

# **Mission Creek**

# **Hydrological Risk Assessment**

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**BC Ministry of Environment**

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## EXECUTIVE SUMMARY

Grainger and Associates Consulting Ltd. and Streamworks Unlimited completed an analysis of Mountain Pine Beetle (MPB) and salvage harvesting-related risks to water quality, water supply, fish habitat and other infrastructure in Mission Creek Community Watershed. Mission Creek is a water source for the Black Mountain Irrigation District (BMID), a major supplier of domestic, commercial and agricultural water supplies the to City of Kelowna. Mission Creek has an area of 605km<sup>2</sup> upstream of the BMID water intake.

The hydrological effects of MPB and salvage harvest forest cover disturbance were analysed using recent research findings on snow accumulation and melt effects under different forest canopy conditions, including the effects of the dead pine trees, non-pine overstory, and understory seedlings, saplings and poles in MPB-attacked stands (Huggard and Lewis, 2008). Canopy change effects are expressed as equivalent clearcut area (ECA).

Stand structure data for ECA modelling was collected in 245 random plots in 30 accessible pine-leading stands (>40% pine) in the hydrologically sensitive upper watershed “snow zone”, in seven South Okanagan watersheds near and including Mission Creek. Over 70% of inventoried pine-leading stands had a non-pine overstory averaging 25 to 69% of total overstory basal area, and healthy understory averaging 560 to 1000 well-spaced stems/ha >1.3m tall. These stands will have a significant hydrological function over time, even if all pine in the stand is dead.

Stand data was used to model two hypothetical watershed level management scenarios. In the “MPB/unharvested” scenario, all pine trees in pine-leading stands are assumed to be killed by MPB, and no further forest harvesting activity takes place in the watershed. In the “full clearcut salvage” scenario all pine-leading stands are clearcut harvested, with the exception of riparian zones, old growth management and other areas designated as long-term reserves by forest licensees. For each scenario, stand ECA data was rolled up into watershed or sub-basin ECA’s for Mission Creek watershed and its eight sub-basins. Actual future watershed management is expected to fall somewhere between these two extreme scenarios.

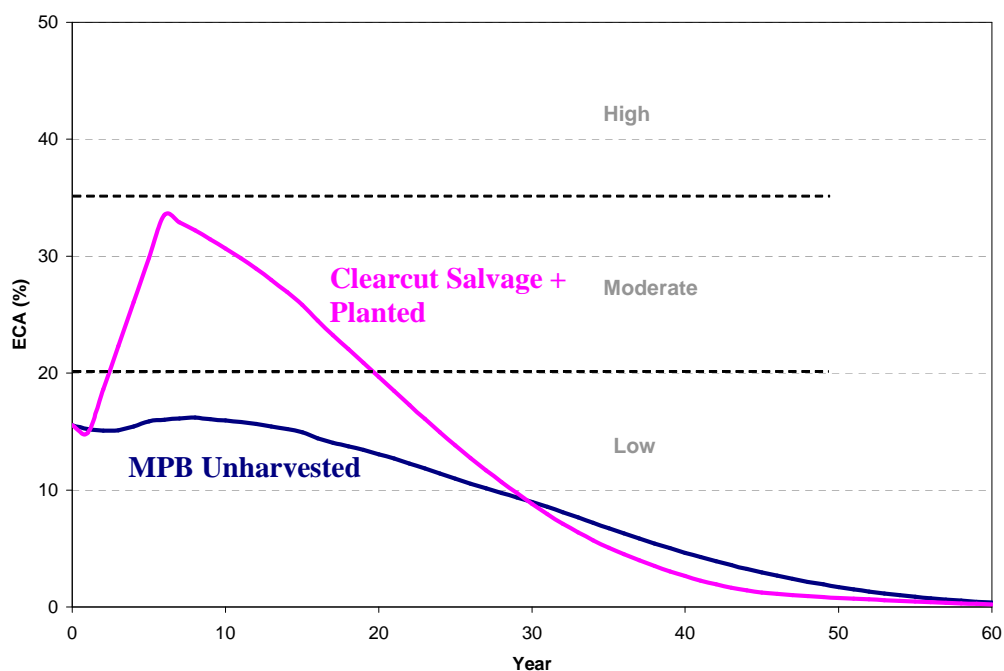


Figure 10. ECA progression for Mission Creek Watershed above BMID intake.

The current watershed ECA is low. Following full pine mortality and no harvesting there is, on average, a Low ECA hazard for approximately 25 years. That is, a significant increase in hillslope surface or subsurface runoff is not expected. For the full pine salvage harvest scenario there is a Moderate incremental ECA hazard lasting for 15 to 20 years. That is, a significant increase in hillslope runoff may or may not occur.

Similarly, the likelihood of increased peak flows following the unharvested MPB scenario is Low, and following the full salvage harvest scenario it is Moderate. However, Mission Creek has a history of excess sediment delivery to mainstem channels from numerous natural landslides, and to a lesser extent from forest and public road developments. Increased sediment from historic landslides has led to mainstem channel widening and erosion of thick unconsolidated stream bank sediments, which causes further erosion and channel widening in a negative feedback loop. This has resulted in long reaches of aggraded mainstem channel with excess sediment loads. These aggraded mid-watershed reaches are highly sensitive to any changes in peak flows and sediment loading, which could result in increased sediment mobilization to lower reaches. Combining the High channel sensitivity with a Low peak flow hazard following the unharvested MPB scenario there will be a Moderate watershed hydrologic hazard at the BMID water intake. Combining the High channel sensitivity with a Moderate peak flow hazard following the full salvage harvest scenario, there will be a High hydrologic hazard at the BMID intake.

The watershed was divided into 8 sub-basins which were analysed separately. Hydrologic hazards varied from Very Low to Very High under either management scenario, depending on differing natural forest types, harvesting histories and natural and development-related geomorphic conditions.

Potential qualitative risks to different watershed and sub-basin elements were determined by combining the hydrologic hazards for the two management scenarios with the consequence values for each of four watershed elements of interest – municipal water quality, water supply, fish resources and other social infrastructure.

The water quality parameters most strongly linked to MPB infestation and salvage logging in Mission Creek watershed will be the presence of fine and coarse sediment in source waters at the BMID intake. This would occur if there are increases in peak flows (floods) and associated mobilization of fine and coarse sediment from stream channel beds and banks. Following the complete mortality of all pine due to MPB and no further harvesting in the watershed, there is a Moderate Risk, which means some increase in fine and coarse sediment delivery to the BMID intake may or may not occur. Following the full salvage of pine-leading stands scenario there is a High risk, and a significant increase in sediment delivery to the BMID intake is considered likely.

While the likelihood of increased flooding is not high with either management scenario, there is so much available sediment in the aggraded Mission Creek mainstem channel, any increases in stream discharge could mobilize sediment. Mission Creek has a history of severe sediment mobilization events to lower reaches, and source water turbidity levels often exceed Interior Health Authority water quality guidelines, requiring water treatment. This is likely to continue under either management scenario.

There is little evidence of links between MPB/salvage effects and the water quality parameters of total organic carbon, true colour, metals and total phosphorous. Measurable change in these parameters in Mission Creek is not expected. The effect of MPB and salvage mortality on growing

season low flows and reservoir storage drawdown will probably not be significant. A much greater change in water supplies is expected with decreased streamflows, increased agricultural demand and changes in freshet timing due to global climate change-related temperature increases.

There are fish present and high habitat values along much of Mission Creek and its major tributaries. Lower Mission Creek has historically been the primary Kokanee and rainbow trout spawning habitat for the entire Okanagan Lake fishery. Fish habitat in lower Mission Creek has been seriously degraded by dyking and channelization through the City of Kelowna and any further impacts to habitat there is considered a Very High consequence. This results in a High Risk of negative impacts following MPB-related pine mortality, mainly due to the potential for increased sediment movement, channel aggradation and a reduction in habitat quality. If there is widespread salvage harvesting the risk of negative impacts on fish habitat in lower Mission Creek below its confluence with Belgo Creek, and the Joe Rich and lower Belgo tributaries will be Very High.

All social infrastructure risk values have a higher risk with the full salvage scenario than with the MPB/unharvested scenario. Risks to housing developments on the Mission Creek fan, forestry roads, forest road-related “gentle-over-steep” landslides and Highway 33 bridge crossings are considered moderate and high for the MPB/unharvested and full salvage scenarios respectively. Risks to private water intakes, private stream crossings and Highway 33 culvert crossings are considered High to Very High respectively, because they are generally built to a lower standard than forestry or public works, or have experienced problems in the past.

Risk mitigation can focus on either protecting and strengthening risk elements, or reducing stand-level MPB and salvage effects. Forests For Tomorrow (FFT) program silviculture activities will promote long term health, economic value and hydrologic function in the forest. However, to date under-planting has not been successful and all ongoing FFT activities we are aware of involve canopy removal. Therefore these activities will not mitigate the short term hydrological impacts of MPB attack and salvage harvesting in Mission Creek.

Riparian management along streams during salvage harvesting will be important in preserving stream stability and habitat quality, large woody debris (LWD) recruitment levels and stream temperatures. Research has found LWD input rates are similar for attacked and non-attacked Okanagan stands, suggesting that riparian zone forests have a significant non-pine component, and will continue to protect stream ecosystem values if left unharvested. At a minimum best riparian management practices for “green wood” harvesting in the Okanagan should be followed when salvage harvesting MPB-attacked stands.

Maintaining forest structure in riparian zones will help mitigate potential impacts to fish habitat. Since we don't know what level of harvesting will occur in the watershed, it would be prudent to periodically update on-site fish habitat assessments for reaches upstream of the fan (last done in 1996), monitor channel and riparian conditions and carry out rehabilitation activities as necessary. Detailed analyses of rehabilitation strategies in the Kokanee spawning habitat on the Mission Creek fan have been completed, with the goal of offsetting habitat degradation that has occurred there as a result of channel modification through the City of Kelowna. Any such efforts should take into consideration the likelihood of increased sediment delivery to those reaches, particularly if widespread salvage harvesting occurs in the watershed.

Landslides have historically played a significant role in stream channel processes in Mission Creek watershed. The majority of sediment introduced to channels from landslides is from

naturally occurring events. However their occurrence and the occurrence of road-related landslides of significant size and frequency indicate that many steeper stream escarpment slopes are only marginally stable, and will fail if disturbed. The most common disturbance would result from hillslope drainage redirection by roads and trails. Particularly in sub-basins where significant increases in peak flows are predicted (Joe Rich and upper and lower Belgo sub-basins), or if significant salvage harvesting is planned for any area near or on steeper stream escarpments, a review of trail and road drainage structures in the area should be completed as described in this report.

We know of no way to reduce the magnitude and duration of the ECA hazard in unharvested MPB-attacked stands, in the absence of an effective under-planting program in those stands. However the risks to most watershed values are not expected to be catastrophic from MPB related stand mortality alone. But incremental risks are higher for all elements at risk in the watershed following the hypothetical scenario of full salvage harvest of all pine-leading stands, compared to the potential risks if all pine-leading stands were left unharvested. Where those post-total salvage risks are High or Very High, reducing those risks to an acceptable level will require managing the amount and location of salvage harvesting in the watershed.

While it makes good hydrological sense to harvest attacked pine stands rather than “green” non-pine stands, removing too much MPB-attacked forest can increase watershed hazards and risks. To manage the incremental hydrologic impact of salvage harvesting it is recommended that:

- licensees should use a hydrological risk assessment methodology that models the effects of the dead pine, non-pine overstory and understory stand structure in dead pine stands over time to get a more accurate picture of ongoing hydrological condition in the watershed, and of the potential incremental impacts of proposed salvage harvesting. Hydrological risk analyses that treat all MPB attacked stands as having little or no hydrological forest function (i.e., as having initial ECA values similar to clearcuts) will seriously underestimate the incremental hydrological risks associated with widespread clearcutting of attacked stands that have hydrologically significant stand characteristics.
- From a strictly hydrological perspective (and we recognize forest managers have to balance many different forest values), the least hydrological impact would result if pine-leading stands with the lowest non-pine overstory component and lowest understory stocking were preferentially targeted for salvage harvest. From the data collected here the stands in the snow zone with least hydrological function would be younger MSdm stands followed by older MSdm stands and then ESSFdc stands (see Figures 6-8 and Appendix B).
- Forest Inventory data suggest there are few pine-leading stands in ESSFxc type forests, which comprise over 50% of the hydrologically sensitive upper elevation snow zone in Mission Creek watershed. While extensive MPB salvage is not expected in these types of stands, should significant harvesting occur there, there will be greater watershed hydrologic impacts than predicted in this study. If in the near future a significant amount of harvesting is planned in ESSFxc areas in upper Mid-Mission or Pearson sub-basins, the analyses completed in this study would underestimate watershed risks, and should be redone.
- We recognize that individual stands within broader biogeoclimatic types will have different characteristics than the average overstory and understory values used in this analysis. Site specific surveys of stand characteristics in areas proposed for harvesting are recommended.

Salvage harvesting should be focused on those stands with the least non-pine overstory and little healthy understory.

The widespread and severe MPB epidemic in B.C. is clear evidence that forests can be subjected to significant unforeseen disturbances, with potentially significant consequences. Because of the types of forests present, the expected hydrological effect of unharvested MPB infestation and pine tree mortality in Mission Creek Watershed is not expected to be catastrophic for most of the identified watershed values (risk elements). Salvage harvesting, if widespread enough, can increase those risks. But with good management of harvesting rates and sites, which recognizes the hydrological function of different pine-leading stand types, some forest development should be possible with a level of risk that is acceptable to watershed stakeholders. However MPB infestation may not be the only significant source of stress on Mission Creek forests in the near future. Global warming and global warming-related disturbances such as other pathogens which could attack other tree types, and fire, etc., are not improbable. A severe Spruce beetle infestation in the widespread spruce balsam stands in the upper watershed, and associated salvage harvesting, could drastically change the risk situation in Mission Creek watershed. We think that part of the determination of what is an acceptable level of risk should include considering the potential hydrological (and other) effects of this and other possible disturbances. To manage for them it would be prudent to apply the precautionary principle and preserve some hydrological function in the watershed above the minimum required to manage only for MPB and MPB-related salvage impacts.

## 1.0 INTRODUCTION

Grainger and Associates Consulting Ltd. and Streamworks Unlimited were retained by the B.C. Ministry of Environment to carry out an analysis of Mountain Pine Beetle (MPB) and salvage harvesting-related risks to water quality, water supply, fish habitat and other infrastructure in Mission Creek Community Watershed (Figure 1, in pocket); as part of a contract to complete similar risk analyses for seven south Okanagan Community Watersheds.

Mission Creek Watershed has an area of approximately 859km<sup>2</sup> and drains into Okanagan Lake through the City of Kelowna, B.C. It is a municipal water source for the Black Mountain Irrigation District (BMID). Sport-fish species within the watershed include Brook Trout and Rainbow trout in the headwater tributaries and lake, and presumably in Mission Creek mainstem reaches. Kokanee and Mountain Whitefish have been identified in the lower reaches of Mission Creek. There are numerous private water licenses and forestry roads and bridges in the watershed.

This report provides an analysis of risks to these watershed values associated with potential changes in the forest following pine mortality due to MPB attack and/or salvage harvesting. Changes in forest cover can affect watershed hydrology, and potentially water quality, quantity and timing.

The project was completed by the team of Bill Grainger, P.Geo. EngL., forest hydrology, risk analysis and project management; Alan Bates, P.Eng., hydrotechnical analysis, channel morphology, sensitivity and restoration; Jennifer Clarke, P. Geo.; background information and water quality, Michele Trumbley; R.P.Bio., fish population and habitat analysis, Dave Huggard, Ph.D., ECA modeling; Stuart Parker, RPF, forest stand data collection and silviculture mitigation options; and Chris Long of Integrated ProAction Corp, GIS data analyses and mapping.

## 2.0 METHODOLOGY

This report utilizes previously published materials on Mission Creek watershed conditions, as well as a helicopter overflight on October 27 and ground inspections on November 27, 2008. Forest overstory and understory were measured in 16 plots in two different areas in Mission Creek on December 12, 2008, as part of a program of 245 plots taken in 30 areas in seven south Okanagan Community watersheds. This detailed stand information was used in modelling the projected hydrological effects of MPB pine mortality and salvage harvesting in Mission Creek and the six other watersheds.

This report also incorporates recent research findings regarding the hydrological effects of MPB-attacked stands over time, and research findings regarding potential stream flow regime changes due to large scale watershed disturbances such as those resulting from MPB and clearcut salvage harvesting.

The watershed risk analysis procedure is presented in Section 2.1. Sections 2.2 and 2.3 explain how forest cover changes, watershed conditions and channel conditions make up the hydrologic hazard. Section 2.4 discusses the linkages between MPB and salvage harvesting-related watershed processes and the various elements potentially at risk in the watershed. Current and

potential future watershed conditions in Mission Creek are assessed in Section 3, to determine potential hydrologic hazards. Section 4 details the presence and/or vulnerability of specific Mission Creek watershed values (or consequences) that could be impacted by those hazards. Section 5 combines the hazards and consequences discussed in Sections 3 and 4 to arrive at qualitative risk ratings for each of the consequences potentially at risk. Section 6 summarizes the various qualitative risks and proposes mitigative measures and management strategies to reduce those risks, where necessary.

## **2.1 RISK ANALYSIS**

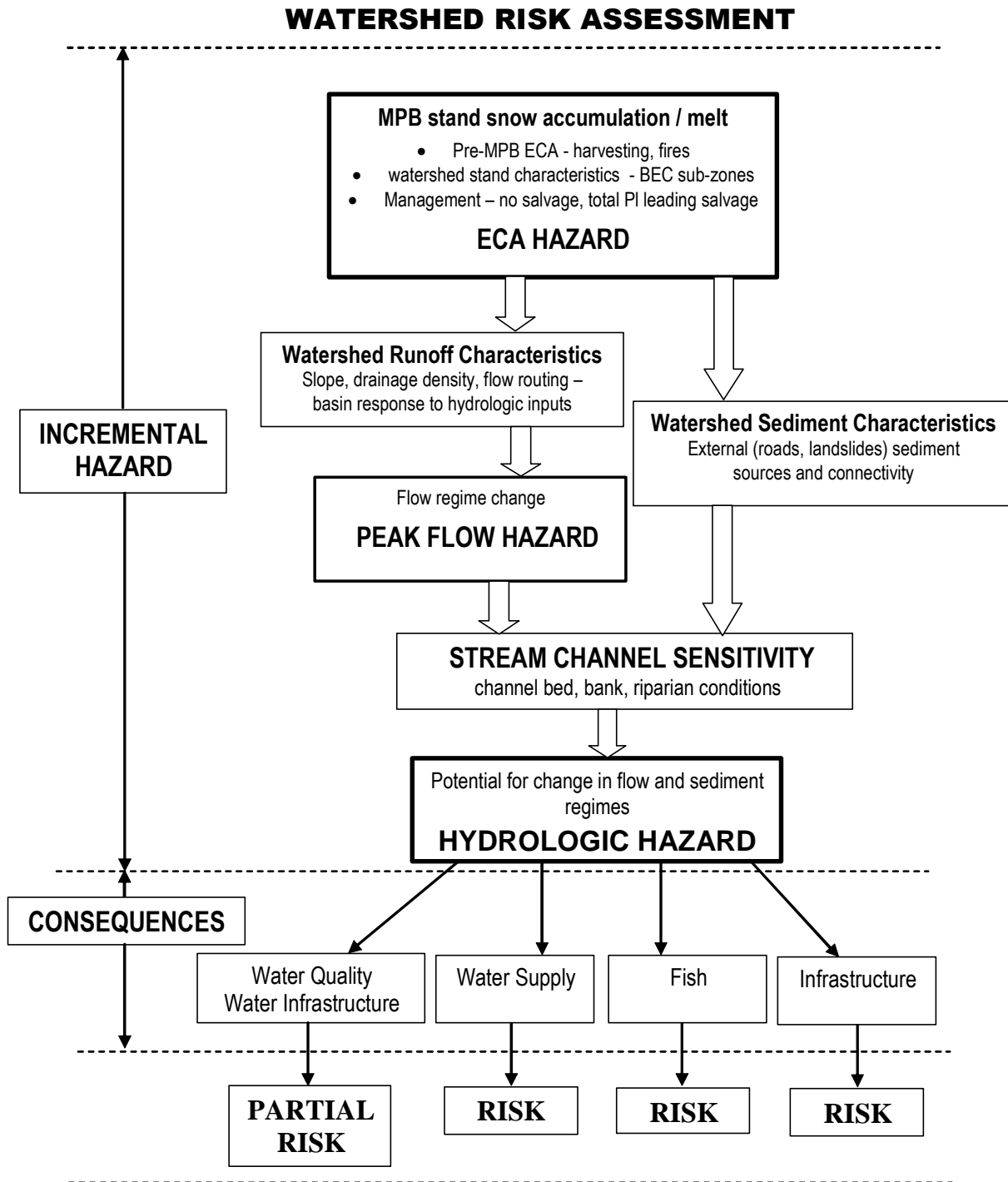
Risk is a product of the incremental (increased) hydrologic hazard due to MPB and salvage harvesting, and each of the consequences which could be impacted by that hazard:

$$\text{Risk} = \text{Hazard} \times \text{Consequence}$$

This is done using a risk matrix, as shown in Appendix A, Risk Assessment Definitions.

Figure 2 shows the risk assessment procedure used in this investigation. The incremental hydrologic hazard starts with changes in the forest canopy, snow accumulation and snow melt. This is expressed as an Equivalent Clearcut Area hazard (ECA). Watershed characteristics – drainage density, slope and routing factors (reservoirs, lakes and swamps) – will determine how the watershed will respond to changes in watershed ECA. A change in the flow regime is expressed as the peak flow hazard. The watershed sediment regime depends largely on pre-existing terrain conditions and the history of landslides and bank erosion, and the resulting sediment regime in stream channels. But ECA effects can also influence hillslope runoff, future landslides and sediment sources.

How the flow hazard will affect stream channels depends on the existing channel conditions, how much sediment is available to be mobilized and how sensitive or robust the channel is to changes in stream flows. This is determined from field observations and previously published channel assessments. The channel sensitivity and flow hazard are combined to form the overall Hydrologic Hazard.



**Figure 2.** Risk Assessment Flow Chart

## **2.2 MPB AND SALVAGE HARVESTING HAZARDS**

### **2.2.1 MPB and salvage stand hydrological effects**

Mountain Pine Beetle and salvage harvesting primarily affect watershed hydrological processes through the loss of forest canopy and ground disturbance; when the pine beetle kills pine trees in a stand, and when clearcut harvesting removes all trees in a stand. These changes can alter the water balance at affected sites and, depending on actual weather and watershed characteristics contribute to: less evapotranspiration and interception losses, increased rain and snow reaching the ground, increased soil moisture and hillslope flow, changes in site level energy balances leading to earlier onset of spring snowmelt, more rapid streamflow response to storms, increased total stream flow and increased magnitude and frequency of peak flows (Winkler et al. 2008).

Ground disturbance and roads can lead to soil compaction, reduced infiltration to groundwater, shallow groundwater interception in road cuts and redirection of intercepted water to streams. These processes can increase the “flashiness” of watershed response to rain and snowmelt inputs, and contribute to elevated peak flows. Our experience with recent forest development in this area is that with current forest harvesting and road drainage practices and the mostly well-drained coarse textured soils found in the region, these effects are relatively small compared to the effect of canopy removal. However poor construction and drainage control on roads can lead to landslides on steep stream escarpments that can introduce excess sediment to streams.

Clearcut harvesting results in complete canopy removal and leads to the maximum hydrological effects mentioned above. In the nival (snow-melt dominated) watersheds of the southern interior, such as Mission Creek, these effects are caused primarily by the accumulation of higher snow packs (expressed as snow water equivalent, SWE) in clearcuts than in forests, and increased melt or ablation rates in clear cuts relative to forests.

There is a large volume of literature concerning the hydrological effects of clear-cutting, in which the extent of forest canopy removal or disturbance is often expressed as the Equivalent Clearcut Area (ECA); where a clear-cut initially has an ECA of 100%, a mature forest has an ECA of zero, and a regenerating forest has an ECA somewhere in between, that is proportional to tree height and stocking (Anonymous, 1999). A watershed ECA value is calculated by combining the ECA's for various treatment and unharvested areas throughout the watershed.

Our experience with analyzing hydrological impacts to watersheds using the ECA concept is that because of the many simplifying assumptions necessary, there is always a large degree of uncertainty regarding the final result, and it is not meaningful to apply watershed ECA results with an accuracy of greater  $\pm 5\%$ . In this report, when discussing the implications of ECA results they are generally rounded to the nearest 5%.

### **2.2.2 MPB and ECA**

In this study we model watershed ECA using the Huggard method (Huggard and Lewis 2008, Lewis and Huggard 2010), which incorporates recent research findings on snow accumulation and melt effects of different forest canopy conditions in MPB attacked stands. This includes modelling the canopy effects of the dead pine, the non-pine overstory and understory seedlings,

saplings and poles. Research throughout BC to quantify the hydrologic function of dead pine trees and secondary structure in pine-leading (>40% pine) MPB infested stands clearly demonstrates the important hydrologic function of unharvested MPB attacked stands, and supports the contention that these effects must be considered when evaluating the potential hydrologic risks associated with MPB related stand mortality relative to salvage logging (Winkler and Boon 2009, Rex et al. 2009, Boon 2008, Redding et al., 2008a, Redding et al. 2008b, Winkler, et al. 2008 and FPB, 2007).

The stand structure data used in modelling Mission Creek ECA was collected in 245 random plots in 30 accessible stands in seven South Okanagan watersheds<sup>1</sup> near Mission Creek, with similar biogeoclimatic (BEC) stand types as Mission Creek, and includes 16 plots taken in Mission Creek watershed. Appendix B, “Summary of Results from South Okanagan Stand Surveys for MPB-ECA Modeling” (Huggard, 2009) presents a summary of those field findings for secondary structure in high elevation BEC zones in this area, and compares those findings with similar secondary stand structure surveys taken elsewhere in the province. Where required this data was supplemented with secondary structure stand data from the North Okanagan and Thompson regions (Vyse et al. 2007), which showed similar results.

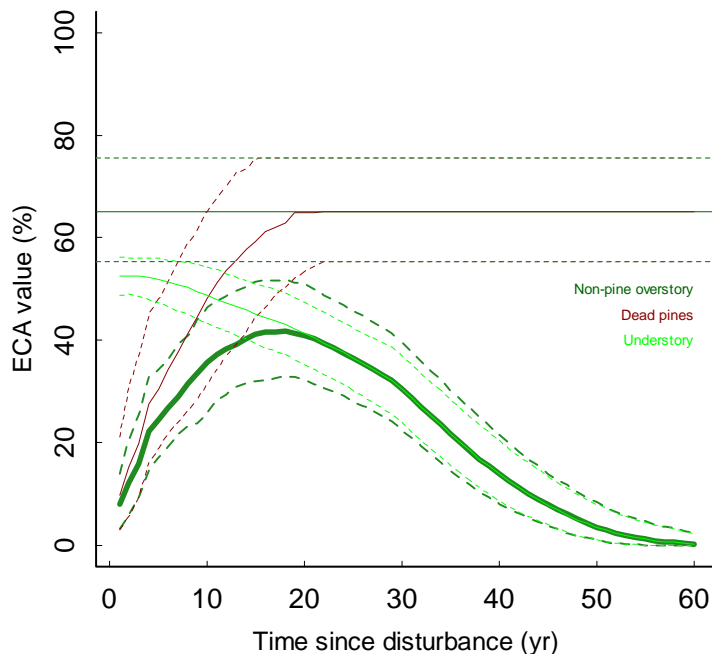
Huggard and Lewis (2008) found the ECA effects of the dead pine trees in a pure pine stand can initially contribute up to 60% ECA reduction in the grey-attack phase. ECA gradually increases over time as dead trees in the pine stand fall to the ground. The ECA of non-pine overstory is considered directly proportional to the percentage of mature non-pine trees in the stand, which is presumed to remain constant over the time period analysed; and which varies greatly between forest types (BEC variants). The understory components affecting ECA include existing poles, saplings and seedlings, and new seedlings, assuming a regeneration delay of 20 years before full stocking. As the understory grows over time, stand ECA is gradually reduced. The change in ECA contribution over time from these three factors is combined into a single curve representing the cumulative growth and/or decay of ECA of the dead pine stand over time. This was done for various BEC variants, percentages of pine in the stand, site productivity indices and other variables. Figure 3 is an ECA progression curve for an unharvested MPB attacked stand, showing the contribution of the three ECA reduction factors (dead pine, non-pine overstory and understory) and the cumulative ECA curve over a 60 year recovery period.

In Figure 3, and in all modelling of unharvested MPB-attacked pine-leading stands, 100% mortality of pine trees in the stand is assumed. However, recent research suggests that in the Okanagan Timber Supply Area the amount of pine mortality after the MPB infestation has largely subsided in 2019 will be about 68%; albeit with a substantial degree of uncertainty around that projection (Walton, 2009). If this turns out to be true, there will be 32% of pine trees left alive that will continue to have a hydrologic function. The distribution of mortality and survival in differing stand types is not known. A sensitivity analysis of watershed ECA with less than total pine mortality was carried out (see Section 3.2.1). Because of the significant uncertainty with the Walton (2009) estimates, stand and watershed analyses shown in this report assume total pine mortality. It should be kept in mind that these analyses may overstate the ECA effect of unharvested MPB attack, and underestimate the difference between

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1. The seven watersheds are Trout, Peachland, Trepanier, Lambly, Mission, Hydraulic and Penticton Creeks.

retention of actual attacked pine stands and salvage harvesting, if pine mortality turns out to be significantly less than 100%.

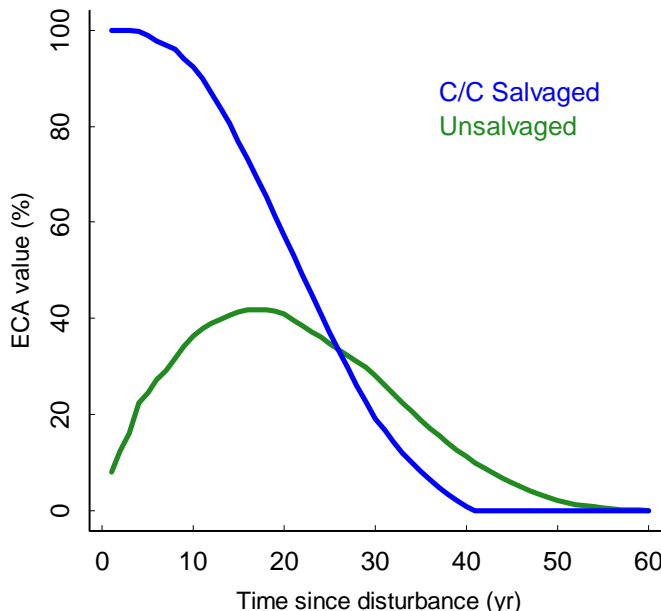


**Figure 3.** ECA projection (heavy green line) for unsalvaged older Montane Spruce BEC variant (MSdm, >110yr) showing the contributions over time of non-pine canopy (black line, showing a constant 35% ECA reduction over time) the dead pine (red line, showing decreasing ECA reduction as dead pines fall down over about 20 years) and understory (light green line). Dashed lines are 95% confidence intervals.

Huggard and Lewis (2008) also conducted sensitivity analyses on many of the critical input parameters, including percent mortality of natural understory, understory species composition, TIPSYP vs. VDYP regrowth modeling, different regeneration stocking delays, and other modeling components/assumptions. Generally the salvage vs. non-salvage ECA curves were found to be most sensitive to the percentage of non-pine overstory, as shown in Figure 3.

It should be noted that the solid lines in Figure 3 are average values of the many different individual site conditions one would encounter in actual stands throughout a particular BEC variant.

ECA curves for clearcut harvested attacked stands were also developed, based on expected regrowth rates of planted stands. Figure 4 shows a comparison of the unharvested and harvested ECA progression over time, for the same stand type shown in Figure 3. Similar curves were developed for all major BEC zones or subzones in the hydrologically important upper portion of the watershed. To arrive at a watershed ECA the cumulative effect of the different ECA progressions in different BEC zones in the watershed is calculated.



**Figure 4.** ECA projections for unsalvaged and clearcut salvaged and planted older MSdm, showing that ECA for unharvested MPB attacked stands never rises above about 40%. There is a 20 to 25 year period where the clearcut salvaged and replanted stand has a significantly higher ECA than the unharvested stand, after which the planted stand recovers slightly ahead of the unharvested stand.

It should be stressed that ECA hazard value alone is not necessarily a good indicator of potential watershed hazards. Each watershed and stream channel will respond differently to changes in forest canopy that ECA values represent, depending on watershed and channel characteristics, as discussed below.

### 2.3 WATERSHED AND CHANNEL SENSITIVITY

Where ECA levels are high, increased runoff is routed down slopes and is collected by channel systems, accumulating flows downward through the watershed. How or whether stand level changes translate into downstream watershed level impacts depends upon the physical attributes of the watershed and channels.

Drainage basin factors that affect runoff sensitivity include steepness, soil drainage properties, drainage density, soil depth (or proximity to an impervious layer), and natural storage (e.g. lakes, wetlands). Some of these characteristics are clearly interrelated; for example a steep basin with poor soil drainage usually has a higher drainage density. Storage features such as lakes and wetlands (either on the channel or floodplain) can attenuate peak flows and lessen the impact of an increased flow regime. As shown in Figure 2 the extent of forest cover disturbance (denoted by ECA) is combined with drainage basin properties and sediment conditions to give a Peak Flow Hazard. Qualitative basin drainage characteristics were assessed for this project using orthophoto/contour maps, field observations and previously published reports.

Channel response to changes in flow regime depends on natural channel attributes, which are a reflection of grade, flow regime and the materials (soil and vegetation) that the channel passes through. Channels respond to increased flows by increasing their capacity, typically by widening through bank erosion (Church, 1993). Channels passing through coarser, erosion resistant materials will respond more slowly to flow regime change, taking decades or more to adjust. Conversely, channels with easily erodible banks will respond rapidly to increases in peak flows.

Channel sensitivities are described in response to increased peak flow/flood frequency, increased sediment delivery and decreased riparian function, and channel change can result from any one of or a combination of these stressors. Increased sediment loading to channels from natural and forestry-related landslides can exceed the carrying capacity of the stream, upsetting the natural equilibrium of the channel. Increased peak flow can result from loss of canopy closure and rapid routing of runoff through the system. This in turn can lead to increased transport of channel sediment, increased bank erosion and widening of the channel to accommodate extra sediment entering a reach. Erosion along the toe of steep banks and valley walls may also lead to increased landslide activity, compounding the sediment increase. Increased peak flows, sediment generation and sediment transport are closely related. The combination of increased peak flows in an erodible channel with high banks can lead to rapid deterioration of channel stability and water quality.

Loss of riparian cover due to MPB is not considered a major issue as the component of pine in wetter riparian zones tends to be less than elsewhere across the landscape. Wei et al, (2007) found similar large woody debris (LWD) input rates in the Okanagan for MPB-attacked and non-attacked stands. Hassan (2008) investigated sites in central BC and concluded that MPB infestation-related wood transfer to the channel in the next 25 years is likely to be relatively small and within the range of typical conditions found in the region. Therefore, in Mission Creek, MPB-related short term increases and long term decreases in LWD recruitment are not expected to be major or to have a significant effect on channel stability and/or fish habitat. If stream riparian zones are included in clearcut areas during timber salvage operations, this loss of riparian vegetation could lead to loss of LWD recruitment, channel stability, stream nutrient and stream temperature issues.

Channel sensitivities were interpreted according to the framework presented in Table C-1 (Appendix C, from Green, 2005) based on field observations, airphoto and map reviews, and observations and conclusions from previously completed channel assessments. Earlier assessments were typically aimed at documenting levels of disturbance in channels. These previously recorded indicators of channel disturbance were interpreted in this assessment as indicators of channel sensitivity or 'robustness'. Where no disturbance was recorded, channel sensitivity was derived from observations of channel type and other morphological features. Channel sensitivities vary along the length of the stream. For the purposes of this assessment, sensitivities were assigned by sub-basin, based on the relative extent and location of sensitive reaches within that sub-basin.

Once channel sensitivity has been determined, it is combined with the Peak Flow Hazard to give a Hydrologic Hazard for the drainage area (Figure 2). The Hydrologic Hazard therefore includes forest cover ECA effects, sub-basin drainage characteristics and channel sensitivity

rolled up into a single hazard reflecting the potential for channel change, and is an expression of expectations regarding peak flows and sediment delivery at the drainage outlet.

## **2.4 ELEMENTS AT RISK**

Watershed elements potentially at risk from the hydrological effects of MPB infestation and salvage harvesting are:

- Water quality and water intake infrastructure, primarily at the BMID water intake.
- Water supply (quantity) at the BMID intake.
- Fish populations and habitat
- Social infrastructure (infrastructure not related to municipal water supply)

### **2.4.1 Water quality and water intake infrastructure**

The water quality element at risk can be expressed as “a sufficient and reliable supply of safe and aesthetically acceptable water” (MoH, 2005), at the Black Mountain Irrigation District (BMID) intake on Mission Creek. As well, potential damage and increased maintenance costs to the BMID intake are considered.

Table 1 shows the various parameters identified by Ministry of Health (MoH) and Ministry of Environment (MoE) stakeholders that, if compromised, could reduce drinking water aesthetic appeal, increase the risk of microbiological activity and impact on human health, and decrease the effectiveness of primary disinfection treatment.

The potential link to MPB and/or salvage effects is evaluated for each parameter, which is judged to be weakly linked, moderately linked, or strongly linked; and the rationale is provided as follows.

**Table 1.** Water quality and water supply infrastructure parameters, Mission Creek

Element at Risk	Effects of Concern	Specific Parameter	Metric	Parameter or Watershed Sensitivity
Drinking Water Quality	Reduced aesthetic appeal and increased risk of microbiological activity. Decreased effectiveness of primary disinfection treatment	FINE SEDIMENT (Turbidity)	NTU	In Mission Creek source waters, turbidity (fine sediment) is characterized as being elevated during the freshet period (April-July) and low during the clear flow period. Watershed is somewhat sensitive to disturbances that will increase fine sediment concentrations in source waters.
		FINE SEDIMENT (Total Suspended Solids)	concentration, mg/L	
		Temperature	°C	Loss of riparian forest shade can result in increased stream temperatures. MPB effects are limited because there is little or no pine in riparian areas. Salvage will remove forest shade if riparian zone is harvested. Salvage harvesting effects will be limited if good long term riparian retention practices are followed.
	Reduced aesthetic appeal and human health effects	True Colour	True Colour Units	Little published evidence to link changes in these water quality parameters to MPB infestation or salvage harvesting
		Total Organic Carbon	concentration, mg/L	
		Metals (select)	concentration, mg/L	
	Total Phosphorous	concentration, mg/L		
	Reduced aesthetic appeal and increased risk of microbiological activity	Nitrate & Nitrite	concentration, mg/L	Difficult to generalize effects on nitrogen cycle due to complexity. However, increased concentrations of dissolved inorganic nitrogen (nitrates and ammonium) are typical. Mission Creek measured nitrogen levels are low.
		Aquatic Flora (algae)	mg per m <sup>2</sup>	Difficult to generalize due to complex interaction between canopy closure, stream temperature, nutrient concentrations, and sedimentation. However, net effect is expected to be an increase in primary production.
	Human health (waterborne pathogens)	Microbiological Indicators	Fecal coliform, E. Coli bacteria	MPB infestation and salvage harvesting could have an indirect effect on microbiological indicators associated if there are changes in range use and recreational activities associated with salvage harvesting access. Microbiol levels in Mission Creek are seasonally (May to October) elevated.
Water Supply Infrastructure	Treatment infrastructure damage	COARSE SEDIMENT	cubic metres	In Mission Creek sediment is mobilized from bank erosion and aggraded channel, so any sediment mobilized can be transferred downstream to intake and other values. Watershed is sensitive to disturbances that will increase coarse sediment production and/or mobilization.

	Parameter not strongly linked to MPB effects, or lack of data to infer trends
	Parameter with some link to MPB effects; can infer potential trends
	Parameter linked to MPB effects; partial risk analysis completed

### **Parameters weakly linked to MPB and salvage harvest effects**

For True Colour, total organic carbon, metals, and total phosphorus there is no published evidence to link changes water quality to MPB infestation and mortality. In general, these parameters are watershed specific and are dependant upon the physical watershed characteristics (i.e. presence of wetlands, organic soils, geological and mineralogical conditions) as opposed to watershed process. Total phosphorous levels, where they might be linked to other potentially-harmful algae conditions in the watersheds, are unknown and the link to MPB and/or salvage effects is potentially complex and unknown.

There is generally a lack of data upon which to infer trends and since these parameters are weakly linked to MPB and salvage-related processes, especially if riparian management is adequate, they are not considered further in this study.

### **Parameters with some link to MPB and salvage harvest effects**

The following parameters are considered to be moderately linked to MPB and/or salvage harvesting effects. There may be some information on particular levels in Mission Creek so that potential post-MPB and salvage trends may be inferred, although not with a high degree of certainty:

#### **Temperature**

Water quality monitoring on Mission Creek between 1996 and 1999 indicate that summer temperatures in Mission Creek are quite high and that the optimal temperature range for rainbow trout eggs is exceeded (MoE, 2008). The aesthetic drinking water guideline was also consistently exceeded during July and August of all years.

Although the loss of riparian forest shade can result in increased stream temperatures, as discussed in Section 2.3, loss of riparian cover due to MPB is not considered a major issue as the component of pine in wetter riparian zones tends to be less than elsewhere across the landscape.

The potential temperature effects of salvage harvesting will depend on appropriate riparian management strategies. Our understanding is licensees intend to maintain reserve zones and management zones along all major streams. Small headwater streams in cut blocks may still be vulnerable to temperature effects, depending on stand composition and riparian management.

#### **Nitrate/Nitrite**

Limited source water monitoring from 1997 to 1999 found nitrate / nitrite concentrations in Mission Creek were below guidelines established for the protection of drinking water and aquatic life in surface waters (MoE, 2008). Water quality objectives for ammonia-nitrogen and nitrite-nitrogen were previously established in Mission Creek due to concerns about cattle waste entering the creek (Swain 1990).

Following both MPB and salvage harvesting increased concentrations of dissolved inorganic nitrogen (nitrates and ammonium) could occur. While elevated stream water nitrate concentrations have been measured following MPB infestation, levels did not exceed drinking water standards (Stednick, 2007). The complexity and interactions of the terrestrial and aquatic nitrogen cycle makes it difficult to predict MPB infestation or salvage harvest effects with any

degree of certainty; however, it is expected any change in nitrite/nitrate concentrations will be small and will not result in any significant increase above drinking water source standards.

### **Aquatic Flora (Algae)**

MPB and salvage harvesting can affect the interrelated processes which can influence the abundance of algae in lakes and streams. These include changes in riparian canopy, stream temperature, nutrient (including phosphorous) concentration, and sedimentation rates. However, the complex interaction of these processes makes it difficult to predict how forest cover changes could affect algae growth in the watershed.

Neither chlorophyll *a*, nor periphytic algae, were measured as part of the 1996-1999 Mission Creek water quality monitoring program. However, total phosphorus concentrations were elevated at the BMID intake (MoE, 2008). Although there are no criteria for total phosphorous in streams, the elevated values suggest that this may be a parameter of interest for lakes within the watershed. Monitoring watershed reservoirs for blue-green algae blooms is recommended, as this algae can form neurotoxins that have been linked to Alzheimer's disease (Aqua Consulting Inc., 2008).

### **Microbiological Indicators**

Elevated concentrations of fecal coliform and *E. coli* at the municipal intake on Mission Creek occur between May and September and most frequently during July-August; a time of year when livestock grazing on Crown range land seek out shade and water in riparian areas (MoE, 2008). The monitoring results suggest that elevated concentrations of microbiological indicators are common in Mission Creek.

MPB infestation and salvage harvesting are not expected to have a significant direct effect on fecal coliform and *E. Coli* levels in Mission Creek. However, changes in access due to a larger forest road network associated with salvage harvesting could have an indirect effect. For example, inadequate sanitary waste management by recreational users and the presence of livestock in stream channels or riparian corridors could contribute to elevated levels of coliform bacteria. Since activities are typically dispersed throughout the watershed and soils act as an effective filtration medium, water contamination may be mitigated through the use of suitable riparian buffers.

Given the fairly widespread road access that exists in the watershed, any increase in fecal coliform and *E. Coli* levels in Mission Creek due to MPB and salvage is expected to be small. However, it will be cumulative with measured existing elevated levels.

### **Parameters strongly linked to MPB and salvage harvest effects**

The water quality parameters most-strongly linked to MPB infestation and/or salvage harvesting are changes in fine and coarse sediment production. Increased sediment production and transport to the BMID water intake is a concern, because the changes in forest canopy affected by MPB and salvage can be similar to the effects of forest harvesting; namely, changes in riparian vegetation, increased magnitude and frequency of peak flows (floods), and sediment production from landslides, surface erosion and stream channel bank and bed sediment mobilization.

### **Fine Sediment**

Increased fine sediment production and transport to the water intake is a concern, because suspended sediment concentrations, measured as turbidity and total suspended sediment (or non-filterable residue) can act as a vector for pathogens that can affect human health, decrease primary disinfection treatment effectiveness, and decrease the aesthetic quality of water, placing additional stress on water treatment facilities.

High turbidity levels are a concern in Mission Creek during high flow periods of April to July. Water quality monitoring between 1996 and 1999 indicates that water quality guidelines for the protection of drinking water and aquatic life are being exceeded during this period (MoE, 2008). Mean monthly turbidity measured at the intake between May and December, 1999 range from 1 NTU in October to 52 NTU in June. BMID (2009) reports average turbidity values in the spring freshet period of 18NTU and a maximum of 270 NTU. The watershed is considered sensitive to disturbances which will increase fine sediment concentrations in Mission Creek at the BMID intake.

### **Coarse Sediment**

Coarse sediment production, measured as bed load, can disrupt or damage water intake infrastructure. We are not aware of any bed load measurements in Mission Creek near the BMID intake. As discussed in Section 2.3, sediment is generated from landslide deposits, bank erosion and the aggraded Mission Creek mainstem channel bed during high flows. That is, any sediment mobilized is already in the channel and can be transported downstream, eventually to the community water intake and other values. Therefore, the watershed is considered sensitive to disturbances that will increase coarse sediment production.

### **Water Quality Risk Analysis Procedure**

A complete risk analysis would consider not only the stream flow and sediment hazards, but also how vulnerable the entire water delivery system could be to sediment impacts, by looking at all the water supply system protection barriers from source to tap, including intake configuration, treatment processes, storage and distribution components, system maintenance, water quality monitoring, operator training, and emergency response planning.

Interior Health Authority B.C. requested we do not evaluate the robustness or vulnerability of the BMID water intake or treatment facilities; rather that we look only at any incremental hazards due to MPB and salvage harvesting that could affect source water quality, supply and infrastructure integrity (Dale Thomas, *pers. comm.*).

Studies that determine potential hazards and identify the elements at risk from those hazards, but do not evaluate their vulnerability are known as partial risk analyses (Wise, *et al.*, 2004). In this analysis the partial risk will be equal to the MPB-related hazardous conditions that could compromise water quality at the BMID intake, which are discussed in Section 3 of this report.

### **2.4.2 Water Supply**

In the South Okanagan risks to water supplies come from changes in climate and watershed conditions that could compromise the ability to meet agricultural and domestic demands during the growing season, when there are large natural moisture deficits. MPB attacked stands lose some canopy function, or are salvage clearcut harvested, in which case 100% of the canopy is

removed. Therefore snowmelt accumulation and melt effects similar to harvesting are expected in MPB and salvaged stands. These can include changes in low flow discharge and in freshet runoff timing, which can affect reservoir drawdown. It is well known from studies of the effects of clearcutting in nival (snowmelt dominated) watersheds of Interior B.C. that a reduction in forest canopy can lead to earlier freshet snowmelt. If the receding limb of the annual hydrograph occurs earlier, this can lead to water users having to access reservoir storage water at an earlier date and therefore for a longer period of time, which can increase the risk of depleting storage before the end of the growing season.

### **2.4.3 Fish**

Sport-fish species within the watershed include Brook Trout (*Salvelinus fontinalis*), and Rainbow trout (*Oncorhynchus mykiss*) in the headwater tributaries and lakes. Kokanee (*Oncorhynchus nerka*) and Mountain Whitefish (*Prosopium williamsoni*) have been identified in the lower reach of Mission Creek.

From a review of available published fish inventories and habitat assessments, stream reaches were assigned a consequence rating based on fish species presence, importance and fish habitat quality (Table 2). Where fisheries information was not available, species presence and habitat quality have been inferred based on stream character, gradient, habitat potential and the presence of known fish habitat upstream (e.g. headwater lakes).

**Table 2.** Stream reach fish consequence value criteria

Consequence Rating	Criteria			
	Fish Species Present	Channel Width (m)	Channel Gradient (%)	Habitat Quality
<b>Very Low</b>	fish absence	<1.5	>20%	fish absence confirmed, minimal fish habitat available, habitat degradation low risk to fish
<b>Low</b>	presence of RB	0-5	16% - 19%	fish absence confirmed and/or habitat with low rearing potential for the fish species present
<b>Moderate</b>	presence of RB, EB	0-5	8% to 15%	habitat quality low to moderate
<b>High</b>	presence of RB, EB, MW	0-20	0% to 8%	fish presence confirmed, habitat quality moderate to high
<b>Very High</b>	presence of RB, EB, BT, KO, MW	0-20	0% to 8%	fish presence confirmed, habitat quality high

Impacts to fish and fish habitat following changes in forest cover due to MPB and salvage harvesting are likely to be similar to forest harvesting effects. As discussed in Section 2.3 significant loss of riparian vegetation due to MPB is not expected. Salvage harvest of riparian vegetation can affect fish shelter, stream temperature, nutrient availability and large woody debris recruitment to streams. Increased peak flows and sediment can alter channel morphology, resulting in degraded spawning, rearing and over-wintering habitat. For each Mission Creek and tributary reach, hydrologic hazards (see Section 3) are combined with the consequence values for each reach (see Appendix C), and for cumulative downstream reaches, using a standard risk matrix (Appendix A).

From a fish conservation perspective Mission Creek is considered sensitive to watershed disturbances that could reduce summer low flows. The potential for low flow regime changes following MPB or salvage harvesting is discussed in Section 3.3.3.

#### 2.4.4 Social Infrastructure

Social infrastructure refers to structures other than the BMID water supply infrastructure. On Mission Creek alone, there are 157 water licenses listed with the Ministry of Environment (MoE). In addition to water quality concerns, infrastructure at these other private intakes is likely sensitive to changes in flow and/or sediment regimes.

Highway 33 crosses Mission Creek just upstream of its confluence with Joe Rich Creek. The Highway also crosses Belgo and Daves Creek. Within the Mission Creek watershed, smaller roads have been constructed to access forest and other resources. No forestry road crossings of the Mission Creek mainstem exist, however, numerous bridge and culvert crossings over tributaries have been installed. Depending on original design allowances, and current structural condition, these crossings may be sensitive to increased flow, sediment load and debris movement.

The City of Kelowna has developed on a paraglacial fan at the mouth of Mission Creek. Over the years, the City has tried to control the channel location through dredging and dyking projects. Alluvial fans are by nature depositional, and constructed channels isolated from floodplains have design limits, hence this area will also be sensitive to increased sediment and/or peak flows.

For each of the elements present, a qualitative vulnerability or consequence rating was determined. This was combined with the hydrologic hazard in a risk matrix (Appendix A) to determine the qualitative incremental risk from increased flooding and sediment movement due to MPB and salvage logging.

## **3.0 WATERSHED CONDITIONS AND HAZARDS**

### **3.1 WATERSHED CONDITION**

#### **3.1.1 Physiography, geology and terrain**

The Mission Creek Community watershed drains portions of the Thompson Plateau into Okanagan Lake on the east side of the valley. Mission Creek passes through the City of Kelowna, BC. The watershed encompasses an area of approximately 860 km<sup>2</sup> ranging in elevation from 342m at Okanagan Lake to a maximum of 2135m at the summit of Jubilee Mountain. Major tributaries to Mission Creek are K.L.O. Creek, Hydraulic Creek, Daves Creek, Belgo Creek, Joe Rich Creek, Pearson Creek, Stanley Creek, and Fish Hawk Creek. Both K.L.O and Hydraulic Creek are separate community watersheds and were not considered in this analysis as they join Mission Creek downstream of the main BMID intake. Other sub-basins and some of their characteristics are listed in Table 3.

Most of Mission Creek watershed is underlain by relatively coarse grained Paleozoic and Proterozoic gneiss and schist (IMAP, 2008). The highlands in Upper Mission sub-basin are largely underlain by Mesozoic granitic intrusive rocks. These coarse grained rocks commonly weather to sandy soils with abundant coarse fragments. There are medium grained Tertiary basalt volcanic rocks underlying the south and east slopes and ridges of Hydraulic, Joe Rich and Pearson Creeks; and in smaller pockets underling ridge tops throughout the watershed. Fine grained shale, mudstone and siltstone sedimentary rocks underlie Lower Mission Creek near Okanagan Lake.

Surficial geology on upland plateaus is comprised of widespread till veneers (<1.0m thick) and blankets (>1.0m thick), except where bedrock is exposed on ridges and steeper valley sidewalls. (Paradis, 2009).

Valley bottoms of Mid to Lower Mission Creek, Belgo Creek, Daves Creek and lower Joe Rich Creeks are erodible sand and gravel fluvial and glaciofluvial deposits forming floodplains, terraces, benches and fans.

**Table 3.** Mission Creek Watershed and sub-basin areas

Sub-basin Name	Sub-basin Area (ha)	Total Tributary Area (ha)	Elevation Range (m)	Reservoirs (acre-ft, elevation)
Upper Mission	6043	6043	1524-2100	Graystoke (4133, 1800m) Fish Hawk Lake (1845, 1808m) Loch Long (507, 1850m) Mission Lake ( <b>uncontrolled</b> , 1853m)
Pearson	7212	7212	920-1920	Loch Lost (uncontrolled)
Joe Rich	4537	4537	800-1600	
Mid-Mission (Residual)	14672	32465	800-1700	
Upper Belgo	4307	4307	1390-1680	Ideal Lake (5537, 1300m)
Lower Belgo (Residual)	13655	17963	800-1800	
Daves Creek	3388	3388	640-1500	Upper Pond Off-channel above Daves (4.6 ha, 650m)
Lower Mission Residual – BMID Intake	6661	60476	700-1500	Lower Pond Off-channel below Daves (2.4 ha, 640m)
Mission Creek (below intake)			460-640	
Fan (below intake)			350-460	

Mission Lake forms the headwaters of Mission Creek at about 1858m elevation in Upper Mission sub-basin near Jubilee Mountain. The outlet is controlled and the lake is managed as a BMID reservoir. Fish Hawk Lake and Graystoke Lakes on the high plateau in Mission Creek sub-basin are also managed as BMID reservoirs. Ideal Lake near the headwaters of Belgo Creek is the largest BMID reservoir (Table 3). Numerous other smaller uncontrolled lakes and wetlands on the plateau drain into Mission Creek. The storage provided by these uncontrolled waterbodies may still help to sustain late season flows in Mission Creek.

The plateau area of the Mission Creek watershed is dominated by rolling, flat (<7%) to gentle (7 to 30%) sloping glaciated terrain (Photo 1). Upland plateau tributaries are generally weakly incised. It is apparent on mapping and aerial photography that the drainage pattern on the plateau trend in a north/south direction, an apparent artefact of historic glaciation in the region. Although the drainage density on the plateau is relatively high, slow routing of runoff through the complex system of low gradient channels, lakes and wetlands can be expected. Most of the

upper plateau area in Mission Creek is currently protected from harvesting by Graystoke Provincial Park.

Fish Hawk Creek, Stanley Creek and upper Mission Creek drop steeply off the plateau and join to form the Mission Creek mainstem following a well-defined, incised valley, approximately 150 to 200m below the plateau elevation. Along lower Fish Hawk Creeks and about 5km of upper Mission Creek below the Fish Hawk confluence (approximately Reach 7, Figure 1) a study, which included mostly unharvested or roaded terrain, identified 95 active and inactive landslides (Westrek, 2000). Based on site visits and a review of 1939 to 1997 air photos, Westrek (2000) concluded that ninety-seven percent of landslides in this limited area were natural occurrences and 75% of terrain disturbance occurred in unlogged portions of the watershed. All landslides in this area occurred in silty sand or sandy silt till, and almost all deposited sediment directly into Fish Hawk Creek or upper Mission Creek mainstems.

Lower Fish Hawk Creek has been subject to a major debris flood/flow sometime between 1965 and 1969 (prior to the construction of an earth-filled dam on Fish Hawk Lake in 1971[Westrek 2000]), with numerous gully sideslope failures (Photo 2), which have delivered significant sediment to upper Mission Creek. The large volume of sediment deposited in Mission Creek from Fish Hawk Creek is expected to be working its way downstream, causing widening and increased bank erosion, undercutting and increased landslides in the already sensitive upper Mission Creek (Photo 3). During the 1997 freshet the second largest peak flow on record occurred, and initiated a large, 250m wide, debris slump (Photo 4) which reportedly diverted or possibly dammed Mission Creek (Dobson 1998).

These very active landslide and bank erosion reaches of Fish Hawk Creek and upper Mission Creek below Fish Hawk Creek have and will continue to supply excess sediment to Mission Creek mainstem. Westrek (2000) concluded, and we concur, that in the lower Fish Hawk / Mission Creek confluence area, future landslide and erosion events were likely, which would continue to supply excess sediment to the channel. They also concluded that increased peak flows could increase the landslide activity and rates of erosion through undercutting of stream banks.

Lower in mid-Mission sub-basin, valley slopes and ridges on both sides of the creek have been extensively harvested during a previous MPB outbreak in the 1980's, with mixed riparian management practices (Photos 5 and 6). Where Mission Creek flows through salvage harvested area upstream of Pearson Creek confluence, Westrek (2000) noted 10 forest road-related landslides in the Mission Creek. Many of these impacted the creek directly, and were not present on pre-logging photographs. Westrek suggests that these could be related to redirection of surface drainage from road ditches, surfaces and cross-ditches onto open slopes that have not previously experienced such flows. Gooding (1998) notes that private land logging of riparian area up to stream banks along Mission Creek above and below the Pearson Creek confluence had weakened banks, with serious bank erosion and stream widening occurring in the 1997 flooding.

There is a large rock slump, presumably in Tertiary Volcanic rocks, on the right hand side of Mission Creek in upper Reach 6. These features are well known in this rock type throughout Southern Interior B.C. (Evans, 1983). From the fresh, unvegetated appearance of the slide

surface, movement may have occurred relatively recently, within the last several hundred years. Ravelling of coarse angular rubble from the toe of the slide approaches Mission Creek, but does not appear to have directly impacted it, or altered its course.

Starting in Reach 6, and continuing downstream through Reach 1 to Okanagan Lake (Figure 1), Mission Creek flows through erodible sand and gravel fluvial, glaciofluvial and glacial outwash deposits, which form floodplains, terraces, benches and fans (Paradis, 2009). For approximately 50km Mission Creek is bounded by generally unconsolidated and erodible sediments. There are numerous occurrences of the Mission Creek mainstem actively eroding and undercutting these thick loose sand, gravel and cobble deposits (Photos 7 and 8). Gooding (1998) observed increased bank erosion as a result of private land clearing and logging at a number of locations along Mission Creek, downstream to the confluence of Joe Rich Creek (Figure 1).

Southwest of Upper Mission Creek, Pearson Creek drains a similar flat to gently sloping upland plateau area, including several small lakes and wetlands. The Pearson Creek valley becomes more defined and incised below about 1600m elevation, towards its confluence with Mission Creek at about 920m elevation. There has been some upland harvesting and both Gooding (1998) and Westrek (2000) note some natural and forest development-related landslides in lower Pearson Creek, but conclude it is much less active than upper Mission Creek. The main channel of Pearson Creek remains relatively undisturbed.

The Upper Belgo Creek sub-basin similarly drains gentle upland plateau areas to the west of Upper Mission Creek. Several tributaries converge in Ideal Lake, forming the headwaters of the Belgo Creek mainstem. At an elevation of about 1300m Ideal Lake is about 500m lower than the other BMID reservoirs in Upper Mission sub-basin. Downstream of Ideal Lake, Belgo Creek passes through a large cutblock (with riparian reserves), becoming increasingly incised as it drops to its confluence with Mission Creek at 800m elevation. A large landslide occurred approximately 3.3 km upstream of Mission Creek, on the moderately steep (50 to 70%) west valley wall of Belgo Creek, which is described as “inherently unstable” with a history of large landslides evident on air photos (BC Ministry of Forests, 1990). This slide occurred on June 12, 1990 and killed three people. It extends over 1500m and covers a land area of 17ha (5ha transport and 12 ha deposition zone [Photo 9]). A major redirection of water from small stream down a deactivated forest access road was determined to be a causative factor in initiating the large landslide (MoF, 1990). The runout zone does not appear to have made it as far as the Belgo Creek channel, but is nonetheless an indicator of the size and destructiveness of landslides that can be caused by road drainage diversions in this area. Through the lower reaches of Belgo Creek valley bottom riparian zones remains largely undisturbed.

Joe Rich Creek drains a small section of lower elevation plateau in the southeast corner of the watershed. The middle section of the creek (Reach 3) is incised and confined by steep valley walls, and in this section several landslides downslope of Highway 33 and the Big White Road contribute sediment to the creek. Further downstream (Reach 2) the creek flows across a broad, flat glacio-fluvial terrace cleared for agricultural use. Riparian vegetation has been almost entirely removed in this area, weakening stream banks which are eroding into the creek (Photo 10). The Regional District of Central Okanagan has undertaken some channel rehabilitation and revegetation works in this area in the past decade aimed at controlling bank

erosion and improving channel stability, but unvegetated banks continue to fail during high flows, introducing sediment to the channel.

In the mainstem Mission channel between Belgo Creek and the BMID intake (Reach 4), at least two major landslides have occurred contributing large amounts of sediment to the channel. A large rotational slump occurred below Highway 33 in the 1980's approximately 2 kilometres upstream of the BMID intake, and also reportedly blocked the mainstem channel (Dobson 1998). A second somewhat smaller failure is evident approximately 4.6 km upstream of the intake, and Mission Creek is actively eroding the toe of the slide (Photo 11). A high cutbank on the outside of a sharp bend approximately 3 kilometres upstream of the intake appears to be a chronic source of sediment.

Daves Creek drains a slightly lower area of the plateau west of Belgo Creek. Extensive harvesting has occurred in the upper basin, and ECA was reported to be 47% in 1998 (Dobson 1998). Daves Creek channel only becomes incised near the downstream end where it drops southward into the Mission Creek valley. There are several large landslides in layered glaciofluvial sediments below Highway 33 in lower Daves Creek (Photo 12) just upstream of its confluence with Mission Creek between the two settling/storage ponds at the BMID intake site. It is likely increased peak flows resulting from high harvest levels in the upper basin have increased bank erosion in the confined lower reaches of Daves Creek

Downstream of the K.L.O Creek confluence (Reach 2), Mission Creek passes through thick erodible unconsolidated sand and gravel fluvial terraces incised into deltaic deposits laid down during deglaciation when the level of Okanagan Lake was higher (proglacial Lake Pentiction) and/or dammed by ice. Nearer the mouth (Reach 1), the City of Kelowna is developed primarily on unconsolidated gravel, sand, silt and clay alluvial fan material deposited by Mission Creek once the lake dropped closer to current levels.

### **3.1.2 Channel conditions and bank stability**

Existing channel conditions in the Mission Creek watershed derived from field and office reviews are described in Table 4. Channel conditions are summarized by sub-basin. Listed channel morphology types represent the predominant morphology of the mainstem channel within that sub-basin (Hogan 1997). Although erosion, transport and deposition typically occur everywhere in a channel system, the sediment regime descriptor provided in Table 4 gives an indication of the dominant sediment process for the mainstem channel in the sub-basin, whether it is overall a source area, a transport or a depositional zone.

Channels on the plateau areas of Upper Mission, Upper Belgo (above Ideal Lake) are typically low gradient and poorly incised, passing through numerous lakes and wetlands. Bank stability and sediment input and transfer are of low concern in these areas. In upper Mission Creek, riparian vegetation is protected from development by Graystokes Park. The likelihood of discernible change at the BMID intake as a result of the disturbances in the plateau areas is very low.

Significant volumes of excess sediment have been introduced to lower reaches of Mission Creek from the numerous natural landslides and bank failures in the Fish Hawk / Mission confluence area, to a lesser extent from logging related sediment sources, and from widespread

natural bank erosion and localized bank weakening due to vegetation removal on private land. This sediment has caused increased channel aggradation, channel widening and increased bank erosion, in a positive feedback loop. The resulting channel aggradation is observed at least as far downstream as the Belgo Creek confluence.

The Fish Hawk Creek debris flood/flow introduced considerable sediment to the upper Mission Creek mainstem and the Mission Creek channel is widened for several hundred metres below the Fish Hawk confluence (Reach 7). Downstream toward the Pearson Creek confluence, the channel becomes increasingly depositional and widened with frequent bar deposits. This pattern continues at least as far as the Joe Rich confluence.

The mainstem channel through the remaining mid-Mission sub-basin (Reaches 5 and 6) has formed low amplitude, irregular to regular meanders along the valley bottom. Bedload from upstream reaches and from bank erosion of unconsolidated alluvial and glaciofluvial deposits have contributed and continue to contribute sediment to the channel. There appears to be minimal LWD function to control movement of sediment in the channel. Woody debris is frequently rafted into large log jams. Channel aggradation and widening are widespread (Photos 13, 14 and 15).

Pearson Creek also has its headwaters on the upper plateau with numerous lakes and wetlands. The mainstem channel descends steadily from the plateau, steepening and becoming more confined as it approaches Mission Creek. The channel is fairly active with high bedload and some areas of aggradation. Riparian vegetation remains undisturbed along most of Pearson Creek and a steady supply of instream LWD helps to stage sediment movement and improve channel resilience. Lower down, lag boulder and bedrock controls maintain channel stability. Active landslides were identified near the lower end of the sub-basin, (Gooding 2002). Pearson Creek passes through erodible glaciofluvial terrace sediments near its confluence with Mission Creek.

Belgo Creek downstream of Ideal Lake flows across a broad valley bottom comprised of glaciofluvial deposits and outwash terraces. The channel becomes aggraded and widened in areas where stream gradients are reduced. Some bank erosion was noted in areas of reduced riparian although riparian vegetation remains undisturbed for most of lower Belgo Creek. Deposits of cobble/gravel bedload from Belgo Creek were noted at confluence with Mission Creek.

In Joe Rich Creek excess sediments from landslides in Reach 3 are deposited in the lower gradient Reach 2, which flows on a flat lying glaciofluvial and fluvial sediments. Culverts at the Highway 33 crossing have plugged as a result of aggradation and infilling at their inlet.

Reach 2 of Joe Rich Creek has been highly impacted by agricultural activities including livestock access and riparian land clearing. Loss of riparian forests have resulted in weakened banks and decreased instream LWD, affecting channel stability. Extensive bank erosion, aggradation and widening have occurred through much of the reach. Aggradation has reduced surface flow, worsening low flow conditions in late summer. This has affected both fish habitat and the availability of water for irrigation. Channel restoration has been undertaken on some properties by the Regional District. This has included bank protection, the installation of

grade controls, riparian planting and livestock fencing – but the problem persist in other reaches (Photo 16).

In the mainstem Mission channel between Belgo Creek and the BMID intake (Reach 4), bars and channel widening are less prevalent and the channel is less aggraded and more stable than upstream in Reaches 5 to 7 (Photo 17). Several large landslides have introduced significant sediment to the channels, which are aggraded and widened downstream of them (Photo 18). Some widening and deposition have occurred along the channel in association with rafted debris piles.

Relatively stable banks along most of Daves Creek have sustained the channel despite extensive harvesting in upper basin, which has reduced riparian vegetation on many of the tributary channels in that area. Where the tributaries accumulate into the mainstem channel, a highly mobile gravel/cobble bedload may be an indicator of elevated or more frequent peak flows. Stable lag boulders and LWD help to control bedload movement in areas downstream. Occasional bedrock controls were noted as the channel becomes more incised toward Mission Creek. Large slope failures in thick glaciofluvial sediments below Highway 33 are directly contributing sediment to the channel a short distance from the BMID intake. Several potentially undersized stream crossings were noted on public roads and private driveways upstream of Highway 33.

Below the BMID intake (Reach 3), Mission Creek flows through alternating sections of bedrock controlled canyon and eroding glaciofluvial sediments with some bank failures and channel aggradation. Riparian vegetation becomes sparse due to drier climate, leaving little instream LWD to control sediment movement or provide cover for fish.

Through the urban development of Reaches 2 and 1, riprap bank protection has been installed on most outside bends. Most of the lower 10km of the stream have been fully channelized, including the construction of dykes adjacent to the channel (Photo 19). Sedimentation downstream of KLO Bridge has been a significant problem since at least 1967 (Burge 2009). Since 1990, sediment has been extracted three times from Mission Creek downstream of KLO Bridge. Lower Mission Creek has been subject to some fish habitat improvements over the past few decades. Recommendations under consideration for the mitigation of sedimentation and the restoration of fish habitat in Mission Creek include the setting back of dykes to form a broader floodplain with improved geomorphic and ecological function (Gaboury and Hawkes 2003).

Forest cover disturbances in the drainage areas below the BMID intake were not analysed in this assessment. However any increases in stream flows and sediment from upstream of the intake site will be passed on to the lower reaches. Potential impacts in this section are included in the discussion below.

**Table 4.** Channel Characteristics and Conditions

Sub-basin Name	Reaches	Mainstem Channel Length (km)	Average Gradient (m/m)	Dominant Morphology Type*	Sediment Regime	Sub-basin/Channel Characteristics
Upper Mission	8,9,10,11	8	0.04	CPc, RPg	Source	High plateau with numerous lakes, wetlands and low gradient channels. Four largest lakes controlled as reservoirs. Area protected by Graystoke Park. North/south trending historic glaciation affecting drainage pattern. Slow routing of runoff through complex drainage. Mainstem concentrates into more confined valley toward downstream end of sub-basin. Fish Hawk Creek has been subject to debris flood/flow. Stored sediment in aggraded channel.
Pearson	1,2,3	15.1	0.06	CPb/c, RPg	Source	Headwaters on high plateau with numerous lakes and wetlands. Mainstem channel descends steadily from the plateau, steepening and becoming more confined as it approaches Mission Creek. Active channel with sediment movement staged by LWD function through middle section. Boulder and bedrock controls in Reach 1. High bedload with some bank erosion and aggradation in lower gradient sections. Riparian has been historically high-graded but remains mostly intact. Recent landslides near lower end (Gooding 1998). Flows through glaciofluvial deposits near Mission Creek.
Joe Rich	1,2,3,4,5,6,7	15.9	0.05	CPc, RPg	Source	Upper reaches on plateau with wetlands and lakes. Reach 3 affected by landslides off Highway 33. Reach 2 passes over glaciofluvial outwash deposit. Reach 2 highly impacted by agricultural activities including livestock access and riparian land clearing. Instream LWD is lacking. Extensive bank erosion, aggradation and widening. Lower channel dewatered during low flow. Some channel restoration has been undertaken.
Mid-Mission (Residual)	5,6,7	26.2	0.03	RPc, CPc	Source	Some plateau area with small tributaries dropping steeply into incised valley. Main channel widened at top end with sediment from Fish Hawk Creek. Reaches 6 and 7 mostly confined with numerous natural high bank failures and landslides directly connected to the channel. A large failure temporarily blocked the channel in 1997. Mainstem channel throughout is mostly aggraded with sediment stored in frequent bars and widened sections. Minimal LWD function to control movement of sediment. Channel aggradation and widening have caused problems for landowners upstream of Joe Rich confluence.

Sub-basin Name	Reaches	Mainstem Channel Length (km)	Average Gradient (m/m)	Dominant Morphology Type*	Sediment Regime	Sub-basin/Channel Characteristics
Upper Belgo	5,6,7,8,9,10	5.4	0.02	RPg	Source	High plateau with numerous lakes, wetlands and low gradient channels. Ideal Lake large reservoir relative to upper basin. Small channels above the lake with some localized impacts associated with roads and riparian harvesting. Slow routing due to low gradient and complex system of lakes and wetlands.
Lower Belgo (Residual)	1,2,3,4	19.3	0.03	CPc, RPg	Source	Moderately sloping terrain with wide valley bottom comprised of glaciofluvial deposits and outwash terraces. Aggraded and widened sections where stream gradients are reduced. Deposits of cobble/gravel bedload at confluence with Mission Creek.
Daves Creek	1,2,3	10.2	0.08	CPc	Source	Extensive harvesting in upper basin. Mobile gravel/cobble bedload with stable lag boulders and LWD. Reduced riparian on upper basin tributaries. Several potentially undersized stream crossings noted. Slope failures associated with Highway 33 directly connected to channel. Several landslides in layered glaciofluvial sediments downstream of Highway 33. Occasional bedrock control in Reach 1.
Lower Mission (Residual)	3,4	10.7	0.01	RPc	Transport	Occasionally confined with some developed floodplain. Channel is generally aggraded with high cobble/gravel bedload. Sediment stored in mid-channel bars. Localized widening and bank erosion. Some sediment inputs from Joe Rich and Belgo Creeks. A large rotational slump occurred in the mid 1980s adjacent to Highway 33. The failure completely blocked the channel and a new channel was subsequently constructed around the toe.
Canyon (below intake)	2	8.4	.02	RPc/g	Transport	Alternating sections of aggraded channel and bedrock controlled canyons. Some raveling (scree) sediment inputs. Sparse riparian due to drier climate. Little LWD function.
Fan (below intake)	1	12.0	.01	RPg	Depositional	Outside bends riprapped and lower half fully channelized adjacent to residential development. Some evidence of deposition in wider sections. Gravel fan at outlet into Okanagan Lake. Fish habitat improvements (riffles) undertaken at some locations.

\*CP = cascade-pool; RP = riffle-pool; c=cobble, g=gravel, b=boulder

### 3.1.3 Channel sensitivity

Channel sensitivities for the Mission Creek watershed were derived from the observations of channel conditions described above and the assessment framework outlined in Table C1 Appendix C. Results are summarized in Table 5. Sensitivity to changes in peak flows, sediment regime and riparian condition are considered separately. Since changes in flow and sediment regime are considered the most likely impacts following MPB and salvage harvesting, a combined sensitivity rating to peak flow and sediment is assigned to each sub-basin. For the purposes of this assessment, assigned ratings generally represent the dominant sensitivity of the mainstem channel in a particular sub-basin. Potential outputs associated with potential channel changes are included in Table 5 to provide an indication of issues that may arise if changes to flow/sediment regimes were to occur.

Channel morphology was monitored in Mission Creek above Fish Hawk and Belgo Creeks between 1999 and 2002. During this brief period channels at those locations showed no change. However, these results are considered inconclusive as flood events during those years were all less than 5 year return period events, which is considered the minimum flood discharge that would be expected to cause significant channel changes (Dobson 2003). Changes during the same period at monitored sites in Belgo Creek were observed as log jams in the surveyed sections disintegrated and reformed. Fish Hawk, Mission above Pearson and Pearson Creek showed changes in morphology despite no significant flood events, suggesting systems are still adjusting from past events. Where channels have not recovered from previous sediment inputs, the areas will be highly sensitive to any additional changes to flow and/or sediment regimes related to MPB.

In this study, channel sensitivities for Mission Creek ranged from Low to High. Reaches with erodible banks and/or extensive stored in-channel sediments were considered most sensitive to increases in peak flows, which are likely to increase bank erosion and mobilize instream sediments. High sensitivity was assigned to most of the Mid-Mission Creek basin mainstem (Reaches 4 to 7), Joe Rich Creek and Daves Creek. Moderate ratings were given to Upper Mission sub-basin reaches (Reaches 8 to 10), Belgo Creek and Pearson Creek. Tributaries to Ideal Lake in upper Belgo were given a Low sensitivity due to the low energy conditions found on the plateau.

Below the intake, Mission Creek was assigned a Moderate sensitivity through Reaches 2 and 3 due to the likelihood of increased aggradation or remobilization of existing sediments, should flow and/or sediment regimes change. The channelized section of Mission Creek through the city of Kelowna (Reach 1) was considered highly sensitive due to the likelihood of increased sediment deposition from upstream sources ultimately reducing channel capacity.

**Table 5: Channel Sensitivity**

Sub-basin Name	To Increased Peak Flow	Comments/ Rationale	To Increased Sediment Delivery	Comments/ Rationale	To Decreased Riparian Function	Comments/ Rationale	Combined Channel Sensitivity	Potential Outputs Associated with Channel Change
Upper Mission	M	Mostly stable, low gradient channels with flood storage in wetlands. Debris flood in Fish Hawk Creek. Material stored in channel may be mobilized.	M	Low potential to move sediment on plateau areas. More stream power toward lower end of Mission and Fish Hawk Creek.	M	Instream LWD plays a role in channel stability and controlling sediment transfer in low gradient streams.	M	Mobilization of coarse sediment in Mission and Fish Hawk Creeks.
Pearson	M	Stable channel with coarse textured substrates well vegetated banks and functioning LWD. Erodible banks in Reach 1.	M	Some in-channel storage capacity for sediment, however most material will pass through. Aggradation could increase bank erosion.	M	Instream LWD plays a role in channel stability and controlling sediment transfer in low gradient sections.	M	Increased storage behind LWD jams leading to channel aggradation, widening and avulsion.
Joe Rich	H	Existing bank erosion problems in Reach 2. Mobilizing stored sediments in Reach 3 will cause further aggradation and widening downstream.	H	Increased sediment will lead to further channel destabilization.	M	Instream LWD plays a role in channel stability and controlling sediment transfer in low gradient sections.	H	Continued channel destabilization in Reach 2.
Mid-Mission (Residual)	H	Peaks flows will mobilize sediment stored in channel. Potential for toe erosion to increase landslide activity.	H	Channel already over-supplied with sediment. Fine sediment will travel all the way to intake.	L	Instream LWD plays a minor role in channel stability and controlling sediment transfer.	H	Mobilization of coarse sediment already in channel. Toe erosion may reactivate bank failures/landslides.
Upper Belgo	L	Mostly stable, low gradient channels with slow routing and flood storage in wetlands.	L	Low potential to move sediment through low gradient channels and wetlands.	M	Instream LWD plays a role in channel stability and controlling sediment transfer in low gradient stream	L	None anticipated.
Lower Belgo (Residual)	M	Stable channel with coarse textured substrates well vegetated banks and functioning LWD. Some floodplain storage.	M	Some in-channel storage capacity for sediment, however most material will pass through.	M	Instream LWD plays a role in channel stability and controlling sediment transfer in low gradient sections.	M	Increased storage behind LWD jams leading to channel aggradation, widening and avulsion.

<b>Sub-basin Name</b>	<b>To Increased Peak Flow</b>	<b>Comments/ Rationale</b>	<b>To Increased Sediment Delivery</b>	<b>Comments/ Rationale</b>	<b>To Decreased Riparian Function</b>	<b>Comments/ Rationale</b>	<b>Combined Channel Sensitivity</b>	<b>Potential Outputs Associated with Channel Change</b>
Daves Creek	H	Peaks flows will mobilize sediment stored in channel. Undersized crossings and erodible banks.	H	Fine sediment will travel short distance to intake.	M	Instream LWD plays a role in channel stability and controlling sediment transfer in low gradient sections.	H	Mobilization of sediment already in channel. Sediment delivery to intake.
Lower Mission Residual (above BMID intake)	H	Peaks flows will mobilize sediment stored in channel. Existing problems with flooding and channel destabilization.	H	Channel already over-supplied with sediment. Fine sediment will travel all the way to intake.	L	Instream LWD plays a minor role in channel stability and controlling sediment transfer.	H	Mobilization of coarse sediment already in channel. Channel destabilization.
Canyon (below intake)	L	Bedrock controlled channel sections. Aggraded with coarse textured substrates in unconfined areas.	L	Sediment inputs will pass through.	L	Instream LWD plays a limited role in channel stability and controlling sediment transfer.	L	Some aggradation of unconfined low gradient sections.
Fan (below intake)	M	Stable channel with armoured banks. Design capacity of channel may be limited.	H	Sediment will be deposited in this reach leading to aggradation and a reduction in channel capacity.	L	Instream LWD plays a limited role in channel stability and controlling sediment transfer.	H	Channel aggradation and over-topping of artificial channel/dykes.

## 3.2 WATERSHED HYDROLOGY

Mission Creek is a snow-dominated (nival) hydrologic system and peak flows occur from April to July. Total annual precipitation is 330mm in Kelowna near Okanagan Lake, with 25% falling as snow; and 703mm at 1250m elevation, with 50% falling as snow. About 50% of the watershed is above 1400m elevation, where the amount of precipitation will be higher yet. At upper elevations approximately 75% of annual precipitation falls as snow, and is largely stored until the spring freshet snowmelt. In general it is estimated that average annual precipitation for Okanagan basins is about 600mm per year, and average annual runoff varies from 120 to 230mm (or 20 to 40% of annual precipitation) per year (Summit, 2005).

Roughly 75% of annual runoff occurs between April and July in response to snowmelt. All historic annual peak flows occur within this spring freshet period, and therefore it is almost exclusively snow melt or rain on snow that produces watershed peak discharges. The watershed area of Mission Creek upstream of the BMID water intake is approximately 605km<sup>2</sup>.

### 3.2.1 Snow sensitive zone

It is widely accepted that for nival (snowmelt dominated) watersheds such as Mission Creek, it is largely the upper portion of the watershed that produces peak flows during the spring freshet melt - because snow in the lower watershed has typically melted prior to peak flows occurring in the lower mainstem (Gluns 2001; Schnorbus and Alila 2004). The H<sub>60</sub> (the contour line above which 60% of watershed area is contained) is commonly used to define the watershed area that is contributing snow melt runoff at the time of peak discharge. It should be noted that the H<sub>60</sub> concept was developed for graded mountain watersheds, and not watersheds with large upland plateaux, such as Mission Creek.

Measurements have been made of the elevation of the receding snowline at the time of peak flows in Mission Creek (Dobson 2004a). In almost all cases the contributing snow zone was less than 60%. Based on six years of observations (1999 to 2004), the position of the snow line in Mission Creek during the freshet period was generally between 1400 and 1600m elevation. The same elevation band was identified as the lower limit of the snow zone by Winkler (1997).

It is reasonable to expect that, depending on snow pack and melt conditions, some variation in the contributing area will occur; and that a rapid melt when the snow line elevation is still relatively low would cause the highest peak flows. The very largest peak flows are likely caused by widespread radiation and/or other energy inputs (e.g., sensible and latent heat transfers and energy advected by rain) occurring simultaneously over a large area of the watershed. This is probably especially true in watersheds where mid and upper elevations consist of relatively low gradient plateaux, as in Mission Creek. In Mission Creek the 1400m elevation is considered the approximate lower limit of the snowmelt contributing zone to mainstem peak flows. The 1400m contour is approximately the H<sub>54</sub> line for Mission Creek. That is, of the 605km<sup>2</sup> drainage area above the BMID intake, about 320km<sup>2</sup> (54%) will have a melting snowpack contributing to peak stream discharge during the spring freshet snowmelt. This is defined as the snow zone in this report.

### 3.2.2 Forest cover changes

#### Stand Level ECA

Figure 5 (in pocket) shows the BEC stand types in Mission Creek watershed, including Interior Douglas Fir (IDF), Interior Cedar Hemlock (ICH), Montane Spruce (MS) and Engelmann Spruce Sub-alpine fir (ESSF). ESSF and MSdm BEC variants located above the H<sub>54</sub> line are coloured. These two variants comprise 68% and 21% respectively of the area of Mission Creek watershed in the snow zone above the H<sub>54</sub> line. ICH stands comprise the remaining 11%. As discussed in Section 2, different ECA progression curves were developed for the different BEC units. Figures 6, 7 and 8 show unharvested and harvested ECA curves for MSdm and ESSFdc BEC variants above the snow line in Mission Creek. As discussed in Section 2.2.2, the unsalvaged curves are based on field measurements of secondary stand structure in Vegetation Resource Inventory (VRI) labelled pine-leading stands in seven south Okanagan watersheds, completed for this project (see Appendix B). The curves shown here assume full pine mortality, full understory survival and a site index (SI) of 15.

ECA progression curves for younger MSdm (Photo 20) are based on 64 plots in 8 pine-leading stands (Figure 6). The measured overstory pine component averages about 90%. Average understory is 280 well-spaced stems per ha (>1.3m tall) per ha. The older MSdm ECA curves (Figure 7) are based on 85 plots in 10 stands with an average overstory pine component of 74.0 % and an average understory of 560 well-spaced understory stems >1.3m tall per ha.

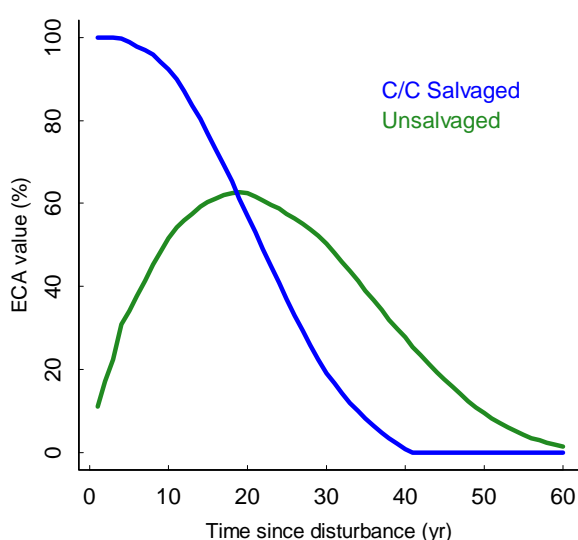


Figure 6. ECA progression in younger pine-leading MSdm stands (70 to 110 yr).

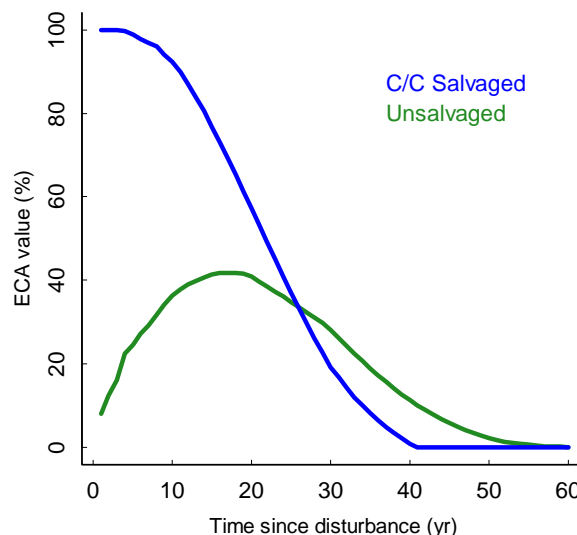


Figure 7. ECA progression in older pine-leading MSdm stands (>110yrs)

ESSFdc ECA curves (Figure 8) are based on 56 plots in 7 stands. In stands labelled as 100% pine or >80% pine, the actual measured overstory pine component averages 30.7%. The rest of the overstory is approximately equal amounts of spruce and balsam. The average understory has 1,000 well-spaced stems (>1.3m tall) per hectare (Photo 21). So, based on the field data, these stands are not actually pine-leading, even though the Vegetation Resources Inventory (VRI) forest cover data indicates that it is.

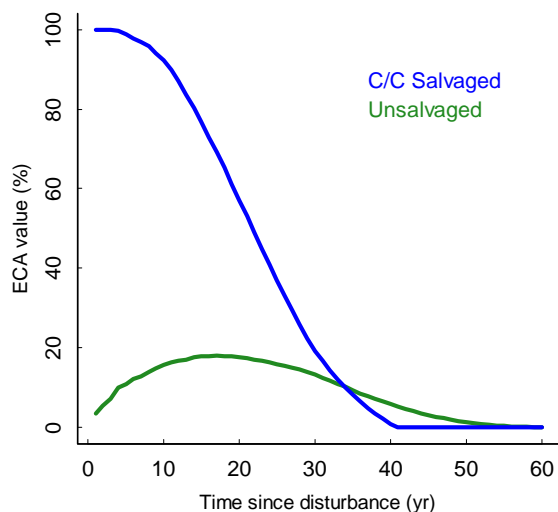


Figure 8. ECA progression in ESSFdc stands

There were no field measurements in the ESSF<sub>xc</sub> variant, which comprises over 50% of the entire watershed area above the H<sub>54</sub> line (see Figure 5). This was because field measurements of stand characteristics were focused on pine-leading stands, and the Provincial VRI data showed this variant had little pine-leading (>40% PI) area to measure - and presumably a relatively low amount of pine for MPB to attack, or to be salvaged harvested.

These assumptions of very little pine overstory in ESSF type forests in the Mission Creek snow zone (which comprise almost 70% of the snow zone) means that because there is little pine for MPB to attack, a small ECA effect is expected following MPB infestation in these stands, as shown in Figure 8. Also, because there is so much non-pine overstory (average 68%) with ongoing hydrologic function after the smaller pine-component is attacked, there is a large difference in the ECA effect when these types of stands are salvaged harvested, as Figure 8 also shows.

### Mission Creek Watershed ECA

Figure 5 shows the drainage area above the H<sub>54</sub> line that defines the snow zone. The following discussion of Mission watershed ECA refers to that upper elevation area that still has some snow pack during spring freshet snow melt. Graystokes Provincial Park, established in 2001, occupies about 61km<sup>2</sup> (19%) of the upper watershed in the snow zone above the H<sub>54</sub> line. Being a Class A Park there will be no harvesting in it. The pine trees in it will be attacked, but as discussed above, according to our field assessment of stand structure and the VRI database, there is very little pine in the BEC types within the park, so little MPB effect is expected.

These three stand type curves shown above, and data for ICH stands from Vyse (2007) were used to generate cumulative harvested and unharvested ECA curves for the watershed area snow zone and sub-basin areas. ECA calculations also included the existing harvesting and fire disturbances in the watershed as of December 2008, based on VRI data and information provided by major forest licensees operating in the watershed, which are held primarily by

Tolko Industries Ltd. and BC Timber Sales, with a small area in the south managed by Weyerhaeuser Canada.

In watershed ECA modelling, MPB attack was phased in over 5 years, and salvage harvesting followed 1 year behind the MPB. Two management scenarios were modelled as shown in Figure 9.

In the “MPB unharvested” scenario (blue line) all pine trees in pine-leading stands are assumed to be killed by MPB<sup>2</sup>, no further forest harvesting activity takes place in the watershed and there is full survival of the measured understory. That is, all stands are retained and there is no salvage harvesting of pine-leading stands and no harvesting of non-pine green wood. In the “clearcut salvage” scenario (pink line) all pine-leading stands are clearcut harvested, with the exception of riparian zones, old growth management areas, unstable terrain and other areas designated as long-term reserves, as contained in GIS layers supplied by forest licensees. These areas are preserved, however if they are pine-leading it is presumed that the pine dies from MPB attack.

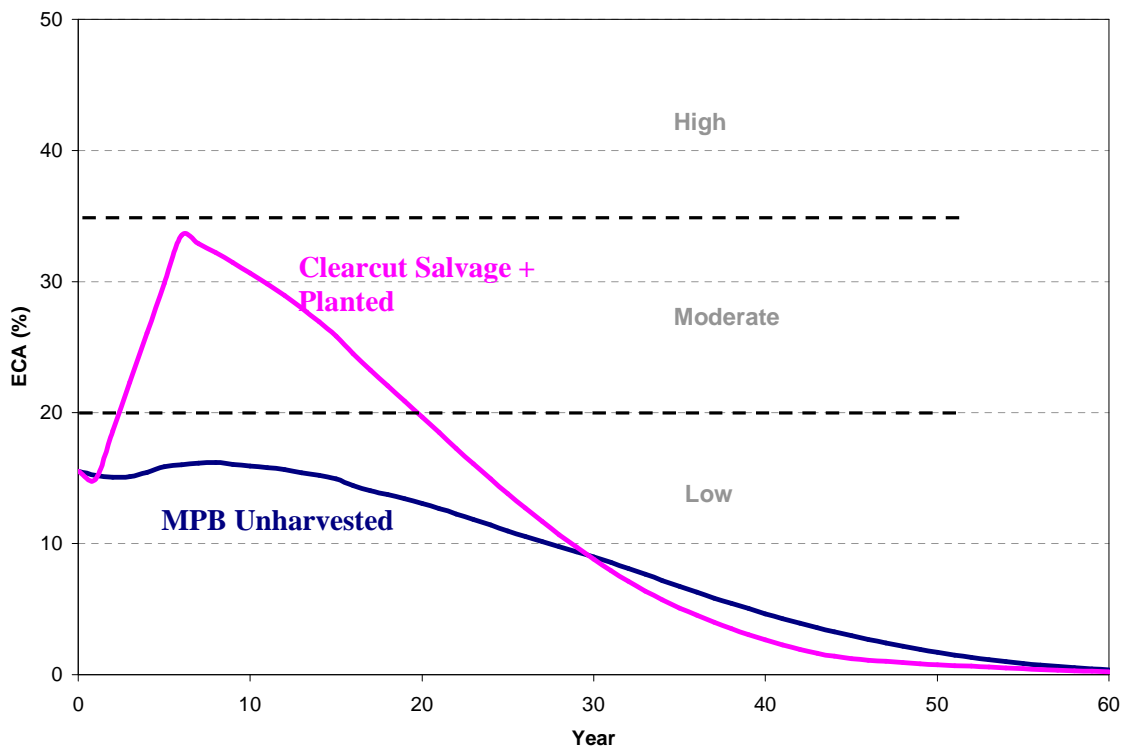
These two potential end points on the possible development continuum were chosen so that the maximum difference in hydrological effects between harvest and non-harvest options could be shown. It is not expected that forest licensees would be able to salvage harvest all non long-term reserve attacked pine; however there may be other interests in the wood, such as bio-fuel users or others we do not currently know about, who could conceivably be able to utilize more of the pine. And the authors have analysed watersheds in other areas where MPB infestation is more advanced, and where ECA values are as high as 75%, because almost all pine-leading stands in a watershed have been salvaged harvested. Showing the maximum possible hydrological effects of different management options gives forest managers information on the widest possible range of potential hydrological risks in the watershed.

Hazard ratings for different ECA levels are also shown in Figure 9. The low ECA hazard range is based on findings that noticeable peak flow increases or peak flow effects are not generally experienced in watersheds with ECA values of 20% or less. Because of this watershed ECA is considered recovered, or a low ECA hazard, when the ECA level is 20% or less.

A moderate ECA hazard indicates that ECA (forest canopy) effects may or may not be noticeable. A high ECA hazard rating indicates that significant ECA effects are likely to occur.

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2. As discussed in Section 2.2.2, this may not be a conservative assumption. In the Okanagan Timber Supply Area pine mortality from MPB is expected to be less than 100% (Walton, 2009). In Mission Creek ECA values following the unharvested MPB scenario are generally low, and a sensitivity analysis using reduced pine mortality did not result in significant differences in ECA progressions. Because of this and because of the uncertainty around final mortality estimates, 100% pine mortality is assumed in all watershed and sub-basin ECA modeling.



**Figure 9.** ECA progressions for Mission Creek Watershed above H<sub>54</sub> elevation, assuming full pine mortality from MPB infestation, full understory survival and no harvest scenario (blue) and full salvage harvest of pine-leading stands scenario (pink).

In Figure 9, the sustained ECA hazard for the MPB/unharvested scenario is approximately the centre of the area under the curve above the low hazard level. The current watershed ECA is low. Following full pine mortality and no further harvesting the ECA level remains low, slowly decreasing to 10% in approximately 30 years. That is, with the overstory and understory survival assumptions made, the ECA effects of MPB mortality (and no further harvesting) noticeable ECA (or snow accumulation and melt) effects are not expected. Similarly, the centre of the area under the ECA curve for the hypothetical full pine-leading stand salvage scenario, relative to the MPB/unharvested curve, suggests there is a sustained Moderate ECA hazard for about 15 years. Within this time period noticeable ECA effects may or may not occur.

These watershed ECA values are the lowest for any of the 7 South Okanagan watersheds examined in this project. The reasons for this are twofold. There was an earlier MPB epidemic in the 1980's resulting in a significant harvested area that has been replanted and is currently experiencing hydrologic recovery. In the unsalvaged scenario in these watersheds, the increasing ECA in what decaying pine stands remain is offset by the decreasing ECA in regenerating past clearcuts. The second reason for low ECA values for both the unharvested and total pine harvest scenarios is that much of the watershed area snow zone is occupied by ESSFxc type forests, which according to the VRI data used in the modeling have a low amount of pine leading stands, as discussed above. This means there is little pine to be attacked in the unharvested MPB scenario, and little salvage harvest expected in the non-pine leading stands of the upper watersheds.

### Sub-basin ECA Analyses

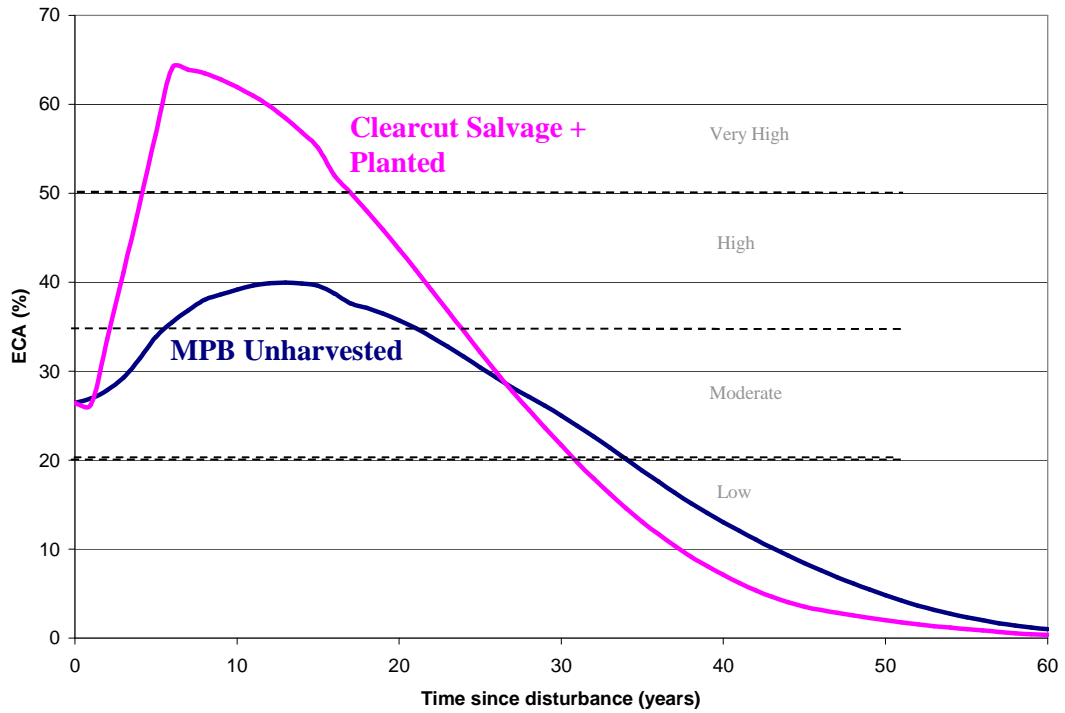
Table 6 shows ECA analyses results for the two ECA scenarios for the each sub-basin in the watershed, for the area in each sub-basin that is above the watershed H<sub>54</sub> line.

Pearson Creek has a similar ECA response as the watershed as a whole, with a low current ECA, a low post-unharvested MPB ECA and a predominantly moderate post total salvage harvest ECA.

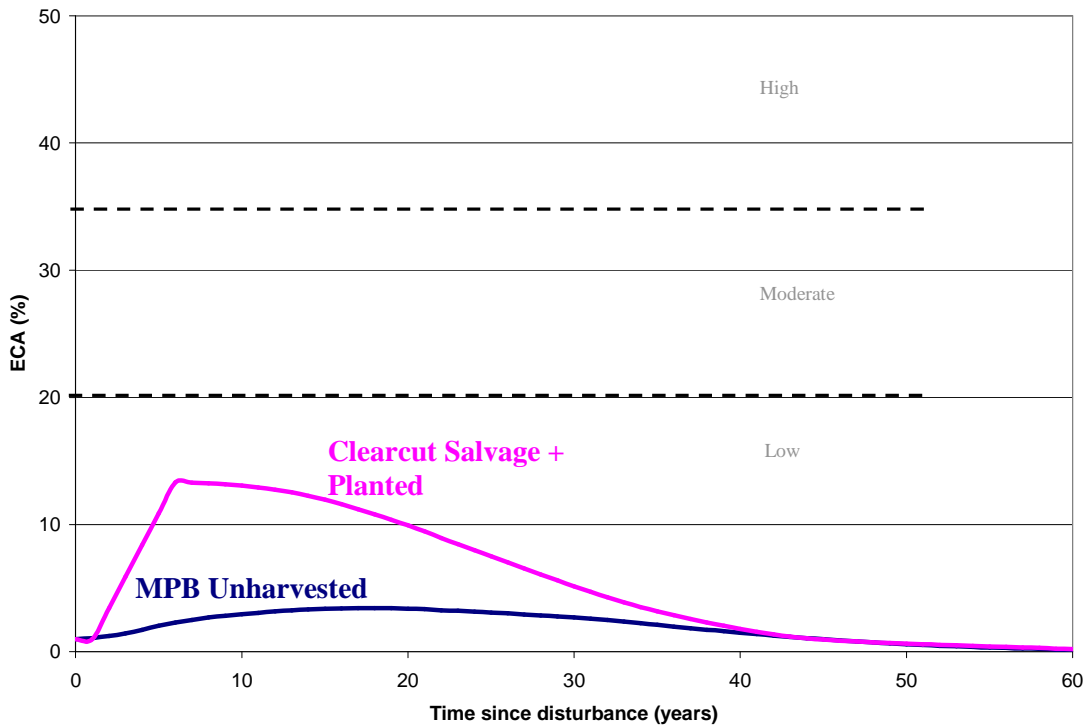
Upper Belgo (Figure 10), Lower Belgo and Joe Rich Creek are somewhat lower elevation sub-basins in the watershed, and show generally higher ECA values than the watershed as a whole. For the unharvested MPB scenario ECA values are mostly moderate. Post total pine salvage harvest ECA values are High to Very High. This is because the snow zone in these watersheds is primarily comprised of MSdm and ESSFdc stands which have, even in pine-leading stands, significant non-pine canopy, with a hydrological function that is lost when the stand is removed by salvage harvesting. They also have significant pine-leading stands that have not been harvested. Only Upper Belgo, above Ideal Lake has sustained Very High post-salvage harvest ECA values (Figure 10).

**Table 6.** Sub-basin ECA above watershed H<sub>54</sub>

Sub-basin Name	Area (ha)	% Total Watershed Area >H <sub>54</sub>	Current ECA (%)	Maximum ECA (%)		Sustained ECA (%)	
				MPB	Full Salvage	MPB	Full Salvage
Upper Mission	6043	100	1	3	13	Low	Low
Pearson	7212	67	8	13	40	Low	Moderate
Joe Rich	4537	27	10	30	50	Moderate	High
Mid-Mission (Residual)	14672	65	18	18	18	Low	Low
Upper Belgo	4307	50	26	40	64	Moderate to High	High to Very High
Lower Belgo (Residual)	13655	54	19	22	47	Low	Moderate to High
Daves Creek	3388	18	41	41	41	Moderate	Moderate
<b>Lower Mission Residual – BMID Intake</b>	60476	54	16	16	34	<b>Low</b>	<b>Moderate</b>



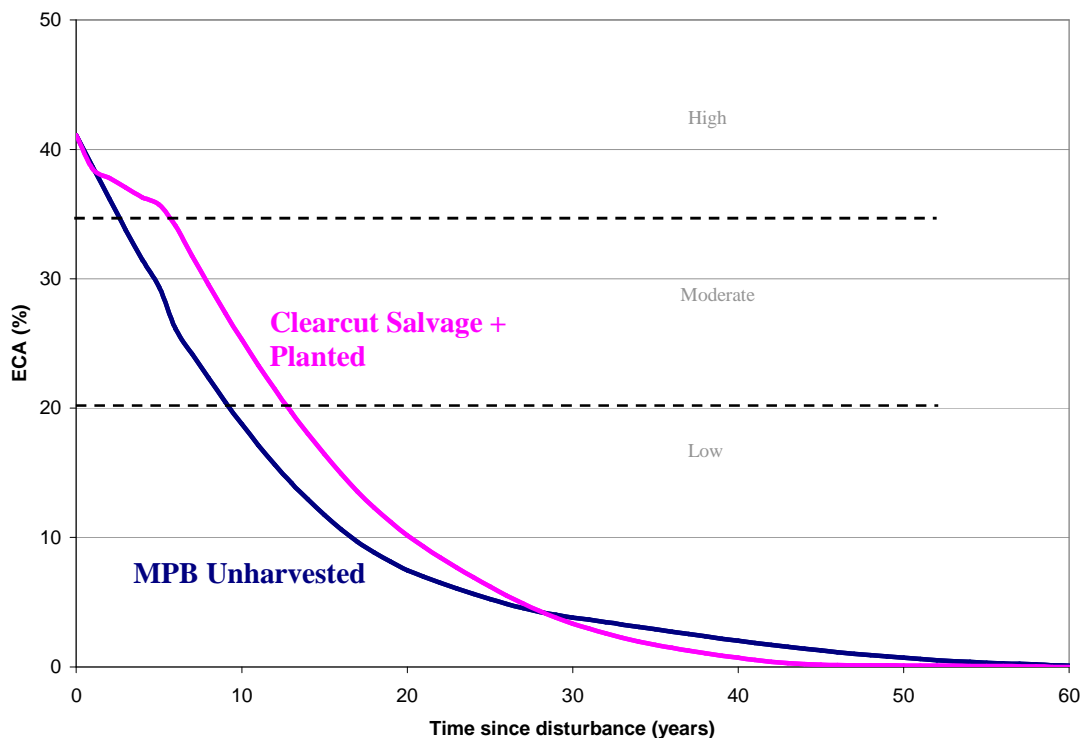
**Figure 10.** ECA progression for Upper Belgo sub-basin. Moderate to High post-unharvested ECA and High to Very High post total pine salvage harvest ECA (note change in ECA axis scale).



**Figure 11.** ECA progression for Upper Mission sub-basin, in Graystokes Provincial Park and with ESSFxc stands, which VRI data shows have very little pine-leading forest.

Upper Mission sub-basin (Figure 11) has a negligible (<1%) current ECA value. Post-unharvested and post-total harvest management scenarios yield very low to low ECA values, because most of the sub-basin is comprised of ESSFxc stands, which the VRI inventory shows have few pine-leading stands to either be attacked by MPB or to be salvage logged. Note that this assumes only MPB salvage harvest will occur in the watershed. Most of the sub-basin is also within Graystones Provincial Park where there will be no salvage harvesting. Upper Mission is entirely within the Mission watershed snow zone above 1400m elevation, and thus has a strong moderating influence on total watershed ECA.

Daves Creek (Figure 12) and Mid Mission residual sub-basins have been extensively logged from the late 1970s through the 1990s. Those harvested areas are now presumed to be successfully planted and restocked, and experiencing ECA (and hydrological) recovery. In Daves Creek ECA due to harvesting alone in 1998 was 47% (Dobson, 1998), and has now decreased to a combined current harvest and MPB ECA of 42%, still the highest in the watershed. But because there is little pine left to harvest and planted stands are recovering, there is no increase expected in ECA from either the unharvested or full harvest scenario over time; and ECA values decrease to Low in about 10 years. In Mid Mission residual conditions are similar to Daves Creek in the lower part of the sub-basin, with extensive past harvesting and current recovery. Because the upper Mid Mission sub-basin is largely ESSFxc forest, there is little pine to be attacked or harvested, and current and future overall ECA levels in Mid-Mission are lower than in Daves Creek.



**Figure 12.** ECA progression for Daves Creek sub-basin with extensive harvesting between the late 1970s through the 1990s, resulting in a currently High ECA. There is little pine left to salvage, planted stands are recovering, and both scenarios decrease to a Low ECA level in about 10 years.

While individual sub-basins show quite different expected ECA progressions over time, the cumulative effects of significant past harvesting and recovery, and of stand types at higher elevations with little pine to be attacked or salvaged - as measured to the BMID water intake, is a relatively low ECA effect following either management scenario (Figure 9).

Finally it is worth remembering that ECA values are only an expression of forest canopy changes in the area being analysed, and the local snow accumulation and melt rate effects of those canopy changes. Whether the expected canopy changes will result in increased stream discharge and geomorphic effects in the watershed will depend on the particular watershed and channel characteristics of the area in question, as discussed below.

### **3.3 HYDROLOGIC HAZARD**

#### **3.3.1 Peak flow hazard**

Peak flow hazard is the potential or likelihood that a sub-basin will develop an elevated flow regime following changes in forest cover (Alila et al. 2007, FBP 2007, Schnorbus and Alila 2004). Prime factors when considering peak flow hazards are the extent of forest canopy loss (ECA) discussed in earlier sections, and the watershed or sub-basin characteristics that control how streamflow will respond to the canopy changes. Sub-basin factors that affect runoff sensitivity include steepness, soil drainage properties, drainage density, soil depth (or proximity to an impervious layer), and existing storage such as reservoirs, lakes, and wetlands. Sub-basin peak flow attenuation potentials are described as 'Poor' (not likely to attenuate peak discharge), 'Moderate' (some potential to attenuate peaks) and 'Good' (likely to significantly attenuate peak flows). Combining ECA hazards with sub-basin attenuation gives a peak flow hazard rating. Where Poor peak flow attenuation is anticipated in a sub-basin, ECA-related increases in runoff translate directly into increased flow regimes. Moderate or Good attenuation will result in peak flow hazards somewhat less than that denoted by ECA alone.

High ECA in a sub-basin with rapidly routed runoff and little opportunity for storage will result in a high likelihood or potential for increased peak flows. A lower ECA and/or opportunities for significant water retention in lakes, wetlands and/or reservoirs will reduce peak flow hazards.

Table 7 presents peak flow hazards for each sub-basin and the Mission watershed as a whole under the two forest management ECA scenarios of 'MPB/unharvested' and 'Full-salvage'. The ECA progressions for the watershed over time and for the two management scenarios are shown in Section 3.2.3. ECA hazards in Table 7 are represented primarily by the qualitative sustained ECA hazard over time.

**Table 7.** Peak flow hazard ratings derived from sub-basin routing characteristics and modelled ECA levels.

Sub-basin	Peak Flow Attenuation Potential	Projected Maximum ECA (Percent)	Sustained ECA Hazard Level	Projected Maximum ECA (Percent)	Sustained ECA Hazard Level	Peak Flow Hazard	
		MPB		Full Salvage		MPB	Full Salvage
Upper Mission	Good	3	Low	13	Low	Very Low	Very Low
Pearson	Poor	13	Low	40	Moderate	Low	Moderate
Joe Rich	Poor	30	Moderate	50	High	Moderate	High
Mid-Mission (Residual)	Poor	18	Low	18	Low	Low	Low
Upper Belgo	Good	40	Moderate	64	(High) Very High	Low	High
Lower Belgo (Residual)	Poor	22	Low	47	(Moderate) High	Low	High
Daves Ck.	Poor	41	Moderate	41	Moderate	Moderate	Moderate
<b>Lower Mission Residual – BMID Intake</b>	Poor	16	Low	34	Moderate	<b>Low</b>	<b>Moderate</b>

## Results

Upper Mission and Upper Belgo Creek are the only sub-basins in the Mission Creek watershed with good potential for peak flow attenuation. The presence of natural lakes and wetlands, as well as the BMID operated reservoirs (Ideal Lake, Fish Hawk Lake, Mission Lake, Graystoke Lake and Long Lake [uncontrolled]) all contribute to a delayed routing of runoff and flood peaks through the sub-basin. Elsewhere in the watershed flood peaks will pass quickly down the major stream channels with little opportunity for storage and Peak Flow Hazards reflect the sustained ECA Hazard.

Reservoirs at the BMID intake are relatively small and are bypassed by the channel so no significant flow attenuation can be expected at the intake or in the lower watershed. Combining this Poor flow attenuation with the Low ECA levels in the Mission watershed following retention of MPB-attacked stands, post-unharvested MPB peak flow hazards remain Low. Anticipated ECA levels resulting from the full salvage scenario are Moderate due to the increased ECA effects of harvesting relative to retention of MPB-attacked forests. Combining this with the Poor attenuation potential yields a post-total salvage peak flow hazard of Moderate for the watershed.

### 3.3.2 Hydrologic Hazard

Hydrologic hazard represents the potential or likelihood of peak flow or sediment impacts to existing channel conditions in response to the projected change in flood regime. Hydrologic hazard ratings are derived from channel sensitivities (Table 5) and peak flow hazard ratings (Table 7), which are combined using a standard risk matrix (see Appendix A, Table A2). Table 8 shows the resulting Hydrologic Hazard values for each of the Mission Creek sub-basins and

for the watershed as a whole at the BMID intake (at the lower end of Mission Residual sub-basin).

**Table 8.** Hydrologic Hazards by Sub-basin

Sub-basin	Sediment Regime and Channel Sensitivity (from Table 5)	Peak Flow Hazard (from Table 7)		Hydrologic Hazard (Peak Flow Hazard Combined with Channel Sensitivity)	
		MPB	Full salvage	MPB	Full Salvage
Upper Mission	M	Very Low	Very Low	VL	VL
Pearson	M	Low	Moderate	L	M
Joe Rich	H	Moderate	High	H	VH
Mid-Mission (Residual)	H	Low	Low	M	M
Upper Belgo	L	Low	High	VL	M
Lower Belgo (Residual)	M	Low	High	L	H
Daves Ck.	H	Moderate	Moderate	H	H
<b>Lower Mission Residual (BMID Intake)</b>	H	Low	Moderate	<b>M</b>	<b>H</b>
Mission Creek (below BMID intake)	L	Low	Moderate	M	H
Fan	H	Low	Moderate	M	H

As discussed in Section 3.1.3, channel sensitivities range from Low to High in the Mission Creek system. The mainstem of Mission Creek, Joe Rich and Daves Creek are considered highly sensitive. When combined with the unharvested MPB related peak flow hazards from Table 7, hydrologic hazards range from Very Low in the upper Mission sub-basin to High in Joe Rich and Daves Creek. The cumulative watershed hydrologic hazard at the BMID intake is considered Moderate under the unharvested MPB scenario.

Full Salvage Hazard ratings remain the same as the unsalvaged MPB Hazards for Upper Mission, Mid-Mission, and Daves Creek. Daves Creek is unchanged as there is little pine left to salvage in the sub-basin. In Upper Mission sub-basin it is assumed no harvesting will occur in Graystoke Park. In lower Mid-Mission there is little pine left to harvest following the extensive 1980's MPB salvage and in the forest type in the upper basin there are presumed to be few pine-leading stands to be salvaged harvested.

In the other sub-basins Hazard ratings following full salvage increase by one step, or more, over the non-salvage scenario. Similarly, the cumulative hydrologic hazard at the BMID intake is considered Moderate under the MPB scenario and High following the full salvage scenario.

Note that these hazard ratings are not due to an expected significant increase in peak flows over current levels, which have a low likelihood following MPB attack and a moderate likelihood following full salvage. Rather, they reflect the sensitivity of the Mission Creek mainstem above the intake, which is aggraded and has significant excess sediment stored in the channel. This sediment can be easily mobilized by even small increases in peak flows, increasing sediment loads and potentially increasing bank erosion and landslide activity in the watershed. Following the unharvested MPB management scenario a Moderate Hydrologic Hazard means a noticeable increase in sediment movement may or may not occur. Following the full salvage harvest scenario, a High Hydrologic Hazard means that fine and coarse sediment loading would likely increase at the BMID intake.

### **3.3.3 Low-flow hazard**

It is widely accepted that extensive clearcutting increases annual water availability, growing season soil moisture and potentially stream flows; because removing the trees decreases interception and evapotranspiration water losses associated with the forest. The effect of MPB mortality and salvage is expected to be similar.

The widespread removal of forest cover can expose the melting spring snow pack to greater energy inputs, causing it to melt faster so that the freshet melt and associated peak flows occur earlier. This shift in the hydrograph can result in earlier depletion of soil moisture and a longer and more severe soil moisture deficit later in the growing season. However this earlier drying due to freshet advancement is likely to be at least partially offset by the expected increase in available moisture due canopy loss and decreased interception and evapotranspiration losses.

A literature review and workshop attended by most research forest hydrologists in B.C. to address low flow issues in Interior B.C. snowmelt dominated hydrologic regimes, such as Mission Creek, concluded that; “Forest management generally increases water volume - no case studies relevant to snowmelt-dominated regimes reported a decrease in water quantity as a result of forest harvesting” (Pike and Scherer, 2003). The likelihood of MPB mortality and salvage negatively affecting unregulated growing season low flow stream discharges in Mission Creek is considered low.

An earlier freshet snow melt can also necessitate earlier withdrawal from reservoir storage and therefore earlier reservoir depletion later in the growing season. For the three controlled reservoirs in Upper Mission Ck. sub-basin, which comprise 59% of total reservoir storage in the watershed (see Table 3), the expected future hydrological effects of MPB and salvage harvesting-related forest mortality is Low (see Figure 11), and advancement of reservoir drawdown is also expected to be minor. For Ideal (Belgo) Lake Reservoir, which is the largest in the watershed and supplies 41% of reservoir storage, the expected hydrological effect of MPB-related stand mortality is generally Moderate (see Figure 10), but the expected effect of full salvage harvesting of attacked pine stands is Very High – because there are lots of existing pine-leading stands with significant non-pine component, which if extensively harvested will have a significant hydrological effect. Although whether this effect includes a significant advancement of freshet timing is uncertain.

To estimate what effects the expected high ECA values could have on freshet timing and reservoir drawdown, the results of 24 paired-watershed and numerical modelling studies of the

effects of forest disturbance (harvest, fire, MPB) on peak flow timing were reviewed (Pike and Scherer 2003, Alila, et al. 2007 and FBP 2007).

In those studies there was a large variability between study watershed sizes and conditions, forest disturbance or treatment and in the resulting measured freshet timing, which was between 0 and 20 days earlier in treated or disturbed watersheds than in control watersheds. There were also large differences in annual freshet timing within an individual study. For instance Alila et al. (2004) found that in Whiteman Creek their model predicted that over the 76 years of simulated climatic record the average freshet advancement over the control was 4 days. However individual annual freshet timing varied from 2 days later to 40 days earlier. Our conclusion is that this is an area that requires more study, and there is too great an uncertainty around study results to extrapolate from them to Upper Belgo Creek, other than to say that if there will be any noticeable effect it will be to advance freshet timing. The evidence suggests, but is not conclusive, that the effect will be relatively small. If so it will not significantly affect reservoir storage in the later growing season in Ideal Lake Reservoir.

### **3.4 CLIMATE CHANGE**

Studies of recent past and expected future climate change effects suggest there will be several major effects on BMID water demand, supply and timing.

Analyses of recent climate patterns suggest there will be less runoff. Rodenhuis et al. (2007) found that in nival Okanagan basins, annual mean streamflow decreased by 7 to 14% over the last 30 years. Extrapolating forward, estimates of expected decreases in natural annual flows for Okanagan streams are in the range of 20% by 2020 and 39% by 2050 (Summit, 2004). There is also expected to be a decrease in freshet peak flows, as more precipitation falls as rain in the winter and there is less stored snow at the start of the freshet.

Secondly, there will be increased agricultural demand. It is estimated climate change related temperature increases and dryness during the growing season will increase water use for agriculture and residential irrigation (which comprise 85% of BMID water use) by 16% in 2020 and 30% in 2050 (Summit, 2004).

Higher temperatures will also result in earlier snowmelt and annual spring hydrograph peak. As discussed in Section 3.3.3, earlier spring runoff results in earlier hydrograph recession, and possibly earlier storage use and greater growing season reservoir drawdown. The magnitude of the combined effects of climate change-related decreased water availability, increased demand and earlier storage depletion are not known.

Changes in forest cover can also affect water supply. Decreased snow sublimation and evapotranspiration losses will mean more water availability for runoff, both as accumulated snow for the freshet and water availability during the growing season. As well, models predict canopy loss will mean an earlier onset to the freshet. As discussed in Section 3.3.3 the MPB/salvage effect growing season low flows is not expected to be significant; and in general is expected to be small relative to climate change effects.

### **3.5 WILDFIRE**

Concerns have been raised about increased risks of wildfires and severe wildfires in stands and watersheds where there is widespread MPB mortality, presumably because dead pine trees are seen as increased fuel load relative to live pine stands. Extensive wildfire, and locally severe wildfires, can create changes in the hydrological functioning of forests, and increase flood and other hydrogeomorphic risks to downstream values (Scott and Pike, 2003).

It has been noted, in a study of fire occurrence and effects in MPB attacked and non-attacked stands in Colorado, that: “Although it is widely believed that insect outbreaks set the stage for severe forest fires, the few scientific studies that support this idea report a very small effect, and other studies have found no relationship between insect outbreaks and subsequent fire activity. Based on current knowledge, the assumed link between insect outbreaks and subsequent forest fires are the norm . . . is not well supported, and may in fact be incorrect or so small an effect as to be inconsequential for many or most forests” (Romme et al. 2007).

The reason proposed for this finding is that weather may be a more important factor than stand condition, and where drought has increased the fire hazard in all stands, both live and dead fuels will carry fire (Romme et al. 2007). In lodgepole pine stands in the 1988 Yellowstone fires, Lynch (2006) found that MPB-affected areas had only an 11% higher probability of burning compared to un-infested areas.

There is some agreement that for the one to two-year period following attack, when the trees still retain their needles, there is an increased crown fire hazard. After the needles have fallen, the risk of crown fire and fire behaviour potential is reduced for one to several decades. Fire risk may then return to pre-fire intensity levels as dead trees fall and fast growing understory vegetation provide fuels. (Romme et al. 2007; Duffy, C.D., Superintendent, Fuel Management, Fire Management Section, Protection Branch, MoF, Victoria, pers. comm. 2008).

Presumably for these reasons, advice to the Chief Forester of BC Forest Service regarding MPB-related salvage harvesting has been: “Increased risk of fire in MPB-affected stands has been postulated by many, but evidence in the literature is equivocal (e.g., Turner and Carroll 1999). Conducting salvage operations based on the premise of reducing fire risks is not recommended, except in the wildland-urban interface” (Eng 2004). We agree with this statement and recommend that, except in the wildland-urban interface, and possibly in small tributary watersheds (<10 to 20km<sup>2</sup>) with high property or infrastructure values on the fan, widespread salvage of MPB attacked stands should not be carried out if the prime management objective is to reduce fire risk.

## **4.0 CONSEQUENCES**

### **4.1 WATER QUALITY AND INFRASTRUCTURE**

Mission Creek is a community watershed supplying drinking water to the city of Kelowna and the Regional District of Central Okanagan. The Black Mountain Irrigation District services approximately 21,000 people comprised of single and multi-family residences, commercial, industrial, institutional and irrigation connections (BMID 2007).

There are over 160 licensed diversions on Mission Creek alone, some dating back to the 1800s. Additional licensed withdrawals are issued on most of the tributaries of Mission Creek. Of the total licensed volume of water withdrawn from Mission Creek by BMID, approximately 70% is allocated for irrigation use. The remainder is allocated for domestic use, private intakes for irrigation, storage and conservation for fisheries activities, livestock watering, and private domestic licenses.

The domestic water intake for the Black Mountain Irrigation District (BMID) is located approximately 20 km upstream from Okanagan Lake on Mission Creek. Water is diverted from Mission Creek into a Class IV water treatment plant where water is treated by a coagulation and flocculation system and is then released into the lower reservoirs, where settling occurs. The water is then chlorinated and moved through a fine screen prior to entering the distribution system.

As discussed in Section 2.4.1, the water quality parameters most-strongly linked to MPB infestation and/or salvage harvesting are those related to peak flows and fine and coarse sediment production. At the request of IHA this study looks only at the flooding and sediment hydrologic hazards that could impact a sufficient and reliable supply of safe and aesthetically acceptable water at the BMID intake, and does not consider the vulnerability of the BMID water supply and treatment system. Those potential impacts at the BMID water intake are considered the consequence in the partial risk analysis completed below.

## **4.2 WATER SUPPLY**

Three reservoirs in Mission Creek Watershed – Ideal (Belgo), Graystokes, Fishhawk (and James Lake which is diverted from Scotty Creek outside Mission Creek watershed) have a total of 13,500 acre-feet of storage for municipal use. Loch Long reservoir (507 acre-feet) has been used to augment fish flows during August to October low flows.

Total annual BMID consumption from 2003 to 2007 ranged from approximately 9500 acre-feet to 13,700 acre-feet. Depending on how much precipitation occurs and how it is distributed throughout the year there is generally 40 to 45% total storage remaining at the end of the year (BMID Annual Reports, 2005, 2006, 2007). Following the dry summer and fall of 2003 there was only about 26% of total storage remaining (BMID Annual Report, 2003).

Low flows in lower Mission Creek in late August and early September 2003 were less than the deemed to be optimum for Kokanee spawning, and there was not enough storage in the entire system to maintain adequate flows for spawning and incubation through the subsequent fall and winter. A study of fish flow volumes concluded that increased enforcement of water license terms and conditions to eliminate unauthorized diversions that deplete fish flows would be necessary during dry years, and that options to increase storage in the Mission Creek should be examined (Dobson, 2004b).

Recently an inter-agency group has developed target conservation flows in lower Mission Creek (WMC, 2010). Using the last 50 years of streamflow records to model water management scenarios, they concluded that without severe demand management about 20% of the time conservation flows would be 50% or less of target flows. However this did not include releases from Loch Long, which would increase the reliability of conservation flows.

There is no mention in the study of the expected decrease in flows and increases in demand due to global warming effects. Given those very real expected effects, it is likely that any significant decrease in August to October water supplies in Mission Creek would be considered a serious consequence.

### **4.3 FISH**

Mission Creek is the most important spawning tributary for kokanee and fluvial rainbow trout on Okanagan Lake. Historically, Mission Creek supported over 80% of the stream spawning Kokanee and over 65% of the Rainbow Trout in Okanagan Lake (Gaboury and Slaney 2003). As stated in the Okanagan Lake Action Plan, restoration of fish habitat in Lower Mission Creek is considered fundamental to recovery of the spawning and rearing habitats of kokanee and rainbow trout in Okanagan Lake (Andrusak et al. 2001 in Gaboury and Slaney 2003). Minimum fisheries flows are critical to survival and recovery of the Okanagan lake sports fishery (WMC, 2010).

Sport-fish species resident within the watershed include Brook Trout (*Salvelinus fontinalis*), and Rainbow trout (*Oncorhynchus mykiss*) in the headwater tributaries and lakes. Mountain Whitefish (*Prosopium williamsoni*) have been identified in the lower reach of Mission Creek. Based on available information, Mission Creek fish presence and habitat values for all reaches are presented in Appendix D, along with a fish consequence ranking for that reach, based on criteria presented in Table 2 (Section 2.4.3).

Figure 13 (in pocket) summarizes fish habitat consequence ratings for each macro-reach. Where reaches within one sub-basin have different consequence values, the highest value is assigned to that sub-basin. Where there was no fish information available for a reach, it is given a similar or one consequence class lower value, based on channel character, gradient and likelihood of fish presence.

No specific fisheries information was available for mainstem Mission Creek Reaches 5 through 9. Given the relatively low gradient, size and favourable character of the channel, and the presence of fish stocks upstream (Mission Lake and Stanley Creek), these reaches were inferred to provide habitat for fish and were considered sensitive to channel disturbance (high consequence rating).

### **4.4 SOCIAL INFRASTRUCTURE**

Table 9 outlines the assumptions used to develop expected vulnerability of infrastructure other than the BMID intake, to increased hydrologic hazards and the assigned vulnerability ratings.

**Table 9. Social Infrastructure Vulnerability Rating**

Item at Risk	Key Post MPB/salvage Issues	Comments	Vulnerability Rating
Licensed Water Intakes	Increased peak flows, local aggradation, increased turbidity, increased debris movement, supply (low flows).	Private intakes are often 'home-made' and unable to withstand flooding/debris impact. Constructed weirs susceptible to burial by bedload. Most will have no provision for filtering of suspended fines.	<b>H</b>
Forestry Roads	Increased peak flows, increased scour, increased debris movement at crossings. Drainage redirection on plateau roads and gentle-over-steep landslides on steeper stream sidewalls.	Road culverts may not have design capacity for increased peak flows, sediment or debris, which can plug or reduce structure capacity. Overflows may be near steep terrain with potential for landslides. Forestry bridges are less sensitive to flow increases.	<b>M</b>
Private Bridge Crossings (Agricultural lands and Driveways)	Increased peak flows, increased scour, increased debris movement.	Many constructed to a low standard without hydrologic and/or engineering input. Often poorly founded on abutments. Often constructed on relatively low banks (floodplain).	<b>H</b>
Highway 33 Culverts (Daves Creek, Joe Rich Creek)	Increased peak flows, increased sediment leading to local aggradation, increased debris movement.	Potential to exceed capacity during peak flow events. Aggradation and debris accumulation may reduce capacity. Problems have previously occurred at both of these sites.	<b>H</b>
Highway 33 Bridges (Belgo Creek, Mission Creek)	Increased peak flows, increased sediment leading to local aggradation, increased debris movement.	Current bridge capacities on Mission and Belgo Creeks appear more than adequate, however both are located in depositional zone. Aggradation may reduce capacity and/or affect alignment. Some risk of damage to abutments or piers.	<b>M</b>
Residences and Development on Fan	Increased peak flows and flooding potential, increased sediment leading to local aggradation, increased debris movement causing jams.	Current channel appears well-incised and armoured but design capacity of structures may be exceeded with higher peak flows, aggradation and/or debris jams.	<b>M</b>

On Mission Creek alone, there are 157 water licenses listed with the Ministry of Environment (MoE). Fifteen licenses are registered with BMID as the local waterworks authority. There are also licenses with the City of Kelowna, the Regional District of Central Okanagan and the Westbank Indian Band. The MoE Fish and Wildlife Science and Allocation Section has twelve licenses for the use of water for conservation. Most of the privately held licenses are for domestic water use, irrigation and stock watering purposes. Other than the BMID licenses on the reservoirs, there are no licenses on Mission Creek above the Pearson Creek confluence.

Water licenses also exist on many tributaries to Mission Creek including Daves Creek, Joe Rich Creek, and Belgo Creek. These licenses supply domestic and irrigation water for farms and ranches in the lower (privately owned) portions of these valleys. Some homes and farms also have licenses on minor tributaries and springs in or adjacent to their property. Inspections of other individual water licence 'points of diversion' were not made, however it is assumed that these installations would be sensitive to increased peak flows or sediment loading.

Many kilometres of forestry road have been developed in the Mission watershed, mostly associated with harvesting in the upper plateau areas. The number of stream crossings estimated in the watershed above the BMID intake was 504 in 1998, including all tributaries (Dobson 1998). This number has likely increased with continued development. No comprehensive review of bridge capacities or forest road crossings, etc., was undertaken. Cumulative runoff effects will be less nearer the headwaters on the upper plateau. Where existing or proposed forest roads are on steeper slopes or within several hundred metres of steep-walled streams incised into the plateau, inadequate road drainage structures could lead to drainage redirection and landslides.

Rural properties along Mission Creek above Highway 33, Daves Creek, Belgo Creek and Joe Rich Creek have constructed bridge crossings for private access (driveways). The quality and capacity of these structures are likely quite variable and some are probably quite vulnerable to changes in flow regime and/or debris transport.

Highway 33 crosses Daves Creek on a sharp bend immediately above the intake site. Road drainage problems in this area have caused slope failures and sediment inputs. In the past, the culverts at the Highway 33 crossing of Joe Rich Creek have been blocked by sediment resulting in water overtopping the roadway. Increased peak flow and/or sediment loading from MPB or salvage harvesting could exceed the water and/or sediment capacity of these crossings resulting in impacts to water quality at the BMID intake.

Highway 33 crosses Mission Creek a short distance upstream of the Joe Rich confluence. Channel migration and bank erosion have threatened a residence just upstream of the bridge and changes to channel morphology could ultimately affect alignment of the channel through the bridge. The highway bridge crossing of Belgo Creek appears to provide adequate capacity, however there has been some bank erosion immediately upstream which could ultimately threaten the east abutment.

Reach 1 of Mission Creek between the canyon section and Okanagan Lake is highly developed with residential housing on at least one side for most of its length through the City of Kelowna. Over time, sediment transported from upstream will be deposited on the fan, leading to

aggradation and reduced channel capacity. The Mission Creek channel has been dredged three times since 1990 near the top of Reach 1. This is an expensive and disruptive undertaking, and may cause further channel destabilization (Burge 2009). Without dredging, increased sedimentation combined with changes to the flow regime could increase the frequency of flooding on the fan.

## 5.0 RISK ANALYSIS

### 5.1 WATER QUALITY AND INFRASTRUCTURE

Table 10 summarizes the partial risk analysis for water quality at the BMID water intake. The hydrologic hazard, which includes both incremental peak flow and sediment movement hazards, is the cumulative watershed Hydrologic Hazard at the lower end of the Mission Residual, at the BMID water intake (see Table 8).

**Table 10.** Partial risk analysis for BMID water intake.

Reach	Hydrologic Hazard (peak flow and sediment)		Water Quality Element at Risk: BMID Water Intake		Partial Risk	
	MPB	Full Salvage	Fine sediment impacts	Coarse sediment impacts	MPB	Full Salvage
Mission Residual	Mod	High	less aesthetic appeal, more microbiological activity, less effective primary treatment	Intake damage, maintenance	Mod	High

For the MPB infestation scenario (with no salvage harvesting) there is a Moderate Risk. In other words, following full MPB-related pine mortality a significant increase in fine and coarse sediment delivery to the BMID intake may or may not occur. With the full salvage of pine-leading stands scenario there is a High risk. That is, a significant increase in fine and coarse sediment delivery to the BMID intake is considered likely.

### 5.2 WATER SUPPLY

The consequence of potential decreases in later growing season water supplies on fish flows and other users is considered high. However, as discussed in Section 3.3.3, the effect of MPB and salvage mortality on growing season low flows will probably not be significant. Therefore the MPB-related risk to water supplies in Mission Creek is considered low.

As discussed in Sections 3.4, a much greater change in decreased streamflows and freshet timing is expected due to global climate change-related temperature increases, depending on the temperature increases that occur in the Okanagan over time.

### 5.3 FISH

For each sub-basin, hydrologic hazards (Table 8) are combined with the fish consequence values (Appendix E, Table 2) using a standard risk matrix (Appendix A, Table A1), to arrive at the fish habitat risk ratings in Table 11. As with consequence values, within a sub-basin

different reaches may have different risks. The risk value is defaulted to the highest risk reach in the sub-basin.

**Table 11.** Risks to Fish Values by Sub-basin

Sub-basin Name	Hydrologic Hazard (From Table 8)		Fish Consequence Rating	Risks to Fish habitat	
	MPB	Full Salvage		MPB	Full Salvage
Upper Mission	VL	VL	VH	M	M
Pearson	L	M	VH	M	H
Joe Rich	H	VH	H	VH	VH
Mid-Mission (Residual)	M	M	H	H	H
Upper Belgo	VL	M	H	L	H
Lower Belgo (Residual)	L	H	H	M	VH
Daves Ck.	H	H	M	H	H
Lower Mission Residual ( to BMID Intake)	M	H	H	H	VH
Fan	M	H	VH	VH	VH

Following the MPB/unharvested scenario, risks to fish habitat are generally Moderate to High in lower mainstem sub-basins, because mainstem consequence values are High to Very High and even the possibility of negative impacts (moderate hydrologic hazard) yields a High potential risk. With the full salvage scenario risks are High to Very High in most lower mainstem reaches

A Very High consequence rating was assigned to Reaches 1 and 2 on the Mission Creek fan, which is considered Kokanee spawning habitat. When combined with Moderate (post-MPB) and High (post-Full Salvage) hydrologic hazards, the risk to fish habitat in this reach is Very High following either scenario.

Degradation to fish habitat in the mainstem channels would likely result from increased sediment mobilization and deposition, causing aggradation, reduction in pool depths, cementing of substrates and generally a reduction in habitat quality, especially in spawning areas.

#### 5.4 SOCIAL INFRASTRUCTURE

To determine infrastructure risk ratings the hydrologic hazard derived for the watershed is combined with infrastructure vulnerability ratings presented in Table 9, using a standard risk matrix (Appendix A, Table A2). The cumulative watershed hydrologic hazard at the BMID intake is used in the social infrastructure risk analysis. Except for forest roads, social infrastructure is located lower in the watershed, where cumulative watershed effects will be felt. Forest roads occur in all sub-basins, which have different hydrologic hazard ratings. For simplicity the cumulative watershed hydrologic hazard rating is used for forest roads as well. A more detailed forest road risk analysis for can be carried out by using the individual sub-basin hazard values shown in Table 8.

**Table 12.** Social Infrastructure Risk Ratings

Item at Risk	Consequence Vulnerability Rating	Hydrologic Hazard		Infrastructure Risk Ratings	
		MPB	Full Salvage	MPB	Full Salvage
Licensed Water Intakes	H	M	H	H	VH
Forestry Roads and road-related gentle-over-steep landslides	M	M	H	M	H
Private Bridge Crossings (Agricultural lands and Driveways)	H	M	H	H	VH
Highway 33 Culvert Crossings (Daves, Joe Rich)	H	M	H	H	VH
Highway 33 Bridge Crossings (Mission, Belgo)	M	M	H	M	H
Residences and Development on Fan	M	M	H	M	H

Following the unharvested MPB attack scenario, risks to infrastructure range from Moderate to High. Following the hypothetical full salvage scenario risks range from High to Very High. High to Very High risks have been assigned to private water intakes and private bridge crossing licenses as a result of an inferred sensitivity of these installations to increases in sediment movement impacts. Most privately constructed works are done to a lower standard than forest or provincial roads, or municipal water intakes.

Forestry road drainage structures may have limited capacity for increased flows or sediment and debris movement, which, particularly following the full salvage scenario, may cause failure of those structures. This can result in redirected drainage and, if near steeper incised stream

escarpments, increased risks of large damaging landslides, similar to those which have occurred in the past in this watershed.

High risks have also been assigned to the Highway 33 culvert crossings on Daves and Joe Rich Creeks. Problems have previously occurred at both these sites and upgrades have not been undertaken. Risk ratings for Highway 33 bridges crossings have been assigned Moderate to High risks respectively under the MPB and Full salvage scenarios. Problems could occur at the bridge sites if channel aggradation significantly reduced the available bridge opening, or in the case of Mission Creek, substantially changed the channel alignment. Abutments could be threatened by channel destabilization and/or erosion.

Channel infrastructure and residences on the fan would be subject to a Moderate risk of flooding post-MPB, potentially increasing to a High risk under the hypothetical full-harvest scenario. The most likely scenario for problems on the fan would involve accumulated sediments filling the constructed channels (over time) eventually allowing extreme peak flows to overtop dykes causing flooding of adjacent properties. Monitoring and maintenance (dredging) of the channel system could anticipate and prevent this type of failure, however other problems are often associated with this approach (Burge 2009).

## **6.0 CONCLUSIONS AND RECOMMENDATIONS**

### **6.1 CONCLUSIONS**

The water quality parameters most strongly linked to MPB infestation and salvage logging in Mission Creek watershed are increases in peak flows (floods) and associated mobilization of fine and coarse sediment from stream channel beds and banks. Following the complete mortality of all pine and with no further harvesting in Mission Creek watershed there is a Moderate Risk, which means some increase in fine and coarse sediment delivery to the BMID intake may or may not occur. Following the full salvage of pine-leading stands in the watershed an increase in the size and frequency of floods is expected to last for 15 to 20 years, and a significant increase in sediment delivery to the BMID intake is expected. Source water turbidity levels have been and will continue to present a problem at the BMID water intake, in terms of meeting Interior Health Authority water quality guidelines. MPB mortality alone may or may not result in a noticeable increase in turbidity, but high salvage harvest levels will likely exacerbate turbidity problems. In particular, high levels of salvage harvesting in the Joe Rich, Upper Belgo and Lower Belgo sub-basins will increase risks lower in the watershed. The low amount of pine-leading stands in the upper Mid-Mission and Pearson Creek sub-basins shown in existing forest cover inventories would suggest significant salvage harvesting is not warranted there. Harvesting in those types of stands in upper Mid-Mission and Pearson Creek sub-basins will increase downstream risks even more than MPB salvage harvesting in other sub-basins.

There is little evidence of links between MPB and salvage effects and the water quality parameters of total organic carbon, true colour, metals and total phosphorous, and measurable change in these parameters in Mission Creek are not expected. The effect of MPB and salvage mortality on growing season low flows will probably not be significant. Therefore the MPB and salvage harvest-related risk to water supplies in Mission Creek is considered low. A much

greater change in decreased streamflows and freshet timing is expected due to global climate change-related temperature increases.

There are fish present and high habitat values along much of the Mission Creek mainstem. This results in a High Risk of negative impacts following MPB-related pine mortality, mainly due to increased sediment movement, channel aggradation and a reduction in habitat quality. If there is widespread salvage harvesting the risk of negative impacts on fish populations in these lower mainstem reaches will be Very High. The likelihood of negative impacts is even more likely in Kokanee spawning habitat in Reaches 1 and 2 on the Mission Creek fan, where risks to fish habitat are Very High following either management scenario.

All social infrastructure risk values have a higher risk for the full salvage scenario than for the MPB/unharvested scenario; because of the increased hydrologic hazard associated with clearcut salvaging in the types of stands present in the Mission Creek watershed. Risks to residences on the Mission Creek fan, forestry roads, forest road-related “gentle-over-steep” landslides and Highway 33 crossing are considered moderate and high for the unharvested MPB and full salvage scenarios respectively. Risks to private water intakes and private stream crossings in the watershed are considered High to Very High respectively, because they are generally built to a lower standard than forestry or public works.

## **6.2 RISK MITIGATION**

Recommendations to reduce risks focus on either protecting and strengthening risk elements, or reducing stand-level MPB and salvage effects.

### **6.2.1 FOREST FOR TOMORROW ACTIVITIES**

The Forest For Tomorrow program was created to respond to the MPB infestation in B.C. Its mandate is to improve the future timber supply and address risks to other forest values. Discussions with program administrators and others involved in the program in the Okanagan provided information on FFT activities being carried out the Southern Interior. These are:

- rehabilitation of MPB attacked immature or small diameter stands (>70% pine, <50yrs) with some economic recovery (clearcut harvest, site prep, replanting)
- rehabilitation of attacked plantations (site preparation, which destroys the plantation, and replanting)
- rehabilitation of attacked mature stands with no commercial value (cut, pile, burn, plant). This is expensive and is considered unlikely to be widely implemented.

Hydrologically, these treatments are the same as clearcutting and have the same effect in removing stand hydrologic function, if the treated stands have some hydrological function at the outset. However, it is our understanding that overstory and understory composition in stands proposed for treatment are assessed, and stands with significant non-pine overstory and healthy understory are not treated, but are left to recover naturally. Therefore these treatments will not significantly increase the short term ECA in the watershed. On the other hand the treatments promote more rapid recovery and a healthier and more economically viable stand.

It appears that activities that could increase forest health and productivity, while maintaining the existing hydrological function of the attacked stand, such as under-planting mature attacked stands, have had little success. This is due to the expense and to high seedling mortality from hares and rodents, which apparently can survive better in the attacked forest than in a clearcut (Stuart Parker RPF, pers. comm.). Other trials are underway (Doug Lewis RPF, pers. comm.) which may address outstanding under-planting issues. Currently we know of no operational under-planting of attacked stands being done by FFT or others.

FFT activities that are being implemented will improve the long term health and economic value of the forest, and in the long term help restore hydrological forest function; but they will not mitigate the potential short term hydrological impacts of MPB attack and salvage harvesting in Mission Creek, as discussed in this report.

## **6.2.2 Risk Mitigation Recommendations**

### **Riparian Management**

As discussed in Section 2.3, riparian management along streams during salvage harvesting will be important in maintaining short and long term temperature and large woody debris recruitment levels, and to preserve stream stability and fish habitat quality. Given that research has found LWD input rates are similar for MPB attacked and non-attacked Okanagan stands, riparian zones in MPB attacked stands should be preserved. At a minimum best riparian management practices for “green wood” harvesting in the Okanagan should be followed when salvage harvesting MPB-attacked stands.

### **Fish Habitat Management**

Maintaining good riparian condition and instream LWD throughout the watershed will help to mitigate potential impacts on fish habitat. Since the effects of unharvested MPB-attack are uncertain and we don't know what level of harvesting will occur in the watershed, it would be prudent to periodically update on-site fish habitat assessments for reaches upstream of the fan (last done in 1996), monitor channel and riparian conditions and carry out rehabilitation activities as necessary. Detailed analyses of rehabilitation strategies in the Kokanee spawning habitat of Reaches 1 and 2 on the Mission Creek fan have been completed (Burge 2009 and 2010, Gaboury and Hawkes 2003 and 2004). Rehabilitation efforts will help offset habitat degradation that has occurred there as a result of channel modification through the City of Kelowna. Any such efforts should take into consideration the likelihood of increases in sediment delivery to those reaches, particularly if widespread salvage harvesting occurs in the watershed.

### **Forest Road Drainage Management**

Numerous natural landslides and some public highway and forest road-related landslides have occurred in the watershed in the past (see Section 3.1). In all cases they occurred on steeper stream valley walls and escarpments where tributary and mainstem streams are incised into flat to gentle sloping upland plateaus. While most sediment loading to stream channels is the result of naturally occurring landslides, their occurrence, and the occurrence of road-related landslides indicates that many slopes are only marginally stable, and will fail if disturbed. In Southern Interior B.C. the most common forest development-related disturbance resulting in landslides is interception, concentration and redirection of surface and/or subsurface hillslope drainage, by roads and trails located on gentle gradient slopes, onto moderately steep (50-70%)

to steep (>70%) gradient slopes, not previously subject to concentrated water flows. (Jordan 2002, Grainger 2002). This results in landslides on the steeper slopes and the process is known as “gentle-over-over steep” (GoS) landslides. Particularly in sub-basins where significant increases in peak flows are predicted (Joe Rich and upper and lower Belgo sub-basins) or if significant salvage harvesting is planned in any area, a review of trail and road drainage structures (ditches, ditch blocks, culverts, cross-ditches, bridges, etc.) located within 200 to 400m of steeper stream escarpment slopes is recommended. Any structure which appears to be operating near its capacity, to be damaged or otherwise compromised so that it is not working at its design capacity, or is otherwise insufficient to accommodate some increase over historic flows, should be upgraded to accommodate larger flows. Reviews and drainage plans designs should be carried out by a geotechnical professional with expertise in mitigating GoS landslides.

### **Stand and Watershed ECA Hazard Management**

We know of no way to reduce the magnitude and duration of the ECA hazard in MPB-attacked unharvested stands in the absence of an effective under-planting program. However the incremental risks related to unharvested MPB-related ECA hazards are moderate to BMID water quality and water supply infrastructure, and low to water supply. Post unharvested MPB risks are moderate for most other infrastructure, high for private water intakes and crossings and high to very high for fish values in lower mainstem stream reaches.

Even though hazards related to changes in forest cover (ECA) - whether from MPB mortality or clearcut salvage harvesting - are relatively low in Mission Creek watershed; ECA hazards are higher following the full salvage harvest scenario than following the unharvested MPB scenario. Therefore incremental risks are higher for all elements at risk in the watershed following the hypothetical scenario of full salvage harvest of all pine-leading stands, compared to the potential risks if all pine-leading stands were left unharvested. To reduce those risks to an acceptable level will require managing the amount and location of salvage harvesting in the watershed.

While it makes good hydrological sense to harvest attacked pine stands rather than “green” non-pine stands, removing too much MPB-attacked forest will increase watershed hazards and risks. To manage the incremental hydrologic impact of salvage harvesting it is recommended that:

- licensees use a hydrological risk assessment methodology that models the effects of non-pine overstory and understory stand structure in dead pine stands to get a more accurate picture of the hydrological condition of the watershed, and of the potential impacts of proposed salvage harvesting. Hydrological risk analyses that treat all MPB attacked stands as having little or no hydrological forest function (i.e., as having initial ECA values similar to clearcuts) may seriously underestimate the incremental hydrological risks associated with widespread clearcutting of attacked stand that have hydrologically significant stand characteristics.
- From a strictly hydrological perspective (and we recognize forest managers have to balance many different forest values), the least hydrological impact would result if pine-leading stands with the lowest non-pine overstory component and lowest understory stocking were preferentially targeted for salvage harvest. From the data collected here the stands in the snow zone with least hydrological function would be younger MSdm stands followed by older MSdm stands and then ESSFdc stands (see Figures 6-8 and Appendix B).

- Forest Inventory data suggest there are few pine-leading stands in ESSFxc stands, which comprise over 50% of the hydrologically sensitive upper elevation snow zone in Mission Creek watershed. While extensive MPB salvage is not expected in these types of stands, should significant harvesting occur there, there will be greater watershed hydrologic impacts than predicted in this study. If in the near future a significant amount of harvesting is planned in ESSFxc stands in upper Mid-Mission or Pearson sub-basins, the risk analyses as done in this study would underestimate risks, and should be redone.
- We recognize that individual stands within broader biogeoclimatic types will have different characteristics than the average overstory and understory values used in this analysis; site specific surveys of stand characteristics in areas proposed for harvesting are recommended. Salvage harvesting should be focused on those stands with the least non-pine overstory and little healthy understory.
- The widespread and severe MPB epidemic in B.C. is clear evidence that forests can be subjected to significant unforeseen disturbances, with potentially significant consequences. Because of the types of forests present, the expected hydrological effect of unharvested MPB infestation and pine tree mortality in Mission Creek Watershed is not expected to be catastrophic for most of the identified watershed values (risk elements). Salvage harvesting, if widespread enough, can increase those risks. But with good management of harvesting rates and sites which recognizes the hydrological function of different pine-leading stand types, forest development should be possible with a level of risk that is acceptable to watershed stakeholders. However MPB infestation may not be the only significant source of stress on Mission Creek forests in the near future. Global warming and global warming-related disturbances such as other pathogens which could attack other tree types, and fire, etc., are not improbable. A Spruce beetle infestation in the widespread spruce balsam stands in the upper watershed, and associated salvage harvesting, could considerably change the risk situation in Mission Creek watershed. We think that part of the determination of what is an acceptable level of risk should include considering the potential hydrological (and other) effects of this and other possible disturbances. To manage for them it would be prudent to apply the precautionary principle and preserve some hydrological function in the watershed above the minimum required to manage only for MPB and MPB-related salvage impacts.

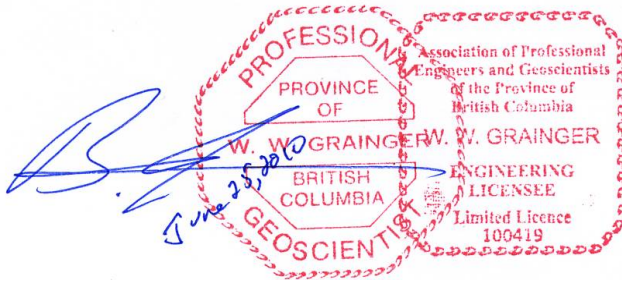
## 7.0 CLOSURE

This investigation has been carried out in accordance with generally accepted Geoscience and Engineering practice. Geoscience and Engineering judgement have been applied in developing the conclusions and recommendations in this report. No other warranty is made, either expressed or implied.

We trust that this report satisfies your present requirements. Should you have any questions or comments, please contact our office at your convenience.

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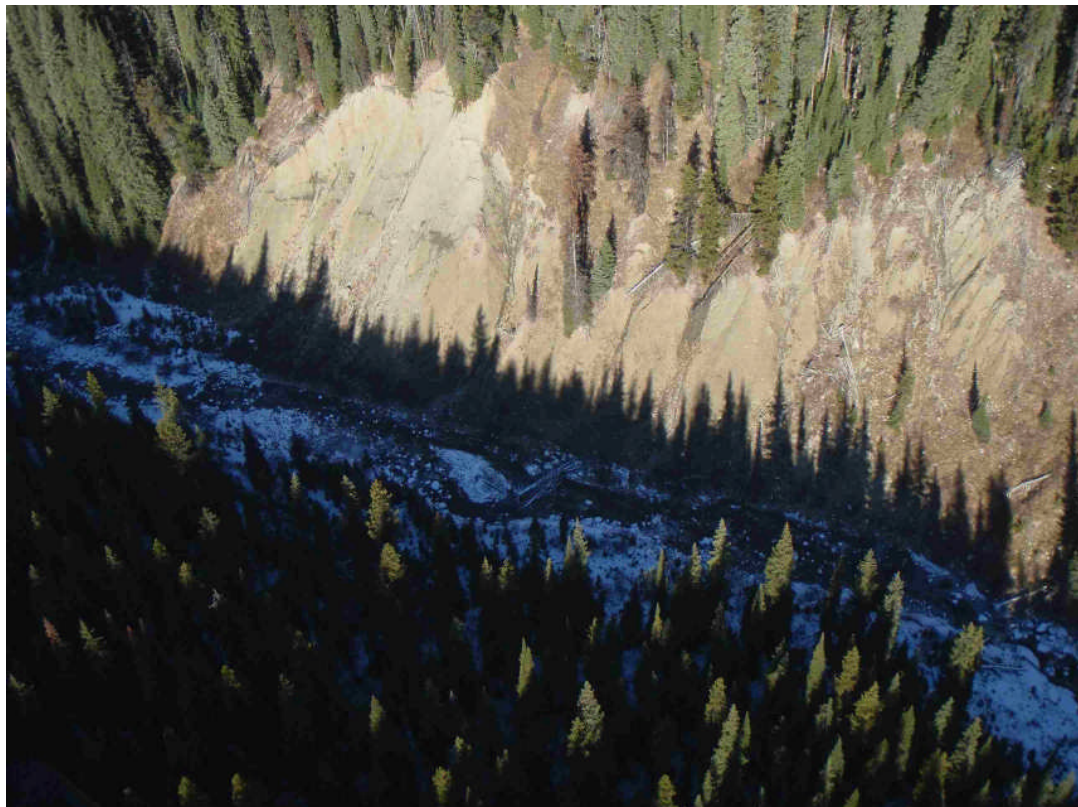
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# PHOTOS



**Photo 1.** Broad gently sloping upland plateau of Mission Creek watershed, in Belgo Creek drainage. Large clearcut with regeneration in foreground harvested in 1980s.



**Photo 2.** Typical failing till sideslope of lower Fish Hawk Creek, delivering sediment to channel.

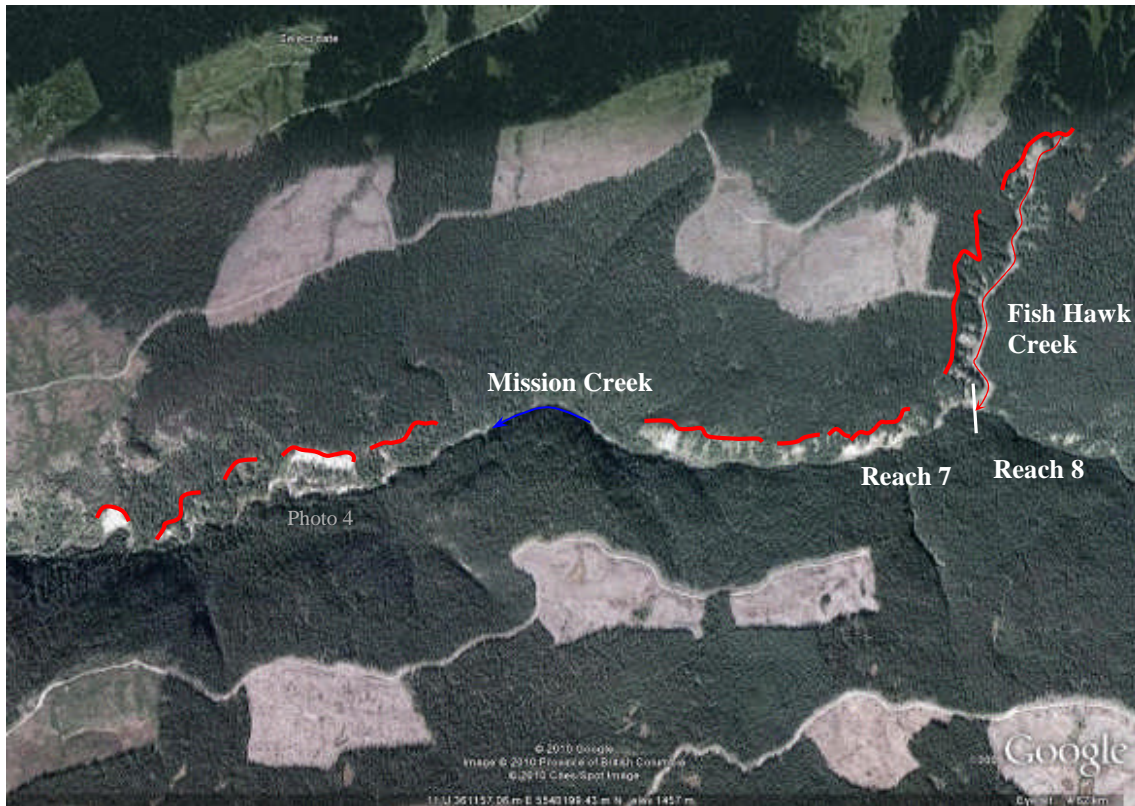


Photo 3. Lower Fish Hawk Creek debris flood/flow to junction of Upper Mission Creek (narrow red arrow), with numerous large landslides over time into both Creeks (thick red lines). Most cutblocks and roads in photo postdate landslides, which are not related to forest development (Google Earth image).



Photo 4. 250m long debris slump in Reach 6 Mission Creek. Initiated during 1997 high peak flows.



**Photo 5.** Regenerating valley sidewalls of Mission Creek in Reach 6, intensively harvested in 1980's.  
Note riparian reserve in steep gully to right of photo.



**Photo 6.** Regenerating 1980's harvesting, with no riparian retention  
around section of tributary gully to Mission Creek (Reach 6)



**Photo 7.** Mission Creek (Reach 5) bank erosion of thick sand, gravel and cobble glaciofluvial and fluvial sediments.



**Photo 8.** Mission Creek (Reach 4) bank erosion of thick sand, gravel and cobble glaciofluvial and fluvial sediments.



**Photo 9.** 1500m long, 17ha landslide responsible for 3 fatalities on Philpot Road in 1990, caused by drainage redirected along forest road.



**Photo 10.** Section of Joe Rich Creek floodplain on private land, with flood plain vegetation removed and severe bank erosion.



**Photo 11.** Reach 4, about 4.5km upstream of BMID intake. Large debris slump and Mission Creek eroding thick toe of slide



**Photo 12.** Typical large debris slump downslope of Highway 33 in lower Daves Creek.



**Photo 13.** Reach 6 Mission Creek, aggraded and widened (Oct 27 2008)



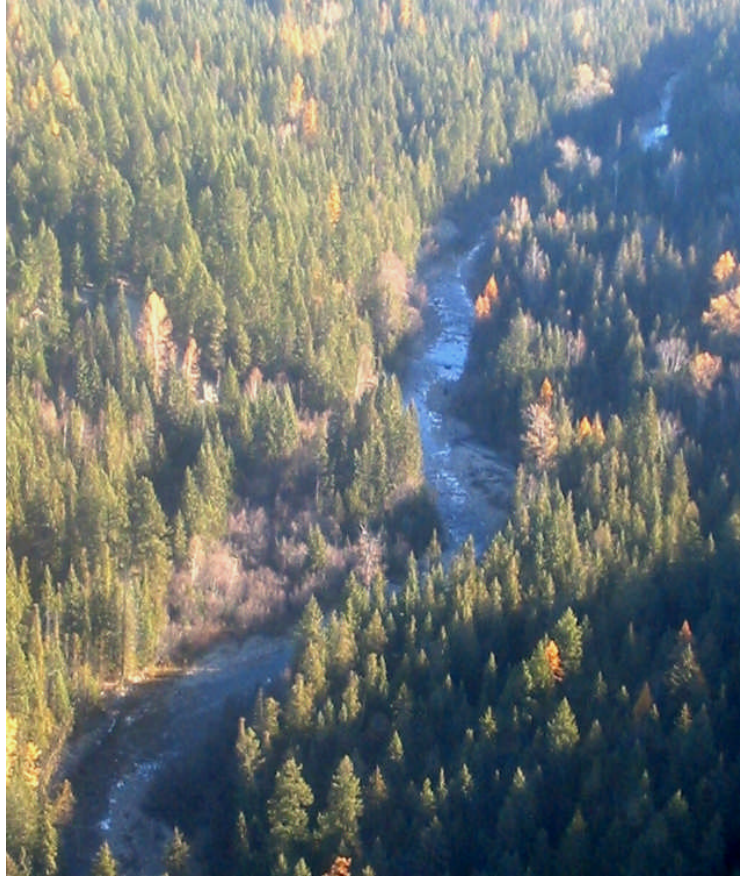
**Photo 14.** Lower end of Reach 6, aggraded and widened (Oct 27 2008).



**Photo 15.** Reach 5 Mission Creek, aggraded and widened (Oct 27 2008).



**Photo 16.** Joe Rich Creek Reach 2. Bank weakened by removal of riparian vegetation; eroding and causing channel aggradation.



**Photo 17.** Mission Creek Reach 4, generally less aggraded than upstream reaches.



**Photo 17.** Reach 4, Mission Creek aggraded section of channel below large debris slump 4.5 km upstream of BMID intake.



**Photo 19.** Reach 1 of Mission Creek, channelized and dyked. Okanagan Lake in background.



**Photo 20.** Young (70-110 yrs) MSdm stand in upper Belgo sub-basin.  
Almost pure pine overstory and limited Balsam understory (<200 stems/ha)



**Photo 21.** Typical ESSFdc stand with dominant Spruce and Balsam overstory and >1000 stems/ha understory seedlings, saplings and poles.

## Appendix A:

### Risk Analysis Definitions

## Appendix A: Risk Analysis Definitions

Risk is defined as the product of hazard and consequence:

$$\text{Hazard} \times \text{Consequence} = \text{Risk}$$

In this report, hazards are the likelihood of specific hydrological changes in the watershed due to MPB infestation and salvage harvesting-related modifications in watershed forest cover.

Consequences are the presence of some element of value, such as a “sufficient and reliable supply of safe and aesthetically acceptable water” at the District of Summerland intake, which could be impacted by a specific hydrologic hazard. Where the risk analysis focuses on a hazard which will impact a particular element, but does not include details of the vulnerability, robustness or economic value of the element, it is known as a “partial risk analysis” (Wise, *et al.*, 2004).

Where the vulnerability and/or the value of the element are considered, the analysis is referred to in this report as the incremental risk. For instance in this report the vulnerability of infrastructure such as bridges, etc., are considered. Incremental means an increase in risks due to the specific hazard and its ultimate source, which in this case are MPB-related stand mortality and associated salvage harvesting.

In all cases the hazards and consequence ratings are qualitative. Hazard ratings are expressed as very low, low, moderate, high or very high. As shown in Table 1, these can be understood as meaning the specific hazardous event is rare, unlikely - but possible, possible - may or may not occur, likely to occur and very likely or almost certain to occur, respectively. Consequence ratings are also expressed as very low to very high (5 classes - Table A1) or as low to high (3 classes), if there is not enough known about the element at risk to realistically discern more than 3 levels of its environmental or social value and/or vulnerability.

Table A1. Risk matrix with 5 hazard and consequence classes.

<b>Hazard</b> - Likelihood of Occurrence	<b>Consequence</b>				
	<b>Very Low</b> (insignificant)	<b>Low</b> (minor)	<b>Medium</b> (medium)	<b>High</b> (major)	<b>Very High</b> (catastrophic)
<b>Very High</b> (almost certain)	Moderate	High	High	Very High	Very High
<b>High</b> (likely)	Moderate	Moderate	High	Very High	Very High
<b>Moderate</b> (possible)	Low	Low	Moderate	High	High
<b>Low</b> (unlikely, but possible)	Very Low	Very Low	Low	Moderate	Moderate
<b>Very Low</b> (rare or unknown)	Very Low	Very Low	Low	Low	Moderate

Adapted from Wise, *et al.*, 2004.

Table A2. Risk matrix with 5 hazard and 3 consequence classes.

Hazard	Consequence		
	Low	Moderate	High
Very High	High	Very High	Very High
High	Moderate	High	Very High
Moderate	Low	Moderate	High
Low	Very Low	Low	Moderate
Very Low	Very Low	Very Low	Low

The description of qualitative risk terms are similar to hazard descriptions; a very low risk means any impact or damage to the element at risk is very unlikely, a low risk means minor impact or damage could occur but is not considered likely, a moderate risk means some impact or damage may or may not occur, a high risk means that significant impact or damage to the element at risk is considered likely, and a very high risk means very significant impacts or damage are considered very likely.

There are other risk matrices in common use. Table A3 is a 5 x 5 matrix used by B.C. Ministry of Health and B.C. Ministry of Environment in the Comprehensive Drinking Water Source to Tap Assessment Guideline (MoH, 2005). In that matrix risk ratings are weighted towards the consequence values and the resulting risk ratings are more conservative (higher risk rating) than Tables A1 and A2, which are used in this report.

Table A3. Risk matrix suggested in Comprehensive Drinking Water Source to Tap Assessment Guideline

Hazard - Likelihood of Occurrence		Consequence				
		Insignificant (1) VL	Minor (2) L	Medium (3) M	Major (4) H	Catastro-phic (5) VH
Almost Certain (A)	VH	M	H	VH	VH	VH
Likely (B)	H	M	H	H	VH	VH
Possible (C)	M	L	M	H	VH	VH
Unlikely (D)	L	L	L	M	H	VH
Rare (E)	VL	L	L	M	H	H

Adapted from MoH, 2005.

The accompanying report provides a qualitative evaluation of potential hydrologic hazards associated with MPB attack and salvage harvesting. Suggestions as to qualitative values that could be applied specific consequences are made in this report, so that a risk analysis procedure for the specific hazards can be presented. However the final determination of consequence values, the risk analysis methodology and risk matrix used are the responsibility of watershed stakeholders. Risk assessment, which uses the risk analysis results and includes a determination of what level of risk is acceptable, and what steps should be taken to mitigate that risk, is entirely the responsibility watershed stakeholders.

## Appendix B:

### Summary of South Okanagan Stand Survey Results.

Prepared by Dave Huggard.

## Summary of Results from South Okanagan Stand Surveys for MPB-ECA Modeling

Data summary by David Huggard (Jan 2009). From field data collection by Stuart Parker (Nov-Dec 2008) for Grainger and Associates Consulting Ltd.

### Executive Summary

This field study measured overstory composition and understory density in 30 stands, representing 6 major pine-leading stand types in MSdm and ESSFdc forest, which comprise most of hydrologically important upper elevations of the south Okanagan watersheds studied. The field study is one component of projecting effects of mountain pine beetle (MPB) and salvage on hydrological equivalent clearcut area (ECA). At least 8 plots per stand, for a total of 245 plots, were used to measure total and well-spaced densities (stems per hectare, sph) of seedlings, saplings and poles by species, and basal area of overstory by species, following suggested provincial methods for surveying “secondary structure”. MPB attack status of overstory pines was also recorded.

In ESSF, the 7 surveyed stands labelled as pure pine or pine-leading were found to have only 30% pine basal area, with spruce and subalpine fir equally common. [This is not due to MPB mortality, because MPB-killed pine were included in these surveys.] Older (>110 yr) pine-leading stands in the MS averaged 65% pine, with a mix of subalpine fir, spruce and Douglas-fir. Mid-seral (<110 yr) pine-leading stands in MS were closer to 90% pine.

Understory densities ranged from high in ESSF to moderately high in older MS to moderately low in mid-seral MS. Counting only trees >1.3m tall that meet spacing and acceptability criteria for good stocking, and excluding lodgepole pine poles (>7.5cm dbh) because these may be killed by MPB, understory densities in ESSF averaged nearly 1000 sph. In MS stands >110yr old, density of these well-spaced understory trees averaged 560 sph, while mid-seral MS stands had 280 sph.

In terms of stocking of individual plots, 60% of ESSF plots had at least 1000 well-spaced sph, somewhat higher than the 40% of plots stocked at this level in Kamloops area ESSFdc (Vyse et al. 2007). In MS >110 yr, 30% of plots had at least 1000 well-spaced sph, while 65% had at least 400 well-spaced sph. Only 11% of mid-seral MS plots were stocked at 1000 well-spaced sph, while 32% were stocked at 400 well-spaced sph. These MS values are also comparable to results from Vyse et al. in Kamloops area MS stands (15-39% of plots stocked at 1000 sph, 40-70% at 400 sph).

Overall, these surveys suggest that ESSF stands should show little effect of MPB on ECA, because of dominant non-pine overstory and high understory stocking. Older pine-leading MS stands will also receive a substantial contribution to reducing post-MPB ECA from non-pine overstory and a substantial understory. Mid-seral (<110 yr) MS stands will have only a small initial contribution due to limited non-pine overstory and moderately low understory levels, although the existing understory will help speed up post-MPB recovery. As in other areas that have been surveyed in the Southern Interior, non-pine overstory and existing understory are important components of pine-leading stands in the southern Okanagan highlands.

The effects on ECA projections of non-pine overstory and existing understory – along with other stand components – are presented in detail in a separate report. An example of a plot showing the ECA projections for MPB attacked stands and clearcut salvaged attacked stands used in modeling watershed ECA projections for South Okanagan Community Watersheds follows this summary.

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## Summary of Results from South Okanagan Stand Surveys for MPB-ECA Modeling

*Purposes:* This study was undertaken to provide information on:

1. Canopy composition,
2. Understory trees,
3. Current status of mountain pine beetle (MPB) attack,

in pine-leading stands in the south Okanagan highlands<sup>1</sup>, as part of a project evaluating the effects of MPB and salvage options on hydrological equivalent clearcut area (ECA). The project focused on 6 combinations of age and reported pine percentages in mature pine-leading stands in ESSFdc1 and 2, and MSdm1 and 2. Canopy composition and existing understory are important parameters in projecting MPB effects on ECA and the relative short- and long-term benefits of salvaging and planting versus leaving affected stands unsalvaged. Information on percentages of pine and non-pine canopy species is provided by forest cover maps, but can be of low reliability. Understory surveys in pine-leading stands have been conducted in MS and ESSF in adjacent areas, but in the absence of local surveys, opinions about understory were diverse for the south Okanagan pine-leading stands. The information on current MPB attack allows ECA projections to start at current conditions in each watershed.

### Methods

#### *Sample design*

Six stand types compose the majority of the pine-leading stands in the hydrologically important upper elevations of the south Okanagan watersheds (Table 1).

**Table 1. Six stand types sampled in the higher elevations of south Okanagan watersheds.**

<b>BEC subzone</b>	<b>Pine (VRI %)</b>	<b>Age (yr)</b>	<b>Percent of total PI area</b>	<b>Polygons</b>	<b>Plots</b>
ESSFdc	100	70-130	6.7	4	32
	<80	>130	4.7	3	24
MSdm	100	70-110	22.9	8	64
	100	>110	25.2	10	85
	<90	70-90	2.4	2	16
	<80	>150	6.0	3	24
			68.0	30	245

A total of 30 forest cover polygons to sample were chosen randomly from the set of relatively accessible stands of these types, with effort roughly proportional to the area of each type. Polygons were on both sides of Okanagan Lake (ESSFdc1 and MSdm1 on the east side, ESSFdc2 and MSdm2 on the west side).

#### *Field measurements*

At least eight plots spaced 50m apart were surveyed in each polygon for a total of 245 plots. In each plot, seedlings (0.3-1.3m tall), saplings (>1.3m tall to 7.5cm dbh) and poles (7.5-15cm dbh) were measured in 3.99m-radius plots. Total and well-spaced undamaged stems were tallied by species for each layer. With the size of the plot, there is a maximum of 8 well-spaced stems per plot (=1600 stems per hectare). Canopy trees ( $\geq 15$  cm dbh) were counted by species using a BAF 2 prism. Status of attack by mountain pine beetles was recorded for canopy pines: none, green attack, red attack or grey attack.

<sup>1</sup> The study area includes the Mission, Hydraulic, Penticton, Lambley, Trepanier, Peachland and Trout Creek Community Watersheds.

### *Analysis*

Results from the two variants of each subzone were combined, because there were limited samples in each and no obvious differences in the results.

Species composition of the canopy was summarized for each plot, then averaged for each polygon, and finally the polygons were averaged within a stand type. Percent composition was based on basal area (BA), because that was provided by the prism plots. BA is assumed to provide a reasonable representation of canopy composition, which is directly relevant to ECA.

Density of each species, of all non-pine species, and of all species combined was calculated for each plot, then averaged for the polygon, separately for seedlings, saplings and poles, for sapling+poles combined and for all three layers combined. Averages and standard errors (SE) in a stand type were calculated. For saplings and poles, these values were calculated separately for all trees, and for well-spaced trees. Additionally, the density of all species of saplings plus all species of poles *except* lodgepole pine were also summarized, for all trees and just well-spaced trees. This value is probably the most relevant for regeneration after MPB (which is assumed to kill the pole-size lodgepole pine). This total density was summarized by stand type, and also by the combination of stand type and watershed (allowing watersheds to be compared within any stand types that they share).

Following the approach of Coates et al. (2006) and Vyse et al. (2007)<sup>2</sup>, we also summarized the proportion of plots in each stand type that were stocked at minimum levels from 200 stems per hectare (sph), 400 sph...through 1600 sph. This was done separately for all understory layers combined (seedlings, saplings, poles), saplings+poles combined, and for well-spaced saplings+poles. These values were compared to results from Vyse et al. in ESSF and MS subzones in the Kamloops area, and to stocking results from Nigh et al. (2008)<sup>3</sup>.

The percentage of canopy lodgepole pine in four MPB attack stages – no attack, green, red and grey attack – was summarized by stand type and also by the combination of stand type and watershed.

## **Results**

### *Canopy composition*

The two ESSF stand types, including stands labelled 100% pine, had roughly equal basal areas of pine, spruce and subalpine fir (Table 2). Even in stands labelled as pure pine, the maximum percentage of pine in the canopy was 63.7%, while one of these stands had no pine. The prevalence of non-pine canopy suggests that MPB will have only small effects on ECA in ESSF stands in this area. [Note: Pines killed by MPB were included in these canopy surveys, so the results are not due to pine being removed by MPB.]

In the MS, stands labelled as 100% pine had 86.3% and 74.0% pine basal area, for mid-seral and mature stands, respectively. The stands >110 years had a larger component of

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<sup>2</sup> Coates, K.D., C. Delong, P. Burton and D. Sachs. 2006. Draft Interim Report. Abundance of Secondary Structure in Lodgepole Pine Stands Affected by the Mountain Pine Beetle. Bulkley Valley Centre for Natural Resources Research and Management 22 p.

Vyse, A., C. Ferguson, D. Huggard, J. Roach and B. Zimonick. 2007. Regeneration below lodgepole pine stands attacked or threatened by mountain pine beetle in the Kamloops Timber Supply Area. Thompson Rivers University, Kamloops, BC. Available from Alan Vyse or Dave Huggard.

<sup>3</sup> Nigh, G.D., J.A. Antos and R. Parish. 2008. Density and distribution of advance regeneration in mountain pine beetle killed lodgepole pine stands of the Montane Spruce zone of British Columbia. *Can. J. For. Res.* 38:2826-2836. They present total trees for each of their plots, but include trees down to 10cm height. They also provide information on the overall proportions of trees in each height class. An approximate idea of the stocking of saplings+poles in each plot was obtained by assuming that the overall proportion of trees 1-10m tall (24.8% of understory trees) applied to each plot. Results were combined for dry, mesic and wet sites, as these shared a similar range of variation in plot-level stocking.

subalpine fir and spruce than the 70-100year stands. Mid-seral stands labelled as having <90% pine averaged 91.1% pine, with Douglas-fir being the other substantial component in the two sampled stands. In contrast, the three mature stands labelled as <80% pine averaged 33.0% pine basal area, with subalpine fir, spruce and Douglas-fir all common. The non-pine components will make at least a moderate contribution to reducing ECA effects of MPB in MS, even in “pure pine” stands.

**Table 2. Canopy composition in six pine-leading stand types.**

BEC	Stand type		Canopy composition (%BA)				PI range (%)		n
	Pine (%)	Age (yr)	PI	BI	Sx	Fd	Min	Max	
ESSFdc	100	70-130	33.3	35.5	31.2	0.0	0.0	63.7	4
ESSFdc	<80	>130	26.8	31.2	42.0	0.0	25.0	29.7	3
MSdm	100	70-110	86.3	8.6	3.9	0.2	62.9	100.0	8
MSdm	100	>110	74.0	11.0	12.3	2.6	30.6	100.0	10
MSdm	<90	70-90	91.1	1.8	0.8	6.3	83.7	98.4	2
MSdm	<80	>150	33.0	36.4	19.0	11.5	24.7	39.2	3

Notes: MSdm 100% 70-110yrs and >110yrs contained 0.9% and 0.2% aspen, respectively

#### *Stage of mountain pine beetle attack*

MPB appears to have begun to attack the surveyed mid-seral ESSF stands only recently, with 89.8% of mature pines not attacked, and more green attack than red or grey (Table 3). Attack rates are also still low in the older ESSF stand type, with 73.3% of pines not attacked. In older ESSF, though, the attack began a few years ago, with equal amounts of grey and red attacked trees.

Attack rates are somewhat higher in most MS stands, with a mix of older versus more recent attack stages in the different types. The old, mixed species stands, despite not having a high percentage of pine, had high rates of attack, with only 15.5% of pines not attacked.

**Table 3. Percentage of canopy lodgepole pine (PI) in different stages of mountain pine beetle attack, by stand type.**

BEC	Stand type		PI Attack status (%)			
	Pine (%)	Age (yr)	None	Green	Red	Grey
ESSFdc	100	70-130	89.8	5.0	1.4	3.8
ESSFdc	<80	>130	73.3	1.8	12.3	12.7
MSdm	100	70-110	68.5	13.7	10.6	7.1
MSdm	100	>110	64.0	9.1	16.2	10.7
MSdm	<90	70-90	73.6	0.9	15.1	10.4
MSdm	<80	>150	15.5	19.2	39.4	25.9

Much of the variation in attack rates in MS stand types seems to be due to different amounts of MPB in different watersheds (and the fact that stand types are not equally spread across the watersheds.) The Bear Lambly watershed had very few pines that were not attacked, even in ESSF where MPB activity was otherwise low (Table 4). Except in the ESSF, the Trepanier watershed also had high attack rates, but with a higher percentage of recent green attacked pines than Bear Lambly. The Peachland watershed had moderate attack rates, while attack rates are still low in the Hydraulic, Mission and Trout watersheds. Although, these results are based on only 1 or 2 stands in each stand type in each watershed, they agree with MPB survey results for the watersheds provided by Ministry of Forests and Range.

Table 4. Percentage of canopy lodgepole pine (PI) in different stages of mountain pine beetle attack, by stand type and watershed.

BEC	Stand type		Watershed	PI Attack status (%)			
	Pine (%)	Age (yr)		None	Green	Red	Grey
ESSFdc	100	70-130	Penticton	84.6	7.5	2.1	5.8
			Trepanier	100.0	0.0	0.0	0.0
ESSFdc	<80	>130	Bear Lambly	31.6	5.3	36.8	26.3
			Mission	100.0	0.0	0.0	0.0
			Penticton	88.2	0.0	0.0	11.8
MSdm	100	70-110	Hydraulic	70.0	14.3	7.9	7.8
			Trepanier	43.8	25.2	17.3	13.7
			Trout	92.2	2.0	5.8	0.0
MSdm	100	>110	Bear Lambly	5.6	0.0	61.1	33.3
			Hydraulic	95.7	0.0	2.2	2.2
			Mission	71.4	22.2	3.2	3.2
			Peachland	47.6	14.2	19.9	18.3
			Trepanier	0.0	34.5	41.4	24.1
			Trout	92.1	2.1	4.0	1.9
MSdm	<90	70-90	Peachland	100.0	0.0	0.0	0.0
			Trepanier	47.2	1.9	30.2	20.8
MSdm	<80	>150	Bear Lambly	13.2	10.5	39.5	36.8
			Peachland	33.3	25.0	41.7	0.0
			Trepanier	0.0	22.2	37.0	40.7

#### Densities of understory trees

Saplings were roughly 3 times as abundant as pole-sized understory trees overall, except in mid-seral MS stands where saplings were rarer (Table 5). Saplings tend to be clustered more than poles, so that *well-spaced* saplings and poles are about equally common.

Non-pine understory trees were most common in ESSF, with about 2500 stems per hectare, of which almost 1000 sph are well-spaced (Table 5). Subalpine fir is dominant. The understory in these stands is close to “well-stocked”. There are few understory pines in these stands.

Well-spaced non-pine understory is fairly sparse in mid-seral MS stands, with 213 or 281 well-spaced sph in the two mid-seral stand types (Table 5). There is, however substantial pine understory in these types, raising the density of well-spaced understory trees to 413 or 688 sph. Well-spaced understory trees are denser in older MS, dominated by subalpine fir. Well-spaced totals for all species are 600 and 726 sph in the two types of older MS. All these values only include trees >1.3m height.

**Table 5. Densities of poles, saplings and poles+saplings combined (with SE), total and well-spaced (WS), by species and stand type.**

BEC	Stand type		Layer	Lodgepole pine (/ha)		Subalpine fir (/ha)		Spruce (/ha)		All non-pine (/ha)		All species (/ha)	
	Pine (%)	Age (yr)		Total	WS	Total	WS	Total	WS	Total	WS	Total	WS
ESSFdc	100	70-130	poles	13 (13)	6 (6)	544 (112)	319 (28)	106 (41)	44 (12)	650 (126)	363 (30)	663 (139)	369 (26)
			saplings	0	0	1663 (444)	513 (82)	131 (62)	75 (42)	1794 (484)	588 (118)	1794 (484)	588 (118)
			combined	13 (13)	6 (6)	2206 (384)	831 (90)	238 (51)	119 (37)	2444 (407)	950 (117)	2456 (401)	956 (113)
ESSFdc	<80	>130	poles	50 (29)	17 (17)	442 (51)	308 (58)	108 (85)	100 (76)	550 (52)	408 (22)	600 (80)	425 (38)
			saplings	0	0	1833 (639)	508 (60)	208 (123)	67 (55)	2067 (517)	583 (68)	2067 (517)	583 (68)
			combined	50 (29)	17 (17)	2275 (652)	817 (106)	317 (205)	167 (131)	2617 (467)	992 (88)	2667 (443)	1008 (101)
MSdm	100	70-110	poles	647 (285)	397 (152)	75 (26)	59 (23)	69 (42)	56 (32)	153 (67)	119 (55)	800 (275)	516 (147)
			saplings	206 (120)	9 (7)	225 (130)	109 (52)	131 (58)	53 (23)	356 (162)	163 (64)	563 (170)	172 (62)
			combined	853 (403)	406 (155)	300 (153)	169 (72)	200 (75)	109 (39)	509 (222)	281 (110)	1363 (408)	688 (161)
MSdm	100	>110	poles	276 (129)	177 (95)	148 (67)	120 (54)	41 (14)	35 (14)	189 (69)	155 (56)	465 (127)	332 (92)
			saplings	25 (11)	5 (5)	934 (252)	366 (85)	36 (13)	23 (7)	970 (257)	390 (85)	995 (255)	395 (84)
			combined	301 (130)	182 (95)	1081 (288)	487 (124)	77 (23)	58 (18)	1159 (299)	545 (127)	1459 (259)	726 (114)
MSdm	<90	70-90	poles	325 (250)	188 (138)	150 (150)	117 (117)	13 (13)	13 (13)	225 (100)	150 (25)	550 (350)	338 (163)
			saplings	25 (25)	13 (13)	525 (475)	50 (25)	88 (88)	13 (13)	613 (563)	63 (38)	638 (588)	75 (50)
			combined	350 (275)	200 (150)	675 (625)	138 (113)	100 (75)	25	838 (663)	213 (63)	1188 (938)	413 (213)
MSdm	<80	>150	poles	8 (8)	0	225 (66)	175 (66)	50 (29)	50 (29)	275 (88)	225 (88)	283 (92)	225 (88)
			saplings	0	0	1458 (512)	358 (179)	92 (92)	17 (17)	1550 (603)	375 (189)	1550 (603)	375 (189)
			combined	8 (8)	0	1683 (567)	533 (243)	142 (96)	67 (33)	1825 (663)	600 (277)	1833 (660)	600 (277)

Notes: MSdm <90% pine, 70-90yrs also included 63 Fd poles/ha, with 50/ha well-spaced

A few cedars and aspens (not shown) occurred in the understory at a few sites.

WS = well-spaced

A heavy MPB infestation can kill pole-sized lodgepole pine. The best summary of surviving understory densities expected after severe MPB is therefore sapling and poles of non-pine species, plus saplings only of lodgepole pine. Densities of this group are around 2500 sph in ESSF, 1800 sph in old MS, declining to about 800 in mid-seral MS (Table 6). ESSF has nearly 1000 well-spaced sph of this group, older MS has about 600 sph and mid-seral MS has 250 sph. These levels could be described as “almost stocked”, “half stocked” and “mostly unstocked”, respectively.

**Table 6. Total and well-spaced (WS) densities of saplings+poles combined, but excluding lodgepole pine poles (with SE).**

Poles+Saplings total density (no PI poles)			Pole+Sapling density (/ha; no PI poles)	
BEC	Stand type Pine (%)	Age (yr)	Total	WS
ESSFdc	100	70-130	2444 (407)	950 (117)
ESSFdc	<80	>130	2617 (467)	992 (88)
MSdm	100	70-110	716 (215)	291 (107)
MSdm	100	>110	1184 (298)	550 (126)
MSdm	<90	70-90	863 (688)	225 (75)
MSdm	<80	>150	1825 (663)	600 (277)

Note: WS = well-spaced

#### *Plot-level stocking distribution*

The above values are stand-level averages. It is also important to look at what proportions of individual plots are stocked to different stocking levels. The summaries include results for all understory layers (seedlings+saplings+poles), for just saplings+poles, and for well-spaced saplings+poles.

With all understory trees, or all saplings+poles, the majority of ESSF stands are stocked to the highest levels examined (1600 sph; Table 7). Over half of the plots in ESSF stand types are stocked to 1000 sph with well-spaced trees<sup>4</sup>. The stocking levels are moderately higher than levels reported by Vyse et al. for ESSFdc3 stands in the Kamloops area. [Note: Vyse et al. reported on “acceptable trees”, based on height, stem form and lack of disease, but no spacing criterion, so these results are not completely comparable to the well-spaced densities reported here.]

**Table 7. Percentage of individual plots in ESSF that are stocked to different levels (stems per hectare, SPH), for all understory layers (seedling+sapling+poles), saplings+poles only, and well-spaced saplings+poles, with comparison to results from Vyse et al.**

ESSF Study	BEC	Pine (%)	Age (yr)	Plots	Layers	Percent of plots with understory density >= specified SPH							
						200	400	600	800	1000	1200	1400	1600
This study	ESSFdc	100	70-130	32	All	97	97	94	91	91	91	91	91
					Saplings+Poles	97	97	91	84	81	78	66	66
					Saplings+Poles well-spaced	97	97	88	66	56	34	28	9
This study	ESSFdc	<80	>130	24	All	100	100	100	100	100	100	100	100
					Saplings+Poles	100	96	96	96	92	92	92	88
					Saplings+Poles well-spaced	96	92	83	79	63	46	25	13
Vyse et al	ESSFdc3	PI leading	>60		All	100	100	100	100	100	100	100	100
					Saplings+Poles	100	92	72	64	56	48	36	36
					Saplings+Poles acceptable	84	64	56	48	40	36	20	20

<sup>4</sup> Given the plot size and the minimum spacing for a well-stocked tree, the maximum physically possible value for well-spaced stocking is 1600 sph.

In mid-seral MS stands, half the plots are stocked at 800 sph with all understory layers, but more than half the plots have <400 sph of well-spaced saplings+poles (Table 8). Older MS stands have more than half their plots stocked to 1600 sph with all layers, but half the plots have less than 600-800 sph of just well-spaced saplings+poles. 29% of plots in these older MS stands had <200 well-spaced sph. Vyse et al. found similar plot-level stocking distributions for the drier MSxk2, and moderately higher stocking in MSdm3 plots. Nigh et al. reported generally lower understory stocking in mature MS stands in the Merritt area<sup>5</sup>.

**Table 8. Percentage of individual plots in MS that are stocked to different levels (stems per hectare, SPH), for all understory layers (seedling+sapling+poles), saplings+poles only, and well-spaced saplings+poles, with comparison to results from Vyse et al. and Nigh et al.**

MS Study	BEC	Pine (%)	Age (yr)	Plots	Layers	Percent of plots with understory density $\geq$ specified SPH							
						200	400	600	800	1000	1200	1400	1600
This study	MSdm	100	70-110	64	All	73	66	53	50	47	38	33	25
					Saplings+Poles	69	58	44	36	30	22	19	16
					Saplings+Poles well-spaced	48	31	20	16	14	13	3	0
This study	MSdm	100	>110	85	All	86	75	69	64	61	58	55	53
					Saplings+Poles	76	67	58	48	46	44	39	32
					Saplings+Poles well-spaced	71	64	45	41	32	19	6	5
This study	MSdm	<90	70-90	16	All	81	69	56	50	44	31	31	25
					Saplings+Poles	81	63	44	38	31	31	19	19
					Saplings+Poles well-spaced	75	38	0	0	0	0	0	0
This study	MSdm	<80	>150	24	All	100	92	88	83	83	79	75	67
					Saplings+Poles	96	88	75	75	71	58	50	42
					Saplings+Poles well-spaced	71	67	54	46	25	17	13	8
Vyse et al	MSdm3	PI leading	>60		All	97	96	96	95	92	92	92	89
					Saplings+Poles	91	82	69	58	55	51	49	43
					Saplings+Poles acceptable	88	70	57	45	39	27	26	22
Vyse et al	MSxk2	PI leading	>60		All	94	83	75	64	56	51	46	42
					Saplings+Poles	81	62	48	40	31	23	18	14
					Saplings+Poles acceptable	60	40	29	24	15	11	7	5
Nigh et al	MS	>70	Mature	28	Saplings+Poles (approx)	61	39	25	14	7	7	7	7

<sup>5</sup> The Nigh et al. values are approximate calculated values that may not be equivalent to the survey results from this study or Vyse et al.

## Appendix C:

# Channel Sensitivity Methodology

## Appendix C: Channel Sensitivity Methodology

**Table C-1** (adapted from Green, 2005) is a framework for assigning channel sensitivity ratings based on characteristics from field, airphoto and map observations.

Alteration	Channel Sensitivity Rating (H, M, L)	Channel Attributes that May Contribute to Channel Sensitivity
Increased Peak Discharge and/or Flood Frequency	Low	<ul style="list-style-type: none"> <li>▪ Channel experiences frequent natural, large peak flow events (e.g. steep watershed, rapid runoff, high snow pack).</li> <li>▪ Channel has endured high flow events in the past with little evidence of long term change.</li> <li>▪ Channel exhibits a natural resiliency to bank and bed scour/erosion (e.g. bedrock controls, extensive colluvial or lag deposits, well-vegetated, deep-rooted riparian vegetation).</li> <li>▪ Abundant instream LWD, debris jams and lag boulders that augments channel and bank stability through energy dissipation.</li> <li>▪ Frequent sizeable lakes, wetland areas and/or broad floodplain able to store significant water volume and attenuate flood peaks.</li> </ul>
	Moderate	<ul style="list-style-type: none"> <li>▪ Range or combination of attributes listed above and below.</li> </ul>
	High	<ul style="list-style-type: none"> <li>▪ Channel does not experience frequent flood events (dark mossy substrates, mature vegetation to high water mark).</li> <li>▪ Relatively recent flood events (past 20 years) have caused significant disruption of channel and/or bank stability.</li> <li>▪ Channel segments with fine textured banks and substrates that are susceptible to scour/erosion.</li> <li>▪ Lacking in channel structure (e.g. instream LWD, lag boulders, bedrock) that would absorb flow energy.</li> <li>▪ Little or no lakes, overflow channels, floodplain or low gradient wetland segments that would attenuate/store flood peaks.</li> </ul>
Increased Sediment Delivery [Fine suspended and Coarse bedload sediment should be considered separately]	Low	<ul style="list-style-type: none"> <li>▪ Channel experiences frequent high volumes of sediment delivery from upstream/upslope sources (e.g. numerous natural landslides, ravelling banks, naturally aggraded channel).</li> <li>▪ Evidence of older, connected landslides and/or debris flows with minimal evidence of long term changes to channel stability.</li> <li>▪ Abundant locations for sediment storage, such as frequent functioning debris jams or low gradient, unconfined sections that arrest bedload movement.</li> <li>▪ Slow-flowing, meandering stream with insufficient power to transport bedload and allow some settling/filtering (e.g. frequent wetland segments).</li> <li>▪ Stable/resilient banks that will resist widening following sediment storage/aggradation.</li> <li>▪ Coarse sediment is easily passed through the channel system with minimal accumulations (in context of watershed, may lead to issues downstream – see notes).</li> </ul>
	Moderate	<ul style="list-style-type: none"> <li>▪ Range or combination of attributes listed above and below.</li> </ul>
	High	<ul style="list-style-type: none"> <li>▪ Channel does not experience frequent high volumes of sediment delivery from upstream/upslope sources (e.g. dark mossy substrates, deep pools, broadly graded substrates).</li> <li>▪ Evidence of channel destabilization in response to isolated sediment events (e.g. older, connected landslides have caused aggradation/channel widening downstream).</li> <li>▪ Channel has little or no sediment storage capacity such that increases in sediment delivery are likely to cause channel aggradation, lateral erosion and/or avulsion.</li> <li>▪ Fine sediment is rapidly passed through with little opportunity for settling/filtering (reducing water quality downstream).</li> <li>▪ Channel has frequent erodible banks that will allow channel widening in response to aggradation and contribute further sediment to the channel.</li> </ul>
Decreased Riparian Function	Low	<ul style="list-style-type: none"> <li>▪ Channel flows through area of naturally low-growing riparian vegetation (e.g. wetland, alpine area or avalanche pathway).</li> <li>▪ Channel is not dependant on LWD to provide channel or bank stability (e.g. bedrock controlled, colluvial and/or lag deposits, steeper Step-Pool or Cascade-Pool morphology types).</li> <li>▪ Channel has experienced localized decreased riparian condition in the past (e.g. wildfire, harvesting) with little indication of long term instability.</li> <li>▪ Channel is not dependant on LWD to control bedload movement.</li> <li>▪ Channel is not dependant on riparian vegetation to maintain fish habitat values, including instream LWD, food sources and/or stream temperature moderation.</li> </ul>
	Moderate	<ul style="list-style-type: none"> <li>▪ Range or combination of attributes listed above and below.</li> </ul>
	High	<ul style="list-style-type: none"> <li>▪ Channel is dependant on LWD to provide channel or bank stability (e.g. erodible banks, Riffle-Pool morphology type).</li> <li>▪ Channel has experienced localized decreased riparian condition in the past (e.g. wildfire, harvesting) resulting in local destabilization.</li> <li>▪ Channel is dependant on LWD to control bedload movement.</li> <li>▪ Channel is dependant on riparian vegetation to maintain fish habitat values, including instream LWD, food sources and/or stream temperature moderation.</li> </ul>

## Appendix D:

### Mission Creek Fish Values by Reach

Prepared by Michele Trumbley, R.P. Bio.



## Trumbley Environmental Consulting Limited

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V1E 4N6

March 31, 2009

### **RE: Fisheries Information on the Mission Creek Watershed as one of Seven Identified Okanagan Community Watersheds**

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#### **MISSION CREEK**

The Mission Creek watershed is situated on the east side of Okanagan Lake near Kelowna. Mission Creek mainstem (WSC<sup>1</sup> 310-794400) flows into Okanagan Lake. The watershed has been delineated into eight sub-basins including Upper Mission (above Stanley confluence), Pearson, Joe Rich, Lower Belgo (to top of reach 3), Upper Belgo (reach 4+), Mid Mission (reaches 5, 6, 7, Belgo confluence to Stanley confluence), Lower Mission (intake to Belgo Creek confluence) and Daves Creek. Mission Creek is a major Kokanee spawning stream for Okanagan Lake. Kokanee spawn from the mouth of Mission Creek upstream to Hollywood Road in Kelowna (upstream of the spawning channel in Mission Creek Park). The lower reaches of Mission Creek were not within the watershed boundary delineated. The fish and fish habitat investigation is one component of several factors used to develop an overall risk rating for MPB<sup>2</sup>.

#### **FISH SPECIES**

Sport-fish<sup>3</sup> species within the watershed include Brook Trout (*Salvelinus fontinalis*), and Rainbow trout (*Oncorhynchus mykiss*) in the headwater tributaries and lakes. Kokanee (*Oncorhynchus nerka*) and Mountain Whitefish (*Prosopium williamsoni*) have been identified in the lower reach of Mission Creek.

#### **OBSTRUCTIONS**

Obstructions to upstream fish migration include the following: a 1.5m beaver dam located at UTM 11/346066/5543744 on a tributary to Belgo Creek (WSC 310-794400-46600). Within the tributary to tributary 46600-47200 (WSC 310-794400-46600-47200-XXX) (UTM 11-350330-5537303 of confluence) there is a 10m high cascade by 42m long, 400m upstream of the confluence. A 15m high cascade over 60m length 700m upstream from the confluence of unnamed tributary, (WSC 310-794400-46600-47200-XXXX) was documented. On Mugford Creek, a 27m high by 60m long cascade was located 60m upstream of the mouth of the channel. In reach 2 of Mugford Creek, a 1.7m rock falls was

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<sup>1</sup> WSC – Watershed Code

<sup>2</sup> MPB – Mountain Pine Beetle

<sup>3</sup> Sport-fish as defined by the Forest Practices Code, Fish-Stream Identification Guidebook. pg 4.



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located. In a tributary to Ideal Lake a 32m high cascade by 70m long, was located 22m upstream from Ideal Lake. In an unnamed tributary to Loch Katrine Creek Big Oichie outlet (WSC 310-79400-89700-43700) a log jam 0.3m at UTM 11-36769-5538058 was documented

**RISK ASSESSMENT**

A consequence table was developed to identify reaches of special concern because the likely effect of MPB on fish and fish habitat within the Mission Creek Watershed is largely unknown. The sub-basins were delineated into macro-reaches which were used to target sensitive areas (Table 2). Therefore mitigation strategies can be developed in target areas where negative impacts are probable.

**Table 1 outlines the criteria utilized in determining the consequences for fish and fish habitat.**

Priority	1	2	3	4
Consequence Rating	Fish Species Present	Habitat Quality	Channel Gradient %	Average Channel Width (m)
VL	fish absence	fish absence confirmed, minimal fish habitat available, habitat degradation low risk to fish	>20%	<1.5
L	presence of RB	Fish Absence Confirmed and/or habitat with low rearing potential for the fish species present	16% - 19%	0-5
M	presence of RB, EB	habitat quality low to moderate	9% to 15%	0-5
H	presence of RB, EB, MW	fish presence confirmed, habitat quality moderate to high	0% to 8%	0-20
VH	presence of RB, EB, KO, MW	fish presence confirmed, habitat quality high	0% to 8%	0-20

Note: VL – Very Low  
 L – Low  
 M – Moderate  
 H – High  
 VH – Very High



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**Table 2 – Mission Creek Watershed Consequence Rating**

Stream Name	WSC	Reach	Average Channel Width (m)	Gradient (%)	Species Present	Habitat Quality	Consequence Rating
Mission Creek	310-794400	1	No data	5%	EB (hatchery), KO (hatchery and wild 1995), MW (1969), RB (wild and Hatchery),	No obstructions to fish passage. Spawning channel created for KO. KO spawning habitat, annual assessments from mouth to Hollywood Rd. Reach 1 is a major spawning ground for RB	<b>VH</b> - presence of KO, EB, RB and spawning grounds
Mission Creek	310-794400	4	No data	1	EB, RB	Potential rearing habitat	<b>H</b> – RB, EB, potential rearing habitat
Mission Lake	00625OKAN	10	N/A	N/A	RB (wild and hatchery)	overwintering habitat.	<b>VH</b> - overwintering habitat
Daves Creek	310-794400-31600	1-3	No data	No data	(RB, EB)	Connection to Mission Creek	<b>M</b> - fish presence suspected,
Prather Creek	310-794400-31600	1	No data	No data	(RB, EB)	Trib to R1 Daves Creek	<b>M</b> - fish presence suspected. Field verification is recommended
Grouse Creek	310-794400-39800	1	No data	No data	(RB, EB)	Browne lake at headwaters, flows to Hydraulic. Trib to R4 of Mission	<b>M</b> - fish presence suspected. More information is needed.
Cardinal Creek	310-794400-41400	1	No data	20% (TRIM)	(No Fish)	Trib to R4 of Mission	<b>VL</b> - fish absence defaulted due to gradient of 20%. Field verification is recommended.
Belgo Creek	310-794400-46600	1-4	No data	2%	(RB)	Major trib to R5 of Mission. Belgo Creek sub-basin	<b>H</b> - presence of RB in upper reaches and in Ideal Lake, headwaters of Belgo Creek.
Ideal Lake	00567OKAN	Reach of 5 Belgo Creek	N/A	N/A	RB	Provides overwintering habitat.	<b>H</b> - headwaters of Belgo Creek, overwintering and rearing habitat.



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**Table 2 – Mission Creek Watershed Consequence Rating**

<b>Stream Name</b>	<b>WSC</b>	<b>Reach</b>	<b>Average Channel Width (m)</b>	<b>Gradient (%)</b>	<b>Species Present</b>	<b>Habitat Quality</b>	<b>Consequence Rating</b>
Belgo Creek	310-794400-46600	6	No data	1% (TRIM)	RB (wild hatchery)	Main stem of Belgo Creek, upstream of Ideal Lake.	<b>H</b> – Proximity to Ideal lake, presence of RB and low stream gradients.
Tributary to Belgo Creek	310-794400-46600	1	2.68	6	NFC (ARC Environ. FHIP)	1.5m beaver Dam at 11/346066/5543744. Site 1	<b>L</b> - fish absence suspected.
Wollaston south Lake	00507OKAN	2	N/A	N/A	RB Hatchery	Lake provides overwintering habitat.	<b>H</b> - overwintering and rearing habitat in the headwaters of Belgo Creek.
Trib to Belgo Creek	310-794400-46600-4100	1	No data	No data	(RB)	Suspect fish presence due to connection to Belgo Creek.	<b>M</b> - suspected RB TRIM does not show any significant gradient changes
Trib to Belgo Creek	310-794400-46600-47200	1	1.9	5	RB	Site 8. Electrofishing survey caught fish 3.3km upstream from the confluence with Belgo Creek	<b>H</b> - Confirmed presence of RB. Low channel gradients.
Trib to Belgo Creek	310-794400-46600-47200	2	1.3	13	(RB)	Site 10. No barriers, no fish were captured. suspected fish presence.	<b>M</b> - field verification of fish presence is recommended.
Trib to tributary 46600-47200	310-794400-46600-XXX (UTM 11-350330-5537303 of confluence)	1	1.4	12	No Fish above the first cascade.	10m high cascade by 42m long, 400m upstream of confluence. A 15m high cascade x 60m length 700m upstream from the confluence. Site 9	<b>L</b> - confirmed fish absence upstream of cascade. There is 400m of accessible habitat.



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**Table 2 – Mission Creek Watershed Consequence Rating**

Stream Name	WSC	Reach	Average Channel Width (m)	Gradient (%)	Species Present	Habitat Quality	Consequence Rating
Trib to tributary 46600-47200	310-794400-46600-47200-5950	2	1.6	6	(RB)	No barriers to upstream migration of fish. Site 7,	<b>M</b> - suspected presence of RB, small channel, no headwater source of fish.
Trib to Belgo	310-794400-46600-54400	1	No data	No data	RB	RB presence due to confirmed RB in tributary and the tributary is lake headed.	<b>H</b> - presence of RB, proximity to the mainstem of Belgo Creek and the tributary is lake headed (WBID 00641OKAN and 00634OKAN).
Trib to tributary -46600-54400	310-794400-46600-54400-8330	1	No data	No data	RB	RB rearing habitat	<b>H</b> - presence of RB and is lake headed (WBID 00641OKAN and 00634OKAN).
Tributary to Belgo Creek	00641OKAN	3	N/A	N/A	(RB)	RB suspected, fish sampling will be required to confirmed fish presence / absence.	<b>H</b> - suspected RB present as RB is confirmed in downstream tributaries. The lake will provide overwintering habitat.
Tributary to Belgo Creek	00634OKAN	2	N/A	N/A	(RB)	Fish presence suspected. Fish sampling will be required to confirmed fish presence / absence.	<b>H</b> - suspected RB present as RB is confirmed in downstream tributaries. The lake will provide overwintering habitat.
Hilda Creek	310-79400-46600-60300	2	1.5-5	2	RB	Good rearing & spawning habitat	<b>H</b> - RB present, good rearing and spawning habitat
Trib to Hilda Creek	310-794400-46600-60300-3800	1	No data	No data	RB	Potential rearing habitat	<b>H</b> - RB present and is lake headed by WBID 00532OKAN.



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**Table 2 – Mission Creek Watershed Consequence Rating**

Stream Name	WSC	Reach	Average Channel Width (m)	Gradient (%)	Species Present	Habitat Quality	Consequence Rating
Unnamed lake	00523OKAN	2	N/A	N/A	(RB)	Overwintering habitat for Hilda Creek tributary.	<b>H</b> - overwintering habitat for resident RB in downstream tributaries. .
Mugford Creek	310-794400-46600-66400	1	3.4	2	(RB) (No fish upstream of cascade)	Trib to Ideal Lake. 27m high X 60m long cascade located 60m upstream of mouth	<b>VL</b> - Mugford creek only provides 60m of accessible habitat.
Mugford Creek	310-794400-46600-66400	2	1.8	11	No Fish	1.7m rock falls	<b>VL</b> - fish absence confirmed
Trib to Mugford Creek	310-794400-46600-66400-XXX	1	1.0	8	No Fish	Site 5 <sup>4</sup>	<b>VL</b> - fish absence confirmed
Trib to Ideal Lake	310-794400-46600-68300	1	1.4	5	(RB)	32m high cascade X 70m long, 22m upstream from Ideal Lake Site 6 Small lakes in the headwaters may be able to support fish. Fish presence in the lakes is unknown.	<b>M</b> - field sampling of the headwater lake to confirm fish presence/absence is recommended. The cascade may be an obstruction of the upstream migration of fish.
Leech Creek	310-794400-47300	1	No data	14% (TRIM)	(RB, EB)	Trib to R5 of Mission	<b>M</b> - no obstructions documented to prevent the migration of fish from Mission Creek. Field sampling is recommended to confirm fish presence or absence.

<sup>4</sup> Fish Inventory and Stream Classification: Mugford Creek, Unnamed tributaries to Belgo Creek and Ideal Lake, Wildstone Resources Ltd. 1998. Sites 5 to 10



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**Table 2 – Mission Creek Watershed Consequence Rating**

<b>Stream Name</b>	<b>WSC</b>	<b>Reach</b>	<b>Average Channel Width (m)</b>	<b>Gradient (%)</b>	<b>Species Present</b>	<b>Habitat Quality</b>	<b>Consequence Rating</b>
Joe Rich Creek	310-794400-47400	1	No data	5%	RB	Trib to R5 Mission	<b>H</b> - abundant upstream habitat, in Joe Rich Creek
Joe Rich Creek	310-794400-47400	2	No data	No data	RB (Kingfisher, Fish Collection Summary Report, April 1998)	The channel flows through agricultural area in reach 2. Orthophotos show low levels of riparian vegetation present.	<b>H</b> - reduced riparian vegetation due to agriculture activities may increase sedimentation. RB presence is confirmed.
Joe Rich Creek	310-794400-47400	6	No data	No data	RB	No data available, fish presence is confirmed.	<b>M</b> - confirmed RB. No other information was available.
Schram Creek	310-794400-47400-19300	1	No data	20% (TRIM)	(RB)	Trib to reach 2 Joe Rich Creek	<b>L</b> - the 20% gradient of the channel will restrict fish utilization of the tributary. Field verification of fish presence/absence is recommended.
Tress Creek	310-794400-47400-33400	1	No data	11% (TRIM)	RB	Trib to reach 3 Joe Rich Creek	<b>M</b> - presence of RB and moderate gradients.
Pearson Creek	310-79400-57800	1	No data	6%	RB	Trib to reach 6 Mission.	<b>H</b> - confirmed RB and low gradients.
Foolhen Creek	310-794400-57800-10900	1	No data	No data	RB	Trib to reach 1 Pearson Creek	<b>H</b> – confirmed RB present, low channel gradients.
Stevenson Creek	310-794400-57800-45000	1	No data	No data	RB (Spawning location FISS 8002)	Trib to reach 2 Pearson Creek	<b>VH</b> - spawning location for RB documented, and the tributary is lake headed by Loch Lost Lake.
Loch Lost Lake	00843OKAN	2	N/A	N/A	RB	Overwintering and rearing habitat for Pearson and Stevenson Cr.	<b>VH</b> - overwintering and rearing habitat for Stevenson Creek and Pearson Creek.



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**Table 2 – Mission Creek Watershed Consequence Rating**

Stream Name	WSC	Reach	Average Channel Width (m)	Gradient (%)	Species Present	Habitat Quality	Consequence Rating
Boyce Creek	310-794400-61300	1	No data	No data	RB	Tributary to reach 6 Mission Creek	<b>H</b> - confirmed RB presence and the tributary is lake headed by a small lake that supports RB.
Trib to Boyce Creek	310-794400-61300-58200	1	No data	No data	RB	Tributary to reach 2 Boyce Creek	<b>H</b> - confirmed RB presence and the tributary is lake headed by a small lake that supports RB.
Trib to Boyce Creek	310-794400-61300-90200	1	No data	No data	RB	Site 4, Tributary to reach 4 Boyce Creek	<b>H</b> - confirmed RB presence and this reach includes a lake headed by a small lake that supports RB.
Lees Lake	00563OKAN	2	N/A	N/A	(RB)	Potential to provide overwintering habitat.	<b>H</b> - field sampling is required to determine fish presence/ absence.
Stanley Creek	310-794400-84600	1	No data	No data	RB (spawning location)	Tributary to reach 7 of Mission Creek.	<b>VH</b> - confirmed spawning location and the tributary is lake headed by Loch long Lake.
Loch Long Lake	00718OKAN	Reach 2 of Stanley Creek	N/A	N/A	RB	Overwintering and rearing habitat potential.	<b>VH</b> - will provide overwintering habitat for resident RB of Stanley Creek.
Stanley Creek	310-794400-84600	3	4.3	1	(RB)	Site 2	<b>H</b> – low gradient, connects Loch long Lake and Loch Oichie Lake that are both confirmed fish bearing. Will likely provide rearing habitat.
Loch Oichie Lake	00739OKAN	Reach 4 of Stanley Creek	N/A	N/A	RB	Overwintering and rearing habitat potential.	<b>H</b> - overwintering and rearing potential in the lake.



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**Table 2 – Mission Creek Watershed Consequence Rating**

<b>Stream Name</b>	<b>WSC</b>	<b>Reach</b>	<b>Average Channel Width (m)</b>	<b>Gradient (%)</b>	<b>Species Present</b>	<b>Habitat Quality</b>	<b>Consequence Rating</b>
Loch Katrine Creek	310-79400-89700	Reach 1	No data	No data	RB	No habitat information available.	<b>M</b> – RB confirmed however no habitat information was available.
Greystoke Lake	00669OKAN	Reach 2 of Loch Katrine Creek	N/A	N/A	RB	Overwintering and rearing habitat potential.	<b>H</b> – overwintering habitat
Loch Katrine Lake	00760OKAN	Reach 4 of Loch Katrine Creek	N/A	N/A	RB	Overwintering and rearing habitat potential.	<b>M</b> – RB presence, potential for overwintering and rearing habitat.
Unnamed trib to Loch Katrine Creek Big Oichie outlet	310-79400-89700-43700	1	0.69	2	(RB)	Log jam 0.3m at 11/36769/5538058 Site 3	<b>L</b> – small channel width, field verification of fish presence absence recommended.
Big Oichie Lake	310-79400-89700-43700	2	N/A	N/A	(RB)	Overwintering and rearing habitat potential. Verification of fish presence is recommended.	<b>L</b> – field verification of fish presence recommended.
Fish Hawk Creek	310-794400-85100	1	No data	5%	(RB)	Tributary to reach 8 Mission Creek	<b>M</b> – low channel gradients, RB presence upstream in Fish Hawk Lake.
Fish Hawk Lake	00578OKAN	Reach 2 of Fish Hawk Creek	N/A	N/A	RB	Overwintering and rearing habitat potential	<b>M</b> – overwintering potential in Fish Hawk Lake.

*Fish Species Codes:*

RB – Rainbow Trout

EB- Brook Trout

KO – Kokanee

(species) – suspected fish presence

NFC – No fish caught

NS – Not Sampled



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### **MITIGATION STRATEGIES**

Mitigations to maintain fish presence is often difficult to determine. The impacts of MPB will ultimately reduce riparian cover. The dynamics of stream ecosystems are dependent on the presence of intact multi stage riparian zones. The LWD<sup>5</sup> and CWD<sup>6</sup> supplies organics to the channel thereby enabling the growth of invertebrates used as food for fish. Insect drop from adjacent riparian vegetation also provides a valuable food source for fish. In addition, riparian vegetation provides important value in maintaining stream temperatures and limiting bank failure and sloughing. The influx of sediment into a channel increases turbidity which aside from having detrimental effects by clogging fish gills, it also inhibits feeding which is sight dependent. Therefore, an important mitigation strategy is to encourage the growth of riparian vegetation in areas where very high and high value consequences were identified. Planting of a mixed stand will provide habitat in areas where MPB has removed the adjacent riparian vegetation.

In addition, point sources of sediment should be targeted and rectified. Water flows should be monitored to ensure minimal flows during critical periods which include summer months where fish may be stranded.

### **SUMMARY OF RISKS TO FISH HABITAT:**

This summary is to be used in conjunction with the Channel Evaluation Table and summarized according to sub-basin.

Lower Mission (intake to Belgo Creek confluence): The Lower Mission residual includes reach 4 of Mission Creek and all the tributaries flowing into it. Reaches 1-3 were outside of the study area however were documented in table 2. Historical data was not available for reach 4 or Grouse Creek therefore the consequence ratings were high and moderate, respectively and based on gradient and connection to fish. Cardinal Creek had a channel gradient of 20% and was defaulted to non-fish and thus a very low consequence rating. Rainbow trout and Brook trout are sensitive to sedimentation and increased peak flows.

Daves Creek: Rainbow trout and Brook trout are suspected in Dave's Creek Sub-basin which drains into reach 4 of Mission Creek. No data was available for this sub-basin however fish are suspected. A moderate consequence rating was assigned based upon the connectivity to Mission Creek.

Joe Rich: The Joe Rich Sub-basin flows into reach five of Mission Creek. Rainbow trout have been documented throughout the sub-basin. Habitat quality within reach one of Joe Rich Creek is high however agricultural activities have resulted in degraded riparian

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<sup>5</sup> LWD – large woody debris

<sup>6</sup> CWD – coarse woody debris



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conditions in reach 2. Sedimentation issues were documented in 1998 and will likely reduce habitat quality downstream in Mission Creek. Schram and Tress Creeks contained low and moderate habitats, respectively based on channel gradients.

Pearson Creek: The Pearson Creek Sub-basin contains Pearson Creek, Foolhen Creek and Stevenson Creek. Both Pearson and Foolhen Creeks contained rainbow trout however no channel data was available. Therefore the habitat quality was deemed high based upon the presence of rainbow trout and the low gradients. Stevenson Creek contained documented spawning habitat in addition to Lost Loch Lake in the headwaters. Therefore the consequence rating for Stevenson Creek was very high due to available spawning and rearing habitat in the channel and the potential for overwintering in Loch Lost Lake.

Lower Belgo (to top of reach 3): The Belgo Creek Sub-basin contains the mainstem of Belgo Creek and several steep gradient tributaries. Habitat data was unavailable however rainbow trout were documented upstream in Ideal Lake. A consequence rating of high was assigned to Belgo Creek due to the connection upstream and downstream to rainbow trout and low channel gradients.

Mid Mission (reaches 5, 6, 7 Belgo confluence to Stanley confluence): The Mid Mission Residual contains rainbow trout throughout several headwaters lakes in addition to the channels. Reach one of Stanley Creek contains quality spawning habitat and was assigned a very high consequence rating. Boyce Creek and the headwater lakes also contain rainbow trout and provide rearing and overwintering habitat.

Upper Belgo (reach 4+): Belgo Creek, upstream of reach 3, contains rainbow trout. High habitat values were assigned to the headwater lakes however Mugford Creek was rated as very low habitat value. Belgo Creek contained high habitat values upstream of Ideal Lake.

Upper Mission (above Stanley confluence): Rainbow trout are documented within this sub basin. Data describing habitat present within the sub-basin is limited. Mission Lake contains overwintering and rearing habitat and was assigned a consequence rating of VH (very high). The remainder of the sub-basin contained moderate to high habitat value.



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### REFERENCE MATERIAL

Reports for Mission Creek Watershed include:

- Fish Inventory and Stream Classification\_ Mugford Creek, Unnamed tribs to Belgo Creek and Ideal Lake. Wildstone Resources Ltd. 1998
- Fisheries Management Plan for Okanagan Main Valley Lakes. Fisheries Staff 1980
- FISS 8002, Belgo Creek (WSC 310-794400-46600), Ern Lake (WSC 310-794400-22400-5700) Fish Hawk Lakes (WSC 310-794400-85100), Fish Lake (WSC 310-794400-22400-44900-3240) Greystoke Lake (310-794400-89700), Haynes Lake (WSC 310-794400-22400-51300), Ideal Lake (WSC 310-794400-46600), Loch Katrine (WSC 310-794400-89700), Loch Katrine Creek (WSC 310-794400-89700), Loch Long (WSC 310-974400-84600) Loch Lost (WSC 310-794400-57800-45000) loch Oichie (WSC 310-794400-84600), Long Meadow Lake (WSC 310-794400-22400-44900-3240), Stanley Creek (WSC 310-794400-84600), Stevenson Creek (WSC 310-794400-57800-45000)
- FISS 8012 Joe Rich Creek (WSC 310-794400-47400)
- FISS 8212, Greystoke Lake (310-794400-89700), Joe Rich Creek (WSC 310-794400-47400), Mission Creek (WSC 310-794400) Mission Lake (WBID 00625OKAN) Pearson Creek (WSC 310-794400-57800), Priest Creek (WSC 310-794400-0290) 01-JAN-1994, wild
- FISS BCLKS-3323, 08JUL-1948, Ideal Lake (WSC 310-794400-46600)
- FISS BCLKS-3599, Loch Long (WSC 310-974400-84600) 07-SEP-1977,
- FISS BCLKS-5662, Ideal Lake (WSC 310-794400-46600)
- FISS HQ0267 Hilda Creek (WSC 310-79400-46600-60300), unnamed tributary WSC 310-794400-46600-54400, unnamed tributary (WSC 310-794400-46600-60300-3800)
- FISS HQ1119, Joe Rich Creek, Tress Creek (WSC 310-794400-47400-3340) (WSC 310-794400-47400)
- FISS HQ1120, Foolhen Creek (WSC 310-79400-57800-10900), Pearson Creek (WSC 310-794400-57800), Stevenson Creek (WSC 310-794400-57800-45000), unnamed tributary WSC 310-79440-53400, unnamed tributary WSC310-794400-54400, unnamed tributary WSC 310-79400-56200, unnamed tributary WSC 310-79400-57800-12000, unnamed tributary WSC 310-794400-57800-12000-3450
- FISS HQ1121, Hilda Creek (WSC 310-79400-46600-60300), unnamed tributary WSC 310-794400-46600-41000, unnamed tributary WSC 310-794400-74400, unnamed tributary WSC 310-794400-76300, unnamed tributary WSC 310-794400-76300-09200, unnamed tributary WSC 310-794400-78300, unnamed tributary 310-794400-80200, unnamed tributary WSC 310-794400-82100, unnamed tributary WSC 310-794400-82500,



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- FISS HQ1122, Hilda Creek (WSC 310-79400-46600-60300), Unnamed tributary WSC 310-794400-46600-54400
- FISS HQ1124, Mugford Creek (WSC 310-794400-46600-66400), unnamed tributary WSC 310-794400-46600-47200, unnamed tributary WSC 310-794400-46600-47200-5950, unnamed tributary WSC 310-794400-46600-68300,
- FISS HQ1621 Boyce Creek (WSC310-794400-61300), unnamed tributary WSC 310-794400-61300-53400, Unnamed tributary WSC 310-794400-61300-58200, Unnamed tributary WSC 310-794400-61300-90200

Should you have any questions regarding the content of this report, please contact the undersigned at your convenience.

Thank-you

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