experience soil erosion, ravelling sediment, and small sediment-laden flows where runoff becomes concentrated.
Post-Wildfire Hazards:	Based on high percentage of total area burned and pre-existing steep catchment physiography (characterized by the Melton Ratio) there is a high likelihood of post-wildfire debris flood on the ephemeral tributary channels. Due to the percentage of >40% gradient sloping terrain that burned at moderate to high severity there is an elevated risk of erosion, sediment-laden flooding, and shallow landslide activity. The larger Smith Creek catchment area has pre-existing impacts from a 2014 wildfire and has an elevated likelihood of peak flow impacts due to the overall high percentage of affected area.

	Smith Creek Watershed (Upslope of Copper Ridge Dr)		Smith Creek Tributary	Davidson Creek & Adjacent Face Unit	John Moore Creek	Unnamed McDougall Creek Tributary
Downstream Elements at Risk						
	Copper Ridge Drive Culvert	Private Property & Downstream Reaches of Smith Creek (Map 007)	Wild Horse Drive	Private Property (2280 Paramount Dr), CWK Water Reservoir and infrastructure, Shannon Hills Pl	Private property and domestic water intake (2202 Bartley Rd)	Private property and domestic water intake (2202 Bartley Rd)
Hazard Level - Likelihood of Event P(H)						
Flood / Debris Flood	High		Low	High	High	High
Debris Flow	Moderate		Low	High	High	High
Landslide/Rockfall	Low		Low	Low	Low	Low
Spatial Likelihood of Impact P(S:H)						
Flood / Debris Flood	High	High	High	High	High	High
Debris Flow	Moderate	Low	Low	High	High	High
Landslide/Rockfall	Low	Low	Low	Low	Low	Low
Partial Risk P(HA) = P(H) x P(S:H)						
Flood / Debris Flood	Very High	Very High	Moderate	Very High	Very High	Very High
Debris Flow	Moderate	Low	Very Low	Very High	Very High	Very High
Landslide/Rockfall	Very Low	Very Low	Very Low	Very Low	Very Low	Very Low

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

APPENDIX – PHOTOS (Upland Creeks – Smith, Davidson, John Moore and Unnamed McDougall Tributary)

Photo 1: Upper Smith Creek in area of 2014 Wildfire along 2023 Fire Guard access trail. Note, moderate slopes and fine-textured (highly erodible) soils (Upper Smith-1).

Photo 2: John Moore Creek near fan apex, with evidence of shallow seasonal flow (John Moore-1).

Photo 3: Downslope fan of John Moore Creek, with indistinct channel (John Moore-2)

Appendix C3 Watershed Report Cards & Photographs – McDougall Creek Watershed

McDOUGALL CREEK WATERSHED REPORT CARD (UPSTREAM OF BARTLEY ROAD)

	Area (sq. km)	% Burned	% High Burn Severity	% Mod Burn Severity	Melton Ratio	% Mod and High Burn Severity on >40% slopes	Dominant Hydro-Geomorphic Process	Post-Wildfire Hazard Level for Dominant Process
Watershed Total (upstream of Bartley Rd):	39.2	63.4	31.1	19.3	0.16	22	Flood	High
Tributary 1 Subbasin:	8.7	76.3	32.7	26.3	0.28	27	Flood	High

General Watershed /Subbasin Conditions:	The watershed area delineated above Bartley Road is distinguished from the lower gradient urbanized reaches within the Okanagan Valley. The upslope watershed was extensively burned (over 60%) and over half of this was burned at a moderate to high vegetation burn severity. This level of severity represents a loss of forest providing hydrologic function. Therefore, there is a high potential for increased runoff volume and flow, and an increased likelihood for sedimentation into and along the stream channel.
Terrain Conditions:	Burned areas include steep mainstem valley sideslopes that are directly connected to the mainstem channel. Over 20% of the watershed burned at a moderate to high severity and is also situated on slopes >40% gradient. The connectivity of steep slopes to McDougall Creek constitutes a high potential for sediment delivery to the channel.
Mainstem Stream Channel/Riparian Conditions:	Burn severity along the mainstem channel varies. Riparian vegetation, particularly along lower reaches, is a mixed deciduous and coniferous forest type. The total length of the mainstem and larger tributary channels burned at high severity is ~5 km. These reaches are vulnerable to windfall and loss of riparian function. This increases the risk of channel destabilization, debris jams, sediment loading, and water quality impacts due to loss of shade.
Post-Wildfire Hazards:	High peak flow hazard (due to aggregate of burned area) and high sediment bulking potential. Bulking will most likely arise from valley sideslope instability, stream channel erosion, and from instability along tributary subbasins. On the mainstem McDougall Creek, the higher sediment bulking may potentially transform a peak flood event into a debris flood. There is a high potential for post-wildfire peak flow and debris flood (and potentially debris flow) along the larger tributaries to McDougall Creek and a high potential for landslide and debris flow from small steep tributaries that are directly connected to the mainstem channel.

	Elements at Risk (within watershed area upstream of Bartley Road)			
	Resource and Recreation Road along Valley Bottom	Resource Bridges on McDougall Creek	Domestic Water Intakes	Downstream Reaches of McDougall Creek (see Map 007)
Hazard Level - Likelihood of Event P(H)				
Flood / Debris Flood	High			High
Debris Flow	Moderate (on steep tributaries only)			Low
Landslide/Rockfall	High			Low
Spatial Likelihood of Impact P(S:H)				
Flood / Debris Flood	High	High	High	High
Debris Flow	High	High	High	Low
Landslide/Rockfall	High	Low	Low	Low
Partial Risk P(HA) = P(H) x P(S:H)				
Flood / Debris Flood	Very High	Very High	Very High	Very High
Debris Flow	Very High	Very High	Very High	Very Low
Landslide/Rockfall	Very High	Moderate	Moderate	Very Low

Notes:
Watershed area is measured as the area upstream of the fan apex below the canyon at Bartley Road.

APPENDIX – PHOTOS (McDougall Creek)

Photo 1: McDougall Creek fire guard crossing at POI (view upstream).

Photo 2: McDougall Creek lower canyon with abundant sediment sources to the channel (McDougall-1).

Photo 3: Water intake structure on McDougall Creek within lower canyon (view downstream) (McDougall-1).

Photo 4: Water intakes accessed off the end of Bartley Road on lower McDougall Creek.

Photo 5: Middle reaches of McDougall Creek with burned riparian forest and connected to steep, burned valley side slopes (McDougall-2)

Photo 6: Sediment wedge (200-300 cubic metres) in McDougall Creek (McDougall-3)

Photo 7: Resource road bridge over McDougall Creek mainstem channel (McDougall-4)

Photo 8: Moderate burn severity along riparian forest and adjacent slopes. Note scattered green canopy, needle cover mantling soil surface, and weak soil-water repellency (McDougall-5).

 Photo 9: High vegetation burn severity area, with observed sediment-laden runoff along road and variable soil-water repellency (McDougall-6)	 Photo 10: Deactivated road crossing on Tributary 1 channel (Mc-Dougall-7)

Appendix C4 Watershed Report Cards & Photographs – Rose Valley Reservoir

ROSE VALLEY RESERVOIR WATERSHED REPORT CARD

	Area (sq. km)	% Burned	% High Burn Severity	% Mod Burn Severity	% Mod and High Burn Severity on >40% slopes	Melton Ratio	Dominant Hydro-Geomorphic Process	Post-Wildfire Hazard Level for Dominant Process
Watershed Total (upstream of Dam):	10.7	94.3	50.9	33.8	41.2	-	Surface Erosion	High
RV Tributary 1 Subbasin:	0.3	100	56.4	39.9	76.9	0.91	Debris Flow	High
RV Tributary 2 Subbasin:	1.0	98.6	60.4	31.8	44.8	0.72	Debris Flow	High
RV Tributary 3 Subbasin:	1.4	97.5	59.2	31.3	44.2	0.57	Debris Flow	Moderate

General Watershed /Subbasin Conditions:	The Rose Valley Reservoir watershed includes the slopes immediately upslope of the reservoir and several (3) sub-basins delineated at the north end of the reservoir. Slopes above the reservoir are moderately-steep to steep bedrock-controlled slopes that are sparsely forested and thinly mantled with till and colluvium sediments. There are no well-defined water courses other than the inflow channel at the north end. The watershed and sub-basin areas were extensively burned (overall 95%) and most at moderate to high burn severity and mostly at the north end of the catchment. Due to the coarse-textured surficial materials it is anticipated that water repellency may not be pervasive. However, where thicker sediments occur, particularly along the reservoir shoreline, there is a high potential for surface erosion, ravelling, rockfall, and shallow landslide activity.
Terrain Conditions:	A relatively high percentage (~40%) of steep (>40% gradient) terrain in the watershed was burned at moderate to high burn severity. Due to the coarse-textured surficial materials it is anticipated that water repellency may not be pervasive. However, where thicker sediments occur on steeper slopes, particularly along the reservoir shoreline, there is a high potential for surface erosion, ravelling, rockfall, and shallow landslide activity. The small tributary basins have a Melton Ratio indicative of a debris flow dominant process and each catchment has a corresponding downslope alluvial or debris flow fan.
Mainstem Stream Channel/Riparian Conditions:	The only perennial stream entering the reservoir is from the inflow channel at the north end of the lake. Additional inflows are piped into the resevoir from a diversion structure and pipeline from Lambly Creek. Wildfire along the reservoir shoreline has impacted the riparian function leading to an increased likelihood for sediment delivery.
Post-Wildfire Hazards:	The dominant post-wildfire hydro-geomorphic processes affecting the Rose Valley Reservoir are surface erosion, sediment-laden runoff, ravelling, rockfall, and shallow landslides. Thin soils and lack of surface drainages reduces the likelihood for hydrologic processes such as flooding or debris flow. Debris flow and debris flood processes are anticipated along steep tributary catchments at the north end of the watershed. However, these catchments are not well-connected by surface water to the reservoir.

	Rose Valley Reservoir Watershed Area				**RV Tributary 3**	**RV Tributary 2**	**RV Tributary 1**
	Elements at Risk						
Elements at Risk	Rose Valley Dam	Domestic Water Quality in Reservoir	Recreation Trails within Portion of Rose Valley Regional Park	Recreation Trails within Crown Land portion of Watershed	Domestic Water Quality in Reservoir	Private Land (530 Rose Valley Rd)	
Hazard Level - Likelihood of Event P(H)							
Flood / Debris Flood	Low (assumes attenuation at reservoir)				High	High	High
Debris Flow	-				Moderate	High	High
Landslide/Rockfall	Moderate				Low	Low	Low
Surface Erosion	High				Moderate	Moderate	Moderate
Spatial Likelihood of Impact P(S:H)							
Flood / Debris Flood	Moderate	High	Low	Low	Low (assumes no surface water connection)	High	n/a
Debris Flow	n/a	n/a	n/a	n/a	Low	High	n/a
Landslide/Rockfall	Moderate	Moderate	Moderate	Moderate	Low	Low	n/a
Surface Erosion	Low	High	Moderate	Moderate	Low	Low	n/a
Partial Risk P(HA) = P(H) x P(S:H)							
Flood / Debris Flood	Low	Moderate	Very Low	Very Low	Moderate	Very High	n/a
Debris Flow	n/a	n/a	n/a	-	Low	Very High	n/a
Landslide/Rockfall	Moderate	Moderate	Moderate	Moderate	Very Low	Very Low	n/a
Surface Erosion	Moderate	Very High	High	High	Low	Low	n/a

Notes:
Watershed area is measured as the area upstream of POI (Dam) or the fan apex for tributaries.

APPENDIX – PHOTOS (Rose Valley Reservoir)

Photo 1: View north of the Rose Valley Dam and Reservoir (RV Dam POI).

Photo 2: Steep, rocky slopes above the Rose Valley Dam (RV Dam POI). Photo Credit: S. Wensley, Larratt Aquatic.

Photo 3: Panorama view of the burned slopes on the south side of the Rose Valley Reservoir. (Photo Credit: S. Wensley, Larratt Aquatic)

Appendix C5 Watershed Report Cards & Photographs – Faulkner, Keefe and Luluwap Creeks

Ministry of Forests - BC Wildfire Service
Post-Wildfire Natural Hazards Risk Analysis

FAULKNER, KEEFE, and LULUWAP CREEK WATERSHEDS REPORT CARD

	Area (sq km)	% Burned	% High Burn Severity	Melton Ratio	% Mod and High Burn Severity on >40% slopes	Dominant Hydro-Geomorphic Process	Post-Wildfire Hazard Level
Upper Faulkner Creek:	1.6	76.4	5.7		24.9	Localized surface erosion and rockfall	High (localized)
Keefe Creek (Partial):	2.3	24.6	1.9		4.2	Sediment-laden flooding	Moderate (localized)
Lower Luluwap Creek:	0.9	74.3	24.1		15.9	Sediment-laden flood and surface erosion	High
Upper Luluwap Creek:	0.7	100	50.8	0.74	67.6	Debris flow	High

General Watershed /Subbasin Conditions:	All catchments within this area of interest, with the exception of Upper Luluwap Creek, are urban catchments with some upslope forested areas that have burned. Many of the upslope areas are sparsely vegetated, or potentially may have had fire-smart measures to reduce burn severity. Thus, although considerable areas have burned, the overall impact on runoff and surface erosion is limited to localized sites.
Terrain Conditions:	Slopes within these catchments have moderate gradients upslope of the developed areas. There are localized areas where runoff is directed onto steeper slopes and/or incised gullies. Minor surface erosion and ravelling of exposed soils (where there are isolated pockets of high burn severity for example) is anticipated.
Mainstem Stream Channel/Riparian Conditions:	Not applicable due to urban development. Stream channels are tightly constrained and integrated within the storm water drainage network.
Face Unit Conditions:	The face unit between Keefe Creek and Luluwap Creek was extensively burned. Upslope areas are steep, bedrock-controlled slopes. For these areas, elevated rates of surface water runoff may be expected, and nuisance-level sedimentation and ravelling erosion may occur. Where pre-existing rockfall hazards are present, these would continue to occur. The lower slopes (generally downslope of Bear Creek Road) have several deeply incised gullies that may direct sediment-laden flows to Westside Road, and potentially to private properties located along Westside Road.
Post-Wildfire Hazards:	Upper Luluwap Creek has a Melton Ratio that indicates potential for debris flow (0.74) and based on the degree of burn (100% burn and 50% at high severity) the potential debris flow hazard rating is high. The other urbanized catchments are more likely to be impacted by small-scale sediment-laden runoff and surface erosion.

	Upper Faulkner Creek		Keefe Creek (Partial)		Lower Luluwap Creek		Upper Luluwap Creek	Face Unit (btwn Keefe and Luluwap)
	Elements at Risk							
	RV Access Road	Strata at Rosalee Lane	Private property and Bear Creek Road	Intersection of Bear Ck Rd and Westside Rd	Westside Road and Domestic Water Intake	Raymer Bay Regional Park	Private property (744 & 752 Petterson Road)	Westside Rd and Private property
	Hazard Level - Likelihood of Event P(H)							
Flood/Debris Flood	Low		Low		High		High	Low
Sediment-Laden Flood	Moderate		Moderate		High		High	High
Debris Flow	Low		Low		Low		High	Low
Rockfall, Surface Erosion and Ravelling	High (localized)		Moderate		High		Low	High (localized)
	Spatial Likelihood of Impact P(S:H)							
Flood/Debris Flood	Low	Low	Low	Low	High	High	High	Low
Sediment-Laden Flood	Moderate	Moderate	High	High	High	High	High	High
Debris Flow	Moderate	Moderate	Low	Low	Low	Low	High	Low
Rockfall, Surface Erosion and Ravelling	High (250 m long section)	Moderate	High	High	High	High	Moderate	High
	Partial Risk P(HA) = P(H) x P(S:H)							
Flood/Debris Flood	Very Low	Very Low	Very Low	Very Low	Very High	Very High	Very High	Very Low
Sediment-Laden Flood	Moderate	Moderate	High	High	Very High	Very High	Very High	Very High
Debris Flow	Low	Low	Very Low	Very Low	Very Low	Very Low	Very High	Very Low
Rockfall, Surface Erosion and Ravelling	Very High	High	High	High	Very High	Very High	Low	Very High

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

APPENDIX – PHOTOS (Faulkner, Keefe, and Luluwap Creeks)

Photo 1: Upper Faulkner Creek along Rose Valley Dam Access Road – Pre-existing rockfall hazard along west side of road (Faulkner-1).

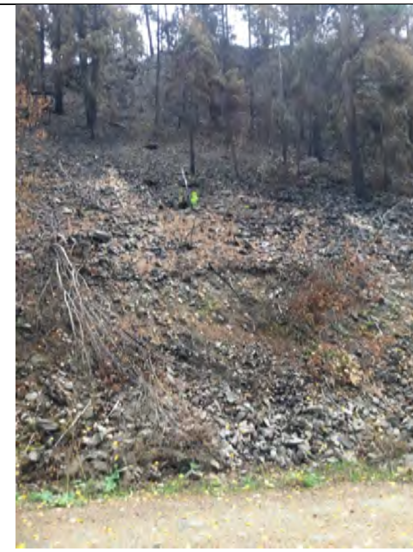

Photo 2: Upper Faulkner Creek along Rose Valley Dam Access Road – moderate to high burn severity along 250 m long section of steep colluvial slopes on east side constitutes increased rockfall hazard (Faulkner-2).

Photo 3: Moderate severity burn upslope of Rosalee Lane strata development. Note burned swale directing flow towards homes (Faulkner-3)

Photo 4: Rock-lined channel and concrete culverts on Faulkner Creek in front of Mar Jok Elementary School (Faulkner-4).

Photo 5: Shallow ditch along Bear Creek Rd (at McNaughton) with small culvert under mailbox. Note recent sediment in ditch (arrow) (Keefe-1)

Photo 6: Burned gully, view upslope from Bear Creek Road. Note recent sediment movement in gully (arrow) (Keefe-2)

Photo 7: Sediment-filled ditchline along Bear Creek Road, at Westside Road (Keefe-3)

Photo 8: Partly-plugged 400 mm and 250 mm culverts under Bear Creek Road (Keefe-3)

Photo 9: Water intake structures on Lower Luluwap Creek, upslope of Westside Road (upslope of Lower Luluwap-1)

Photo 10: Lower Luluwap Creek crossing at Westside Road (damaged 600 mm culvert) (Lower Luluwap-1)

Photo 11: View upslope from end of Petterson Road towards Upper Luluwap Creek catchment area. Note, thick sand and gravel sediments (Upper Luluwap-1)

Photo 12: View of ditch line along Petterson Road (at Bear Creek Road), conveys surface water runoff from Upper Luluwap Creek area.

Appendix C6 Watershed Report Cards & Photographs – Lambly (Bear) Creek and Bear Creek Road Area

LAMBLY (BEAR) CREEK WATERSHED REPORT CARD

	Area (sq. km)	% Burned	% High Burn Severity	% Mod Burn Severity	Melton Ratio	% Mod and High Burn Severity on >40% slopes	Dominant Hydro-Geomorphic Process	Post-Wildfire Hazard Level for Dominant Process
Watershed Total:	243.6	12.2	5.6	4.6	0.1	4.5	Flood / Channel Instability	Low / High
Upper Lambly (upstream of CWK Intake):	231.8	8.2	3.5	3.2	0.1	2.1	Flood / Channel Instability	Low / High
Tributary 1 (aka Blue Grouse Ck):	1.1	97.9	53.1	37.9	0.8	29.5	Debris Flow	High
Tributary 2 (upslope Bear Ck Rd):	0.4	99.3	76.7	19.7	0.92	81.4	Debris Flow	High
Cedar Creek:	3.1	91.5	60.8	23.6	0.43	67.1	Debris Flood	High
Cedar Creek Tributary:	0.4	89.0	71.4	14.4	0.91	79.5	Debris Flow	High

General Watershed /Subbasin Conditions:	The wildfire affected areas downstream from (approx.) Bald Range Creek (representing 12% of the total watershed area). The burn severity was higher on the south side of Lambly Creek. Affected elevations are all below the snow-sensitive elevation (~1300 m). The small Cedar Creek tributary sub-basin was 92% burned, with 61% at high severity. Slopes on the north side of the lower watershed in the Blue Grouse Mountain area include sparsely forested, dry, grassland areas. The lower reaches of Lambly Creek flow through a bedrock canyon before reaching Westside Road and then through the large alluvial fan, which contains the Bear Creek Provincial Park campground.
Terrain Conditions:	There is an increased likelihood of instability along the steep, glaciofluvial scarp slopes flanking the lower mainstem channel and a potential for increased landslide and rockfall activity along the burned slopes above Lambly Creek. Lower gradient terraces above the mainstem create a slight disconnect between the burned areas upslope, except where the terrace has been downcut by tributary streams. This is the case for the Cedar Creek tributary. The tributary catchments have an elevated likelihood for post-wildfire debris flow and debris flood activity, indicated by the Melton Ratio, high percentage burned, and high percentage of steep terrain burned.
Mainstem Stream Channel/Riparian Conditions:	Approximately 10.5 km of mainstem channel were burned at moderate and high severity (4 km upstream of intake and 6.5 km downstream of intake). Much of this is steeply incised bedrock canyon with a narrow valley bottom. However, lengths of burned riparian forest are tightly connected to the channel and represent a loss of riparian function including shade, and stream channel stabilization. Loss of function will result in increased sediment delivery, woody debris delivery due to windfall leading to formation of debris jams.
Post-Wildfire Hazards:	There is a low post-wildfire peak flow hazard due to low aggregate of burned area. There is elevated sediment bulking potential arising from post-wildfire response on tributary streams and from the burned riparian forest upstream of the CWK water intake. There is a high likelihood for post-wildfire debris flow activity on some of the small, steep tributaries upslope of Lambly Creek with the potential to impact private property and public roads. Loss of forest and water repellant soils along the valley side slopes will increase the potential for surface erosion, ravelling, and landslide activity.

	Lambly Creek Mainstem					**Trib 1 (aka Blue Grouse Ck)**	**Trib 2**	**Cedar Creek and Cedar Creek Tributary**			
	Elements at Risk										
Elements at Risk	Bear Ck Provincial Park Campground and Bridge	Westside Road Bridge	CWK Diversion & Intake (incl. access road)	CWK Pipeline	Bear Creek Road	Bear Main FSR Crossing	Private property (524 Bear Creek Rd) and Bear Creek Road	Private property above Bear Creek Road (910 Bear Creek Rd)	Bear Creek Road Crossing	Private property below Bear Creek Road (875 & 779 Bear Ck Rd)	CWK Pipeline Crossing and Access Road
	Hazard Level - Likelihood of Event P(H)										
Flood / Debris Flood	Low					High	High	High	High	High	High
Debris Flow	Low					High	High	High	High	High	High
Channel Bank Instability	High (pre-existing instability on the fan area)					n/a	n/a	n/a	n/a	n/a	n/a
Landslide/Rockfall	High hazard along steep slopes adjacent to mainstem channel and downslope of Bear Creek Road (localized sites)					Low	Low	Moderate	High (localized)	High (localized)	High (localized)
	Spatial Likelihood of Impact P(S:H)										
Flood / Debris Flood	Moderate	High	High	Low	Low	High	Moderate	High	High	High	High
Debris Flow	Low	Low	Low	Low	Moderate (upslope)	High	Moderate	High	Moderate	Moderate	Moderate
Channel Bank Instability	High	Low	High	Moderate	Low	n/a	n/a	n/a	n/a	n/a	n/a
Landslide/Rockfall	n/a	n/a	High (localized)	High (localized)	High (localized)	Low	Moderate	Moderate	Low	Moderate	Moderate
	Partial Risk P(HA) = P(H) x P(S:H)										
Flood / Debris Flood	Low	Low	Moderate	Very Low	Very Low	Very High	High	Very High	Very High	Very High	Very High
Debris Flow	Very Low	Very Low	Very Low	Very Low	Low	Very High	High	Very High	High	High	High
Channel Bank Instability	High	Moderate	Very High	High	Moderate	n/a	n/a	n/a	n/a	n/a	n/a
Landslide/Rockfall	n/a	n/a	Very High (localized)	Very High (localized)	Very High (localized)	Very Low	Low	Moderate	Moderate (localized)	High (localized)	High (access road)

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

APPENDIX – PHOTOS (Lambly (Bear) Creek)

Photo 1: Lambly Creek bridge crossing within the Bear Creek Provincial Park Campground, showing good clearance (Lambly-1).

Photo 2: Lambly Creek bridge crossing on Westside Road, showing good clearance (Lambly-2).

Photo 3: View south from Bear Lake Main FSR to the severely burned bedrock slopes along Lambly Creek. Elevated rockfall and shallow landslide hazard. (Lambly-3)

Photo 4: Sediment-laden flow downslope of Bear Lake Main FSR. Noted culvert crossing is plugged with sediment (Lambly-4)


Photo 5: Moderate to high burn severity in cut block along upper slopes on north side of watershed in OHV Trail area. Hazards include windfall, root holes, and exposed soils (Lambly-5)


Photo 6: Moderate burn severity in cut block (Lambly-5). Note vegetative recovery.


Photo 7: High burn severity in mid-watershed area on south side of Lambly Creek near cut block (accessed by helicopter) (Lambly-9)

Photo 8: Mostly plugged culvert inlet on upslope side of Bear Lake Main FSR at Blue Grouse Creek crossing (Blue Grouse-1)

Photo 9: Culvert outlet and burned slope below Bear Lake Main FSR at Blue Grouse Creek crossing (Blue Grouse-1)

Photo 10: Lambly Creek Diversion Structure (Lambly-6 (Lambly-6 - POI at Intake))

Photo 11: Lambly Creek Diversion – Water Intake at arrow (Lambly-6 (POI at Intake))

 Photo 12: Lambly Creek, view upstream from diversion (Lambly-6)	 Photo 13: Lambly Creek channel upstream of diversion, view of old weir structure. Note burned riparian forest in floodplain (Lambly-7)
 Photo 14: Lambly Creek channel downstream from diversion. Note undercut banks, abundant substrate sediment, and burned riparian forest (Lambly-8)	 Photo 15: View of steep burned slopes below Bear Creek Road. Water pipeline ROW is visible along toe of slope adjacent to Lambly Creek (Bear Ck Rd-1)

Photo 16: Stratified glaciofluvial and glaciolacustrine sediments exposed along side slopes above water pipeline and Lambly Creek (Bear Ck Rd-2)

Photo 17: View along edge of burned steep slopes below Bear Creek Road (Bear Ck Rd-1)

Photo 18: View downslope from Bear Creek Rd towards Lambly Creek (Bear Ck Rd-3)

Photo 19: View of small debris-flow gully upslope of Bear Creek Rd (Bear Ck Rd-3)

 Photo 20: View downslope along fan of small debris flow gully. Note that Bear Creek Road is located at the distal end of the fan (Bear Ck Rd-3)	 Photo 21: Overview of lower Cedar Creek catchment at Bear Creek Road crossing (photo provided by L. Jensen 910 Bear Ck Rd)
 Photo 22: Cedar Creek crossing at Water Pipeline (500 mm plastic pipe and 200 mm plastic pipe). Note, burned log stringers. (Cedar-1)	 Photo 23: Cedar Creek, view upstream from water pipeline crossing (Cedar-1)

Photo 24: Incised section of Cedar Creek, downslope of Bear Creek Rd. Note shallow landslide activity and eroded streambanks (Cedar-2)

Photo 25: Pond at Cedar Creek at private driveway crossing (Cedar-3)

Photo 26: 800 mm culvert on Cedar Creek at Bear Creek Rd (Cedar-4)

Photo 27: View upstream from culvert at Bear Creek Road, along private driveway (944 Bear Ck Rd). Cedar Creek flows along ditchline on left side of photo (dry at time of assessment) (Cedar-4)

Photo 28: View downstream from Bear Creek Road at culvert crossing. Note abundant colluvium, and hummocky terrain indicative of past flood events. (Cedar-4)

Photo 29: Domestic Water Intake on Cedar Creek (photo provided by L. Jensen 910 Bear Ck Rd) (Cedar-5)

Photo 30: View of slopes adjacent to Cedar Creek Tributary, which is an ephemeral channel. Note small-scale soil erosion along slope (Cedar Trib-1)

Photo 31: Lower end of colluvial fan on Lambly Tributary 2 (no visible channel) located south of 524 Bear Creek Road (Lambly Trib2-1)

Photo 32: View upslope to gully on Lambly Trib 2 showing shallow colluvial deposits across fan area (Lambly Trib 2-2)

Photo 33: View upslope into gully on Lambly Trib 2. Domestic water well is located in channel (above the fan) (Lambly Trib2-3).

Appendix C7 Watershed Report Cards & Photographs – Westside Road Tributaries and Face Units

Ministry of Forests - BC Wildfire Service
Post-Wildfire Natural Hazards Risk Analysis

WESTSIDE ROAD TRIBUTARIES AND FACE UNIT SLOPES REPORT CARD

	Area (sq km)	% Burned	% High Burn Severity	Melton Ratio	% Mod and High Burn Severity on >40% slopes	Dominant Hydro-Geomorphic Process	Post-Wildfire Hazard Level for Dominant Process
Cinnabar Creek	1.4	26.9	7	0.69	21.3	Debris Flow	Low
Dimetri Creek	1.14	62.3	10	0.79	22.7	Debris Flow	High
Cedar Gulch	0.56	74.2	38	1.14	60.6	Debris Flow	High
Cedar Gulch-2	0.43	98.4	48	0.91	TBD	Debris Flow	High
Wilson Creek	1.26	74.7	26	0.79	52.1	Debris Flow	High
Oldman Creek	1.42	90.1	42	0.76	46.1	Debris Flow	High
Jennie Creek	1.57	98.4	76	0.59	25.7	Debris Flow	High
Unnamed Creek	0.86	98.3	57	0.95	39.8	Debris Flow	High

General Conditions:	This area includes several small (less than 2 sq. km) steep catchments and face units along Westside Road north of Lambly (Bear) Creek within the RDCO. The fire extended from the height of land all the way downslope to Okanagan Lake, affecting lakeshore development clusters and scattered rural properties. The high severity burn was situated mostly at an upper mid-slope elevation, with moderate burn severity occuring throughout. Many streams are ephemeral and do not flow year-round. However, the catchments are capable of producing debris flows if certain conditions and/or events occur.
Terrain Conditions:	Slopes within the area are generally moderately sloped with steeply incised gullies. Upper slopes are benchy and bedrock-controlled, with surficial materials increasing in thickness at and below Westside Road. Cutslopes along Westside Road are broadly characterized by bedrock exposures. Thin exposures of glaciofluvial and glaciolacustrine sediments mantle bedrock exposures. Pre-existing instability is predominantly small-scale rockfall activity. Several tributary catchments exhib field indicators of debris flow activity, including boulder deposition at or below Westside Road. Although infrequent, the steep tributary catchments have the capability of producing moderate sized debris flow events and, the ffects of wildfire will increase the likelihood of occurrence.
Mainstem Stream Channel/Riparian Conditions:	Streams flowing through the area are moderately well-confined to Westside Road. The streams have relatively small, steep fans and Westside Road is roughly located at the fan apex. Streamflows infiltrate within-channel sediments and fan deposits and transition to groundwater seepage along lower slopes closer to the lake.
Face Unit Slopes:	The wildfire affected slopes above and below Westside Road, extending approximately 12 km north of Traders Cove. Face unit slopes, located in between the delineated tributaries are subject to post-wildfire natural hazards such as sediment-laden flooding, landslides, surface erosion and rockfall. These hazards are expected to occur where drainage is concentrated into small gullies and where Elements at Risk are located directly below steep, burned slopes.
Post-Wildfire Hazards:	Post-wildfire impacts may include small-scale landslides along steep gully sideslopes and headwalls, resulting in sediment loading into the channel. Depending on stream gradient, these channels have the potential to generate larger-scale debris flows. However, the trigger mechanism is very much dependant upon rainfall (volume and intensity). Steep, bedrock-controlled cutslopes along Westside Road may experience increased frequency of rockfall and small sediment-laden runoff through areas burned at high severity. There are also numerous small gullies and steep slopes above Westside Road that may be capable of small debris flow events, sediment-laden flows, and/or landslide activity. These areas are subject to higher level of hazard during intense rainstorm events.

	Cinnabar Creek		Dimetri Creek		Cedar Gulch and Cedar Gulch-2		Wilson Creek		Oldman Creek		Jennie Creek		Unnamed Creek	Face Unit Slopes
	Elements at Risk													
Elements at Risk	Westside Rd	Private Property d/s Westside Rd (strata at 3985 Westside Rd)	Westside Rd	Private Property d/s Westside Rd (3645/3625/3595 Westside Rd)	Westside Rd	Private Property d/s Westside Rd (incl. Lake Okanagan Resort) & 2731/2677 Westside Rd	Westside Rd, Wilson Landing Fire Hall (2396 Westside Rd)	Private Property d/s Westside Rd incl Camp Owaissi (2411 Westside Rd)	Westside Rd	Private Property u/s (2326 Westside Rd) and several lots along Westside Pl	Westside Rd	Private Property u/s Westside Rd (1750 Westside Rd)	Westside Rd	Westside Rd and Private Properties along Face Unit
	Hazard Level - Likelihood of Event P(H)													
Flood / Debris Flood	Low		High		High		High		High		High		High	Low
Debris Flow	Low		High		High		High		High		High		High	Sediment-laden flood - High (localized)
Landslide/Rockfall	n/a		n/a		n/a		n/a		n/a		n/a		n/a	High (localized)
	Spatial Likelihood of Impact P(S:H)													
Flood / Debris Flood	Moderate (upgraded culvert)	Moderate (upgraded culvert)	Moderate (upgraded culvert)	Moderate (upgraded culvert)	High (no culvert)	High	Moderate (past mitigation works TBC)	Moderate (past mitigation works TBC)	High (culvert inlet blocked)	High (culvert inlet blocked)	High	Moderate	High	Low
Debris Flow	High	High	High	High	High (no culvert)	Moderate	Moderate (past mitigation works TBC)	Moderate (past mitigation works TBC)	High (culvert inlet blocked)	High (culvert inlet blocked)	High (culvert inlet partly blocked)	Moderate	High (culvert not observed)	High (localized)
Landslide/Rockfall	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	High (localized)
	Partial Risk P(HA) = P(H) x P(S:H)													
Flood / Debris Flood	Low	Low	High	High	Very High	Very High	High	High	Very High	Very High	Very High	High	Very High	Very Low
Debris Flow	Moderate	Moderate	Very High	Very High	Very High	High	High	High	Very High	Very High	Very High	High	Very High	Very High (localized)
Landslide/Rockfall	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	Very High (localized)

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

APPENDIX – PHOTOS (Westside Road Tributaries and Face Units)

Photo 1: Old debris flow levee and boulders within gully upslope of Westside Road along Cinnabar Creek (Cinnabar-1).

Photo 2: New 900 mm culvert with concrete baffles and rock armour on Cinnabar Creek crossing Westside Road (Cinnabar-1).

Photo 3: New 1200 mm culvert with trash rack and rock lined channel on Dimetri Creek at Westside Road (Dimetri-1)

Photo 4: Example of wide ditches along Westside Road that can capture and detain sediment-laden runoff from burned slopes above (Westside-1)

 Photo 5: Severely burned gully along Cedar Gulch Creek upslope of Westside Road (Cedar Gulch-1)	 Photo 6: View of thick sand and gravel deposits along Cedar Gulch at Westside Road (no culvert) (Cedar Gulch-1_
 Photo 7: View downslope along Cedar Gulch Creek gully below Westside Road towards Lake Okanagan Resort (Cedar Gulch-1)	 Photo 8: View upslope towards two culverts under Westside Rd on Wilson Creek (Wilson-1)

Photo 9: View upslope along Wilson Creek fan, with scattered boulders on ground surface (Wilson-2)

Photo10: View downslope towards Wilson's Landing Fire Hall (red roof) along the depositional fan area upslope of Westside Road (Wilson-1). Culvert is located at arrow.

Photo 11: Shallow, discontinuous berm along upslope edge of Fire Hall Parking lot (Wilson-1)

Photo12: View upslope along Wilson Creek, upstream of the fan. Channel is contained within steep-sided gully. (Wilson-3)

Photo 13: Slopes at ~600 m elevation showing benched slopes and upper slope breaks at gully headwalls (north of Wilson Creek) (Wilson-4)

Photo14: View upslope along bedrock-controlled reach of Wilson Creek. Abundant rockfall and exposed soils available to the channel (Wilson-5).

Photo 15: Bedrock canyon along Wilson Creek, note narrow trail (access to water license) downstream (Wilson-6)

Photo16: Water flowing across old trail crossing on Wilson Creek, mid-watershed (Wilson-6)

Photo 17: A 400 mm culvert along an old resource road traversing the top of Wilson Creek gully. (Wilson-7)

Photo18: Steep (50-75%) slopes into the Wilson Creek gully. Note abundant soil disturbance from windfall. Small debris slides observed in area (Wilson-8)

Photo 15: View upslope from Westside Road into Oldman Creek catchment (Oldman-1). The inlet to a 500 mm culvert is buried.

Photo16: Inlet of 1000 mm culvert on Jennie Creek at Westside Road is mostly blocked with sediment (Jennie-1)

Photo 17: View upslope along Jennie Creek, note scattered boulders. Constructed trail extends up along north (right side of photo).

Photo18: View downslope along Jennie Creek towards Westside Road. Direct connectivity to the road area downslope (Jennie-1)

Photo 19: Newer 1200 mm culvert with concrete baffle and rock-lined ditch along Westside Road.

Photo 20: Rock cut with rockfall protection fencing along Westside Road.

Appendix D CGL General Conditions and Terms of Use

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

Glossary of Technical Terms

Glossary of Technical Terms

(definitions obtained from Hope, et al. (2015), Wilford, et al. (2009), Pike, et al. (2010), and Wise, et al. (2004))

Alluvial - Deposited by running water.

Alluvial Fan - A relatively flat to gently sloping landform composed of predominantly coarse-grained soils, shaped like an open fan or a segment of a cone, deposited by a stream where it flows from a narrow mountain valley onto a plain or broad valley, or wherever the stream gradient suddenly decreases.

Burn (or fire) severity - a general term that most commonly describes the combined effects of both flaming and smouldering. Burn severity, in broad terms and as applied in the British Columbia risk assessment procedure, refers to the effects of the fire on both the forest canopy and understory (vegetation burn severity) and on the forest floor and soil (soil burn severity). It provides vital information for soil erosion, hydrologic, and landslide assessment.

Catchment - A geographic area drained by a single major stream; consists of a drainage system comprised of streams and often natural or man-made lakes. See *Drainage Basin* or *Watershed.*

Colluvium - Loose, weathered material brought to the foot of a cliff or some other slope by gravity.

Consequence - the effect on human well-being, property, the environment, or other things of value; or a combination of these. Conceptually, the consequence is the change, loss, or damage to the elements at risk caused by the landslide.

Debris - An accumulation of unsorted fragments of soil, rock, and sometimes large organic material (e.g., tree limbs). Also used to describe organic material transported within streams.

Debris Flood – A type of flood process described as a hybrid between a flood and a debris flow. The event involves the transport of large volumes of sediment and woody debris down gully/stream systems by large volumes of water. Debris floods do not behave as coherent flows as the main constituent is water. Debris floods have sediment concentrations of 20–47% by volume and characteristically have significant sediment deposits beyond the channel.

Debris Flow – A type of fast-moving landslide that moves along a steep channel or gully. It is particularly dangerous to life and property because they move quickly, are capable of transporting bouldery debris, and often occur without advance warning.

Debris Flow Fan - A relatively steep sloping landform shaped like an open fan or a segment of a cone, deposited by a debris flow where it exits from a narrow mountain valley onto a plain or broad valley, or wherever the channel gradient suddenly decreases. Sometimes referred to as colluvial fan.

Debris Slide or Slump – A type of landslide described as displacement of soil or rock as an unbroken mass, or in a broken-up mass of material.

Debris Torrent - A term no longer used in British Columbia. See D*ebris Flow*.

Drainage Basin - Total land area draining to any point in a stream, as measured on a map, aerial photo, or other horizontal, two-dimensional projection. See *Catchment* or *Watershed*.

Elements at Risk – Features of social, environmental, and economic value (or simply elements) are humans, property, the environment, and other things of value, or some combination of these that are put at risk (adapted from CSA 1997).

Ephemeral Stream - A stream, whose channel is always above the water table, which flows briefly in direct response to precipitation, receiving no continued supply of water from snowmelt or springs. Also referred to as an intermittent stream.

Flood – Overland flow of water beyond its normal confines, over what is normally dry land. The most common type of flood in British Columbia is generated by rainfall and/or snow melt.

Geomorphic (Geomorphology) – Relating to the form of landscape or the processes occurring on the earth surface. Part of a discipline of science that aims to interpret landforms based on their origin and development.

Glaciofluvial - The processes, sediments, and landforms associated with glacial meltwater streams.

Glaciolacustrine - Pertaining to, or characterized by, glacial and lacustrine processes or conditions applied especially to deposits made in lakes.

Groundwater – Water that occurs below the ground surface within rock fractures and soil pore spaces.

Gully - A landform characterized as a steep-sided valley (or ravine) cut by concentrated runoff, mass movement, or a combination of both, occurring along a hillside composed of erodible sediments. A smaller-scale gully that is less incised (shallow) and often less-steep is referred to as a topographic swale.

Hazard - A source of potential harm, or a situation with a potential for causing harm, in terms of human injury; damage to property, the environment, and other things of value; or some combination of these (CSA 1997). With respect to landslide risk management, the landslide is the source of potential harm—it is the hazard. A future landslide that has no harmful potential is not a hazard but is simply a natural geological or geomorphological process or feature.

Hydro-geomorphic processes – a technical word comprised of the combination of "hydrologic" and "geomorphic" to represent a range of both processes occurring in a watershed.

Hydrologic (Hydrology) – Relating to water and the effects of water on the land. The science that describes and analyzes water, its properties, its circulation, and its distribution over the Earth's surface in natural and disturbed environments.

IDF Curve (Rainfall Intensity–Duration Frequency) Curve - A curve showing the relationship between rainfall depth (or intensity) and storm duration for a given station for different return periods.

Landslide – a general term for the movement of a mass of rock, debris, or earth down a slope. Landslide types include debris flows, debris slides or slumps, and rockfall.

Likelihood - is used to provide a qualitative estimate of probability, referred to as a probability rating. Likelihood estimates are typically expressed using relative qualitative terms, such as *very low* to *very high* or *very unlikely* to *almost certain*.

Peak Flow – The greatest stream discharge recorded over a specified period of time, usually a year but often a season, or even a single event (as in storm peak flows).

Perennial Stream - Stream that flows all year round, regardless of weather conditions.

Probability of landslide occurrence is an estimate of the chance for a landslide to occur. An estimate of probability is expressed quantitatively, using a number between 0 (a landslide will not occur) and 1 (a landslide will certainly occur).

Rain-on-Snow Event - Rainstorms that result in large stream flows due to the combined effects of heavy rainfall and snowmelt runoff.

Return Period - The time to the recurrence of an event, from statistical analysis of data, based on the assumption that observations are equally spaced in time. A return period of 100 years means that, on average, an event of this magnitude or greater is not expected to occur more often than once in 100 years. It is calculated as the inverse of the probability of occurrence ($R = 1/p$).

Risk Analysis - The systematic use of information to identify hazards and estimate the probability and/or severity of injury or loss to people, property, the environment, or other things of value (CSA, 1997; Wise et al. 2004). A post-wildfire risk analysis usually describes, implicitly or explicitly, the change in hazard or risk due to the wildfire (the incremental hazard or risk), although the background or pre-existing risk is noted.

Risk - The chance of injury or loss as defined as a measure of the probability and the consequence of an adverse effect to health, property, the environment, or other things of value (adapted from CSA 1997).

Rock Fall - The relatively free falling or precipitous movement of a newly detached segment of bedrock of any size from a cliff or other steep slope; it is the fastest form of mass movement and is most frequent in mountain areas and during spring when there is repeated freezing and thawing of water in cracks in the rock.

Soil burn severity - A relative measure that describes the effect of a fire on ground surface characteristics and soil conditions that affect soil hydrologic function.

Stakeholders - Any individual, group, or organization able to affect, be affected by, or believe they might be affected by, a decision or activity. Note that decision-makers are stakeholders (CSA 1997).

Surficial Geology - Geology of surficial deposits, including soils; the term is sometimes applied to the study of bedrock at or near the Earth's surface.

Terrain - A region of the Earth's surface considered as a physical feature, which can be described by relief, roughness, and surface material.

Terrain Stability - Slope stability from a regional perspective as opposed to the study of the stability of an individual slope.

Vegetation burn severity - is a relative measure that describes the effect of a fire on vegetative ecosystem properties.

Watershed - Also referred to as a drainage basin or catchment area. Watersheds are the natural landscape units from which hierarchical drainage networks are formed. Watershed boundaries typically are the height of land dividing two areas that are drained by different river systems.

Watershed Assessment - A process for evaluating the cumulative impacts, over time and space, of all land use activities within a given watershed on variables such as stream flows, sediment regime, riparian health, and landscape and stream channel stability. The process can also be used to assess the potential impacts of proposed future land use activities.

Watershed Morphometrics – these are topographic measurements, completed by GIS analysis, of a watershed that are used to provide a first approximation of the dominant hydro-geomorphic processes.

Sources:

Canadian Standards Association (CSA). 1997. Risk Management: Guidelines for Decision Makers. CAN/CSA-Q850-97. Ottawa, ON.

Hope, G., P. Jordan, R. Winkler, T. Giles, M. Curran, K. Soneff, and B. Chapman. 2015. Post-wildfire natural hazards risk analysis in British Columbia. Province of B.C., Victoria, B.C. Land Management Handbook No 69. www.for.gov.bc.ca/hfd/pubs/Docs/Lmh/LMH69.htm

Pike, R.G., T.E. Redding, R.D. Moore, R.D. Winker and K.D. Bladon (editors). 2010. Compendium of forest hydrology and geomorphology in British Columbia. B.C. Ministry of Forests and Range, Forest Science Program, Victoria, B.C. and FORREX Forum for Research and Extension in Natural Resources, Kamloops, B.C. Land Management Handbook No. 66. www.for.gov.bc.ca/hfd/pubs/Docs/Lmh/Lmh66.htm

Wilford, D.J., M.E. Sakals, W.W. Grainger, T.H. Millard, and T.R. Giles. 2009. Managing forested watersheds for hydrogeomorphic risks on fans. B.C. Ministry of Forests and Range, Forest Science Program, Victoria, B.C. Land Management Handbook No. 61. www.for.gov.bc.ca/hfd/pubs/Docs/Lmh/Lmh61.htm

Wise, M.P., G.D. Moore, and D.F. VanDine (editors). 2004. Landslide risk case studies in forest development planning and operations. B.C. Ministry of Forests, Research Branch, Victoria, B.C. Land Management Handbook No. 56. <http://www.for.gov.bc.ca/hfd/pubs/Docs/Lmh/Lmh56.htm>