Trout Creek Hydrological Risk Assessment

Prepared for:

BC Ministry of Environment

Prepared by:

Grainger and Associates Consulting Ltd.
Salmon Arm, BC

and

Streamworks Unlimited
Salmon Arm, BC

April, 2009

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EXECUTIVE SUMMARY

Grainger and Associates Consulting Ltd. and Streamworks Unlimited carried out an analysis of Mountain Pine Beetle (MPB) and salvage harvesting-related risks to water quality, water supply, fish habitat and other infrastructure in Trout Creek Community Watershed. Trout Creek, a 755km^2 area draining into Okanagan Lake just south of the town of Summerland B.C., is the primary water source for domestic, commercial and agricultural users in the District of Summerland (DoS).

The hydrological effect of MPB and salvage harvest forest cover disturbance was analysed using recent research findings on snow accumulation and melt effects under different forest canopy conditions accounting for dead pine trees, non-pine overstory, and understory seedlings, saplings and poles in MPB-attacked stands (Huggard and Lewis, 2008).

Stand structure data for ECA modelling 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 Trout Creek. Over 70% of these VRI labelled pine-leading stands had healthy understory, averaging 560 to 1000 well-spaced stems/ha >1.3m tall, and non-pine overstory averaging 25 to 69% of total overstory basal area. These stands will have a significant hydrological function, even when all pine in the stand is dead.

Stand data was used in modelling two watershed level management scenarios. In the "MPB/unharvested" scenario, all pine trees in pine-leading stands are assumed to be killed by MPB, and no further forest harvesting activity takes place in the watershed. In the "full clearcut salvage" scenario all pine-leading (>40% pine) stands are clearcut harvested, with the exception of riparian zones, old growth management areas, unstable terrain and other areas designated as long-term reserves by forest licensees.

For these two scenarios, stand ECA data was rolled up into watershed or sub-basin ECA's for Trout Creek watershed and 11 sub-basins. For Trout Creek Watershed at the DoS intake, the ECA progression over time for the two scenarios is shown in Figure 1. For the MPB/unharvested scenario there is as a moderate incremental ECA hazard lasting about 25 years; and for the full salvage harvest scenario there is a high incremental ECA hazard lasting about 20 years.

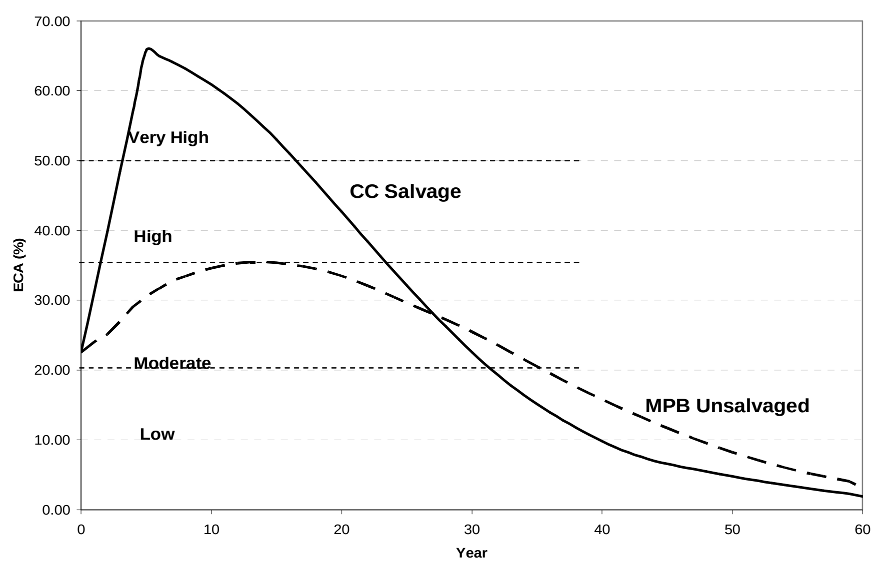

Figure 1. ECA Progressions in Trout Creek above H_{50} for two management scenarios.

A 41 year peak flow record and flood-frequency curve was synthesized for Trout Creek. Based on 11 studies of flood frequency changes following watershed forest cover disturbance (8 of them in the Okanagan) a shift in the Trout Creek flood frequency curve was projected for the 20 year period of sustained high ECA hazard following the full salvage harvest scenario. It is estimated that what has historically (1966 to 2007) been the 50 year flood would be approximately the 20 year flood, 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.

Watershed and sub-basin ECA levels were combined with watershed and sub-basin characteristics - steepness, soil drainage properties, drainage density and natural or artificial storage - to determine peak flow hazards; or the likelihood a given canopy disturbance would result in a change in peak flows. The peak flow hazards were combined with channel sensitivity to determine hydrologic hazards, which included the expected magnitude and frequency of expected changes in peak flows and sediment mobilization from channel beds and banks. Potential qualitative risks to different watershed and sub-basin elements were determined by combining the hydrologic hazards for each of the two management scenarios with the consequence values for each of the four watershed elements of interest.

In most watershed reaches, watershed and channel characteristics were relatively robust, and the peak flow and hydrologic hazards did not change much from the original ECA hazard ratings, for either management scenario. Exceptions included a few reaches where previous high harvest levels or where forest, agricultural or urban development had disturbed the channel. These were located in Camp Creek, in mainstem reaches 8-12 located above the DoS intake where the floodplain had been cleared of all vegetation for grazing and crops, and Reach 1A on the Trout Creek fan at Okanagan Lake. In these reaches there was a high hydrologic hazard with the MPB/no harvest scenario, and a very high hydrologic hazard if the full salvage harvesting scenario occurred.

The study looked at all water quality parameters identified by Interior Health Authority and Ministry or Environment stakeholders. There is little evidence linking MPB and salvage processes with total organic carbon, true colour, total phosphorus and metal concentrations in source waters. Changes in temperature, nitrate/nitrite, algae and microbiological indicators (fecal coliform and E. Coli) can be moderately linked to MPB and salvage harvest processes. In Trout Creek increases in temperature and microbiological indicator levels are expected to be small, if any, but these would be cumulative with levels already seasonably above optimum levels. No significant increase in the existing low source water nitrate/nitrite levels is expected. Algae levels are not known, and their formation processes are complex. Monitoring for algae has been recommended elsewhere and this seems prudent. For all these parameters there is not enough background data, or a detailed enough understanding of their linkages to MPB and salvage effects, to carry out further risk analyses.

Coarse and fine sediment concentrations can be strongly linked to MPB and salvage processes through increased peak flows and sediment mobilization from channel beds and banks, where most sediment in this system originates. Fine sediment (turbidity) can affect water aesthetics, human health and water treatment efficacy. Coarse sediment can damage water intakes. Following the full MPB-related pine mortality and no salvage harvesting scenario, there is a moderate incremental risk of sediment impacts at the DoS intake. That is, a perceptible increase in peak flows and associated fine and coarse sediment delivery to the DoS water intake may or may not occur; and should it occur increases are not expected to be large. This slightly elevated risk will continue for approximately 25 years, until re-growing stands re-establish forest hydrological function to a point where noticeable effects are no longer expected.

With the full salvage of all pine-leading stands scenario, there is a high risk of sediment impacts at the DoS intake for approximately 20 years, until planted stands re-establish hydrological function. During this period a significant increase in peak flows and associated fine and coarse sediment delivery to the DoS water intake is considered likely.

The main effect of MPB mortality and/or salvage harvesting on water supplies would be advancement of spring freshet runoff, requiring earlier and longer use of reservoir storage and an increased risk of storage depletion before the end of the growing season. From the available literature no definite conclusion could be drawn on the expected magnitude of this effect. Climate change is predicted to advance freshet timing by approximately 20 days by 2020, over long term historic norms. Any change due to MPB or salvage will by cumulative with the climate change effect.

Each stream reach was assigned a fish habitat consequence value based on species present and habitat quality. This was combined with the hydrologic hazard to determine the risk to fish habitat for each sub-basin, for both management scenarios. With the MPB/no harvest scenario most tributaries have at most a moderate risk of negative impacts and there is high risk in the Trout Creek mainstem. In the disturbed reaches of Camp Creek, mainstem Reaches 8-12 and Reach 1A on the fan there is a very high risk to fish habitat. With the full salvage scenario there is a high risk in most tributaries and a very high risk in the Trout Creek mainstem and in the three disturbed sections.

For flood protection works and the Highway 97 crossing on the fan, forestry roads and the KVR-TransCanada Trail, there are low to moderate risks from the MPB/no harvest scenario; and a high risk to private bridges and water intakes. For the full salvage scenario all risks are one rating higher. There are moderate risks for elements on the fan, high risks to forestry roads and the KVR trail and very high risks to private farm bridges and water intakes.

Recommendations to reduce risks focus on either protecting and strengthening risk elements, or reducing stand-level MPB and salvage effects. While Forest For Tomorrow (FFT) program activities will promote long term health, economic value and hydrologic forest function; because all ongoing FFT activities we are aware of involve canopy removal (underplanting has not been successful) they will not mitigate the short term hydrological impacts of MPB attack and salvage harvesting in Trout Creek. It will be important that best management practices for riparian management are followed during salvage harvesting.

Stream channel restoration should be pursued in the three stream sections where channel structure and fish habitat have been degraded by past human activities. Channel rehabilitation would improve channel resiliency to increased peak flows, reduce fine and coarse sediment mobilization to lower reaches and the DoS water intake, and improve fish habitat through the treated and immediate downstream reaches.

In the absence of an effective under-planting program for MPB attacked stands, we know of no way to reduce the MPB-related ECA hazards at the stand level. However the incremental risks due to MPB stand-level hazards to DoS water quality and most social infrastructure are moderate. MPB-related risks are high to some fish values and private infrastructure.

The higher incremental risks associated with large scale salvage can be reduced by managing the level and location of salvage harvesting. It is recommended that:

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

- modelling should be based on an accurate picture of secondary stand structure in the watershed. The data collected for this study is a good start, and could be augmented with additional secondary stand structure obtained by random sampling in Trout Creek, based on updated VRI information expected in 2009.

- The least hydrological impact will result if pine-leading stands with the least non-pine overstory component and least understory stocking are preferentially targeted for salvage harvest. The data collected here indicates stands in the snow zone with least hydrological function would be younger MSdm stands followed by older MSdm stands and then ESSFdc stands. However individual stands within these broader BEC units will vary, and site specific evaluations of stand structure should supersede these broader recommendations in making harvesting management decisions to minimize hydrologic impacts.

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. Global warming -related and other pathogens (spruce or fir beetle and others) and other disturbances such as fire, etc., are not improbable. Part of the determination of acceptable risk should include considering the potential hydrological effects of these other possible disturbances. To manage for them it would be prudent to apply the precautionary principle and preserve some hydrological function in the watershed above the minimum required to manage for only MPB and MPB-related salvage impacts.

Because of the types of forests present in the South Okanagan, the expected hydrological effect of MPB infestation and pine tree mortality in the Trout Creek Watershed are not expected to be catastrophic for any of the identified watershed values (risk elements), or even significant for most of them. Although our results show that extensive salvage harvesting can increase hydrologic impacts, with good management of harvesting rates and sites that recognizes the hydrological functions of different pine-leading stand types, some forest development should be possible with a level of risk that is acceptable to watershed stakeholders.

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 Trout Creek Community Watershed (Figure 1); as part of a contract to complete similar risk analyses for seven south Okanagan Community Watersheds

Trout Creek Community Watershed area is approximately 755km^2 and drains into Okanagan Lake just south of the town of Summerland B.C. It is the primary water source for domestic, commercial and agricultural users in the District of Summerland. There are high fish values throughout much of the Trout Creek mainstem. Highway 97, the major Okanagan valley north-south highway crosses Trout Creek on its fan. There are also residence on the fan, and numerous forestry road crossings and private water intakes in the watershed.

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

The project was completed by the team of Bill Grainger, P.Geo., 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 Trout Creek watershed conditions, as well as a helicopter overflight on November 5, 2008 and ground investigation of watershed and channel conditions in selected locations on November13, 14 and 24, 2008. Forest overstory and understory were measured in 48 plots in six different areas in Trout Creek, as part of a program of 250 plots taken in 30 areas in seven south Okanagan Community watersheds. This detailed stand information was use in modelling the projected hydrological effects of MPB pine mortality and salvage harvesting in Trout 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 Trout Creek are assessed in Section 3, to determine potential hydrologic hazards. Section 4 details the presence and/or vulnerability of specific Trout Creek watershed values (or consequences) that could be impacted by those hazards.

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

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

2.1 RISK ANALYSIS

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

Risk = Hazard x Consequence

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

Figure 1 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 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.

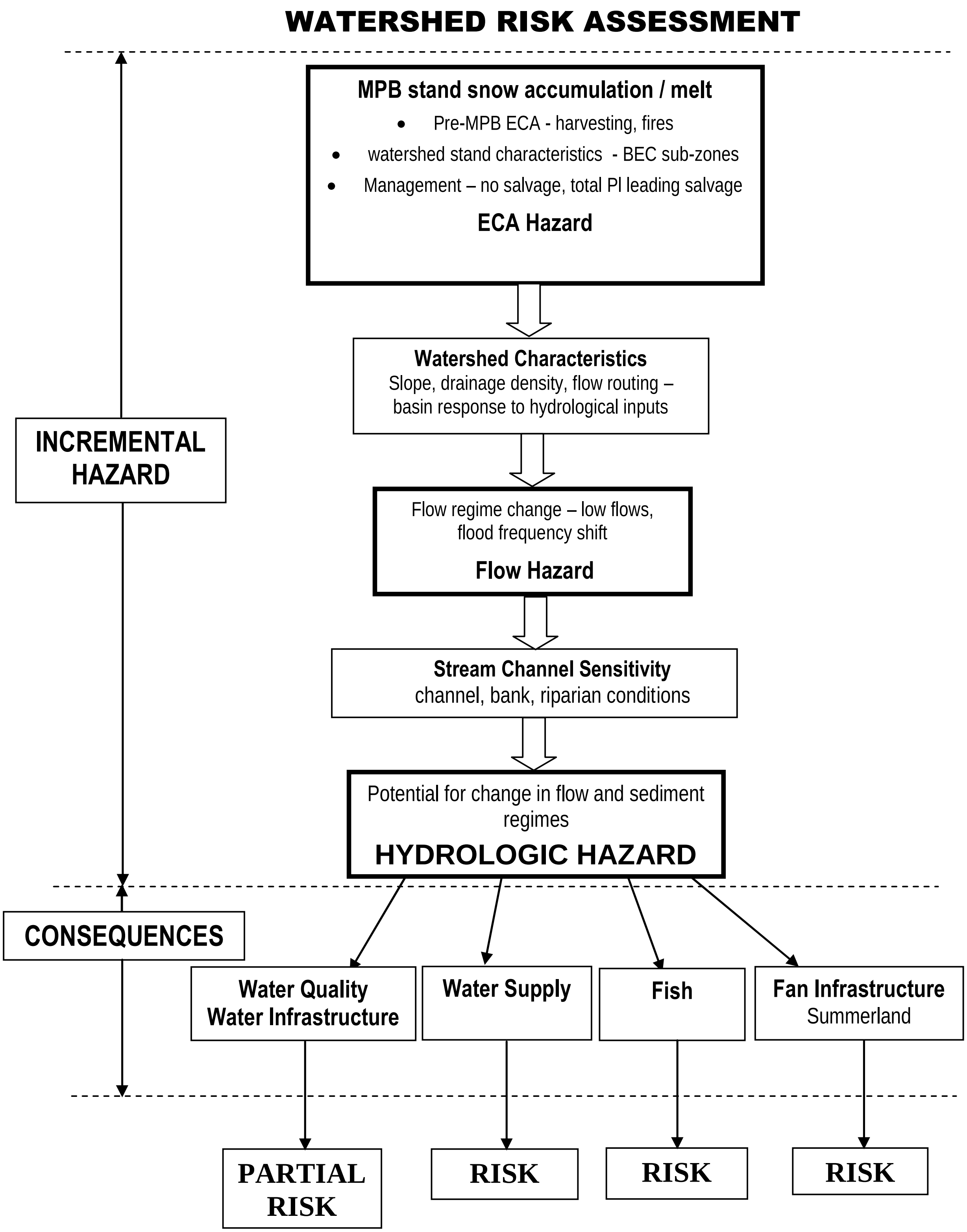

Figure 2. Risk Assessment Flow Chart

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, 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 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 mostly well-drained coarse textured soils, these effects are relatively small compared to the effect of canopy removal, and this is assumed to be the case in this analysis.

Clear-cutting 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 Trout Creek, these effects are caused primarily by the accumulation of higher snow packs (expressed as snow water equivalent, SWE) in clear cuts 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 Clear Cut Area (ECA); where a clear-cut has initially has an ECA of 100%, a mature forest has an ECA of zero, and a regenerating forest has an ECA somewhere in between that is proportional to tree height and stocking (Anonymous, 1999). A watershed ECA value is calculated by combining the ECA’s for various treatment and unharvested areas throughout the watershed.

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

2.2.2 MPB and ECA

In this study we model watershed ECA using the Huggard method (Huggard and Lewis, 2008), which incorporates recent research findings on snow accumulation and melt effects of different forest canopy conditions in MPB attacked stands. This includes modelling the canopy effects of the dead pine, the non-pine overstory and understory seedlings, saplings and poles. Research throughout BC to quantify the hydrologic function of dead pine trees and secondary structure in pine-leading (>40% pine) MPB infested stands clearly demonstrates the important hydrologic function of unharvested MPB attacked stands, and supports the contention that these effects must be considered when evaluating the potential hydrologic risks associated with MPB related stand mortality relative to salvage logging (Redding *et al.*, 2008a, Redding *et al.* 2008b, Winkler, *et al.* 2008 and FPB, 2007).

The stand structure data used in modelling Trout Creek ECA was collected in 245 random plots in 30 accessible stands in seven South Okanagan watersheds[1] near Trout Creek, with similar biogeoclimatic (BEC) stand types as Trout Creek, and includes 48 plots taken in Trout Creek watershed. Appendix B “Summary of Results from South Okanagan Stand Surveys for MPB-ECA Modeling” presents a summary of those field findings for secondary structure in high elevation BEC zones in this area, and compares those findings with similar secondary stand structure surveys taken elsewhere in the province. Where required this data was supplemented with secondary structure stand data from the North Okanagan and Thompson regions (Vyse *et al.* 2007), which showed similar results.

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

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

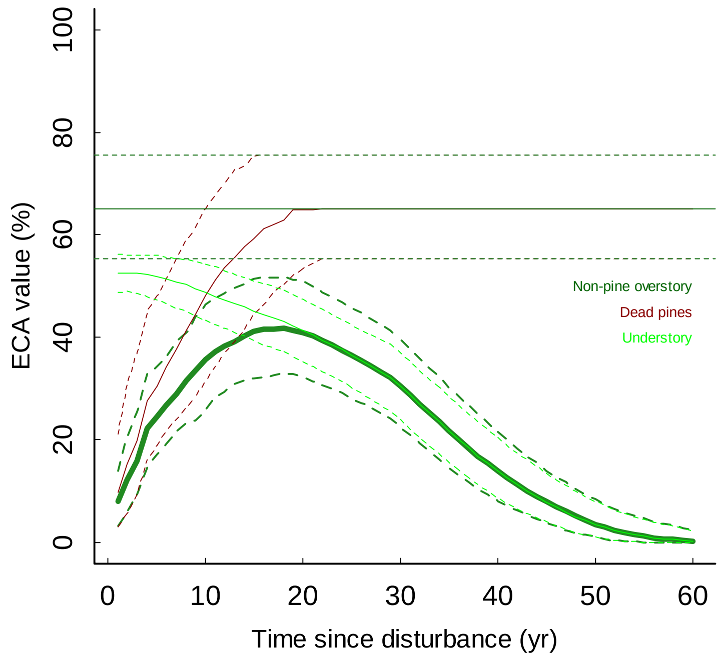

Figure 3. ECA projection (heavy green line) for unsalvaged older Montane Spruce BEC variant (MSdm, >110yr) showing the contributions over time of non-pine canopy (black line, showing a constant 35% ECA reduction over time) the dead pine (red line, showing decreasing ECA reduction as dead pines fall down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

It should be noted that the solid lines in Figure 3 are average values of the many different individual site conditions one would encounter in actual stands of a particular BEC variant. For instance, in high pine component stands there will be sites with very little understory, and other sites with a well-stocked understory.

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

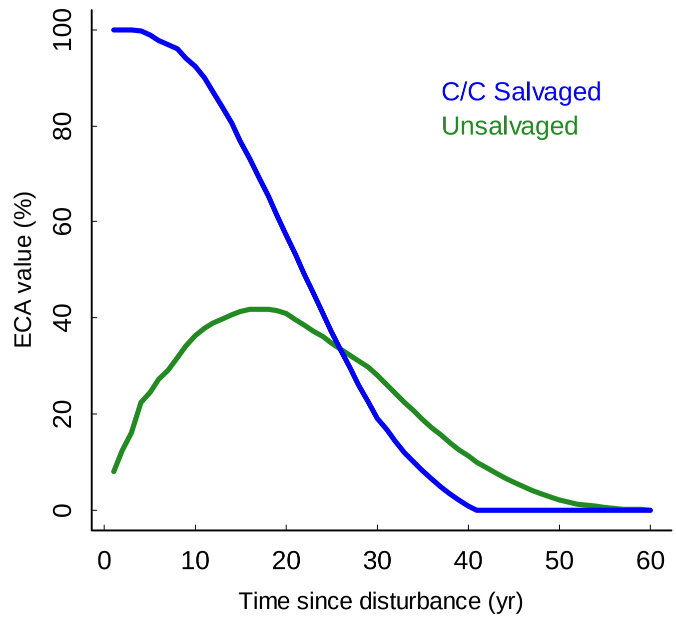

Figure 4. ECA projections for unsalvaged and clearcut salvaged and planted older MSdm, showing that ECA for unharvested MPB attacked stands never rises above about 40%. There is a 20 to 25 year period where the clearcut salvaged and replanted stand has a significantly higher ECA than the unharvested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

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

2.3 Watershed and Channel Sensitivity

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

Drainage basin factors that affect runoff sensitivity include steepness, soil drainage properties, drainage density, soil depth (or proximity to an impervious layer), and natural storage (e.g. lakes, wetlands). Some of these characteristics are clearly interrelated, for example, a steep basin with poor soil drainage usually has a higher drainage density. 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, soils 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). 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. Channels passing through coarser, erosion resistant materials will respond more slowly to flow regime change, taking decades or more to adjust.

Table C-1 in Appendix C is a framework for assigning channel sensitivity ratings using characteristics from field, airphoto and map observations based on Green (2005). Channel sensitivities are described in response to increased peak flow/flood frequency, increased sediment delivery and decreased riparian function, and can result from any one or a combination of these stressors.

In this assessment, sensitivity focuses on the first two stressors in Table C-1, increased flow and sediment generation. In Trout Creek few significant sediment sources, such as landslides and road erosion, were identified outside of the stream bed and banks. Therefore most sediment is generated from channel beds and banks during high flows, and increased peak flows and sediment generation are closely related.

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 Trout 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 fish habitat. It will be critical that salvage harvest plans maintain appropriate riparian reserves to preserve stream stability and habitat quality and temperature.

Channel sensitivities were interpreted according to the framework presented in Table C-1, 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 and observed indicators of disturbance were assumed to also be indicators of channel sensitivity or ‘robustness’. These results were carried forward into this assessment. Channel sensitivities vary along the length of the stream. For the purposes of this assessment, sensitivities were assigned by sub-basin, based on the relative extent and location of sensitive reaches within that sub-basin.

Many channels in the Okanagan originally developed during deglaciation under sustained high flow regimes no longer in effect. Since that time, the channels have reduced in size but still run over deposits of oversized fluvial materials (lag deposits). Channels flowing over these coarser substrates are more likely to remain stable under increased discharge. Some watersheds in the Okanagan have experienced widespread historical wildfire, as evidenced by even-aged stands. The burned areas likely resulted in elevated downstream flow regimes for a period following the wildfire. Channels in these watersheds will be less sensitive to peak flow change, having previously endured increased flow regimes.

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

2.4 ELEMENTS AT RISK

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

- Water quality and water intake infrastructure, primarily at the District of Summerland (DoS) water intake.
- Water supply at the DoS intake.
- Fish populations and habitat
- Social infrastructure (infrastructure not related to municipal water supply)

2.4.1 Water quality and water intake infrastructure

The water quality element at risk can be expressed as "a sufficient and reliable supply of safe and aesthetically acceptable water" (MoH, 2005), at the District of Summerland water intake on Trout Creek. As well, potential damage or increased maintenance costs to the DoS water intake are considered.

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

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

Table 1. Water quality and water supply infrastructure parameters

Element at Risk	Effects of Concern	Specific Parameter	Metric	Parameter or Watershed Sensitivity
Drinking Water Quality	Reduced aesthetic appeal and increased risk of microbiological activity. Decreased effectiveness of primary disinfection treatment	**FINE SEDIMENT** (Turbidity)	NTU	In Trout Creek source waters, turbidity (fine sediment) values are very high on a seasonal basis during the spring freshet, and show some correlation between stream discharge and fine sediment concentration. Turbidity values are somewhat elevated up to 6 months of the year. *Watershed is sensitive to disturbances that will increase fine sediment concentrations in source waters.*
		FINE SEDIMENT (Total Suspended Solids)	concentration, mg/L	
		Temperature	^{o}C	Loss of riparian forest shade can result in increased stream temperatures. MPB effects are limited because there is less pine in riparian areas. Salvage will remove forest shade if riparian zone is harvested. With long term riparian retention, salvage effects will be limited.
	Reduced aesthetic appeal and human health effects	True Colour	True Colour Units	Little published evidence to link changes in these water quality parameters to MPB infestation or salvage harvesting
		Total Organic Carbon	concentration, mg/L	
		Metals (select)	concentration, mg/L	
	Reduced aesthetic appeal and increased risk of microbiological activity	Total Phosphorous	concentration, mg/L	
		Nitrate & Nitrite	concentration, mg/L	Difficult to generalize effects on nitrogen cycle due to complexity. There have been increased concentrations of dissolved inorganic nitrogen (nitrates and ammonium) following MPB mortality . Trout Creek nitrogen levels are low.
		Aquatic Flora (algae)	mg per m^2	Difficult to generalize due to complex interaction between canopy closure, stream temperature, nutrient concentrations, and sedimentation. However, net effect is expected to be an increase in primary production. Algae levels in Trout Creek are unknown.
	Human health (waterbourne pathogens)	Microbiological Indicators	Fecal coliform, E. Coli bacteria	MPB infestation and salvage harvesting could have an indirect effect on microbiological indicators if there are changes in range use and recreational activities associated with salvage harvesting access. Microbiological levels in Trout Creek are elevated for more than 6 months of the year.
Water Supply Infrastructure	Treatment infrastructure damage	**COARSE SEDIMENT**	cubic metres	In Trout Creek, most sediment is mobilized from bed and bank erosion in the channel, so any sediment mobilized can be transferred downstream to intake and other values. *Watershed is sensitive to disturbances that will increase coarse sediment production.*

(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

Parameters weakly linked to MPB and salvage harvest effects
For True Colour, total organic carbon, metals, and total phosphorus there is little published evidence to link changes in water quality to MPB infestation and mortality. In general, these parameters are watershed specific and are more dependant upon the physical watershed characteristics (i.e. presence of wetlands, organic soils, geological and mineralogical conditions) as opposed to watershed forest cover changes.

There is no source water data we are aware with which to infer past levels for these parameters in Trout Creek. Since these parameters are considered weakly linked to MPB and salvage-related processes, especially if riparian management is adequate, they are not considered further in this study.

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

Temperature
In Trout Creek, measured stream temperature through the summer months (June-September) regularly exceeded guidelines for aquatic life and drinking water. Mean weekly maximum temperatures in the summer, measured between 1996-1999, ranged from 14^{o}C to 21^{o}C (MOE, 2008). Stream temperatures of $\leq$15^{o}C are considered optimum.

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. Wei et al, (2007) found similar large woody debris (LWD) input rates for MPB-attacked and non-attacked stands in the Okanagan, which suggests that wholesale loss of riparian forest canopy and streamside exposure to significantly increased incident solar radiation is unlikely in MPB attacked areas.

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.

While it is expected any change in Trout Creek stream water temperatures due to MPB and salvage will be small, any change would be an increase in temperatures already seasonally above optimum levels.

Nitrate/Nitrite
Limited source water monitoring from 1997 to 1999 found nitrate / nitrite concentrations in Trout Creek were well 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

We are not aware of any monitoring of Trout Creek source waters for chlorophyll *a* or algae, but monitoring has been recommended because of a possible relationship between neurotoxins produced by algae and Alzeheimer's disease (Agua Consulting Inc., 2008).

MPB infestation and salvage harvest can affect the interrelated process which can influence the abundance of aquatic flora in lakes and stream. 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. We agree with the previous recommendation to monitor source waters for chlorophyll *a* or algae.

Microbiological Indicators

Fecal coliform and E. Coli levels in Trout Creek regularly exceeded drinking water guidelines for bacteriological safety between April and October, as measured between 1997 to 1999 (MOE, 2008).

MPB infestation and salvage harvesting are not expected to have a significant direct effect on fecal coliform and E. Coli levels in Trout 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 Trout Creek, any increase in fecal coliform and E. Coli levels in Trout 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 DoS water intake is a concern, because the changes in forest canopy affected by MPB and salvage can be similar to the effects of forest harvesting; namely, changes in riparian vegetation, increased magnitude and frequency of peak flows (floods), and sediment production from landslides, surface erosion and stream channel bank and bed sediment mobilization.

Fine Sediment

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

In addition, significant increases in fine sediment concentrations may place additional stress on the treatment facilities. For example, the DoS water treatment facility which came on line in 2007 is dealing with post-treatment sludge management issues (AECOM, 2008) that is presumably related to fine sediment and other suspended matter source water concentrations.

Turbidity levels in Trout Creek, measured at the intake from 1997-1999, are greater than 1 NTU for at least six (6) months of the year (MOE, 2008). Mean daily averages increased through the spring freshet, with peaks of 303 NTU in 1997 (20 year return period flood), 212 NTU in 1998 (approx. 4 year return period flood), and 171 NTU in 1999 (approximately 3 year return period flood). Secondary turbidity peaks occurred in the late summer and fall, most likely associated with convective storms. This limited source water monitoring suggests that in Trout Creek source waters turbidity values are very high on a seasonal basis during the spring freshet, are somewhat elevated up to 6 months of the year and show some correlation between stream discharge and fine sediment concentration. Therefore the watershed is considered sensitive to disturbances that will increase fine sediment concentrations in source waters.

Coarse Sediment

Coarse sediment production, measured as bed load, can disrupt or damage water intake infrastructure. We don't know of any bed load measurements in Trout Creek mainstem near the DoS water intake. As discussed in Section 2.3, most sediment is generated from channel bed and bank erosion during high flows. That is, any sediment mobilized is already in the channel and can be transported downstream, eventually to the community water intake and other values. Therefore the watershed is considered sensitive to disturbances that will increase coarse sediment production.

Water Quality Risk Analysis Procedure

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

Interior Health Authority B.C. requested we do not evaluate the robustness or vulnerability of the District of Summerland 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 DoS water intake (Dale Thomas, pers. comm.). The source water quality findings of this investigation can be used as input to a more comprehensive “Source to Tap Risk Assessment” that water purveyors are required to complete (MoH, 2005).

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

2.4.2 Water Supply

In Trout Creek risks to water supply come from changes in watershed conditions that could compromise the ability of storage to meet agricultural and domestic demands during the growing season, when there is a large natural moisture deficit in the watershed. MPB 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 cover can lead to earlier freshet snowmelt. This can lead to water users having to access storage water at an earlier date and therefore for a longer period of time, which can increase the risk of depleting storage before the end of the growing season.

MPB attacked stands lose some canopy function, depending on stand characteristics, or are salvage clearcut harvested, in which case 100% of the canopy is removed. Therefore snowmelt timing effects similar to harvesting are expected in MPB and salvaged stands.

A steady increase in water demand in the District of Summerland is expected in the future (Aqua Consulting Inc., 2008). Any decrease in storage capability to meet that demand would be considered a high consequence. This study looks at the potential MPB and salvage harvesting related-hazard of an earlier freshet snow melt and an increased likelihood of earlier reservoir depletion.

2.4.3 Fish

Sport fish species within the watershed include Brook Trout (Salvelinus fontinalis) and Rainbow trout (Oncorhynchus mykiss) in headwater tributaries and lakes. Mountain Whitefish (Prosopium williamsoni) and Kokanee (Oncorhynchus nerka) have been identified in the lower reach of Trout Creek. There are longnose sucker, prickly sculpin, longnose dace, largescale sucker and redsided shiner in headwaters lakes and streams. 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	9% 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, 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 those hazards considered in studies of forest harvesting effects. These include loss of riparian vegetation which can affect fish shelter, stream temperature, nutrient availability and large woody debris recruitment to streams. Increased peak flows and sediment can alter channel morphology, resulting in degraded spawning, rearing and over wintering habitat. For each Trout Creek and tributary reach, hydrologic hazards are determined (see Section 3) and combined with the consequence values for each reach (see Appendix C), and for cumulative downstream reaches, using a standard risk matrix (Appendix A).

2.4.4 Social Infrastructure

Social infrastructure refers to infrastructure other than the DoS water intake. This includes Highway 97 crossing and flood protection dykes on the Trout Creek fan, private farm bridges and water intakes along the Trout Creek mainstem, the KVR Trans-Canada Trail and forestry road bridges throughout the watershed. For each of these elements a qualitative vulnerability or consequence rating was determined. This was combined with the hydrologic hazard in a risk matrix (Appendix A) to determine the qualitative incremental risk from increased flooding and sediment movement due to MPB and salvage logging.

3.0 WATERSHED CONDITIONS AND HAZARDS

3.1 WATERSHED CONDITION

3.1.1 Physiography, geology and terrain

The Trout Creek Community watershed drains portions of the Thompson Plateau into Okanagan Lake on the west side of the valley near Summerland, BC. The watershed encompasses an area of approximately 755 km^2 ranging in elevation from 342 m at Okanagan Lake to a maximum of 1,923 m at the summit of Kathleen Mountain. Biogeoclimatic (BEC) zones occurring within the watershed include: Bunchgrass (BG), Ponderosa Pine (PP), Interior Douglas Fir (IDF), Montane Spruce (MS) and Engelman Spruce Sub-alpine fir (ESSF).

Upper Trout Creek is dominated by a rolling, glaciated plateau between elevations of 1300 and 1900m. This area is predominantly in the MS and ESSF BEC zones and accumulates considerable snow pack during the winter months. The plateau is formed mostly from ablation tills with some glacio-fluvial deposits. Soils are predominantly coarse-grained and moderate to well-drained. Drainage density of streams on the plateau is low to moderate. Numerous lakes and wetlands exist in this area, some of which have been dammed for use as water reservoirs.

Photo 1. Broad gently sloping upland plateau area of Trout Creek.

Trout Creek originates at the Headwater Lakes, initially flowing west/southwest through a series of low gradient wetlands before turning south and entering a well defined U-shaped glaciated valley. Bedrock exposures are apparent along some of the steeper valley wall sections. Underlying bedrock is mostly igneous (plutonic, intrusive) with some areas of volcanics. The bedrocks types in the watershed typically weather into coarse grained soils. Soils remain well-drained and drainage density generally decreases in the middle watershed due to lower snow accumulations and improved soil drainage.

The valley bottom is inferred to contain significant glaciofluvial deposits (terraces, erosional scarps, and plains), including sand and gravel with some silt. Thick till blankets are also common in the valley bottoms adjacent to glaciofluvial deposits (Dobson 2006). A broad deposit in the valley bottom between Lost Chain Creek and Camp Creek has been cleared for agricultural use.

Photo 2. Cleared glaciofluvial/fluvial floodplain in Lower Trout Residual (Reach 9).
Note long eroding unprotected bank.

Gullying is an active geomorphologic process in some locations where thick surficial materials remain on the steep sidewalls of some incised tributary creeks. The few landslides that exist in the watershed occur in the steep sidewall gullies through the middle section of Trout Creek.

Photo 3. Typical lower Trout Creek above DoS water intake (Reach 3).

The community intake is located at an elevation of approximately 650m just before the channel enters a steep sided, bedrock controlled canyon. Water is drawn off above a constructed weir and diverted into an open ditch line leading to the storage and treatment facilities.

The canyon and fan reaches are downstream of the DoS intake and their drainage areas are not included in analyses of hydrologic impacts to the intake. However because of the relatively steep channel gradient and confined channel through the canyon downstream of the intake, any increases in stream flows and sediment at the intake will be transported through the canyon to the fan.

Darke Creek and Dark Reservoir Lake water is licensed to the Meadow Valley Irrigation District. According to local information, there is very little flow in Darke Creek downstream of the Meadow Valley system (WMC, 2005, Aqua Consulting Inc., 2008). It is assumed that this water is fully allocated and utilized by that District, and is unavailable to contribute to Trout Creek above the DoS intake. Therefore, Darke Creek sub-basin is not included as part of the Lower Trout Creek Residual (Figure 1).

Several slope failures have occurred within the canyon downstream of the intake, and some sections chronically ravel into the creek. A deep-seated landslide known as the 'Perpetual Slide' is also a chronic source of sediment. The canyon reach of Trout Creek is an ongoing major sediment source to the fan, relative to sediment generated by the rest of the watershed.

Land adjacent to the canyon is drier and well-drained, typical of the Ponderosa Pine BEC zone. Agricultural and residential development also increases as Trout Creek approaches the town of Summerland.

Photo 4. Steep eroding canyon below District of Summerland water intake (Reach 1B).

Trout Creek has a large alluvial fan at the mouth where it enters Okanagan Lake. While much of the fan volume is probably due to periglacial processes (formed during deglaciation), the lack of channel incision suggests some level of fan forming processes are still active. The channel on the fan has been straightened and dyked to protect adjacent agricultural and residential areas from flooding.

Photo 5. Trout Creek fan and stream outlet on Okanagan Lake (Reach 1A).

Table 3. Trout Creek Watershed and sub-basin areas

Sub-basin Name	Sub-basin Area (km^2)	Cumulative Area (km^2)	Sub-basin Area above H50 line [1400m] (km^2)	Elevation Range (m)	Reservoirs
Headwaters	49.9	49.9	31.3	1280-1814	Cresent Lake, Headwater Lakes
North Trout	50.9	50.9	44.9	1190-1830	Whitehead Lake
Upper Trout Residual (above Thirsk)	142.8	243.6	75.7	1036-1920	
Camp Creek	36.7	36.7	20.5	980-1930	Chapman Lake
Tsuh Creek	17.8	17.8	12.9	950-1600	Tsuh Lake
Lost Chain Creek	40.7	40.7	33.8	910-1750	
Bear Paw Creek	22.3	22.3	14.0	825-1750	
Bull Creek	47.7	47.7	33.7	800-1960	
Isintok Creek	45.4	45.4	32.8	780-1940	Isintok Lake
Lower Trout Residual (below Thirsk)	185.3	639.6	35.9	620-1950	Thirsk Reservoir
Darke Creek*	76.6	76.6	23.9	700-1600	Darke Lake

*Darke Creek and Dark Reservoir Lake water is licensed to the Meadow Valley Irrigation District. It is assumed that this water is fully utilized by that District, and does not to contribute to Trout Creek above the DoS intake.

3.1.2 Channel conditions and bank stability

Existing conditions in the Trout Creek watershed derived from field and office reviews of existing report (Dobson, 1998, 2001, 2004 and Dobson *et al.* 2004, 2006) are summarized in Table 4. Channel conditions are summarized by sub-basin although some issues may only apply to specific reaches within that sub-basin. Average channel gradients are just that, and actual channel gradients will vary from the mean. Listed channel morphology types represent the predominant morphology of the mainstem channel within that sub-basin (Hogan 1996). Morphologies of some sections or tributaries in the sub-basin will certainly vary. Although erosion, transport and deposition clearly 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.

Most channels in Trout Creek watershed appear to be stable and robust. Channel types are predominantly Cascade/Pool with cobble or boulder substrates (Photo 6). Riffle/Pool channel types with gravel substrates are found in lower gradient sections. Banks are typically composed of relatively coarse glacio-fluvial and/or colluvial deposits and are relatively resistant to erosion especially when vegetated with mature trees. Some lower gradient sections have developed floodplains and/or flow through finer sediments deposited during deglaciation (glacial outwash, glacial-fluvial and/or till deposits). Along incised mainstem channel sections, and in the lower reaches of tributary streams, bedrock is frequently exposed in the bed and banks.

Photo 6. Stable Trout Creek channel with lag boulders and cobble bed.

Disturbed reaches occur in Camp Creek and in Reaches 8-12 on the Trout Creek mainstem downstream of the Thirsk Reservoir. Disturbance in Camp Creek may be related to elevated peak flows and/or associated with forest harvesting (Dobson 2006). Reaches 8 through 12 on Trout Creek pass through private land cleared for agriculture. The reaches are low gradient with erodible banks and reduced riparian vegetation (Photos 2 and 7). Bank scour and aggradation is evident and channel avulsions have occurred in the past in this area.

Photo 7. Lower Trout Residual Reach 9 through cleared agricultural land with eroding banks.

Downstream of the community intake, Trout Creek flows through a bedrock controlled canyon. Several slope failures have occurred in this section, as well as chronic ravelling in sections of the canyon walls (Photo 4). A deep-seated landslide known as the 'Perpetual Slide' is a chronic source of sediment on the north side of the Trout Creek canyon. Slide dimensions are approximately 425m x 425m (length x width) and from 12 to 24m in depth. The slide is believed to have initiated between 1914 and 1917, presumably as a result of increased pore pressure related to the establishment of orchard irrigation (Noseworthy et al., 2002).

Trout Creek has a large alluvial fan at the stream mouth where it enters Okanagan Lake. The channel on the fan has been straightened and dyked to protect adjacent agricultural and residential areas from flooding. Some aggradation in the channel on the fan has occurred during past flood events.

Photo 8. Trout Creek fan and Highway 97 crossing.

Table 4. Channel Characteristics and Conditions (*continued on following page*)

Sub-basin Name	Reaches	Mainstem Channel Length (km)	Average Gradient (m/m)	Dominant Morphology Type	Sediment Regime	Sub-basin/Channel Characteristics
Headwaters	18 to 21	6.8	0.06	CPc	Source	Numerous interconnected lakes and wetlands. Moderate to low drainage density. Low gradient tributary areas. Minor bank scour and disturbed stone lines. Some localized road and livestock impacts.
North Trout	1 to 3	14	0.03	CPb/c	Source	Wetlands and small lakes on upper plateau. Moderate drainage density. Steady gradient along incised mainstem. Stable robust channel with mossy boulder substrates. Occasional disturbed stone line. Old failure off Whitehead Road.
Upper Trout Residual (above Thirsk)	13 to 17	19.5	0.01	RPc	Transport/Depositional	Small lakes in upper plateau areas. Wetlands/floodplain and low gradients along main channel above North Trout and below Empress confluence. Steady gradient along mainstem between North Trout and Empress (Reach 15). Indistinct drainage divide with Osprey Lake. Minor bank scour and disturbed stone lines. Some localized road and livestock impacts.
Camp Creek	1, 2	9.9	0.07	CPc	Source	Small lakes near divide. Moderate drainage density. Steep confined lower canyon. Small alluvial fan/deposits on Trout Creek floodplain. Channel is slightly aggraded through much of the middle reaches and severely aggraded near the lower end and the KVR crossing. Some evidence of peak flow problems and livestock impacts. Riparian is cleared below KVR crossing. KVR culvert is obstructed by beaver dam.
Tsuh Creek	1 to 3	6.9	0.09	SPc	Source	Tsuh Lake at upper end. Poorly defined divide near Eneas Lakes. Moderate drainage density. Steep confined lower canyon. Small alluvial fan/deposits on Trout Creek floodplain. Stable with well-developed stone lines and some moss cover. Disturbed channel section and avulsion associated with natural log jam. Some LWD function.
Lost Chain Creek	1 to 4	8.7	0.08	SPb	Source	Small lakes/wetlands near divide. Moderate to low drainage density on plateau. Steep confined lower canyon. Slightly aggraded section with out-sloped banks, otherwise stable robust channel.
Bear Paw Creek	1 to 3	10.3	0.08	n/a	Source	Wetlands along channels on upper plateau. Moderate drainage density. Steep confined lower canyon. Moderately to highly robust channel with mossy substrates and good LWD function.
Bull Creek	1, 2	12	0.07	CPc/b	Source	Steady, moderate gradients along tributaries in upland areas. Moderate drainage density. Steep confined lower canyon. Stable and moderately to highly robust from the headwaters to the Trout confluence. Past avulsion site caused localized aggradation. Boulder substrates.

Sub-basin Name	Reaches	Mainstem Channel Length (km)	Average Gradient (m/m)	Dominant Morphology Type	Sediment Regime	Sub-basin/Channel Characteristics
Isintok Creek	1 to 6	12.6	0.07	SPb	Source	Isintok Lake at upper end. Poorly defined drainage divide. Moderate drainage density. Low gradient upper channel flowing into steep confined lower canyon. Moderately to highly robust, boulder/cobble dominated channel. History of natural landslides and associated debris floods. Historic debris floods have caused channel avulsions on the fan near Trout Creek. Large raveling failure in canyon.
Lower Trout Residual (below Thirsk)	8 to 12	10.2	0.01	RPg	Depositional/Source	Low gradient channel flowing through cleared agricultural lands. Meandering with occasional flood channel/abandoned channel. Occasional connected wetland area. Tributaries partly dewater on floodplain/fan deposits. Moderate to low tributary density. Bank scour, extensive sediment bars and levees, and uniform substrates. Aggraded low gradient sections, separated by more robust boulder/cobble dominated sections. Occasional channel avulsions. Livestock impacts and reduced riparian vegetation. Damaged farm bridge.
Lower Trout Residual (below Thirsk)	2 to 7	17.1	0.02	CPc	Transport	Steady, moderate gradient along mainstem below agricultural areas. Mostly confined with occasional minor floodplain. Moderate to low tributary density. Moderately to highly robust. boulder/cobble dominated channel. Stable with extended riffle sections that are partially to moderately aggraded. Occasional areas of localized bank erosion. Limited LWD and reduced channel complexity. Three landslides in Reach 7 have been rehabilitated.
Darke Creek	1 to 7	14	0.01	CPc	Depositional	Darke Lake at upper end and other small lakes on plateau. Channel diminishes in size as it flows through middle (agricultural) reaches, likely influent stream (lost to groundwater). Channel is low gradient roadside ditch near lower end. Steep tributaries from plateau to valley bottom. Some localized road and livestock impacts.
Bedrock Canyon (below intake)	1B	11.9	0.02	CPc, RPg	Transport/Source	Confined channel with steady gradient and steep, frequently raveling, bedrock canyon walls. Some deep-seated (Perpetual Slide) and shallow slope instabilities. Chronic fine sediment source. Few tributaries in this section.
Fan (below intake)	1A	1.9	0.01	RPc	Depositional	Dyked, channelized, and straightened for much of its length. Falls approximately 2km from Okanagan Lake. Multiple channels at mouth. Cleared of debris.

3.1.3 Channel sensitivity

Using the assessment framework outlined in Table C1, channel sensitivities for the Trout Creek watershed are summarized in Table C2. 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 (riparian change is not expected to be significant), 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 described in the table to provide an indication of issues that may arise if changes to flow/sediment regimes were to occur. These issues may never be realized if the sub-basin is not hydrologically sensitive and/or pine stands are not widespread (see Section 3.3.).

Three areas in the Trout Creek watershed have been identified as having channel sections highly sensitive to changes in peak flows and/or sediment regimes. These areas are: Camp Creek; Reaches 8-12 in lower Trout Creek; and Trout Creek on the fan near Okanagan Lake (below the community intake). Camp Creek and Reaches 8-12 on lower Trout have demonstrated problems in the past and increased peak flows and/or sediment loading will likely compound or accelerate these processes. Reduced riparian vegetation along Trout Creek Reaches 8-12 has increased the sensitivity of the channel by reducing bank strength. Relatively low gradients will encourage deposition of sediments delivered from upstream, leading to aggradation, widening and further instability. Similarly, additional sediment delivered to the Trout Creek fan will accelerate typical fan processes of aggradation and new channel development (avulsion).

Channels in the remainder of the Trout Creek watershed have moderate or low sensitivity ratings and are judged to be fairly robust; that is, able to accommodate some change in flow and/or sediment regimes without affecting channel stability. Banks and beds are generally composed of coarse materials, including occasional bedrock and lag deposits. Riparian areas remain mostly intact. Channels did not appear to destabilize or exhibit significant widespread or persistent impacts in response to high flow events in the past.

3.2 HYDROLOGY AND FLOOD REGIME

Trout Creek watershed is a nival (snowmelt dominated) watershed although summer convective storms have caused occasional high flows. The average annual total precipitation for the Trout Creek watershed is approximately 550mm with approximately 60% of the total precipitation occurring as snowfall. Average monthly precipitation ranges from 15 to 35mm.

Significant flood events occurred in Trout Creek in 1972, 1993, 1996 and 1997. The flood of record occurred in May 1972 with an estimated discharge of 71.6 m^3/s. Mean annual peak daily discharge is approximately 23 m^3/s. Average annual discharge for Trout Creek at the mouth according to published data is 2.1 m^3/s.

3.2.1 Snow sensitive zone

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

Measurements have been made of the elevation of the receding snowline at the time of peak flows in several south Okanagan watershed (Dobson, 2004a, 2004b, 2004c), including Trout Creek (Dobson, 2004d). While data was collected for only a few years in each watershed, results suggest a decreasing area (higher elevation) of contributing snow zone as one moves south in the Okanagan. In almost all cases the contributing snow zone was less than 60%. Based on four years of observations (2001 to 2004), Dobson concluded that the position of the snow line in Trout Creek, above which freshet snow melt contributes to mainstem peak flows, is between 1400 and 1550m elevation.

It is reasonable to expect that, depending on snow pack and melt conditions, some variation in the contributing area will occur; and that a rapid melt when the snow line (elevation) is still relatively low would cause the highest peak flows. The very largest peak flows are likely caused by widespread radiation and/or other energy inputs (e.g., sensible and latent heat transfers and energy advected by rain) occurring simultaneously over a large area of the watershed. This is probably especially true in watersheds where mid and upper elevations consist of relatively low gradient plateaux, as in Trout Creek. Therefore in this study the 1400m elevation is used as the line defining the lower limit of the snowmelt contributing zone to mainstem peak flows. Approximately 50% of Trout Creek watershed area is above this line, so it is called the H_{50} line, as shown in Figure 5.

3.2.2 Forest cover changes

Stand Level ECA

Figures 5 shows the BEC stand types in Trout Creek watershed located above the H_{50} line that defines the hydrologically important snow zone. MSdm, ESSF and IDFdk stands comprise 69%, 23% and 8% respectively of the area of Trout Creek watershed in the snow zone. As discussed in Section 2, different ECA progression curves were developed for the different BEC units above the H_{50} line. Figures 6, 7 and 8 show unharvested and harvested ECA curves for three BEC units.

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

The ESSF plot (Figure 6) is based on 56 plots in 7 ESSFdc stands. In stands labelled as 100% pine or <80% pine, the actual measured overstory pine component averages 30.7%. The rest of the overstory was approximately equal amounts of spruce and balsam. The average understory has 1000 well-spaced stems (>1.3m tall) per ha.

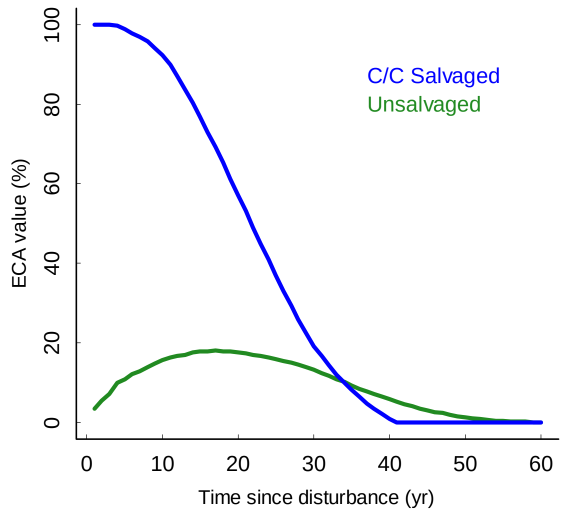

Figure 6. ECA progression in ESSF pine-leading stands.

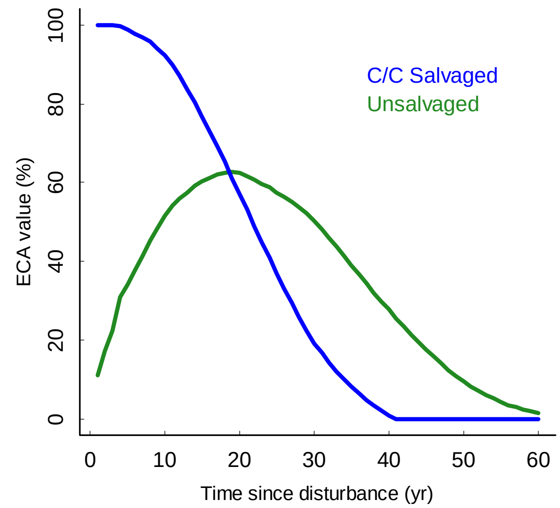

Figure 7. ECA progression in younger pine-leading MSdm stands (70 to 110 yr).

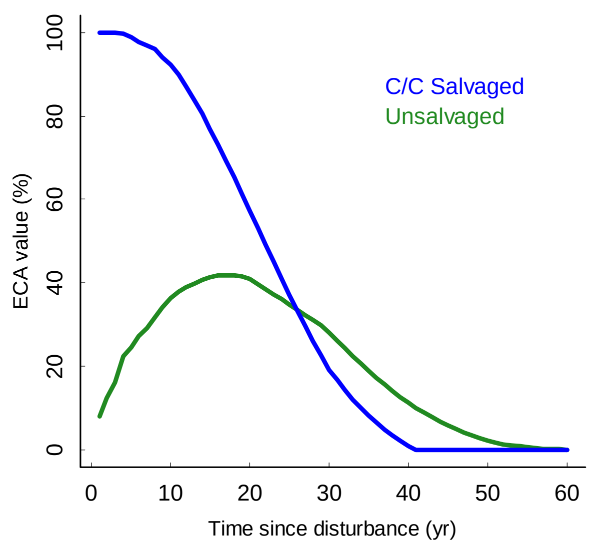

Figure 8. ECA progression in older pine-leading MSdm (> 110yrs) stands.

The younger MSdm plot (Figure 7) is based on 64 plots in 8 pine-leading stands. The measured overstory pine component averages about 90%. The average understory is average understory stocking of 280 well-spaced stems per ha (>1.3m tall) per ha. The older MSdm plot (Figure 8) is 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.

These curves and one for IDF stands using data from Vyse (2007) were used to generate cumulative harvested and unharvested ECA curves for the watershed area and all sub-basin areas above the H_{50} line. ECA calculations also included the existing harvesting and fire disturbances in the watershed as of December 2008, based on VRI data and information provided by forest licensees operating in the watershed – Tolko Forest Industries, Gorman Bros. Lumber Ltd. and BCTS, Okanagan-Shuswap Business Area.

Watershed ECA

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

In the "MPB unharvested" scenario (green line) all pine trees in pine-leading stands are assumed to killed by MPB, and no further forest harvesting activity takes place in the watershed. 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 clear cut salvage scenario (purple line) all pine-leading stands are clearcut harvested, with the exception of riparian zones, old growth management areas, unstable terrain and other areas designated as long-term reserves, as contained in GIS layers supplied by forest licensees. These areas are preserved, however if they are pine-leading it is presumed that pine dies from MPB attack.

In Figure 9 the MPB/unharvested scenario assumes full mortality of pine in pine-leading stands (>40% pine), and full survival of the measured understory.

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

Hazard ratings for different ECA levels are also shown in Figure 9. The low ECA 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 when the ECA level is reduced to 20%.

The moderate ECA hazard indicates that ECA (forest canopy) effects may or may not be noticeable, and if effects are noticeable, they are not expected to be large. A high ECA hazard rating indicates that significant ECA effects are likely; and a very high rating expresses a greater certainty about the expected occurrence of very significant effects.

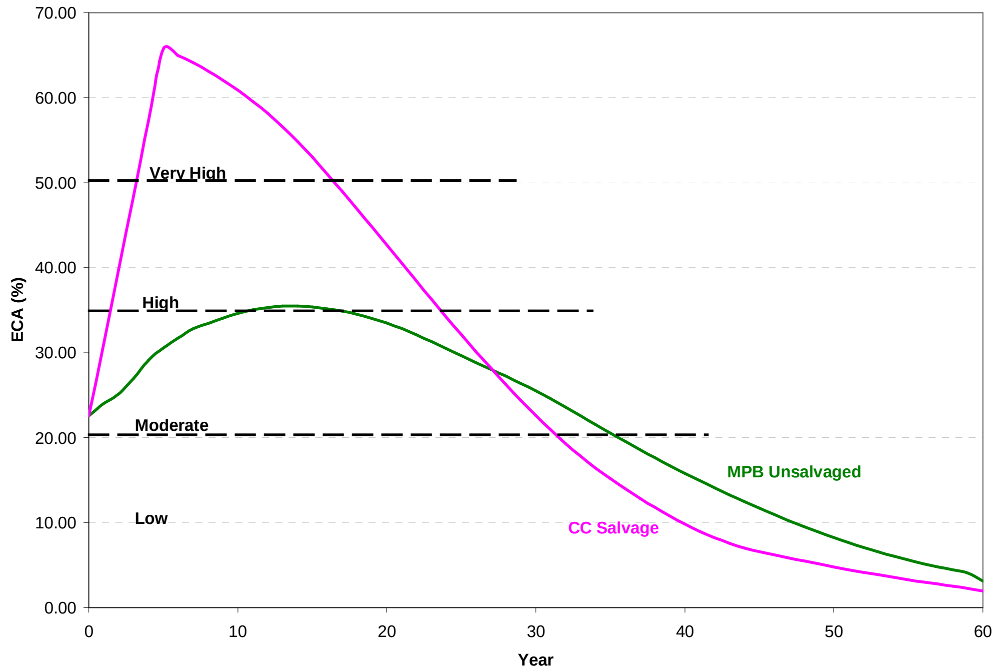

Figure 9. ECA and ECA hazard projections for Trout Creek Watershed above H_{50} elevation, assuming full pine mortality from MPB infestation and full understory survival for MPB and no harvest scenario (green) and full salvage harvest of all pine-leading stands scenario (purple).

In Figure 9, we interpret the sustained ECA effect for the MPB/unharvested scenario as approximately the centre of the area under the curve above the low hazard level. Therefore, there is a moderate ECA hazard for approximately 25 years. The sustained ECA effect of the total clearcut salvage scenario is a high hazard for approximately 20 years. That is, with the overstory and understory survival assumptions made, the ECA effects of MPB mortality (and no further harvesting) may or may not be noticeable, and if there are noticeable effects they are not expected to be large. Similarly, the centre of the area under the ECA curve for the hypothetical full pine-leading stand salvage scenario suggests a high ECA hazard for 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 stand effects of total and partial pine mortality in unharvested pine-leading stands in the watershed (Figure 10); and total and partial understory survival in unharvested attacked pine-leading stands and (Figure 11).

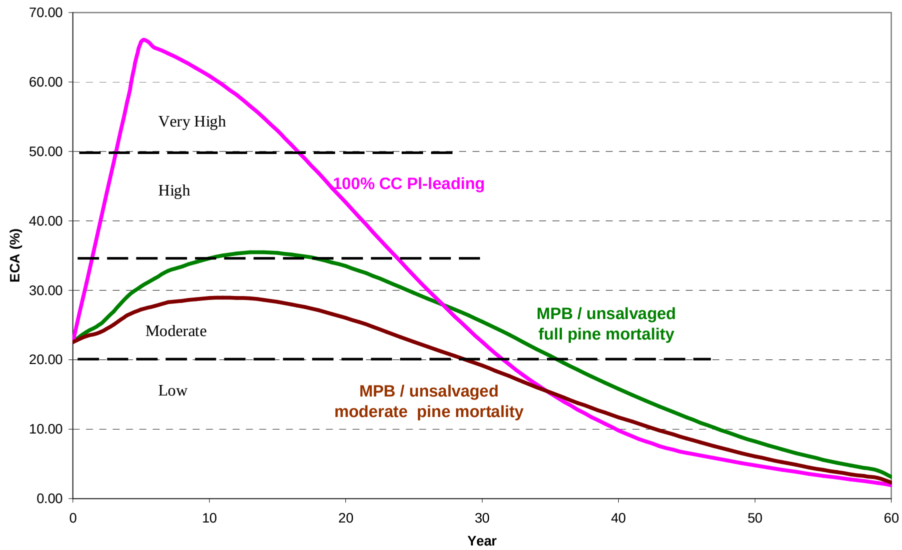

Figure 10. Trout Creek ECA progression for total salvage of pine-leading stands (purple); and MPB/ unharvested with full understory survival and two pine mortality scenarios - with 100% pine mortality (green) and with moderate pine mortality (brown) – see text for details.

The moderate pine mortality scenario assumes MPB attacks all canopy pine trees in 50% of ESSF pine-leading stands (many of which actually appear to be dominated by non-pine), 65% of MS stands <110 years old and 80% of MS stands >110 years. Remaining pine-leading stands are not affected. In the moderate MPB attack scenario maximum ECA is reduced from about 35% to approximately 30% and the watershed ECA recovers (to less than 20%) about 5 years earlier, slightly earlier than the total salvage and replant scenario recovery.

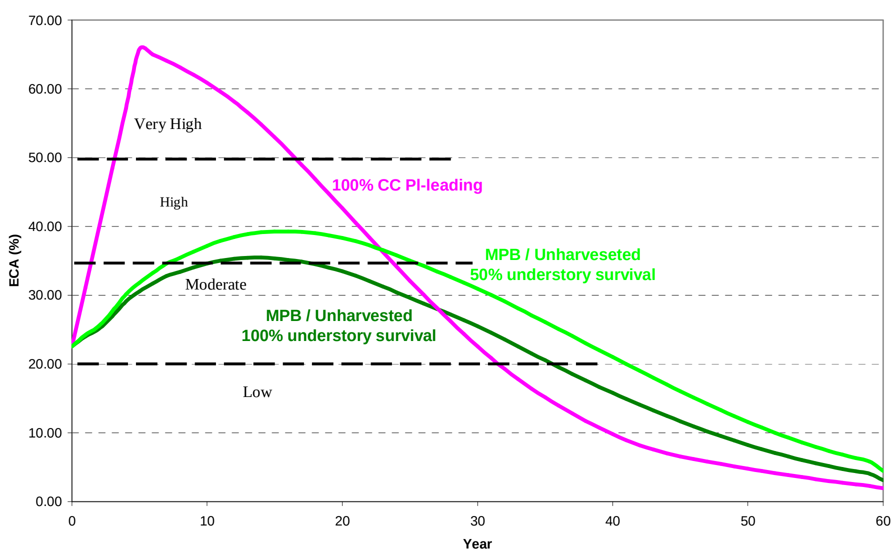

Figure 11. Trout Creek ECA progression for total salvage of pine-leading stands (purple); and two MPB mortality / no salvage scenarios - with 100% understory survival (dark green) and with 50% understory survival (light green).

With only 50% understory survival in the MPB/unharvested scenario, the maximum ECA increases to about 39% from the maximum of 35% expected with full understory survival, and the time to recovery (20% ECA or less) is extended to about 35 years from 30 years. This does not significantly change the sustained MPB/unharvested scenario ECA remaining predominantly in the moderate hazard range.

It is not known what future survival of mature pine and the understory will be in pine-leading stands in Trout Creek. These sensitivity analyses, which probably bracket the reasonable range of possibilities, show some shift in the MPB/unharvested scenario watershed ECA value. However the relative ECA picture between the full harvest and non-harvest scenarios does not substantially change with these changes in understory and pine survival. For the remainder of this report the ECA hazard assumes full pine mortality and full understory survival.

All of the above ECA scenarios were completed for all Trout Creek sub-basins as well as the watershed above the DoS water intake. Maximum ECA values and the sustained ECA hazard (low, moderate, high) for all sub-basins and for both MPB/unharvested and full harvest scenarios are shown in Table 6 in Section 3.3.1, below.

3.2.3 Watershed modelling and reservoir routing

A watershed model for Trout Creek was developed by Water Management Consultants (WMC) and presented in the 2005 Trout Creek Water Use Plan. Processes modelled included temperature, precipitation, evapotranspiration, snow evaporation and melt, and losses to groundwater for the period 1937 to 2002. The main purpose of the model was to assess water availability, although flood control and climate change issues were also discussed. The model was calibrated against Camp Creek flows and reservoir levels documented between 1993 and 2003. Reservoir routing within the model was set up according to operational rules applied to the reservoirs at that time (note: headwater reservoirs were combined into a single operating reservoir). As a further check, modelled results were calibrated against other available operational data (1997-2003).

WMC (2005) concluded that for a 200 year design flood event, available flood storage (approximately 5% of the flood volume prior to the peak) would not be sufficient to have an effect on the magnitude of flood peaks. It was recommended to the District to not operate the reservoirs explicitly for flood control. Since completion of this study, Thirsk Lake Dam has been raise to increase storage capacity in Thirsk Lake.

To update these findings, we used the HEC-HMS program to verify that the increased storage capability was not sufficient to reduce flood peaks in the lower watershed. HEC-HMS is a model developed by the US Army Corps of Engineers to simulate hydrologic response in a watershed. The reservoir routing component of the model was used to simulate the detention and attenuation of assumed inflow hydrographs entering the recently improved Thirsk Lake reservoir.

The new Thirsk reservoir configuration was modelled using the Trout Creek 1997 flow hydrograph (representing a 20 return period event) for inflow. Outflows under an ‘already full’ and a ‘fully drawn down’ scenario were simulated. The results suggest, if in a given year there is a large snowpack, it may be possible to drain down reservoirs prior to the freshet peak and absorb (attenuate) some of the peak hydrograph, without compromising water supplies (i.e. the reservoir could be refilled immediately post-peak). Careful monitoring of snowpack, creek discharge and management of reservoir outlet controls would be required to accomplish the desired effects.

3.2.4 Historical flood frequency analyses

Trout Creek discharge was gauged by Water Survey of Canada (WSC) from 1970 to 1992. Camp Creek, a tributary of Trout Creek, has been continuously gauged since 1966, with data available up to 2006. Camp Creek flows were converted to Trout Creek flows using a ratio of the two drainage areas according to the following formula (Watt, 1989):

$$Q_{Trout} = Q_{Camp} \times [\text{Drainage Area}_{Trout}/\text{Drainage Area}_{Camp}]^{n}$$

The value of 'n' was determined through calibration using the overlapping gauge records available from WSC. A value of n=0.94 generated the best fit for the corresponding flood peaks through the range of data. Annual peak flows converted from Camp Creek records using the above formula (with n=0.94) for the period 1970 to 1982 are plotted along with recorded Trout Creek peaks in Figure 12.

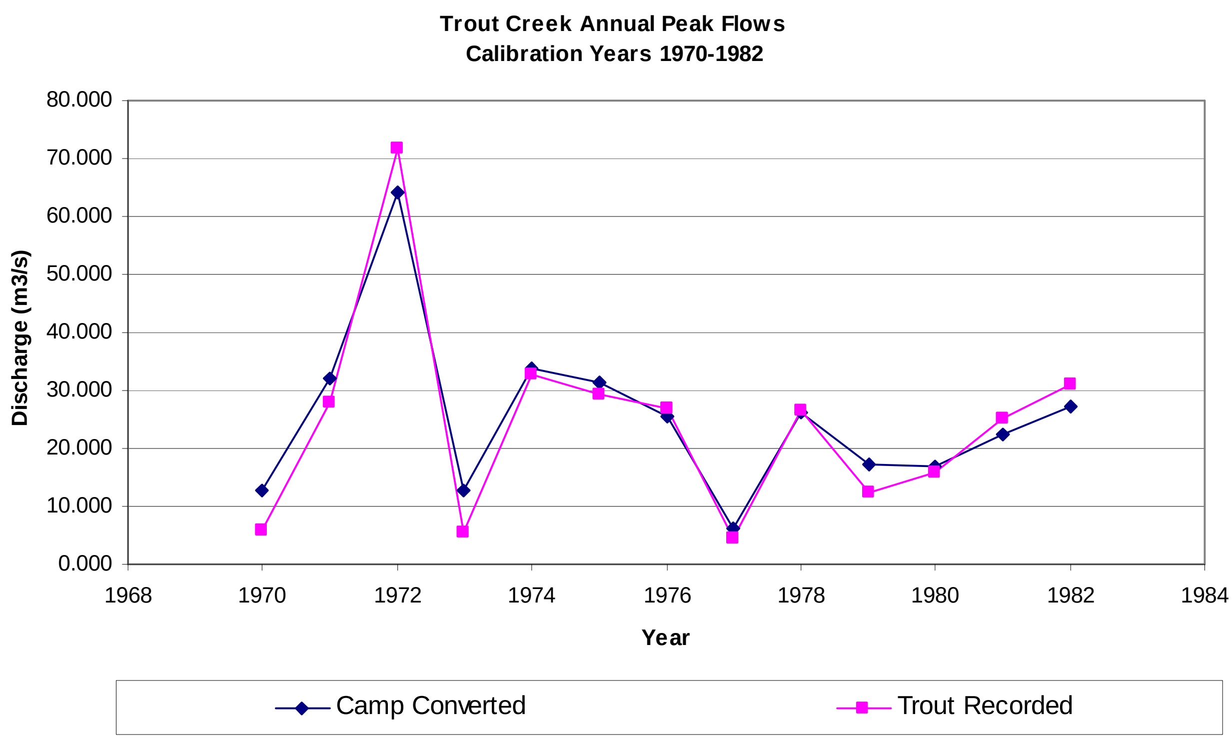

Figure 12. Comparison of Trout Creek annual peak flows and converted Camp Creek annual peaks (adjusted for sub-basin area) for the years both gauges were in operation simultaneously.

Using the relationship derived above, a 41 year record for Trout Creek was synthesized using measured flow data from Camp Creek. Annual flood peaks from the synthesized record were listed and a frequency analysis of maximum daily discharge was conducted using Consolidated

Frequency Analysis (CFA) software. A three parameter Log-Normal distribution was found to best fit the data. The results of the analysis are shown below in Figure 13.

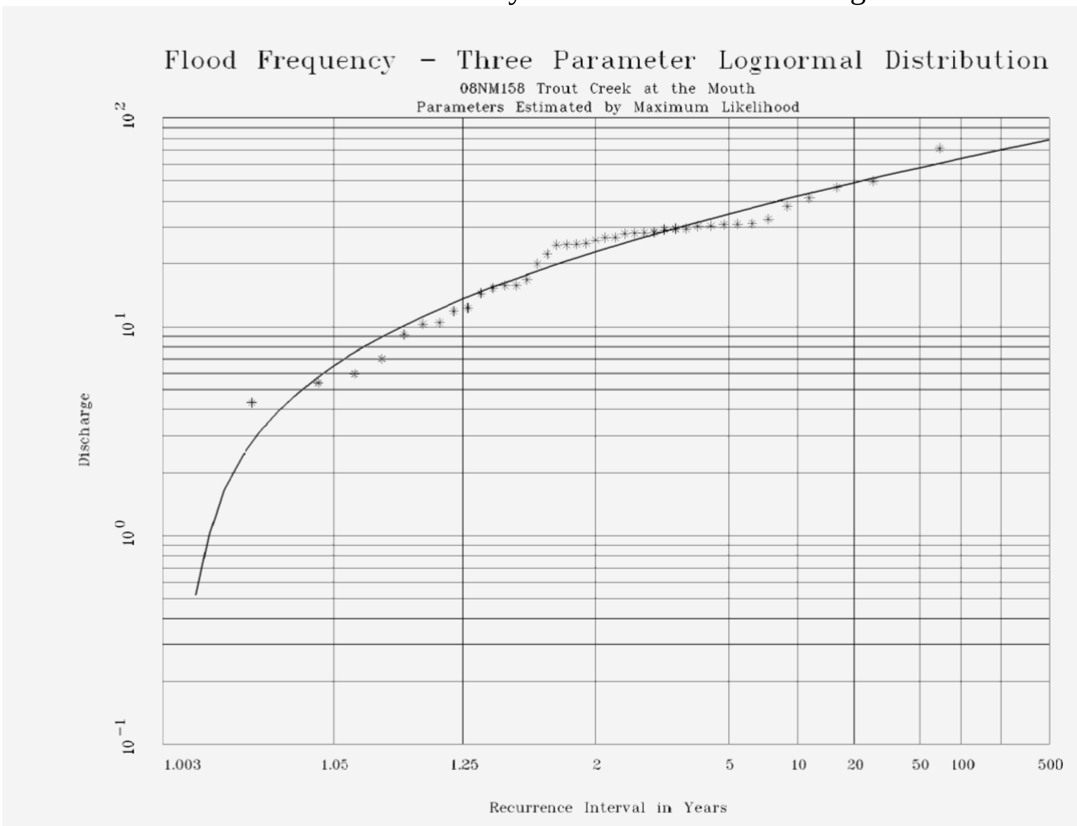

Figure 13. Trout Creek flood frequency curve.

Table 5 lists peak discharge values for flood frequencies, as derived from the above flood frequency curve:

Table 5. Trout Creek return period / discharge values

Return Period (years)	Peak Discharge (m^3/s)
2	22.9
5	34.7
10	42.1
20	49.0
50	57.7
100	64.0
200	70.3

A previous flood frequency analysis for Trout Creek was completed one year after the 1972 flood. Details of the analysis were not available, however the results are described in the Trout Creek Groundwater Study (Thurber 1973). Peak discharge on May 31, 1972 was estimated to be 71.6 m^3/s. Using a short period of record, the analysis conducted at that time suggested a return period for the event around 45 years. The 200 year flow derived from the short record was 127 m^3/s. This was the design flow used in the development of flood protection works in lower Trout Creek. According to the updated frequency analysis presented here, which uses 34 more years of data collected after 1973, a discharge of 127 m^3/s represents an event with a return period greater than 500 years. Similarly, the return period for the 1972 event is increased from a 45 year event to a 200 year event with the longer data set. This discrepancy between the previous and current analysis is likely an artefact of the differing data sets, or possibly a reflection of increased storage capacity and more active flow management since 1973. In the previous section, watershed modelling concluded that reservoir management had little effect on peak flows unless carefully directed flood mitigation was undertaken. Hence, it is assumed that this discrepancy is largely the result of a longer data set.

It is apparent in Figure 13 that the plotted point for the 1972 event does not fall on the fitted curve. Small adjustments to the slope of the fitted line can result in significant changes to estimated discharges for long return period events. Extrapolating 41 years of record to estimate a 200 year return period event is always an 'educated guess', however the recent analysis should be an improvement on previous estimates with the addition of 34 more data points.

One conclusion from this analysis is that the flood protection works on the Trout Creek fan were developed to accommodate what the longer data set shows to be considered a very rare, extreme event, possibly more than the probable maximum flood for Trout Creek.

3.2.5 Flood frequency shift

Spring peak flow generation in nival watersheds is a complex process involving snow pack, forest cover, microclimatology and weather. Extensive literature reviews of research findings on the relationship between harvesting and peak flows, largely through paired-watershed studies, have concluded that there is wide variability between 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 (Pike and Scherer, 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 from several numerical modelling watershed studies of Interior B.C. watersheds, which look at changes in flood frequency following widespread watershed forest cover disturbances including fire, MPB and harvesting (Alila, *et al*. 2007, FPB 2007, Schnorbus et al. 2004). Appendix D-Flood Frequency Analysis provides details of that analysis. From the 11 watersheds modelled a change in flood frequency in Trout Creek is extrapolated (Figure 14).

This is the estimated shift in flood frequency resulting from the sustained 50% ECA expected with the total salvage harvesting scenario in Trout Creek (see Figure 9). Given the level of uncertainty whether the "moderate" peak flow effects associated with the MPB/unharveseted scenario will be noticeable, it is not possible or meaningful to extrapolate a flood frequency shift for that scenario.

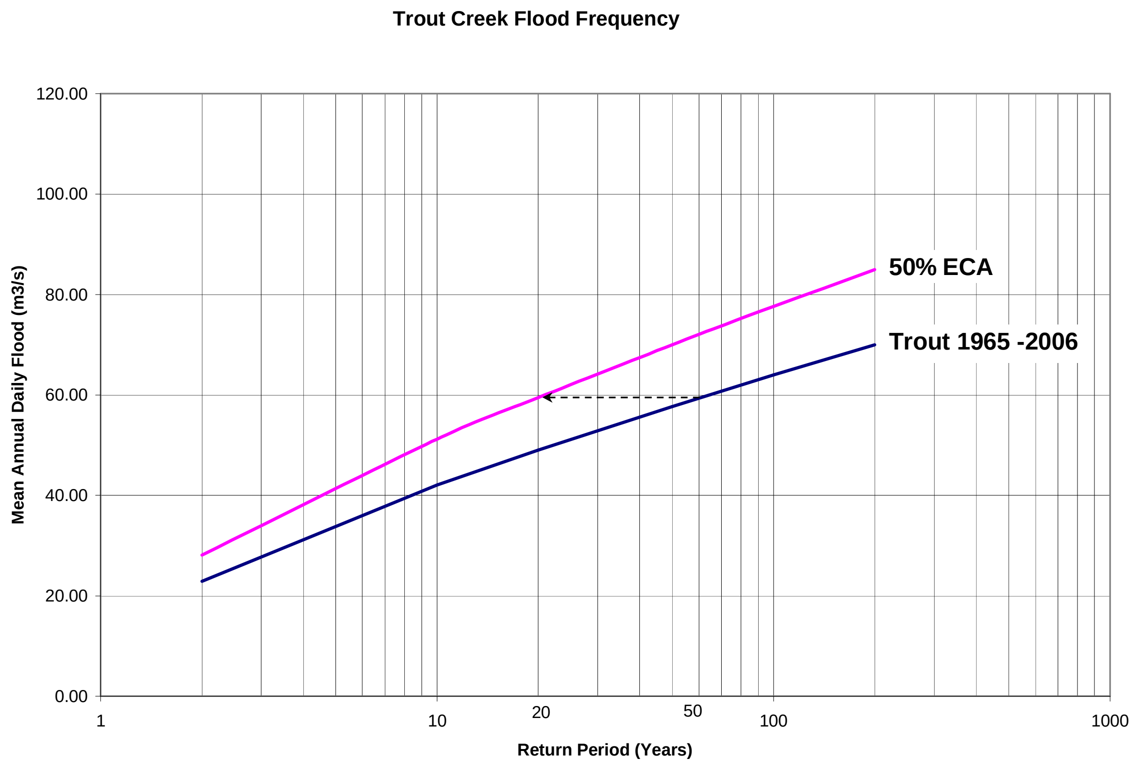

Figure 14. Estimated flood frequency shift for Trout Creek expected for the two decade period of sustained 50% ECA associated with the total clearcut salvage scenario.

There are a great many assumptions and different watershed conditions in the modelled watersheds, and therefore a significant degree of uncertainty in the modelling results that this flood frequency shift is extrapolated from. Nonetheless we would expect a shift of approximately this magnitude in Trout Creek if all pine-leading stands are harvested. For approximately the 20 year period shown in Figure 9, what had been the 50 year return period flood would be expected to occur, on average 2 to 3 times more frequently, or about once every 20 years.

As well, all other return period floods would also be expected to occur with roughly the same increase in frequency during that 20 year period. For instance the 200 year flood (similar to the 1972 event) would occur, on average every 40 to 50 years. The probability of what had been the 200 year event, but would now be the 50 year event, occurring in that 20 year period is 0.33, or about a one in three chance[2]. This would normally be considered a high hazard (Wise, *et al*. 2004), which supports an ECA hazard rating of high for the full salvage harvest scenario.

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2. The long-term probability Px, of an event with return period R occurring within a period of x years is $Px = 1-(1-1/R)^x$. Therefore the probability of a 50yr flood occurring in a 20 year period is $P_{20} = 1-(1-1/50)^{20} = .33$.

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

Table 6 presents peak flow hazards for each sub-basin in the Trout Creek watershed (watershed residual ECA values are cumulative) under the two management scenarios of 'MPB/unharvested' and 'Full-salvage'. ECA curves for the two management scenarios were derived for each sub-basin using the same modelling procedure used to derive the watershed ECA curves shown in Figure 9. The same hazard ranges shown in Figure 9 were also used to determine a qualitative sustained ECA hazard value for each sub-basin.

Sub-basin peak flow attenuation potentials are described as 'Poor' (not likely to attenuate peak discharge), 'Some' (some potential to attenuate peaks but not significant) and Good (likely to attenuate peak flows). Combining ECA hazards with sub-basin response gives a peak flow hazard rating. Where little peak flow attenuation is anticipated in a sub-basin, ECA-related increases in runoff translate directly into increased flow regimes.

Results

Assuming widespread MPB infestation and no salvage harvesting, Trout Creek has a 'moderate' hazard of flow regime change at the DoS intake. This is based on the anticipated level of forest canopy loss and the drainage features of the watershed. Several tributary sub-basins (Tsuh, Lost Chain, Bear Paw, Bull) have been assigned a 'high' flow hazard value due to the amount of pine found in those areas, and the relative steepness of the drainages. The headwaters sub-basin has a 'low' peak flow hazard, mostly due to the amount of storage (lake and wetland) available in that sub-basin.

Subject to full clearcut salvage harvesting, the hazard rating for the Trout Creek watershed increases to 'high' and the high pine sub-basins to 'very high'.

Table 6. Peak flow hazard ratings derived from Sub-basin routing characteristics and modelled ECA levels

Sub-basin	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
Headwaters	Good	31.7	M	60.7	**H**	L	M
North Trout	Some	27.7	M	45.4	**H**	M	**H**
Upper Trout Residual (above Thirsk) Reaches 13 to 17	Some	32.8	M	61.8	**H**	M	**H**
Camp Creek	Poor	31.8	M	59	**H**	M	**H**
Tsuh Creek	Poor	42.5	**H**	73.1	**VH**	**H**	**VH**
Lost Chain Creek	Poor	49.9	**H**	87.6	**VH**	**H**	**VH**
Bear Paw Creek	Poor	50	**H**	80.6	**VH**	**H**	**VH**
Bull Creek	Poor	42.3	**H**	68.6	**VH**	**H**	**VH**
Isintok Creek	Some	38	M	69	**VH**	M	**VH**
Lower Trout Residual (below Thirsk) Reaches 8 to 12	Some	36.6	M	65.1	**H**	M	**H**
Lower Trout Residual (below Thirsk) Reaches 2 to 7 – DoS Intake	Some	36.2	M	63.8	**H**	M	**H**
Bedrock Canyon 1B (below intake)	Poor	36.2	M	63.8	**H**	M	**H**
Fan 1A (below intake)	Poor	36.2	M	63.8	**H**	M	**H**

Note: Darke Creek sub-basin is not assessed as it does not contribute flow to Trout Creek under most conditions.

3.3.2 Hydrologic hazard

Hydrologic hazard represents the potential or likelihood of impacts to existing channel systems in response to a projected level of forest canopy disturbance. Hydrologic hazard ratings are derived from channel sensitivities (Table C-2) and peak flow hazard ratings (Table 6), and are presented for Trout Creek watershed sub-basins in Table 7.

There are few point sources of sediment (e.g. landslides) in the Trout Creek watershed, upstream of the intake. With few exceptions, identified sources are generally localized, often not connected to stream channels, and do not appear to generate large volumes of sediment. Sediment in the system originates for the most part from erosion and scour of bed and banks. Any increased sediment hazard is therefore closely correlated with the peak flow hazard. An increased flow regime will increase stream power and therefore erosive ability. When flood frequencies increase, channels adapt by increasing capacity through widening (Church, 1993). Therefore existing bank erosion sites will be activated by increased peak flows.

The 'Hydrologic Hazard' presented here represents a combination of hazards related to increased peak flows from changes to forest cover and changes to the sediment regime, including both fine (suspended) and coarse (bedload) sediment. The potential magnitude of a peak flow (flood frequency) shift resulting from decreased forest cover has been discussed in Section 3.2.5.

As discussed in Section 3.1.3, most channels in the Trout Creek system are fairly robust and will resist widening in the shorter term. If decreased forest cover conditions persist for several decades, some adjustment of these channel sections may eventually initiate. Localized bank erosion may increase, however minor and/or short term increases in annual or peak flows is not expected to lead to widespread channel destabilization. Based on the predicted magnitude of the flow change, the sub-basin characteristics and the channel sensitivity, these channel sections have a 'moderate' hydrologic hazard.

A few reaches, notably Reaches 8-12 on the Trout mainstem and lower Camp Creek, have been identified as more sensitive to peak flow change, likely to produce sediment and have a high likelihood for increased flows following MPB and/or salvage harvesting. These reaches have a 'high' hydrologic hazard and will likely respond more quickly to increased flow regimes through bank erosion and widening. Bank erosion along these reaches is expected to generate both fine and coarse sediment and as longer channel segments destabilize, become a significant source. Coarse (bedload) and fine (suspended) sediment rely on different modes of transport, and lead to different issues at the DoS intake.

Table 7. Hydrologic Hazards by Sub-basin

Sub-basin	Channel Sensitivity (from Table 6)	Peak Flow Hazard (from Table 7)		Hydrologic Hazard (Peak Flow Hazard Combined with Channel Sensitivity using Risk Matrix)	
		MPB	Full salvage	MPB	Full Salvage
Headwaters	L	L	M	VL	L
North Trout	L	M	**H**	L	M
Upper Trout Residual (above Thirsk) Reaches 13 to 17	M	M	**H**	M	**H**
Camp Creek	**H**	M	**H**	**H**	**VH**
Tsuh Creek	L	**H**	**VH**	M	**H**
Lost Chain Creek	L	**H**	**VH**	M	**H**
Bull Creek	L	**H**	**VH**	M	**H**
Bear Paw Creek	L	**H**	**VH**	M	**H**
Isintok Creek	L	M	**VH**	L	**H**
Lower Trout Residual (below Thirsk) Reaches 8 to 12	**H**	M	**H**	**H**	**VH**
Lower Trout Residual (below Thirsk) Reaches 2 to 7 - DoS Intake	M	M	**H**	M	**H**
Bedrock Canyon (below intake) Reach 1B	M	M	**H**	M	**H**
Fan (below intake) Reach 1A	**H**	M	**H**	**H**	**VH**

There is little opportunity for filtering or settling of suspended (fine) sediments between the high hazard reaches and the community intake. Degraded water quality (in the form of increased turbidity) can be expected to occur as a result of increased peak flows. For the MPB/unharvested scenario only lower Camp Creek and Reaches 8 to 12 of the lower Trout Creek residual have high hydrologic hazard ratings above the DoS intake. This high rating is due to a high channel sensitivity to increased flows; the moderate peak flow hazard (Table 7) indicates there is uncertainty whether increased flows will actually occur. The cumulative moderate hydrologic hazard at the DoS intake includes the possibility of fine sediment transport from these upstream reaches, and it is concluded that increased turbidity following MPB mortality may or may not occur, and if it does the impact is not expected to be large.

With the full salvage scenario there is a high likelihood of significantly increased peak flows acting on the high sensitivity reaches, and therefore a very high hydrologic hazard in the two sensitive reaches (Lower Residual 8 to 11, and lower Camp Creek), as well as numerous tributary reaches with a high hydrologic hazard below Thirsk Lake and above the DoS intake. Therefore there will be a high cumulative hydrologic hazard following the hypothetical scenario of total salvage of all pine-leading stands, and it is considered likely there will be significantly increased turbidity at the DoS intake.

While some component of coarse sediment will likely be mobilized in Reaches 8-12, it will probably be stored within those reaches, or deposited in low gradient sections within Reach 7 downstream. Some volume of coarse sediment may also be delivered to the system from localized sites in the tributaries connecting below Thirsk reservoir. Increased peak flows may enable the mobilization of some coarse material already stored in the mainstem channel and the tributaries connecting below Reach 7, resulting in a minor increase in coarse sediment at the intake. However, large volumes of coarse sediment are not expected to be transported to the community intake with the ‘moderate’ coarse sediment hydrologic hazard. Due to the anticipated increase in peak flow hazard and associated ability to transport coarse sediment, a ‘high’ coarse sediment hydrologic hazard has been assigned for those reaches under a total clearcut salvage scenario.

Downstream of the intake, in the bedrock canyon, the “Perpetual Slide” and other ravelling sediment sources will likely be aggravated by an increase in peak flows. Toe erosion along the base of the steep slopes may undermine and reactivate existing failures and/or initiate new failures. The result will be increased coarse and fine sediment loads downstream on the fan. Aggradation on the fan has been documented following historical flood events. The frequency and or magnitude of downstream aggradation on the fan can be expected to increase proportionally with increased flood frequency. The lowest reach of Trout Creek on the fan has been assigned a ‘very high’ hydrologic hazard.

3.3.3 Low flow hazard

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 Trout 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 low flow stream discharges in Trout Creek is considered low.

However widespread removal of forest cover can also expose the melting spring snow pack the spring to greater energy inputs, causing it to melt faster so that the freshet melt and associated peak flows occur earlier. This shift in the hydrograph can necessitate earlier use of reservoir storage and therefore earlier reservoir depletion later in the growing season, as shown in Figure 15.

Alila, *et al*., 2007, looked at changes in freshet peak flow magnitude and timing in Okanagan watersheds by modelling 100% clearcutting of watersheds (See Appendix D). The average timing in peak flow advance was from 0 to 4 days, with Camp Creek, a Trout Creek tributary, and Whiteman Creek, on the west side of Okanagan Lake north of Trout Creek, showing the largest advance (4 days).

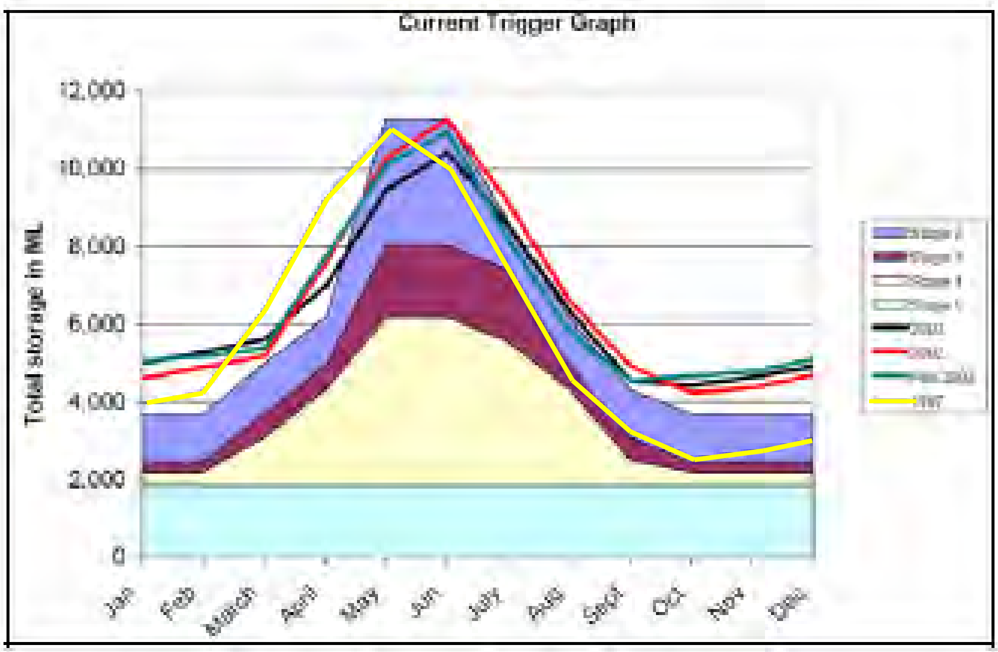

Figure 15. Trout Creek annual storage hydrograph for sample years, with water use management stages. Stages are storage scenarios prior to raising Thirsk Dam, which trigger increasing water use restrictions from Stage 2 through Stage 5. The coloured curves show water storage over time for various years, under an water user Operating Agreement governing water consumption rates. (From Aqua Consulting Inc., 2008).

In 1987 (yellow line, Figure 15), even though maximum reservoir storage was realized, the reservoir drawdown began approximately 30 days earlier than normal, presumably because of an earlier freshet peak due to natural variability in climatic conditions. As Figure 15 shows, this resulted in decreased reservoir storage availability in August and September. Any additional advancement of freshet runoff due to MPB and salvage-related effects could add to the natural climatic variation in freshet timing, and result in an earlier freshet, earlier reservoir use and decreased storage availability later in the growing season.

The results of 24 paired-watershed and numerical modelling studies of the effects of forest disturbance (harvest, fire, MPB) on earlier peak flows were reviewed (Pike and Scherer 2003, Alila, *et al.* 2007 and FBP 2007).

There was a large variability between study watershed sizes and conditions, forest disturbance or treatment and in the resulting measured freshet timing, which was between 0 and 20 days earlier in treated or disturbed watersheds than in control watersheds. There were also large differences in annual freshet timing within an individual study. For instance Alila *et al.* (2004) found that in Whiteman Creek their model predicted that over the 76 years of simulated climatic record the average freshet advancement over the control was 4 days. However individual annual freshet timing varied from 2 days later to 40 days earlier. Our conclusion is that this is an area that requires more study, and there is too great an uncertainty around study results to extrapolate from them to Trout Creek, other than to say that:

- if there will be any noticeable effect it will be to advance freshet timing, which could affect reservoir storage in the later growing season, and,
- the forest cover disturbance caused by the full salvage harvest scenario, and hence potentially freshet advancement, would be greater than the effect of MPB mortality and the no harvest scenario (see Figure 9).

3.4 CLIMATE CHANGE

The Okanagan Basin Climate Change Study projects an increase in temperature of about 1^{o}C of all months by 2020 (WMC, 2005). This will have two major effects on DoS water demand and supply.

There will be increased agricultural demand. With each increase of 1^{o}C it is estimated irrigation will require a 10% increase in total demand from April through October, which corresponds to 940 acre feet (WMC, 2005).

Higher temperatures will result in earlier snowmelt and an approximately 20 day earlier freshet melt and annual hydrograph peak, as shown in Figure 16 for Camp Creek. As discussed in Section 3.3.3 earlier spring runoff results in earlier storage hydrograph recession, earlier use of reservoir storage, earlier reservoir drawdown and less available stored water supply in the latter part of the growing season. If severe enough this would lead to increased restrictions on water use in DoS.

The combined effects of increased demand and earlier storage depletion were modelled with the water users Operating Agreement (prior to raising the dam on Thirsk Lake). In the 67 year modelling period, with a 1^{o}C increase in temperature, there would be 26 occurrence of Stage 4 and 4 occurrences of Stage 5 (see Figure 15), which would require severe use restrictions. Without the climate change temperature increase there would be no Stage 4 and 5 occurrences. Presumably in response to this possibility, Thirsk Dam has been raised, adding 25% more storage to Thirsk Lake. Figure 17 shows the same annual water demand curves as Figure 15 for select years, if there had been the additional storage now available in Thirsk Lake.

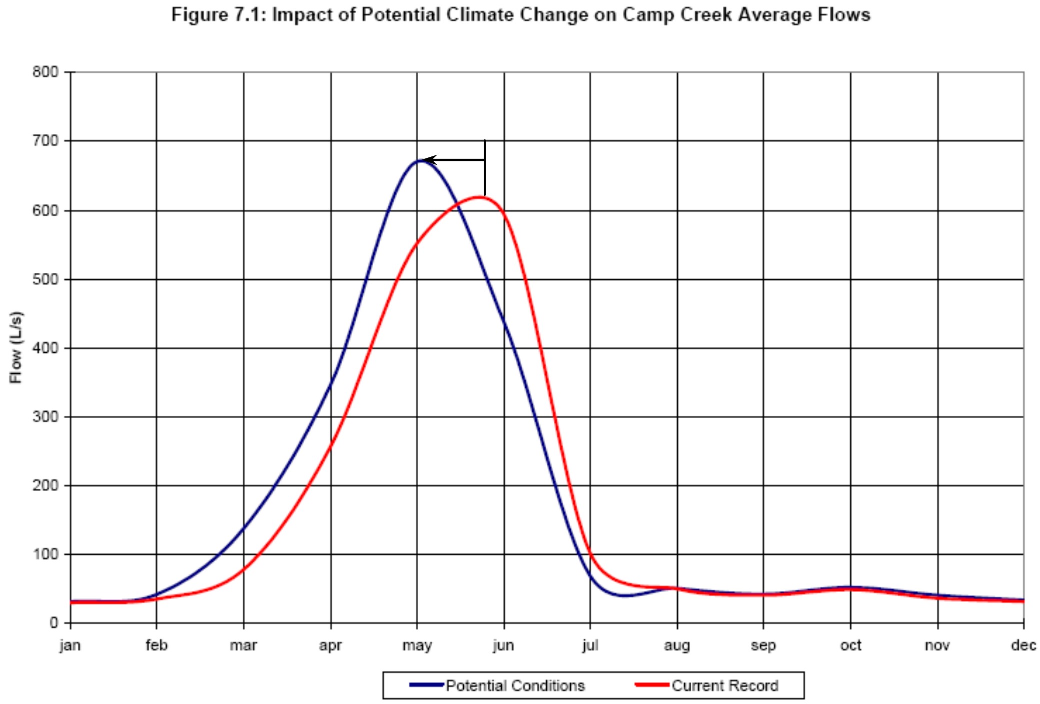

Figure 16. Projected climate change impact on freshet peak timing in unregulated flows in Camp Creek with a 1°C temperature increase predicted by 2020 (From: WMC, 2005).

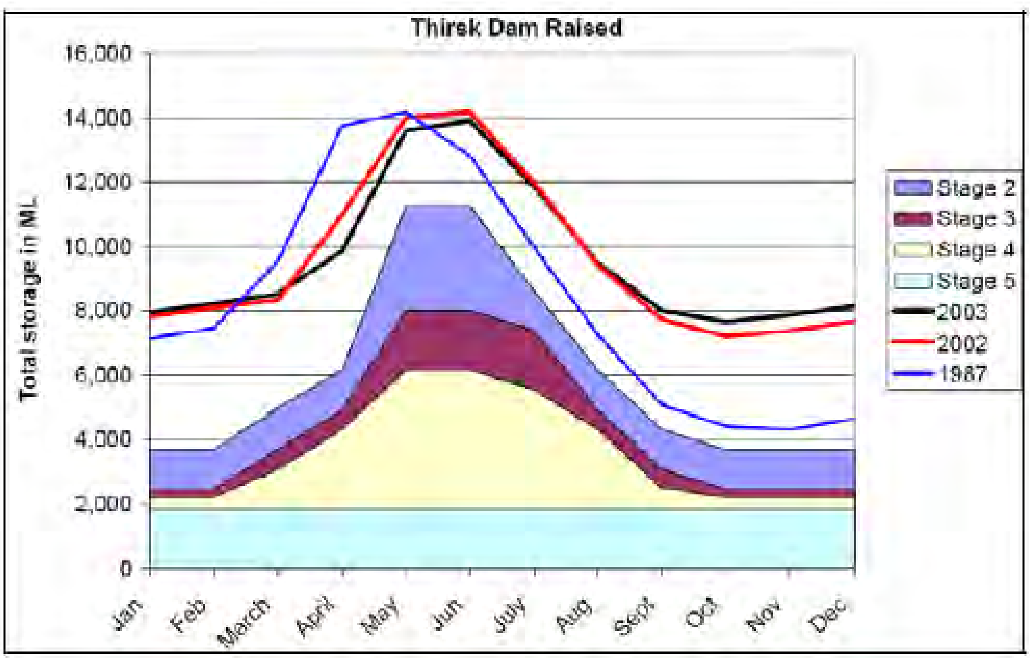

Figure 17. Water use stages and modelled use in specific years, with the additional storage available since Thirsk Dam was raised in 2008.

Climate change-related runoff timing effects will probably be cumulative with natural annual climate variability in freshet timing, and with MPB and salvage harvesting effects, should there be any. One can see from Figure 17 that, even with the increased storage available in Thirsk Lake, if reservoir filling and drawdown occurred an additional 20 days earlier in 1987, storage conditions in August and September would move into higher Operating Agreement stages, with restrictions on water use coming into effect.

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. But 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 management objective is to reduce fire risk.

4.0 CONSEQUENCES

4.1 WATER QUALITY AND INFRASTRUCTURE

Trout Creek is a Community Watershed that supplies irrigation and domestic water to the District of Summerland (DoS). Trout Creek satisfies approximately 90% of the District demand, with the remainder coming from Eneas Creek. DoS services approximately 4,100 residential users, 269 commercial users and 1,151 irrigation users (WPC, 2005). Of the total annual licensed volume of water, approximately 78% of the water is allocated to irrigation and the remaining for domestic consumption. The District of Summerland holds 13 water licenses; the remaining 32 domestic and irrigation water licenses are privately held.

The domestic water intake for the District of Summerland is located approximately 9 km upstream from Okanagan Lake on Trout Creek (Figure 1). In the summertime, water is transported from the intake site through an open flume for approximately 1.5 km into a large storage reservoir. In the winter, water is diverted into the municipal storage reservoir via buried pipe. From the storage reservoir water is directed into a new (2007) water treatment plant and then distributed for domestic consumption and irrigation use. For some irrigation users, water is drawn out of the reservoir prior to chlorination and is distributed using a separate pipe network.

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 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 DoS water intake, which is considered the consequence in a partial risk analysis. The vulnerability or other details of the DoS water supply and treatment system are not considered here.

4.2 WATER SUPPLY

A steady increase in water demand in the District of Summerland is expected in the future, from both increased population in DoS and from increased temperatures due to global climate change. Any decrease in the capability of available storage to meet that demand would be considered a high consequence.

4.3 FISH

Sportfish species within the watershed include Brook Trout (Salvelinus fontinalis) and Rainbow trout (Oncorhynchus mykiss) in the headwater tributaries and lakes, and throughout most Trout Creek mainstem reaches. Rainbow Trout are found in many tributary reaches. Mountain Whitefish (Prosopium williamsoni) and Kokanee (Oncorhynchus nerka) have been identified in the lower reach of Trout Creek. Trout Creek fish presence and habitat values for all reaches are presented in Appendix C, along with a fish consequence ranking for that reach, based on criteria presented in Table 2 (Section 2.4.3)

Figure 18 summarizes fish habitat consequence ratings for each reach. In general, fish habitat is widespread through the watershed, mostly due to naturally and/or artificially stocked lakes on the upper plateau. High fish habitat consequence ratings have been assigned to the entire length of the Trout Creek mainstem including the Headwaters Lakes. A 'very high' fish habitat rating has been assigned to Reach 1A on Trout Creek (fan) due to use of the area by kokanee for spawning. Although it has a high potential for spawning kokanee, current production is negligible due to flood control (channelization), seasonal low flows, and sediment from the 'Perpetual' landslide (Dobson 2006).

Most of the tributaries to Trout Creek have been assigned 'moderate' or 'low' ratings due to the lower habitat values associated with steeper gradients. Fish are assumed to be present wherever lakes are located in the headwaters.

4.4 SOCIAL INFRASTRUCTURE

Social infrastructure in the Trout Creek watershed (other than the community intake) include: urban and agricultural development on the fan and floodplain, the Highway 97 bridge, the KVR (now part of the Trans-Canada trail, logging road bridges, other private crossings (access and farm bridges) and other smaller licensed domestic and irrigation water intakes.

As discussed in Section 3.2.4., flood protection works near the mouth of Trout Creek were designed to accommodate extremely rare flood events. The improved channel and dykes should continue to protect urban and agricultural development on the fan.

The highway bridge appeared to accommodate the 1972 flood event with minimal damage. Improvements to the bridge have been made since that time, including scour protection. The highway crossing is therefore considered to exhibit a low vulnerability to flow regime change.

In some locations, the KVR (trans-Canada trail) is threatened by bank erosion, mostly due to its near constant proximity to the Trout Creek mainstem. Several bridges along the KVR have been upgraded and the elevated running grade generally provides more than adequate capacity. The KVR culvert crossing of Camp Creek is currently obstructed by a beaver dam, severely reducing its capacity.

Several farm bridges were noted to be failing, collecting debris and/or causing other issues in the channel. Those structures already having difficulty with the current flow regime will likely be immediately affected by relatively minor increases in peak flows and/or debris movement. A private bridge was washed away in lower Trout Creek during the 1972 flood (Thurber 1973).

Logging bridges over the main channel appeared to be for the most part well-constructed with adequate capacity. The bridge crossing Trout Creek on the Lost Chain Main may constrict the channel (Dobson 2001). Detailed analyses of existing bridge capacities were not conducted.

Twenty-seven privately managed water licenses are currently listed for Trout Creek. Of these, eighteen are for domestic use, the other nine being established for irrigation purposes. Several other licenses exist on tributaries in the watershed, [including Darke Creek – not relevant], Camp Creek, Empress Creek and other small springs. Infrastructure associated with these varies from gravity fed plastic pipes to permanent pump houses.

The following table outlines the assumptions used to develop infrastructure vulnerability. A detailed investigation of the vulnerability of individual structures/installations was not undertaken. These ratings represent an assumed general vulnerability based mostly on past performance of structures during floods of known frequency and magnitude.

Table 8. Social Infrastructure Vulnerability Rating

Item at Risk	Key Issues	Comments	Vulnerability Rating
Flood Protection Dykes	Increased peak flows, accelerated (coarse sediment) aggradation.	Dykes/channel were designed for >200 return period event. Riprap banks. No problems in 1997 flood. Aggradation may reduce channel capacity over long term. Few residences adjacent to channel.	**L**
Highway 97 Crossing	Increased peak flows, increased scour.	Survived 1972 event (Thurber 1973). Bridge has been upgrade/improved several times since 1972. Added scour protection. No issues in 1997.	**L**
Forestry Road Bridges	Increased peak flows, increased scour, increased debris movement.	No issues documented in 1997. Lost Chain FSR identified as a potential constriction (Dobson 2001). May not be designed for additional peak flow + debris.	**M**
KVR- Trans-Canada Trail	Increased peak flows, accelerated bank erosion, increased scour and debris movement through bridge sites.	Bridges typically well above channel. Some bridges have piers. Frequently close to channel in constricted reaches. Subject to undermining through bank erosion. Camp Creek culvert has existing issues.	**M**
Private/Farm Bridges	Increased peak flows, increased scour, increased debris movement.	At least one failing bridge identified. Under-designed and/or constructed. Abutments frequently encroach on channel, subject to scour. Low clearances.	**H**
Licensed Water Intakes	Increased peak flows, local aggradation, increased turbidity, increased debris movement, low flows (availability).	Intakes are often 'home-made' and unable to withstand flooding/debris impact. Constructed weirs susceptible to burial by bedload. Most will have no provision for filtering of suspended fines.	**H**

5.0 RISK ANALYSIS

5.1 WATER QUALITY AND INFRASTRUCTURE

Table 9 summarize the partial risk analysis for water quality at the DoS water intake. The hydrologic hazard, which includes both incremental peak flow and sediment hazards, is taken from Table 7 – Sub-basin Hydrologic Hazard Ratings for Lower Trout Residual (Reaches 2 to 8) which has the DoS intake at the lower end of Reach 2.

Table 9. Partial risk analysis for DoS water intake.

Reach	Hydrologic Hazard (peak flow and sediment)		Water Quality Element at Risk: DoS Water Intake		**Partial Risk**	
	MPB	Full Salvage	Fine sediment	Coarse Sediment	**MPB**	**Full Salvage**
Lower Trout Residual Reaches 2 - 7	Moderate	High	less aesthetic appeal, more microbiological activity, less effective primary treatment	Intake damage, maintenance	**Moderate**	**High**

For the MPB / no salvage harvest scenario there is a moderate peak flow and coarse and fine sediment risk to water quality and infrastructure at the intake. In other words, with full MPB-related pine mortality, some increased peak flows and associated fine and coarse sediment at the DoS intake may or may not occur, and if they do occur increases are not expected to be large.

If there is full salvage of all pine-leading stands, the peak flow and coarse and fine sediment risk to water quality and infrastructure at the DoS intake would be high. That is a significant increase in peak flow magnitude and frequency is considered likely (see Figure 14). A significant increase in fine (suspended) and coarse (bed load) sediment is also likely with this management scenario.

There is higher risk to municipal water quality associated with extensive salvage harvesting, because that harvesting removes the reduced, but still significant, hydrological function of much of the MPB attacked forest, as illustrated in the lower ECA curve for the infested forest as shown in Figure 9.

Note that the hydrologic hazard and partial risk values are the same as the ECA hazard values – moderate for MPB/unharvested and high for full salvage. So processing the ECA hazard through watershed and channel conditions does not increase or decrease the original hazard values; which means we did not find Trout Creek watershed and channel, for the most part, to be particularly sensitive to hydrologic disturbance. Therefore it will largely be management of the extent and rate of forest harvesting in the watershed that will control what actual level of risk is realized following the MPB infestation in Trout Creek Watershed. Exceptions are mainstem Reaches 8 to 12 and lower Camp Creek, for which mitigation strategies are discussed below in Section 6.

5.2 WATER SUPPLY

The consequence of potential decreases in later growing season water storage availability due to earlier use and drawdown of Trout Creek reservoirs is considered high.

As discussed in Sections 3.4 significantly earlier freshet timing is expected due to global climate change-related temperature increase. As discussed in Section 3.2.2, there may be some advancement in freshet timing due to MPB and salvage harvesting-related changes in forest cover in Trout Creek watershed; however it cannot be said with any certainty whether that effect will be significant or even noticeable, even with the total salvage of pine-leading stands management scenario. With the lesser effect of the MPB and no harvest scenario, it is unlikely a significantly earlier freshet would occur.

The risk of compromised water supply availability is probably significantly greater from global climate change-related temperature increases than from MPB and salvage harvesting effects. Nonetheless, any advancement in freshet timing due to MPB and salvage would be cumulative with climate change effects; and it is likely the increased forest cover effects of the full salvage harvest scenario would have a greater chance of affecting freshet timing than the MPB and no harvest management scenario (see Figure 9).

5.3 FISH

Table 11 provides risk ratings for fish habitat based on sub-basin hydrologic hazard (Table 8) and fish consequence values (Table D-1).

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. The hydrologic hazard is generally cumulative to the downstream end of the sub-basin. Where fish habitat is located in lakes near the upper end of the sub-basin, the hydrologic risk is diminished. Risk ratings in tributary basins generally represent risks near the lower end of the sub-basin as it approaches its confluence with Trout Creek. Risks in residual sub-basins generally represent risks to habitat values along the Trout Creek mainstem.

Under the MPB only scenario, 'high' risks to fish habitat occur in all mainstem reaches of Trout Creek, with 'very high' risks assigned to Reaches 8-12, Camp Creek and the fan. Mainstem Reaches 8-12 and Camp Creek have a very high risk as a result of higher channel sensitivity resulting from previous anthropogenic disturbances. The Trout Creek fan has a higher risk rating due to inferred 'very high' fish habitat values (kokanee spawning) near the lake and anthropogenic modifications to the channel. The remaining tributary channels and the Headwater Lakes area have been assigned 'moderate' risk ratings.

Table 10. 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
Headwaters	VL	L	**H**	M	M
North Trout	L	M	**H**	M	**H**
Upper Trout Residual (above Thirsk) Reaches 13 to 17	M	**H**	**H**	**H**	**VH**
Camp Creek	**H**	**VH**	**H**	**VH**	**VH**
Tsuh Creek	M	**H**	M	M	**H**
Lost Chain Creek	M	**H**	M	M	**H**
Bear Paw Creek	M	**H**	M	M	**H**
Bull Creek	M	**H**	M	M	**H**
Isintok Creek	L	**H**	M	M	**H**
Lower Trout Residual (below Thirsk) Reaches 8 to 12	**H**	**VH**	**H**	**VH**	**VH**
Lower Trout Residual (below Thirsk) Reaches 2 to 7	M	**H**	**H**	**H**	**VH**
Bedrock Canyon 1B (below intake)	M	**H**	**H**	**H**	**VH**
Fan 1A (below intake)	**H**	**VH**	**VH**	**VH**	**VH**

Under a full salvage scenario, all of the ‘moderate’ risk ratings increase to ‘high’ and most of the ‘high’ risk ratings increase to ‘very high’. This is a result of the increased hydrologic risk associated with loss of forest cover from extensive clearcut harvesting.

To mitigate risks, any improvements made to channel/bank stability (other than channelization or placement of riprap) will benefit fish habitat locally and downstream.

5.4 SOCIAL INFRASTRUCTURE

Assuming most existing social infrastructure is located near the lower end of the Trout Creek watershed, risk ratings can be developed using the hydrologic hazards derived for the lower mainstem channel (i.e. 'moderate' under the MPB scenario and 'high' under the clearcut salvage scenario (Table 7). Hydrologic hazard is combined with infrastructure vulnerability ratings presented in Table 9 to generate the infrastructure risk ratings summarized in Table 11.

Table 11. Social Infrastructure Risk Ratings

Item at Risk	Consequence Vulnerability Rating	Hydrologic Hazard (For Trout Creek Mainstem - Table 8)		Infrastructure Risk Ratings	
		MPB	Full Salvage	MPB	Full Salvage
Flood Protection Works	L	M	**H**	L	M
Highway 97 Crossing	L	M	**H**	L	M
Forestry Roads	M	M	**H**	M	**H**
KVR-TransCanada Trail	M	M	**H**	M	**H**
Private/Farm Bridges	**H**	M	**H**	**H**	**VH**
Licensed water Intakes	**H**	M	**H**	**H**	**VH**

Anticipated increases in peak flows associated with MPB and/or salvage harvesting are not expected to cause problems with major infrastructure items associated with the District of Summerland or Ministry of Transportation. Increases in bedload may eventually cause aggradation on the fan, reducing channel capacity. Thurber (1973) estimated 0.6m of deposition following the 1972 event. At some point channel dredging may be again required.

Some improvements to forestry crossings may be required if predicted peak flow increases are realized. The KVR/Trans-Canada Trail may require some maintenance where affected by bank erosion. Ponding of Camp Creek upstream of the KVR, caused by the beaver obstructed culvert, could lead to failure of the culvert/railway fill and a catastrophic release of collected water into Trout Creek at Reach 11.

Privately owned and developed bridges and water intakes are more likely to experience problems as a result of flow regime change. This is mostly a reflection of lower budget approaches to installation with little or no requirements for design. Existing problems were identified in the Trout Creek watershed. Changes in peak flows will make matters worse.

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The water quality parameters most strongly linked to MPB infestation and salvage logging 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 in Trout Creek watersheds (with no further harvesting) significantly increased peak flows and associated increased fine and coarse sediment at the DoS intake may or may not occur, and if it does, increases are not expected to be large. Following the full harvest of all pine-leading stands in the watershed, significantly increased peak flows and sediment delivery to the DoS intake are likely to occur.

Little advancement of freshet timing and associated late growing season water supply shortages are expected following the MPB/unharvested scenario. Larger impacts to later season water shortages would be expected following the full salvage scenario, but there is so much uncertainty about how large an effect this could be (how many days earlier maximum freshet flows could occur) that we do not make specific management recommendations for this issue. Management recommendations to address other impacts will likely adequately address MPB/salvage-related freshet advancement as well. While the effect on freshet advancement and later growing season water supplies from global climate change are expected to be larger than MPB/salvage impacts, the latter effects will be cumulative with climate change impacts.

There have been higher than optimum temperature and microbiological indicator (fecal coliform and E. Coli) levels in Trout Creek in the past. While post MPB/salvage effects are not expected to be large, they will be cumulative with pre-existing elevated levels. For nitrates/nitrite and algae significant effects are not expected. 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 Trout Creek are not expected.

There are high fish presence and habitat values along the entire Trout Creek mainstem. Where channel morphology has been degraded because of prior human activities (Lower Residual Reaches 8 to 12, lower Camp Creek and the Trout Creek fan) there is high channel sensitivity to additional disturbances, a high hydrologic hazard and a very high risk to fish values from both the MPB/unharvested and full salvage scenarios. Mitigation measures to reduce these risks in these reaches are presented in Section 6.3. For the remaining Trout Creek mainstem reaches there is a high risk to fish values from the MPB/unharvested scenario and a very high risk from the full harvest scenario.

For most tributary reaches fish values are considered moderate, hydrologic hazards are generally low to moderate, and there is a moderate risk from the MPB/unharvested scenario. Because there is a high hydrologic hazard in these reaches from the full salvage scenario, there is a high risk to fish values in most tributary reaches following full salvage harvesting.

All social infrastructure risk values have a higher risk for the full salvage scenario than for the MPB/unharvested scenario; because clearcutting in the full salvage scenario removes the existing hydrologic function of MPB attacked pine-leading stands, increasing hydrologic hazards. Risks to highway and flood protection works on the Trout Creek fan are considered low and moderate for the MPB/unharvested and full salvage scenarios respectively. Risks to the KVR-TransCanada Trail and forestry roads in the watershed are moderate to high respectively. Risks to private bridges and water intakes along the mainstem are considered high to very high respectively, because they generally have less of a designed or built safety factor.

Mitigation measures for high or very high risks can be focused on strengthening and/or protecting elements at risk, or on reducing stand-related MPB and salvage effects.

6.2 FORESTS FOR TOMORROW ACTIVITIES

The Forests For Tomorrow (FFT) 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 harvesting (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 treated stands have some hydrological function at the outset. Therefore these treatments can increase the short term ECA and potential hydrological impacts in the watershed. On the other hand the treatments promote more rapid recovery and a healthier and more economically viable stand.

It appears that activities that could increase forest health and productivity, while maintaining the existing hydrological function of the attacked stand, such as under-planting mature attacked stands, have had little success. This is due to the expense and to high seedling mortality from hares and rodents, which apparently can survive better in the attacked forest than in a clearcut. Our understanding is that under-planting is not considered a viable management option to mitigate potential MPB and salvage harvest hydrological impacts at this time

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 Trout Creek, as discussed in this report.

6.3 RECOMMENDATIONS

Strengthening Risk Elements

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

Stream channel restoration should be pursued in those reaches which have had channel structure and fish habitat degraded by past human activities. These are Lower Trout Residual Reaches 8 to 12 and lower Camp Creek and on the fan. Appendix E shows an example restoration design and details of restoration techniques prepared for a similarly impacted stream. If implemented, restoration would improve channel resiliency to increased peak flows, reduce fine and coarse sediment mobilization to lower reaches and the DoS water intake, and improve fish habitat through the treated and immediate downstream reaches.

Reducing Watershed Hazards

Modeling of the improved Thirsk Reservoir undertaken for this project indicates that it should be possible to attenuate flood peaks by managing reservoir filling in the spring, at least for events up to the 1997 freshet (estimated to be a 20 year return period event). Management would involve keeping the reservoir drained down until shortly before the peak, and reaching full pool on the declining limb of the hydrograph. Peak flow timing could be anticipated by monitoring snow recession near the H50 elevation. It is recommended that watershed supply managers further investigate the feasibility of flood control using existing reservoirs and outlet facilities as it may ultimately benefit channel stability (and hence water quality at the intake).

In the absence of an effective under-planting program for MPB attacked stands, we know of no way to reduce the MPB-related ECA hazard at the stand level. However the incremental risks related to the strictly MPB stand-level hazard are mostly moderate to the DoS water supply and social infrastructure, and high to some private infrastructure and fish values.

The higher incremental risks associated with complete salvage harvest of all pine-leading stands in Trout Creek watershed can be managed by managing the level and location of salvage harvesting. While it makes good hydrological sense to harvest attacked pine stands rather than "green" non-pine stands, there is still significant hydrological function in most pine-leading stands in Trout Creek. Removal of too much of that functioning attacked forest will increase risks in the watershed (see Figure 9). It is recommended that:

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

- Modelling of secondary stand structure should be based on an accurate picture of actual stand structure in the watershed. The data collected in seven south Okanagan watersheds used in this investigation is the only available random sampling of stand overstory and understory structure we are aware of in this area. Although limited, it is a good basis for the type of MPB attacked stand and watershed hydrological modelling we are recommending in the Okanagan. However, more is better. It is apparent from our results that the local VRI data, particularly in under-estimating the non-pine component of stands identified as pine-leading, is somewhat to quite inaccurate. New, and presumably more accurate VRI data is being prepared and is scheduled to be released starting in 2009. It would improve ECA and hydrologic risk modelling to carry out additional transparent, random and reproducible secondary stand structure sampling with a methodology similar to that used in this report (Huggard, 2009. Appendix B) or other similar studies completed in MPB infested areas of B.C. (Vyse, *et al.* 2007 and Coates, *et al*. 2009).

- From a strictly hydrological perspective (and we recognize forest managers have to balance many different forest values), the least hydrological impact would result if pine-leading stands with the lowest non-pine overstory component and lowest understory stocking were preferentially targeted for salvage harvest. From the data collected here the stands in the snow zone with least hydrological function would be younger MSdm stands followed by older MSdm stands and then ESSFdc stands (see Figures 6-8 and Appendix B). We recognize that individual stands within these broader classifications will have different characteristics, and it is understood that site specific evaluations of stand structure should supersede these broader recommendations in making harvesting management decisions.

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. However MPB infestation may not be the only significant stressor on Trout Creek forests in the near future. Global warming and global warming- related pathogens which could attack other tree types (spruce or fir beetle and others) and other disturbances such as fire, etc., are not improbable. Part of the determination of acceptable risk should include considering the potential hydrological effects of these other possible disturbances. To manage for them it would be prudent to apply the precautionary principle and preserve some hydrological function in the watershed above the minimum required to manage only for MPB and MPB-related salvage impacts.

Because of the types of forests in the South Okanagan, the expected hydrological effect of MPB infestation and pine tree mortality in Trout Creek Watershed are not expected to be catastrophic for any of the identified watershed values (risk elements), or even significant for most of them. Although salvage (and other) harvesting will increase hydrologic effects, with good management of harvesting rates and sites that recognizes the hydrological function of different pine-leading stand types, some forest development should be possible with a level of risk that is acceptable to watershed stakeholders.

7.0 CLOSURE

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

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

Prepared by: and

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

Alan Bates, P.Eng.
Consulting Engineer
Streamworks Unlimited

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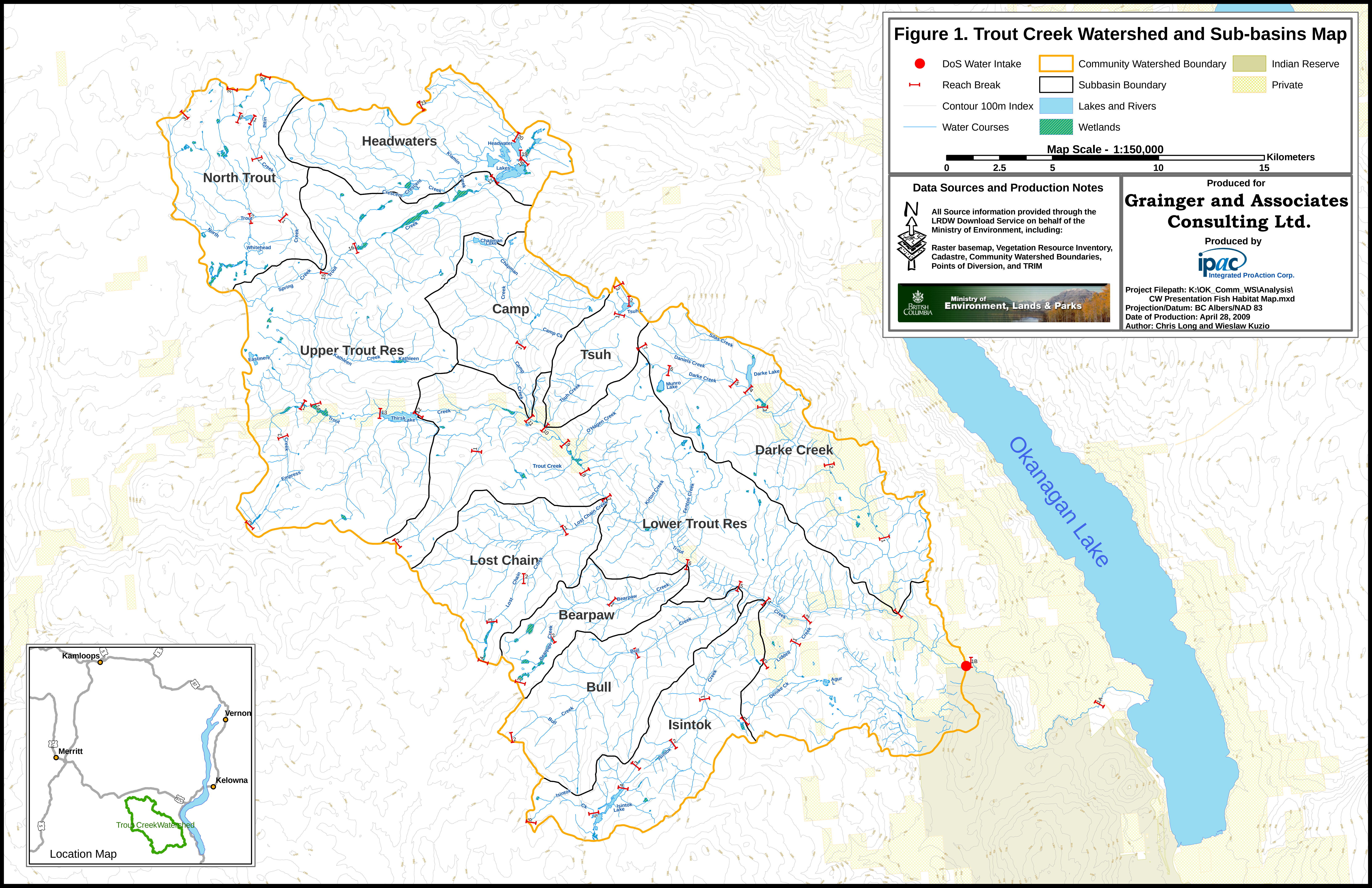

Figure 1. Trout Creek Watershed and Sub-basins Map

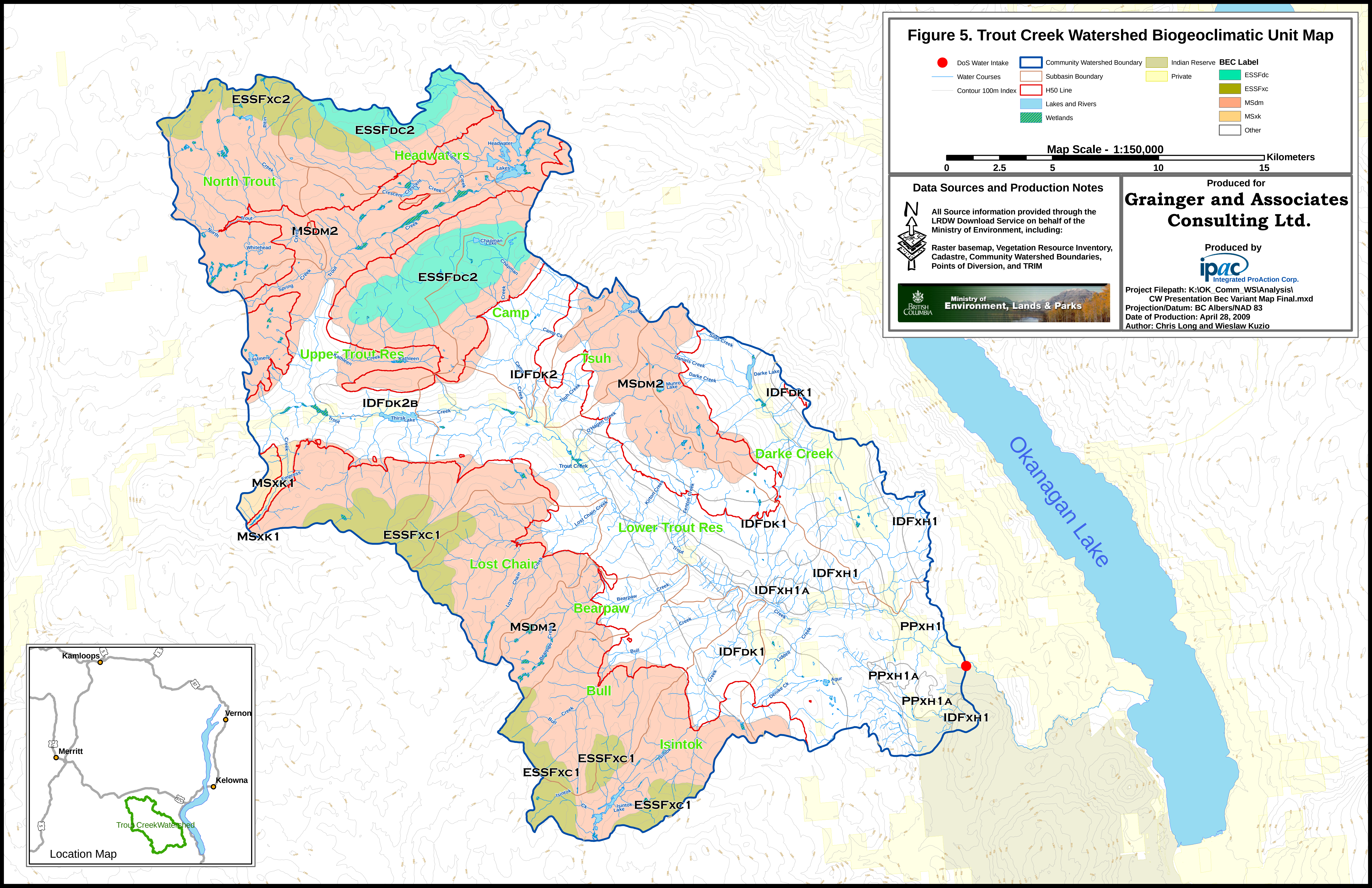

Figure 5. Trout Creek Watershed Biogeoclimatic Unit Map
DoS Water Intake
Water Courses
Contour 100m Index
Community Watershed Boundary
Subbasin Boundary
H50 Line
Lakes and Rivers
Wetlands
Indian Reserve
Private
BEC Label
ESSFdc
ESSFxc
MSdm
MSxk
Other
Map Scale - 1:150,000
0
2.5
5
10
15
Kilometers
Data 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 Bec Variant Map Final.mxd
Projection/Datum: BC Albers/NAD 83
Date of Production: April 28, 2009
Author: Chris Long and Wieslaw Kuzio
ESSFxc2
ESSFdc2
Headwaters
North Trout
MSdm2
ESSFdc2
Camp
Upper Trout Res
IDFdk2
Tsuh
MSdm2
IDFdk2b
IDFdk1
Darke Creek
MSxk1
MSxk1
ESSFxc1
Lost Chain
Lower Trout Res
IDFdk1
IDFxh1
IDFxh1
IDFxh1a
Bearpaw
MSdm2
PPxh1
IDFdk1
Bull
PPxh1a
PPxh1a
IDFxh1
Isintok
ESSFxc1
ESSFxc1
ESSFxc1
Okanagan Lake
Kamloops
Vernon
Merritt
Kelowna
Trout Creek Watershed
Location Map

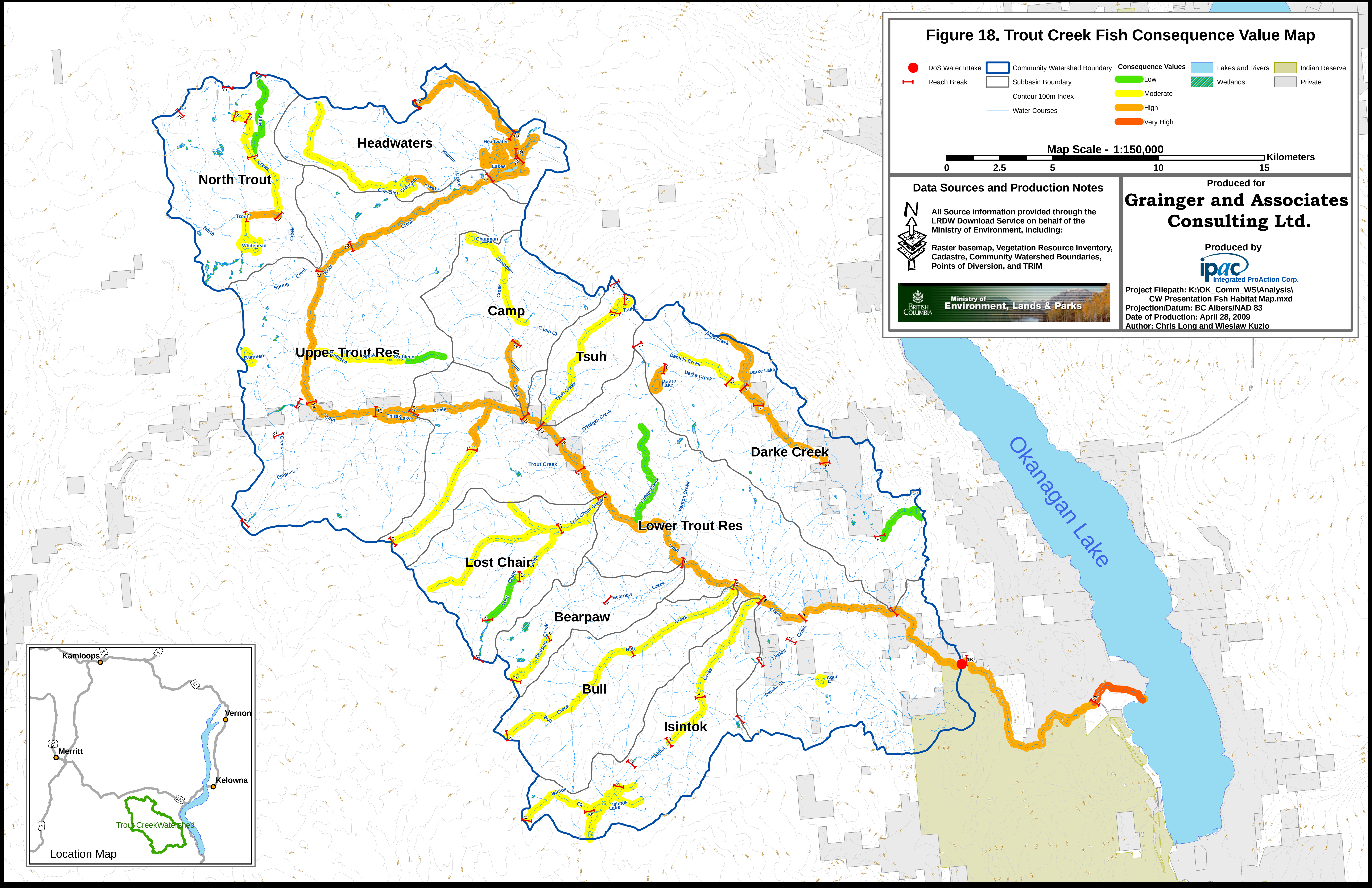

Figure 18. Trout Creek Fish Consequence Value Map