Penticton Creek Hydrological Risk Assessment

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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 Penticton Creek Community Watershed. Penticton Creek has a 194km^2 basin draining into Okanagan Lake through the City of Penticton. It is a primary water source for domestic, agricultural and other users in the City of Penticton (CoP).

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 Penticton 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 ECAs. Figure 10 shows the results for the watershed above the CoP intake.

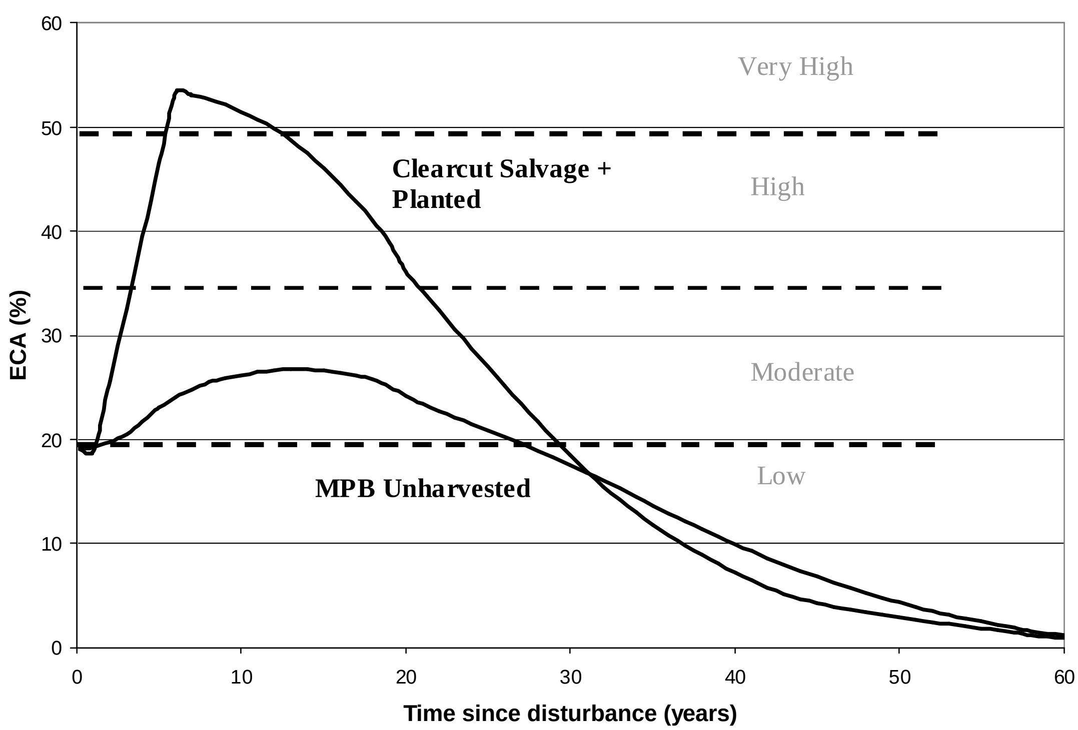

Figure 10. ECA hazard projections for Penticton Creek Watershed at CoP intake.

The current ECA for the Penticton 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 sustained 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, drainage density and natural or artificial storage – specific to Penticton 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 Penticton Creek. The watershed has some reservoir storage but much high elevation "snow zone" drainage area is uncontrolled and does not pass through the Penticton Lake Reservoir; overall the watershed peak flow attenuation is Moderate. Combining the Moderate flow attenuation potential with the 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 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. Following the unharvested MPB scenario there would be Moderate peak flow hazard.

Peak flow hazards were combined with channel sensitivity to increased peak flows, sediment and riparian conditions, to determine the hydrologic hazard for each of the two management scenarios. Mainstem channels are moderately sensitive to disturbance. Therefore 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 other infrastructure.

The water quality parameters most strongly linked to MPB infestation and salvage logging in Penticton 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 CoP intake may occur, but a significant increase in levels is not expected. 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 CoP intake is likely to occur. Source water turbidity levels would continue to present a problem at the CoP water intake, in terms of meeting Interior Health Authority water quality guidelines.

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). 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. Because Penticton Creek watershed has some reservoir storage, the risk of impacts to late growing season water availability is less than in many other Okanagan watersheds.

There are fish present and high habitat values along much of the Penticton Creek mainstem and some tributaries. 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 in the watershed the risk of negative impacts on fish populations in Penticton Creek will be Very High.

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 Penticton Creek watershed snow zone. Risks to private water intakes in the watershed, forestry roads, road-related "gentle-over-steep" landslides and urban developments on the Penticton Creek fan are considered Moderate following the unharvested MPB scenario and High following the full salvage scenario.

Recommendations to reduce risks can focus on protecting and strengthening risk elements, or on reducing stand-level MPB and salvage effects. Forests 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. Therefore these activities will not mitigate the short term hydrological impacts of MPB attack and salvage harvesting in Penticton 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.

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 CoP water quality and water supply infrastructure, Low to water supplies and Moderate for other infrastructure in the watershed. Only for fisheries values are risks High to Very High in lower mainstem reaches, and it would be prudent to periodically update on-site fish habitat assessments (last done in the mid-1990's), monitor channel and riparian conditions and carry out rehabilitation activities as necessary.

In any area where significant salvage harvesting is planned, a review of trail and road drainage structures (ditches, ditch blocks, culverts, cross-ditches, bridges, etc.) located within 400m of steeper stream escarpment slopes is recommended. Any structure which appears to be operating near its capacity, to be damaged or otherwise compromised so that it is not working at its design capacity, or is otherwise insufficient to accommodate some increase over historic flows, should be upgraded to accommodate larger flows.

Incremental risks are higher for almost 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 pine and non-pine overstory and understory stand structure in dead pine stands to get a more accurate picture of the hydrological condition of the watershed, and of the potential impacts of proposed salvage harvesting. Hydrological risk analyses that treat all MPB attacked stands as having little or no hydrological forest function (i.e., as having initial ECA values similar to clearcuts) may seriously underestimate the incremental hydrological risks associated with widespread clearcutting of attacked stands that have hydrologically significant stand characteristics.

- From a strictly hydrological perspective (and we recognize forest managers have to balance many different forest values), the least hydrological impact would result if pine-leading stands with the lowest non-pine overstory component and lowest understory stocking were preferentially targeted for salvage harvest. From the data collected here the stands in the snow zone with least hydrological function would be younger MSdm stands followed by older MSdm stands and then ESSFdc stands (see Figures 7-9 and Appendix B).

- We recognize that individual stands within broader biogeoclimatic types will have different characteristics than the average overstory and understory values used in this analysis; site specific surveys of stand characteristics in areas proposed for harvesting are recommended. Salvage harvesting should be focused on those stands with the least non-pine overstory and little healthy understory.

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

1.0 INTRODUCTION

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

Penticton Creek Watershed has an approximately 194km^2 area and drains into Okanagan Lake through the City of Penticton. It is the primary water source for domestic, commercial and agricultural users in the City of Penticton (CoP), currently supplying about 75% of city's demand. There is fish presence and good fish habitat along the lower Penticton Creek mainstem, and in upper watershed tributaries that have headwater lakes.

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 can affect watershed hydrology, and potentially water quality, quantity and timing.

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

2.0 METHODOLOGY

This report utilizes extensive previously published materials on Penticton Creek watershed conditions, as well as a helicopter overflight on November 05 and ground inspections on November 14 2008. Forest overstory and understory were measured in 32 plots in four different areas in Penticton Creek on December 6 2008, as part of a program of 245 plots taken in 30 areas in seven South Okanagan Community watersheds. This detailed stand information was used in modelling the projected hydrological effects of MPB pine mortality and salvage harvesting in Penticton 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 Penticton Creek are assessed in Section 3, to determine potential hydrologic hazards. Section 4 details the presence and/or vulnerability of specific Penticton Creek watershed values (or consequences) that could be impacted by those hazards.

Section 5 combines the hazards and consequences discussed in Sections 3 and 4 to arrive at qualitative risk ratings for each of the consequences potentially at risk.

Section 6 summarizes the various qualitative risks and proposes mitigative measures and management strategies to reduce those risks, where necessary.

2.1 RISK ANALYSIS

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

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

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

Figure 2 shows the risk assessment procedure used in this investigation. The incremental hydrologic hazard starts with changes in the forest canopy, snow accumulation and snow melt. This is expressed as an Equivalent Clearcut Area hazard (ECA). Watershed characteristics – drainage density, slope and routing factors (reservoirs, lakes and swamps) 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.

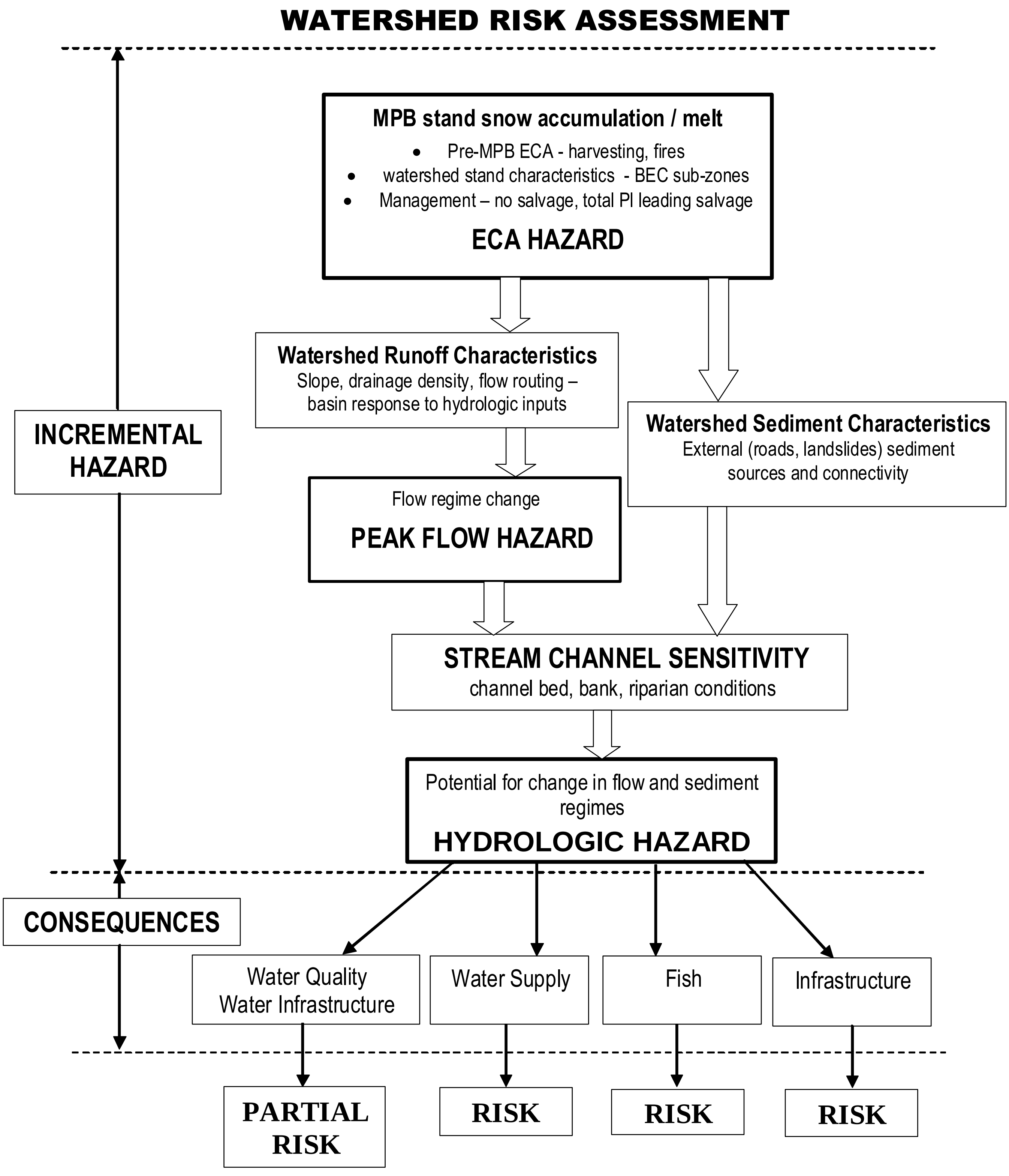

Figure 2. Risk Assessment Flow Chart

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 Penticton 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 ECAs 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, Lewis and Huggard, 2010), which incorporates recent research findings on snow accumulation and melt effects of different forest canopy conditions in MPB attacked stands. This includes modelling the canopy effects of the dead pine, the non-pine overstory and understory seedlings, saplings and poles. Research throughout BC to quantify the hydrologic function of dead pine trees and secondary structure in pine-leading (>40% pine) MPB infested stands clearly demonstrates the important hydrologic function of unharvested MPB attacked stands, and supports the contention that these effects must be considered when evaluating the potential hydrologic risks associated with MPB related stand mortality relative to salvage logging (Winkler *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 Penticton Creek ECA was collected in 245 random plots in 30 accessible stands in seven South Okanagan watersheds[1] near Penticton Creek, with similar biogeoclimatic (BEC) stand types as Penticton Creek, and includes 24 plots taken in Penticton 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.

In Figure 3, and in all modelling of unharvested MPB-attacked pine-leading stands, 100% mortality of pine trees in the stand is assumed. However recent research suggests that in the Okanagan Timber Supply Area the amount of pine mortality after the MPB infestation has largely subsided in 2019 will be about 68%; albeit with a substantial degree of uncertainty around that projection (Walton, 2009). If this turns out to be true, there will be 32% of pine trees left alive that will continue to have a hydrologic function. The distribution of mortality and survival in differing stand types and across the landscape is not known. A sensitivity analysis of watershed ECA with less than total pine mortality was carried out (see Section 3.2.3). Because of the significant uncertainty with the Walton (2009) estimates, stand and watershed analyses shown in this report assume total pine mortality. It should be kept in mind that in doing so these analyses may overstate the ECA effect of unharvested MPB attack, and underestimate the difference between retention of attacked pine stands and salvage harvesting, if pine mortality in Penticton Creek watershed turns out to be significantly less than 100%.

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

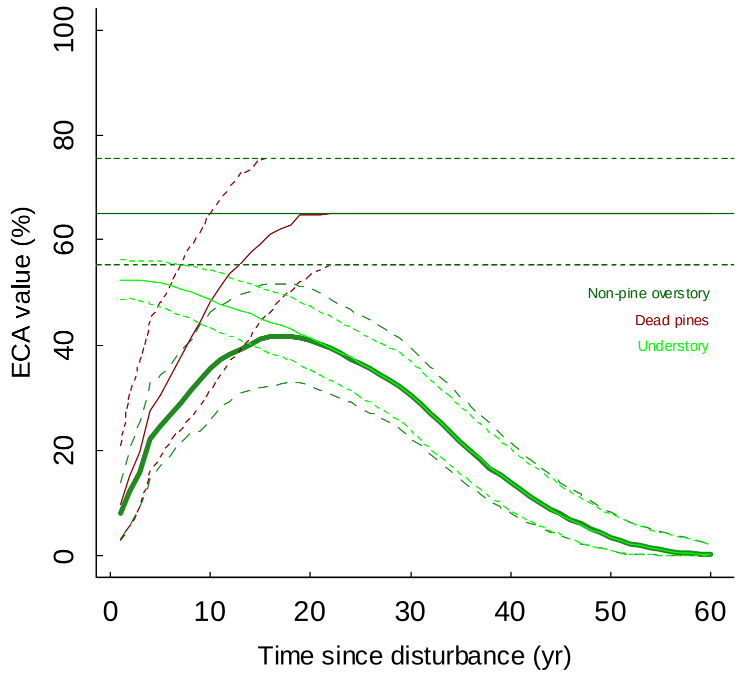

Figure 3. ECA projection (heavy green line) for unsalvaged older Montane Spruce BEC variant (MSdm, >110yr) showing the contributions over time of non-pine canopy (black line, showing a constant 35% ECA reduction over time) the dead pine (red line, showing decreasing ECA reduction as dead pines fall down 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.

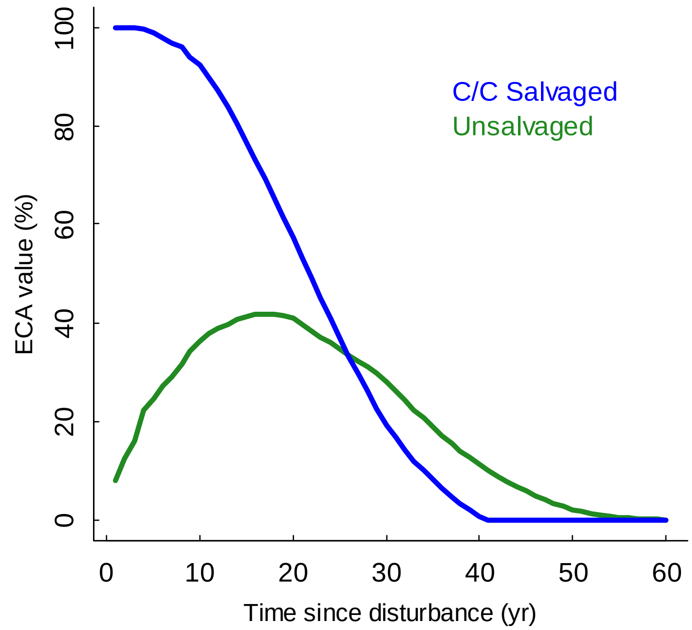

Figure 4. ECA projections for unsalvaged and clearcut salvaged and planted older MSdm, showing that ECA for unharvested MPB attacked stands never rises above about 40%. There is a 20 to 25 year period where the clearcut salvaged and replanted stand has a significantly higher ECA than the unharvested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

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

Loss of riparian cover due to MPB is not considered a major issue as the component of pine in wetter riparian zones tends to be less than elsewhere across the landscape. Wei et al, (2007) found similar large woody debris (LWD) input rates in the Okanagan for MPB-attacked and non-attacked stands. Hassan (2008) investigated sites in central BC and concluded that MPB infestation-related wood transfer to the channel in the next 25 years is likely to be relatively small and within the range of typical conditions found in the region. Therefore, in Penticton 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 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 (Appendix C, from Green 2005) based on field observations, airphoto and map reviews, and observations and conclusions from previously completed channel assessments. Earlier assessments were typically aimed at documenting levels of disturbance in channels. These previously recorded indicators of channel disturbance were interpreted in this assessment as indicators of channel sensitivity or ‘robustness’. Where no disturbance was recorded, channel sensitivity was derived from observations of channel type and other morphological features. Channel sensitivities vary along the length of the stream. For the purposes of this assessment, sensitivities were assigned by sub-basin, based on the relative extent and location of sensitive reaches within that sub-basin.

Once channel sensitivity has been determined, it is combined with the Peak Flow Hazard to give a Hydrologic Hazard for the drainage area (Figure 2). The Hydrologic Hazard therefore includes forest cover ECA effects, sub-basin drainage characteristics and channel sensitivity rolled up into a single hazard reflecting the potential for channel change, and is an expression of expectations regarding peak flows and sediment delivery at the drainage outlet.

2.4 ELEMENTS AT RISK

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

- Water quality and water intake infrastructure, primarily at the City of Penticton (CoP) water intake.
- Water supply (quantity) at the CoP 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 City of Penticton (CoP) intake on Penticton Creek. Water quality parameters and monitoring results in Penticton Creek are discussed in MoE (2008), EarthTech (2005) and Giles (2006). Because it relates to the reliability of supplies, potential damage and increased maintenance costs to the CoP intake are also considered in this section.

Table 1 (page 15) 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 a rationale is provided.

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 in 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. True Colour levels are seasonally elevated in Penticton Creek source waters (EarthTech, 2005).

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 Penticton 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.

Table 1. Water quality and water supply infrastructure parameters

<table>
<tr><th>Element at Risk</th><th>Effects of Concern</th><th>Specific Parameter</th><th>Metric</th><th>Parameter or Watershed Sensitivity</th></tr>
<tr><td rowspan="10">Drinking Water Quality</td><td rowspan="3">Reduced aesthetic appeal and increased risk of microbiological activity. Decreased effectiveness of primary disinfection treatment</td><td>FINE SEDIMENT (Turbidity)</td><td>NTU</td><td rowspan="2">In the past turbidity (fine sediment) in Penticton Creek source waters has been sufficiently elevated during the spring freshet that supplies are supplemented with water from Okanagan Lake during this period. Watershed is sensitive to disturbances that will increase fine sediment concentrations in source waters.</td></tr>
<tr><td>FINE SEDIMENT (Total Suspended Solids)</td><td>concentration, mg/L</td></tr>
<tr><td>Temperature</td><td>^{o}C</td><td>Loss of riparian forest shade can result in increased stream temperatures. MPB effects are limited because there is frequently little or no pine in riparian areas. Salvage will remove forest shade if riparian areas are harvested. Salvage effects will be limited if good long term riparian retention practices are followed.</td></tr>
<tr><td rowspan="3">Reduced aesthetic appeal and human health effects</td><td>True Colour</td><td>True Colour Units</td><td rowspan="4">Little published evidence to link changes in these water quality parameters to MPB infestation or salvage harvesting. Penticton TCU regularly exceeds water quality standards.</td></tr>
<tr><td>Total Organic Carbon</td><td>concentration, mg/L</td></tr>
<tr><td>Metals (select)</td><td>concentration, mg/L</td></tr>
<tr><td rowspan="3">Reduced aesthetic appeal and increased risk of microbiological activity</td><td>Total Phosphorous</td><td>concentration, mg/L</td></tr>
<tr><td>Nitrate & Nitrite</td><td>concentration, mg/L</td><td>Difficult to generalize effects on nitrogen cycle due to complexity. However, increased concentrations of dissolved inorganic nitrogen (nitrates and ammonium) are typical. Penticton Creek nitrogen levels are low.</td></tr>
<tr><td>Aquatic Flora (algae)</td><td>mg per m^2</td><td>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 Penticton Creek have been made.</td></tr>
<tr><td>Human health (waterbourne pathogens)</td><td>Microbiological Indicators</td><td>Fecal coliform, E. Coli bacteria</td><td>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 Penticton Creek are elevated for a large part of the year.</td></tr>
<tr><td>Water Supply Infrastructure</td><td>Treatment infrastructure damage</td><td>COARSE SEDIMENT</td><td>cubic metres</td><td>In Penticton Creek, sediment is deposited in the channel or is mobilized from bed and bank erosion in the channel, so any sediment mobilized can be transferred downstream to the CoP water intake and other values. Watershed is considered sensitive to disturbances that will increase coarse sediment production.</td></tr>
</table>

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

MOE (2008) monitoring indicates that water within the lower portion of Penticton Creek is subject to excessive summertime heating and is unlikely to meet the aesthetic drinking water guideline during most summer months. While it is expected any change in Penticton Creek stream water temperatures due to MPB will be small, any change would be an increase in temperatures already seasonally approaching maximum acceptable levels. Good management of salvage harvesting of all size streams will be necessary to avoid additional cumulative temperature effects.

Nitrate/Nitrite

Limited source water monitoring from 1997 to 1999 found nitrate/nitrite concentrations in Penticton 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 Penticton 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 Alzheimer's disease (Aqua 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

Penticton Creek source waters have elevated microbiological indicator levels, with elevated fecal coliform and E. Coli values from June to August (MOE, 2008). In 2005 raw water quality at the Penticton Water Treatment plant showed that fecal coliform counts ranged from 0 – 2419 CFU/100 mL and E. Coli counts ranged from 0 – 73 CFU/100mL (94 samples). The results suggest that elevated concentrations of microbiological indicators are common in Penticton Creek source waters.

MPB infestation and salvage harvesting are not expected to have a significant direct effect on fecal coliform and E. Coli levels in Penticton 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 Penticton 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 CoP water intake is a concern, because the changes in forest canopy affected by MPB and/or salvage can be similar to the effects of forest harvesting. These include 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. Suspended sediment can also decrease the aesthetic quality of water and decrease primary disinfection treatment effectiveness, placing additional stress on water treatment facilities.

The MOE (2008) water quality monitoring summary report had insufficient turbidity data to characterize levels in Penticton Creek. However it is understood that Penticton Creek has frequently elevated turbidity levels and that poor water quality during the spring freshet compels CoP to pump water from Okanagan Lake, and not use Penticton Creek as a source for drinking water during this period. This suggests that Penticton Creek source waters turbidity values are high on a seasonal basis during the spring freshet. Therefore, the watershed is considered sensitive to disturbances that will increase fine sediment production.

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 Penticton Creek near the CoP intake. As discussed in Section 2.3, in gently-sloping upland areas most sediment is generated from channel bed and bank erosion during high flows. In lower more deeply incised reaches sediment from natural or development-related valley wall slope failures can introduce significant sediment to the channel, where it can be transported downstream, eventually to the community water intake and other downstream elements. Increased bedload sediment can cause changes in channel morphology which can negatively impact the 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.

As noted above CoP has an advanced water treatment system. However the Interior Health Authority requested we do not evaluate the robustness or vulnerability of the CoP 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 CoP water intake (Dale Thomas, pers. comm.).

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

Supply and demand analyses of the CoP water supplies indicate that enough water is available from the Penticton Creek intake to supply the entire city well into the future (EarthTech 2005). Because of significant reservoir storage capacity, Penticton Creek is considered less susceptible to reservoir depletion due to earlier snowmelt than many other Okanagan community watersheds.

2.4.3 Fish

Sport-fish species within the watershed include Brook Trout (Salvelinus fontinalis), and Rainbow trout (Oncorhynchus mykiss) in the headwater tributaries and lakes. Kokanee (Oncorhynchus nerka) has been identified in the lower reach of Penticton 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).

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. As discussed in Section 2.3 significant loss of riparian vegetation due to MPB is not expected. Salvage harvest of riparian vegetation can affect fish shelter, stream temperature, nutrient availability and large woody debris recruitment to streams. Increased peak flows and sediment can alter channel morphology, resulting in degraded spawning, rearing and over-wintering habitat. For each Penticton Creek and tributary sub-basin, hydrologic hazards (see Section 3) are combined with the consequence values for each sub-basin (see Appendix D), 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 City of Penticton (CoP) water supply infrastructure. Only one privately held water license exists on Penticton Creek, permitting diversion of flows for watering at a development in Reach 1 below the CoP intake. Privately held water licenses for domestic and irrigation use exist on several tributaries in the Residual sub-basin, including Ker Creek, Luke Creek, Kerluke Creek, Selinger Creek and Steward Creek.

Only one crossing of Penticton Creek exists between the CoP intake and Greyback Lake. This is a forestry road crossing near the Dennis Creek confluence, approximately 1 km downstream of the Greyback Lake dam. Numerous forestry road crossings also can be found on tributaries in the watershed, mostly on the east side of the valley.

Penticton Creek below the intake essentially passes through the middle of the City of Penticton. The City has developed on top of a fan and valley sediments deposited during de-glaciation of the region 10,000 years ago. Through the main part of town, the creek has been channelized into a stepped floodway, with rock and concrete gradient controls/drop structures. The banks have either been rock armoured or concrete-lined. Numerous roadway and pedestrian crossings exist along the channel as it heads toward the south end of Okanagan Lake. Some evidence of old natural channels exist on the historic fan. It is possible that the current channel may be fully artificial.

3.0 WATERSHED CONDITIONS AND HAZARDS

3.1 WATERSHED CONDITION

3.1.1 Physiography, geology and terrain

Penticton Creek has a watershed area of approximately 194 km^2 (174 km^2 above the CoP intake) ranging in elevation from 342 m at the confluence with Okanagan Lake to 2,134 m at the summit of Greyback Mountain. Major tributaries to Penticton Creek include Steward, Harris, Municipal, Selinger, Deep, Reed, James, Denis and Corporation Creeks. Major sub-basins and some of their characteristics are listed in Table 3.

Penticton Creek has the highest elevation of major watersheds draining into Okanagan Lake. Most of the watershed is dominated by a rolling, flat (<7%) to gentle (7 to 30%) sloping, glaciated upland plateau between 1300 and 1800m elevation (Photo 1). Drainage density of streams on the plateau is low due to the relatively gentle terrain, well-drained soils and dry climate.

Most of the mid to upper watershed is underlain by Mesozoic Intrusive rocks. The northwest corner and the lower watershed below the Municipal Creek confluence with Penticton Creek are underlain by Proterozoic to Palaeozoic Shuswap Metamorphic gneiss and schist. Slopes are commonly bedrock controlled with a thin soil cover. Soils are derived from sandy glacial moraines and some finer grained glaciolacustrine deposits. Soil horizons are generally low in clay and high in coarse fragments, leading to low water holding capacity and well-drained surface soils (Winkler 2006). Small areas in the upper region of the watershed contain soils derived from volcanic ash. (MoF and MoE, 1991).

A steep walled valley is incised into the plateau along the mainstem channel below about 1300m elevation, as Penticton Creek drops from the high upland plateau to Okanagan Lake (Photo 2). The valley sidewalls (escarpment) are frequently gullied, with steep slopes ranging from 60% to 100%. Much of these lower valley walls appear to be incised into bedrock, however there are several large landslides in thick unconsolidated material that have contributed sediment to Penticton Creek mainstem in the past, and continue to do so.

A review of 1938, 1970 and 2007 air photos shows a group of three debris slides initiating at the slope break from the plateau to the steeper Penticton Creek escarpment; near an unnamed stream just north of Deep Creek (which drains Deep Lake), in mainstem Reach 5. Photos 3 and 4 show that slide in 1938 and in 2004. In 1938 the configuration of the slide is similar to today. There is a road and numerous skid trails that could have disrupted slope drainage, redirecting water onto the steep escarpment and initiating Landslide 1; or it could be a natural event unrelated to upslope activities. In any case, however and whenever it was initiated it likely delivered a large amount of sediment to Penticton Creek, resulting in downstream channel aggradation. It has also likely continued to periodically deliver sediment to the creek in the 70 years or so since it was first recorded on the aerial photography.

There is a second notable landslide located about 2800m downstream from Landside 1 (about 900m downstream of the Municipal Creek confluence), also initiating on the upper west mainstem escarpment. It is a 140m long debris slide that enters a stream, transitioning to a 350m long debris flow that delivers sediment to the Penticton Creek mainstem. It is not visible on earlier air photos, and presumably initiated sometime after 1970. It is in a large burn that occurred in 1972 and there are roads and harvesting upslope of it; however its cause is uncertain.

Most lower escarpment slopes appear to be underlain by bedrock. While these slopes are relatively resistant to erosion and sediment transport to streams, compared to unconsolidated sediment deposits observed higher on the escarpment, some erosion of bedrock by channels was noted on lower mainstem and tributary escarpment slopes (Photo 5). Overall however, Penticton Creek and its lower tributaries are predominantly incised into bedrock which is relatively resistant to erosion.

The relatively few, but large and persistent landslides observed in unconsolidated sediments on upper escarpment slopes are an indication that there are areas more sensitive to disturbance; and they have probably contributed significant sediment to streams, influencing channel morphology. However they are likely now contributing significantly less sediment than earlier in their history.

Dobson (1998) reports that the majority of forest development in the Penticton Creek watershed has taken place since the early 1970s, with clearcutting the dominant silviculture system in both historic and more recent forest development. Earlier air photos going back 80 years do show roads and lots of skid trials in some areas, which could have led to terrain disturbances, as discussed above. Large burned areas are visible on older photos, particularly a large area of the mid to lower watershed which burned around 1970. Some streams, particularly Municipal Creek appear to be disturbed in 1938 and 1970, and were actively transporting larger sediment loads than today, probably as a result of these landscape level disturbances.

Both cattle grazing and recreational activities take place along with forest development in the watershed. Weyerhaeuser Canada Ltd. (Forest License A18674) and British Columbia Timber Sales (BCTS) are currently operating in the watershed.

Upper Penticton Creek was dammed in 1967 to form Greyback Lake reservoir (see Photo 1). Two dams have been constructed at the Greyback Lake site (at 1580 and 1588m elevation) to store water for release during the drier months. Approximately 19% of watershed is located above Greyback Lake. Another reservoir was constructed in 1967 midway through the watershed (at 584m elevation) to give gravity head for a 3 kilometre diversion tunnel through Campbell Mountain which provides irrigation flows to farms, orchards and wineries along Naramatta Road north of Penticton (Earthtech 2005). A third reservoir has been developed at the community intake by the construction of a 16m high concrete dam.

Several other smaller lakes and wetlands exist in the watershed, mostly at higher elevations; including Reed Lake at the headwaters of Reed Creek, Howard Lake at the headwaters of James Creek, and a chain of small lakes at the headwaters of Corporation Creek. Some of these small lakes have been controlled and used as reservoirs in the past.

Table 3. Penticton Creek Watershed and sub-basin areas, above CoP intake.

Sub-basin Name	Sub-basin Area (ha)	Total Tributary Area (ha)	Elevation Range (m)	Reservoirs (surface area/elevation)
Greyback	31860	31860	1650-2135	Greyback Lake (101 ha/1580 / 1588m) Corporation Lakes (7 ha/1700m, abandoned)
Dennis	9200	9200	1520-2135	
Municipal	2691	2691	1100-2000	
Penticton Residual (above intake)	105940	149691	480-1620	Reed Lake (6 ha/1820m, inactive) Howard Lake (8ha/1910m, abandoned) Campbell Mountain Diversion Basin (1 ha/584m) Intake Reservoir (2 ha/471m)
Penticton Creek (below intake)	-	-	350-840	All of the above

3.1.2 Channel conditions and bank stability

Existing conditions in the Penticton 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.

Portions of Upper Penticton Creek and Denis Creek have been monitored as part of a long term study into the effects of forest harvesting on water resources. The Upper Penticton Creek Watershed experiment uses a before-after-control-intervention, paired-watershed design to quantify changes in streamflow, water quality, channel morphology and aquatic habitat following logging and forest regrowth. The study was initiated in 1984 and is on-going. Three sub-basins (240, 241 and upper Dennis Creek, all approximately 5 km^2 in drainage area) are being monitored and the results compared as portions of the basins are logged. There are some lodgepole pine forests types that have been subjected to MPB mortality and salvage harvesting over the course of the study.

Water quality in all three of the study streams is generally high, however increases in concentrations of nitrogen and phosphorus, as well as fecal coliform, have been observed as the logging rate has increased. The water in all three creeks is highly coloured during peak flow events. Elevated suspended sediment concentrations are observed in spring and during fall rains. At no time have sediment concentrations exceeded 20 mg/L of water and most were lower than 5 mg/L (Winkler 2006). Although water quality in all study streams is generally high, statistically significant changes have been observed as the area logging has increased, particularly in Dennis Cr. where more than 50% of the watershed area has been harvested. A decline in turbidity following the final logging pass indicates that sediment delivery to streams observed during the first season following logging subsequently decreases. While increased turbidity and sediment levels in study streams appear to be associated with logging operations, the effect is short lived (2 to 3 years post-logging) in the low gradient, sediment-supply limited channels found in the study area (Giles 2008).

Other channels above Grayback Lake draining the relatively flat upper plateau area are relatively small, with intermittent low gradient and low stream power watercourses flowing through relatively coarse materials. Channels also flow through occasional wetlands. These plateau streams are assumed to behave similarly to the adjacent monitored streams described above. Greyback Lake provides an opportunity for suspended sediment to settle, minimizing the downstream effects of drainage above the lake. Routing peak flows from these smaller streams through Grayback Lake will attenuate the downstream peak hydrograph.

Municipal Creek drains a high broad valley through a series of wetlands. Harvesting has been fairly extensive in the upper basin, however riparian areas have been mostly left undisturbed. While the channel has been de-stabilized by landscape level disturbances in the past, it is currently described as stable with coarse substrates and moss covered lag boulders. Some areas of fine-textured banks exist. Sediment generated in these sections is retained in low gradient and wetland sections. Three landslides in Municipal Creek have been documented as the channel becomes more incised as it steepens toward Penticton Creek (Dobson 1998). The channel morphology changes to boulder steps in the lower steeper section.

The Penticton Creek mainstem channel below Graystoke Lake becomes increasingly incised as it flows south. The channel is mostly stable riffle-pool with coarse substrates. The valley walls become increasingly higher with exposed bedrock valley walls. As discussed in Section 3.1.1 two large landslides on the west side of the valley have been sediment sources to the mainstem. Numerous gullies have formed along the valley walls, with some ravelling of coarse material into the channel. Although the channel is mostly confined, there is some fluvial floodplain in the valley bottom providing some buffering from the canyon wall sediment sources. Some aggradation and channel avulsions have occurred on this narrow floodplain (Photo 6), indicating there is excess sediment that is periodically mobilized during extreme peak flows.

Observations of the Campbell Mountain reservoir when largely emptied for maintenance indicate there is a large amount of sediment deposited behind the dam which likely requires periodic removal (Photo 7). Some channel aggradation has occurred in the mainstem channel a short distance upstream of both the Campbell Mountain diversion basin and the lower intake reservoir, due to forced gradient change reducing velocities as flows approach the reservoirs.

Penticton Creek below the CoP intake is almost entirely channelized to Okanagan Lake. Old creek channels on the fan have been infilled and developed. The channel is tightly constricted by urban development on fan, and concrete and riprap have been used to stabilize the banks and prevent flooding. Constructed riffles/weirs were added in some areas to control energy, bedload movement and improve fish habitat. Near the upstream end towards the intake, the channel has been dredged and the excavated materials (mostly cobbles) have been used to construct rough berms/dykes. There are numerous road and footbridge crossings as the channel passes through the City of Penticton to Okanagan Lake.

Forest cover disturbances in the drainage area below the District intake were not analysed. However, any increases in stream flows at the intake will be carried through to the channel downstream as it passes through Penticton. 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
Greyback	9,10,11	3.6	0.05	CPc, RPg	Source	Low relief plateau area, high snow accumulation zone. Channels are small and intermittent with occasional wetlands. Some mapped channels may not exist as shown. Paired watershed study in the sub-basin (with Dennis Creek). Some increase in turbidity and streamflow following harvest but channels remain stable with little evidence of bank erosion and good LWD function. Low gradient, low stream power with relatively coarse substrates and bank materials. Greyback Lake will capture any suspended sediment and attenuate peak runoff at the lower end.
Dennis	1,2	3.5	0.09	CPg/c	Source	Similar to upper Penticton Creek described above. Extensive existing harvest with little channel response. Riparian intact on mainstem, reduced on some tributaries. Increased fine sediment following harvest operations.
Municipal	1,2,3, 4,5	8.4	0.03	CPc/b, RPg	Source	Channel stable with coarse substrates and moss covered lag boulders. Fine-textured banks with three landslides documented. Steep channel interspersed with low gradient sections through wetlands. Sediment passes through steeper sections and is stored in low gradient sections. Overbank sand deposits. Natural blowdown provides LWD to channel. Boulder steps in lower steeper section.
Penticton Creek Residual (above intake)	2,3,4,5, 6,7,8	18.3	0.06	CPc/b	Source/ Transport	Mainstem channel increasingly incised toward downstream end. Steep-sided, bedrock controlled canyon. Numerous gullies along valley walls, some raveling of coarse material. Evidence of old landslides impacting channel. Channel mostly stable with coarse substrates and bedload with bedrock controls. Aggraded channel sections upstream of Campbell Mountain diversion basin and the lower intake reservoir due to increased bedload from mainstem landslides.

Penticton Creek (below intake)	1	4.5	0.03	CPc	Depositional	Creek below intake site is almost entirely channelized to Okanagan Lake. Channel tightly constricted by development on fan. Constructed riffles/weirs to control energy, bedload movement and improve fish habitat. Aggraded sections above control points. Near the upstream end, the channel has been dredged with excavated materials used to construct dykes. Concrete and riprap lined channel with numerous road and footbridge crossings toward lake.

*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 Penticton 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.

On-going research in the upper Penticton and Dennis Creek basins suggests the smaller channels are not sensitive to minor increases in flow regime or sediment. In these channels documented increases in peak flows do not appear to have resulted in widespread bank erosion. Water quality has deteriorated somewhat in response to harvest operations, but the introduction of fine sediment has not led to channel instability. Any increase in peak flows or sediment in the upper sub-basin will be buffered by Greyback Lake. James Creek and Reed Creek are likely similar to Dennis Creek.

Municipal Creek has experienced some problems in the past with landslides and erodible banks. Hillslopes are coupled to the channel in the lower reaches and sediment deposits have been identified. Municipal Creek would be moderately sensitive to increases in peak flows (erosive power) and coarse sediment inputs.

The Penticton Creek mainstem downstream of Greyback Lake has also experienced sediment input due to landslides, but sediment contributions from these older features is likely much less now than when they initially occurred. Lower bedrock valley walls are also relatively resistant to stream erosion and are not expected to be a significant ongoing sediment source. Historic sediment inputs appear to have accumulated in low gradient sections above the Campbell Mountain diversion reservoir and the intake reservoir (Photo 7). The relatively flat valley bottom between the canyon walls appears to be comprised mostly of coarse fluvial and glaciofluvial sediments. The channel will likely continue to migrate within the narrow floodplain, reworking the valley bottom deposits. However channel migration is ultimately confined by the bedrock valley walls. Although the bedload is high, recent inputs are probably less than in earlier periods. The channel is considered stable in its limited migrating form. Increased peak flows and/or new sediment inputs would lead to more frequent bed mobilization and localized aggradation.

Downstream of the intake on the Penticton Creek fan, very little natural channel exists. In the upper portion, along Penticton Ave, the channel has been dredged and excavated materials placed beside the channel (Photo 8). Outside bends have been riprapped and concrete grade controls (weirs) have been constructed. Although coarse sediment sourced in the upper watershed is prevented from entering the lowest reaches by the reservoirs, some mobile bed and bank materials remain in this section. Downstream through the city, Penticton Creek has been fully channelized with concrete bed, banks, and control weirs (Photo 9). These artificial channels are generally not sensitive to small increases inflow and/or sediment, however, structure maintenance is required to ensure long term stability. Materials mobilized in the upper section of this reach could aggrade and reduce channel capacity in the lower section, increasing flood risk and/or requiring further channel clearing/dredging. The City of Penticton occupies the alluvial fan of Penticton Creek and overbank flows related to a failure or over-topping of the constructed channel could follow any number of routes to Okanagan Lake, resulting in significant damage to private and public property.

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
Greyback	L	Channels are small, intermittent, with low gradients and frequent wetlands. Routing is slow through the sub-basin.	L	Channel is sediment supply-limited. Movement of sediment reduced by low gradients, low stream power, relatively coarse substrates.	M	LWD plays a role in channel stability in RPc reaches, including improved bank stability and controlling sediment transport.	L	None anticipated
Dennis	L	Long term monitoring has noted minimal channel response to existing high level of disturbance in the sub-basin (Giles 2008).	L	Channel is sediment supply-limited. Movement of sediment reduced by low gradients, low stream power, relatively coarse substrates.	M	LWD plays a role in channel stability in RPc reaches, including improved bank stability and controlling sediment transport.	L	None anticipated
Municipal	M	Coarse textured substrates with fine-textured, erodable banks and coupled hillslopes. Wetlands will store runoff in upper reaches.	M	Fine-textured erodable banks with existing landslides. Lower channel coupled to hillslopes. Low gradient sections/wetlands in upper basin will filter and store sediment.	M	LWD plays a role in channel stability in RPc reaches, including improved bank stability and controlling sediment transport.	M	Increased flows could increase bank erosion and sediment loading.
Penticton Residual (above intake)	M	Robust channel with coarse textured substrates. Stored sediment in aggraded sections may remobilize. Occasional bedrock controls.	M	Sediment inputs will accumulate in low gradient sections, especially above reservoirs. High bedload channel.	L	LWD plays a minor role in channel stability, bank stability and sediment transport.	M	Continued aggradation in vicinity of sediment basin.
Penticton Creek (below intake)	M	Mostly channelized and riprapped. Some material may be mobilized by high flows resulting in localized aggradation.	M	Sediment is limited by upstream reservoirs. Aggraded sections have been dredged in past. Deposition may reduce capacity of artificial channel downstream.	L	Not currently dependant on riparian vegetation to maintain channel stability.	M	Continued aggradation in upper section may reduce channel capacity. Increased stream power through channelized section.

Riparian areas appear to be mostly intact along most channels in the Penticton watershed. No access to most of the Penticton Creek mainstem has been developed for forest harvesting. Evidence of a fire upstream of the Campbell Mountain diversion reservoir may have affected riparian vegetation in middle Penticton Creek. Riparian vegetation has been removed by clearcutting along some tributaries in the upper Reed and Dennis Creek basins. Along Penticton Creek below the CoP intake riparian vegetation has been replaced by riprap and concrete bank armouring. 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

Penticton Creek is a snow-dominated (nival) hydrologic system and peak flows occur from late April to mid-June. The total annual precipitation for the region ranges from approximately 250 mm in the valley bottom, with 29% occurring as snow, to 700 mm at 1250 m where 53% occurs as snow (Dobson 1998). The watershed experiences warm to hot summer temperatures and mild winters.

3.2.1 Historic flood frequency

Penticton Creek has been used as a water source since early settlement in the area. Numerous control structures have been built and decommissioned over the years, and gauged stream flows do not represent natural flows. No recent natural hydrograph data exist for the entire watershed.

Three small upper basins (~5 km^2) have been gauged above any control structures for the Upper Penticton Creek Watershed Experiment (Two-Forty Creek, Two-Forty-One Creek and Dennis Creek). It is not reasonable to extrapolate the data from these small basins in the high snowpack zone to represent flows in the larger (174 km^2) watershed.

To synthesize a natural (uncontrolled) flood frequency relationship, data from Water Survey of Canada (WSC) gauge on Penticton Creek below Harris Creek (155 km^2) from 1971 to 1981 (adjusted for area), augmented by data from Penticton Creek near the mouth (177 km^2) from 1950 to 1955 (prior to dam construction), was used to generate a 17 year record for the watershed. Flows from this record were used to produce the following Flood-Frequency relationship:

Return period (years)	Discharge (m^3/sec)
2	14
5	18
10	20
20	23
50	26
100	28
200	31

Figure 5. Penticton Creek Flood Frequency Data

This relationship has been developed to demonstrate the magnitude of a potential uncontrolled flow regime in the watershed. These values should not be used for design work or flood management without further investigation and analysis.

3.2.2 Snow sensitive zone

It is widely accepted that for nival (snowmelt dominated) watersheds such as Penticton 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). This is known as the snow line or the watershed Hline.

Measurements have been made of the elevation of the receding snowline at the time of peak flows in several south Okanagan watersheds, including Penticton Creek (Dobson 2004*)*. Based on very limited observations the position of the snow line in Penticton Creek during the freshet period (as extrapolated from stream discharge records for nearby smaller watersheds) the snow line (or Hline) was estimated at 1520m elevation. This is a higher elevation snow line than in other watersheds we have looked at as part of this study, but Penticton Creek is a higher elevation watershed. The 1550m elevation contour that was used as the snow line in this report is approximately the H_{60} line for Penticton Creek – that is 60% of Penticton Creek watershed area is above this elevation.

3.2.3 Forest cover changes

Stand Level ECA

Figure 6 (in pocket) shows the biogeoclimatic (BEC) stand types in Penticton Creek watershed, including Ponderosa Pine (PP), Interior Douglas Fir (IDF), Montane Spruce (MS) and Engelmann Spruce Sub-alpine fir (ESSF). MSdm and ESSF BEC variants located above the H_{60} line are coloured. These two variants comprise 74% and 26% respectively of the area of Penticton Creek watershed in the snow zone above the H_{60} line. As discussed in Section 2, different ECA progression curves were developed for the different BEC units. Figures 7, 8 and 9 show unharvested and harvested ECA curves for three BEC units above the snow line in Penticton 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 7) are based on 56 plots in 7 ESSFdc stands. In stands labelled 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).

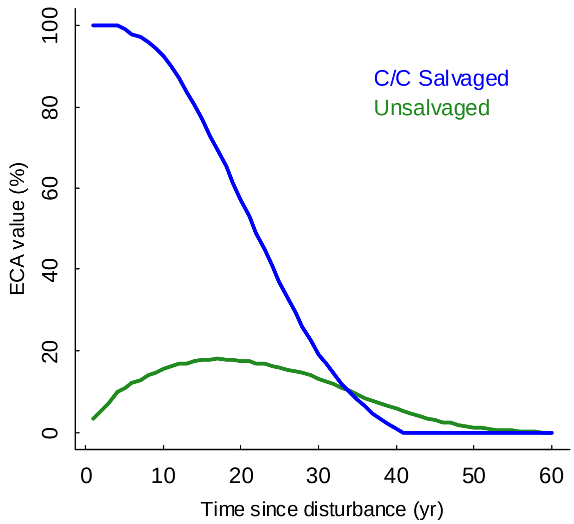

Figure 7. ECA progression in ESSF pine-leading stands.

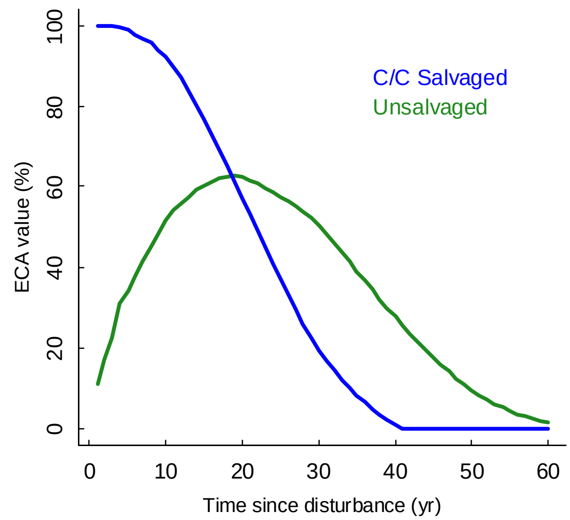

Figure 8. ECA progression in younger pine-leading MSdm stands (70 to 110 yr).

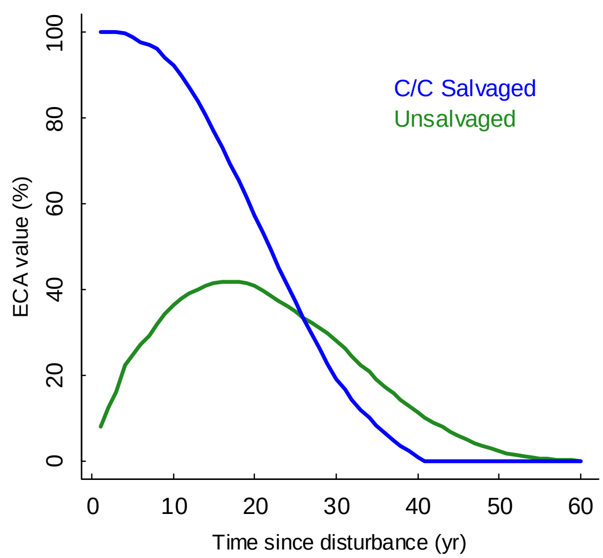

Figure 9. ECA progression in older pine-leading MSdm (> 110yrs) stands.

The younger MSdm ECA curves (Figure 8) 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 9) 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.

Penticton Creek Watershed ECA

Using this stand ECA information, cumulative harvested and unharvested ECA curves for the watershed area and sub-basin areas were generated. 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 – primarily Weyerhaeuser Canada as well as BCTS Okanagan-Shuswap Business Area for a small area at the south end of the watershed.

In watershed ECA modelling, MPB attack was phased in over 5 years, and salvage harvesting followed 1 year behind the MPB attack. Two management scenarios were modelled as shown in Figure 10.

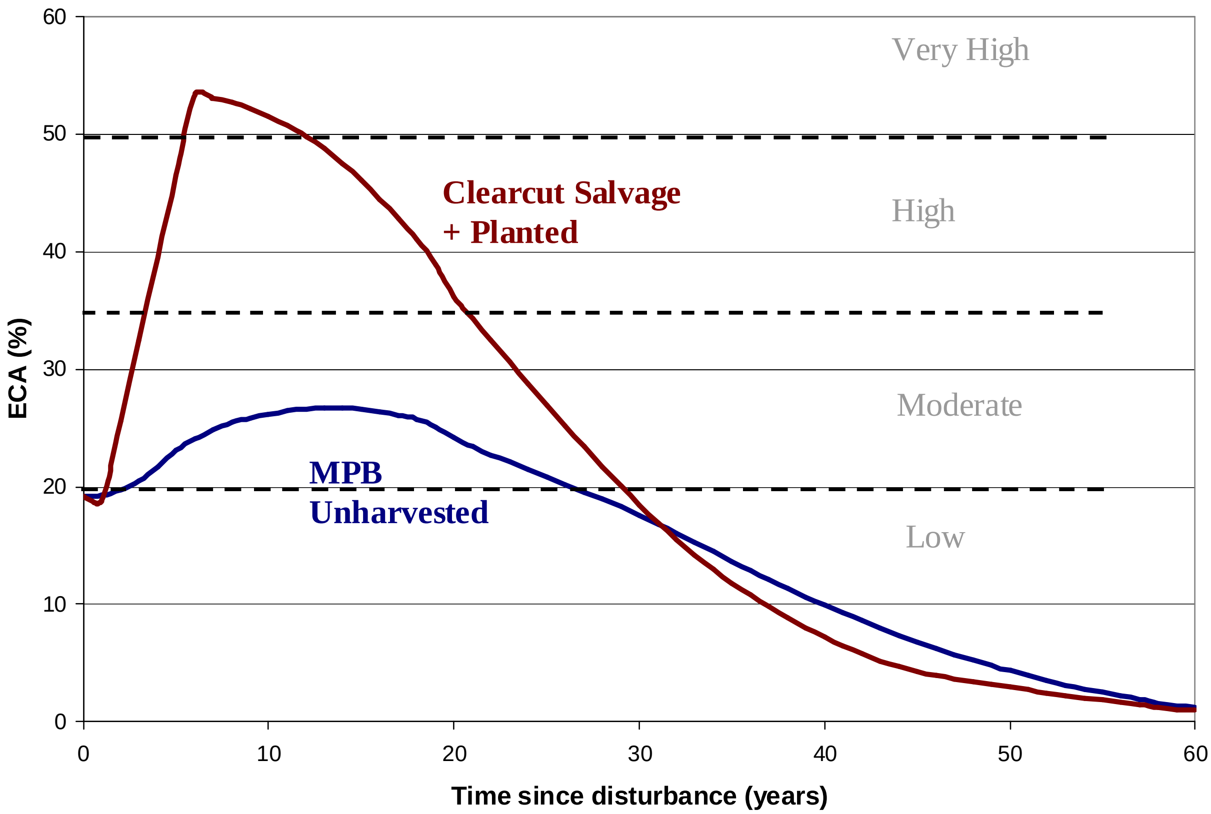

Figure 10. ECA hazard projections for Penticton Creek Watershed above H_{60} elevation, assuming full pine mortality from MPB infestation, full understory survival for unharvested MPB and no further harvesting (blue) and full salvage harvest of all pine-leading stands (brown).

In the “unharvested MPB” scenario (blue line) all pine trees in pine-leading stands are assumed to be 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 (brown 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.

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 10. 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.

In Figure 10, the sustained ECA hazard for the MPB/unharvested scenario is the 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. Similarly, the average position of the ECA curve for the hypothetical full pine-leading salvage scenario, relative to the MPB/unharvested curve, suggests there is a sustained High ECA hazard for 15-20 years. Within this time period significant ECA effects are considered 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 Greyback, Dennis Creek, Municipal Creek and Lower Penticton Residual sub-basins (See Figure 1). Results are summarized in Table 6.

Results for Municipal Creek and the Lower Penticton Residual sub-basins (above the watershed H_{60} elevation) were similar to those for the whole watershed. Post full salvage ECA values are High for 15 to 20 years and post unharvested MPB ECA values are Moderate for about 25 years.

Table 6. Penticton Creek and Sub-basin ECA Summary

Sub-basin Name	Area (ha)	% Total Watershed Area >H60	Current ECA	Maximum ECA (%)		Sustained ECA (%)	
				MPB	Full Salvage	MPB	Full Salvage
Greyback Lk	31860	30	19.7	23	65	L	VH
Dennis CK	9200	9	42.8	43	43	M	M
Municipal Ck	2691	23	19.9	25	48	M	H
Penticton Ck Watershed (at CoP intake)	149691	100	**19.1**	**27**	**53**	**M**	**H**

The Greyback Lake sub-basin shows mainly lower ECA values following the unharvested MPB scenario, but a longer period of High to Very High ECA values following the full salvage scenario (Figure 11). This is because there is a lot of unharvested ESSF type stands in Greyback sub-basin, which field plots showed have a lot of non-pine overstory in supposed pine-leading stands (see Figure 7), and a lot of post-MPB hydrologic function which will be removed when salvage harvested. This results in a low ECA following MPB attack of what pine there is, and a much higher ECA following salvage of the entire mixed pine and non-pine stands. The sustained ECA following the unharvested MPB scenario

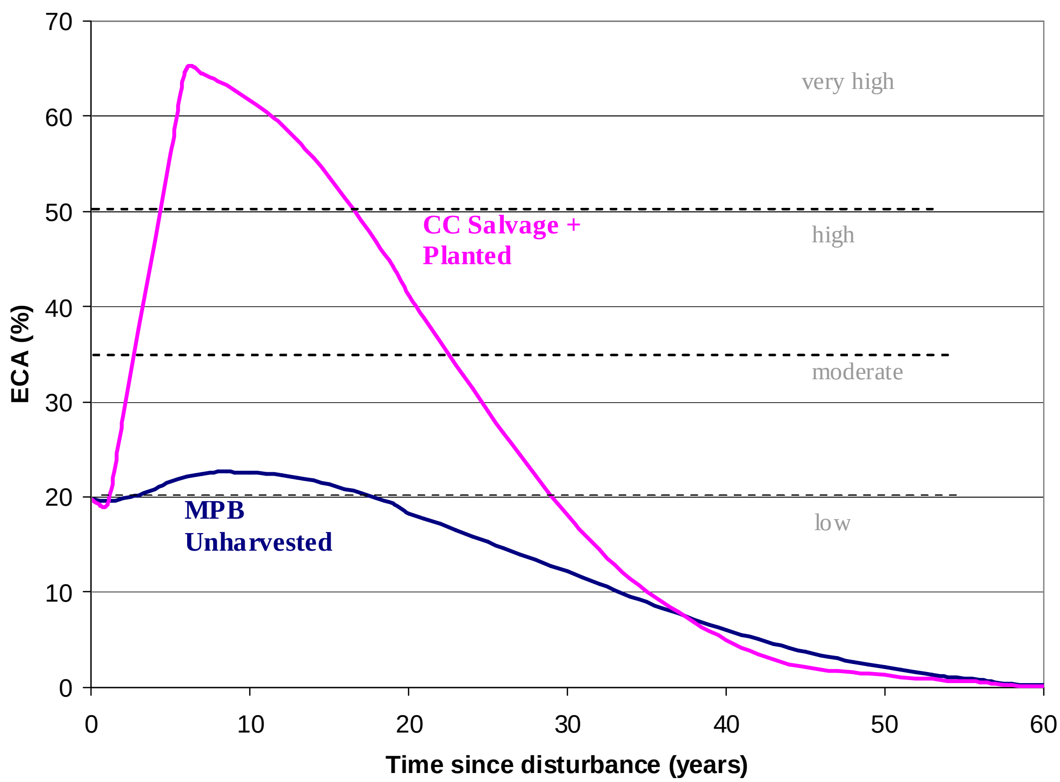

Figure 11. Greyback Lake sub-basin ECA. Post salvage ECA values are High to Very High for about 25 years. Post unharvested MPB attack ECA values remain predominantly Low.

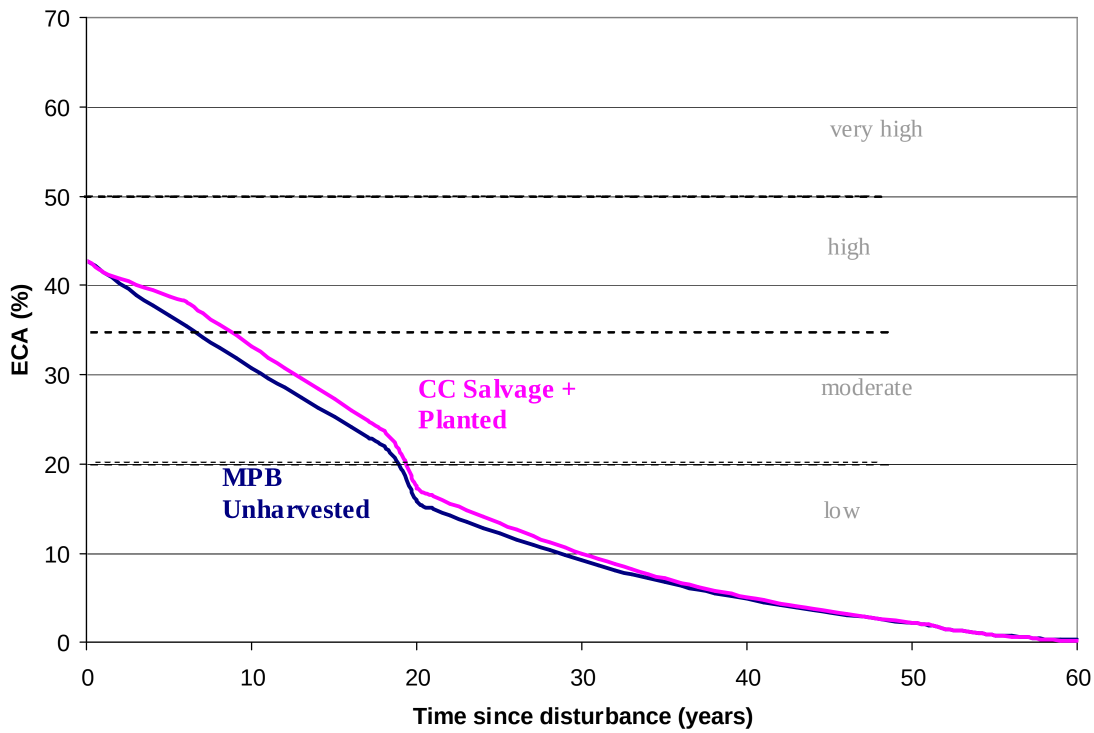

Figure 12. Dennis Creek sub-basin ECA. Current ECA values are High and in both management scenarios. ECA values continually decrease to Low in about 20 years. Due to past harvesting there is very little pine leading forest left to harvested in this sub-basin.

In Dennis Creek (Figure 12), almost all the pine-leading stands in the basin have been harvested; much in the mid to late 1990's and some in the lower watershed around 1980. There is virtually nothing left to salvage, so the ECA for both the unharvested and harvested scenarios are almost identical. Although the current ECA is high, having at least two harvesting entries has allowed some stands to begin to recover before the next entry. This has kept the ECA in Dennis Creek from reaching the Very High levels that result if a lot of pine-leading stands are harvested at once, as is the case in the hypothetical full salvage scenario in Greyback Lake sub-basin (Figure 11). Now in Dennis Creek sub-basin all stands are recovering and ECA continually decreases from its current High level to a Low ECA in about 20 years. The sustained ECA in Dennis Creek is predominantly Moderate for about 20 years, for both scenarios.

3.2.4 Flood frequency shift

ECA values describe changes in forest canopy closure that 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 (see Appendix E for a detailed discussion).

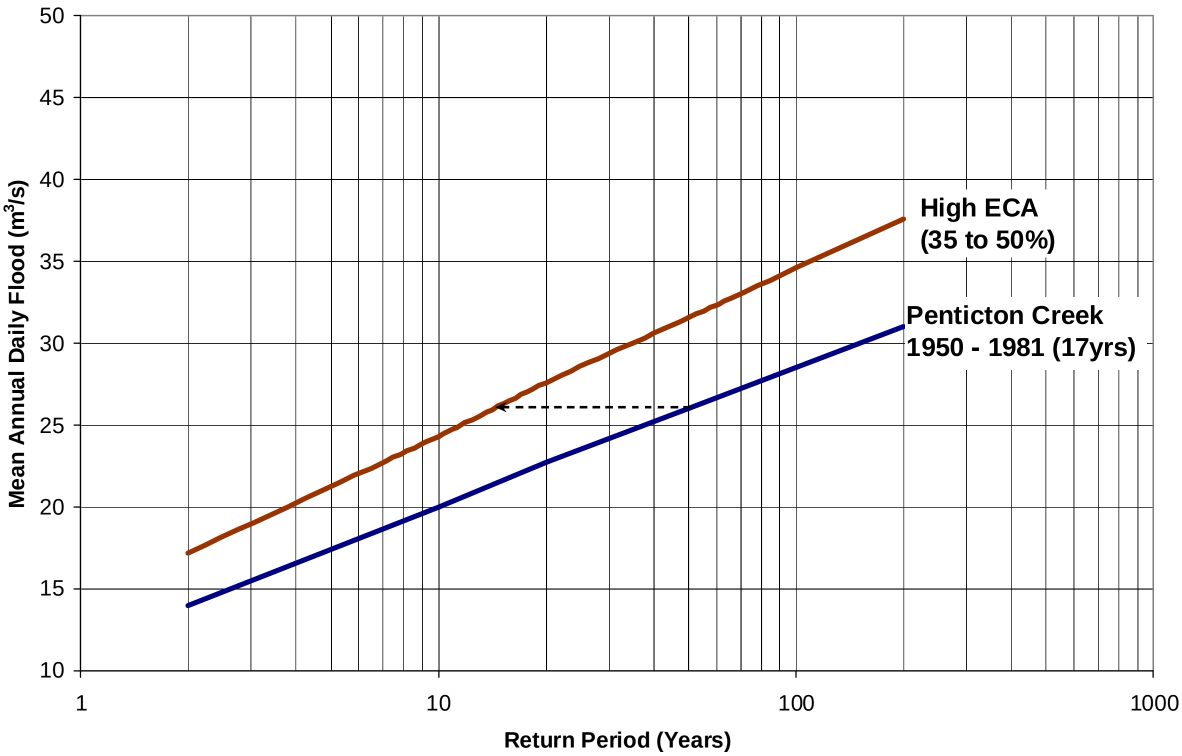

Figure 13. Estimated flood frequency shift (for hypothetical uncontrolled flood) in Penticton Creek with a sustained High ECA for 15 to 20 years following the complete harvest of pine-leading stands, based on the expected response of an average, uncontrolled mid-sized Okanagan Watershed.

Figure 13 shows that following the full salvage harvesting scenario the historic 50 year flood is expected to occur approximately every 15 years; and all other magnitude floods would similarly be expected to occur more frequently. This also means that if there is full salvage harvest of pine-leading stands, floods larger than have been experienced in recent times are more likely to occur. This flood frequency shift is expected to last for about 15 to 20 years. With a moderate ECA, such as that expected to last about 25 years after total MPB pine mortality and no further harvest, some increase in flood frequency, and shift in the flood frequency curve, may occur, but a significant flood frequency shift is not expected.

This is the flood frequency shift expected for an average uncontrolled Okanagan watershed with the modelled forest canopy (or ECA) changes shown. Section 3.3 looks at the specific characteristics of Penticton Ck watershed to determine if this expected flood frequency shift is reasonable, following particular management scenarios and the resultant change in forest canopy.

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 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 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 Penticton 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. 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

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
Greyback	Good	23	L	65	VH	VL	H
Dennis	Poor	43	M	43	M	M	M
Municipal	Poor	25	M	48	H	M	H
Penticton Creek Watershed (at CoP intake)	Moderate	27	M	53	H	**M**	**H**
Penticton Creek (below intake)	Moderate	27	M	53	H	M	H

Results

The two basins forming the Greyback reservoir are large enough to attenuate the flood peaks of the relatively small streams and drainage basins upstream of the reservoir. Early season runoff is likely used to fill up the reservoir in preparation for the dry season. When the reservoir is at full pool, peak flow attenuation will still occur to a lesser degree. Since flood peaks will be attenuated, the ECA hazard in Greyback sub-basin has been downgraded one level to give a Peak Flow hazard one hazard class lower than the ECA hazard.

Although Dennis and Municipal Creeks have high elevation lakes and wetlands, these are not extensive enough to diminish peak flows in those sub-basins. No peak hydrograph attenuation is anticipated in these tributaries and the listed peak flow hazard is a purely a reflection of the extent of expected MPB/salvage canopy loss (ECA) in the sub-basin.

Due to the cumulative effects of the three main storage reservoirs in the Penticton Creek watershed (Greyback, Campbell Mountain diversion and the reservoir at the intake) some attenuation of flood peaks in the lower system may occur. This will depend on whether the reservoirs are drawn down prior to peak flow season, and if any water is being diverted through the Campbell mountain pipeline during the peak flow period. Generally peak flows in Penticton Creek occur in May or June, before the normal irrigation season. It may be good management by the water purveyors to allow the typically more turbid peak flows to pass through the system and then fill the reservoirs on the declining limb of the spring hydrograph once water quality improves, in which case less reservoir attenuation will occur. A moderate potential for flood peak attenuation leaves the peak flow hazard unchanged from the ECA hazard.

Combining the mostly 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 mostly High to Very High (Dennis Creek is Moderate as little pine remains in the sub-basin). Combining this with the Moderate watershed attenuation potential, the post-salvage watershed Peak Flow hazard is High.

3.3.2 Hydrologic hazard

Hydrologic hazard represents the potential or likelihood of peak flow or sediment impacts to existing channels. 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 Penticton 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
Greyback	L	VL	H	VL	M
Dennis	L	M	M	L	L
Municipal	M	M	H	M	H
Penticton Watershed (at CoP intake)	M	M	H	M	H
Penticton Creek (below intake)	M	M	H	M	H

As discussed in Section 3.1.3, channel sensitivities are generally Low to Moderate in the Penticton 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 aggraded sections of Penticton Creek, and cause bank erosion in sections of Municipal Creek. Increased sediment movement and a decline in water quality at the CoP intake may result following 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 Penticton 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 Penticton 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 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, we reviewed the results of 24 paired-watershed and numerical modelling studies of the effects of forest disturbance (harvest, fire, MPB) on earlier peak flows (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. (2007) 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 Penticton 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 10) would be greater than the effect of the MPB mortality and 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 CoP water demand, supply and timing. Analyses of recent climate patterns suggest there will be less runoff. Rodenhuis et al.(2007) found that in nival Okanagan basins, annual mean streamflow decreased by -7 to -14% over the last 30 years. A decrease in water yield is predicted in Penticton Creek of 15% by 2050 and 30% by 2080. (EarthTech and Aqua, 2005). 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 in the Okanagan. 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 in Penticton Creek 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 Penticton 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 in the near future 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

Penticton Creek is a Community Watershed supplying drinking water to the City of Penticton (CoP). About 75 to 80% of Penticton Creek water withdrawals are for domestic use (residences, commercial, industry, institutional, parks and leakage) with the rest going to agricultural use. Penticton Creek providing on average 80 to 90% of the domestic water supply, with the rest coming from Okanagan Lake (EarthTech, 2005; 1997 to 2005 data). Penticton Creek also supplies about 80% of irrigation supplies, with the rest coming from Ellis Creek. Greyback Lake Reservoir at 1588m elevation in the upper watershed is the only significant operating storage. Irrigation withdrawals from Penticton Creek are through a 3 kilometre diversion tunnel through Campbell Mountain from a small reservoir at 584m elevation. There is also a small reservoir at 471m elevation for domestic withdrawals at the Penticton Water Treatment Plant.

In 1986 in Penticton there was a Giardiasis (Beaver Fever) outbreak linked to Penticton Creek water with more than 300 confirmed cases. Subsequently the City constructed an advanced water treatment system consisting of coagulation, flocculation, sedimentation, filtration and disinfection, with the dual sources of Okanagan Lake and Penticton Creek. Water for irrigation diverted through Campbell Mountain is not treated prior to use by local farms and orchards located north of the city.

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 CoP intake, and does not consider the vulnerability of the CoP water supply and treatment system. Those unspecified impacts at the CoP water intake are considered the consequence in the partial risk analysis completed below.

4.2 WATER SUPPLY

It appears that in recent years actual withdrawals from Penticton Creek have been substantially less than the available licensed capacity (EarthTech, 2005). The large storage capacity of the Greyback Lake Reservoir and water availability from Ellis Creek lead EarthTech (2005) to conclude that the long term water supply appears secure for the City of Penticton for the foreseeable future both from the source capacity and licensing aspects. 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) in the headwater tributaries and lakes. Kokanee (Oncorhynchus nerka) has been identified in the lower reach of Penticton Creek. Penticton 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 14 summarizes fish habitat consequence ratings for each macro-reach. In general, fish habitat is widespread through the watershed, mostly due to the presence of lakes at the headwaters of each stream. A Very High fish habitat consequence rating has been assigned to Reach 1 of Penticton Creek below the intake due to the seasonal presence of kokanee from Okanagan Lake. Fish ladders have been installed to permit fish passage around channel stabilization structures in Reach 1.

Upstream of the intake, High fish habitat consequence ratings have been assigned for most mainstem channels and low gradient tributary channels reaches with headwater 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 Penticton Creek watershed above the City of Penticton are relatively few. One privately held water license exists on Penticton Creek below the CoP intake. Privately held water licenses for domestic and irrigation use exist on several tributaries in the Residual sub-basin, including Ker Creek, Luke Creek, Kerluke Creek, Selinger Creek and Steward Creek.

Only one crossing of Penticton Creek exists between the CoP intake and Greyback Lake. This is a forestry road crossing near the Dennis Creek confluence, approximately 1 km downstream of the Greyback Lake dam. Numerous forestry road crossings also can be found on tributaries in the watershed, mostly on the east side of the valley. Detailed inspections and analyses of existing forestry road crossings were not conducted. However, it is unlikely earlier or recently constructed crossings were designed to accommodate the potentially increased hillslope runoff following MPB attack and salvage harvesting. Where existing or proposed forest roads are on steeper slopes or within several hundred metres of steep-walled streams incised into the plateau, inadequate road drainage structures could lead to drainage redirection and landslides.

Penticton Creek below the intake passes through the middle of the City of Penticton. Through the main part of town, the creek has been channelized into a stepped floodway, with rock and concrete gradient controls/drop structures. The banks have either been rock armoured or concrete-lined (Photos 8 and 9). Numerous roadway and pedestrian crossings exist along the channel as it heads toward the south end of Okanagan Lake. This artificial channel is likely insensitive to minor changes in peak flow, assuming it has been designed to some excess capacity and is maintained in good condition. Failure of any part of this channel could have significant consequences in the adjacent high density developments.

Some aggradation is apparent in the upper section of Reach 1 along Penticton Avenue. This may be the result of grade controls installed in the channel. Material dredged from the channel has been piled alongside the creek (Photo 8).

Table 9 outlines the assumptions used to develop infrastructure vulnerability. There was no comprehensive review of individual urban or forest road crossings, etc.

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).	Few existing licenses relatively high up on tributaries. Intakes are often 'home-made' and unable to withstand flooding/debris impact. Private intakes will have no provision for filtering of suspended fines.	**M**
Forestry Roads	Increased peak flows, increased scour, increased debris movement. Drainage redirection on plateau roads and gentle-over-steep landslides on steeper stream sidewalls.	Only one crossing of the mainstem channel. Most FSR crossings on small creeks on the plateau. Landslides on stream escarpment below roads and cutblocks.	**M**
Urban Development on Fan	Increased peak flows, increased sediment leading to local aggradation.	Numerous road and footbridge crossings. Some sediment stored in aggraded area downstream of intake. Channel liner and bank protection is aging and may require maintenance. Channel failure has the potential to do extensive damage to adjacent residential and commercial areas.	**M**

5.0 RISK ANALYSIS

5.1 WATER QUALITY AND INFRASTRUCTURE

Table 10 summarizes the partial risk analysis for water quality at the CoP water intake. The hydrologic hazard, which includes both incremental peak flow, channel erosion and sediment hazards is from Table 8.

Table 10. Partial risk analysis for CoP water intake.

Reach	Hydrologic Hazard (peak flow and sediment)		Water Quality Element at Risk: CoP Water Intake		**Partial Risk**	
	MPB	Full Salvage	Fine sediment impacts	Coarse sediment impacts	**MPB**	**Full Salvage**
Penticton 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 CoP 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 CoP 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 Penticton 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 in Penticton Creek 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 harvesting-related risk to water supplies in Penticton Creek is considered Low.

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. Although some high value fish habitat exists in larger tributaries, risks in the Penticton Residual sub-basin represent risks to habitat values along the Penticton 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
Greyback Lake	VL	M	H	**L**	**H**
Dennis Creek	L	L	H	**M**	**M**
Municipal Creek	M	H	M	**M**	**H**
Penticton Residual (above intake)	M	H	H	**H**	**VH**
Penticton Creek (below intake)	M	H	VH	**VH**	**VH**

Following the MPB/unharvested scenario risks to fish habitat in the lower watershed above the intake are potentially High, and downstream of the CoP intake risks are Very High because the mainstem consequence ratings are High to Very High and even the possibility of negative impacts yields a High potential risk. Under the full salvage harvest scenario risks in the lower mainstem are Very High, both above and below the intake. 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 (next page).

Risks to private water licenses are Moderate to High following the Unharvested MPB and full harvest scenarios respectively, as a result of inferred sensitivity of these installations to increases in fine sediment. Most private water intakes operate without filtering or disinfection.

Risks to forestry road crossings will be variable as they are mostly at higher elevations on plateau on tributaries where local hydrological hazards will depend on local harvest levels. Risks to forestry roads may result if existing culverts and bridges have no excess capacity during peak flows.

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	M	M	H	**M**	**H**
Forestry Roads and road-related landslides.	M	M	H	**M**	**H**
Urban Development on Fan	M	M	H	**M**	**H**

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. This could lead to significant drainage diversions, which, if they occur near steeper stream escarpments could initiate large landslides that could directly impact downslope streams, similar to Landslides 1 and 2 on the Penticiton Creek mainstem (See Section 3.1.1).

Risks to residences on the fan have been rated as Moderate under MPB and High under the full salvage scenario. Actual risks will depend on the original design capacity of the channel system and maintenance of its features. Mobilization of existing sediment and aggradation could reduce channel capacity on parts of the fan. This combined with higher peak flows due to the full salvage scenario could result in overtopping of the artificial channel and damage to private property.

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The water quality parameters most strongly linked to MPB infestation and salvage logging in Penticton 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 Penticton Creek watershed there is a Moderate Risk, which means some increase in peak flows and fine and coarse sediment delivery to the CoP intake may occur, but a significant increase is not considered likely. 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 CoP intake is likely to occur. Source water turbidity levels have been and will continue to present a problem at the CoP water intake, in terms of meeting Interior Health Authority water quality guidelines. MPB mortality alone may not result in a noticeable increase in turbidity, but high salvage harvest levels will likely exacerbate turbidity problems. 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 Penticton Creek are not expected.

Reservoir storage in Penticton Creek will mitigate both MPB and salvage-related freshet timing change effects on reservoir withdrawal timing and growing season low flows and it is considered unlikely that significant effects will occur following either management scenario. 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.

There are fish present and high habitat values in most of the sub-basins and in the Penticton Creek mainstem. There is a High Risk of negative impacts following MPB-related pine mortality in the lower Penticton Residual mainstem, and a Very High risk in Penticton Creek on its fan through the City of Penticton. Risks are 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 High in much of the upper watershed and Very High in much of the Penticton Creek mainstem.

All social infrastructure risk values are higher 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 Penticton Creek watershed snow zone. Risks to private water intakes in the watershed, forestry roads and road-related "gentle-over-steep" landslides and urban developments on the Penticton Creek fan are considered Moderate following the unharvested MPB scenario and High following the full salvage scenario.

6.2 RISK MITIGATION

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

6.2.1 Forests for Tomorrow Activities

The Forests 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 Penticton Creek, as discussed in this report.

6.2.2 Risk Mitigation Recommendations

Riparian Management

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

Fish Habitat Management

Maintaining good riparian condition and instream LWD throughout the watershed will help to mitigate potential impacts on fish habitat. There are High risks to fish habitat following unharvested MPB-attack and while we don't know what level of harvesting will occur in the watershed, a significant harvest level could increase those risks. It would be prudent to periodically update on-site fish habitat assessments (last done in the mid-1990's), monitor channel and riparian conditions and carry out rehabilitation activities as necessary.

Forest Road Drainage Management

Some large landslides of uncertain origin have occurred in the watershed in the past (see Section 3.1.1). In all cases they occurred on steeper stream valley walls and escarpments where tributary and mainstem streams are incised into flat to gentle sloping upland plateaus, with upslope forest roads and harvesting. While not widespread, they are thought to have affected the sediment regime in Penticton Creek mainstem; and indicate that some steeper stream escarpment slopes are only marginally stable and will fail if disturbed. In Southern Interior B.C. the most common forest development-related disturbance resulting in landslides is interception, concentration and redirection of surface and/or subsurface hillslope drainage, by roads and trails located on gentle gradient slopes, onto moderately steep (50-70%) to steep (>70%) gradient slopes, not previously subject to concentrated water flows. (Jordan 2002, Grainger 2002). This results in landslides on the steeper slopes and the process is known as "gentle-over-over steep" (GoS) landslides. In any area where significant salvage harvesting is planned, a review of trail and road drainage structures (ditches, ditch blocks, culverts, cross-ditches, bridges, etc.) located within 400m of steeper stream escarpment slopes is recommended. Any structure which appears to be operating near its capacity, to be damaged or otherwise compromised so that it is not working at its design capacity, or is otherwise insufficient to accommodate some increase over historic flows, should be upgraded to accommodate larger flows. Reviews and drainage plans designs should be carried out by a geotechnical professional with expertise in mitigating GoS landslides.

Stand and Watershed ECA Hazard Management

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

ECA hazards are higher for almost all watershed values following the full salvage harvest scenario. Therefore incremental risks are higher for all elements at risk in the watershed following the hypothetical scenario of full salvage harvest of all pine-leading stands, compared to the potential risks if all pine-leading stands were left unharvested. To reduce those risks to an acceptable level will require managing the amount and location of salvage harvesting in the watershed.

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

- licensees use a hydrological risk assessment methodology that models the effects of pine and non-pine overstory and understory stand structure in dead pine stands to get a more accurate picture of the hydrological condition of the watershed, and of the potential impacts of proposed salvage harvesting. Hydrological risk analyses that treat all MPB attacked stands as having little or no hydrological forest function (i.e., as having initial ECA values similar to clearcuts) may seriously underestimate the incremental hydrological risks associated with widespread clearcutting of attacked stand that have hydrologically significant stand characteristics.

- From a strictly hydrological perspective (and we recognize forest managers have to balance many different forest values), the least hydrological impact would result if pine-leading stands with the lowest non-pine overstory component and lowest understory stocking were preferentially targeted for salvage harvest. From the data collected here the stands in the snow zone with least hydrological function would be younger MSdm stands followed by older MSdm stands and then ESSFdc stands (see Figures 7-9 and Appendix B).

- We recognize that individual stands within broader biogeoclimatic types will have different characteristics than the average overstory and understory values used in this analysis; site specific surveys of stand characteristics in areas proposed for harvesting are recommended. Salvage harvesting should be focused on those stands with the least non-pine overstory and little healthy understory.

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

7.0 CLOSURE

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

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

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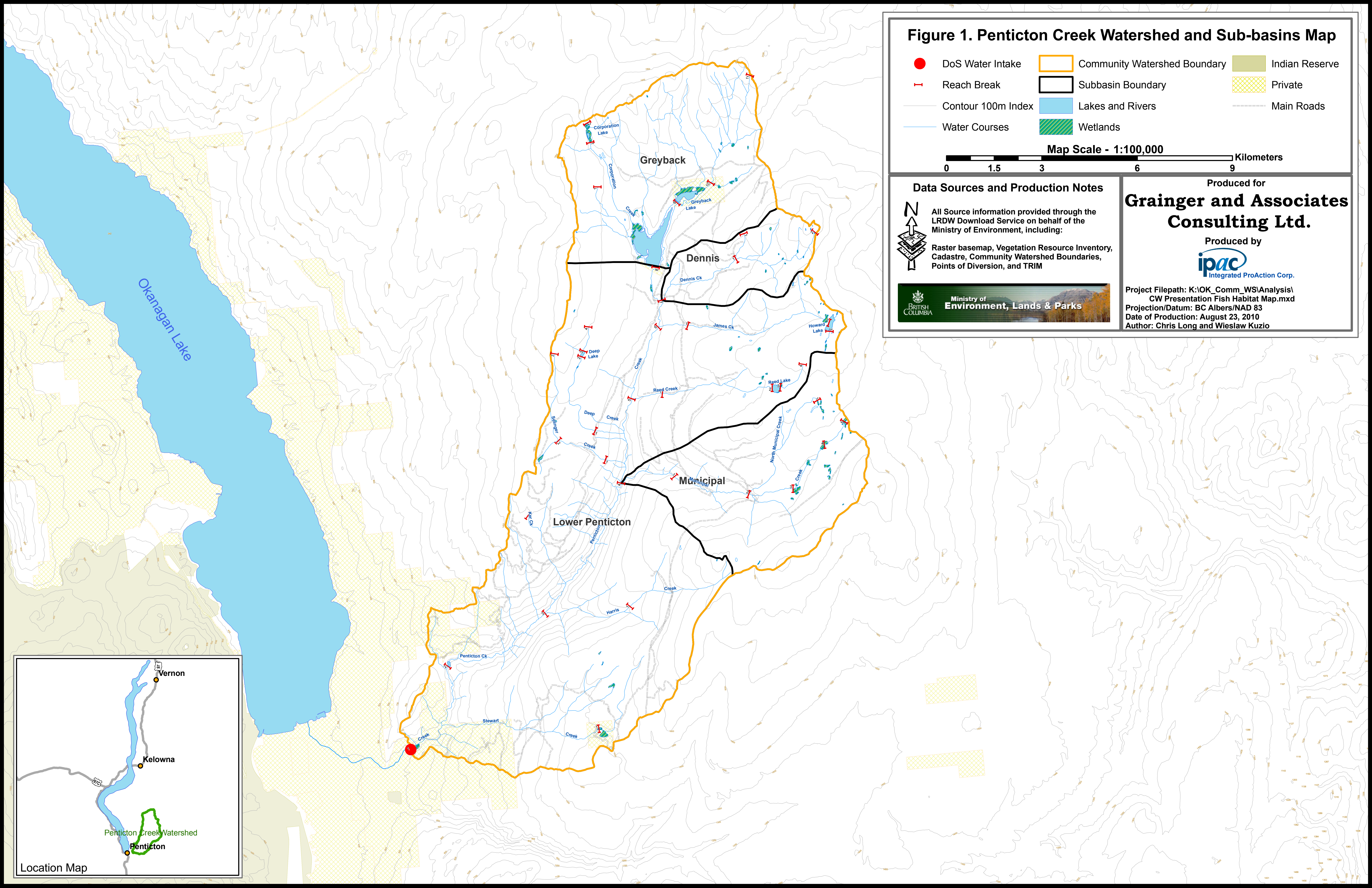
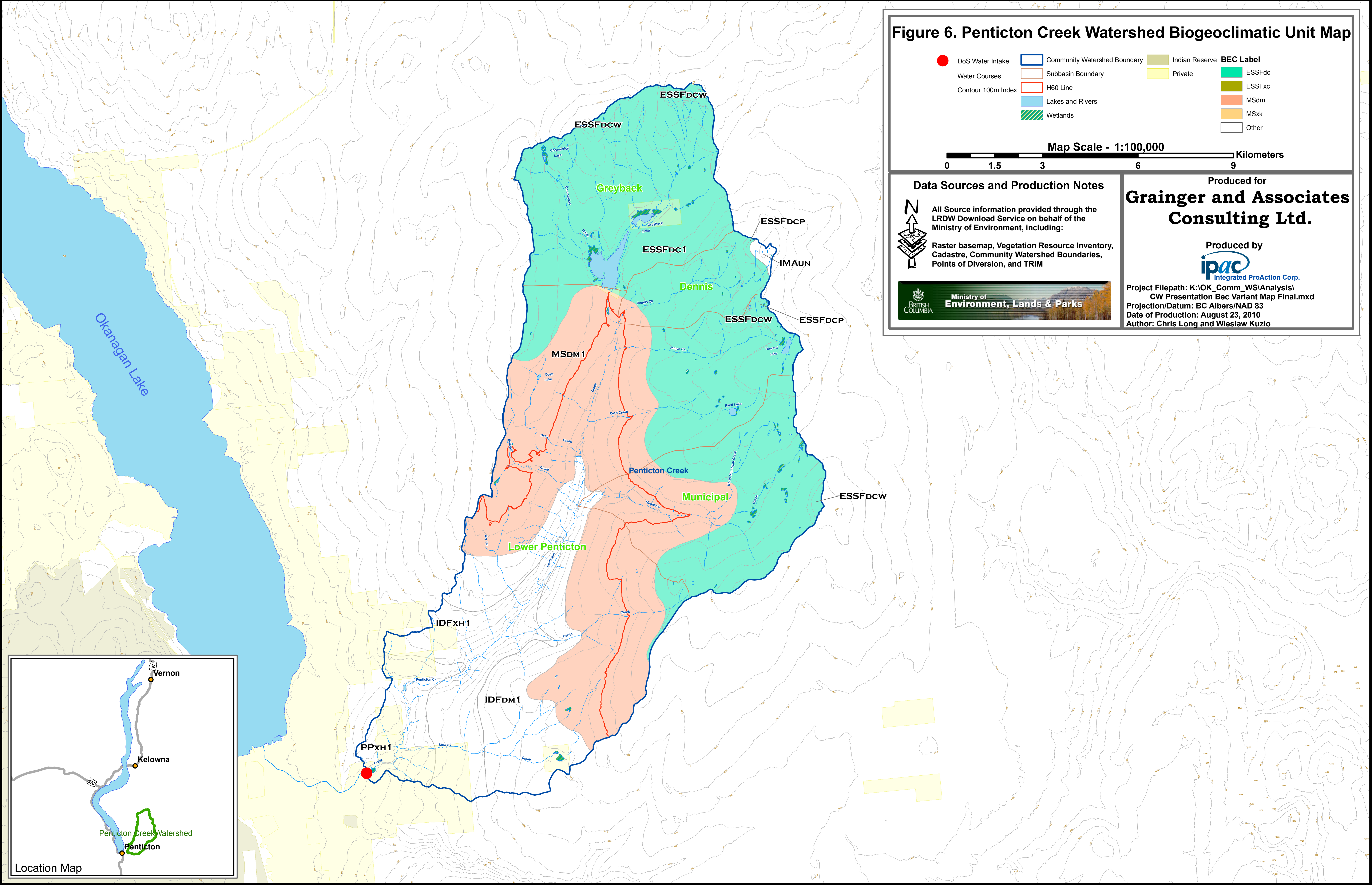


Figure 1. Penticton Creek Watershed and Sub-basins Map
DoS Water Intake
Reach Break
Contour 100m Index
Water Courses
Community Watershed Boundary
Subbasin Boundary
Lakes and Rivers
Wetlands
Indian Reserve
Private
Main Roads
Map Scale - 1:100,000
0
1.5
3
6
9
Kilometers
Data Sources and Production Notes
N
All Source information provided through the LRDW Download Service on behalf of the Ministry of Environment, including:
Raster basemap, Vegetation Resource Inventory, Cadastre, Community Watershed Boundaries, Points of Diversion, and TRIM
British Columbia
Ministry of Environment, Lands & Parks
Produced for
Grainger and Associates Consulting Ltd.
Produced by
ipac
Integrated ProAction Corp.
Project Filepath: K:\OK_Comm_WS\Analysis\ CW Presentation Fish Habitat Map.mxd
Projection/Datum: BC Albers/NAD 83
Date of Production: August 23, 2010
Author: Chris Long and Wieslaw Kuzio
Okanagan Lake
Greyback
Dennis
Municipal
Lower Penticton
Corporation Lake
Corporation Creek
Greyback Lake
Dennis Ck
James Ck
Howard Lake
Deep Lake
Deep Creek
Reed Creek
Reed Lake
North Municipal Creek
Creek
Municipal
Stellinger Creek
Ker Ck
Penticton
Harris
Penticton Ck
Stewart
Creek
Location Map
Vernon
Kelowna
Penticton
Penticton Creek Watershed
97
97C

Figure 6. Penticton Creek Watershed Biogeoclimatic Unit Map



Data Sources and Production Notes

All Source information provided through the LRDW Download Service on behalf of the Ministry of Environment, including:

Raster basemap, Vegetation Resource Inventory, Cadastre, Community Watershed Boundaries, Points of Diversion, and TRIM

British Columbia Ministry of Environment, Lands & Parks

Produced for

Grainger and Associates Consulting Ltd.

Produced by

ipac Integrated ProAction Corp.

Project Filepath: K:\OK_Comm_WS\Analysis\ CW Presentation Bec Variant Map Final.mxd
Projection/Datum: BC Albers/NAD 83
Date of Production: August 23, 2010
Author: Chris Long and Wieslaw Kuzio

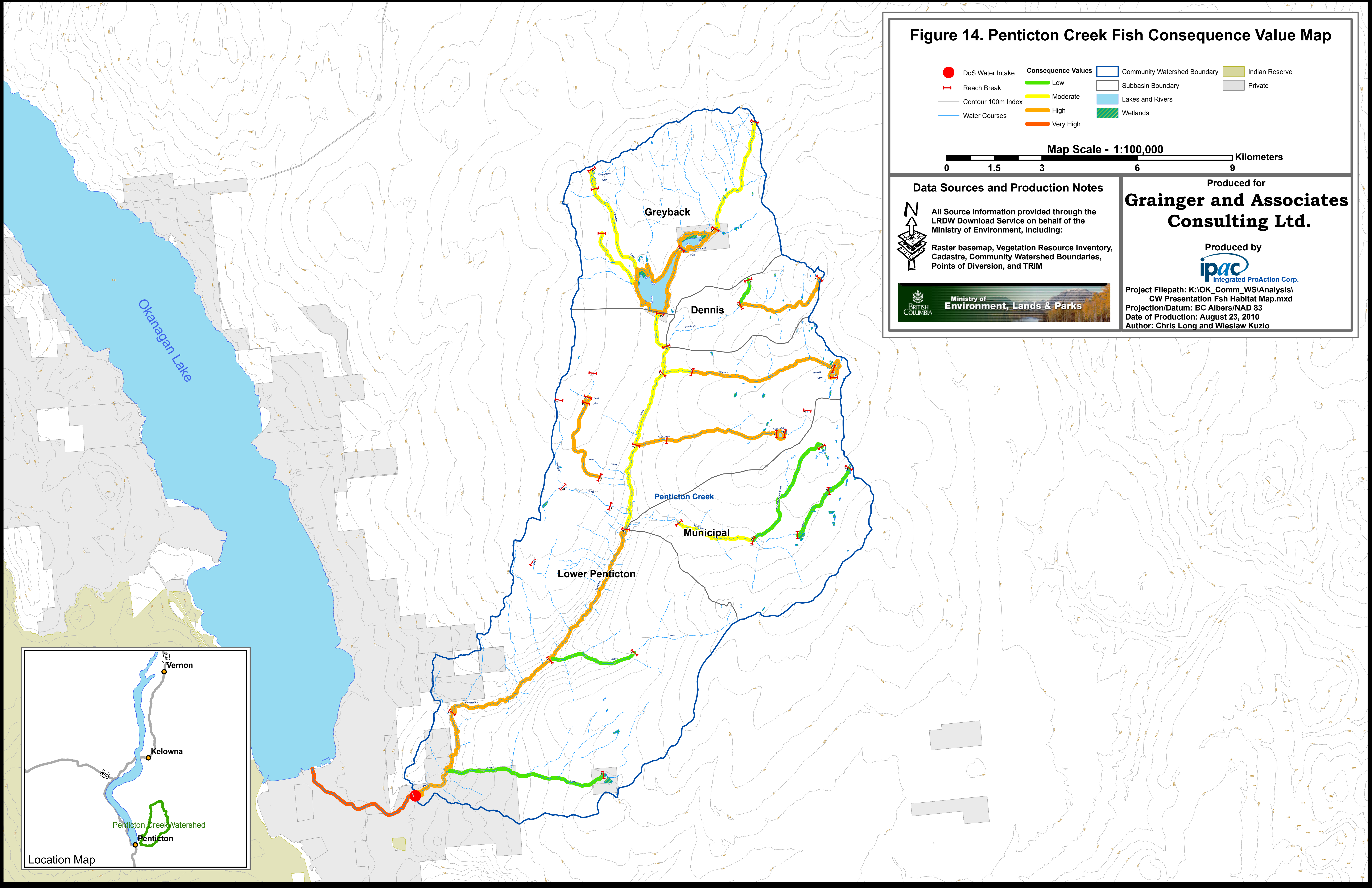


Figure 14. Penticton Creek Fish Consequence Value Map

PHOTOS

Photo 1. Broad gently sloping upland plateau of Penticton Creek with Greyback Lake Reservoir.

Photo 2. Incision of Penticton Creek mainstem into upland plateau, with moderately steep to steep escarpment slopes.

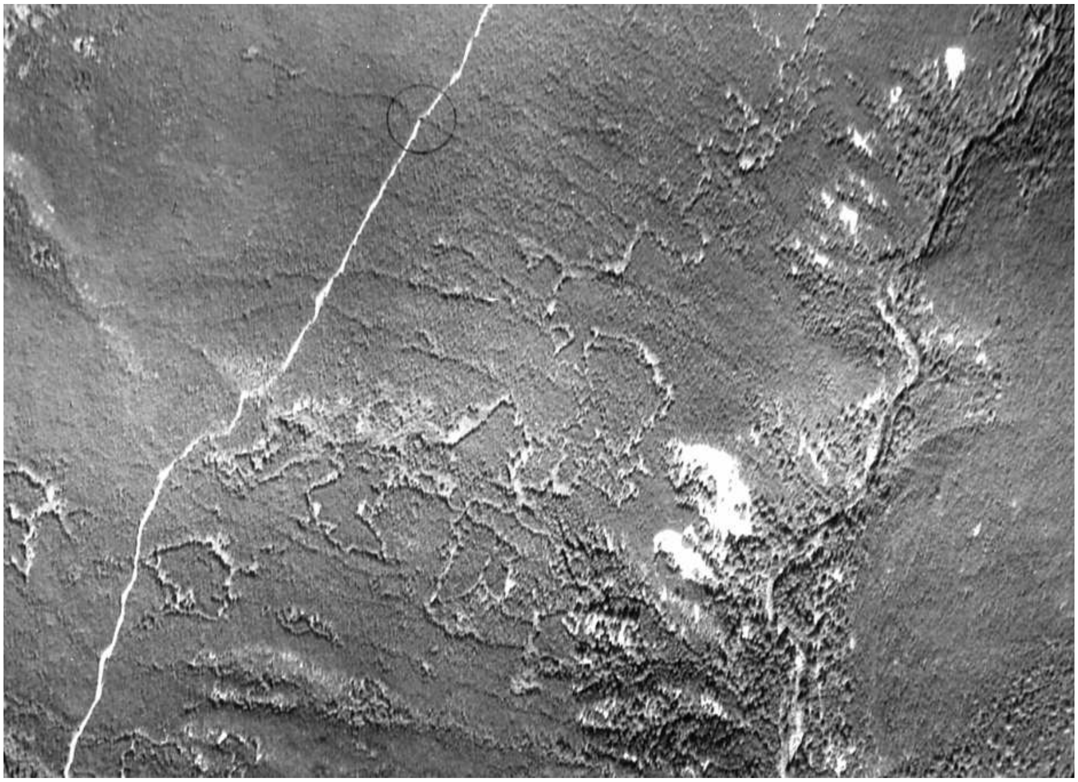


Photo 3. Group of slope failures forming Landslide 1 on west Penticton Creek escarpment, between Reed and Municipal Creek in 1938 air photo (BC106:81). Note several smaller slope failures upstream, and aggraded (bright) mainstem starting just downstream of those landslides.

Photo 4. Google image of Landslide 1 from 2004 photography; still contributing some sediment to Penticton Creek mainstem. Smaller upstream slides are largely revegetated.

Photo 5. Eroding bedrock escarpment in lower Penticton Creek.

Photo 6. Penticton Creek channel avulsion on narrow floodplain in deeply incised reach upstream of Campbell Mountain Irrigation diversion reservoir. Note bedrock control on left bank.

Photo 7. Intake reservoir for Campbell Mtn. irrigation diversion on Penticton Creek mainstem, largely emptied for maintenance and likely for removal of accumulated sediment from behind dam, which is stored to right of stream.

Photo 8. Channelized Penticton Creek on fan. Note dredged sediment stored on left bank.

Photo 9. Concrete grade controls and channelization on the Penticton Creek fan.

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, PhD.

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

Notes: MSdm <90% pine, 70-90yrs also included 63 Fd poles/ha, with 50/ha well-spaced
A few cedars and aspens (not shown) occurred in the understory at a few sites.
WS = well-spaced

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

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

Poles+Saplings total density (no Pl poles)

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

Note: WS = well-spaced

Plot-level stocking distribution

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

With all understory trees, or all saplings+poles, the majority of ESSF stands are stocked to the highest levels examined (1600 sph; Table 7). Over half of the plots in ESSF stand types are stocked to 1000 sph with well-spaced trees[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						Percent of plots with understory density >= specified SPH							
Study	**BEC**	**Pine (%)**	**Age (yr)**	**Plots**	**Layers**	**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						Percent of plots with understory density >= specified SPH							
Study	**BEC**	**Pine (%)**	**Age (yr)**	**Plots**	**Layers**	**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.

Alteration	Channel Sensitivity Rating (H, M, L)	Channel Attributes that May Contribute to Channel Sensitivity
Increased Peak Discharge and/or Flood Frequency	Low	▪ 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.
	Moderate	▪ Range or combination of attributes listed above and below.
	High	▪ 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.
Increased Sediment Delivery [Fine suspended and Coarse bedload sediment should be considered separately]	Low	▪ 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).
	Moderate	▪ Range or combination of attributes listed above and below.
	High	▪ 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.
Decreased Riparian Function	Low	▪ 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.
	Moderate	▪ Range or combination of attributes listed above and below.
	High	▪ 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.

Appendix D:

Penticton Creek Fish Values by Reach

Prepared by Michele Trumbley, R.P. Bio.

Trumbley Environmental Consulting Limited

Attn: Bill Grainger, P.Geo. March 31, 2009
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RE: Fisheries Information on the Penticton Creek Watershed as one of Seven Identified Okanagan Community Watersheds

PENTICTON CREEK

The Penticton Creek watershed is situated on the south shore of Okanagan Lake in the city of Penticton. Penticton Creek mainstem (WSC[1] 310-630100) flows into Okanagan Lake. For the purposes of this project, the watershed has been delineated into 4 sub-basins including Penticton Residual, Municipal Creek, Dennis Creek and Greyback Lake Sub-basins. Reach one is situated outside of the study area however was considered due to the effects of upstream activities. 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*) in the headwater tributaries and lakes. Kokanee (*Oncorhynchus nerka*) has been identified in the lower reach of Penticton Creek.

OBSTRUCTIONS

Obstructions to upstream fish migration include a 35m cascade chute in reach 6 of Penticton Creek (UTM 11 324432 5497134). In reach 1 of Reed Creek a 55m cascade chute as well as a 1.6m and 1.9m falls is documented at UTM 11 232820 5495559. Within reach 2 of Dennis Creek a 0.3m dam is located at UTM 11 327122 5499264, which may be a partial barrier to fish migration. There is a 12.9m cascade chute located at UTM 11 327122 5499264 on an unnamed tributary to Dennis Creek (WSC 310-6330100-73800). A 52m cascade/chute (11 323742 5501389) was documented reach 1 of an unnamed tributary to Greyback Lake (WSC 310-630100-79446).

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

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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 Penticton Watershed is largely unknown. The sub-basins were delineated into macro-reaches which were used to target sensitive areas (Table 2). Therefore mitigation strategies can be developed in target areas where negative impacts are probable.

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

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

Stream Name	WSC	Reach	Average Channel Width (m)	Gradient (%)	Species Present	Habitat Quality	Consequence Rating
Penticton Creek	310-630100	1	9.6	1	RB,EB, KO,	Documented KO spawning habitat in reach 1	**VH-**Presence of KO, RB, EB.
Penticton Creek	310-630100	2	11.5	2	RB,EB	.A 2.5m dam is located at the outflow of the reservoir which may restrict the migration of fish into reach 2.	**H** -Presence of RB, EB, rearing and staging habitat.
Penticton Creek	310-630100	3	11.5	2	RB, EB	A 4m dam at the reach 2 break may restrict the migration of fish into reach 3	**H-** presence of RB and EB.
Penticton Creek	310-630100	4	5-15	5-10	RB, EB	Fish habitat value is unknown	**H-** presence of RB and EB.
Penticton Creek	310-630100	6	1.38	13	RB, EB	NFC 35m cascade/chute at 11 324432 5497134 Site 9. RB and EB are present upstream of the cascade, therefore RB and EB would be able to access the reach.	**M-** presence of RB and EB, however there is barriers to the upstream migration of fish.
Greyback Lake/ Penticton Reservoir	01216OKAN, 01217OKAN	9	N/A	N/A	RB stocked 1971 to 2008	Overwintering and rearing habitat potential, max depth of 4.5m	**H-** overwintering and rearing potential.
Stewart Creek	310-630100-18500	1	2.8	13-22	(RB, EB)	Poor staging and overwintering habitat, bank erosion	**L**- suspected RB in lower reach, steep gradient
Harris Creek	310-630100-38200	1	6.0	9	NFC	Site 1, (RB) in lower 400 m of reach 1, several cascades may be barrier to fish	**L-** no fish were captured, fish absence has not be confirmed.

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Table 2 – Penticton Creek Watershed Consequence Rating

Stream Name	WSC	Reach	Average Channel Width (m)	Gradient (%)	Species Present	Habitat Quality	Consequence Rating
Ker Creek	310-630100-41600	1	3.0	66 (TRIM)	NF	Steep gradient in lower reach, destabilized bank	**VL**- steep gradients and is defaulted non fish bearing.
Municipal Creek	310-630100 53600	2	5.7	6	(RB, EB)	0.8 log jam at 11 326052 5492315. Site 2, moderate habitat quality	**M-** suspected fish presence, with low channel gradients.
Municipal Creek	310-630100 53600	4	5.4	6	NFC	Site 3	**L-** no fish were captured limited upstream habitat, series of wetlands.
Municipal Creek	310-630100 53600	9	2.6	6	NFC	Site 4	**L-** no fish were captured limited upstream habitat, series of wetlands.
Tributary to Municipal Creek	310-630100-53600-51200	1	3.92	6	NFC	Site 5	**L-** no fish were captured limited upstream habitat, series of wetlands.
Selinger Creek	310-630100-55800	1	N/A	40	NFC	Steep gradient	**VL**- defaulted fish absence due to steep gradients.
Selinger Creek	310-630100-55800	2	3.9	9	NFC	Site 6, poor staging habitat	**VL**- defaulted fish absence due to steep gradients downstream.
Deep Creek	310-630100-59800	2	2.35	11	RB	Site 7, self sustaining fishery in Deep Lake	**H-**confirmed presence of RB, the tributary is lake headed.
Deep Lake	01248OKAN	3	N/A	N/A	RB	Self sustaining fishery, natural reproduction	**H**- over wintering habitat.

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Table 2 – Penticton Creek Watershed Consequence Rating

Stream Name	WSC	Reach	Average Channel Width (m)	Gradient (%)	Species Present	Habitat Quality	Consequence Rating
Reed Creek	310-630100-62800	1	7.45	15	NFC (EB, RB) Lake headed.	55m cascade/chute, 1.6m falls and 1.9m falls at 11 232820 5495559. Site 8	**H**- tributary is lake headed, downstream migration of RB, EB.
Reed Lake	01258OKAN	3	N/A	N/A	Stocked with EB & RB	Contains RB and EB in Reed Lake	**H –** Overwintering and staging habitat for Reed creek.
James Creek	310-630100-70800	1	1.85	>20	RB	Site 10, Lake headed, a 25m falls is located at the confluence	**M-** RB confirmed, small channel widths, lake headed.
James Creek	310-630100-70800	2	5.23	7	RB	Site 11, lake headed	**H-** proximity to Howard Lake.
Howard Lake	01247OKAN	3	N/A	N/A	Stocked with RB to 1962-1982, resident RB	Potential overwintering and rearing habitat	**H**- fish presence confirmed, overwintering and staging habitat for James Creek.
Dennis Creek	310-630100-73800	2	3.22	9	RB in 1999	0.3m dam at 11 327122 5499264. Site 12	**H**- RB present, proximity to Penticton Creek
Tributary to Dennis Creek	310-630100-73800-81044	1	1.33	9	NFC	12.9m cascade/chute at 11 327564 5499556. Site 13, dry at time of sampling	**L**- cascade is located upstream of the confluence with Dennis Creek, may prevent the upstream migration of fish.
Greyback Lake	01216OKAN	9	N/A	N/A	RB	Overwintering and rearing potential	**H-** provides overwintering habitat.
Greyback Lake	01217OKAN	10	N/A	N/A	RB	Marsh upstream Greyback Lake	**H-** provides rearing habitat.

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Table 2 – Penticton Creek Watershed Consequence Rating

Stream Name	WSC	Reach	Average Channel Width (m)	Gradient (%)	Species Present	Habitat Quality	Consequence Rating
Tributary to Greyback Lake	310-630100-79446	1	1.21	1	NFC (RB) downstream of cascade/chute	52m cascade/chute at 11 323742 5501389. Site 14	**M**- fish presence not confirmed above the cascade chute. The lower reaches of the tributary may provide habitat to RB in Greyback lake.
Corporation Creek	310-630100-79800	1	3.22	14	Stocked with RB 1971 & 1975 RB captured in 1999	Site 15, grass marsh with no discernable channel	**M-** RB present and the tributary is lake headed**.**
Corporation Lake	01207OKAN	2	N/A	N/A	Stocked with RB	Average depth of 4.5m, documented as unmanageable	**M**- provides rearing habitat.
Tributary to Penticton Creek	310-630100-88357	11	1.57	5	RB	Site 16, good staging habitat	**M**- fish presence assumed. Tributary is upstream of Greyback Lake.

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

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MITIGATION STRATEGIES

Mitigations to maintain fish presence is often difficult to determine. The impacts of MPB will ultimately reduce riparian cover. The dynamics of stream ecosystems are dependent on the presence of intact multi stage riparian zones. The LWD[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.

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 KISH HABITAT

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

Penticton Residual: Penticton Creek contains high quality habitat however the tributaries within the Penticton residual often contain low quality habitat. Deep Creek and Reed Creek contained high quality habitat due to the presence of headwater lakes. Reed Lake and Penticton Creek contained Brook trout which are susceptible to sedimentation.

Dennis Sub-Basin: The Dennis Creek sub-basin had an average gradient of 9% and contained high quality habitat.

Municipal Sub-Basin: Habitat within the Municipal sub-basin was low to moderate. The average gradient within the sub-basin was 3%

Greyback Lake : Rainbow Trout are confirmed in Corporation creek and lake , however there is limited available habitat in the remaining tributaries. Greyback Lake provided overwintering habitat for rainbow trout

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

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

Thank-you

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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 ($53km^2$) Creeks (all from Alilla et al. 2007); and 240(5 km^2) Creek (from Schnorbus et al. 2004). Two are in the upper Fraser River basin (Naver Ck.[658 km^2] from Allila et al. 2007) and Baker Ck. (1570 km^2 – FPB 2007). 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 1/35 the size of Penticton Creek and Baker Creek about 9 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 a tributary of Trout Creek located on the west side of Okanagan Lake, across from Penticton Creek.

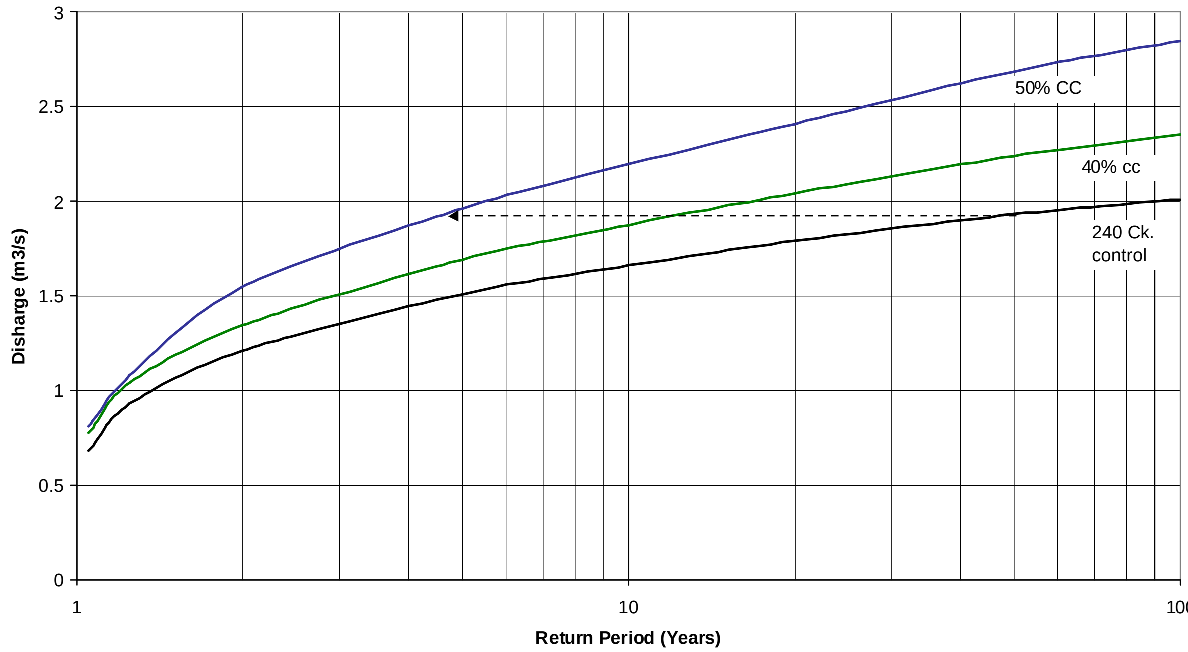

Figure C-1. Modelled flood frequency for 240 Creek, a 5km^2 tributary of Penticton Creek, with 40% and 50% clearcutting of upper watershed. With 50% clearcutting the 50 year flood would be expected to occur on average every 5 years. Data from Schnorbus *et al.* 2004.

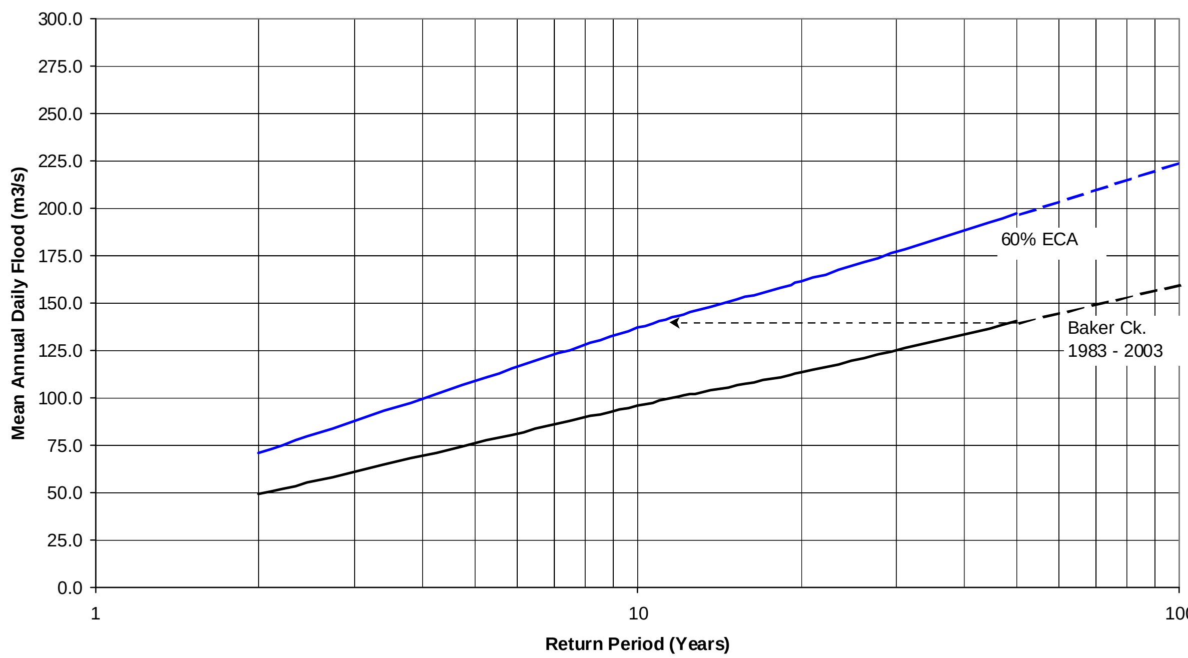

Figure C-2: Modelled flood frequency shift for Baker Creek (1570km^2) with approximately 60% ECA, from clearcutting and MPB pine mortality. The 50 year flood becomes about the post-treatment 11 year flood. Data from FPB 2007.

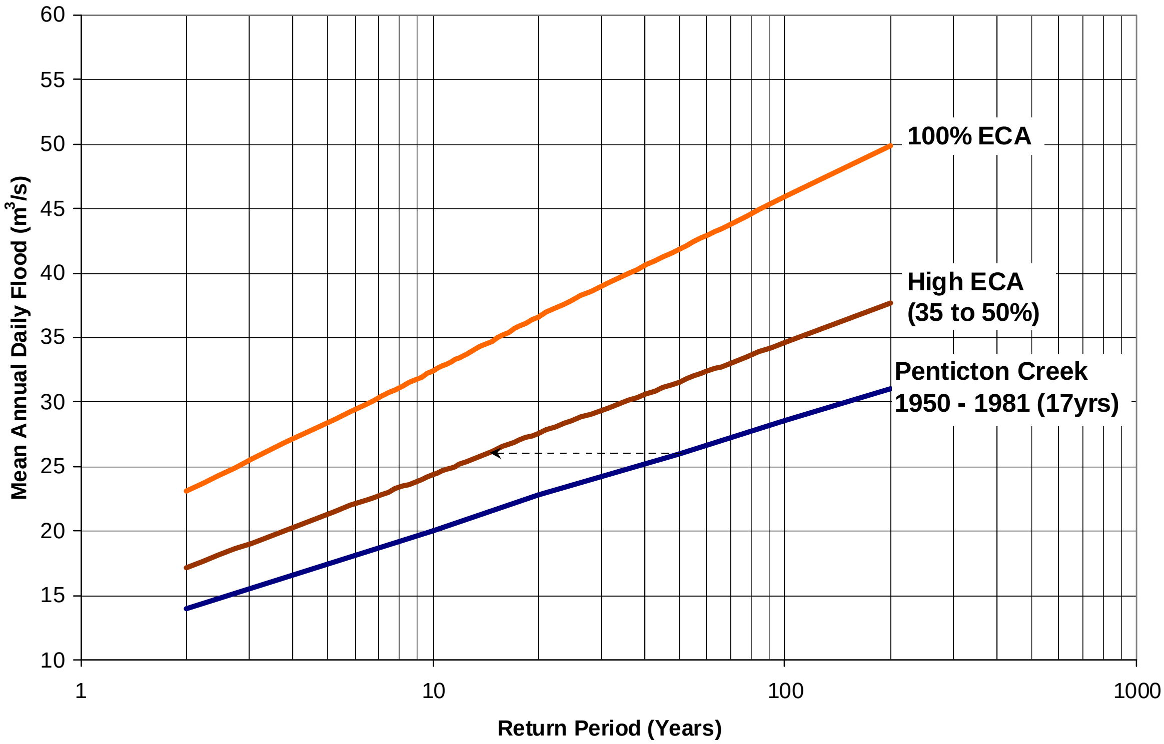

Figure C-3. Modelled flood frequency shift for Penticton Creek (uncontrolled), extrapolating from a "typical" Okanagan watershed (Allila et al., 2007) with a high (35 to 50%) ECA. The historic 50 year flood becomes the 15 year post-treatment flood for the 15 to 20 year period of sustained high ECA

To extrapolate to the expected flood frequency shift in Penticton Creek with the total salvage scenario, which has an extended High ECA Hazard (see Figure 10), 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 Penticton 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)

Figure C-3 shows the expected flood frequency shift in Penticton Creek if 100% of the watershed were clearcut (from Allila et al. 2007); and the expected shift following salvage harvesting of all pine-leading stands in the watershed, which would result in a sustained High ECA for 15 to 20 years. It is estimated that following total salvage harvesting the 50 year return period flood would be expected to occur on average every 15 years.