
# Summary of the Forests and Water Workshop November 1–2, 2016 Kelowna, BC

**J. Jones, R. Smith, G. Jost, R. Winkler, D. Spittlehouse, N. Neumann, R. McCleary, A. del Campo, X. Wei, Y. Wang, M. Gonzalez-Sanchis, A. García-Prats, I. Bautista, D. Wilford, C. Brown, K. Giles-Hansen, K. Sherman, H. Waters, D. Lewis, E. Valdal, R. Clark, G. Horel, & S. Lapp**

## Editor's Foreword

All content submitted as part of a workshop/conference summary article undergoes technical review by a minimum of three members of the Journal's technical review committee but has not necessarily been peer reviewed by an expert in the field.

Workshop summaries are presented as-is to improve awareness and provide a publicly accessible record of content presented during the respective event. The results presented are not intended to be definitive. Interested readers are encouraged to contact individual author(s) for more detail and to seek out primary publications from these studies when citing or subsequently using information.

## Introduction

With population growth, climate change, and increasing forest disturbance, understanding the complex relationships between forests and water is key to sustaining future forest resources, aquatic habitats, and water supplies. Research into forest and water interactions continues to expand our understanding of ecohydrological processes and our ability to assess the hazards associated with natural and human-related forest disturbances.

In July 2015, 170 presentations at the *4th International Conference on Forests and Water* described new research related to forest disturbances and hydrologic processes in a changing environment (a portion of which were recently published in the journal *Ecohydrology* http://onlinelibrary.wiley.com/doi/10.1002/eco.v10.2/issuetoc). This conference stimulated considerable local interest in establishing an annual workshop focussed on translating research results into operational guidance. The first of these workshops (November 2015) attracted over 100 participants and focussed on the effects of forest disturbances and climate change on hydrologic response, streams, and water quality. In November 2016, a second workshop was held to address topics directly related to watershed assessments in community-, fisheries-sensitive, and timber-valued watersheds.

This article provides short summaries of presentations at the 2016 Kelowna workshop, highlighting key messages and providing contact information for further reference.


*Jones, Smith, Jost, Winkler, et al. (2018). Summary of the Forests and Water Workshop, November 1–2, 2016, Kelowna, BC. http://confluence-jwsm.ca/index.php/jwsm/article/view/10/4 . doi: 10.22230/jwsm.2018v2n1a1*

Keynote Address

## Myths and Facts about Forests and Water

**J. Jones**

Based on the past few decades of forest hydrology research in Oregon, this presentation evaluated the scientific basis for forest management rules in the Pacific Northwest (steep, wet forest lands). The presentation addressed how these rules simplify or possibly distort science findings, which may involve more complexity than can be incorporated into simple rules.

Based on a review of research in the region over the past 50–60 years, the presentation evaluated the validity of four general statements about forests and forest hydrology that may have been used to construct forest management rules. These statements are: (1) Forestry treatments have equal (equivalent) effects. (2) Treatment effects are additive. (3) Effects on hydrology are independent of other factors (landslides, wood in streams, climate change). (4) The system returns to pre-treatment level (hydrologic recovery). Examples addressed: a) too much water – peak flows, snow, roads in small and large basins, and b) too little water – hydrologic drought.

### Key Points

Science findings indicate that the four general statements are overly simplistic. In fact, they should be revised to state: (1) Forestry treatments (roads, harvest, etc.) have ~~equivalent~~ interactive effects. (2) Treatment effects are ~~additive~~ multiplicative. (3) Effects on hydrology ~~are independent of~~ interact with other factors (landslides, wood in streams, climate change. (4) The system ~~returns~~ does not return to pre-treatment level (no hydrologic recovery).

Scientists have an important role in formulating guidelines for forest management with appropriate precision. Institutional and social context matters. Simple guidelines may prevail when institutional capacity and tolerance for experimentation are low, whereas context-dependent guidelines may require high institutional capacity and tolerance for experimentation. Forest management guidelines should build on findings from long-term small watershed experiments, analysis of gauging of large rivers above/below dams, and on presenting findings from multiple perspectives (big vs. little effects).

### Link

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Presentation

## Effects of Forest Plantations on Low Flows in the Pacific Northwest

**J. Jones**

After 100 years of plantation forestry in the Pacific Northwest, and with growing concern over water scarcity, there is considerable controversy about the effects of plantation forestry on streamflow, especially summer low flow. Streamflow response to plantation forestry, over many decades, in small headwater basins versus larger watersheds, and with climate change, is not well understood. New research analysed 60 years of records from eight small paired watersheds in the H.J. Andrews experimental forest, and from 25 above-dam sites in the Columbia River basin, to better understand these long-term effects.

### Key Points

Over the 50-year period of record, June through September streamflow in the small headwater basins, with 34- to 43-year-old plantations of Douglas-fir, declined by 50% relative to the controls, forested with 150- to 500-year-old Douglas-fir and western hemlock. These changes are attributed to significantly higher rates of evapotranspiration in young Douglas-fir forests, particularly during dry summers. The length of summer streamflow deficits increased with drought; however, no warming-related changes in flow were observed. In the control basins, streamflow did not change over the period of record.

In contrast, summer streamflow has declined since 1950 in many of the above-dam reference watersheds in the Columbia River basin, most frequently in late August. Increased summer flow deficits in these larger watersheds may limit aquatic habitat, exacerbate stream warming, and alter both water


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yield and timing. The effects of past forest management and natural disturbances may be further affected by climate change in both small and larger watersheds.

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## Presentation

### Opportunities for Desynchronizing Catchment Runoff During Peak Flow

**R. Smith, G. Jost, R. Winkler, & D. Spittlehouse**

Forest management has the potential to synchronize (or desynchronize) snowmelt runoff across a watershed that, in turn, can alter the timing and/or magnitude of flood events. Synchronization processes are complex due to varying climatology, watershed characteristics, and distribution of forest cover disturbance with respect to aspect and elevation. Figures 1 and 2 illustrate generalized effects on snowmelt dynamics and runoff response. In particular, disturbances on slopes with high solar exposure (e.g., south-facing) have a greater potential to effect runoff synchronization than slopes with low solar exposure.

This presentation summarised the implementation of the RAVEN hydrological modelling framework for investigating runoff synchronization and associated impacts on peak flows in the 241 Creek sub-basin (474 ha, 1600–2025 m) within the Upper Penticton Creek Watershed (UPC) experiment. Harvesting occurred in the sub-basin from 1992–2007. Several synchronization scenarios were investigated, each involving harvest over 33% of the basin. The scenarios were developed from a landscape stratification combining two solar-exposure classes (high and low) and three elevation bands. RAVEN was run using a 100-year synthetic meteorology dataset.

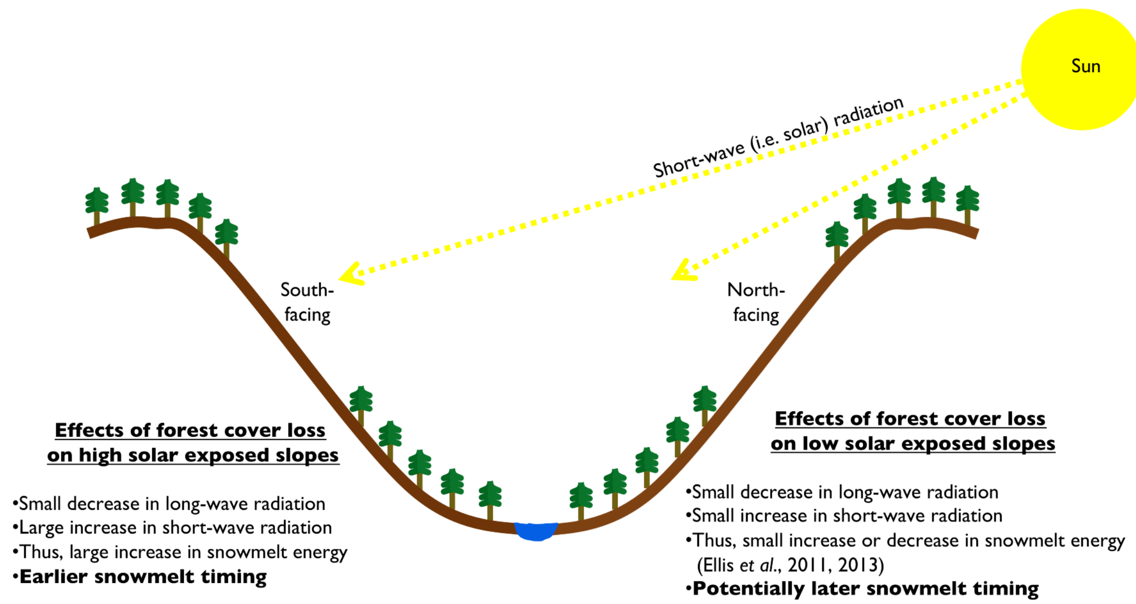


*Figure 1. The effects of forest cover and topographic position on the snowpack energy balance and snowmelt timing.*

## Key Points

Key findings of the modelling work include

- Most commonly, high-elevation disturbance results in the largest peak-flow increases.
- Low-elevation disturbance may be important in watersheds that are small and/or have low relief.
- Harvesting in low—solar/high-elevation areas combined with high solar—middle elevation areas appears to partially mitigate peak flow increases associated with forest-cover disturbance.



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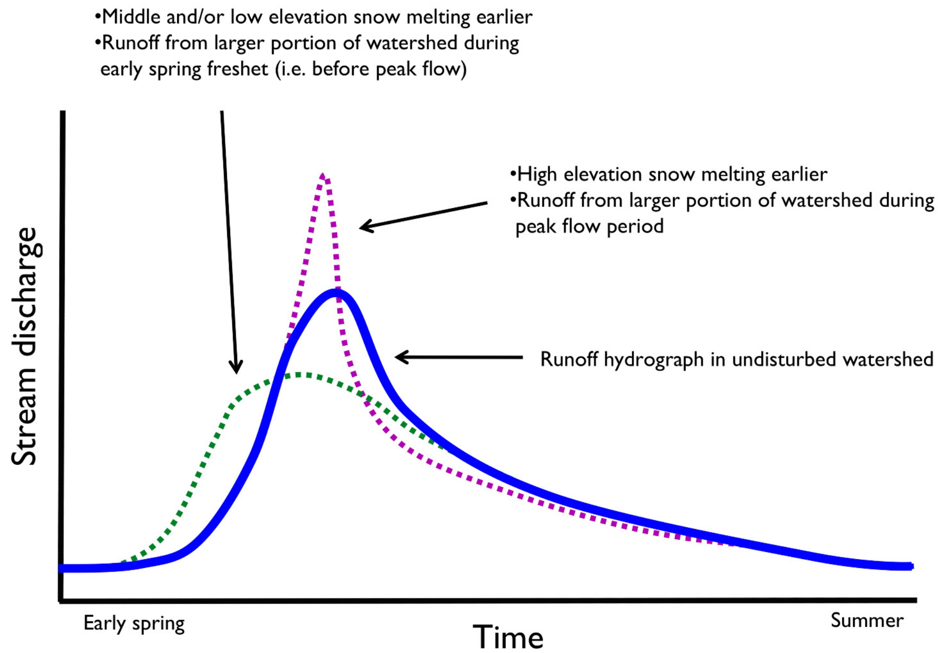


*Figure 2. Potential changes to the spring freshet hydrograph as influenced by runoff synchronization within a watershed.*

The RAVEN modelling framework was an efficient means to explore the impacts of forest harvesting on runoff synchronization and peak flows. Further work will investigate the influences of watershed shape, size, and elevation range, and different climates (e.g., dry Okanagan vs. interior wet belt) on synchronization effects.

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Presentation

## Forests, Groundwater, and Ground-Surface Water Interactions

**N. Neumann**

Some degree of groundwater–surface water interactions occur in all landscapes. Most resource managers recognise the importance of considering these interactions in their land management plans, and the British Columbia *Water Sustainability Act* explicitly refers to management of activities that may impact the hydraulic connections between surface water bodies and aquifers. However, subsurface water flow patterns and their interactions with streams, lakes, and wetlands are often complex and difficult to measure. Resource managers may lack an understanding of the nature of these connections or the tools available to assess the degree of connectivity in their region. The purpose of this presentation was to provide a primer on groundwater–surface water interactions in forested headwater landscapes.

## Key Points

As water moves through a landscape, it will usually not remain at the surface or in the ground. Instead, water moves back and forth between these two flow-paths (Neumann and Curtis, 2016). Surface water bodies (streams, rivers, lakes, wetlands, etc.) can be generally categorised as "gaining" water from an aquifer or as "losing" water (Winter et al., 1998). The direction of flow is determined by the differences in water levels. When the water table in an aquifer is higher than the water level in a stream (or any water body), water flows toward the stream (the "gaining" condition). When the water level in a stream is higher than the water table in the adjacent aquifer, water percolates through the streambed or bank and recharges the groundwater (the "losing" condition). In some situations, a surface water body might be gaining along one bank and losing along the other (referred to as throughflow). Surface and groundwater are therefore the same water; these labels only describe where we find that water at a given time.


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Usually, the water table mimics the local topography; it is higher in upland areas, and lower in depressions. After snowmelt or a rainy period, the water table is higher (closer to the ground surface). During a dry period, the water table is lower. At the same time, the water level in the stream rises and falls in response to such things as precipitation, changes in land cover, or upstream reservoir releases. This means that gaining and losing conditions can fluctuate from one season (or even day) to the next.

Baseflow is the portion of streamflow contributed by groundwater. The amount of baseflow in a river or stream varies widely from one system and location to another, but it's clear that most aquatic ecosystems rely on contributions from groundwater (Winter et al., 1998). The upper reaches of a headwater stream are often losing, though at some point along the channel the water table may be high enough that gaining conditions occur. In other words, a headwater stream is expected to transition from losing in its upper reaches to gaining in its lower (Winter et al., 1998). The location of this transition will largely depend on weather conditions (especially the amount of precipitation) and local geology or geomorphology. Baseflow contributions also change over the year. If a stream stops flowing during the dry season, the local water table is lower than the streambed, a condition which may be present year-round or only during the dry season.

Some streams, ponds, or wetlands are more sensitive to changes in groundwater level than others. At some locations, minor changes to the water table will not alter flow patterns. This would be expected in high-relief catchments if the shape of the water table follows the surface topography. However, where the water table and lake or stream has similar elevations, relatively small changes may reverse flow patterns. This is most likely to occur in relatively flat areas, where a naturally gaining stream may become losing if the water table is lowered. This type of change may result in the drying of a stream, wetland, or shallow lake as baseflow is lost. Pumping of groundwater at rates that exceed recharge will cause the water table to drop at a regional scale. Where groundwater has a long residence time and can only be naturally recharged slowly, it may require years to decades of effort to raise the water table and restore connections with streams and lakes.

Resource managers should avoid or minimize activities that affect groundwater–surface water interactions, especially where there is a small difference between the water table and the stream, lake, or wetland. While it is obvious that activities near shorelines and riparian zones can impact the connections between surface water bodies and adjacent aquifers, land-cover changes in the terrestrial part of the watershed are also important if they affect the water table or how groundwater is recharged. The impacts of land-cover change depend on a complex set of factors, and their relative importance varies between catchments and regions. These impacts may occur rapidly or slowly over time, but recovery or restoration usually requires decades.

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## Presentation

### Connecting Forest Management with Downstream Environmental Flow Needs and Licenced Water Supplies

**R. McCleary**

In British Columbia, the new *Water Sustainability Act* recognizes the importance of maintaining sufficient flows to conserve ecosystem function through two separate provisions. First, decision-makers are required to consider environmental flow needs (EFN) when making water allocation decisions. The EFN of a stream is defined as the volume and timing of water flow required for proper functioning of the aquatic ecosystem. Second, when reduced streamflow during drought has the potential to cause irreversible harm to an aquatic ecosystem, licenced water use can be curtailed through an order. In the interior regions of British Columbia, water extraction and alteration of the natural hydrograph increases in the lower portions of the watersheds that are developed for agriculture and human habitation. These lower reaches also have high environmental flow needs and associated water use conflicts, particularly during the late summer due to the overlap in human use and the salmon spawning period.

Recent hydrological research in the British Columbia Interior has shown that clearcutting has the potential to advance the timing of snowmelt and increase the magnitude of the freshet (Winkler et al., 2017). The effects of these forest harvest practices on late summer flow levels are less clear and the subject of ongoing research. Furthermore, most research has focussed on hydrological impacts in headwater basins in close proximity to the areas of forest harvest. Given the frequent late-summer water-use conflicts that occur in the lower reaches of larger watersheds in the British Columbia Interior, some preliminary work was conducted to screen the recent research in the forested uplands for a potential signal that may be relevant at larger watershed scales.

## Key Points

The British Columbia Ministry of Forests, Lands, Natural Resource Operations & Rural Development (FLNR) is responsible for drought response and is endeavouring to shift from reactive to proactive management of water during periods of shortage. This will be achieved via the following:

1. Optimized management of water storage:
    - as snow;
    - in the soil;
    - in aquifers; and
    - in reservoirs.
2. Improved streamflow forecasting:
    - at the sub-basin scale;
    - accounting for basin physiography; and
    - accounting for land use.
3. Improved communication that:
    - targets the specific water users who can prevent ecosystem harm by implementing additional water conservation measures;
    - is developed in advance and can change in response to weather and streamflow trends;
    - recognizes that some water users are more prepared for drought than others, and that those who invest in preparedness will have benefits that may not be experienced by everybody; and
    - encourages widespread conservation and appreciation of water.

The following are considerations for watershed assessment and management.

1. The point of interest should be downstream of the forested land base and include valuable and vulnerable habitats.
2. Peak flow hazard remains an important risk indicator.
3. Snow and soil water storage elements should be managed to conserve late summer flows.

Riparian zones and the shallow aquifers that they support are important for baseflow generation during late summer. Forest and range management practices that conserve these ecological functions can be important for meeting downstream water use and environmental flow needs.

A number of topics for future research have also been identified.

There is a need to determine to what degree the earlier freshet associated with forest harvest translates to reduced late summer baseflow.

During the late summer, rainfall-driven flow pulses provide important cues and migration opportunities for salmon. While the scientific knowledge around the effects of forest harvest in the British Columbia Interior on the spring snowmelt portion of the hydrograph has improved, the effects of forest harvest on streamflow during other seasons require additional study. Rainfall interception, evapotranspiration, and soil moisture storage will be important processes to consider during such studies.

Additional work is required to understand the effects of increased peak flows related to climate change and forest harvest on these habitats, and also to assist with restoration of these reaches following damage from extreme events.

## Link

*Water Sustainability Act* and environmental flow needs: http://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-licensing-rights/water-policies/environmental-flow-needs

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## Presentation

### Managing Forests for Water and Enhanced Climate Resilience

**A. del Campo, X. Wei, Y. Wang, M. Gonzalez-Sanchis, A. García-Prats, and I. Bautista**

Important decisions in forest planning and management, such as rotation length, species composition, and silvicultural system, are typically designed to maximize and sustain timber production. This approach might not be sustainable in places where other goods and services are demanded or stressed, particularly in water-limited, semiarid, and drought-prone regions. An alternative water-centered forest management approach might be considered in these cases in order to enhance not only an optimization of the forest's water balance, but also to improve its climatic resilience, tree growth, and vigor. Ecohydrology-based silviculture aims to manipulate and quantify the water cycle in forests according to specific objectives and may present many opportunities to make silviculture more effective under water-scarcity scenarios. This presentation summarized an ecohydrology-based approach for improved forest management, focusing on research which has improved our understanding of forest and water relationships as affected by forest management in water-limited environments.

In this summary, the effects of forest management were addressed at different experimental sites located in semiarid eastern Spain (pine plantation, oak-coppice forest, and post-fire pine sapling regeneration). Some preliminary results from Upper Penticton Experimental Watershed plots in B.C., Canada, are also introduced here. In all cases, these examples represent situations where thinning/clearing is performed to overcome water/drought limitations while enhancing other multiple benefits. Control and thinning plots are compared in terms of hydrological performance, tree growth, soil properties and nutrient cycles, climate sensitivity, and reduced risk of wildfire. This summary focusses on the water balance.

## Key Points

In general, forest management (decrease in tree density) in semiarid eastern Spain significantly affected interception, throughfall, stemflow, transpiration, soil moisture, and deep infiltration at the experimental sites (del Campo et al., 2014; González-Sanchis et al., 2015). There is a clear trend of increasing infiltrated water (blue water) over evapotranspiration (green water) especially in wet years, thus increasing the ratio of blue to green water with decreasing cover (Figure 3). Runoff was negligible in all cases because of favourable soil conditions for infiltration (Di Prima et al., 2017). The water balance indicates that the main effect of thinning is a reduction in interception losses, which are very high in the controls (up to 45% of the gross rainfall), and the consequent increase in throughfall is mainly diverted into deep infiltration after the treatments. At the same time, there was a general diminishing of stand transpiration after thinning despite the fact that individual tree transpiration increased after management (Fernandes et al., 2016). Soil and understory evaporation showed fewer differences among treatments, from which it may be inferred that, in spite of clearing vegetation, soil evaporation was not substantially increased (del Campo et al., 2014). These effects were observed even in drier years for a colder site, whereas in the case of a drier/warmer site the increase in net precipitation (lower interception) was not followed by an increase in deep infiltration (del Campo et al., 2015). Therefore, it is important to note that thinning could be less effective in terms of blue water production under dry/warm conditions, and in that case more detailed analysis would be required. In any case, it should be noted that soil water was always higher in treated stands.

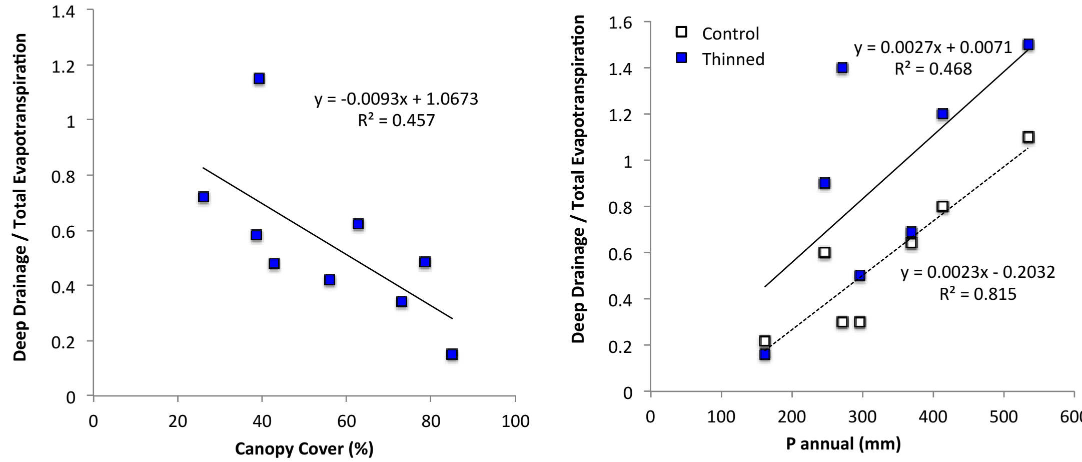


***Figure 3. Variation of the blue/green water ratio (B/G) with respect to the canopy cover in nine experimental plots (left) and with respect to the annual precipitation for control and treatment plots (right). Regressions are significant at p-value <0.05.***

In the Upper Penticton Experimental Watershed, preliminary results are aligned to those of the Spanish plots, even though the hydrologic regimes differ: the water use of individual trees during the growing season increased after thinning, but total stand transpiration decreased, likely due to a lower number of trees in the stands. Here, the control averaged 4.9 cm/h in tree sap velocity, whereas intermediate- (mean spacing between trees of 1.5–2 m) and high-intensity thinning (mean spacing 3 m) averaged 8.8 and 10.5 cm/h, respectively. On the contrary, volumetric soil moistures observed in the summer of 2016 were 9.0, 16.4, and 15.1% on average for control, medium-, and high-intensity thinning treatments, respectively, so that treated trees consumed more water but the treated stands maintained higher levels of soil water.

All thinning treatments improved tree water use efficiency in comparison with the control, proportional to the thinning intensity. Likewise, climate–growth relationships demonstrated that thinning makes trees less sensitive to water shortages, indicating that trees in the non-thinned plot need to rely more heavily on current-year precipitation than those thinned, confirming that forest management increases the resilience to climate variations (Fernandes et al., 2016).

Focusing on the important relationships between water and forest management, it is possible to develop hydro-economic models that define the optimal forest-water management scenario and planning horizon by maximizing the present net value of the net benefit of a stand, taking into account the value of timber (or biomass) yields, the cost of the silvicultural operations, and the value of the additional groundwater recharge produced by the forest management. This allows evaluating and designing integrated management of the forest–water binomial (García-Prats et al., 2016). These authors reported a groundwater recharge increase from 513 mm to 2,435 mm between the no-management and the optimized scenario respectively.

## Conclusion

Hydrology-oriented or ecohydrology-based silviculture presents many opportunities for effective forest and water production under water-scarcity scenarios, and makes it possible to explicitly integrate changes in groundwater recharge induced by forest management with the value of the additional water supplied to the system. Coupling our experimental results with modelling has also proved to be extremely useful for analyzing and understanding the effects of forest management on the water balance at broader spatial and temporal scales (see references: Manrique-Alba et al., 2015, Fernandes et al., 2016, González-Sanchis et al., 2015, Ruíz-Pérez et al., 2016).

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## Risk Management in Forest Hydrology: An Overview of Key Concepts and Roles
**D. Wilford**

Managing forested watersheds for hydrogeomorphic risks on fans (i.e., applying Land Management Handbook 61) requires an understanding of risk management. Risk is the probability of a specific event occurring and the consequences, or adverse effects, of that event on specific elements. Risk management involves three steps: (1) risk analysis, (2) risk assessment, and (3) action and monitoring.

Step 1 is the *risk analysis*, which is undertaken by a forest hydrologist with input from forest professionals, managers, and potentially other specialists. A risk analysis can be quantitative or qualitative, but definitions are required. The first step in a risk analysis is to determine "elements at risk" (e.g., alluvial fans, infrastructure, fish, water licences, etc.). Central to this is to identify possible damaging processes, the spatial and temporal exposure of elements, and their vulnerability and worth. This exploration is led by a forest professional with input from a forest hydrologist and other professionals as required. This helps to identify the scope and detail of the analysis.

In a risk analysis, the hydrologist identifies potentially damaging processes or hazards, their magnitude, and the likelihood/probability of occurrence. For example, a high-magnitude flood with a low frequency of occurrence would have a moderate hazard rating. This may be applied to different hazards individually (i.e., landslides, floods, debris flows, sediment production, etc.). Hazard analysis includes identifying existing hazards (i.e., natural plus those due to existing development) and incremental hazards related to forest development plans. Once the hazards have been determined, the next step taken by the hydrologist is to complete a risk analysis. Risk is defined as the product of hazard * consequence, which is the extent of damage to elements at risk. An example of a qualitative risk analysis matrix is shown in Figure 4. The analysis may be applied to different elements at risk individually, such as safety, infrastructure, or fish habitat.

| | **Consequence Rating** | | |
|---|---|---|---|
| **Hazard Rating** | **High** | **Moderate** | **Low** |
| **Very high** | Very high | Very high | High |
| **High** | Very high | High | Moderate |
| **Moderate** | High | Moderate | Low |
| **Low** | Moderate | Low | Very low |
| **Very low** | Low | Very low | Very low |

***Figure 4. An example of a qualitative risk analysis matrix (adapted from Wise et al., 2004).***

Step 2 is the *risk assessment,* which is undertaken by forest professionals, usually with some direction from managers. The focus is to consider the risk analysis and determine the acceptability of proceeding with planned developments. What needs to be balanced are public expectations, First Nations interests, corporate considerations, legislated standards, and certification requirements. There are three possible conclusions.

1. The risks are acceptable, so plans can proceed.
2. The risks are acceptable (tolerable) with risk control measures, so plans can proceed.
3. The risks are not acceptable, so the plans need to be revisited or cancelled.

When control measures are considered, it is important that they have a proven track record and they should be discussed with the hydrologist (and potentially other professionals), and also communicated to the operators.

Step 3 involves *implementing the plans and monitoring the effects*. Based on the potential consequences it is necessary to ensure plans are implemented as intended. Supervision and potentially training may be required. Monitoring is critical and should be designed and resourced in advance of operations.

To summarize, risk management in forest hydrology involves three steps.

1. Risk analysis undertaken by a hydrologist with input from a forest professional.
2. Risk assessment undertaken by a forest professional with input from a hydrologist.
3. Action and monitoring undertaken by a forest professional.

When these steps are followed, forest professionals should feel confident in applying Land Management Handbook 61 (Wilford et al., 2009).

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Presentation

## Using LiDAR in Watershed Assessments

### C. Brown

The use of remotely sensed data for land management and planning is accelerating in use as these products improve in accuracy and are reduced in cost. This presentation describes the use of LiDAR for performing watershed assessments, and specifically details the delineation of flow location and accumulation area (streams), the delineation of watershed boundaries, the mapping of legacy roads, and the mapping of vegetation disturbance/recovery.

### Key Points

LiDAR is an active type of remote sensing where laser pulses are emitted from a sensor and returned to the sensor to determine highly accurate X, Y, Z coordinates of the target. With modern aircraft-mounted sensors, > 500,000 pulses are emitted each second. Typical LiDAR acquisition products include: 3D point cloud, digital elevation model (DEM at 1 metre or better); contours (1m interval); bare earth hillshade; and canopy height model (CHM) (Figure 5). These products can be used for several watershed assessment tasks.

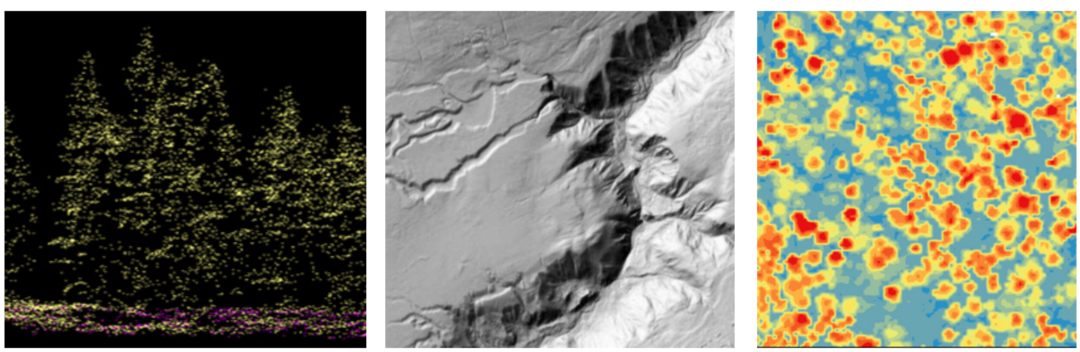

***Figure 5. Example data acquisition products from LiDAR: a) Point cloud-profile view; b) Hillshade – plan view; c) Canopy height – plan view.***

***Mapping streams with flow accumulation models and DEM***

LiDAR-derived DEM can be used to generate flow accumulation models, which are used to map streams and drainage. Each 1m x 1m cell has a flow direction assigned based on the elevation of its neighbours. The uphill cells that contribute flow to each pixel are determined. Flow accumulation areas are then used to map streams based on a predicted contribution-area threshold expected to produce overland flow (Figure 6).

***Mapping watershed units, flow direction, height of land***

Watershed boundaries can also be derived from LiDAR data. Drainage points are derived from the drainage network based on flow direction and elevation. Watershed units are defined as areas that drain to a common drainage point. This process is largely automated with the main input being


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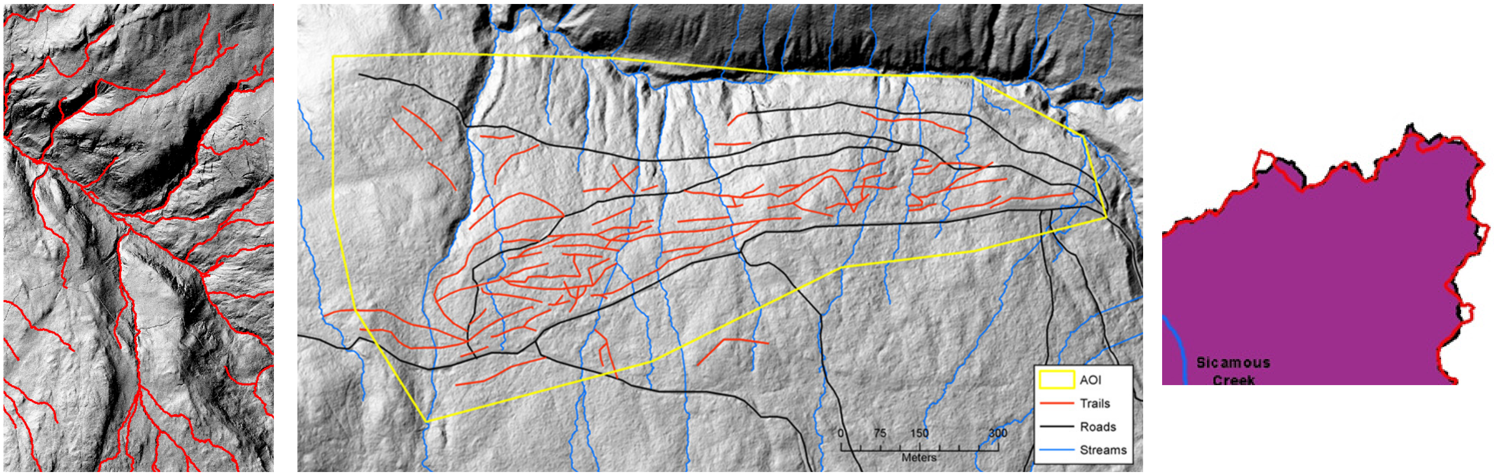


***Figure 6. Mapping of streamflow paths (left), watershed boundaries (right), and legacy roads and trails (centre) using LiDAR.***

LiDAR-derived terrain data; however, some manual editing of the DEM is required to correct drainage in the vicinity of roads. Derived watershed boundaries can then be compared to historical estimates to note any potential differences (Figure 6) in boundary locations and areas.

***Mapping legacy roads and trails***

Roads and trails from past harvesting practices have implications for current forest hydrology and planned forest development (e.g., drainage diversions onto steeper terrain). Where LiDAR pulses are able to get to the ground, these structures can be accurately mapped off the bare earth hillshade image (Figure 6). Risks associated with older infrastructure can then be investigated and rehabilitation works may be recommended.

***Mapping of vegetation disturbance/recovery***

Concepts of hydrologic recovery are based on tree height and density. Traditional polygonal forest inventory data provides generalized and often inaccurate height data for young stands. LiDAR can be used to provide highly detailed and spatially accurate information on tree heights and densities, thus improving estimates of hydrologic recovery for equivalent clearcut area (ECA) calculations (Figure 7).

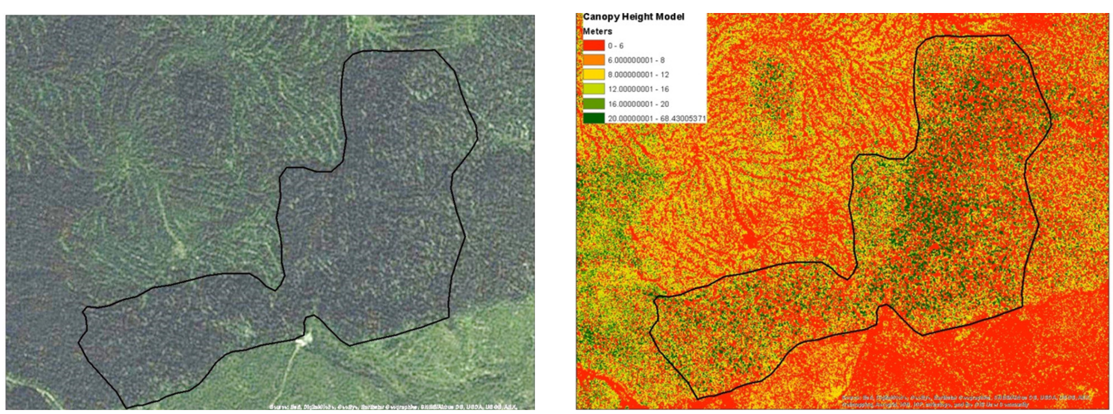


***Figure 7. Left: Mature stand, VRI classified areas as 163 years old, 27.2 m tall. Right: LiDAR shows more detailed range of stem heights and canopy gaps.***

Key points presented at the workshop related to the use of LiDAR to calculate ECA included recommendations to:

1. Focus on assigning a single height to stand polygons to avoid classifying small natural stand openings/gaps within polygons as disturbance. Only assess disturbed (e.g., logged/burnt) polygons to avoid assigning ECAs to short natural stands (e.g., alpine areas).

2. Use a 5m x 5m CHM grid containing maximum height. LiDAR height data provides very accurate heights at fine spatial scales, so it must be spatially generalized for ECA purposes (i.e., a 1m x 1m grid CHM is too fine, whereas a 5m x 5m grid CHM seems reasonable and would ensure at least 400 stems per hectare are present).
3. Use the height profile of 5m x 5m CHM pixels in the stand polygon to determine the height class where >50% of the polygon area meets/exceeds a given height. This appears to be the best option for assigning a "recovery height" for disturbed stands because it is not influenced by outliers like residual retention or areas of roads/landings.

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**Presentation**

## Considering Water Resources in the Timber Supply Review—Present and Future

**K. Giles-Hansen and K. Sherman**

British Columbia's Provincial timber supply review (TSR) process considers water resources in a number of ways. However, exactly how water is incorporated is not commonly understood. This presentation provided information about how water is incorporated into the TSR and provides suggestions for future improvements.

### Key Points

In accordance with Section 8 of the *Forest Act*, the allowable annual cut (AAC) of a management unit [timber supply area (TSA) or tree farm licence (TFL)] must be determined by the Chief Forester at least every 10 years. The timber supply review (TSR) process supports these AAC determinations by carrying out a strategic-level long-term timber supply analysis. The process starts by collating the applicable data; this includes spatial inventories of vegetation, ecosystems, and operational constraints, as well as non-spatial information about tree growth, silviculture treatments, forest disturbances, and other non-timber considerations. A forest estate model is then set up and multiple scenarios are run to provide long-term forecasts of timber supply under different assumptions. The results assist the Chief Forester in setting a suitable AAC.

Water resources are one of many non-timber values considered in a TSR. However, the TSR process is currently very timber-centric. The focus is primarily on timber supply, while non-timber values are modeled as constraints or limits to harvesting. Forest harvesting has many impacts on hydrology; however, modelling limitations often preclude inclusion at the strategic scale (e.g., water quality, channel morphology). This is due to limitations such as processing power, model constraints, and lack of data availability and knowledge at the appropriate scales. The two main ways that water resources are incorporated into TSR are: application of harvest disturbance limits to riparian reserve and management zones (RRZs and RMZs); and application of disturbance limits to watersheds.

RRZs and RMZs are areas where harvesting is controlled around streams (no harvest in reserve zones and specified maximum disturbance in management zones), lakes, and wetlands (limited partial harvesting for salvage is sometimes considered appropriate). In the TSR process, buffers of varying widths are usually applied according to stream (e.g., S1, S2 – S6), wetland, or lake class and removed from the timber harvesting land base (THLB), to reflect the current practice of limiting harvest in these areas. The accuracy of this hinges on a well-classified and complete stream dataset throughout the management area. This data is not necessarily available throughout the province, which may lower the accuracy significantly. An example of this is in the current Fort Nelson TSA TSR, in which an 18.7% non-spatial reduction is being used to account for RRZs and RMZs because they were not mapped (FLNRO, 2017). In the Kalum TSA, the proportion reserved in RRZs and RMZs was calculated in harvested areas where licensees have produced stream classifications. This percentage was then extrapolated to the rest of the TSA where no stream classifications exist (MFR, 2010). When spatial data for stream classification is not available, RRZs and RMZs are often represented by an average percentage removal. This is the case in the most recent 100 Mile House TSR, where a GIS exercise in 12 mapsheets was used to calculate a 2.7% reduction that was applied throughout the TSA (FLNRO, 2012). In other TSRs, stream width and gradient assumptions are applied to the *Freshwater Atlas* stream dataset to provide the best approximation of stream classification, such as in the Kootenay Lake TSA (MFR,


*Jones, Smith, Jost, Winkler, et al. (2018). Summary of the Forests and Water Workshop, November 1–2, 2016, Kelowna, BC.*
*http://confluence-jwsm.ca/index.php/jwsm/article/view/10/4 . doi: 10.22230/jwsm.2018v2n1a1*

2008) and Cassiar TSA (FLNRO, 2013). Improving and standardizing this dataset represents a large opportunity to advance the representation of water considerations in the TSR process.

In TSR, disturbance limits are also applied to community watersheds, fisheries-sensitive watersheds, and other watersheds to represent modified harvest in these areas. A maximum disturbance rate within the unit is commonly set with a rule such as 1% harvested per year, a maximum of 30% less than 6-m height, or an equivalent clearcut area (ECA) threshold. ECA curves are used to estimate hydrologic recovery. In B.C., the curves are generally height-based, from the interior/coastal watershed assessment procedure guidebook (IWAP/CWAP), assuming that the proportion of hydrological recovery is correlated with stand height. Recently, there has been an update to the circa 1995 IWAP recovery curves in Extension Note 116, as long-term data from research sites in the Southern Interior has become available (Winkler and Boon, 2015). These curves are increasingly being incorporated into management plans and timber supply. Although height-based recovery curves are the standard throughout much of Canada, there are other methods, such as in parts of Alberta where recovery estimates are based on the percent of cumulative mean annual increment (CMAI). The formal TSR process is tightly coupled to the concept of "current practice", with the default approach being either to use the methods used in the previous TSRs or to employ the Province's default value listed in policy or regulation. However, there is room to incorporate new ideas within the TSR process as sensitivity analyses, or in parallel processes such as the silviculture strategies.

## Conclusions

There are several ways to improve and refine how non-timber resources such as water are incorporated into TSR. Firstly, as the definition of "current practice" is continuously changing, new management objectives will arise for water. These will need to be incorporated effectively into the future TSR process and modelling framework. As a speculative example, the introduction of B.C.'s *Water Sustainability Act* may require that forest managers consider potential impacts on low flows. If altered management for low flows becomes current practice, TSR will need to incorporate it—possibly through indirect indicators such as disturbance level, disturbance pattern, or road density.

Secondly, technological advances that increase model functionality and the integration of forest estate models with other types of modelling will increase what can be included at the strategic scale. For example, forest estate models do not currently consider hillslope water movement or physical hydrology. Climate change, carbon, and many wildlife elements are presently dealt with external to the timber supply model. To provide forest management direction and inform harvest planning, timber supply models should incorporate hydrological values as accurately as possible. Outside of TSR, optimization models (e.g., *Patchworks*, Woodstock-Stanley) are being used to optimally locate harvest while considering a wide range of timber and non-timber values. TSR most commonly uses simulation models (e.g., FSSAM, FPS) to find a reasonable harvest level, and varies one factor at a time to see its impact on the harvest level. However, forest planners and stakeholders may demand more realistic and spatially explicit forecasting in the future.

Thirdly, improving the correctness and completeness of the spatial and non-spatial information that TSR draws upon will increase the accuracy and operational utility of TSR analysis (e.g., a consistent province-wide field-classified stream dataset).

## Link

TSR website: https://www.for.gov.bc.ca/hts/tsas.htm

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Presentation

## Watershed Assessment: A User's Perspective

### H. Waters

Tolko Forest Industries Ltd. completes watershed assessments in any watershed where there has been a major forest health event, where there is significant downslope risk, or where there are cumulative effects concerns. Key concerns regarding watershed assessments include the reliance on equivalent clearcut area (ECA) as an indicator of watershed health and of potential changes with forest development, and on the implications of new information, such as the revised recovery curves (Winkler and Boon, 2015) that are used to calculate ECA.

Foresters require watershed assessments to help manage identified or potential issues related to:

- water quality;
- water quantity;
- timing of flows;
- stream channel stability;
- fish habitat;
- cumulative hydrologic effects;
- potential downslope values at risk; and
- appropriate levels of harvest and road construction.

Watershed assessments, as they pertain to cutblocks and roads, include five main components.

1. Assessment and summary of current condition, focusing on:
    - history of issues and concerns in the watershed;
    - field inspections;
    - streamflows; and
    - current ECAs.
2. Assessment and summary of planned cutblocks and roads, focusing on:
    - relationship of planned cutblocks and roads to current condition findings; and
    - planned ECAs.
3. Assessment and summary of potential for additional future development, both temporally and spatially. Sub-components focus on:
    - green/yellow/red light approaches to additional development based on a peak-flow hazard rating determined using ECA thresholds, and on an assessment of channel sensitivity, sediment dynamics, and conditions of riparian areas; and
    - link to hydrologic hazards.
4. Recommendations and results of:
    - current condition findings;
    - planned cutblocks and roads; and
    - potential for additional future development
5. Consideration of other potential cumulative impacts such as range and recreation use.

Users of watershed assessments are particularly concerned about the reliance on ECA as a threshold, i.e., a single number trying to summarize complex hydrologic systems that include

- the presence or absence of significant wetlands, lakes, or storage reservoirs;
- terrain feature types;
- aspect/gradients;
- slope variations;
- deep or shallow snow zones;
- spatial location/distribution of past and proposed harvesting;
- source of height data (VRI, modeled growth since harvest, LiDAR); and
- changing weather patterns—more rain/less snow.


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Some users question whether there is a safety factor built into current ECA thresholds. Of further operational concern are the implications of the new (Winkler and Boon, 2015) recovery curves, which suggest that "recovery" takes longer than previously believed, on watershed assessment recommendations, and to timber availability tied to ECA thresholds.

## Conclusions

There are several important remaining questions relating to watershed assessments.

1. Are we placing too much emphasis on ECAs in watershed assessments?
2. Are there documented issues with channel stability, peak flows, low flows, timing of flows, and water quality?
3. Should we place more emphasis on what initiates destabilization of stream channels and try to predict when that might occur?

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Presentation

## Applications of Strategic Watershed Assessment to Values-Centered Resource Management

**D. Lewis and E. Valdal**

The Province of B.C. is implementing the Cumulative Effects Framework (CEF) as a means to improve the way resource values are assessed and managed. Cumulative effects can create real costs through unintended impacts to values, resulting in economic, social, and cultural implications such as onerous and lengthy permitting processes, conflicts among tenure holders, and requirements for corrective actions. A key objective of the CEF is to bring together, and provide open access to, the most current information on the current condition and trend of values.

Fundamental to the CEF is a shift from project-centred assessments to values-centered assessments. This approach shifts away from a largely "project-specific" focus that considers only the effects of the local project footprint on individual values, often without consideration of other land uses, other natural resource sector (NRS) activities, or natural processes affecting the value at broader spatial scales.

## Key Points

The B.C. Ministry of Forests, Lands, Natural Resource Operation & Rural Development (FLNR) has developed assessments for resource values such as visual quality, moose, mule deer, grizzly bear, old-growth forest, marten, forest biodiversity, fish, and watershed condition. To assess watershed conditions, the application of a strategic GIS-indicator-based procedure lends itself well to a values-centred approach by identifying factors that may contribute to cumulative watershed effects (CWE) and the potential for negative impacts to downstream values. The information has enabled improved communication in government–government discussions or stakeholder engagements regarding government's expectations for the management of values, and has supported the development of new objectives or policy revisions.

Specifically, CWEs are changes in watershed processes, such as runoff regimes, riparian function, water quality, and channel morphology, as a result of land use activities and (or) natural processes (Scherer, 2011). For example, CWEs can occur when human-caused changes coincide with infrequent natural environmental conditions (Scherer, 2011), resulting in increases in the magnitude or frequency of often rare and potentially harmful conditions (e.g., prolonged low flow periods or elevated stream temperatures) or disturbance events (e.g., floods). A values-centered assessment considers all land use factors that can contribute to CWE at the watershed scale, and can contribute to meaningful management interventions at the scale at which managers can affect change.

To capture the multi-scale nature of CWE on downstream values, the watershed assessment procedure utilizes a hierarchal reporting structure of large watersheds, watersheds, basins, sub-basins, and residual units (Figure 8). The hierarchal assessment units (AU) structure is important when considering CWE of upstream activities on downstream points of interest for each value (i.e., location of spawning habitats, water intakes, infrastructure—not limited to highway bridge crossings), as the location can vary across scales.

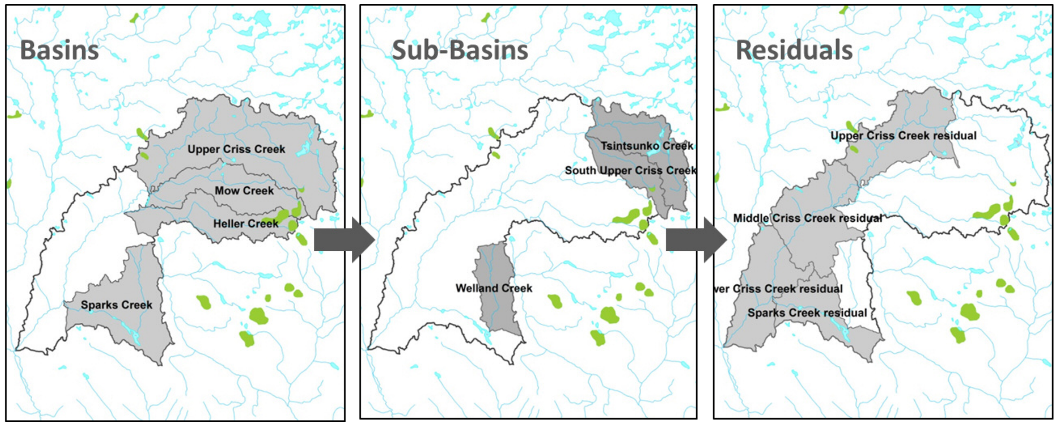


***Figure 8. An example illustrating the hierarchal structure of assessment units (AUs) including basins (left), sub-basins (middle), and residual units (right) nested within the Criss Creek watershed near Kamloops.***

The CWE assessment procedure uses a risk-based approach, where risk is the product of hazard and consequence defined by the risk equation *Risk = Hazard * Consequence*. Hazards identified in the procedure relate to key watershed processes that can be affected by CWE, including:

1. *Streamflow effects*—increased frequency and magnitude of hydro-geomorphic events (floods, bank erosion, channel instability, debris floods, and debris flows);
2. *Sediment generation and delivery*—reduced water quality and channel geomorphological effects as a result of sediment input to streams from roads, landslides, or other upslope sources; and
3. *Riparian Function*—reduced channel bank stability, stream shading, and large woody debris inputs

Indicators are combined to develop response potential ratings that reflect the inherent hydrologic or geomorphic sensitivity of each AU to land use and disturbance. Hazard ratings express the likelihood of hazard occurrence, which varies depending on response potential and the extent of land use disturbance (Figure 9).

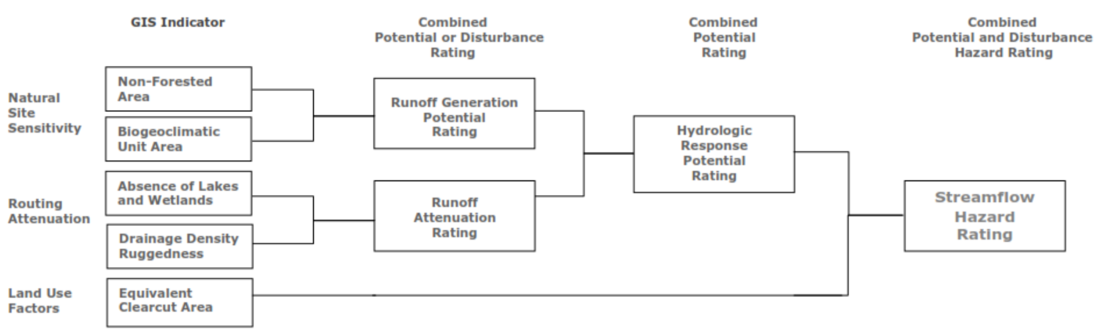


***Figure 9. Diagram illustrating the relationship between indicators and ratings for streamflow hazard as applied in the GIS-indicator-based assessment procedure.***

Hazard ratings are intended to be used with consequence ratings derived for downstream ecological and socio-economic values to derive risk ratings. Consequence ratings express the potential loss or damage to downstream values, and the specific elements at risk which comprise those values.

## Future Work

As part of the CEF's commitment to open access to information, a key next step in the CEF implementation will be to publish materials required to support decisions, including

- the strategic GIS-indicator-based watershed assessment procedure;
- watershed current condition and trend reports for the Kamloops, Merritt, Okanagan, and Lillooet TSAs; and
- GIS spatial layers used in values assessments and online-mapping resources for proponent and public use.

Further work will include implementation of the CEF policy and procedures to support further use of values-centered assessments in a variety of decision support applications, from project-level screening to supporting implementation of new objectives for aquatic values using regulatory tools such as B.C.'s new *Water Sustainability Act*.

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**Presentation**

## Water Source Assessment to the Tap

**R. Clark**

In BC, at all levels of government (First Nations, federal, provincial, and municipal), water licensees and tenure holders have a shared responsibility for source water protection. Federal and Provincial legislation, including the *Water Sustainability Act (Water Act)* and *BC Drinking Water Protection Act,* regulates work in and around water sources, management of water resources, and the delivery of drinking water. It is the water utility or licensee's responsibility to provide safe drinking water to its customers. This requires a clear understanding of the source area, land use, and the risks to the water supply in order to ensure that treatment levels are adequate and to assist in developing future surface and groundwater treatment objectives.

### Key Points

Source assessments identify risks to drinking water (before treatment) from activities on the land and provide recommendations to reduce risks to human health. In BC, most watersheds are multi-use; consequently, every water source has its own risks. In urban and rural watersheds, for example, stormwater, septic systems, transportation systems, and agriculture may all affect water quality. In Crown land watersheds, forestry, roads, creek crossings, cattle, recreational use, illegal dumping, dams, and water storage systems are all of concern.

Greater Vernon Water (GVW) uses a collaborative approach in which Technical Advisory Committee members representing all partners in the source area work together to identify threats and undertake mitigating actions for source water protection. In forestry, sediment delivery from roads at stream crossings has been identified as a moderate to high risk. In response, Tolko provides annual stream crossing and culvert inspections data, the GVW reviews forest development plans, costs of LiDAR acquisition are shared (such as in 2016), and watershed hydrology is assessed. To reduce risks associated with range, best management practices such as off-stream watering, fencing, debris placement, riders to manage cattle movement, and communication with ranchers have been implemented. Responses to increased recreational use, unregulated camping, and off-road vehicles include public education, development of strategies to reduce impacts (including a shared venture with Recreation Sites and Trails BC at Grizzly Reservoir) and increased compliance and enforcement efforts.

The two most significant hydrologic concerns are two or more consecutive years of drought and increased peak flows resulting from loss of forest cover and climate change. Responses to these concerns have included

- updates to the *Drought Management Plan* in 2011 and 2016;
- establishment of a snow, soil moisture, groundwater, and reservoir inflow data monitoring network; collaboration with FLNR on establishing Fisheries—Environment Flow Needs, and a water balance study;
- a 2016 dam inundation study; and
- improved dam surveillance and management.

## Conclusions

It is important to remember that a water licensee is not a regulator in water source protection. Water licensees do not have authority related to land use practices on Crown land or land within municipal boundaries. A water licensee relies on Federal and Provincial Acts, regulations, stewardship plans, best management practices, and local government bylaws and policies to protect the water resource from the impacts of land use in the watershed.

## Link

http://www.rdno.ca/index.php/services/engineering/water/greater-vernon-water/watershed-source-assessments-and-protection

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**Presentation**

## Considerations for Watershed Assessments in Coastal BC Environments

**G. Horel**

The coast of British Columbia has many islands, fjords, and small primary watersheds draining to the ocean. These features result in a number of "face units" (i.e., slopes draining directly to the ocean with only small streams such as S6s). In coastal environments, there are also larger regional watersheds with multiple tributary basins and sub-basins. On the mainland coast, for example, some large watersheds drain through the coast range from the interior, resulting in a mixture of interior and coastal hydrology conditions. Most of the islands, and much of the outer mainland coast, are not connected to the highway system. As a result, access is often limited and a challenge for field work.

Interface areas are geographically limited, occurring mainly on the south and east coasts of Vancouver Island north to Campbell River, the Port Alberni valley, the Squamish-Whistler Area, and the Sunshine Coast. Elsewhere, interface areas are localized around small scattered communities. First Nations concerns and values are very significant throughout this region. In addition to the common values found throughout the province, values and risk elements on the coast include estuaries, fish farms, commercial shellfish beds, karst, and cultural features. On eastern Vancouver Island there are extensive private managed forest land holdings. Most of the community watersheds for the larger communities on Vancouver Island fall within these private lands.

Large areas of the coast fall under *Land Act* orders to establish land use objectives. These include Clayoquot Sound, Haida Gwaii and Great Bear Rainforest orders. The Higher Level Plan Order for Vancouver Island continues from the *Forest Practices Code of British Columbia Act* (as with similar Higher Level Land Use Plan orders in the Interior). The Haida Gwaii and Great Bear orders have specific legal objectives for fish habitat, upland streams, and active fluvial units (fans and floodplains), and specify high levels of retention. The Clayoquot Sound order gives legal standing to the principles of sustainable ecosystem management set out in the 1995 report of the Clayoquot Sound Scientific Panel.

Annual precipitation varies from under 1,000 mm on southeastern Vancouver Island to more than 5,000 mm at the higher elevations on the windward side of Vancouver Island, Haida Gwaii, and the central and north mainland coast. Peak stream flows occur from rain or rain-on-snow and occur multiple times per year in response to weather events. Maximum annual peaks most commonly occur between November and February, although in the very high precipitation zones there have been annual peaks recorded in most months. Peak stream flows do not occur in the absence of rain. In the Chemainus watershed, on the east side of Vancouver Island in the dry to intermediate zone (1500-2500 mm/year), peak flows correlate most significantly to 3-day total rainfall. Peak flows on coastal watersheds are often of very short duration, and subside quickly when rain stops. Also in the Chemainus River watershed, hydrometric data show that streamflows can increase by an order of magnitude in 24 hours, and fall back to pre-storm levels 48 hours later. Maximum snow-water equivalent in high-elevation snow courses on Vancouver Island typically occurs in April–May, and is generally not coincident with peak flows. High-elevation snowpacks elevate monthly discharge in late spring and early summer, and sustain stream flows into the summer months.

The outer coast experiences severe windstorms and intense storm cells. Windstorms greater than 60 km/hr occur multiple times per year. Post-harvesting open-slope (clearcut) landslides are associated with rainfall zones ≥3000 mm/year. Windthrow is a significant management issue for riparian buffers on parts of the outer coast and is also associated with landslides when it occurs in potentially unstable terrain.

## Key Points

Important considerations for conducting watershed assessments in coastal watersheds are as follows:

- Hydrologic regimes and geomorphic processes, and consequently streamflow and terrain responses to forest removal, are different to those in Interior watersheds, and drive different management strategies.
- On most of the coast, harvest- and road-related landslides and windthrow have greater potential to affect stream channels than harvest- or road-related stream flow changes. "Clearcut" landslides are a particular concern in outer coastal areas.
- Rain-on-snow peak flows are the hydrologic events of concern for forest management. The relative magnitude of potential harvest-related changes to these events may be different between the "dry" and "wet" zones of the coast; data and published studies are particularly scarce in the outer coastal "wet" zone.
- Hydrologic recovery curves developed for Interior forest stands cannot be assumed to be valid for coastal stands. Hydrologic recovery curves have been developed using data from coastal research sites; however, the body of data, especially long-term data, supporting these curves is considerably smaller than that available for the Interior. The uncertainty must be taken into consideration when making recommendations for risk management of stream flow effects.
- Legal orders that cover large areas of the coast have provisions that must be addressed in watershed assessments. In addition, the extensive private land holdings on Vancouver Island (which encompass most of the major community watersheds), have specific challenges with respect to sharing of proprietary information, access for field work, and common management objectives.

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Presentation

## Incorporating Climate Change into Watershed Assessments
## S. Lapp

A variety of different watershed assessment procedures (WAPs) are used across B.C. as tools to help forest managers understand the type and extent of current water-related problems in a watershed. These procedures also assist in recognizing the possible hydrologic implications of proposed forestry-related development. WAPs commonly derive current conditions based on analysis of ECA and peak-flow hazards, channel stability, surface erosion, mass wasting, and riparian condition. Climate change can have important effects on these components, and this presentation discusses steps to incorporating climate change into watershed assessment procedures.

## Key Points

Climate is expected to change in British Columbia, and the magnitude of changes for the most part are site specific. In general, BC will see:

- increased winter and summer temperatures;
- increased occurrence of intense winter storms/extreme events;
- wetter winters;
- dryer summers in south;
- wetter summers in north;
- increased intensity and amount of precipitation; and
- increased wind speeds.


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In general, snowpack changes will vary depending on location and relative elevation. The snowline may shift to higher elevations and move further north. Projections of increased precipitation may lead to increased snowpack at high elevations. Changes to the amount of snow will affect seasonal and annual water supplies.

There are many potential hydrologic changes with respect to projected climate change. These include

- increased water temperatures;
- decreased snow accumulation and accelerated melt;
- earlier freshet and increased peak flows;
- rain-on-snow events;
- extended low flow periods (summer and fall);
- increased stress on road drainage structures;
- increased saturated slopes and landslides;
- decreased water quality; and
- reduction in return period of extreme events (e.g., 1:100 will become 1:50).

Climate change projections and their potential effects on hydro-geomorphic processes need to be taken into account in watershed assessments, along with the range of uncertainty. This understanding will then help those using the assessment to consider the influence of future climates on peak-flow hazards, channel stability, surface erosion, mass wasting, and riparian condition. Planning can then occur for road maintenance and deactivation, riparian management, stream crossing design, and location of harvest blocks and roads to minimize the potential hazard to hydro-geomorphic processes. Overall, water management in light of probable future climate conditions is key.

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## Summary

The 2016 southern Interior Forests and Water Workshop focussed on translating research results into guidance for operational application and sharing knowledge to help improve our understanding of the complex relationships between forests and water. Trade-offs between simplified, operationally focussed guidelines and more complicated, context-dependent guidelines were discussed, as was the role of institutional and social contexts in developing management rules and best operational practices.

Scale, physiography, and surface–groundwater connections all influence the effects of forest disturbance and regrowth on peak and low flows through snowmelt synchronization, evapotranspiration, and hydraulic connectivity. During periods of drought, disturbance-related effects on low flows become more severe, increasing risks to already vulnerable aquatic habitat. Where water is scarce, hydrology-oriented silviculture, such as stand density management, presents opportunities for improved forest growth and water production. Evaluating the risks to infrastructure, water licences, or fish habitat associated with forest development involves the identification of possible damaging hydrologic and geomorphic processes, as well as the exposure and vulnerability of elements at risk to these processes. New remote sensing technology such as LiDAR greatly improves the delineation of watershed boundaries, flow networks, legacy roads, and vegetation disturbance plus recovery. Improved spatial data will also help to refine the incorporation of water resources into future timber supply analyses and will improve watershed-specific and broader-scale cumulative effects assessments. Understanding source areas, land use, and risks to water supplies is key to delivering safe drinking water and sustaining aquatic ecology across the diverse range of hydrologic regimes found in BC, particularly in light of future climate change.

## Acknowledgements

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