Wolverton Creek Hydrogeomorphic Assessment and Risk Analysis

(Apex File: HA-06-KL-01)

Coolie Lake

Prepared For: Stan Hadikin, R.P.F.
Kalesnikoff Lumber Co. Ltd.
P.O. Box 3000
Highway 3A
Thrums ,B.C.

Prepared By: Kim Green, P.Geo., M.Sc.
Apex Geoscience Consultants Ltd.
1220 Government Street,
Nelson, B.C.

December 5, 2006

APEX GEOSCIENCE CONSULTANTS LTD.

Table of Contents

List of Figures

List of Tables

List of Photos

Introduction

Stan Hadikin, R.P.F, development forester for Kalesnikoff Lumber Co. Ltd. requested a hydrogeomorphic assessment for Wolverton Creek to assist in guiding forest development in the upper portion of the watershed that is included in their operating area. Wolverton Creek supplies consumptive-use water to the Wolverton Water Users. Fish are present in Wolverton Creek (B.C. Ministry of Fisheries Fishwizard data base). Coolie Lake at the headwaters of Wolverton Creek contains rainbow trout. Wolverton Creek is also reported to contain rainbow along the lower reaches from the Slocan River up to the first set of falls.

The purpose of this hydrogeomorphic assessment is to:

1. Identify hydrogeomorphic processes affecting runoff, peak flows, sediment delivery and sediment transport in the watershed.
2. Provide a qualitative risk analysis that assesses the sensitivity of Wolverton Creek to increases in peak flows, increases in sediment delivery or changes to riparian function and estimates the likelihood of impacts to aquatic values in the catchment given past development/disturbance and proposed development.
3. Provide recommendations for forest management to minimize the likelihood of impacts to aquatic values associated with proposed development.

Methods

Wolverton Creek was field assessed on September 27th by K. Green, P.Geo. and on October 4th 2006 by K. Green and D. Thorburn (Kalesnikoff). Roughly 500 metres of the channel above Naychuck Road and 2.5 km of channel in the headwaters portion was field assessed. The outlet of Coolie Lake was also inspected during the field investigation. The central portion of the stream was not field assessed due to poor access and the presence of steep bedrock canyons. Observations regarding sediment sources, sediment delivery mechanisms, sediment transport, channel morphology and historical flooding were made during the field review as well as an assessment of riparian condition and function. Additional information regarding the physical condition of the watershed and hillslope processes was gained through analysis of recent air photographs, terrain stability maps, forest cover and development maps.

Information reviewed as part of this assessment includes:

- Domestic Watershed Assessment of Cowie Creek Watershed, Wolverton Creek Watershed and Wolverton to Langill Face Unit (Henderson, 1999),
- Terrain Hazard Assessment: Wolverton Creek and Langill Face Unit Study Area (Butt, 1999),
- Water quality and quantity reports for Wolverton Creek (Passmore Labs, 1999, 2000; Quamme, 2002, 2003, 2004),
- Air photographs (2000),
- Fire history information for the Goose/Gander area (J. Parminder, pers. Comm.)

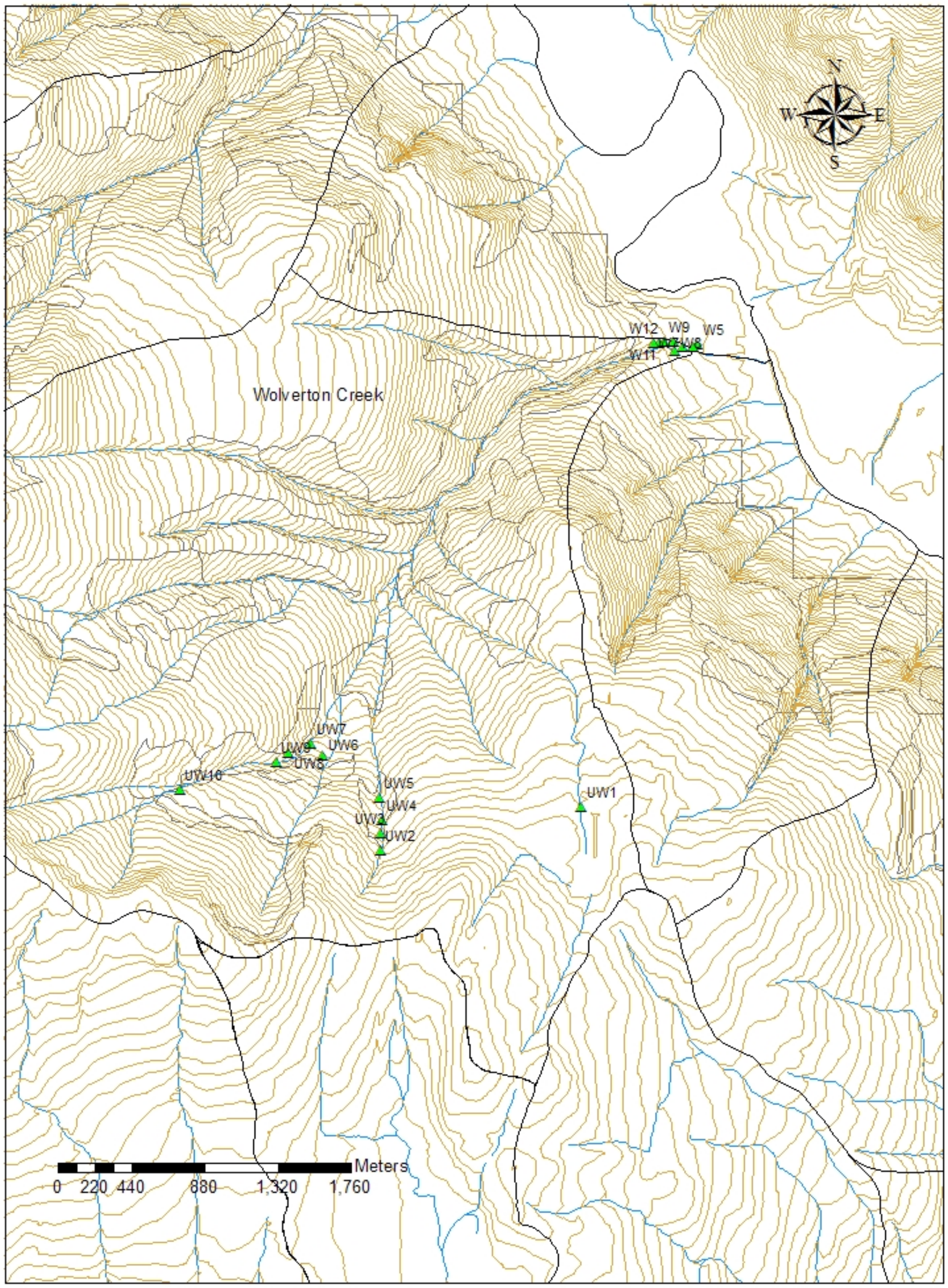

Figure 1. Map of study area showing portions of the traversed channels with GPS field sites.

Background Information

Physiography

Wolverton Creek is a 15 km^2 watershed located in the Valhalla Ranges in the Selkirk Mountains approximately 20 kilometres north of Castlegar, B.C.. Wolverton Creek flows northeast into the Slocan River at Passmore.

Elevation ranges from 500 metres at the confluence with Slocan River to 2160 metres along a north trending ridge that forms the height of land between Wolverton Cr and Airy Cr.

Wolverton Creek is characterized by a broad, moderate gradient basin above 1000 metres that is drained by at least 6 equally spaced headwater tributaries. The headwater tributaries converge into a single channel between 1200 to 1000 metres. Below 1000 metres the channel of Wolverton Creek is confined in a narrow, steep-sided, bedrock controlled valley.

Coolie Lake is a small (5 ha) shallow lake situated in a bedrock depression along the southern boundary at the headwater of Wolverton Creek. A Forest Service recreation site is present in the vicinity of Coolie Lake. The recreation site is mainly utilized in summer and fall months by fishers and hunters.

Figure 2. Satellite image showing distribution of 1970's and 1980's cut blocks in upper Wolverton Creek.

Geology

Wolverton Creek is underlain by coarse crystalline granitic intrusive rocks and highly foliated metamorphic gneiss of the Valhalla Metamorphic Complex (B.C. Map Place website: http://webmap.em.gov.bc.ca/mapplace/minpot/bcgs.cfm). Surficial geology consists of veneers of sandy, blocky colluvium at the upper elevations and veneers and blankets of sandy to silty till, over most of the mid elevation slopes. Thick deposits of sandy glaciofluvial sediments occur on the lower elevation side-slopes that drain down towards the Slocan River (Butt, 1999).

Disturbance / Development History

Logging activities commenced in Wolverton Creek in 1973. Six cut blocks totalling 267 hectares or roughly 17.6 % of the watershed area were removed from in the headwater portion of the catchment between 1974 and 1984.

Forest cover in the unharvested areas consists of a mixed stand of balsam fir and spruce or, Douglas fir, larch and pine of age class 5 and 6 (~ 80 to 120 years). Several forest cover polygons in the south central portion of the catchment are identified as age class 8 and 9 (> 140 to over 250 years).

The presence of large areas with age class 5 to 6 stands suggests the last major forest fire in the Wolverton catchment occurred roughly 100 years ago.

Climate (Braumandle and Curran, 1992)

Biogeoclimatic zones in the study area include the Dry Warm subzone of the Interior Cedar Hemlock (ICHdw) below about 1100 metres elevation. The main valley bottom between approximately 1100 and 1500 metres lie within the Columbia – Shuswap Moist Warm subzone variant of the Interior Cedar Hemlock (ICHmw2). The mid and upper slopes above approximately 1500 to 1600 metres are within the Selkirk variant of the Wet Cold Engelmann Spruce Subalpine Fir subzone (ESSFwc). A very small area of the upper slopes above roughly 1900 – 2000 metres lie within the Wet Cold Engelmann Spruce Subalpine Fir Parkland (ESSFwcp) and Alpine Tundra (AT).

Mean annual runoff for the upper elevations of the Norns Range is between 500 and 600 millimeters (Obedkoff, 2002). Approximately 80 percent of the total annual runoff occurs between the months of April to August (Obedkoff, 2002).

Average annual maximum snow accumulation recorded on April 1st, at 1100 metres in Kokanee Park roughly 15 kilometres to the east is over 1100 mm (snow water equivalent).

Hydrometric and water quality summary

Water quality and quantity has been monitored on Wolverton Creek since 1999 through a partnership agreement between Kalesnikoff and Wolverton Community Water Users. Water level, turbidity, total suspended solids, water temperature, conductivity and fecal coliform have been measured several times a month through a manual sampling program (Passmore Labs 2000, Integrated Ecological Research, 2002, 2003, 2004). The objective of the monitoring program is to collect baseline water quality and quantity data preceding further forest development activity in the catchment.

Table 1. Summary of recorded peak discharge and total suspended sediment for Wolverton Creek From 1999 – 2004.

Date	Q (m3/s)	Cause	TSS (mg/L)
4/13/2004	2.5	Warm T	3.3
05/03/2004	4.75	Warm T	2.4
3/13/2003	12.28	Rain	11.7
5/25/2003	8.5	Warm T	28.5
5/28/2002	27.3*	Rain	73.8
6/29/2002	10.73	T/Rain	103
5/24/2001	14.05	Warm T	9.9
05/03/2000	9.76	Rain	?
5/22/2000	9.76	Warm T	?
11/13/1999	12.61	Rain	?
6/17/1999	16.12	Warm T	26.3

- Anomalously high discharge that is possibly erroneous.

An analysis of the recorded data indicates that peak discharge in Wolverton Creek is a function of both antecedent temperature and precipitation. Peak flows associated with precipitation have occurred in fall, winter and late spring months. Peak flows associated with warm temperatures occur between mid-April and mid-June. The largest peak flow on record (27.3m3/s) is associated with a late spring rain event.[1]

The maximum recorded total suspended sediment (TSS) in Wolverton Creek is associated with high discharge combined with precipitation. The largest recorded TSS occurs during the spring freshet period.

[1] This discharge is suspicious as it is exceptionally large when compared to discharges measured in similar sized watersheds in the Southern Selkirks, it exceeds the maximum gauge height included in the calibration of gauge height – discharge for the period of gauging and, it is nearly 2 times the discharge associated with a similar gauge height included in the calibration exercise for the following year (2003-2004).

Observations

Headwater reaches

Photo 1. View from FSR looking north at upper Wolverton Creek. 1980's logged blocks are evident on the southeast aspect slopes.

The upper reaches of the headwater tributaries of Wolverton Creek above roughly 1500 metres elevation have a steep (> 30%) bedrock and boulder cascade morphology. Most of the headwater channels are confined in bedrock gullies or flow over bedrock outcrops and coarse colluvium. The largest headwater tributary surveyed as part of this study has a bank full width of 2 metres at the FSR crossing.

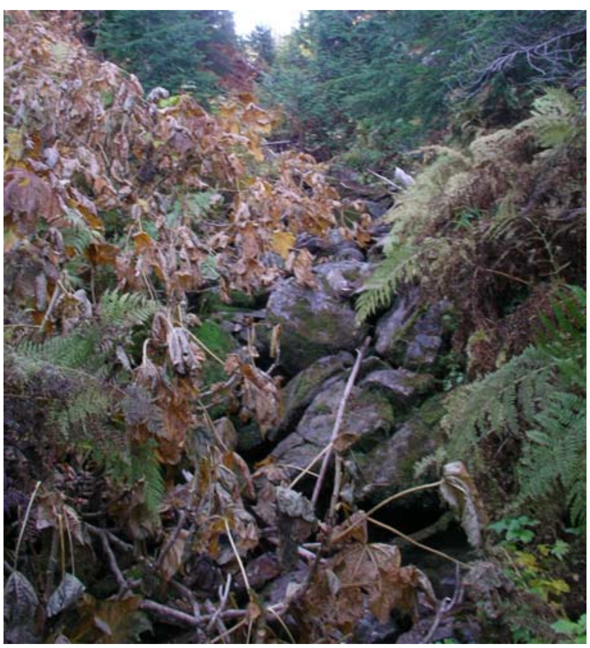

Photo 2. Headwater tributary of Wolverton Cr. above FSR at UW2 (Figure 1). Channel has very steep (>35%) colluvial boulder and bedrock cascade morphology

Riparian vegetation includes devils club, alder and rhododendron. Balsam fir and hemlock occur along gully side slopes. The mobile bed load in the headwater channels is mostly cobbles (>20cm) and finer sediment. Large woody debris (LWD) does not appear to be present or functioning in the channel above approximately 1500 metres due to the steep colluvial nature of the channels. Very little water was flowing in any of the headwater the channels observed during the field inspection.

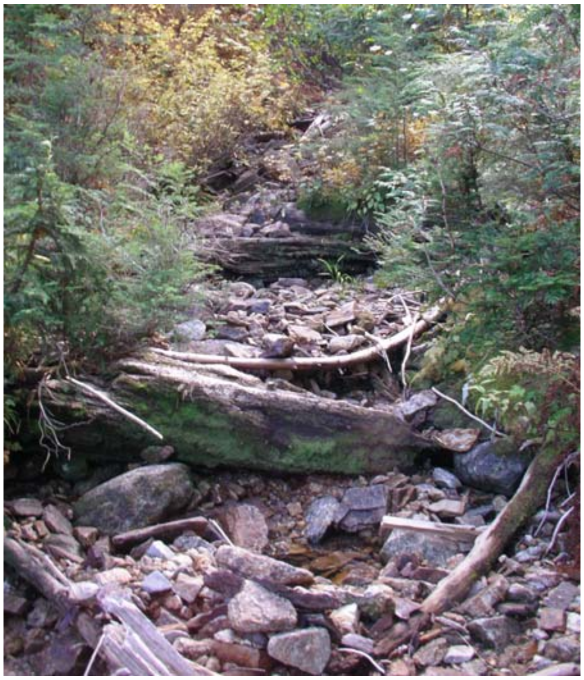

Photo 3. Headwater tributary of Wolverton Creek below the FSR crossing at UW3 (Figure 1). Old LWD entered the channel following a fire. LWD is functioning in the channel to retain bed load and moderate sediment transport rate. Functioning LWD is very old – at least 100 yrs. Riparian area in this section of channel has been logged so no LWD will be available for recruitment for many decades.

Below approximately 1500 metres both of the channels traversed had LWD step pool morphologies with gradients ranging between 15% and 28% and bank full widths of just over 2 metres. Bedrock and boulder cascades occur locally along the length of both channels. Most of the large woody debris functioning in the channels is old and burnt and appears to have entered the channel roughly a century ago following a forest fire. Single pieces and jams of LWD occur every 2 to 5 metres in the channel. Most of the LWD is recruited from up to 20 metres up slope from the channel margins. A large volume of sediment ranging from small boulders to gravel is retained behind the single pieces and jams of LWD. The boulder to gravel bed load is bright suggesting that relatively large volumes of sediment are moving annually.

Central Reaches

Photo 4. Looking downstream on small tributary east at GPS site UW6 (Figure 1).

Below approximately 1200 metres the channel gradient steepens to greater than 20 % and bedrock is exposed in the channel bed and side slopes. The morphology of the channel consists of bedrock and boulder falls and cascades. Mobile bed load consists of sub-angular to sub-rounded boulders, cobble and gravel. LWD is less significant in controlling channel structure or moderating bed load transport through this section. Local scour of channel banks and bright bed load suggest that Wolverton Creek experienced a high peak discharge in the last several years.

Debris floods appear to be the dominant channel forming mechanism in the central reaches of the headwater tributaries. Mobile bed load consists of angular to sub angular boulders and cobbles. Broken pieces of woody debris occur in the channels an along channel margins.

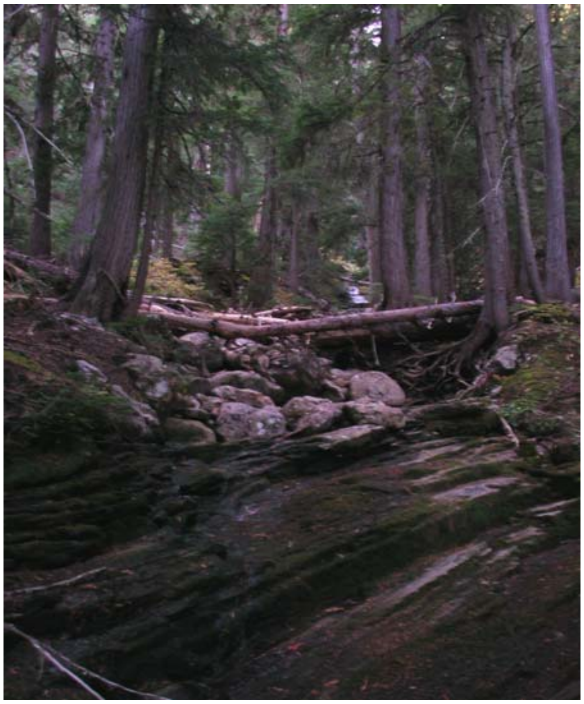

Photo 5. Looking upstream on northern traversed tributary at UW7 (Figure 1).

Debris levees are present along channel margins in unconfined sections of the headwater tributaries. The age of the levees is unclear. Some of the trees appear to be partially buried by the levees but most of the trees appear to have established on top of the levees suggesting the levees are at least 100 years old.

Lower Reaches

Photo 6. Looking upstream at site W5. Bed load is very coarse textured. Morphology is boulder cascade to step pool.

The lower reaches of Wolverton Creek between the lowest bedrock falls and the confluence with the Slocan River have a boulder cascade morphology. The channel width ranges from 6 to 10 metres wide and channel gradient ranges from 6 to 14%. The bed load consists of large sub-rounded boulders (d90 = 76cm) and finer sediment. Moss and lichen on the largest boulders suggest these have not moved for at least a decade but most of the smaller material (<40 cm) appears to move annually.

Photo 7. Cedar along channel bank on lower Wolverton illustrates armouring function of roots.

The lower reaches of Wolverton Creek are entrenched in places up to 2 meters into a 25 metre wide valley flat formed by past flood deposits. There is no functioning LWD in the channel. Cut stumps along channel margins suggest logging has occurred in the recent past. It also appears that this section of the channel has been cleared of LWD. Riparian vegetation consists mainly of small diameter (<40cm) cedar, Douglas fir and cottonwood. Cedar has established along channel margins and is providing some armouring to channel banks (Photo 7).

Coolie Lake

The channel at the outlet of Coolie Lake was dry at the time of the field inspection. The channel, where confined has a bank full width of 1.7 metres and a depth of 0.2 metres. The channel bed consists of coarse, platy, angular colluvium derived in situ from bedrock outcrops adjacent to and underlying the channel. In general the stream is unconfined and flows in multiple channels over the forest floor. There is no obvious riparian ecosystem developed adjacent to this channel. These observations suggest that the channel contains flowing water for only a portion of the year and that the velocity of the flow at the outlet of the lake is low so that there is no bed load transport along this portion of the channel.

Hydrogeomorphic Risk Analysis

A qualitative hydrogeomorphic risk analysis provides a framework to identify aquatic values of concern, document critical watershed processes that are linked to aquatic values and guide recommendations for sustaining or improving aquatic values within a watershed. The analysis considers *channel sensitivity*; the likelihood of observable negative changes to aquatic values given changes to stream discharge, rate of sediment delivery and riparian function and *hydrological hazard*; the probability of changes to watershed processes given existing and proposed development.

Channel sensitivity to changes in watershed processes is independent of existing or proposed development. It is determined entirely by the geomorphic nature of the watershed and stream channel. Each channel has unique physical characteristics determined by the geology, glacial history, climate, physiography, and elevation - aspect distribution of hillslopes that result in low, moderate or high sensitivities to the different watershed processes. Channel sensitivity is determined through a combination of field assessment, current and historical air photograph review, and regional hydrometric and climate information.

Hydrological hazard is defined as the probability of a significant change in watershed processes occurring given existing or proposed development. Hydrological hazards associated with forest development can include increased hillslope runoff and stream discharge (Wemple and Jones, 2003, Schnorbus and Alila, 2004), increased rate of sediment delivery to streams (Gomi and Sidle, 2003), and direct impacts to channel and bank stability and aquatic habitat (Faustini and Jones, 2002) caused by streamside logging.
Hydrological hazard ratings of 'Low', 'Moderate, and 'High' are a qualitative assessment of the probability of an event (i.e. increase in stream discharge, increases in sediment delivery) occurring given existing and proposed development. Hydrological hazard is determined by considering the extent and location of the existing and/or proposed development within the context of long-term natural variability in watershed condition and processes.

The risk of impact to aquatic values is determined by combining the level of channel sensitivity to a watershed process with the hazard rating (Table 1). For the purpose of this risk analysis a significance change in a watershed process is one that results in a sustained, observable negative change to an aquatic value. For example, a significant change in sediment delivery would result in sustained, observable negative changes to water quality, channel stability or aquatic habitat.
For this analysis the risk rating is determined for the main stem channel at the water intake.

Table 2. Determination matrix for hydrologic risk (Modified from B.C. MoF, 2002).

RISK	Low Hazard	Moderate Hazard	High Hazard
Low Sensitivity	Very Low	Low	Moderate
Moderate Sensitivity	Low	Moderate	High
High Sensitivity	Moderate	High	Very high

A more comprehensive description of the rational used to estimate channel sensitivity and hydrological hazard is presented in tables in Appendix 1.

Wolverton Creek Analysis

Aquatic values of concern in Wolverton Creek include:

- Water quality at the intake;
- Channel stability on the fan;
- Aquatic habitat below the falls

The sensitivity, hazard and risk for Wolverton Creek is described below and summarized in Table 3.

Stream Discharge

Wolverton Creek has a high sensitivity to increases in stream discharge. A substantial percentage of the coarse textured bed load of Wolverton Creek appears to be mobile during annual peak flows. Increases in the magnitude or duration of peak flows would likely result in significant increases in bed load transport through the lower main stem channel.

Peak flows in Wolverton Creek are controlled by snowmelt from the broad, moderate gradient, forested slopes above approximately 1000 metres. The existing level of harvest in Wolverton Creek is calculated at 17.6% of the total watershed area assuming no hydrological recovery of the existing cut blocks (based on block areas determined by D. Thorburn). The level of harvest for the area above 1000 metres, which more accurately reflects the area contributing to peak discharge, is estimated at 19%. The existing cut blocks are situated at equal elevations but are distributed across different aspects of the headwater basin which may contribute to some degree to desynchronization of snow melt.

Studies in snow-dominated mountain environments of western North America suggest that increases in peak discharge become significant once the level of harvest reaches approximately 25 percent (Schnorbus and Alila, 2004 Stednick, 1996; Troendle et al., 2001). Based on the current scientific literature, the existing level of development represents a low likelihood of increased peak flows in the lower main stem channel of Wolverton Creek.

There is a moderate risk of impacts to water quality, channel stability and aquatic habitat in Wolverton Creek associated with increases in stream discharge. The level of risk is associated with the inherent sensitivity of Wolverton Creek to increases in peak flows and not the result of the existing level of development.

Sediment Delivery

Wolverton Creek has a high sensitivity to increases in sediment delivery. Few natural sediment sources occur along the length of the headwater or main stem channels. A well-developed network of steep channels through the upper elevations of the watershed and limited in-channel storage capacity would result in relatively rapid transport of sediment to the lower reaches. Increases in suspended sediment associated with upstream soil disturbance would likely be noticeable relative to the naturally low levels of suspended sediment recorded throughout most of the year in Wolverton Creek.

There is a low likelihood that the existing development in upper Wolverton Creek has resulted in significant increases in sediment delivery that have caused sustained negative impacts to channel stability or aquatic habitat. Limited road development and moderate to gentle gradient slopes have resulted in minimal exposure of mineral soil on roads or cut slopes in the upper elevation areas where forest development has occurred.

There is a moderate risk of sustained negative changes to water quality, channel stability and aquatic habitat associated with increases in sediment delivery in Wolverton Creek. The risk rating is due to the inherent sensitivity of Wolverton Creek to increases in sediment delivery and not the hazard associated with existing development.

Riparian Function

Wolverton Creek has a moderate sensitivity to disturbances to riparian function. Roots of coniferous and deciduous vegetation along the mid to upper reaches of Wolverton Creek provides bank stability and large diameter coniferous trees (40 cm or larger) incorporated into the channel bed provide bed load storage and channel bed stability.

Riparian vegetation likely plays a limited role with respect to moderating stream temperature in Wolverton Creek. The catchment is predominantly north aspect, which limits direct exposure to solar radiation and headwater tributaries are confined in moderate to steep sided gullies that naturally shade the channel during parts of the day. In addition, shallow coarse textured soils throughout the watershed are highly pervious allowing rapid downslope movement of surface and soil water.

Harvesting of riparian vegetation along portions of four headwater tributaries has resulted in local deficits of LWD available for recruitment. Although LWD is still present and functioning in the channels in these locations it is likely that over the next several decades, as the old LWD breaks apart, the rate of bed load transport through these sections of channel will increase. Logging and clearing on the private land portion of Wolverton Creek below the lowest bedrock falls has also resulted in a decrease in riparian function, including a complete lack of functioning LWD and removal of stream side vegetation that would have provided bed load stability and bank armouring through this portion of the channel.
Wolverton Creek is assessed as having a moderate likelihood of impacts to riparian function associated with past harvesting.

The risk to channel stability on the fan of Wolverton Creek due to decreased riparian function from the existing development is assessed as moderate (Moderate sensitivity x Moderate hazard = Moderate risk).

Table 3. Summary Risk Analysis for Wolverton Creek

Watershed Process	Channel Sensitivity rating	Hydrological Hazard rating	Risk (sensitivity x hazard)	Comments
Stream Discharge	**High** – Wolverton Creek is assessed as having a high sensitivity to increases in peak discharge due to the steep gradients and large volume of mobile bed load.	**Low**	**Moderate**	Peak flows in Wolverton Creek are a function of snow melt from the broad headwater basin above ~ 1000 metres. The existing level of development represents a low likelihood of increases in peak flows.
Sediment Delivery	**High –** Wolverton Creek has a naturally low level of suspended sediment, steep gradients and limited sediment storage capacity.	**Low**	**Moderate**	Limited road and trail development and moderate slope gradients results in minimal potential for sediment delivery associated with existing development.
Riparian Function	**Moderate** – Riparian vegetation along portions of the middle and lower reaches are dependent on LWD to moderate bed load transport and provide bank stability.	**Moderate**	**Moderate**	Past logging of riparian vegetation in the upper headwater reaches and along the lower main stem channel has resulted in sustained negative impacts to aquatic habitat and channel stability in the lower reaches of Wolverton Creek.

Discussion

A hydrogeomorphic risk analysis has determined there is a moderate risk to water quality, aquatic habitat and channel stability on the fan of Wolverton Creek associated with development related increases in peak flows but a low likelihood of increased peak flows associated with the existing level of development. There is a also a moderate risk to water quality, aquatic habitat and channel stability on the fan of Wolverton Creek associated with development related increases in sediment delivery to the headwater tributaries. However, the likelihood of increases in sediment delivery associated with existing development is low due to the minimal amount of exposed soils and the moderate gradient slopes in the headwater area. In both cases the risk rating is a function of the inherent sensitivity of Wolverton Creek to increases in peak discharge and increases in sediment delivery. Wolverton Creek is also assessed having a moderate risk of impacts associated with decreased riparian function. The mid-reaches of Wolverton Creek are dependent on LWD to provide channel stability. In addition the root systems from mature coniferous and deciduous trees provide armouring to the channel banks through the middle and lower reaches. Harvesting in the upper elevations and private land logging along the lower reaches has resulted in decreased in riparian function in these areas.

Wolverton Creek is forested to the headwaters at just over 2000 metres with a mixed stand comprising spruce, balsam fir and pine, larch and Douglas fir. The catchment of Wolverton Creek consists of a broad, moderate gradient headwater basin that is drained by numerous headwater tributaries. The headwater tributaries converge into a single main stem channel at approximately 1000 metres elevation. The physical configuration of Wolverton Creek results in limited desynchronization of snowmelt and a rapid delivery of melt water to the main stem channel. In addition, the general north aspect results in maximum potential for snow accumulation and the capacity for snow to remain at the upper elevations during cool spring weather.

Observations along the lower reaches of Wolverton Creek above Naychuck Road indicate that the last major debris flood occurred roughly 50 to 100 years ago which also corresponds approximately to the timing of the last major forest fire in the headwater portion of the catchment.

The mechanism of major flood events in Wolverton Creek likely includes some combination of deforestation in the headwater portion of the catchment, cool spring temperatures that result in delayed snowmelt and rapid warming possibly combined with heavy rain.

Stand level research by Winkler and Roach (2005) has determined that clear cut harvest of mixed spruce, fir, pine stands – similar to the stands in the upper elevations of Wolverton Creek, can result in increases in snow accumulation of upwards of 50%. Winkler's study also suggests that hydrological recovery does not occur in these stands as quickly as previously suggested in the Interior Watershed Assessment Procedure Guidebook (Anon. 1995). In addition, Winkler and others (2005) and Buttle and others (2005) have determined that melt rates in partially regenerated juvenile stands actually increase relative to the melt rate in the clear cut so that, in the decades following clear cutting, the effect on peak flows are likely to increase before they begin to return to pre-harvest conditions.

Recommendations

To avoid increasing risk to water quality, aquatic habitat and channel stability on the fan of Wolverton Creek the following recommendation regarding future development in the headwater portion of the watershed are provided:

1. Avoid increasing the level of harvest above 25% in the area above 1000 metres. Do not consider juvenile stands in the existing cut blocks as partially 'hydrologically'recovered as this concept likely does not apply in this situation[2].
2. Where possible utilize partial harvest systems that maintain at least 50% of the forest canopy that is most effective at snow interception. Studies of partial cutting undertaken in similar forested mountain catchments in Colorado suggest a direct linear relationship between the percent basal area removal and percent increase in peak snow water accumulation so that a 50 % basal area removal represents a 50% decrease in peak snow water compared to a clear cut (Troendle, 1987).
3. Avoid small patch cuts of between 2 and 10 tree heights in diameter. Small patch cuts result in the greatest increase in peak snow water accumulation of all silviculture systems and also result in a delayed snow melt that has a greater likelihood of contributing to increases in the duration and/or magnitude of peak flows (Troendle and others, 1987)

[2] Synoptic snow water equivalent (SWE) measurements could be undertaken over a range of hillslope aspects in mid to late March to determine the influence of the canopy of the juvenile stands on snow interception.

4. Do not construct roads or trails on steep slopes that will result in large areas (eg. > 2 metres) of exposed mineral soils in cut slopes or fill slopes. Limiting exposed mineral soils will reduce the potential for sediment delivery to streams.
5. Maintain natural drainage patterns on roads and trails. Avoiding concentration of water in ditchlines will limit the likelihood of surface erosion and the potential for road related terrain instability.

Closure

The information in this hydrological assessment report is for the sole use of Kalesnikoff Lumber Co. ltd. and is intended to provide guidance for forest management in Wolverton Creek. The recommendations in this report are based on field observation of active hydrologic and geomorphologic processes in the watershed and on information collected from numerous sources. In addition, the recommendations presented in this report consider the results of recent studies from western North America that identify the effects of harvesting on hydrologic response of interior, snow-dominated mountainous watersheds. Some of the more relevant studies are listed in the Literature Cited section of this report.

The recommendations provided in this report are intended to maintain or improve the hydrologic condition of the watershed.

(original signed by author)

Kim Green, P.Geo. M.Sc.
Apex Geoscience Consultants Ltd.

Literature Cited

Braumandle, T.F., and M. P. Curran (editors), 1992. A field guide for site identification and interpretation for the Nelson Forest Region. B.C. Ministry of Forests, Land Management Handbook No. 20.

Butt, G. 1999. Terrain Hazard Assessment Wolverton Creek and Langill Face Unit Study Area. Prepared for Kalesnikoff Lumber Co. Ltd. 32 pgs + maps and appendices.

Buttle J.M., C.J. Oswald, and D.T. Woods. 2005. Hydrologic Recovery of Snow Accumulation and Melt Following Harvesting in Northeastern Ontario. Proceedings of the 62nd EASTERN SNOW CONFERENCE, Waterloo, ON, Canada 2005. Pgs 83 – 91.

Faustini, J.M. and J.A. Jones, 2003. Influence of large woody debris on channel morphology and dynamics in steep, boulder-rich mountain streams, western Cascades, Oregon. Geomorphology 51, pp. 187-205.

Gomi, T. and R.C. Sidle, 2003. Bed load transport in managed steep-gradient headwater streams of southeastern Alaska. Water Resources Research, Vol. 39, No. 12, 1336.

Henderson Environmental Consulting Ltd. 1999. Domestic Watershed Assessment of the Cowie Creek Watershed, Wolverton Creek Watershed and Wolverton to Langill Face Unit. Prepared for Kalesnikoff Lumber Co. Ltd., Thrums B.C. 20 pgs + appendices and maps.

Obedkoff, W, 2002. Streamflow in the Kootenay Region. B.C. Ministry of Sustainable Resource Management, Water Information Section, Aquatic Information Branch. 19 pgs + datasheets and maps.

Passmore Laboratory Ltd. 2000. Wolverton Creek: Report on Year 1 Water Monitoring for Quantity and Quality. June 17, 1999 – July 24, 2000. 4 pgs + maps and figures.

Passmore Laboratory Ltd. 2001. Wolverton Creek: Report on Year 2 Water Monitoring for Quantity and Quality. October 17, 2000 – October 17, 2001. 22 pgs + maps and appendices.

Quamme, D. 2003. Wolverton Creek 2002 Water Resource Inventory. Prepared for Kalesnikoff Lumber Co. Ltd. Thrums B.C. 26pgs + appendices and maps.

Quamme D. 2004. Wolverton Creek 2003 Water Resource Inventory. Prepared for Kalesnikoff Lumber Co. Ltd., Thrums B.C., 30pgs + appendices and maps.

Quamme D. 2005. Wolverton Creek 2004 Water Resource Inventory. Prepared for Kalesnikoff Lumber Co. Ltd, Thrums B.C., 32 pgs + appendices and maps.

Schnorbus, M. and Y. Alila. 2004. Forest harvesting impacts on the peak flow regime in the Columbia Mountains of Southeastern British Columbia: An investigation using long-term numerical modeling. Water Resources Research, Vol 40.

Stednick J.D., 1996. Monitoring the effects of timber harvest on annual water yield. Journal of Hydrology, 176, pages 79-95.

Troendle C.A. 1987. The potential effect of partial cutting and thinning on streamflow from the subalpine forest. Res. Pap. RM-274. Fort Collins, Co.: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 7 pgs.

Troendle C.A., M.R. Kaufmann, R.H. Hamre and R.P. Winokur, 1987. Management of Subalpine Forests: Building on 50 Years of Research. Gen. Tech. Rp. RM-149. Fort Collins, Co.: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station.

Troendle, C.A., Wilcox, M.S., Bevenger, G.S., and L.S. Porth, 2001. The Coon Creek Water Yield Augmentation Project: Implementation of Timber Harvesting Technology to Increase Streamflow. Forest Ecology Management 143, pages 179 to 187.

Wemple, B.C. and J.A. Jones, 2003. Runoff production on forest roads in a steep mountain catchment. Water Resources Research, Vol 39. No. 8, 1220.

Winkler, R. and J. Roach, 2005. Snow Accumulation in B.C.'s Southern Interior Forests. *In* Streamline *Watershed Management Bulletin Vol. 9/No. 1 Fall 2005*.

Winkler R.D., D.L. Spittlehouse and D.L. Golding, 2005. Measured differences in snow accumulation and melt among clearcut, juvenile and mature forests in southern British Columbia. *In* Hydrological Processes Vol. 19. pgs. 51-62.