Peachland Creek Hydrological Risk Assessment

Prepared for:

BC Ministry of Environment

Prepared by:

Grainger and Associates Consulting Ltd.
Salmon Arm, BC

and

Streamworks Unlimited
Salmon Arm, BC

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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 infrastructure in Peachland Creek Community Watershed. Peachland Creek has a 142km^2 area draining into Okanagan Lake about 4km south of the Town of Peachland. It is a primary water source for domestic, agricultural and other users in the District of Peachland (DOP).

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 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 modeling was collected in 245 random plots in 30 accessible pine-leading stands in the hydrologically sensitive upper watershed "snow zone", in seven South Okanagan watersheds near and including Peachland Creek. Over 70% of these VRI labelled 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, even when all pine in the stand is dead.

Stand data was used to model two watershed level management scenarios. In the unharvested MPB scenario, all pine trees in pine-leading stands (>40% pine) 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 of these scenarios, stand ECA data was rolled up into watershed or sub-basin ECA's for Peachland Creek watershed and its four sub-basins.

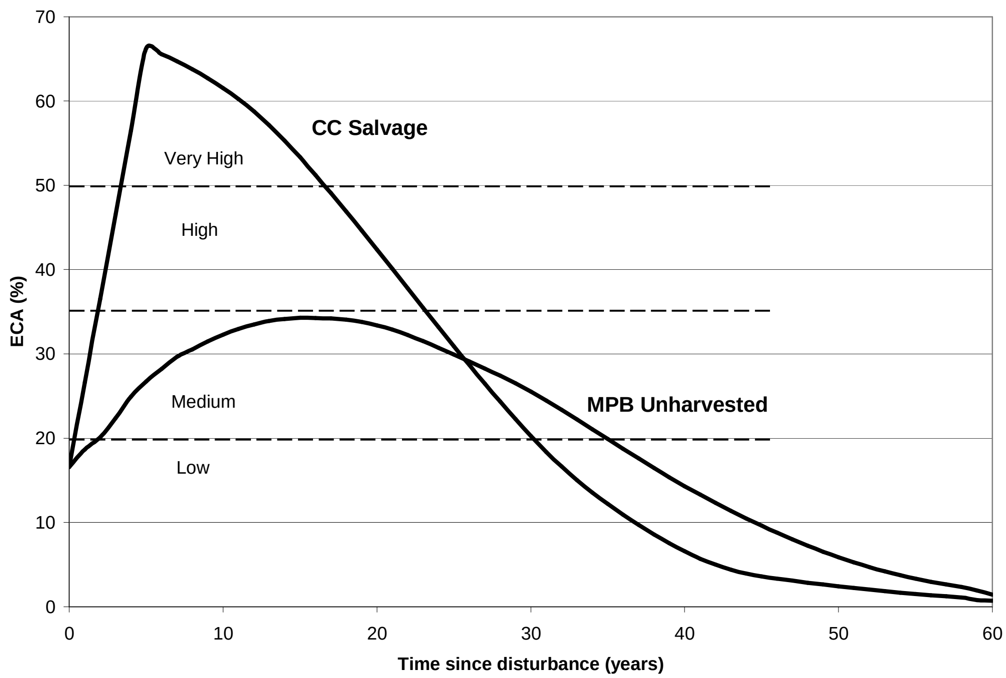

Figure 9. ECA hazard projections for Peachland Creek Watershed at DOP intake.

The current ECA for the Peachland Creek watershed is Low. Following full pine mortality and no harvesting there is a Moderate ECA hazard for approximately 25 years; and following the full salvage harvest scenario there is a High to Very High incremental ECA hazard lasting about 20 years. It is clear there is a much greater change in forest canopy and thus watershed ECA following clearcut salvage harvesting than if MPB-attacked stands are left unharvested.

Watershed and sub-basin characteristics – steepness, soil drainage properties, drainage density and natural or artificial storage – specific to Peachland Creek were reviewed, and combined with ECA levels to determine peak flow hazards; or the likelihood a given canopy disturbance would result in a change in peak flows in Peachland Creek. The watershed has some reservoir storage but 60% of high elevation "snow zone" drainage area is uncontrolled and does not pass through the Peachland Lake Reservoir. There are no other confounding watershed characteristics that would significantly reduce peak flow generation. Combining the mixed watershed flow attenuation potential with the High to Very High post-salvage harvest ECA, there would be a High post-salvage peak flow hazard. Based on previous studies in the Okanagan and elsewhere, a High peak flow hazard is expected to result in an increased occurrence of all size peak flows, or floods. For example, following total pine salvage it is estimated that what has historically been the 50 year flood would occur, on average, every 20 year years. That is, an event the size of the current 50 year flood is 2 to 3 times more likely to occur following full salvage harvesting; and this effect would last for about 20 years. Also larger floods, which have not been experienced in recent times, are also more likely to occur in this period.

Peak flow hazards were combined with channel sensitivity to changes in runoff, sediment and riparian conditions; to determine the hydrologic hazard for each of the two management scenarios; and channels are moderately sensitive to disturbance. Watershed hydrologic hazards are Moderate for the unharvested MPB scenario and High for the full harvest scenario.

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 the four watershed elements of interest – municipal water quality, water supply, fish resources and infrastructure.

The water quality parameters most strongly linked to MPB infestation and salvage logging in Peachland 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 the watershed there is a Moderate Risk, which means some increase in fine and coarse sediment delivery to the DOP 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 peak flows and sediment delivery to the DOP intake is likely to occur. Source water turbidity levels will continue to present a problem at the DOP water intake, in terms of meeting Interior Health Authority water quality guidelines. MPB mortality alone may or may not result in noticeably increased turbidity, but high salvage harvest levels likely will.

Little advancement of freshet timing and associated late growing season water supply shortages are expected following the unharvested MPB scenario. Larger impacts to later season water shortages would be expected following the full salvage scenario, but there is a lot of uncertainty about how large an effect this could be (i.e. how many days earlier maximum freshet flows could occur). As well, reservoir storage will limit freshet advancement effects to some extent. The MPB and salvage harvesting risks of freshet advancement and impacts to later growing season water supplies are considered Low. They are expected to be smaller than global climate change impacts, although effects will be cumulative. There is little evidence of links between MPB/salvage effects and total organic carbon, true colour, metals and total phosphorous. Measurable changes in these parameters in Peachland Creek are not expected, following either management scenario.

There are fish present and high habitat values along most of the Peachland and Greata Creek mainstems. This results in a High Risk of a reduction in habitat quality following MPB-related pine mortality, due to increased sediment movement and channel aggradation. If there is extensive salvage harvesting the risk of negative impacts on fish populations will be Very High. The likelihood of negative impacts is even more likely where fish habitat values are Very High (Reaches 4, 2 and Reach 1, a high value Kokanee spawning area).

All social infrastructure risks are higher for the full salvage scenario than for the unharvested MPB scenario; because of the increased hydrologic hazard associated with clearcut salvaging in the types of stands present in the Peachland Creek watershed snow zone. Risks to forestry roads, Highway 97 and adjacent housing developments on the Peachland Creek fan are considered Moderate for the unharvested MPB scenario and High for the full salvage harvest scenario. Risks to private water intakes in the watershed are considered High to Very High respectively, because they are generally simply built, provide no treatment and are therefore quite vulnerable to sediment impacts.

Recommendations to reduce risks focus on protecting and strengthening risk elements, or on reducing stand-level MPB and salvage effects. Forest For Tomorrow (FFT) program 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. These activities will not mitigate the short term hydrological impacts of MPB attack and salvage harvesting in Peachland Creek.

Riparian management along streams during salvage harvesting will be important in maintaining short and long term large woody debris recruitment levels, and in preserving stream stability and fish habitat quality. 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.

Reservoir filling and release could be timed so the reservoir is filling throughout the freshet, thereby reducing freshet peak flows in lower reaches and reducing downstream impacts. Given that there could be increased peak flows following MPB attack, and that there are likely to be significant peak flow increases following widespread salvage harvesting in the watershed, it would be prudent to develop the infrastructure and procedures to manage reservoir filling and runoff to reduce freshet peak flows.

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. However, the incremental risks related to unharvested MPB-attacked stands are Moderate to DOP water quality and water supply infrastructure and probably Low to water supplies. Unharvested MPB-related risks are Moderate for most other infrastructure in the watershed, except for the three private water licenses, for which risks are High because of their high vulnerability.

High mainstem fish values have a potential High risk of impacts. Since the effects of 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 fish habitat assessments, monitor channel and riparian conditions and carry out rehabilitation activities as necessary. In Very High value Reaches 1, 2 and 4, mitigation could include rehabilitating natural and man-made sediment point sources, such as those at and upstream of the FSR mainline crossing; and rehabilitating riparian vegetation where it has been depleted through natural or human activities.

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 pine-leading stands were all 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) 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 ESSF stands (see Figures 6-8 and Appendix B).
- We recognize that individual stands within these broader BEC types will have different characteristics; 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 Peachland Creek Watershed is not expected to be catastrophic for any of the identified watershed values (risk elements). With good management of harvesting rates and sites that 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 stressor on Peachland Creek forests in the near future. Global warming and global warming-related disturbances such as other forest pathogens, and fire, are not improbable. 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 these potential 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 Peachland Creek Community Watershed (Figure 1- in pocket); as part of a contract to complete similar risk analyses for seven South Okanagan Community Watersheds

Peachland Creek Watershed has an area of approximately 142km^2 and drains into Okanagan Lake south of the town of Peachland. It is a water source for domestic, commercial and agricultural users in the District of Peachland (DOP). Peachland Creek currently supplies about 50% of district demand, but long range plans propose to have it meet most of the district water needs. There is widespread fish presence and good fish habitat throughout the Peachland Creek watershed.

This report provides an analysis of risks to watershed values associated with potential changes in the forest following pine mortality due to MPB attack and salvage harvesting. Changes in forest cover 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 extensive previously published materials on Peachland Creek watershed conditions, as well as a helicopter overflight on October 27 and ground inspections on November 12 and 13 2008. Forest overstory and understory were measured in 37 plots in five different areas in Peachland Creek on December 3 and 4 2008, as part of a program of 245 plots taken in 30 areas in seven South Okanagan Community watersheds. This detailed stand information was use in modelling the projected hydrological effects of MPB pine mortality and salvage harvesting in Peachland 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 Peachland Creek are assessed in Section 3, to determine potential hydrologic hazards. Section 4 details the presence and/or vulnerability of specific Peachland 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:

Risk = Hazard x 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) determine how the watershed will respond to changes in watershed ECA. A change in the flow regime is expressed as the flow hazard. How the flow hazard will affect stream channels depends on the existing channel conditions, 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.

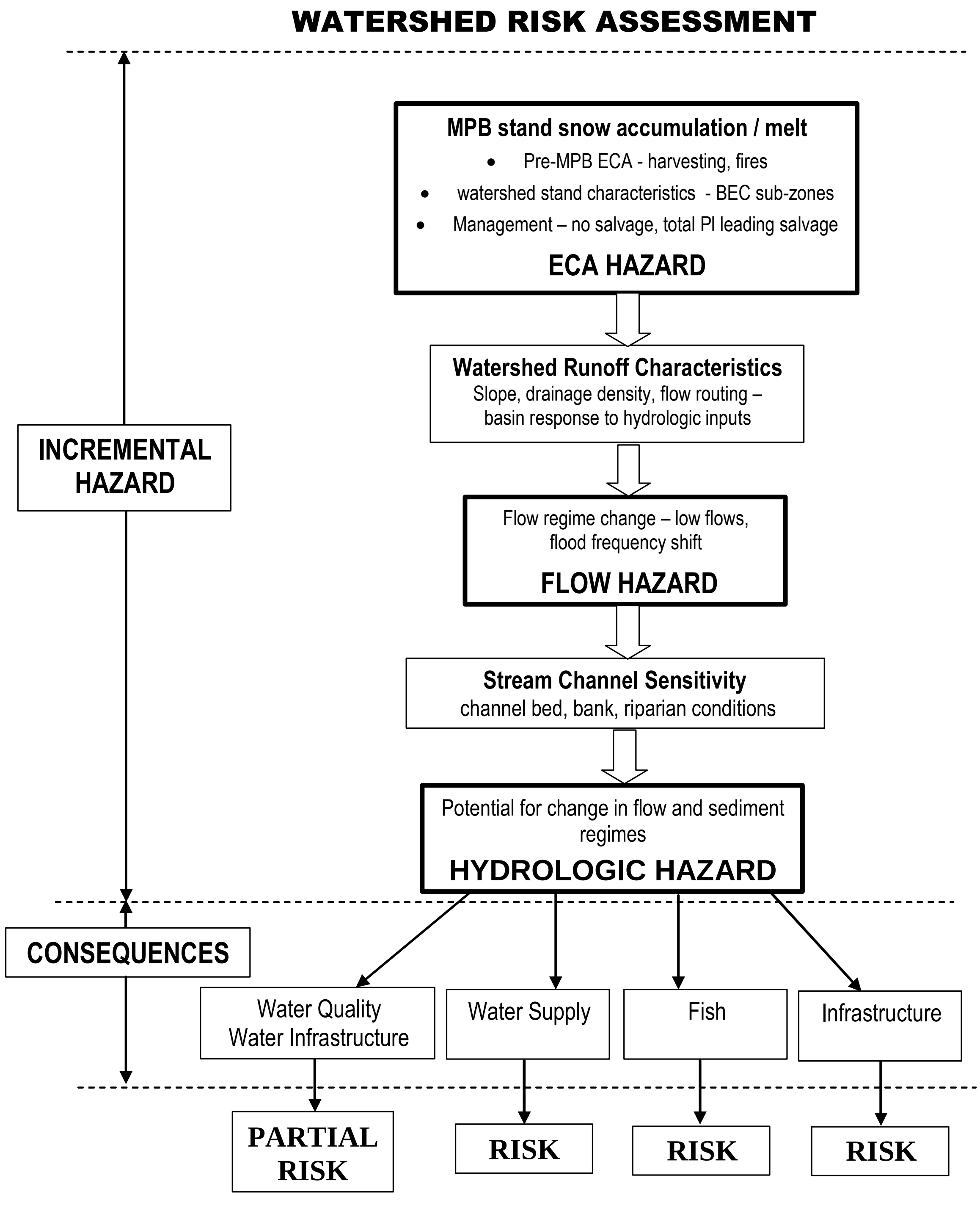

Figure 2. Risk Assessment Flow Chart

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 trees. These can alter the water balance at affected sites and, depending on actual weather and watershed characteristics, contribute to: less evapotranspiration and 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, and this is assumed to be the case in the following analysis.

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 Peachland 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 ±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), 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 *et al.* 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 Peachland Creek ECA was collected in 245 random plots in 30 accessible stands in seven South Okanagan watersheds[1] near Peachland Creek, with similar biogeoclimatic (BEC) stand types as Peachland Creek, and includes 37 plots taken in Peachland Creek watershed. Appendix B, "Summary of Results from South Okanagan Stand Surveys for MPB-ECA Modeling" 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.

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

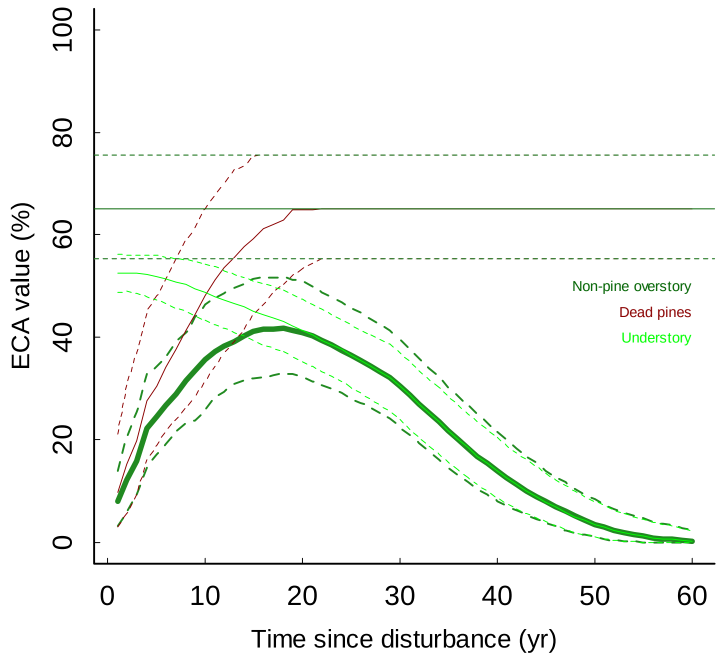

Figure 3. ECA projection (heavy green line) for unsalvaged older Montane Spruce BEC variant (MSdm, >110yr) showing the contributions over time of non-pine canopy (black line, showing a constant 35% ECA reduction over time) the dead pine (red line, showing decreasing ECA reduction as dead pines fall down 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, TIPSY 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 of a particular BEC variant. For instance, in high pine component stands there will be sites with very little understory, and other sites with a well-stocked understory.

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. The cumulative effect of the different ECA progressions in different BEC zones in the watershed is calculated, to arrive at a watershed ECA.

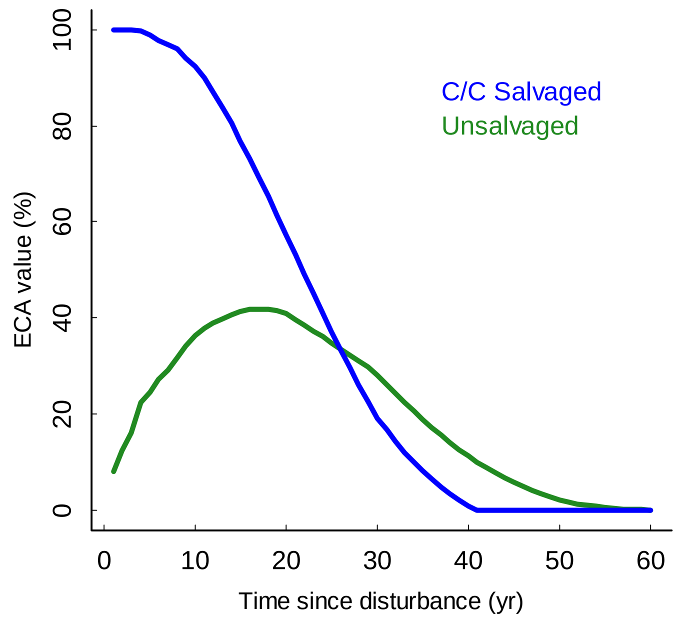

Figure 4. ECA projections for unsalvaged and clearcut salvaged and planted older MSdm, showing that ECA for unharvested MPB attacked stands never rises above about 40%. There is a 20 to 25 year period where the clearcut salvaged and replanted stand has a significantly higher ECA than the unharvested 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 an ECA value represents, 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 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 or a combination of these stressors.

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 Peachland 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. Loss of riparian cover following clearcutting small stream riparian zones has previously been raised as a concern in Peachland Creek (Dobson, 1999), and harvesting practices during timber salvage operations 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 (from Green, 2005), based on field observations, airphoto and map reviews and previously completed channel assessments. Earlier assessments were typically aimed at documenting levels of disturbance in channels and observed indicators of disturbance were assumed to also be indicators of channel sensitivity or 'robustness'. These results were carried forward into this assessment. 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 District of Peachland (DOP) water intake.
- Water supply (quantity) at the DOP 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 District of Peachland (DOP) intake on Peachland Creek. Water quality parameters and monitoring results in Peachland Creek are discussed in MoE (2008), Urban Systems (2007), Dobson (2006), Summit Environmental (2004), MoE (1990) and Swain (1990). Because it relates to the reliability of supplies, potential damage and increased maintenance costs to the DOP intake are also considered in this section.

Table 1 shows the various parameters identified by Interior Health Authority (IHA) and Ministry of Environment (MoE) stakeholders that, if compromised, could reduce drinking water aesthetic appeal, increase the risk of microbiological activity and impacts to 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

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 Peachland Creek source waters, turbidity (fine sediment) routinely exceeds Drinking Water Quality guidelines during the Apr-June freshet period and requires treatment. Hence, the lower watershed is considered sensitive to disturbances that will increase fine sediment concentrations.
		FINE SEDIMENT (Total Suspended Solids)	concentration, mg/L	
		Temperature	^{o}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. Peachland TCU regularly exceed water quality standards.
		Total Organic Carbon	concentration, mg/L	
		Metals (select)	concentration, mg/L	
	Reduced aesthetic appeal and increased risk of microbiological activity	Total Phosphorous	concentration, mg/L	
		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. Peachland Creek nitrogen levels are low.
		Aquatic Flora (algae)	mg per m^2	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. No measurement of indicators in Peachland Creek have been made.
	Human health (waterbourne 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. Microbiological levels in Peachland Creek are elevated for a large part of the year.
Water Supply Infrastructure	Treatment infrastructure damage	**COARSE SEDIMENT**	cubic metres	In Peachland Creek, most sediment is mobilized from bed and bank erosion in the channel, so any sediment mobilized can be transferred downstream to the DOP water intake and other values. Watershed is considered sensitive to disturbances that will increase coarse sediment production.

	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 land use issues.

Due to the historical presence and treatment of discharge from the Brenda Mine into Peachland Creek, there is a fair amount of water quality monitoring data that includes concentrations of metals. Since metals, and other above-listed parameters are weakly linked to MPB and salvage-related processes, particularly when 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 Peachland Creek so that potential post-MPB and salvage trends may be inferred, although not with a high degree of certainty:

Temperature
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 reserves 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. Concerns regarding harvesting of small stream riparian zones in Peachland Creek have been raised (Dobson, 1999), and to minimize cumulative temperature effects best practices for small stream riparian retention should be followed.

MOE (2008) monitoring indicates that maximum temperatures at the DOP community water intake rarely exceed drinking water guidelines, but were close to the maximum guideline level of 15^{o}C at times. While it is expected any change in Peachland Creek stream water temperatures due to MPB and salvage will be small, any change would be an increase in temperatures already seasonally approaching maximum acceptable levels.

Nitrate/Nitrite
Limited source water monitoring from 1997 to 1999 found nitrate/nitrite concentrations in Peachland Creek were below guidelines established for the protection of drinking water and aquatic life in surface waters (MOE, 2008).

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)
Neither chlorophyll *a*, nor periphytic algae, were measured as part of the 1996-1999 Peachland Creek water quality monitoring program. Monitoring watershed reservoirs for blue-green algae blooms is recommended, as this algae can form neurotoxins that have been linked to Alzeheimer's disease (Agua Consulting Inc., 2008).

MPB and salvage harvesting can affect the interrelated processes which can influence the abundance of aquatic flora in lakes and streams. These include changes in riparian canopy, stream temperature, nutrient 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.

Microbiological Indicators
Elevated concentrations of fecal coliform and E. coli at the DOP intake on Peachland Creek were recorded between May and September and between November and December (MOE, 2008), suggesting that elevated concentrations of microbiological indicators in Peachland Creek are common for much of the year.

MPB infestation and salvage harvesting are not expected to have a significant direct effect on fecal coliform and E. Coli levels in Peachland 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 already exists in the watershed any increase in fecal coliform and E. Coli levels in Peachland Creek 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 DOP 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 the aesthetic quality of water and decrease primary disinfection treatment effectiveness, placing additional stress on water treatment facilities.

Turbidity measurements in Peachland Creek source waters in the mid-watershed (above the Greata confluence) and near the DOP water intake, showed that during the April to June freshet period mean values exceeded the 1 NTU treatment standard set by Interior Health Authority (Dobson 2006). To address total colour and pathogens, as well as turbidity, DOP is exploring a water supply and treatment option in which Peachland Creek supplies most of the districts water needs. One of the main reasons for increased reliance on Peachland Creek is that more advanced water treatment will be required to meet IHA 4-3-2-1-0 treatment standards, and this would allow the entire district to be serviced by one water treatment plant at the Peachland Creek source, at an estimated cost of $12.5M (Urban Systems, 2007).

Although source water turbidity levels in Peachland Creek are not as high as in some other South Okanagan community water supplies, they are nonetheless a concern which will require significant expense to address. Seasonal turbidity measurements show some correlation between stream discharge and fine sediment concentration. Therefore the watershed is considered sensitive to disturbances that will increase fine sediment concentrations in source waters.

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 Peachland Creek near the DOP intake. As discussed in Section 2.3, most sediment is generated from channel bed and bank erosion 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 downstream elements. Increased bedload sediment can cause changes in channel morphology and negative impacts to water intake and other infrastructure. Therefore, the watershed is considered sensitive to changes in peak flows that will increase coarse sediment production and movement.

Water Quality Risk Analysis Procedure

A complete risk analysis would consider not only the stream flow and sediment hazards, but how vulnerable the entire water delivery system could be to sediment impacts; by looking at all the water supply system protection barriers from intake 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 DOP 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 at the DOP water intake (Dale Thomas, pers. comm.). The source water quality findings of this investigation can be used as input to a more comprehensive "Source to Tap Risk Assessment" that water purveyors are required to complete (MoH, 2005).

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 DOP 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 watershed conditions that could compromise the ability of storage to meet agricultural and domestic demands during the growing season, when there are large natural moisture deficits. MPB and salvage-related effects most likely to be noticed are changes in runoff timing. 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 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. MPB attacked stands lose some canopy function, or are salvage clearcut harvested, in which case 100% of the canopy is removed. Therefore snowmelt timing effects similar to harvesting are expected in MPB and salvaged stands.

In the 1960s Peachland Creek was diverted from its natural course to supply Peachland Lake, which has had its storage capacity increased by a dam at the outlet of the lake. Assessment of the Peachland Creek watershed indicates that enough water is available from the Peachland Creek intake to supply the entire District well into the future (Urban Systems, 2007). The District is developing a water treatment and supply option that utilizes Peachland Creek for nearly 100% of District water supplies, with Okanagan Lake as a back up supply for extreme low flow periods and emergencies. Because of reservoir storage capacity, Peachland Creek is considered less susceptible to reservoir depletion due to earlier snowmelt than most other Okanagan community watersheds.

2.4.3 Fish

Sport-fish species within the watershed include brook trout (Salvelinus fontinalis), and rainbow trout (Oncorhynchus mykiss). Kokanee (Oncorhynchus nerka) have been identified in the lower reach of Peachland 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). The Ministry of Environment holds water licenses on Peachland Creek to maintain minimum conservation flows in the creek. DOP infrastructure is used to meet the demands of these conservation licenses.

Table 2. Stream reach fish consequence value criteria

Consequence Rating	Criteria			
	Fish Species Present	Channel Width (m)	Channel Gradient %	Habitat Quality
Very Low	fish absence	<1.5	>20%	fish absence confirmed, minimal fish habitat available, habitat degradation low risk to fish
Low	presence of RB	0-5	16% - 19%	fish absence confirmed and/or habitat with low rearing potential for the fish species present
Moderate	presence of RB, EB	0-5	8% to 15%	habitat quality low to moderate
High	presence of RB, EB, MW	0-20	0% to 8%	fish presence confirmed, habitat quality moderate to high
Very High	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 are likely to be similar to forest harvesting effects. These include loss of riparian vegetation which 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 Peachland 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).

2.4.4 Social Infrastructure

Social infrastructure refers to structures other than the DOP water supply infrastructure, which in Peachland Creek include three privately owned domestic water intakes and numerous forestry road crossings of mainstems and tributaries. Highway 97 crosses Peachland Creek near the mouth, and there has been some residential development on the fan. For each of these elements 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 Peachland Creek Community watershed drains portions of the Thompson Plateau into Okanagan Lake on the west side of the valley near Peachland, BC. The watershed encompasses an area of approximately 142 km^2 ranging in elevation from 342m at Okanagan Lake to a maximum of 1820m at the divide near Brenda Mines. Major tributaries to Peachland include Mile Creek and Greata Creek. Tributaries to Greata Creek include Bolivar Creek and Bolingbroke Creek.

Peachland Lake, at elevation 1270m, was developed in the 1960's as a storage reservoir, originally as supply for Brenda Mines, located just north of upper Peachland Creek in the Trepanier Creek Drainage. Subsequent to mine closure in 1994, Peachland Lake has been used exclusively by the District of Peachland (DOP). Approximately 19% of watershed is located above Peachland Lake. Several other smaller lakes and wetlands exist in the watershed at mid- to high elevations, including Glen Lake on upper Greata Creek.

Table 3. Peachland Creek Watershed and sub-basin areas

Sub-basin Name	Sub-basin Area (ha)	Total Tributary Area (ha)	Elevation Range (m)	Reservoirs
Upper Peachland	2345	2345	1200-1830	Peachland Lake
Greata Creek	4482	4482	800-1700	Glen Lake (inactive)
Peachland Mid	4134	8616	800-1520	Wilson Lake (inactive)
Peachland Residual	1419	12380	540-1050	None
Total Peachland Watershed	12380	12380	540-1830	All of the above

Bedrock is mapped mostly as Mesozoic granitic rocks with overlying volcanic rocks present mainly on upland plateaux along drainage divides. Soils in the watershed are typically moderately coarse to coarse textured morainal material with some colluvium on steeper slopes and infrequent glaciofluvial sediments on gentler slopes. Drainage density of streams on the plateau is low due to the relatively gentle terrain and predominantly well-drained soils.

Most of the Peachland Creek watershed is dominated by a rolling, flat (<7%) to gentle (7 to 30%) sloping glaciated upland plateau between elevations of 1000 and 1800m, typical of the Okanagan Highlands Physiographic Region (Photo 1).

Greata Creek and Upper Peachland Creek above Peachland Lake are incised into a moderate (30 to 50%) to moderately steep (50 to 70%) sided valleys. In Upper Peachland Creek there are some landslides and talus slopes on lower valley walls delivering sediment to the mainstem. There is a large slope failure and scoured valley side tributary to Upper Peachland Creek, at the upper end of Reach 8, related to an earlier stream diversion from outside the watershed (Photo 2). In the past it is likely that significant sediment was delivered to the valley bottom and locally impacted Upper Peachland Creek. The low gradient and swampy Reach 8 and Peachland Lake likely limit sediment movement to the lower drainage.

Outside these river valleys, upland plateau tributaries are weakly incised and have very low gradients. Sediment sources upstream of Peachland Lake are buffered by the Peachland Lake, and are not a source of sediment to downstream reaches and the DOP intake.

Below the lake, Peachland Creek is incised into a narrower, steeper, predominantly rock-walled canyon that is increasingly incised and deeper going downstream. Dobson (1999) identified natural stream bank failures above the Peachland Mainline FSR crossing, just upstream of the Greata Creek confluence, as a significant sediment source (see Section 3.1.2). Between the lake and the DOP intake there are a few ravelling canyon sidewalls failures delivering some sediment to Peachland Creek (Photo 3). However most sidewalls are largely bedrock and appear stable, with little sediment delivery to the mainstem (Photo 4).

Because most valley and canyon walls in lower reaches are bounded by fairly stable bedrock, Peachland creek has formed a relatively small fan into Okanagan Lake, compared to other Okanagan Lake tributaries which flow through more erodible materials.

Few road related failures were noted in the previous detailed assessment. One slope failure related to an old spur was identified on Bolivar Creek, a tributary of Greata Creek, approximately 100m upstream of the Peachland FSR crossing of Bolivar Creek (Dobson 1999). This site was re-inspected in 2008 and found to be mostly re-vegetated and no longer a significant sediment concern. Just downstream, the FSR crossing of Bolivar Creek is on a 6m high embankment fill. Some fill slope rill erosion was observed and fill material is being deposited in the creek. Most of the sediment from these sources is subsequently deposited in the lower 100m of Bolivar Creek where it passes through a low gradient wetland complex, and little is mobilized downstream into lower Greata or Peachland Creek.

3.1.2 Channel conditions and bank stability

Existing conditions in the Peachland Creek watershed derived from field and office reviews are described in Table 4. Channel conditions are summarized by sub-basin although some issues may only apply to specific reaches within that 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.

Above Peachland Lake Reservoir in the Upper Peachland Creek sub-basin, stream channels are relatively small with cascade-pool or step-pool morphologies (Dobson 1999). Riparian forests remain undisturbed along the mainstem; however riparian vegetation along some tributaries has been reduced. Some localized bank erosion was noted on a tributary in 1999, possibly related to increased peak flows from a large cutblock (CP 67); and sediment from the Brenda Mines diversion (Photo 2) has likely resulted in local aggradation of Peachland Creek.

However, any sediment originating upstream of Peachland Lake is likely to settle in the reservoir and not be transported into the lower mainstem. The likelihood of discernible change at the DOP intake as a result of the disturbances above the lake is very low.

Downstream of the Peachland Lake, in the Peachland Middle sub-basin, the mainstem channel flows at 3 to 6% gradient with bankfull widths between 3 and 8 metres. It appears to be mostly stable and undisturbed with good LWD function and occasional bedrock controls until it approaches the Peachland FSR crossing. Within a few hundred metres upstream of the FSR crossing, several natural shallow bank failures periodically contribute sediment to the channel (Photo 5), causing severe aggradation towards the crossing. The road crosses the creek over a high fill embankment with a 1500mm culvert providing drainage. A newer 1800mm culvert has been installed several meters above the invert of the 1500mm culvert as a back-up/overflow. This improvement may be an indication of earlier sediment or capacity problems at the site. FSR fillslopes and cutslopes upgrade from the crossing also appear to be a chronic source of sediment.

While Peachland Creek is able to transport sediment through the Middle sub-basin, little sediment is expected to enter from Peachland Lake above. However, the sub-basin itself is a significant source of sediment, with fine and coarse sediment entering the system through bank erosion, directly connected slope failures and road-related point sources. Excess sediment has accumulated in a low gradient section near the FSR crossing.

Greata Creek originates at Glen Lake (elevation 1140m), and flows with an average gradient of 2 to 4%. It is predominantly riffle-pool morphology with abundant woody debris, with a swampy wetland about 1 km downstream of the Bolingbroke Creek confluence. On private land near the confluences of Bolingbroke and Bolivar Creeks, riparian vegetation has been removed and livestock impacts identified (Dobson 1999). Most disturbance is localized and the channel is generally stable with frequent sediment wedges indicating upstream sediment sources. An old road-related landslide previously identified on Bolivar Creek is no longer a concern (see Section 3.1.1). Where the Peachland FSR crosses Bolivar Creek, some rill erosion was observed on the fillslope (Photo 6), which is directly connected to the creek channel and is delivering sediment to it.

Much of the natural channel of Bolingbroke Creek has been buried by the Peachland FSR, and for approximately 1.5 km the creek is essentially the road ditchline (Photo 7). Although the ditch/channel is well-established and crosses some exposed bedrock, whenever it is wet and there is traffic, fine sediment will be introduced to the channel, and this section of road represents a chronic sediment source.

Coarse sediment generated in Bolingbroke and Bolivar Creeks is likely to settle and/or accumulate in the lower gradient middle section of Greata Creek (Reach2). This section of the creek is inferred to be flowing through glaciofluvial (outwash) deposits, which suggest banks may be erodible (Kowall 1986). In the long term, aggradation resulting from sediment deposition could lead to channel widening and destabilization. Several sources of fine sediments were noted in upper the upper Greata basin, including Bolingbroke and Bolivar Creeks. Although some filtering may occur through Reach 2, finer-grained silt and clay may remain in suspension, sustaining turbidity levels downstream. Peak flows may be somewhat attenuated by the increased floodplain storage found in this section. In summary, the low gradient nature of Reach 2 on Greata Creek will help reduce peak runoff and capture some of the sediment generated in the upper Greata Creek sub-basin, including Bolingbroke and Bolivar Creeks.

In the Residual sub-basin the mainstem of Peachland Creek below the confluence of Greata Creek and above the DOP intake was found to be predominantly a stable, cobble channel with mossy lag boulders. Limited LWD function was noted at some sites inspected. The channel is confined within a bedrock canyon for most of its length (see Photo 4). Steep, rocky gullies may contribute some coarse (colluvial) material to the channel (see Photo 3). Some sediment issues and localized bank erosion were observed at a road crossing approximately 800m upstream of the intake. Frequent sediment wedges were noted in the mainstem channel, typically upstream of LWD jams. There are few tributaries in the Residual basin as it passes through the typically drier terrain found at lower elevations.

Downstream of the DOP intake Peachland Creek descends through a deeply entrenched predominantly bedrock canyon to enter Okanagan Lake approximately 4 km south of the town of Peachland. Sediment is likely to flush through the canyon section, with little opportunity to settle or accumulate. Hardy Falls near the lower end of the canyon forms an upstream barrier to fish from Okanagan Lake, including kokanee. A series of artificial weirs (riffles) have been constructed in the low gradient section of Peachland Creek near the lake, to improve conditions for spawning kokanee (Photo 8). By definition, the small fan at the mouth of Peachland Creek has some potential to accumulate sediment, however no evidence of recent deposits or active aggradation was observed.

Forest cover disturbances in the drainage area below the District intake were not analysed. However because of the confined channel through the canyon downstream of the intake, any increases in stream flows and sediment at the intake will be transported through the canyon to Okanagan Lake, and potential impacts are discussed 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 Peachland	7,8,9	9.6	0.04	CPg/c	Source	Upper plateau area, some small wetlands along channels. Brenda Mines tailings ponds short distance over divide. Disturbed tributary of old diversion channel. Low drainage density with small natural channels and generally low gradient. Riparian intact along mainstem but reduced on some tributaries.
Mid Peachland	4,5,6	11.5	0.05	CPg/c, RPg/c	Source	Sub-basin includes mainstem downstream of Peachland Lake and Mile Creek draining Wilson Lake. Localized impacts on mainstem in vicinity of Peachland FSR crossing. Channel predominantly stable with good LWD function and occasional bedrock controls. See Table 5
Greata Creek	1,2,3, 4,5,6	9.6	0.04	RPg/c	Source	Greata mainstem mossy substrates with LWD function and intact riparian. Some cattle/clearing impacts on private land section. Fillslope rill erosion sediment source at Bolivar Creek crossing. Portions of Bolingbroke Creek displaced by road, creating chronic source of fine sediment. See Table 5.
Peachland Residual (above intake)	3	6.4	0.03	RPg/c, CPg/c/b	Transport	Predominantly mossy channel with stable lag boulders but limited LWD function. Some localized impacts at road crossings. Few tributaries in Residual.
Peachland Residual (below intake)	1,2	3.5	0.07	CPg/c, RPg/c	Transport	Mostly bedrock controlled canyon with a relatively small fan at the mouth. Channel is well-incised on the fan with little or no evidence of recent sedimentation. Several instream weirs/riffles have been constructed near the mouth to improve fish spawning habitat.

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

3.1.3 Channel Sensitivity

Using the assessment framework outlined in Table C1 Appendix C, channel sensitivities for the Peachland Creek watershed 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 to occur in association with 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 sensitivity of the mainstem channel in that sub-basin. Potential outputs associated with channel change are included in Table 5 to provide an indication of issues that may arise if changes to flow/sediment regimes were to occur.

Sensitivities of natural channels to increased peak flows in Peachland Creek were considered to be low in previous assessments (Dobson 1999). However, some indications of channel sensitivity were identified during our field review. Working through the rationale presented in Table 5, all of the mainstem channels above the intake were found to be moderately sensitive to increased peak flows. This suggests some channel adjustment can be expected to occur if the flow regime were significantly increased. Evidence of channel adjustment following harvest was noted in a small tributary the upper Peachland sub-basin (Dobson 1999). In Reach 4 bank erosion and landslide activity may also increase as a result of toe erosion in response to increased peak flows.

Sediment transfer in upper Peachland Creek, Greata Creek and Bolivar Creek is limited by low gradient/wetland sections. In some of these areas, sediment may accumulate, leading to channel widening where banks are erodible and/or to avulsion if aggradation is severe. Most channels inspected were considered to be moderately sensitive to an increase in sediment loading.

With the exception of the private land section on Greata Creek, riparian areas appear to be mostly intact along the mainstem channels in the Peachland watershed. The section of Bolingbroke Creek buried by the FSR has reduced riparian structure. Riparian vegetation has been removed by clearcutting along some tributaries in the upper basin. Riparian condition is not expected to change significantly with the invasion of MPB, or following salvage harvesting if good riparian management practices are followed.

3.2 WATERSHED HYDROLOGY

Peachland Creek is a snow-dominated (nival) hydrologic system and (uncontrolled) peak flows occur from late April to mid-June. Total annual precipitation ranges from 400mm at 345m near Okanagan Lake to 650mm at 1500m elevation. At higher elevations approximately 75% of annual precipitation falls as snow, and is largely stored until the spring freshet snowmelt. It is estimated that roughly 75% of annual runoff occurs between April and July in response to snowmelt (Summit 2004).

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 Peachland	M	Upper mainstem is a small channel with intact riparian. Some erosion noted in tributaries below blocks. Likely aggraded below MacDonald diversion.	L	Small channels with occasional low gradient wetland section. Limited ability to move sediment. Some storage.	L	Small channels not as sensitive to reduction in mature riparian, however tree roots enhance bank stability.	**M**	Cumulative effects limited near headwaters. No changes anticipated.
Peachland Mid	M	Peak flows may increase landslide activity through toe erosion. Limited by some bedrock control.	M	Ongoing landslides and bank erosion has caused some channel aggradation.	M	LWD plays a role in channel stability in RPg/c reaches, including improved bank stability and controlling sediment transport.	**M**	Increased flows, erosion and sediment loading could cause additional slope failures leading to downstream aggradation.
Greata Creek	L	Low gradient channel with fine and coarse textured substrates. Stable but erodible banks.	M	Occasional low gradient sections. Some potential for aggradation. Fine sediment may pass through.	M	LWD plays a role in channel stability in RPg/c reaches, including improved bank stability and controlling sediment transport.	**M**	Increased flows, erosion and sediment loading could cause aggradation and widening.
Peachland Residual (above intake)	M	Frequently confined channel with some finer (gravel) substrates near intake. Banks are erodible fluvial deposits.	M	Sediment inputs may cause aggradation and lead to further bank erosion and channel widening.	M	LWD plays a role in channel stability in RPg/c reaches, including improved bank stability and controlling sediment transport.	**M**	Moderate increases in bank erosion, aggradation and channel widening.
Peachland Residual (below intake)	L	Stable bedrock canyon with high capacity to pass flow peaks. Not sensitive to small increases in discharge.	L	Sediment will pass rapidly through this channel section. Little opportunity for settlement or accumulation other than fan.	L	LWD plays a minor role in channel stability due to frequent bedrock controls.	**L**	Minor changes to flow and sediment regimes are not expected to affect channel stability.

Stream discharge peaks are somewhat moderated by the storage volume of Peachland Lake reservoir. Although only about 20% of watershed area is upstream of Peachland Lake, presumably because that area is at higher elevation with greater precipitation and a greater percentage of that falls as snow, is estimated that approximately 75% of the mean annual runoff for the Peachland Creek watershed flows into Peachland Lake, and the much smaller Glen Lake reservoirs (Dobson 2006).

3.2.1 Snow sensitive zone

It is widely accepted that for nival (snowmelt dominated) watersheds such as Peachland 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_{60} (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_{60} concept was developed for graded mountain watersheds, and not watersheds with large upland plateaux, such as Peachland Creek.

Measurements have been made of the elevation of the receding snowline at the time of peak flows in several south Okanagan watershed (Dobson 2004a, 2004b, 2004c and 2004d). In almost all cases the contributing snow zone was less than 60%. Based on four years of observations (2001 to 2004), the position of the snow line in Peachland Creek during the freshet period (as extrapolated from stream discharge records on nearby smaller watersheds) was between 1350 and 1600m elevation (Dobson, 2004a).

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 Peachland Creek. Therefore in Peachland Creek the 1350m elevation is considered the lower limit of the snowmelt contributing zone to mainstem peak flows. The 1350m contour is approximately the H_{40} line for Peachland Creek – that is 40% of Peachland Creek watershed area is above this elevation.

3.2.2 Forest cover changes

Stand Level ECA

Figure 5 (in pocket) shows the BEC stand types in Peachland Creek watershed, including Ponderosa Pine (PP), Interior Douglas Fir (IDF), Montane Spruce (MS) and Engelmann Spruce Sub-alpine fir (ESSF). MSdm, ESSF and IDFdk BEC variants located above the H_{40} line are coloured. These three variants comprise 79%, 12% and 9% respectively of the area of Peachland Creek watershed in the snow zone above the H_{40} line. 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 three BEC units above the snow line in Peachland Creek.

As discussed in Section 2.2.2, the unsalvaged curves are based on field measurements taken for this project of secondary stand structure in Vegetation Resource Inventory (VRI) labelled pine-leading stands in seven South Okanagan watersheds (see Appendix B). The curves shown here assume full pine mortality, full understory survival and a site index (SI) of 15.

ESSF ECA curves (Figure 6) are based on 56 plots in 7 ESSFdc stands. In stands labelled as 100% pine or >80% pine, the actual measured overstory pine component averages 30.7%. The rest of the overstory was approximately equal amounts of spruce and balsam. The average understory has 1,000 well-spaced stems (>1.3m tall) per hectare (ha).

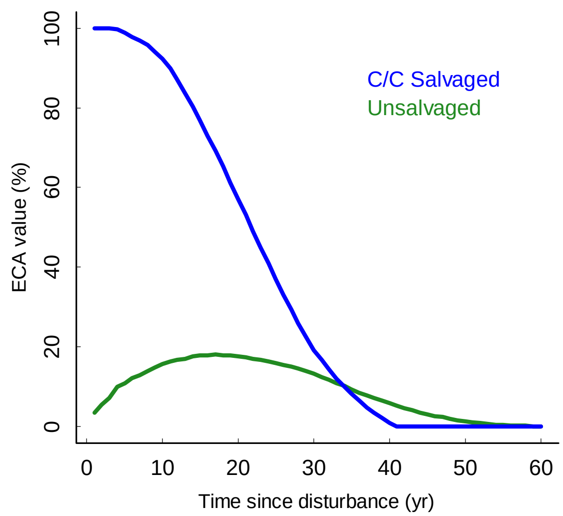

Figure 6. ECA progression in ESSF pine-leading stands.

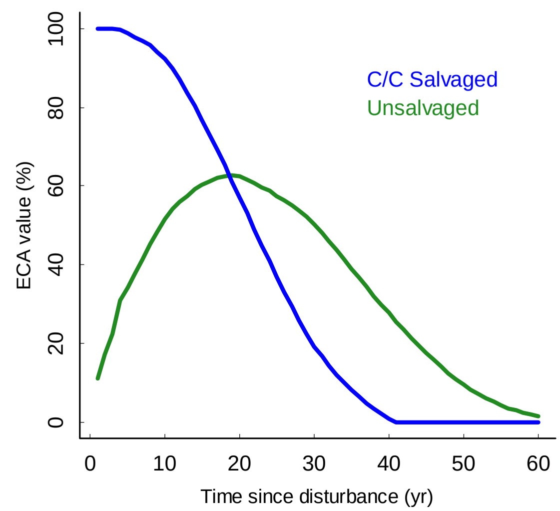

Figure 7. ECA progression in younger pine-leading MSdm stands (70 to 110 yr).

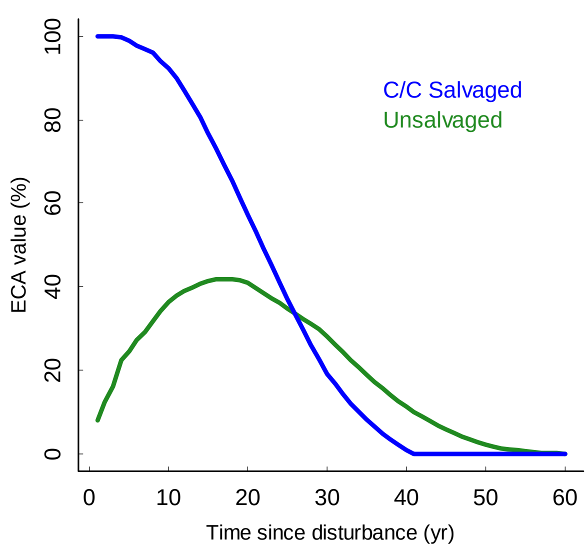

Figure 8. ECA progression in older pine-leading MSdm (> 110yrs) stands.

The younger MSdm ECA curves (Figure 7) are based on 64 plots in 8 pine-leading stands. 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 8) 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.

Peachland Creek Watershed ECA

These three stand type curves, and ECA recovery curves for IDF stands using data from Vyse (2007), were used to generate cumulative harvested and unharvested ECA curves for the watershed area and all 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 forest licensees operating in the watershed – Tolko Industries Limited and BCTS Okanagan-Shuswap Business Area.

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 (green line) all pine trees in pine-leading stands are assumed to killed by MPB, 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 (purple 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 rating 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, and if effects are noticeable, they are not expected to be large. A High ECA hazard rating indicates that significant ECA effects are likely; and a Very High rating expresses a greater certainty about the expected occurrence of very significant effects.

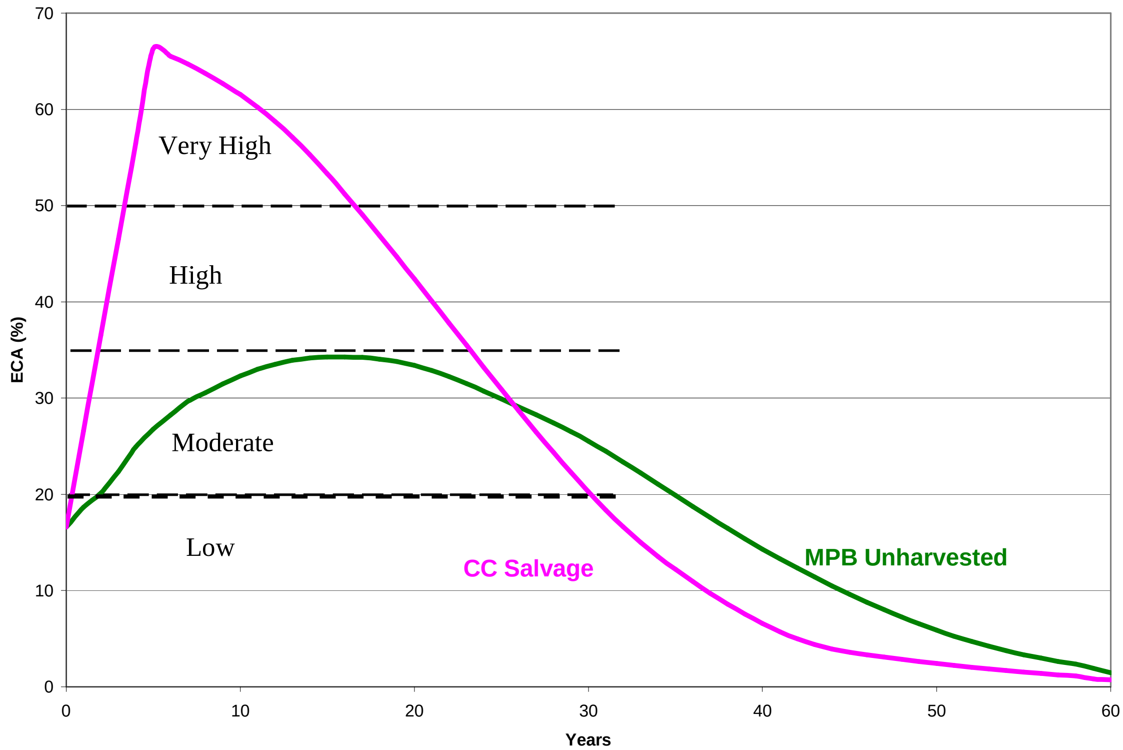

Figure 9. ECA and ECA hazard projections for Peachland Creek Watershed above H_{40} elevation, assuming full pine mortality from MPB infestation and full understory survival for MPB and no harvest scenario (green) and full salvage harvest of all pine-leading stands scenario (purple).

In Figure 9, the sustained ECA hazard for the MPB/unharvested scenario is average position of the curve above the low hazard level. The current watershed ECA is Low. Following full pine mortality and no harvesting there is a Moderate ECA hazard for approximately 25 years. That is, with the overstory and understory survival assumptions made, the ECA effects of MPB mortality (and no further harvesting) may or may not be noticeable, and if there are noticeable effects they are not expected to be large. Similarly, the average position of the ECA curve for the hypothetical full pine-leading stand salvage scenario, relative to the MPB/unharvested curve, suggests there is a sustained a High to Very High ECA hazard for 20 years. Within this time period significant ECA effects are considered very likely.

In addition to these two scenarios, several sensitivity analyses are carried out for a range of possible future forest recovery scenarios. These include modelling the effects of total and partial pine mortality in unharvested pine-leading stands in the watershed and of total and partial understory survival in unharvested attacked pine-leading stands. Modelling 50 to 20% less than full mortality in unharvested MPB-attacked stands decreased maximum ECA values by about 5% and watershed recovery (to 20% ECA) is about 5 years earlier. With only 50% understory survival in the MPB/unharvested scenario, the maximum ECA increases about 5% and recovery is approximately 5 years later. These changes are small compared to the difference between the MPB retention and the full-harvest scenario ECA values.

ECA analyses for the two ECA scenarios were also completed for the Greata Creek, Upper and Mid-Peachland sub-basins (Table 6). The Residual sub-basin has no area above the H_{40} line, does not contribute runoff to freshet peak flows and was not analysed.

Table 6. Sub-basin ECA

Sub-basin Name	Current ECA	Maximum ECA (%)		Sustained ECA (%)		% Total Area >H40
		MPB	Full Salvage	MPB	Full Salvage	
Upper Peachland	24	37	66	M	H	40
Greata Creek	9.6	30	62	M	H	43
Mid	16.5	42	77	H	VH	18
Total Watershed	16.6	34	66	M	H - VH	100

Results were similar to those for the whole watershed for the Greata and Upper Peachland sub-basins. In the Mid-Peachland sub-basin ECA values were higher for both management scenarios. This is because the Mid sub-basin has much smaller snow zone area that other sub-basins (Table 6), so a relatively small harvest rate in this smaller area yields a higher ECA. This does not significantly affect the overall watershed ECA.

Generally in Peachland Creek Watershed and its sub-basins, current ECA levels are Low (10 to 25%), and following pine mortality and no harvesting ECA levels are predominantly Moderate for 20 to 25 years. Following the full pine harvest scenario ECA levels are High to Very High for about 20 years.

3.2.4 Flood frequency shift

The changes in forest canopy closure represented by ECA result in increased snow accumulation and freshet snowmelt rates, which in turn can result in an increased frequency of floods of any particular magnitude, which is known as the flood frequency shift.

Spring peak flow generation in nival watersheds is a complex process involving snow pack, forest cover, microclimatology and weather. This study uses the results of numerical modelling watershed studies for 11 nival, unregulated Interior B.C. watersheds, which look at changes in flood frequency following widespread watershed forest cover disturbances (Alila, et al. 2007, FPB 2007, Schnorbus et al. 2004). That is, computer models of watershed processes are used to predict changes in flood frequency following modelled changes in forest cover conditions in the study watersheds.

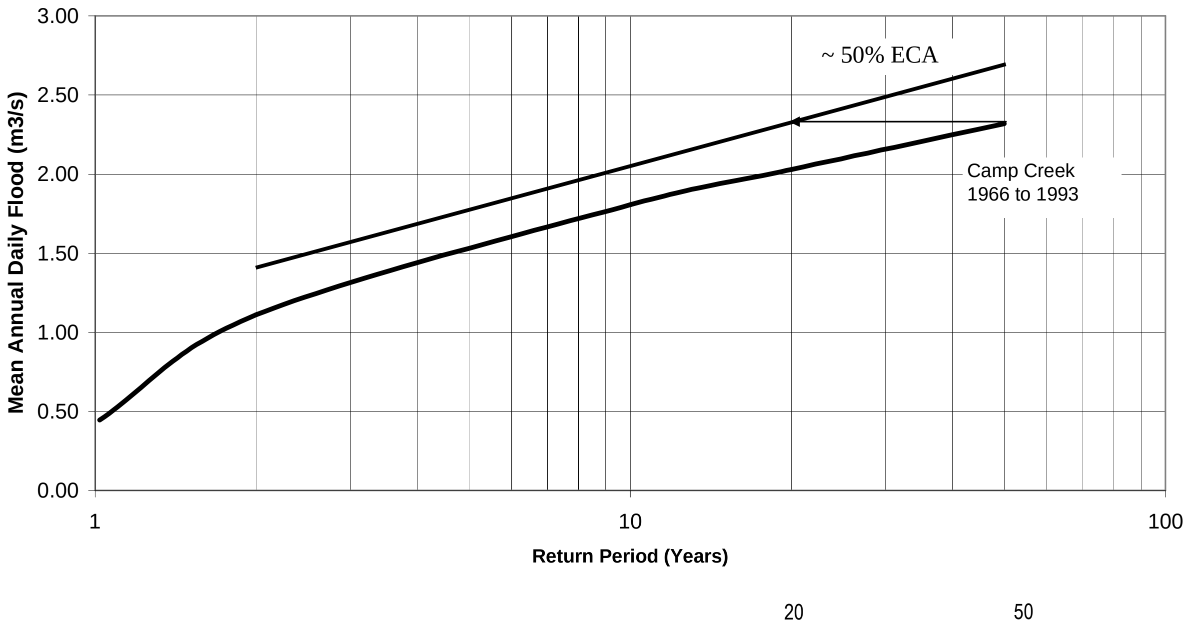

Figure 10. Estimated flood frequency shift mid-sized Okanagan Watersheds with a High ECA hazard.

Figure 10 is a conceptual analysis of the expected change in flood frequency in an typical mid-sized (10's to 100's km^2) Okanagan watershed, given a High (50 %) ECA, as would occur following full salvage harvest in Peachland Creek. In this case Camp Creek is use to represent a typical watershed. Appendix E-Flood Frequency Analysis provides details of that analysis. Camp Creek and Peachland Creek share a common watershed boundary. Camp Creek has a long enough uncontrolled stream discharge record to generate a meaningful flood frequency curve, and this analysis describes unregulated stream discharge conditions.

As shown in Figure 10, assuming a High ECA, the historic 50 year flood is expected to occur approximately every 20 years; and all other magnitude floods would similarly be expected to occur more frequently. This flood frequency shift is expected to last for about 20 years in areas with unregulated flows, such as Greata and Mid-Peachland tributaries, following total salvage harvest of pine leading stands. With a Moderate ECA, such as that expected to last about 25 years after total MPB pine mortality, a noticeable increase in flood frequency, and shift in the flood frequency curve, may or may not occur, and if it does it is expected to be small.

It is important to remember that the above analysis applies to Interior B.C. watersheds with unregulated flows. Watershed characteristics, including a reservoir such as Peachland Lake, can reduce the likelihood of ECA hazard effects resulting in peak flow and hydrological hazards, as discussed below.

3.2.5 Watershed Reservoir Management and Flood Regime

The DOP intake is located at an elevation of approximately 600m, 3.3 km upstream of Okanagan Lake. The watershed area above the District of Peachland (DOP) intake is approximately 125 km^2. At the intake site, a concrete spillway has been set into bedrock to form a diversion dam, allowing the construction of two small settling/storage ponds at the intake site (see Photo 8). The two settling ponds run in series and serve to settle suspended solids carried in the water. A chlorine contact tank is situated immediately downstream of the settling ponds.

The primary flow control and storage reservoir on Peachland Creek is Peachland Lake. Situated at an elevation of 1270m, the reservoir covers an area of approximately 117ha and is capable of storing 13.3 million m^3 of water. Peachland Lake uses its significant storage capacity to capture water from freshet snowmelt and allow it to be utilized during summer months when unregulated flows would be low and demands are high. Flows are released from Peachland Lake to Peachland Creek in a controlled manner through a manually-operated outlet control house. Ministry of Environment has licence to maintain fish flows in Peachland Creek and these are managed by water releases from Peachland Lake.

DOP also holds permits for storage also on Glen Lake at the headwaters of Greata Creek and on Mile Creek (Wilson Lake). Controls on these other sites have been left open at the request of the Ministry of Environment. DOP is considering a new dam to increase storage in Glen Lake (Urban Systems 2007).

In the past, Peachland Creek watershed has been interconnected with both the Trepanier and Trout Creek watersheds to ensure adequate supplies for Brenda Mine in the Trepanier Watershed, just east of upper Peachland Creek. Ditches were constructed to divert water from Headwater Lakes in the Trout Creek watershed into Peachland Lake. Also flows from MacDonald Creek (in the Trepanier Creek watershed) were diverted into Peachland Lake (see Section 3.1.1). It is also possible to divert flows from Wilson Lake on upper Mile Creek (Figure 1) into Silver Lake in the Trepanier Creek watershed. Brenda Mine was closed in 1994 and it is not expected that these diversions in and out of Peachland Creek will be reactivated.

The Upper Peachland Creek area draining into Peachland Lake comprises approximately 19% of the Peachland Creek drainage area above the DOP intake, but approximately 40% of all high elevation "snow zone" area assumed to be contributing snow melt runoff during peak flows[2]. Thus about 60% of the peak flow generating area of the watershed contributes to uncontrolled peak discharges.

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. Prime factors when considering peak flow hazards are the extent of forest canopy loss (ECA) discussed in earlier sections, and the routing characteristics of the affected sub-basin (See Figure 2). Sub-basin factors that affect runoff sensitivity include steepness, soil drainage properties, drainage density, soil depth (or proximity

2. While currently uncontrolled, Glen Lake will likely be in the future (Urban Systems, 2007). There is an additional 7.7% of watershed area above the DOP intake draining into Glen Lake. It is not known when Glen Lake will be upgraded to add to total storage in the watershed.

to an impervious layer), and existing storage such as reservoirs, lakes, and wetlands. 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 Peachland watershed as a whole under the two forest management ECA scenarios of 'MPB/unharvested' and 'Full-salvage'. ECA progressions over time for the two management scenarios are shown in Section 3.2.3 and ECA hazards in Table 7 are represented by the maximum ECA value over time, and the qualitative sustained ECA hazard over time. Reservoir storage and release factors affecting peak flows for sub-basins are discussed in Section 3.2.5. 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.

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 Peachland	Good	37	M	65	H	L	M
Peachland Mid	Poor	42	H	77	VH	H	VH
Greata Creek	Poor	30	M	62	H	M	H
Peachland Watershed	Moderate	34	M	66	H - VH	M	H

Results

Assumed the reservoir is full and discharging during large peak flows, there will still be some reservoir routing effects that will help with peak flow attenuation. Nonetheless, given that most peak flow contributing area in the watershed is uncontrolled, combining the good peak flow attenuation effect in Peachland Lake reservoir and the poor attenuation effects in Peachland Mid and Greata Creek sub-basins, the post-MPB peak flow attenuation for the watershed at the DOP intake is Moderate.

Combining this with the Moderate ECA levels resulting from retention of MPB-attacked stands in the watershed, post-unharvested MPB peak flow hazards are Moderate. Anticipated ECA levels resulting from the full salvage scenario are High to Very High. Combining this with the Moderate watershed attenuation potential, the post-salvage watershed peak flow hazard is High. Except for Upper Peachland sub-basin, for the other sub-basins and the watershed as a whole, a flood frequency shift to similar that predicted in Section 3.2.4 would be expected to occur following full salvage harvesting of pine-leading stands.

3.3.2 Hydrologic hazard

Hydrologic hazard represents the potential or likelihood of peak flow or sediment impacts to existing channel systems 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 Peachland Creek sub-basins and watershed as a whole.

Table 8. Hydrologic Hazards by Sub-basin

Sub-basin	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 Peachland	M	L	M	L	M
Peachland Mid	M	M	VH	M	VH
Greata Creek	M	M	H	M	H
Peachland Watershed	M	M	H	M	H

As discussed in Section 3.1.3, channel sensitivities are generally Moderate in the Peachland Creek system. When combined with the Moderate to High peak flow hazards in Table 7, there are Moderate to High hydrologic hazards. These finding suggest that there is a Moderate likelihood of increased peak flows and increased sediment delivery at the intake under the unharvested MPB scenario and a High likelihood following full pine salvage harvesting. Peak flows would likely mobilize sediment stored in Greata Creek and possibly reactivate bank/slope failures and sediment stored in Reach 4 of Peachland Creek. Widespread channel adjustment may result in the hypothetical scenario of full pine removal.

3.3.3 Low-flow hazard and reservoir storage

It is widely accepted that 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. 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 Peachland 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 Peachland Creek is considered Low.

However widespread removal of forest cover can also 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 necessitate earlier withdrawal from reservoir storage and therefore earlier reservoir depletion later in the growing season.
To estimate what effects the expected MPB and salvage ECA values (Figure 9) 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 earlier peak flows were reviewed (Pike and Scherer 2003, Alila, et al. 2007 and FBP 2007).

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 Peachland 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; and,
- potential freshet advancement following the forest cover disturbance caused by the full salvage harvest scenario (see Figure 9) would be greater than the effect of MPB mortality and the no harvest scenario.

3.4 CLIMATE CHANGE

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

Recent analyses of recent climate patterns suggest there will be less runoff. Rodebnhuis *et al.*(2007) found that in nival Okanagan basins, annual mean streamflow decreased by -7 to -14% over the last 30 years. Modelling of various climate change scenarios on stream flows in Peachland Creek resulted in a predicted decrease in natural annual flows of 18% by 2020 and 34% 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 increased temperature and dryness during the growing season will increase water use for agriculture and residential irrigation (which comprise 85% of district water use) by 16% in 2020 and 30% in 2050 (Summit, 2004). This effect is not considered in the District Water Availability Analysis (Dobson, 2006) which projects that it will be offset by decreased demand due to residential and agricultural conservation measures.

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, earlier use of reservoir storage, earlier reservoir drawdown and less available stored water supply in the latter part of the growing season. The magnitude of the combined effects of

climate change-related decreased water availability, increased demand and earlier storage depletion are not known.
MPB and salvage effects 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, and earlier reservoir drawdown and less supply later in the growing season. As discussed in Section 3.3.3 the MPB/salvage effect on freshet timing on reservoir supplies is expected to be relatively small.

While some climate change effects such as decreased winter snow storage will offset MPB/salvage effects, freshet advancement effects will be cumulative. In general, however, the MPB/salvage effects are expected to be small relative to climate change effects, and will be felt most in the next 10 to 20 years, after which they will likely be negligible relative to climate change impacts.

Because Peachland Creek watershed has significant reservoir storage, the risk of impacts to late growing season water availability is less than in many other Okanagan watersheds. Nonetheless, climate change-related temperature increases will continue. And since these effects will likely be cumulative with natural annual climate variability in freshet timing, which can be significant, in some years there could be serious impacts to water availability during the late growing season.

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-uban interface" (Eng 2004). We agree with this statement and recommend that, except in the wildland-urban interface, and possibly in small tributary watersheds (<10km^2) 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

Peachland Creek is a community watershed supplying drinking water to the Municipality of Peachland that services approximately 1,000 residential and commercial users, and provides irrigation water for about 200 ha of agricultural land. Approximately 85% of water demand is for agricultural and residential irrigation, about 6% is for indoor domestic use and the remaining 9% goes to industrial, commercial, parks, golf courses and leakage losses.

While Peachland Lake reservoir and the Peachland Creek municipal water intake have met approximately 50% of District demand in the past (Dobson, 2006), the District is considering a water treatment and supply option that in the future will utilize Peachland Creek for nearly 100% of District water supplies (Urban Systems, 2007).

Other than the District of Peachland, two water licenses are held by Ministry of Environment Fish and Wildlife Science and Allocation Section for conservation fish flows, and four domestic and irrigation licenses are privately held.

Currently, water treatment consists of two settling ponds situated adjacent to Peachland Creek near the point of diversion. From the lower settling pond, water is directed into a screened chamber for fine particle removal and then into a 1,818m^3 holding reservoir. Water is withdrawn from the reservoir, where some settling of suspended solids could occur, into a chlorination chamber followed by distribution for domestic consumption and irrigation use. During the winter, the settling ponds are bypassed by a buried intake pipe that conveys water directly into the screened chamber. An advanced water treatment plant is being considered for Peachland Creek at an estimated cost of $12.5M (Urban Systems, 2007), to address ongoing turbidity, total colour and pathogen water quality concerns.

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 DOP intake, and does not consider the vulnerability of the DOP water supply and treatment system. Those unspecified impacts at the DOP water intake are considered the consequence in the partial risk analysis completed below, which can later be input to a more comprehensive Source to Tap Risk Assessment (MoH, 2005) that water purveyors are required to complete.

4.2 WATER SUPPLY

The large storage capacity of the Peachland Lake and Glen Lake reservoirs are expected to meet the increased demand projected in the District's 20 Year Growth Plan, under all but the most extreme drought conditions of a 100-year drought lasting longer than one year (Dobson, 2007). Nonetheless, any decrease in the capability of available storage to meet that demand would be considered a High consequence.

4.3 FISH

Sport-fish species within the watershed include brook trout (Salvelinus fontinalis), and rainbow trout (Oncorhynchus mykiss). Kokanee (Oncorhynchus nerka) have been identified in the lower reach of Peachland Creek, which is considered important spawning habitat in the Okanagan Lake system (Kokanee Enumeration Report, 1996). Peachland Creek was stocked with kokanee in 1984 and rainbow trout in 1947 and 1941. Obstructions to upstream fish migration include a 10m falls (Hardy Falls) at the upper limit of Reach 1, which is the upstream limit of kokanee spawning. Although channel gradients >20% are inaccessible to rainbow trout and brook trout, all headwater lakes are known to contain fish; therefore fish presence is likely throughout most of the watershed despite obstructions to fish passage.

Peachland 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 11 summarizes fish habitat consequence ratings for each macro-reach. In general, fish habitat is widespread through the watershed, mostly due to naturally and/or artificially stocked lakes at the headwaters of each stream. High to Very High fish habitat consequence ratings have been assigned for most mainstem channels and lakes. Steeper gradients and obstructed channels result in lower fish habitat consequence ratings along smaller tributaries in the watershed.

4.4 SOCIAL INFRASTRUCTURE

Social infrastructure (infrastructure other than community intake and control structures) in the Peachland Creek watershed are relatively few above the DOP intake. Three private water licenses exist in the watershed and many kilometres of forestry road have been developed.

Private water licenses for domestic and irrigation use are listed on Peachland Creek, Bolivar Creek and Bolingbroke Creek. The licenses on Bolivar and Bolingbroke Creeks are both for domestic use and registered to the same resident, likely the private land owner in upper Greata Creek. The other privately held domestic water license on Peachland Creek is located near the mouth of the creek, downstream of the community intake. Inspections of the private intake sites were not made.

According to the 1999 IWAP, there were 178 forest road crossings in the Peachland Creek watershed at that time. With continued development, this number has likely increased. Some problems were noted at the Peachland mainline/mainstem crossing site, which have resulted in sediment deposition in the channel upstream, as discussed in Section 3.1.2. There are no other forestry road crossings of mainstem Peachland or Greata Creek (other than the Peachland Lake dam). Culverts serving tributaries along active forestry roads appeared adequate for existing conditions; that is, pre MPB infestation. Detailed inspections and analyses of existing crossings were not conducted. However, it is unlikely earlier or recent forest road crossings were designed to accommodate the potentially increased hillslope runoff following MPB attack and salvage harvesting.

As previously mentioned, the Peachland FSR has been constructed alongside Bolingbroke Creek for several kilometres in the Greata sub-basin. The creek has essentially been realigned in the road ditch. The ditch and road may be at risk of erosion should peak flows significantly increase in the sub-basin.

Peachland Creek has a small, predominantly para-glacial alluvial fan at it's outlet on Okanagan Lake, formed shortly after deglaciation 10,000 years ago. This provides a relatively flat area along the shoreline of Okanagan Lake. There are mobile home parks on both sides of the creek on the fan. Highway 97 crosses the creek over a concrete bridge, with limited clearance (Photo 9). Sediment transported from upstream will be deposited on the fan, leading to aggradation, reducing channel and bridge capacity over time. The bridge and highway could potentially be impacted and the potential for flooding on the fan increased.

Table 9 outlines the assumptions used to develop infrastructure vulnerability. No comprehensive review of Highway 97 bridge capacity, individual forest road crossings, etc., was undertaken.

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, low flows (availability).	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.	**H**
Forestry Roads	Increased peak flows, increased scour, increased debris movement.	Most issues documented in 1996 IWAP were addressed through road deactivation in 1997 (Dobson 1999). Only minor problems identified in field review. Original structures may not have capacity for post MPB/salvage increased peak flow + debris. Road adjacent to Bolingbroke susceptible to erosion/flooding.	**M**
Residences on Fan	Increased peak flows, increased sediment leading to local aggradation, increased debris movement causing jams.	Flood history unknown. Current channel appears well-incised but flood potential could increase with higher peak flows, aggradation and/or debris jams.	**M**
Highway 97 Bridge	Increased peak flows, increased sediment leading to local aggradation, increased debris movement.	Current bridge capacity appears adequate. Capacity could decrease with aggradation and/or debris jams.	**M**

5.0 RISK ANALYSIS

5.1 WATER QUALITY AND INFRASTRUCTURE

Table 10 summarizes the partial risk analysis for water quality at the DOP water intake. The hydrologic hazard, which includes both incremental peak flow and channel erosion sediment hazards, is taken from the Hydrologic Hazard ratings for Peachland Residual (Table 8), which has the DOP intake at the lower end of Reach 3.

Table 10. Partial risk analysis for DOP water intake.

Reach	Hydrologic Hazard (peak flow and sediment)		Water Quality Element at Risk: DOP Water Intake		**Partial Risk**	
	MPB	Full Salvage	Fine sediment impacts	Coarse sediment impacts	**MPB**	**Full Salvage**
Peachland Residual (Reaches 1-4)	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 some increase in fine and coarse sediment delivery to the DOP intake may occur. With the full salvage of pine-leading stands scenario there is a High risk. That is, a significant increase in peak flows and sediment delivery to the DOP intake is considered likely.

5.2 WATER SUPPLY

The consequence of potential decreases in later growing season water storage availability due to earlier use and drawdown of Peachland Creek reservoirs is considered High. There is a high degree of uncertainty as whether or how much MPB and salvage harvest-related changes in forest cover will advance spring freshet timing, which could cause an earlier start to reservoir drawdown, and ultimately greater reservoir depletion in the later growing season. While the expected freshet advancement due to MPB pine mortality is not expected to be large, because of the relatively lower forest cover disturbance expected, it will be greater with the full harvest scenario, which will cause significantly increased forest cover and ECA effects (Figure 7). However the relatively large reservoir storage available will mitigate both MPB and salvage-related freshet timing changes, and it is considered unlikely that significant effects will occur following either scenario. Therefore the MPB and salvage harveting-related risk to water supplies in Peachland Creek is considered Low.

As discussed in Sections 3.4, a much greater change in freshet timing, and risks to water supplies, is expected due to global climate change-related temperature increases, depending on the amount of temperature increase that occurs in the Okanagan.

5.3 FISH

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

Note that risks to fish values only occur where fish populations and habitat exists and this risk rating may not represent the entire sub-basin. Since hydrologic hazard is generally cumulative to the downstream end of the sub-basin, risk ratings in tributary basins generally represent risks near the lower end of the sub-basin. Risks in residual sub-basins represent risks to habitat values along the Peachland Creek mainstem within that 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 Peachland	L	M	H	**M**	**H**
Peachland Mid	M	VH	VH	**H**	**VH**
Greata Creek	M	H	H	**H**	**VH**
Peachland Watershed	M	H	VH	**H**	**VH**

Risks to fish habitat are generally potentially High under MPB/unharvested, because mainstem values are High to Very High and even the possibility of negative impacts yields a High potential risk. Risks are Very High under the full salvage scenario. Very High consequence ratings were assigned to Reach 4 and Reaches 1 and 2 of the mainstem downstream of the intake, near the mouth of the creek at Okanagan Lake.

Degradation to fish habitat would likely result from increased sedimentation, 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 hydrologic hazard is combined with infrastructure vulnerability ratings presented in Table 9, as summarized in Table 12.

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 (in Greata)	H	M	H	**H**	**VH**
Licensed Water Intakes (lower in the watershed)	H	M	H	**H**	**VH**
Forestry Roads	M	M	H	**M**	**H**
Residences on Fan	M	M	H	**M**	**H**
Highway 97 Bridge	M	M	H	**M**	**H**

Risks to infrastructure are Moderate to High following MPB attack and High to Very High following the hypothetical the full salvage scenario. Post-MPB High to Very High risks have been assigned to private water licenses as a result of inferred sensitivity of these installations to increases in fine sediment. Most private water intakes operate without filtering or disinfection.

Moderate to High risks to forestry roads may result if existing culverts, bridges and the ditchline that is Bolingbroke Creek, have no excess capacity during peak flows. Aggradation resulting from increased sedimentation may also reduce structure capacity. Channel adjustment to a higher flow regime will include widening, bank erosion and increased LWD recruitment. Existing structures may become overwhelmed and/or blocked by the resulting mobilization of sediment and debris.

Risks to residences on the fan increase to High under the full salvage scenario. Aggradation could reduce channel capacity on the fan. This combined with higher peak flows could result in flooding and channel destabilization on the fan, leading to damage of private property. The Highway 97 crossing has also been assigned a High risk rating under the full-salvage scenario.

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The water quality parameters most strongly linked to MPB infestation and salvage logging in Peachland 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 Peachland Creek watershed there is a

Moderate Risk, which means some increase in fine and coarse sediment delivery to the DOP 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 peak flows and sediment delivery to the DOP intake is likely to occur. Source water turbidity levels have been and will continue to present a problem at the DOP 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.

Little advancement of freshet timing and associated late growing season water supply shortages are expected following the MPB/unharvested scenario. Larger impacts to later season water shortages would be expected following the full salvage scenario, but there is a lot of uncertainty about how large an effect this could be (i.e. how many days earlier maximum freshet flows could occur). As well, reservoir storage will limit freshet advancement effects. The effect on freshet advancement and later growing season water supplies from global climate change is expected to be larger than MPB or salvage harvesting risks to supplies, which are Low. 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 Peachland Creek are not expected.

There are fish present and high habitat values along most of the Peachland and Greata Creek mainstems. 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 extensive salvage harvesting the risk of negative impacts on fish populations will be Very High. The likelihood of negative impacts is even more likely where fish habitat values are Very High (lower Mid Peachland Creek and Reaches 1 and 2 immediately upstream of Okanagan Lake).

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 Peachland Creek watershed snow zone. Risks to highway and adjacent housing developments on the Peachland Creek fan are considered Moderate and High for the MPB/unharvested and full salvage scenarios respectively. Risks to forestry roads in the watershed are Moderate to High respectively. Risks to private water intakes in the watershed are considered High to Very High respectively, because they are generally simply built and provide no treatment.

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 should 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.

To our knowledge, limited operational trials of under-planting mature attacked stands, which could increase forest health and productivity while maintaining the existing hydrological function of the attacked stand, have had little success. This has been 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, pers. comm.). Other trials are underway (Doug Lewis, 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 Peachland 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 large woody debris recruitment levels, and to preserve stream stability and habitat quality. Given that research has found LWD input rates are similar for attacked and non-attacked Okanagan stands, at a minimum best riparian management practices for “green wood” harvesting in the Okanagan should be followed when salvage harvesting MPB-attacked stands.

Reservoir Management

It has been suggested that reservoir filling and release could be better managed to have the reservoir filling throughout the freshet, thereby reducing freshet peak flows in lower reaches and reducing downstream impacts (Dobson, 2006). Given there may be increased peak flows following MPB attack, and there are likely to be significant peak flow increases if there is widespread salvage harvesting in the watershed, we concur that it would be prudent to develop the infrastructure and procedures to manage reservoir filling and runoff to reduce freshet peak flows.

Fish Habitat Management

Maintaining good riparian condition and instream LWD throughout the watershed will help to mitigate these impacts. Since the effects of 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 fish habitat assessments (last done in 1996), monitor channel and riparian conditions and carry out rehabilitation activities as necessary. In Very High value Reaches 1, 2 and 4 mitigation could include rehabilitating natural and man-made sediment point sources, such as those at and upstream of the FSR mainline crossing, and rehabilitating riparian vegetation where it been depleted through natural or human activities.

Stand and Watershed ECA Hazard Management

In the absence of an effective under-planting program for MPB attacked stands, we know of no way to reduce the MPB-related ECA hazard at the stand level. However the incremental risks from MPB-related ECA hazards are Moderate to DOP water quality and water supply infrastructure, Low to water supply, Moderate to High to other infrastructure, and High for fish values in most mainstem stream reaches.

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 risks if pine-leading stands were all left unharvested, because of the expected stand characteristics of pine-leading stands in the watershed. 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 (ie., as having initial ECA values similar to clearcuts) will 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 ESSF stands (see Figures 6-8 and Appendix B).

- We recognize that individual stands within these broader BEC types will have different characteristics; therefore 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 MPB infestation and pine tree mortality in Peachland Creek Watershed is not expected to be catastrophic for any of the identified watershed values (risk elements). With good management of harvesting rates and sites that 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 stressor on Peachland Creek forests in the near future. Global warming and global warming-related disturbances such as other pathogens which could attack other tree types (spruce or fir beetle and others) and fire, etc., are not improbable. We think that part of the determination of what is an acceptable level of risk would include considering the potential hydrological (and other) effects of these 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.

Prepared by: and

Bill Grainger, P.Geo., EngL.
Senior Geoscientist
Grainger and Associates Consulting Ltd.

Alan Bates, P.Eng.
Consulting Engineer
Streamworks Unlimited

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Figures 1, 5 and 11

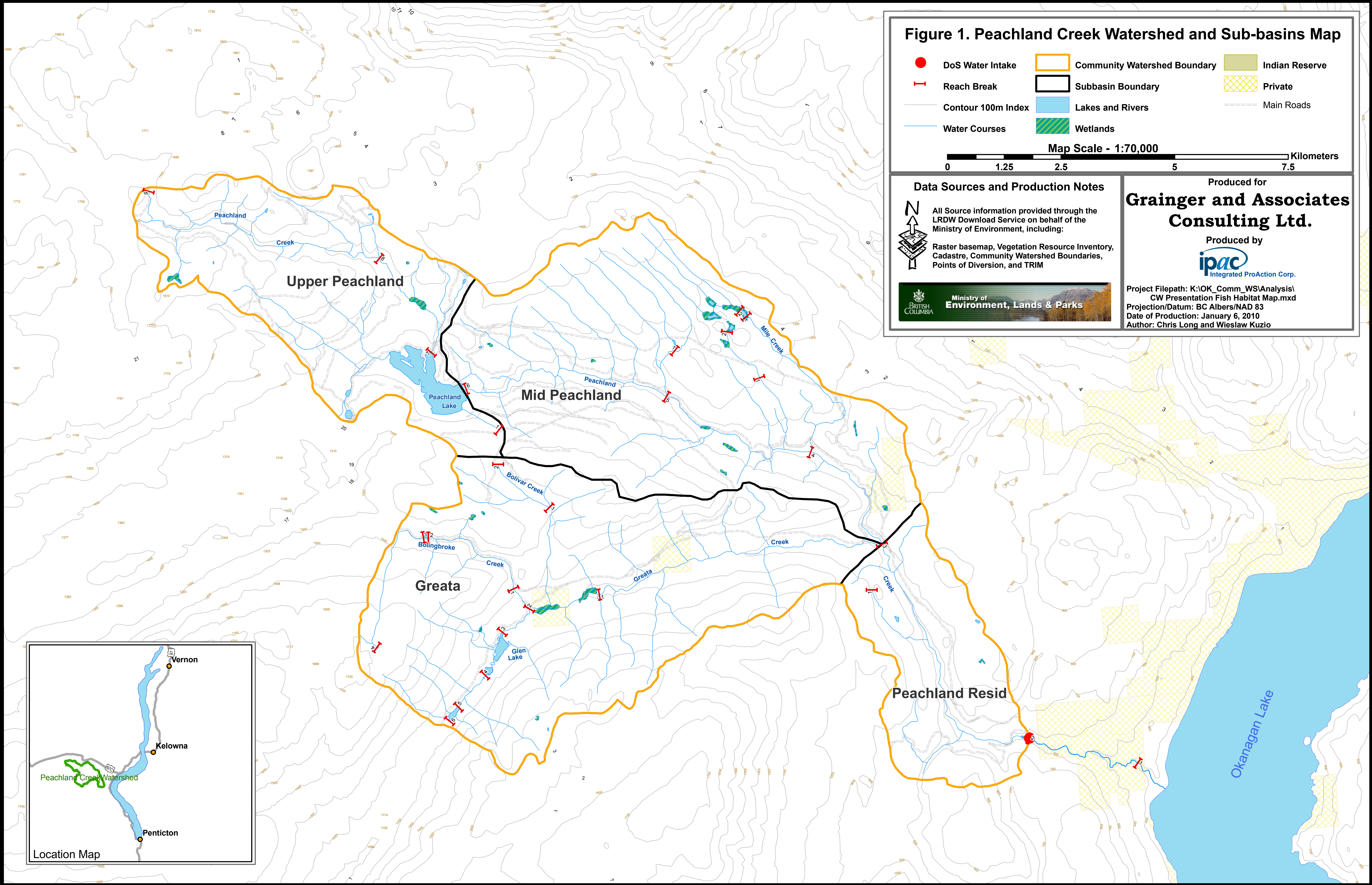

Figure 1. Peachland Creek Watershed and Sub-basins Map

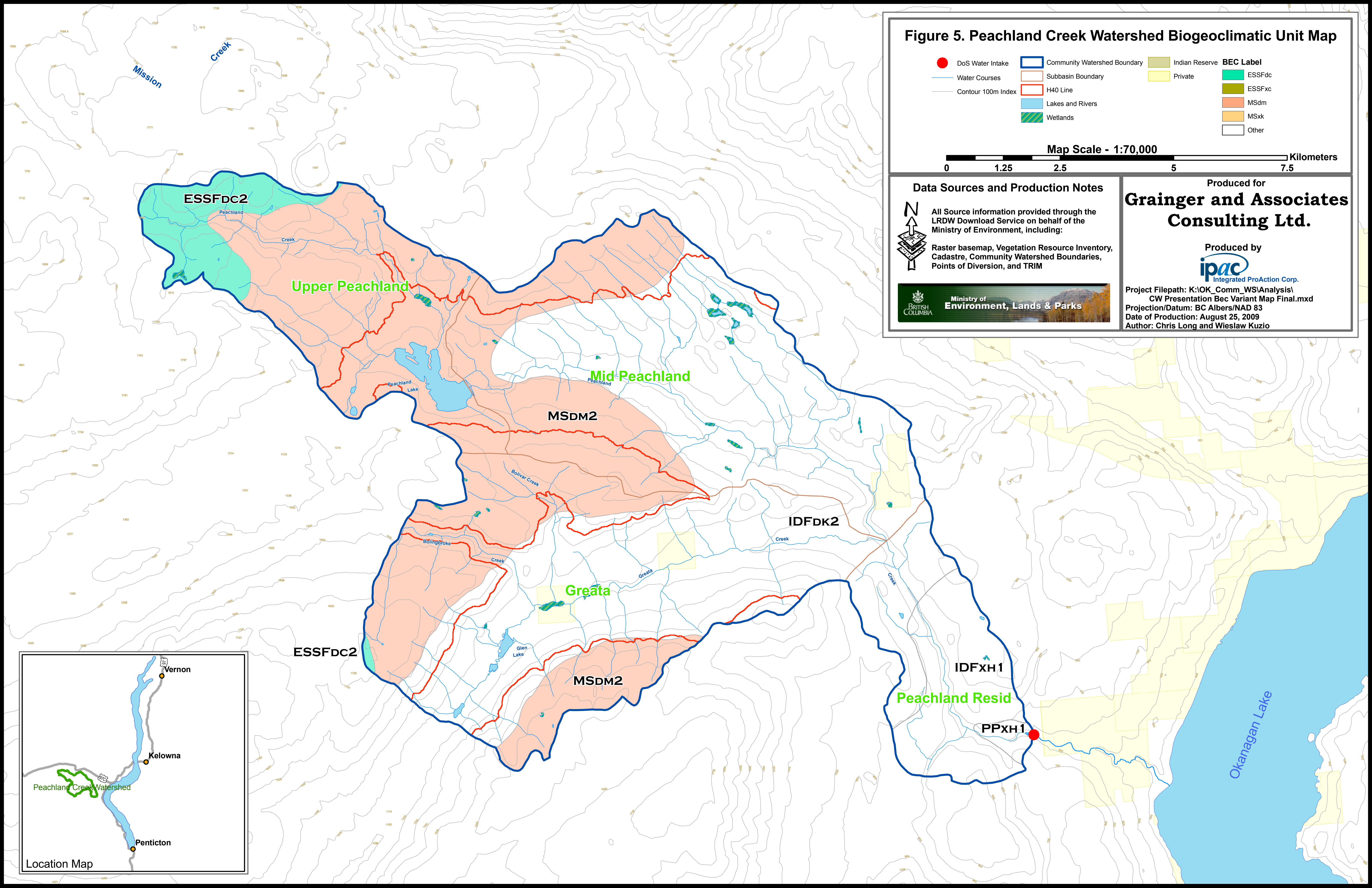

Figure 5. Peachland Creek Watershed Biogeoclimatic Unit Map

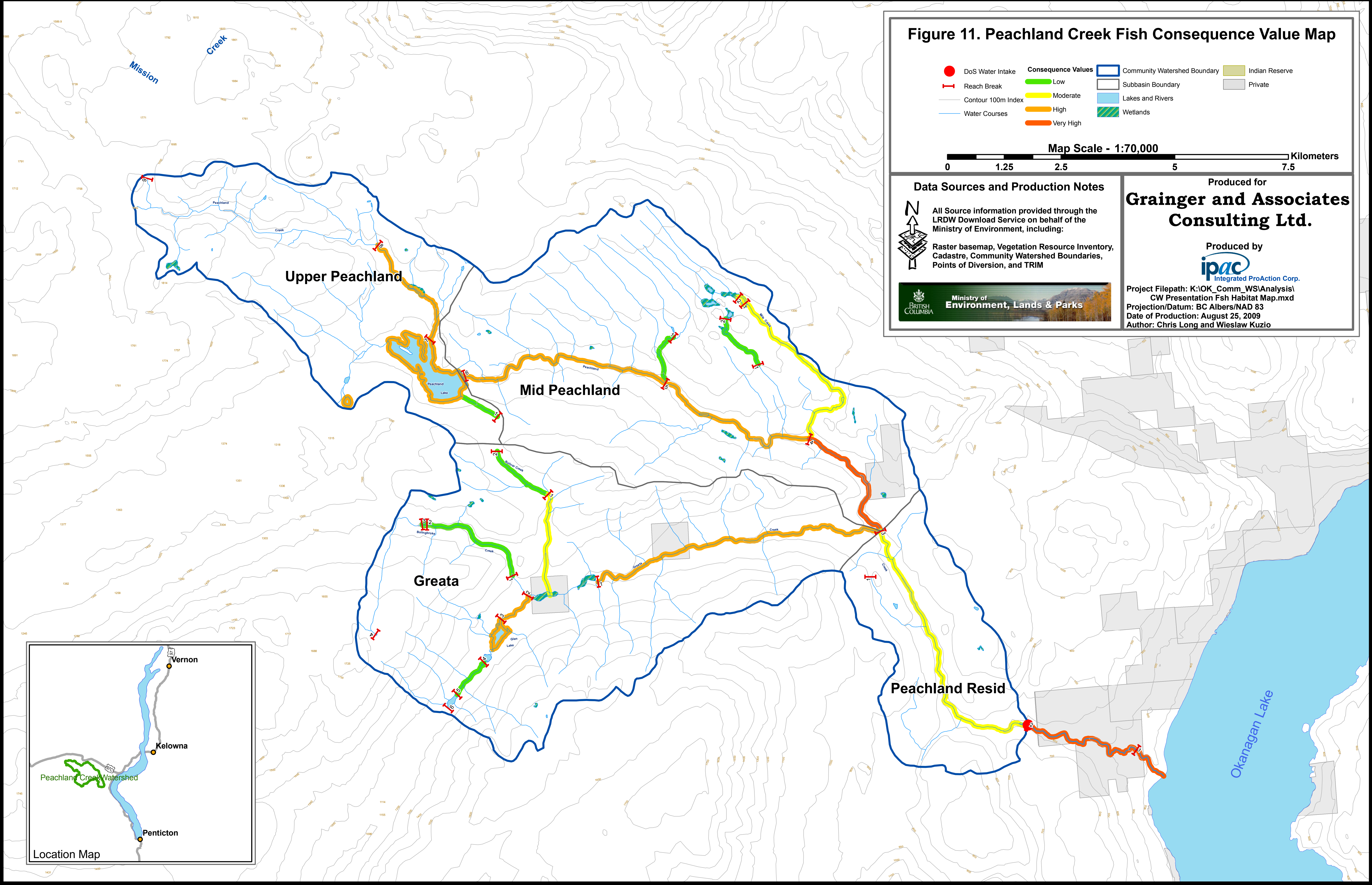

Figure 11. Peachland Creek Fish Consequence Value Map

PHOTOS

Photo 1. Typical Peachland watershed flat to gently sloped upland plateau, looking west from Peachland Lake.

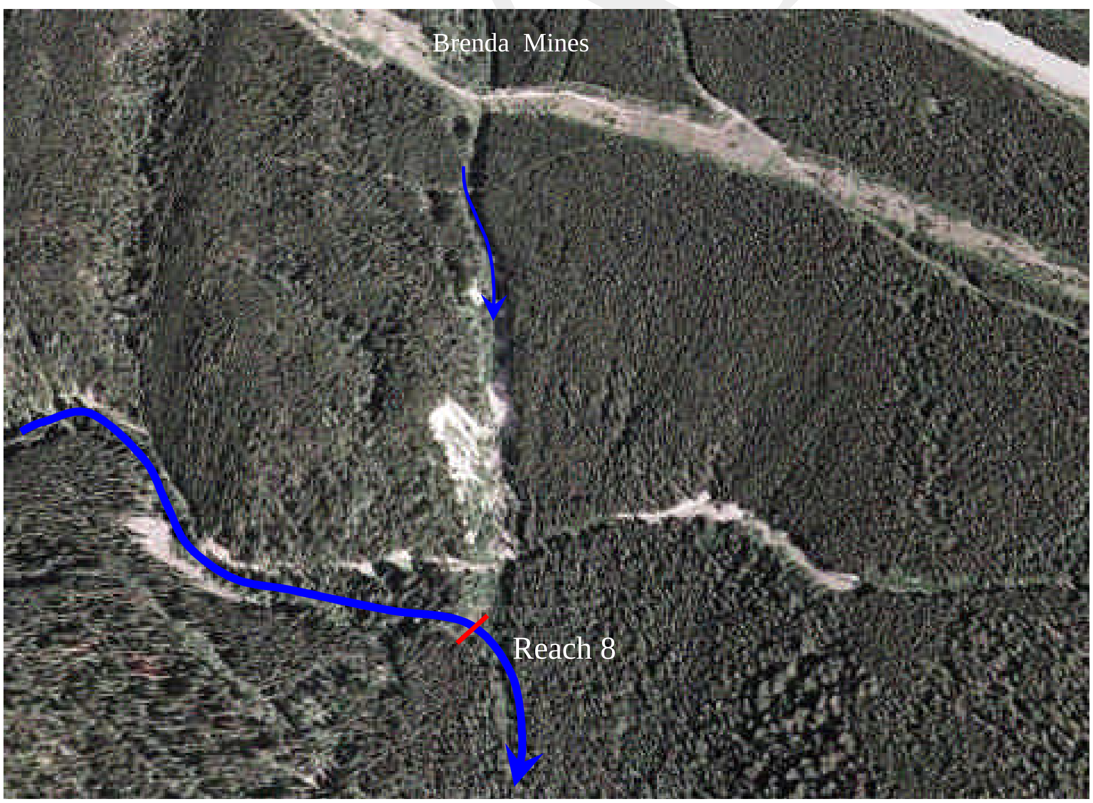

Photo 2. Large landslide and scoured channel of valley wall tributary to Upper Peachland Creek, in old Brenda Mines MacDonald Creek diversion from Trepanier Creek watershed.

Photo 3. Ravelling bedrock and colluvial valley sidewalls of Peachland Creek, about 2.0km upstream of DOP water intake.

Photo 4. Generally stable bedrock and colluvium canyon of Peachland Creek mainstem, between Greata Creek and DOP water intake.

Photo 5. Recently active bank failure into Peachland Creek a short distance above the Peachland FSR crossing.

Photo 6. Rill erosion on Peachland FSR fill at Peachland Creek crossing.

Photo 7. Bolingbroke Creek confined to ditchline of Peachland FSR.

Photo 8. Constructed riffles to improve stability and spawning habitat on Peachland Creek fan.

Photo 9. Settling ponds at District of Peachland water intake.

Photo 10. Highway 97 Bridge over Peachland Creek on the fan. Note limited clearance.

Appendix A:

Risk Analysis Definitions

Appendix A: Risk Analysis Definitions

Risk is defined as the product of hazard and consequence:

Hazard x Consequence = 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.

Hazard - Likelihood of Occurrence	**Consequence**				
	Very Low (insignificant)	**Low** (minor)	**Medium** (medium)	**High** (major)	**Very High** (catastrophic)
Very High (almost certain)	Moderate	High	High	Very High	Very High
High (likely)	Moderate	Moderate	High	Very High	Very High
Moderate (possible)	Low	Low	Moderate	High	High
Low (unlikely, but possible)	Very Low	Very Low	Low	Moderate	Moderate
Very Low (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 5matix used by B.C. Ministry or Health and B.C. Ministry of Environment is 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

		Consequence				
Hazard - Likelihood of Occurrence		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.

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[1], 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.

BEC subzone	Pine (VRI %)	Age (yr)	Percent of total Pl area	Polygons	Plots
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 (≥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.

[1] 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)[2], 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)[3].

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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[2] 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.

[3] 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.

	Stand type		Canopy composition (%BA)				Pl range (%)		
BEC	Pine (%)	Age (yr)	Pl	Bl	Sx	Fd	Min	Max	n
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 (Pl) in different stages of mountain pine beetle attack, by stand type.

	Stand type		Pl Attack status (%)			
BEC	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 (Pl) in different stages of mountain pine beetle attack, by stand type and watershed.

	Stand type			Pl Attack status (%)			
BEC	Pine (%)	Age (yr)	Watershed	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.

Stand type BEC	Pine (%)	Age (yr)	Layer	Lodgepole pine (/ha) Total	WS	Subalpine fir (/ha) Total	WS	Spruce (/ha) Total	WS	All non-pine (/ha) Total	WS	All species (/ha) 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 Pl poles)

BEC	**Stand type: Pine (%)**	**Age (yr)**	**Pole+Sapling density (/ha; no Pl poles): 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[4]. 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	Pl 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

[4] 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[5].

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 >= 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	Pl 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	Pl 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

[5] 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.

<table>
<tr><th>Alteration</th><th>Channel Sensitivity Rating (H, M, L)</th><th>Channel Attributes that May Contribute to Channel Sensitivity</th></tr>
<tr><td rowspan="3">Increased Peak Discharge and/or Flood Frequency</td><td>Low</td><td>▪ Channel experiences frequent natural, large peak flow events (e.g. steep watershed, rapid runoff, high snow pack).
▪ Channel has endured high flow events in the past with little evidence of long term change.
▪ 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).
▪ Abundant instream LWD, debris jams and lag boulders that augments channel and bank stability through energy dissipation.
▪ Frequent sizeable lakes, wetland areas and/or broad floodplain able to store significant water volume and attenuate flood peaks.</td></tr>
<tr><td>Moderate</td><td>▪ Range or combination of attributes listed above and below.</td></tr>
<tr><td>High</td><td>▪ Channel does not experience frequent flood events (dark mossy substrates, mature vegetation to high water mark).
▪ Relatively recent flood events (past 20 years) have caused significant disruption of channel and/or bank stability.
▪ Channel segments with fine textured banks and substrates that are susceptible to scour/erosion.
▪ Lacking in channel structure (e.g. instream LWD, lag boulders, bedrock) that would absorb flow energy.
▪ Little or no lakes, overflow channels, floodplain or low gradient wetland segments that would attenuate/store flood peaks.</td></tr>
<tr><td rowspan="3">Increased Sediment Delivery [Fine suspended and Coarse bedload sediment should be considered separately]</td><td>Low</td><td>▪ Channel experiences frequent high volumes of sediment delivery from upstream/upslope sources (e.g. numerous natural landslides, ravelling banks, naturally aggraded channel).
▪ Evidence of older, connected landslides and/or debris flows with minimal evidence of long term changes to channel stability.
▪ Abundant locations for sediment storage, such as frequent functioning debris jams or low gradient, unconfined sections that arrest bedload movement.
▪ Slow-flowing, meandering stream with insufficient power to transport bedload and allow some settling/filtering (e.g. frequent wetland segments).
▪ Stable/resilient banks that will resist widening following sediment storage/aggradation.
▪ Coarse sediment is easily passed through the channel system with minimal accumulations (in context of watershed, may lead to issues downstream – see notes).</td></tr>
<tr><td>Moderate</td><td>▪ Range or combination of attributes listed above and below.</td></tr>
<tr><td>High</td><td>▪ Channel does not experience frequent high volumes of sediment delivery from upstream/upslope sources (e.g. dark mossy substrates, deep pools, broadly graded substrates).
▪ Evidence of channel destabilization in response to isolated sediment events (e.g. older, connected landslides have caused aggradation/channel widening downstream).
▪ 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.
▪ Fine sediment is rapidly passed through with little opportunity for settling/filtering (reducing water quality downstream).
▪ Channel has frequent erodible banks that will allow channel widening in response to aggradation and contribute further sediment to the channel.</td></tr>
<tr><td rowspan="3">Decreased Riparian Function</td><td>Low</td><td>▪ Channel flows through area of naturally low-growing riparian vegetation (e.g. wetland, alpine area or avalanche pathway).
▪ 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).
▪ Channel has experienced localized decreased riparian condition in the past (e.g. wildfire, harvesting) with little indication of long term instability.
▪ Channel is not dependant on LWD to control bedload movement.
▪ Channel is not dependant on riparian vegetation to maintain fish habitat values, including instream LWD, food sources and/or stream temperature moderation.</td></tr>
<tr><td>Moderate</td><td>▪ Range or combination of attributes listed above and below.</td></tr>
<tr><td>High</td><td>▪ Channel is dependant on LWD to provide channel or bank stability (e.g. erodible banks, Riffle-Pool morphology type).
▪ Channel has experienced localized decreased riparian condition in the past (e.g. wildfire, harvesting) resulting in local destabilization.
▪ Channel is dependant on LWD to control bedload movement.
▪ Channel is dependant on riparian vegetation to maintain fish habitat values, including instream LWD, food sources and/or stream temperature moderation.</td></tr>
</table>

Appendix D:

Hydraulic Creek Fish Values by Reach

Prepared by Michele Trumbley, R.P. Bio.

Trumbley Environmental Consulting Limited

Attn: Bill Grainger, P.Geo. March 31, 2009
Grainger & Associates Consulting Ltd.
Box 427 Salmon Arm, B.C.
V1E 4N6

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

PEACHLAND CREEK

The Peachland Creek watershed is situated on the west side of Okanagan Lake near Peachland. The watershed has been delineated into 4 sub-basins including the Lower Peachland Residual, Greata Sub-basin, Mid Peachland Residual and the Upper Peachland Residual. Peachland Creek (WSC[1] 310-725700) flows into Okanagan Lake. The lower reaches of Peachland Creek are situated outside of the study area however was considered due to the effects of upstream activities. Three headwater lakes, Peachland, Glen and Wilson are within this watershed. Spring Lake is part of the watershed however was excluded from the study area. Peachland Creek was rated 4th out of 12 for importance for Kokanee spawning (Kokanee enumeration report, 1996). Peachland Creek was stocked with Kokanee in 1984 and Rainbow trout in 1947 and 1941. The fish and fish habitat investigation is one component of several factors used to develop an overall risk rating for MPB[2].

FISH SPECIES

Sport-fish[3] species within the watershed include Brook Trout (*Salvelinus fontinalis*), and Rainbow trout (*Oncorhynchus mykiss*). Kokanee (*Oncorhynchus nerka*) have been identified in the lower reach of Peachland Creek.

OBSTRUCTIONS

Obstructions to upstream fish migration include a 10m falls (Hardy Falls) in reach 1 of Peachland Creek which is the upstream limit of Kokanee spawning. Two beaver dams and a log jam are considered obstructions to fish passage however fish were present upstream. Gradients >20% are inaccessible to rainbow trout and brook trout. All headwater lakes are known to contain fish therefore fish presence is likely throughout the watershed despite obstruction to fish passage.

[1] WSC –Watershed Code
[2] MPB – Mountain Pine Beetle
[3] Sport-fish as defined by the Forest Practices Code, Fish-Stream Identification Guidebook. pg 4.

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info@trumbleyenvironmental.ca • www.trumbleyenvironmental.ca

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 Peachland 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. Interpretations of potential habitat quality were at the discretion of the professional biologist. In areas were habitat quality was unknown, an estimated channel width in combination with gradient and connectivity was utilized to predict the consequence rating.

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 – Peachland Creek Watershed Consequence Rating

Stream Name	**WSC**	**Reach**	**Average Channel Width (m)**	**Gradient (%)**	**Species Present**	**Habitat Quality**	**Consequence Rating**
Peachland Creek	310-725700	1	8	2	KO, RB,	10m Falls (Hardy Falls) is the upper limit of KO spawning, RP with gravel, man-made gravel spawning platforms, excellent KO spawning, ample pools for staging (26-50% of area)	**VH** – high quality spawning habitat, KO, RB confirmed
Peachland Creek	310-725700	2	7	4	EB, RB	*Site 2* - Moderate bank erosion problems contributed to sediment d/s, Boulder RP, infrequent pools, adequate staging, side channel fair for juvenile RB	**VH** – high quality habitat, RB, EB confirmed, side channel habitat, bank instability
Peachland Creek	310-725700	4	8	1	(EB, RB)	Moderate bank erosion contributed to sediment d/s, side channel in reach provided minimal rearing for juv, Site 6, gravel cobble RP, adequate flow and frequent pools, good staging and overwintering, deciduous with sparse canopy	**VH** – high quality habitat, RB, EB confirmed, side channel habitat, bank erosion
Peachland Creek	310-725700	5	7	5	(EB, RB)	Beaver dam in reach impeding fish passage (obstruction), Site 14, gravel boulder RP, boulders good instream cover for RB and EB	**H** – high habitat quality, low gradient, fish presence upstream and downstream

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Table 2 – Peachland Creek Watershed Consequence Rating

Stream Name	WSC	Reach	Average Channel Width (m)	Gradient (%)	Species Present	Habitat Quality	Consequence Rating
Peachland Creek	310-725700	6	4.5	3	(RB)	Dam at outlet of Peachland Lake hinder fish migration, flow of water leaves dam at high velocity, moderate bank erosion along reach, Site 17, cobble RP, riffle area d/s of dam, is good spawning for RB and EB	**H** – potential spawning habitat, dam reduces overwintering potential in Peachland Lake
Peachland Lake	00933OKAN	7	N/A	N/A	stocked with 3000 RB annually	Overwintering and rearing habitat for RB	**H** – provides overwintering habitat to upstream tributaries
Peachland Creek	310-725700	8	5	3	(RB)	Site 18	**H** – inflow to Peachland Creek, stream rearing potential, low gradient
Trib to reach 3	310-725700-	1	N/A	28	NFC	Excessive gradient therefore defaulted non-fish, Site 4, coniferous mixed forest	**VL** – gradient >20%
Greata Creek	310-725700-31700	1	5	4	RB, EB	Site 5, cobble boulder SP, fair instream cover – boulders, deciduous trees with sufficient shading	**H** – connection to Peachland Creek, low gradient
Greata Creek	310-725700-31700	3	1	1	RB, EB	Site 9, Gravel RP, extensive marsh and ponds provided good rearing for RB and EB juv, Good spawning habitat for EB and RB at outlet of Glen Lake	**H** – good habitat quality, rearing habitat in ponds, low gradient, spawning potential

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Table 2 – Peachland Creek Watershed Consequence Rating

Stream Name	WSC	Reach	Average Channel Width (m)	Gradient (%)	Species Present	Habitat Quality	Consequence Rating
Glen Lake	01040OKAN	Reach 4 of Greata Creek	N/A	N/A	Stocked annually with 2000 EB & RB	Beaver dam at outlet of Glen Lake	**H** – overwintering and rearing potential in Glen Lake
Greata Creek	310-725700-31700	5	1	1	(EB, RB)	Channel dry, Site 10	**L** – dry channel, possible rearing habitat
Bolivar Creek	310-725700-31700-83300	1	2	5	(RB, EB)	Site 7, cobble, gravel RP, young deciduous forest with sparse shade, limited staging for RB and EB	**M**- suspected fish presence, moderate habitat quality
Bolivar Creek	310-725700-31700-83300	2	<2	6	(RB, EB)	Reach dry,	**L**- low habitat quality, dry channel
Bolingbroke Creek	310-725700-31700-71600	1	2.5	8	(RB, EB)	Site 8, boulder SP, overwintering and staging sparse	**M**- moderate habitat quality RB, EB suspected
Bolingbroke Creek	310-725700-31700-71600	3	2	13	(RB, EB)	Reach 3 is wetland, fisheries habitat poor because low flow and inadequate pool frequency, Site 11, boulder step pool, moderate stream shading	**L**- low habitat quality, low flows and suspected RB, EB
(Wilson) Mile Creek	310-725700-40600	1	4	5	RB	Underground flow 200m u/s of confluence, u/s reaches dry, Site 12, cobble SP, low habitat value	**M**- confirmed RB however, low habitat quality, headwater lake with RB
Wilson Lake	00934OKAN	2	N/A	N/A	RB	Confirmed RB in Lake	**M** - confirmed RB, overwintering potential.
Trib to Peachland Creek	Site 13	2	N/A	7	(RB, EB)	Dry channel, upslope impact is moderate, Site 13, young forest	**L** - low habitat value upstream, dry channel

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Table 2 – Peachland Creek Watershed Consequence Rating

Stream Name	**WSC**	**Reach**	**Average Channel Width (m)**	**Gradient (%)**	**Species Present**	**Habitat Quality**	**Consequence Rating**
Trib to Peachland Creek	Site 15	1	1.5	1	(RB, EB)	Channel dry, high upslope impact potential, Site 15, , low habitat value	**L -** low habitat value, high upslope impact potential.
Trib to Peachland Lake	Site 16	1	1	3	(NF)	1.5m rock falls 10m u/s of confluence	**L**- suspected non fish.
Loon Lake	00948OKAN -71500	1	N/A	N/A	Stocked with EB & RB 1999-2008	Stocked lake	**H**- overwintering potential for upstream habitat, upstream of Peachland Lake.

Fish Species Codes:
RB – Rainbow Trout
EB- Brook Trout
KO – Kokanee
MW – Mountain Whitefish
(species) – suspected fish presence
NFC – No fish caught
NS – Not Sampled
NF- No Fish

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[4] and CWD[5] 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.

[4] LWD – large woody debris
[5] CWD – coarse woody debris

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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 Peachland Residual: Reaches 1 and 2 of Peachland Creek are situated outside of the study area. Kokanee spawing potential is excellent in reaches 1 and 2 and gravel spawning beds have been constructed to improve spawning habitat. A consequence rating of very high was assigned to these reaches based on the importance of kokanee spawning and the influence of upstream activities. Hardy Falls (10m height) is the upstream barrier to kokanee spawning and upstream fish migration.

Greata Sub-basin: The Greata Sub-basin consists of reaches 1-7 of Greata Creek, Glen Lake, Bolingbroke Creek and Bolivar Creek. Reaches 1-4 of Greata Creek were assigned a high consequence rating because of the habitat quality and the presence of rainbow trout and brook trout. The headwaters of Greata, Bolingbroke and Bolivar Creeks were dry and/ or exhibited low flows. This sub-basin contains Brook trout which are sensitive to peak flow and sedimentation.

Mid Peachland Residual: Peachland Creek reaches 4-6 in addition to Mile Creek and Wilson Lake are within the Mid Peachland residual. Moderate bank erosion in reach 4 is contributing to sedimentation downstream. High quality side channel habitat was also documented in reach 4 of Peachland Creek.

Upper Peachland Residual: The Upper Peachland residual consists of all tributaries upstream of Peachland Lake. Peachland Lake is stocked with 3000 rainbow trout annually.

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REFERENCE MATERIAL

Reference material was obtained by the following:

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- Trumbley Environmental Consulting Ltd. 1996. Kokanee Enumeration Report, MELP
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- -FISS HQ1992, Fish Collection Permit Report Reference Number 750, MELP, 1999 for Greata Creek (WSC 310-725700-31700), Peachland Creek (WSC 310-725700)
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- FISS BCLKS-4132, Peachland Reservoir Data Sheet, MELP, 1995 for Peachland Lake (WBID 00933OKAN)
- FISS 8002, Lake Plans – Okanagan Watershed, Peachland Lake (WBID 00933OKAN), Spring Lake (WBID 0106OKAN), Wilson Lake (WBID 00934OKAN), Glen Lake (01040OKAN), MELP, 1995
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- FISS BCLKS 8347, Spring Lake File#: 34020-20-02, MELP, 1995
- FISS BCLKS-3354, Fish Collection Records for Wilson Lake, MELP, June 25, 1950 for Wilson Lake (WBID 00934OKAN)
- FISS 8090, Trumbley Environmental Consulting Ltd, 1994. Hotspot Fish Inventory,

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info@trumbleyenvironmental.ca • www.trumbleyenvironmental.ca

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

Thank-you

Michele Trumbley, R.P.Bio
Trumbley Environmental Consulting Limited

4574 Larkin X Road, Armstrong, B.C. V0E 1B6 • Tel: 250-546-4069 • Fax: 250-546-8796
info@trumbleyenvironmental.ca • www.trumbleyenvironmental.ca

Appendix E:

Okanagan Flood Frequency Shift Analysis

Appendix E: Okanagan Flood Frequency Shift Analysis

Flood generation in nival watersheds is a complex process involving snow pack, forest cover, microclimatology and weather. Flood frequency curves may change with time due to changes in climate, land use (e.g., drainage improvement) and forest cover. Extensive literature reviews of research findings on the relationship between harvesting and peak flows, largely through paired-watershed studies, show great variability in results. There is no single variable – such as the amount of forest cover removed, harvesting system, etc. that allows for a quantitative description of changes in peak flows associated with timber harvesting (Scherer and Pike, 2003). This is because of the wide range of forest management histories, weather conditions and events, physical properties, forest cover types, watershed drainage characteristics, etc., as well as different analytical and statistical methods used in the many studies.

This study uses the results of several recent numerical modeling-based analyses of the relationship between forest canopy changes due to harvesting, MPB infestation, or both, and runoff regime. Numerical modeling removes some of the uncontrolled variables inherent in paired-watershed studies, such as weather history, and allows testing of various treatment hypotheses. In all cases, watershed models were calibrated using some period of existing climate and runoff data. Nonetheless, modeling watershed processes requires making many assumptions, which introduce uncertainties, especially when extrapolating from experimental watersheds to operational situations in different watersheds.

The modelling results for 11 nival Interior B.C. modelled watersheds were reviewed. Nine are in the south Okanagan: (Whiteman (112km^2), Vaseaux above Dutton (255km^2), Bellevue (73km^2), Camp (34km^2), Dave (31km^2), Vaseaux above Solco (112km^2), Pearson (74km^2), Ewer (53km^2) and 240(5 km^2) Creeks. Two are in the upper Fraser River basin (Naver Ck.(658 km^2) and Baker Ck. (1570 km^2). They have different sizes, geographic locations, physical and climatic characteristics and treatments. Baker Ck. and 240 Ck. were modelled with the Distributed Hydrology Soil Vegetation Model (DHSVM) and the rest with the UBC Watershed Model (UBCWM).

Figures C-1 to C-3 show some of the watersheds modelled and the expected flood frequency shifts. 240 Creek is about 1/50 the size of Peachland Creek and Baker Creek about ten times as large.

Camp Creek results are similar to results for Naver Creek and the other mid-sized Okanagan watersheds modelled (Whiteman, Vaseaux 1 and 2, Bellevue, Dave, and Ewer Creeks). Camp Creek is located immediately west of Peachland Creek and shares a watershed boundary with upper Greata Creek, a tributary of Peachland creek.

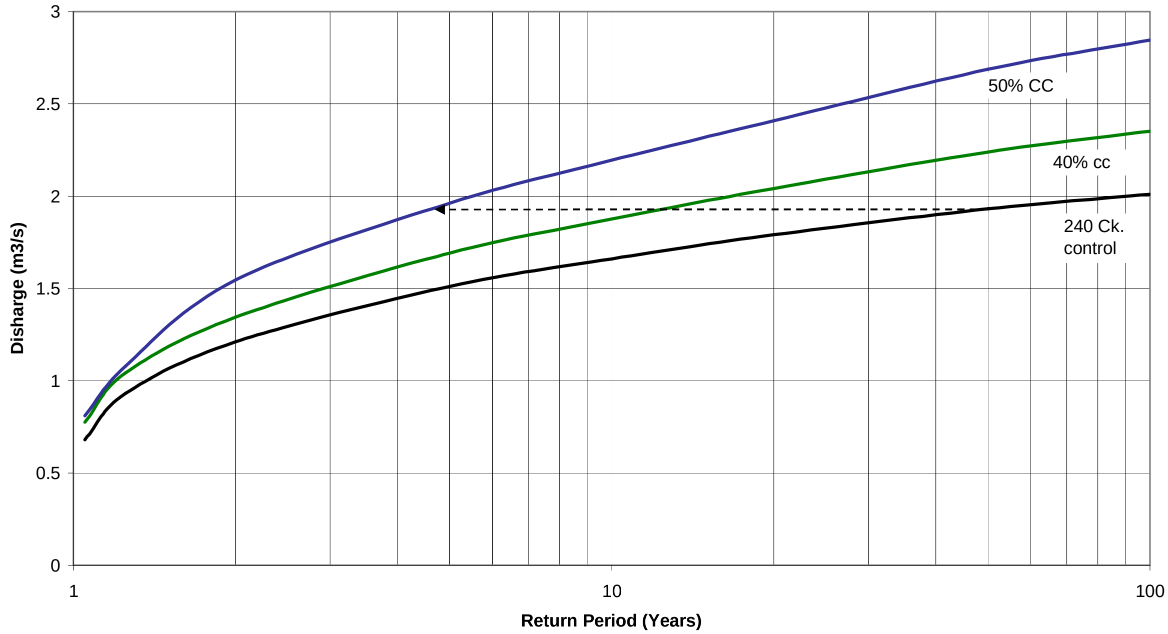

Figure C-1. Modelled flood frequency for 240 Creek, a 5km^2 tributary of Penticton Creek, with 40% and 50% clearcutting of upper watershed. With 50% clearcutting the 50 year flood would be expected to occur on average every 5 years. Data from Schnorbus *et al.* 2004.

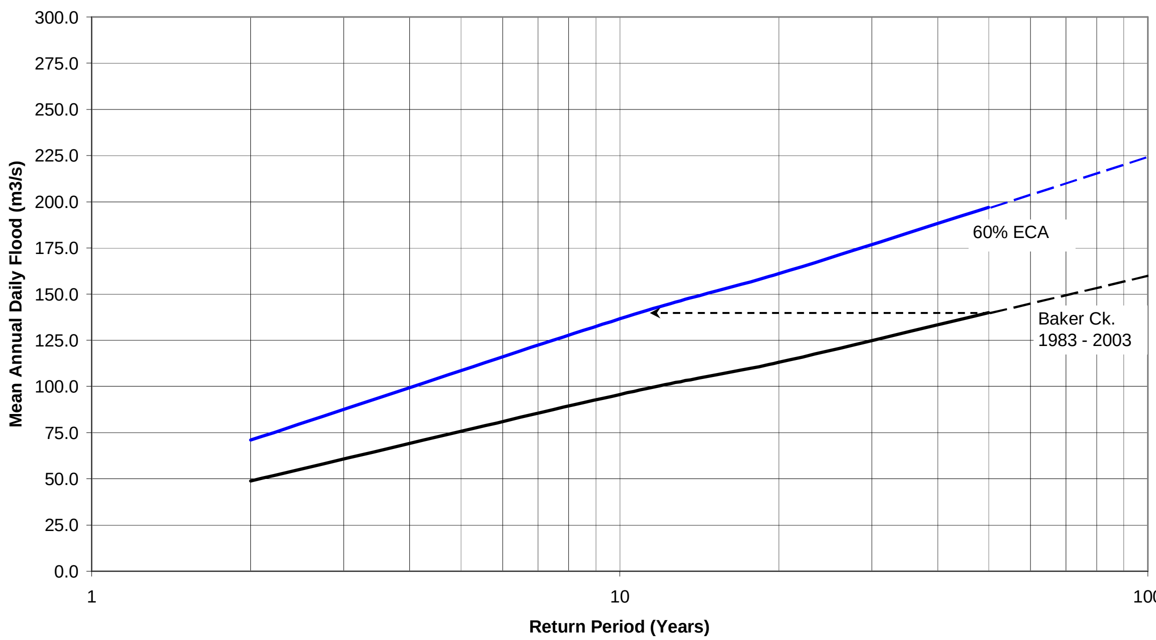

Figure C-2: Modelled flood frequency shift for Baker Creek (1570km^2) with approximately 60% ECA, from clearcutting and MPB pine mortality. The 50 year flood becomes about the post-treatment 11 year flood.

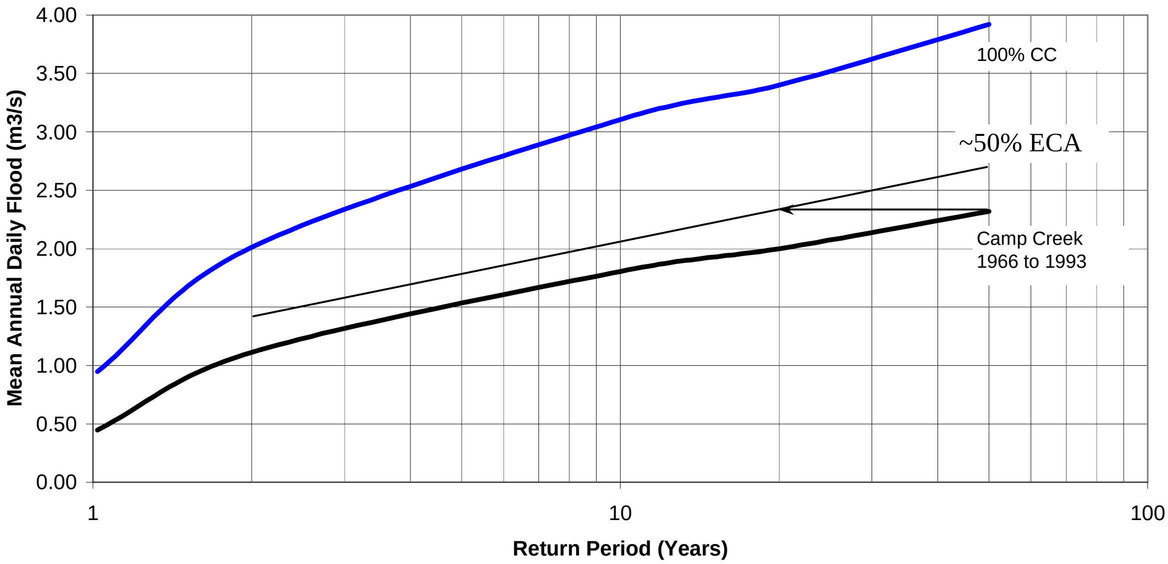

Figure C-3. Modelled flood frequency shift for Camp Creek, a 47km^2 tributary of Trout Creek, which adjoins Peachland Creek. With 100% of forested watershed clearcut harvested the historic 50 year flood becomes the post treatment 3 years flood (Alila et al. 2007). For the estimated "typical" South Okanagan watershed with a high (50%) ECA the historic 50 year flood becomes the 20 year post-treatment flood.

To extrapolate to the expected flood frequency shift in Peachland Creek, with the total salvage scenario having an extended ECA of centered around 50% (see Figure 9) all the modelled results would have to be scaled down (the amount of flood frequency shift reduced); because either the amount of clearcutting and the corresponding ECA is higher in the modelled watersheds, or the watershed area is smaller than Peachland Creek. Smaller watersheds are generally more "flashy" than larger watersheds, and all else being equal, one could expect a smaller change in flood regime in larger watersheds.

We also note the slight divergence between the control and treatment flood regimes, such that larger (longer return period) floods show somewhat larger increases in magnitude than smaller floods (Alila, *et al.* 2009)

On balance, we have extrapolated these results to Peachland Creek using the Camp Creek flood frequency curve to represent a "typical" South Okanagan watershed, such as Peachland Creek. The curve divergence is maintained and the magnitude of flood frequency shift is scaling down from the modelled watersheds, as shown in Figure C-3. It is estimated that following total salvage harvesting the 50 year return period flood would be expected to occur on average every 20 years.