# Nadina Climate Change Vulnerability Assessment:

# Summary of Technical Workshop 3. Impacts on Hydrology

Workshop held, Nov 25, 2010, Smithers, BC.
Summary prepared by Dave Daust, Dec 15, 2010. Dave Wilford and Matt Sakals provided substantial and helpful comments on an earlier draft.

## *Participants*

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|---|
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## *Introduction*

The purpose of this workshop was to develop a high-level conceptual model describing how climate change might affect hydrology and aquatic habitat in the Nadina Forest District. The model will support a vulnerability assessment of the Nadina forest management regime. Hydrology was identified as a valued ecosystem service in an earlier workshop (Daust et al. 2010).

Dave Daust presented an overview of expected climate change in the Nadina. Jeff Anderson presented an overview of how patterns of variability in climate affect streamflow in the region. Then participants developed conceptual models of factors affecting streamflow, sediment input and stream temperature and discussed potential changes related to climate change.

## *Physiography and climate of the Nadina Forest District*

The Nadina falls within the Fraser Plateau hydro-climatic region (Figure 1), bordering the North Coast region on the west side. The western portion of the Nadina is relatively mountainous, with exposed bedrock and incised streams. It is heavily influenced by coastal climate and includes the coastal western hemlock and mountain hemlock, as well as the Engelmann spruce subalpine fir, Biogeoclimatic zones. For the purposes of considering climate change, we treat the eastern plateau portion of the Nadina, including the sub-boreal pine spruce, sub-boreal spruce and Engelmann spruce subalpine fir Biogeoclimatic zones, separately from the western mountains. The eastern plateau contains many small streams and wetlands on shallow, low-relief glaciated terrain.

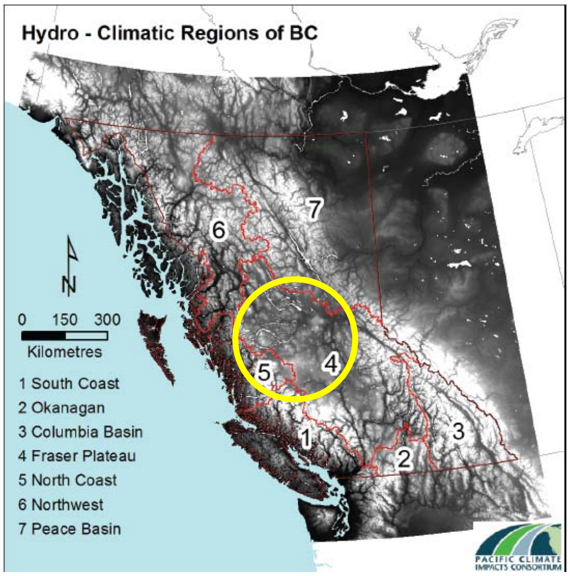

**Figure 1. Hydro-climatic regions of BC (from Rodenhuis et al. 2007). Nadina falls within yellow circle.**

## *Overview of climate change in Nadina*

### Projected climate trends

Climate in the Nadina is expected to get warmer and wetter, on an annual basis, with temperature and precipitation in winter increasing more than in summer (Table 1). A higher proportion of fall/winter/spring precipitation will fall as rain instead of snow (and some of that rain is expected to occur during rain-on-snow events). Spring snowpack water equivalents will decline by 5 to 20% in the eastern plateau and by 20 to 40% in the western mountains (Rodenhuis et al. 2007).

Across the Nadina, summer precipitation may either increase or decrease (range, Table 1). Rainfall in the western mountains may increase while rainfall in the eastern plateau may decrease. Climate projections show an increasing proportion of wetter zones (Interior Cedar Hemlock and Coastal Western Hemlock) in the western mountains and of dryer zones (Interior Douglas Fir) in the interior plateau (data from Tongli Wang for this project). The projected location of the boundary between the wetter and drier zones varies with climate model projection. Climatic trends over the past century also support the projected shift towards a warmer, wetter climate (Rodenhuis et al. 2007).

**Table 1. Median and range (90% of outcomes) of climate variables projected for 2055 in the Bulkley-Nechako Regional District from multiple runs of different climate models using different emissions scenarios ("ensemble" runs). Source: http://plan2adapt.ca**

| **Variable** | **Median Change** | **Range of Change** |
|---|---|---|
| Mean temp (annual) | +1.8 °C | +1.3 °C to +2.7 °C |
| Mean temp (summer) | +1.6 °C | +1.2 °C to +2.8 °C |
| Mean temp (winter) | +1.8 °C | +0.6 °C to +2.8 °C |
| Precip (annual) | +9% | +2 to +16% |
| Precip (summer) | +2% | -7 to +11% |
| Precip (winter) | +11% | -2 to +21% |
| Snowfall (winter) | +7% | -4 to + 16% |
| Snowfall (spring) | -52% | -68 to -10% |
| Growing degree days | +213 (deg x days) | +127 to 394 |
| Frost free days | +18 days | +11 to +29 |

While the overall trend towards increasing temperature and precipitation is well supported, variation among model projections is high. Uncertainty in model predictions arises from stochastic (probabilistic) variables in models, differences in model structure and differences in $CO_2$ emissions assumptions. Also, the models do not include climate oscillations that have historically caused substantial variation in temperature and precipitation among years and decades.

## *Historic climatic variability*

Three scales of climate variability will influence the future climate of the Nadina. Long-term climate trends act over centuries. Within long-term trends, decadal climatic oscillations and yearly "events" cause variability. Climatic oscillations have different temperature and precipitation patterns associated with their alternate phases. The Pacific Decadal Oscillation (PDO) and the El Niño/La Niña Southern Oscillation (ENSO) strongly influence the Nadina climate. The PDO has an approximate 50-70 year period (i.e. about 30 years in each phase). The ENSO is a quasi-periodic climate pattern (Wikipedia). El Niño/La Niña years are interspersed with "normal" years. El Niño events occur every two to seven years and last from a half a year to two years. La Niña events are of similar duration but somewhat less frequent. Synchrony between the warm PDO and warm ENSO correlates with increased wildfire (Heyerdahl et al. 2008). Ideally, climate models should create projections that account for climate oscillations.

The positive (warm) phase of the PDO brings warm waters to coastal BC where they remain "trapped" by water currents in the north pacific basin. Warm water increases coastal air temperature, reducing air pressure and increasing moisture-holding capacity, leading to low pressure systems. Low pressure systems off coastal BC lead to increased winter temperatures and increased precipitation in winter as these systems move inland (Table 2, Table 3). The negative (cool) phase of the PDO produces relatively higher pressure systems that lead to colder, drier winters and cooler summers (and possibly wetter August conditions). The causes of the PDO are not well understood.

**Table 2. Temperature in warm phase of climatic oscillation relative to cool phase, in Nadina (based on Rodenhuis et al. 2007). Arrows show magnitude of difference (three arrows represent roughly $2^0$ C). Winter is December, January, February.**

| | Winter | Spring | Summer | Fall |
|---|---|---|---|---|
| **El Niño (warm ENSO)** | ↑↑↑ | ↑↑ | ↑ | — |
| **Positive (warm) PDO** | ↑↑ | ↑↑ | ↑ | — |

**Table 3. Precipitation in warm phase of climatic oscillation relative to cool phase, in Nadina. Arrows show magnitude of difference (two arrows represent roughly 20% of mean precipitation; arrows in brackets show weak trends). Winter is December, January, February.**

| | Eastern Plateau | | | | Western Mountains | | | |
|---|---|---|---|---|---|---|---|---|
| | **Winter** | **Spring** | **Summer** | **Fall** | **Winter** | **Spring** | **Summer** | **Fall** |
| **El Niño (warm ENSO)** | ↓ | — | (↑) | (↑) | (↓) | — | — | (↑) |
| **Positive (warm) PDO** | (↑) | ↑↑ | —* | — | ↑ | ↑↑ | —* | — |

*August tends to be ↓.

We are currently probably in a negative (cool) phase of the PDO. The last positive (warm) phase spanned approx. 1977 to 2002 and was preceded by a cool phase from 1947 to 1977. The cool PDO may mask some of the temperature and precipitation increases associated with climate change in the Nadina.

The hydrological implications of the PDO are uncertain, but the cool PDO should probably lead to higher summer low flow levels. Cooler, drier winters (associated with the current cool PDO) may build larger snowpacks than warmer, wetter ones, if more precipitation falls as snow and melting declines. If the transition to hot summer conditions is rapid, larger snowpacks should lead to higher spring peak flows. Larger snowpacks should also increase groundwater recharge, leading to higher summer low flows. Additionally, cooler winters may lead to later spring freshets which could in turn lead to higher summer low flows as the “recession curve” shifts to later in the summer. Wetter August conditions, associated with the cool PDO, should also tend to increase summer flows. The cool phase of the PDO is associated with higher salmon escapement.

The warm phase of the PDO will tend to have the opposite effect of the cool phase. Warmer, wetter winters will increase rain on snow events, reduce snowpack and lead to earlier, smaller spring freshets. Increased glacial melt due to warmer weather can mask other hydrological effects of the warm PDO.

The positive (warm) phase of the PDO has a relatively high frequency of El Niño (warm ENSO) years (Mantua et al. 1997). Warm PDO and ENSO phases generate warmer temperatures, but the warm ENSO tends to reduce winter/spring precipitation while the warm PDO increases winter/spring precipitation. Transition periods between PDO phases and El Niño-La Niño events may create different hydrological patterns than those patterns characteristic of a particular phase.

### *General effects on hydrology*

A recent summary of climate model projections for BC summarizes changes to winter and summer weather, to storm-related impacts and to streamflow (Table 4).

**Table 4. Projected changes in winter weather, storm impacts and streamflow in BC (from Pike et al. 2008a, b).**

| Winter | Summer | Storms and their impacts | Streamflow |
|---|---|---|---|
| Temp ↑ | Temp ↑ | Frequency & magnitude ↑ | Earlier freshet |
| Precipitation ↑ | Precipitation ↓ ↑ | Landslides ↑ | Peak flow ↑ ↓ |
| Rainfall ↑ | Evaporative demand ↑ | Avalanche ↑ | Summer low flow ↓ |
| Snowfall ↓ | Plant transpiration ↑ | Erosion ↑ | Low flow period ↑ |
| Snowpack ↓ | Moisture deficits ↑ | Sedimentation ↑ | Perennial stream → intermittent* |
| Snowline up & north | Stream/lake temp ↑ | Big log jams ↑ | Snowmelt → hybrid rain/snow driven |
| Extreme weather ↑ | Risk to salmon ↑ | Channel stability ↓ | Rain on snow events ↑ |
|  |  | Log supply (long term) ↓ |  |

*where snowmelt not stored in ground water

## Streamflow

Climate and vegetation cover are the main factors influencing streamflow (Figure 2). Fall, winter and spring temperatures determine the proportion of precipitation falling as snow, the sublimation and melt rates and, therefore, the size of the snowpack. Spring temperatures and rainfall determine the timing of the spring freshet and along with snowpack determine the magnitude of the spring peak flow.

Streamflow regimes can be characterized by the type of water sources that generate them: snowmelt-dominated, rain-dominated, hybrid (rain and snowmelt) and glacier-augmented (Pike et al 2008b). In the Nadina, streamflow regimes are mainly snowmelt-dominated, which leads to prominent peak flows in spring (e.g., like shown in Figure 3). Some glaciers exist in the Morice headwaters, but do not contribute greatly to spring peakflows, rather they augment summer low flows . As the climate changes in the Nadina, winters are expected to become warmer and wetter, with a higher proportion of precipitation falling as rain (in spring). Snowpacks are expected to decrease by up to 50% in the western mountains and rain on snow events are expected to increase due to warmer temperatures. These changes may shift the snowmelt-dominated regimes to hybrid regimes, resulting in more frequent and higher (“spiky”) peak flows during fall and winter (and possibly ice dams) and earlier and lower spring peak flows (e.g., Figure 4). Such a shift would also reduce the size of the spring recession, which **could have a profound negative effect on aquatic habitat** and could affect the sorting and deposition of finer sediment. Winter recessions are very rapid and do not perform the same degree of sorting function.

In summary, climate change is expected to affect streamflow regimes in several ecologically important ways (Figure 3). Many organisms are adapted to the timing and size of the spring recession (e.g., cottonwood, fish, amphibians, invertebrates). The spring recession provides a relatively stable period of moderate flow and temperature. Long-term changes to the average or variability of the pattern of the recession could negatively impact these organisms. Also, more frequent and spiky peak flows will disturb the benthos and spawning redds. Together, these changes may lower aquatic productivity and/or change the structure of the aquatic community.

Snowmelt and rainfall that reach the ground either flow over land (e.g., over frozen, saturated or otherwise impermeable ground), flow laterally through unsaturated soil, are taken up by plants, or pass into groundwater storage (e.g., aquifers) where they percolate downslope to reach stream channels relatively slowly. Watersheds with large groundwater storage capacity moderate the transfer of precipitation events to streams thereby reducing flashiness, reducing high flows and increasing low flows. Aquifers that store water in the western mountains of the Nadina are relatively shallow and in general have limited storage capacity. They are primarily glacio-fluvial and alluvial fan deposits. Till is a relatively poor aquifer. There are many waterbodies in the interior plateau, giving the appearance of good water storage capacity, however, many of these water bodies are not connected to stream systems (e.g., bogs) and others have limited volumes to contribute to streamflow due to the relatively high elevational base levels of their outlets. I. As well as reducing spring high flows, reduced snowpacks associated with climate change decrease groundwater storage (this is something that has been observed over the past few decades in the Nadina).

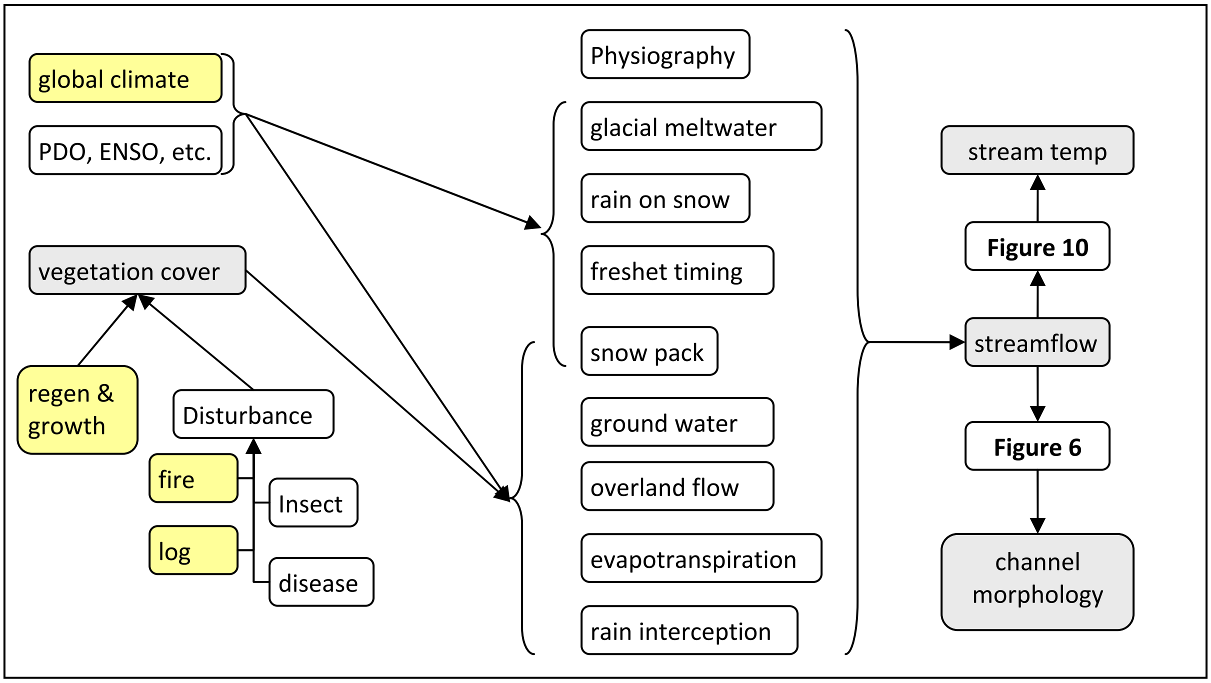

**Figure 2. Conceptual model of factors influencing streamflow. Boxes show biophysical components and processes. Arrows show chains of influence. Grey boxes show key variables. Yellow boxes show human influences.**

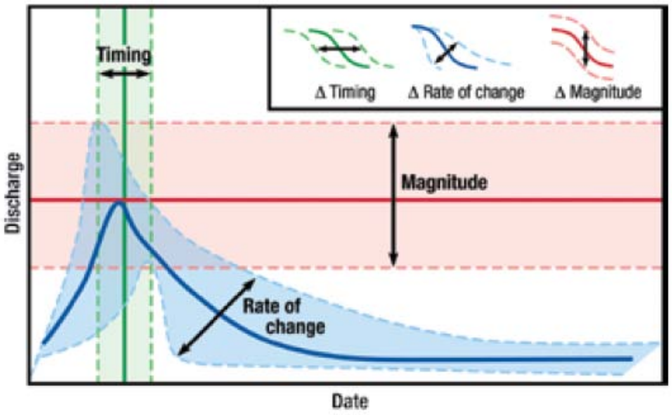

**Figure 3. Aspects of streamflow regimes that may change in response to climate change include the magnitude and timing of flow and the rate of change of flow during the recession. This graph shows a generalized snowmelt-dominated flow regime (Yarnell et al. 2010).**

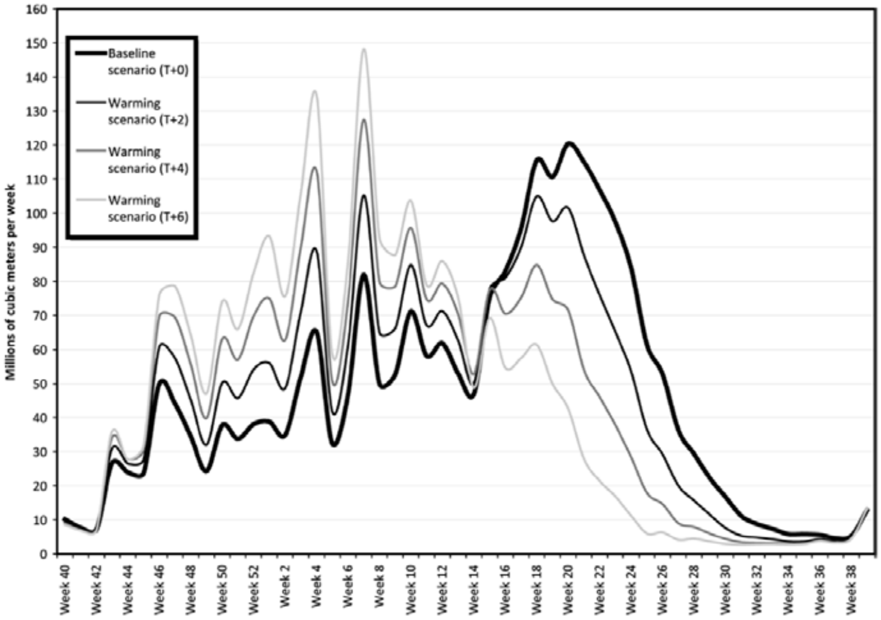

**Figure 4. Modelled streamflow regime in California Mountains varies with assumptions about temperature change (Yarnell et al. 2010). Increased temperatures increase winter high flows and reduce spring high flows. The timing of the spring freshet advances. This concept may apply to the western mountains portion of the Nadina.**

## *Vegetation cover in a watershed*

Vegetation cover buffers the direct effects of precipitation by intercepting rainfall, increasing evapotranspiration, increasing the infiltration capacity of soil, and reducing overland flow (Figure 2). Vegetation affects the snowpack by intercepting snow, intercepting rainfall that leads to rain on snow events, and by filtering solar radiation, reducing snowmelt. Use of water by vegetation also reduces inputs to groundwater and can lead to less inputs to low flows.

Natural and anthropogenic disturbances remove vegetation cover (which grows back over time), reducing interception of rainfall, reducing evapotranspiration and potentially increasing the amount of water transferring to ground water. The net effect can be an increase in water inputs to streams during the low flow period. Stands disturbed by mountain pine beetles can reduce evapotranspiration by about 35% (pers. comm. Dave Spittlehouse, Innovation Branch, Victoria, BC). Areas of (seasonally) high groundwater table may become more common.

As the denuded proportion of a watershed increases, the capacity of the landscape to buffer rainfall events decreases, leading to greater stormflow and rapid changes in streamflows (flashiness), both factors that may increase sediment delivery and channel instability. Over and above the effects of vegetation loss, hot fires damage soil porosity, burn off the absorptive protective litter layer and may create a hydrophobic layer, all of which reduce water infiltration and increase overland flow. With overland flow, a 5 to 10 year precipitation event could cause a 200 year flood. To date, no significant hydrological issues related to fires in the Nadina have emerged, but they have been recognized in the southern interior.

In addition to removing vegetation, logging can also compact soils and alter drainage patterns (e.g., skid trails), affecting infiltration and overland flow, but usually impacts are limited in extent within cutblocks. Road networks and related drainage systems are the most important alteration of natural drainage patterns and can result in significant implications for landslides in gentle-over-steep terrain such as that found in the Nadina (Grainger 2002).

The threshold for vegetation loss in a watershed before streamflow regimes are adversely affected depends greatly on watershed characteristics. A rule of thumb suggests the equivalent clearcut area (ECA) should not exceed 30% without a watershed assessment (Figure 5). ECA tallies disturbance over time but also accounts for the hydrological recovery of stands as they regenerate and grow. When stands with adequate stocking reach 9 m tall (i.e., approximately 20 to 40 years after disturbance depending on site productivity), they are considered to be 90% recovered, hydrologically. Plantations never reach the complex stand structure associated with full hydrological function. Mature and old natural stands are considered to have 100% hydrological function.

Climate change may increase ECA due to increased natural disturbance. Stand-replacing disturbance varies by BEC subzone; it could roughly double due to increased fires, insects and disease (Table 5). A doubling of the stand-replacing disturbance frequency (halving the disturbance return interval) leads to a high proportion of forests (36 to 48% of the SBS) being less than age 30 (approx. hydrologically recovered). Roughly accounting for hydrological recovery, ECA should be about half the proportion of forest less than age 30 (i.e., 18 to 24%). Variation in natural disturbance over time could easily create situations where natural disturbance exceeds the 30% ECA level in the SBS for triggering a watershed assessment. Additionally, stand regeneration, growth and hydrological recovery may be hampered by increases in diseases and other biotic and abiotic stresses related to climate change.

Partial disturbance of a stand (i.e., not fully stand-replacing) also affects ECA. For example, stands disturbed by mountain pine beetles, and that have lost their needles, are assigned an ECA value of 50%. Salvage logging reduces the hydrological function of stands disturbed by mountain pine beetles, at least initially. Beetle-killed stands are hydrologically more functional that logged sites for the first 10 to 25 years following disturbance, but then plantations become more functional (Huggard and Lewis 2007).

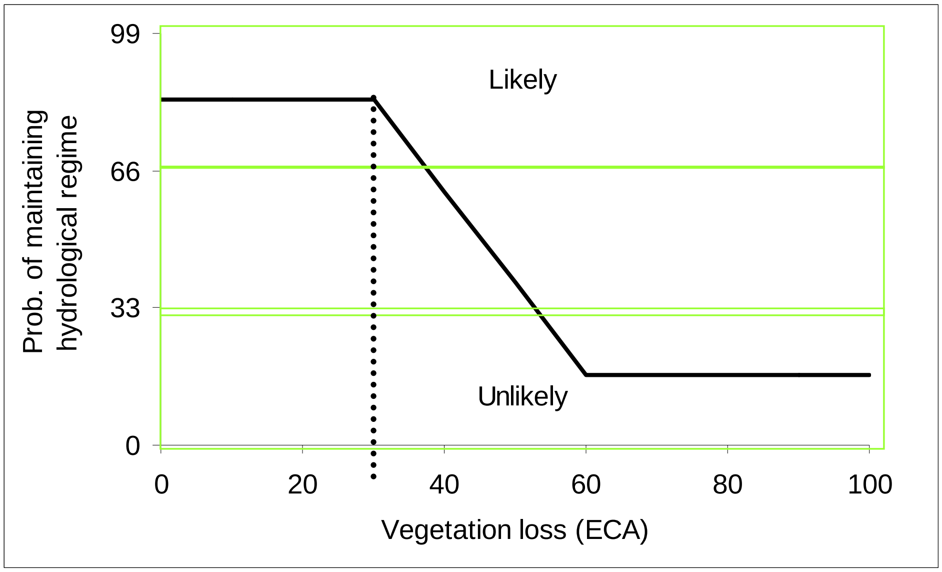

**Figure 5. Hypothesized response of streamflow to vegetation disturbance and regrowth. ECA rescales a time-series of disturbance and hydrological recovery processes into a single metric that expresses the hydrologically equivalent area of totally denuded forest. Watersheds with higher snowpacks are more sensitive to vegetation loss. Due to scale effects, smaller watersheds are more sensitive than larger ones.**

**Table 5. Average proportion of area disturbed within the last 20, 30 and 40 years depends on disturbance return interval, which varies with BEC Subzone (Steventon 2002). Hydrological greenup typically occurs within 20 to 40 years of disturbance. ECA is estimated to equal roughly half of the total area disturbed within 30 years.**

| Subzone | Historic Mean Return Interval | < 20 yr | < 30 yr | < 40 yr | Projected future Return Interval | < 30 yr | Approx. ECA |
|---|---|---|---|---|---|---|---|
| SBPSmc | 91 | 0.20 | 0.28 | 0.36 | 46 | 0.48 | 0.24 |
| SBS dk | 93 | 0.19 | 0.28 | 0.35 | 47 | 0.48 | 0.24 |
| SBS mc | 133 | 0.14 | 0.20 | 0.26 | 67 | 0.36 | 0.18 |
| ESSF mc | 219 | 0.09 | 0.13 | 0.17 | 110 | 0.24 | 0.12 |
| ESSF mk | 689 | 0.03 | 0.04 | 0.06 | 345 | 0.08 | 0.04 |
| ESSF wv | 566 | 0.03 | 0.05 | 0.07 | 283 | 0.10 | 0.05 |

## *Stream channel morphology*

Stream channel morphology strongly influences the quality of aquatic habitat.

### *Average flow years*

Stream morphology is largely determined by streamflow regime (Figure 6). Peak flows, particularly in flood years (i.e., flood return periods of ten years or more), have the largest influence on stream structure. At a given discharge volume, water depth determines the energy available to mobilize sediment (i.e., of different sizes) and large organic debris. Constricted channels (naturally or anthropogenically) are relatively deeper and thus have more erosive energy. Higher peak flows result in greater sediment transport, regardless of the flood-generating mechanism. During the recession limb of the hydrograph  (summer for snowmelt dominated systems), the particle size that can be carried decreases. Long recession periods sort and deposit fine textured material, which contributes substantially to aquatic habitat. Recession has a minor influence on stream structure. Larger rocks and large woody debris that do not move with most peak flows anchor the stream structure (e.g., creating stable riffles and pools).

Nadina stream systems are “low energy” systems relative to coastal ones. Sediment pulses from major flood events take a long time to pass through the system—recovery of stream structure takes time. Large wood does not move easily and provides long-term anchoring.

Currently in the Nadina, peak flows occur in spring and are followed by a long recession period. Climate change could increase the frequency and size of high flows in the fall and early winter and lower the size the spring freshet (e.g., Figure 4). More spiky peak flows could lead to an increase in bedload movement and a decrease in channel stability, with less time between events for channels to become stable. The net result could be a decrease in aquatic productivity.

### *Flood years*

Channel morphology, like forest age class structure, reflects processes of disturbance and recovery. Large disturbances shape the system: periodic floods provide sources of logs and sediment, necessary components of stream structure. The streambed does not recover its characteristic pattern and habitat value until years after a large disturbance (depending on the degree of disturbance, the type of channel, the magnitude of intervening flood events that shift bedload and add more large sediment and debris, etc.).

Above average peak flows alter stream structure and provide large inputs of sediment. They can significantly alter stream structure, including channelizing riffle-pool structures and shifting gravel from spawning beds. Peak flows erode banks, increasing sediment input. Sediment wedges result from substantial sediment inputs and can substantially alter stream morphology for decades as the sediment slowly moves through the channel system. Road prisms adjacent to streams may contribute fine sediment and roads on floodplains and fans can constrain natural stream movement or lead to avulsions. Excess sediment deposition in spawning beds can greatly reduce habitat value, but spawning areas require continuous recruitment of sediment from upstream to replenish sediment lost by fluvial action. Too much fine sediment can blanket spawning beds and reduce spawning gravel quality and benthic production. Too little sediment input leads to coarse bed material. Debris flows and very high flows (e.g., 2 x average peak) mobilize large amounts of bedload and woody debris and alter stream structure by depositing piles of debris in reaches with less energy.

Climate change could increase average yearly peak flow (e.g., due to increased winter precipitation and the shift to rain-on-snow events), leading to increased scour and sediment input (from bank and bed erosion plus potentially landslides). An increase in average peak flow will also increase the frequency of flood events (discharge above a certain level) if variability among years does not decrease (Figure 7). A small increase in flood size, due to climate change, could greatly increase return period. One study suggested that the historic 50 year flood could occur every 5 years (Alila et al. 2009). This also implies that every 50 years, we would see a flood level that the channel may not have experienced for a considerable period of time (i.e., 500 year flood).

Climate change could also increase the year to year variability in peak flows, because warming is expected to increase variability in temperatures and precipitation. An increased mean peak flow, with no change in variability, increases the amount discharged in flood years but also in low flow years, whereas higher variability increases discharge in flood years and decreases discharge in low flow years (Figure 7). An increased frequency of flood events reduces the recovery period between these events. If only the average increases, stream morphology will probably differ from historic patterns, but the new pattern will be relatively stable. If variability increases stream morphology will probably be more unstable. As a rough estimate, a two-fold increase in flood frequency may still allow a sufficient recovery period to maintain characteristic stream structure and habitat; a ten-fold increase would be a severe impact (Figure 8).

Trees that fall into streams may remain in place or be transported downstream during floods. Downed wood may trap sediment, influencing stream morphology and habitat value. Most downed wood usually comes from within 10 m of the stream channel. Streams need large woody debris, however, large down wood is a less common structural feature in interior BC than in coastal BC and the supply of down wood is not expected to be limiting under current forest management practices. Most wood, however, is not functional as fish habitat because it spans the channel.

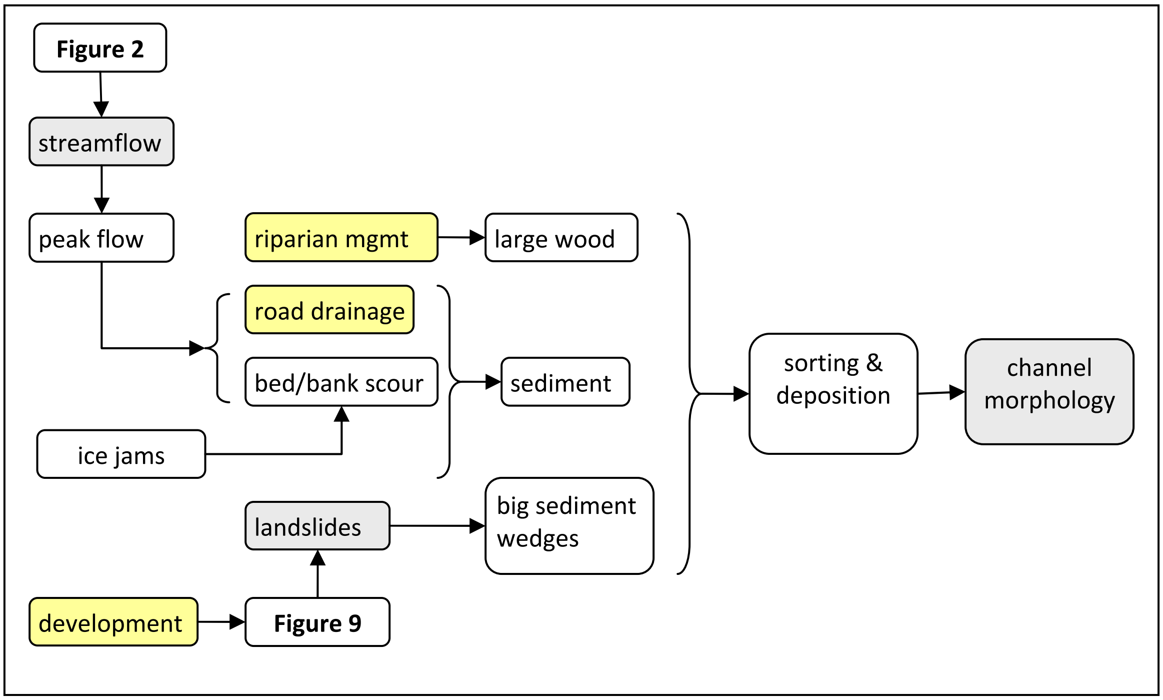

**Figure 6. Conceptual model of factors influencing channel morphology. Boxes show biophysical components and processes. Arrows show chains of influence. Grey boxes show key variables. Yellow boxes show human influences. Landslides include debris flows.**

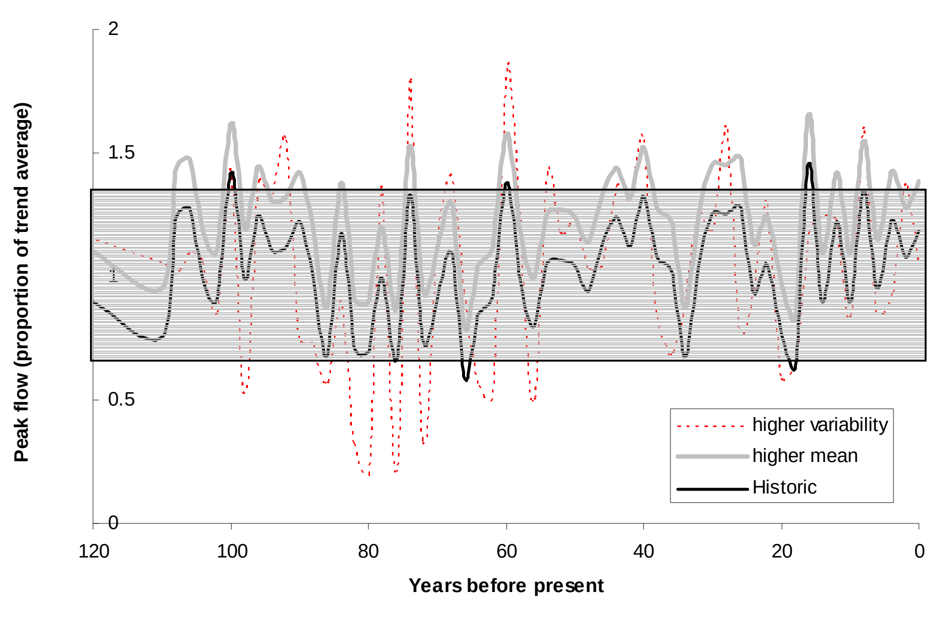

**Figure 7. Hypothetical example of changes to historic peak flow (black line) due to an increase in average peak flow (grey line) and an increase in variability of peak flows (dashed red line). An increased mean and/or an increased variability increase the frequency of flood years (e.g., above grey box). Increased variability also increases the frequency of low peak flows (below the grey box).**

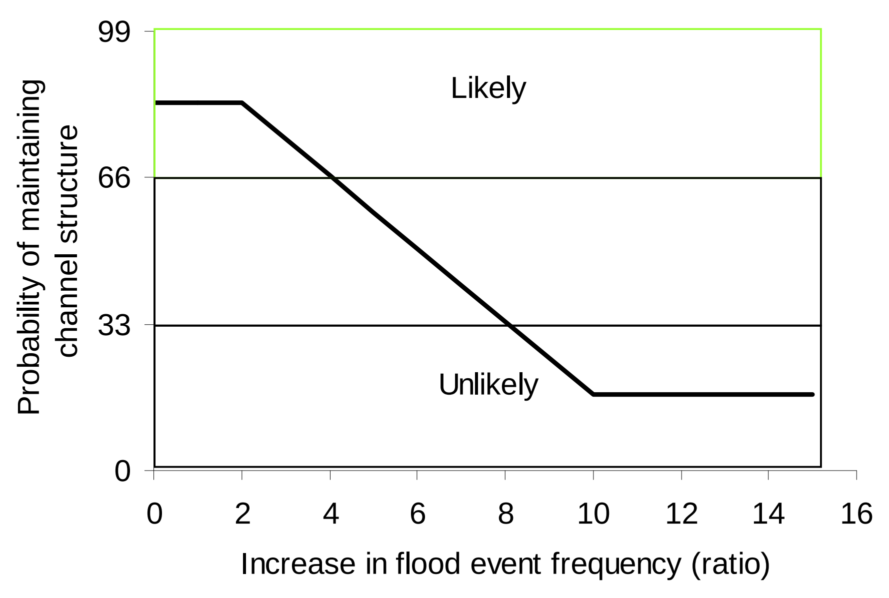

**Figure 8. Hypothesized probability of maintaining aquatic habitat value versus increase in flood frequency.**

## *Water quality*

Water quality is mainly governed by fine sediment input, coming primarily from road drainage structures, road surfaces and natural fine-textured streambanks.

## *Landslides and sediment*

Sediment in Nadina streams comes from several sources (Figure 6; Figure 9). Stream bed and bank erosion (including bank failures) are the main sources of sediment. High peak flows scour stream beds, erode banks, create log jams and can undercut slopes, leading to mass movements (landslides). Heavy rainfall that saturates soil or development activities that destabilise toe slopes can cause slump earth flows. Most landslides in the eastern plateau are slump earth flows, and most are undercut by streams. Deep-seated landslide movement characteristically responds to elevated groundwater tables as a result of prolonged wet periods (seasons). Some deep-seated landslides also occur in the western mountains where shallow landslides are important sediment sources. Shallow landslides are precipitated by 2 to 3 days of heavy precipitation that saturates soils. The connectivity of landslides to stream channels and the ability of a channel to transfer the delivered sediment are important considerations when considering the effect of landslides on channel networks.

While bed and bank erosion can, depending on sediment size, substantially alter stream morphology, major destruction of stream systems is associated with landslides. Landslides and erosion (bed and bank) will probably increase due to increased precipitation and higher peak flows associated with climate change. Also, warmer temperatures can melt permafrost that provides structural support within soils. To date, however, landslides have occurred relatively infrequently in the Nadina. An increase in landslide activity would likely expose channel systems to sediment inputs beyond the current “natural range of variability”.

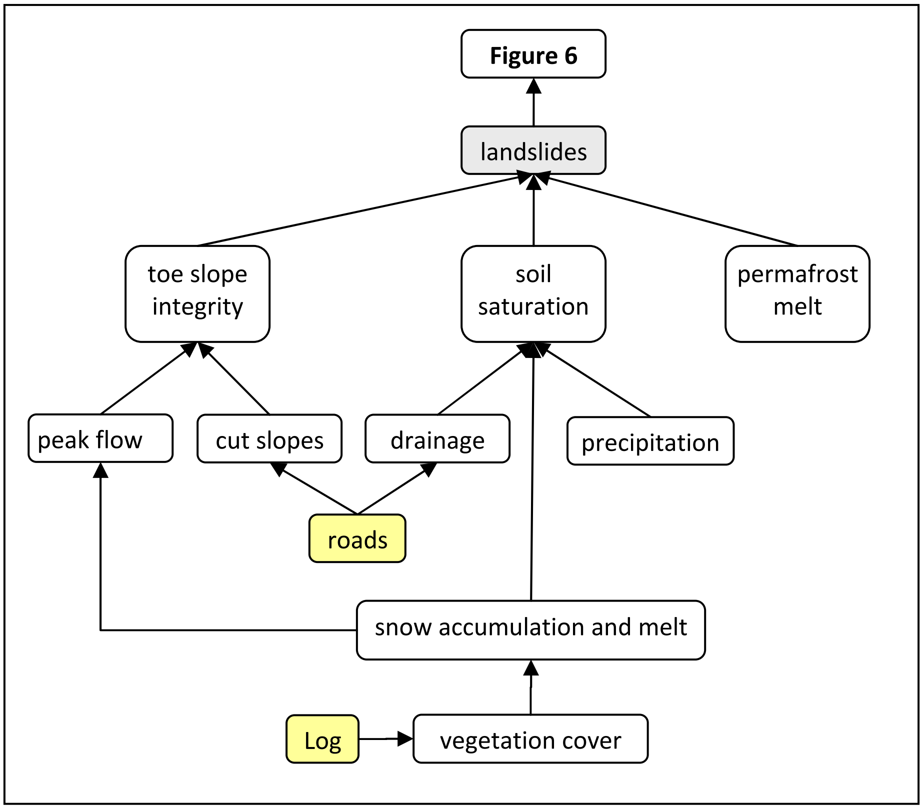

**Figure 9. Conceptual model of factors influencing landslides. Boxes show biophysical components and processes. Arrows show chains of influence. Grey boxes show key variables. Yellow boxes show human influences. Roads include main access roads, on-block roads and skid trails.**

## *Stream temperature*

Stream temperature has a large effect on aquatic communities. Of particular concern, several species of fish are temperature sensitive. Some salmon species and bull trout are especially sensitive. In the Babine, the interior race of sockeye salmon, which includes the naturally early spawning Babine stock, is temperature sensitive. A two degree temperature increase beyond optimal leads to an exponential increase in disease and parasitism in salmon. Currently, ocean conditions have a greater influence on salmon survival than stream conditions. Whether this relationship still holds in the future depends on how oceans and streams each respond to climate change and other anthropogenic forces.

Stream temperature depends on the volume and flow rate of water being warmed, air temperature and solar radiation incidence, among other factors (Figure 10). The spring freshet, glacial meltwater, rainfall and groundwater sources contribute to water volume. Lower volumes of water warm more rapidly and pose higher risk to temperature sensitive fish. Riparian vegetation and stream width (channel morphology) influence solar radiation. Wide channels reduce riparian shading. Higher peak flows, due to climate change, can widen channels. Glacial meltwater and groundwater cools streams, other sources such as ditchlines can have a significant warming effect. Characteristically stream temperatures in the Nadina reach maximums during summer low flow periods.

Summer low flows can be a critical period for resident and rearing fish because stream temperature can be high and escape cover can be high and dry.

### *Summer low flows*

The timing of the spring freshet influences the timing of summer low flows. Later freshets lead to later low flows, all else being equal. Pushing the low flow period into the cooler, wetter weather of autumn can also lead to higher low-flow discharges.

### *Warm water sources*

Road ditches and logged sites with shallow water tables can lead to increased stream temperatures. Such warm water sources are only a problem if they are connected to stream systems. Until roads have shade from regenerating forests their ditchlines can deliver heated water, even if “normal” deactivation has been undertaken. Recognizing this, “hydrological deactivation of roads” (e.g., more cross-ditches than would normally be prescribed) was recommended as a management strategy in the Nadina Watershed years ago (Wilford, pers. comm.).

In the interior plateau sites with shallow water tables and humic gleysol soils (e.g., SBSmc2 07 site series) are relatively common. If these sites are logged, the water table rises and the black soil absorbs solar radiation and heats the water (one site had $28^0$ C water). Where these sites are connected to stream channels the effect on stream temperatures can be significant. Mounding, a practice used to increase plantability of these wetter sites, and disc trenching on other sites to improve seedbed conditions and reduce vegetation competition, can significantly affect soil and surface water movement. The resulting pooling/ponding and subsequent heating of water has the potential to influence stream temperatures (and the hydrograph—peak and low flows).

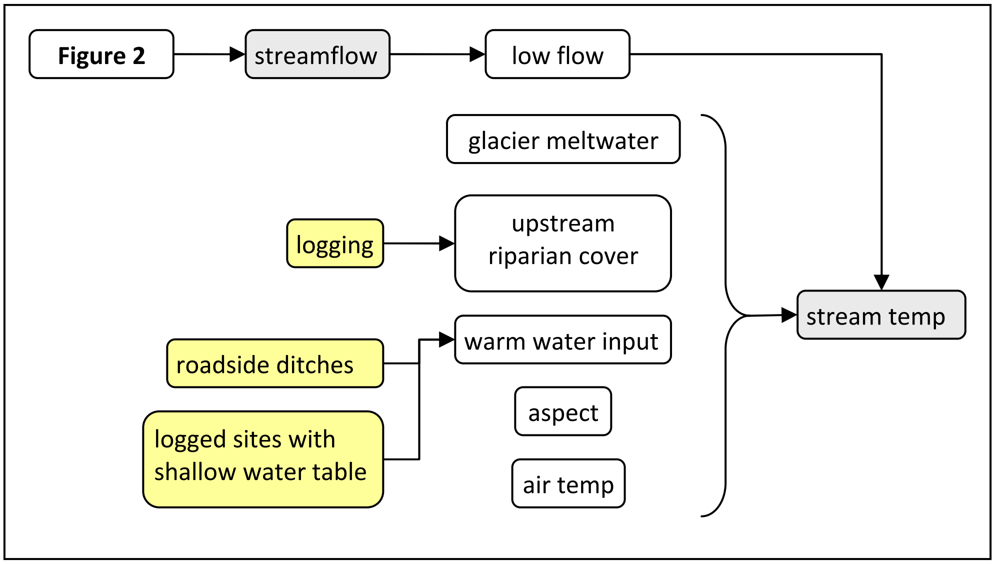

**Figure 10. Conceptual model of factors influencing stream temperature. Boxes show biophysical components and processes. Arrows show chains of influence. Grey boxes show key variables. Yellow boxes show human influences.**

## *Riparian vegetation*

Riparian vegetation around small streams has a large effect on stream temperature because 80% percent or more of the total channel length in a watershed is composed of small 1st order streams.

In temperature sensitive watersheds, riparian vegetation along small streams blocks solar radiation, reducing stream temperature. Because they are narrow, these small streams are typically heavily shaded when vegetation is present. Such shading is most critical during low flow periods that occur in hot sunny weather (e.g., in August), provided the channel has water flow. Low flows and warmer summer temperatures are expected to become more common in the future. Already, increased mean stream temperature in Carnation Creek has been associated with an increase in regional air temperature. Sensitivity to temperature varies by watershed.

In the Nadina, several temperature sensitive watersheds have been identified in land use plans. Currently in these watersheds, reserves are being left around 70% of small streams that flow in August (typical period of low flow and hot weather). Figure 11 shows the hypothesized relationship between riparian cover around small streams and the probability of avoiding lethal temperatures. Riparian vegetation is also retained along larger streams, due to legislation.

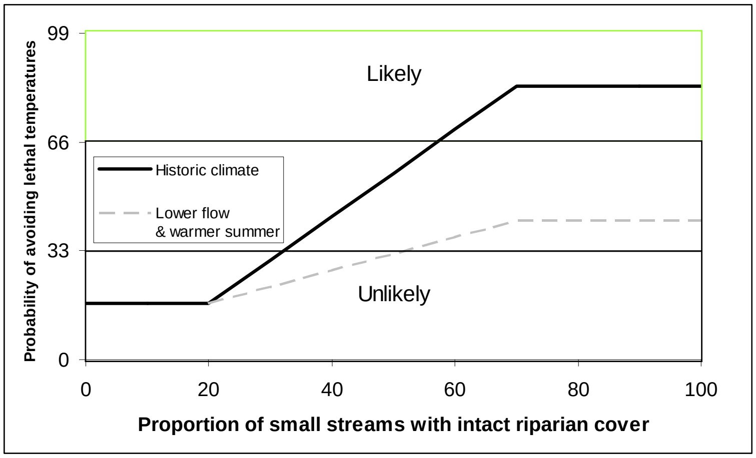

**Figure 11. Hypothesized influence of the proportion of riparian cover along small streams that remains intact on the probability of avoiding lethal temperatures in temperature sensitive watersheds. Uncertainty increases due to lower flows and warmer summers associated with climate change (dashed line) and varies with the sensitivity of the stream system.**

# *Managing hydrology*

## *Management recommendations*

Several recommendations about managing hydrology in the face of climate change arose over the course of the workshop. Many of these recommendations are good practice under the current climate and are already being acted upon. Action becomes more important as the climate warms.

- The western mountains and interior plateau portions of the Nadina have different physiography and climate and should be managed as different hydrological regions.
- Develop climate model predictions that account for climate oscillations (e.g., PDO).
- Develop management strategies that account for climate oscillations. For example, drainage structure designed to last for long periods should account for a higher probability of flooding associated with the warm PDO phase in addition to accounting for climate change.
- Develop a research, monitoring and adaptive management program to monitor climate-induced changes that influence watershed hydrology—including streamflows, channel stability, condition of forests in watersheds (forest health, fire effects, regeneration success), stream temperatures, erosion and suspended sediment.
- Anticipate an increased rate of natural disturbance and manage harvesting accordingly to have a high probability of staying within appropriate ECA limits.
- Evaluate the short term hydrological implications (change to ECA) of salvaging stands disturbed by mountain pine beetles.
- Ensure regeneration assumptions used in ECA calculations are being met: use a resilience-based approach to plantation management to reduce probability of plantation failures; monitor forest health before and after free-growing (SDM reference).
- Design drainage structures for increased flow and bedload transport that may occur under the anticipated climate change scenarios.
- Identify and avoid harvesting sites with shallow water tables that connect to stream systems.
- Ensure appropriate deactivation of roads in temperature sensitive watersheds
- Retain riparian vegetation in temperature sensitive watersheds.

### *Adaptive management*

Management results depend in part on ecological context. Climate change has changed the ecological context. Historically successful management strategies may fail in the future. Learning how to alter management strategies to make them more effective is prudent. Learning can come from scientific literature or from experience in other areas, but ultimately practices need to be tested in the Nadina. Continuing with the historic management regime or adopting current best guesses of how to manage in a changing climate exposes large areas to the same learning curve. A range of practices should be implemented and monitored to both increase the pace of learning and to lower the probability of wide-spread ecological degradation. Preventing damage to aquatic systems is much cheaper than fixing it. Fixing damage (restoration) is rarely successful.

Recommendation: review existing adaptive management and monitoring programs (e.g., Babine Monitoring Framework; Forest and Range Evaluation Program) and develop a collaborative, regional (e.g., Nadina-wide) approach with parties sharing land management responsibility (e.g., government, industry, First Nations) and hydrology experts.

### *Infrastructure design*

Roads have the potential to alter drainage patterns and produce sediment. Ditches, bridges and culverts are designed to accommodate anticipated peak water discharges over their design life. Relatively long-lived structures are designed to accommodate relatively infrequent, but larger floods (e.g., Q refers to discharge, Q100 is the highest discharge in a 100 year period). Historic discharge patterns can be misleading for designing structures that must cope with a wetter and more variable climate that increases peak flows and bed load transport in the Nadina.

Options for addressing climate change include over-engineering structures or accepting different risk levels after examining the costs ($) and benefits (e.g., reduced risk; risk = hazard x consequence) of various options (risk management). Research, monitoring and adaptive management to better understand hydrological change and the benefits of different management options becomes cost effective when uncertainty is high, as is the case under climate change. For example, monitoring could evaluate green-up assumptions that influence ECA, could record changes to flow regimes and channel structure and could monitor bridge maintenance and effectiveness (e.g., similar to old bridge ledgers).

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