2014 Duhamel Creek Hydrogeomorphic study findings

By Kim Green, P.Geo, PhD
Hydrologist, Fluvial Geomorphologist
www.apexgeoconsultants.com
Presentation Outline

- Terms of reference for hydrogeomorphology study
- Scope of work
  - Field work
  - Hydrological analysis
- General physiography of Duhamel Creek
- Channel morphology observations
  - Evidence of past channel and riparian disturbance
- Hydrological analysis
  - Historical annual flood data
  - Flood frequency analysis
  - Field observations of past flood impacts
- Hydraulic geometry of Duhamel Creek
- Hydrogeomorphologic Risk Analysis for Forest Development
- Recommendations for forest management
Terms of reference

- Assess the likelihood of adverse material impacts to water quality and quantity of flows at the intake associated with existing and proposed forest development in the Duhamel Creek Watershed.
  - Adverse material impacts considered here include:
    - Substantial increases in sedimentation at the intake (i.e. above the normal range of variability)
    - Increases in the frequency of floods that could affect the stability of the channel at the intake.
    - Substantial impacts to riparian function that could affect the long term stability of the channel above the intake
- Apply the risk analysis framework of LMH 61 Managing Forested Watersheds for Hydrogeomorphic Risk on Fans to assess the existing and incremental change in risk to (1) water quality at the intake and (2) channel stability at the intake (the elements at risk) associated with existing and proposed development
- Provide recommendations for forest management to minimize impacts to hydrogeomorphologic function of Duhamel Creek
Scope of work

- **Pre-Field component**
  - Investigation of watershed using Google Earth™ imagery and Province of BC air photo and DEM imagery downloaded from the GeoBC database.
  - Preliminary GIS analysis to determine landcover conditions, watershed physiography, reach breaks and to plan field program.

- **Field component**
  - Field survey of channel along the length of the main channel and major tributaries to document physical characteristics of the channel, riparian function and processes of sediment delivery.

- **Post-Field component**
  - Survey data analysis to define hydraulic geometry relations
  - Hydrometric analysis to determine causes and frequency of floods
  - GIS analysis to establish linkages between morphological and hydrological processes in Duhamel Creek
  - Risk Analysis that considers the potential for forest development impacts to processes controlling flood generation and channel structure/stability
  - Development of recommendations for forest management
Physiography of Duhamel Creek

- Area = 57 km² watershed
- 12-kilometre long, single main stem channel that is confined in a narrow, steep-sided valley.
- Mount Grohman at 2296m and Mount Cornfield at 2347m are two the highest points in the watershed.
- Two third-order tributaries (7.4 and 7.2 km2) enter the main stem channel from the west side of the watershed.
- Dozens of snow avalanche/debris flow tributaries occur along both sides of the main stem channel.
- Mean annual precipitation ranges from 800 at lower elevations to approx. 2200 mm annually along upper elevation slopes.
Geology of Duhamel Creek

- Coarse granodioritic rocks of the Nelson Batholith underlie Duhamel watershed.
- Surficial geology includes veneers of sandy, blocky colluvium along the upper and mid-elevation steep valley sides.
- Blankets and veneers of sandy to silty compact till on the mid and lower elevation side-slopes,
- Remnant sandy glaciofluvial terraces along the lower valley slopes in the lower half of the watershed.
Reach delineation on Duhamel

- Duhamel Creek comprises six morphologically distinct reaches.
- Reach 6, the uppermost reach is characterized by a broad, low gradient, U-shaped valley that contains the Six-Mile Lakes and wetlands.
- Reach 5 is a relatively steep gradient, confined, semi-alluvial segment with many snow avalanche/debris flow tributaries.
- Reach 4 is a steep, bedrock confined reach.
Reach 3, like Reach 5, has many debris/avalanche cones impinging on the valley bottom creating lower gradient wetland areas upstream and steeper gradient cascade segments downstream.
The break between Reach 2 and Reach 3 corresponds to the upstream location of the large debris flow fan of Tributary 1.
Reach 2 gradient is controlled by the slope of the southern edge of the debris flow fan. A large amount of the bedload sediment in this reach is derived from debris flows/floods from Tributary 1.
Reach 1, is the fan of Duhamel Creek.
The channel of Duhamel Creek was surveyed from Six Mile Lakes down to the fan.

Information collected included:

- channel morphology
- channel geometry and gradient,
- bedload sediment distribution,
- riparian function
- sediment sources
- disturbance history
Observations of Channel Morphology

Reach 6

- The wide U-shaped valley with lakes and beaver dammed wetlands.
- Avalanche/debris flow cones impinge into the valley bottom creating confined channel segments.
- The valley gradient ranges from less than 1 percent at lakes and wetlands to 4 percent in confined channel segments.
- Mobile bed material is mostly comprised of gravel (<2cm) and sand material but locally increases to small cobbles (12cm) through the steeper (4%), confined segments.
Reach 5

- Boulder cascade to step-pool morphology.
- Angular colluvial boulders from avalanche cones.
- Channel gradient ranges from 14 percent in steeper sections to 3 percent in lower gradient sections upstream from avalanche cones.
- Bed sediment up to 23 cm is mobile annually through steeper reaches and up to approximately 15 cm through the lower gradient segments.
- Large angular colluvium in the channel is moss covered and appears immobile.
- Channel bed is bimodal in appearance with sand and gravel surrounding large colluvial boulders.
Reach 4

- Steep bedrock canyon. Channel gradient averages approximately 10 percent and the channel is confined on both sides by bedrock cliffs.
Reach 3

- Cobble-boulder cascade adjacent to colluvial cones to step-pool morphology in transition areas to low gradient wetlands above the cones.
- Bed material up to approximately 20 cm is mobile annually through step-pool segments.
- Sand and gravel (<2mm) is mobile through the wetland segments.
- Large volumes of fine sediment are stored in the low gradient wetland sections.
- Sediment supplied from steep first order tributaries on either side of the valley.
Reach 2

- Boulder cascade to step-pool morphology.
- Channel gradient ranges from 6 to 12 percent.
- Channel is entrenched 1 meter or more into the valley flat and locally confined by bedrock and boulder levees.
- Most of the sediment in the channel is bright and appears mobile including large boulders up to approximately 80cm in diameter.
2003 – 2014 Photo comparison Reach 2
Duhamel fan

- Boulder step-pool morphology
- Above Highway 3a channel gradient averages 6%
- Boulders to approximately 35 cm diameter are moving annually.
- Past floods have resulted in abandoned channels and a boulder levee along the eastern bank that is approximately 1.3 to 1.5 meters higher than the existing bank full elevation.
Tributary 1 - avalanche/debris flow gully

Looking Upstream

Looking downstream
Tributary 1 above Duhamel Creek
Continuous discharge gauging on Duhamel Creek by Environment Canada started in 1996.

The time-series of annual maximum daily discharge indicates that over the last 20 years of gauging 2012 was the largest flood on record. 1997 was the 2\textsuperscript{nd} highest flood on record.

What causes flooding in Duhamel Creek?
April 2012 Debris flows/slush avalanches on Duhamel Creek (P. Jordan photo)
### Flood Frequency

#### Historical frequency

<table>
<thead>
<tr>
<th>Rank</th>
<th>Year</th>
<th>Discharge</th>
<th>Exc Prob</th>
<th>Rtn Pd</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2012</td>
<td>14.2</td>
<td>3.125</td>
<td>32</td>
</tr>
<tr>
<td>2</td>
<td>1997</td>
<td>13.7</td>
<td>8.333</td>
<td>12</td>
</tr>
<tr>
<td>3</td>
<td>2006</td>
<td>13.2</td>
<td>13.542</td>
<td>7.38</td>
</tr>
<tr>
<td>4</td>
<td>1999</td>
<td>12.6</td>
<td>18.75</td>
<td>5.33</td>
</tr>
<tr>
<td>5</td>
<td>2013</td>
<td>10.6</td>
<td>23.958</td>
<td>4.17</td>
</tr>
<tr>
<td>6</td>
<td>2011</td>
<td>9.93</td>
<td>29.167</td>
<td>3.43</td>
</tr>
<tr>
<td>7</td>
<td>2007</td>
<td>9.9</td>
<td>34.375</td>
<td>2.91</td>
</tr>
<tr>
<td>8</td>
<td>2002</td>
<td>9.57</td>
<td>39.583</td>
<td>2.53</td>
</tr>
<tr>
<td>9</td>
<td>2008</td>
<td>9.1</td>
<td>44.792</td>
<td>2.23</td>
</tr>
<tr>
<td>10</td>
<td>2009</td>
<td>8.83</td>
<td>50</td>
<td>2</td>
</tr>
<tr>
<td>11</td>
<td>1998</td>
<td>7.95</td>
<td>55.208</td>
<td>1.81</td>
</tr>
<tr>
<td>12</td>
<td>2003</td>
<td>7.56</td>
<td>60.417</td>
<td>1.66</td>
</tr>
<tr>
<td>13</td>
<td>1996</td>
<td>7.56</td>
<td>65.625</td>
<td>1.52</td>
</tr>
<tr>
<td>14</td>
<td>1995</td>
<td>7.29</td>
<td>70.833</td>
<td>1.41</td>
</tr>
<tr>
<td>15</td>
<td>2010</td>
<td>6.76</td>
<td>76.042</td>
<td>1.32</td>
</tr>
<tr>
<td>16</td>
<td>2004</td>
<td>6.68</td>
<td>81.25</td>
<td>1.23</td>
</tr>
<tr>
<td>17</td>
<td>2005</td>
<td>6.55</td>
<td>86.458</td>
<td>1.16</td>
</tr>
<tr>
<td>18</td>
<td>2000</td>
<td>6.4</td>
<td>91.667</td>
<td>1.09</td>
</tr>
<tr>
<td>19</td>
<td>2001</td>
<td>6.22</td>
<td>96.875</td>
<td>1.03</td>
</tr>
</tbody>
</table>

#### Log Pearson 3 predicted

<table>
<thead>
<tr>
<th>Rtn Pd</th>
<th>Exc Prob</th>
<th>Discharge</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.003</td>
<td>0.997</td>
<td>4.74</td>
</tr>
<tr>
<td>1.05</td>
<td>0.952</td>
<td>5.835</td>
</tr>
<tr>
<td>1.25</td>
<td>0.8</td>
<td>7.023</td>
</tr>
<tr>
<td>2</td>
<td>0.5</td>
<td>8.697</td>
</tr>
<tr>
<td>5</td>
<td>0.2</td>
<td>11.063</td>
</tr>
<tr>
<td>10</td>
<td>0.1</td>
<td>12.688</td>
</tr>
<tr>
<td>20</td>
<td>0.05</td>
<td>14.295</td>
</tr>
<tr>
<td>50</td>
<td>0.02</td>
<td>16.457</td>
</tr>
<tr>
<td>100</td>
<td>0.01</td>
<td>18.151</td>
</tr>
<tr>
<td>200</td>
<td>0.005</td>
<td>19.91</td>
</tr>
<tr>
<td>500</td>
<td>0.002</td>
<td>22.356</td>
</tr>
</tbody>
</table>
Floods in the past

- Following the 1972 flood dredging and cribbing works on the fan have functioned to limit the damaging overbank flooding on the Duhamel Fan.
- The cribbing contained the 1983, 1997 and 2012 floods.

1956 flood on Duhamel Cr. (Gwen Arnett photo). Photos and information courtesy of Up the Lake website coordinator Randi Jensen (upthelakehistory.wordpress.com)
40 year old cribbing on Duhamel is rotting and starting to fail. In addition the channel is aggrading (filling up) so the old cribbing is offering less protection to dwellings and infrastructure on the fan.
Duhamel Creek display well developed downstream geometry indicating it is a function of the discharge regime (alluvial channel).

The maximum mobile grain size (D90) does not display increasing size in the downstream direction indicating sediment mobility is not well connected downstream.
Hydrogeomorphic risk analysis

- **Risk** is assessed as the product of the **probability** of a hazardous event and the **consequence** of the hazardous event on the element at risk.

\[ R = P \times C \]

- The Duhamel Creek risk assessment considers that (1) water quality at the intake and (2) channel stability at the intake are elements at risk.

<table>
<thead>
<tr>
<th>Likelihood</th>
<th>Consequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Very high</td>
</tr>
<tr>
<td>Low</td>
<td>Moderate</td>
</tr>
<tr>
<td>Very low</td>
<td>Low</td>
</tr>
</tbody>
</table>

- The risk analysis considers two hazardous events; (1) a debris flood in Reach 2 of Duhamel Creek and (2) a flood capable of substantially increasing sedimentation at the intake (i.e. above the normal range of variability).
Field observations indicate that debris flows initiating in Tributary 1 continue for several hundred meters downstream as debris floods once they enter Duhamel Creek.

Field indicators suggest that the last major debris flow in Tributary 1 occurred approximately 20 to 30 years ago (likely 1983).

An investigation of the hydroclimate conditions that trigger debris floods in Tributary 1 suggests that flood magnitude as well as flood duration are important factors.

A frequency analysis using long-term discharge data from 5-mile Creek suggest that the return period of the 1983 flood was between 1:20 and 1:50 years.
Assessing the probability of floods capable of substantially increasing sedimentation

- Dozens of snow avalanche/debris flow tributaries along the length of Duhamel Creek convey sediment from steep headwater reaches to the main stem channel on an annual basis.
- Above Reach 2 much of this sediment (coarser than about 2mm) is deposited and stored in low gradient wetland ‘settling ponds’ located along Duhamel Creek.
- Cumulatively, these wetland segments store 100’s of thousands of cubic meters of fine grained sediment
Because of the occurrence of numerous wetland segments, only exceptional flood events such as the 2012 event (estimated as a 1:30 year return period flood) are capable of substantially increasing the rate of transport of the fine grained sediment to the intake.

Floods of this magnitude are also capable of breaking apart large woody debris jams that are currently storing large volumes of fine textured sediment along the length of Duhamel Creek.
Assessment of Probability and Consequence

Probability:
- The probability of occurrence for both hazardous events is between a 1:20 to 1:50 year return period event.
- This means that it is possible that an event will occur within a human lifespan.
- The qualitative likelihood of both hazardous events (debris flood and sediment mobilizing flood) is assessed as ‘moderate’.

Consequence:
- The assessment undertaken here assumes that the consequence of a hazardous event (debris flood and sediment-mobilizing flood) is ‘high’
- the occurrence of these hazardous events will always cause damage to waterworks structures or cause long term impacts to water quality at the intakes
Given the ‘moderate’ likelihood of (1) a debris flood in Reach 2 and the ‘moderate’ likelihood of a flood capable of substantially increasing sedimentation at the intake.

And

The high consequence of both these events on the intake

The existing risk of these hazardous events on the element at risk is determined to be ‘high’.

<table>
<thead>
<tr>
<th>Likelihood</th>
<th>High</th>
<th>Moderate</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very high</td>
<td>Very high</td>
<td>Very high</td>
<td>High</td>
</tr>
<tr>
<td>High</td>
<td>Very high</td>
<td>High</td>
<td>Moderate</td>
</tr>
<tr>
<td>Moderate</td>
<td>High</td>
<td>Moderate</td>
<td>Low</td>
</tr>
<tr>
<td>Low</td>
<td>Moderate</td>
<td>Low</td>
<td>Very low</td>
</tr>
<tr>
<td>Very low</td>
<td>Low</td>
<td>Very low</td>
<td>Very low</td>
</tr>
</tbody>
</table>
The question of how forest harvesting can change the frequency of flooding in snowmelt watersheds has been investigated in recent scientific studies.

In addition detailed hydrological modeling in near-by Redfish Creek provide some indication of the likely hydrological response to harvesting in a steep, mountain watershed such as Duhamel Creek given increasing levels of harvest and distributions of cutblocks.
Current level of harvesting

<table>
<thead>
<tr>
<th>Harvest date</th>
<th>Area of disturbance (ha)</th>
<th>ECA (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1960’s to 1970’s</td>
<td>106.6</td>
<td>56.8</td>
</tr>
<tr>
<td>1980’s</td>
<td>40.2</td>
<td>27.8</td>
</tr>
<tr>
<td>1990’s</td>
<td>88.1</td>
<td>89.1</td>
</tr>
<tr>
<td>2000’s (not Kalesnikoff)</td>
<td>42.8</td>
<td>42.8</td>
</tr>
<tr>
<td>Kalesnikoff (CP 1, 21, 30 and 40)</td>
<td>205.5</td>
<td>205.5</td>
</tr>
<tr>
<td>Burned area (2004, 2011)</td>
<td>112</td>
<td>112</td>
</tr>
<tr>
<td>Total</td>
<td>595.2</td>
<td>534</td>
</tr>
<tr>
<td></td>
<td>(10.7%)</td>
<td>(9.6%)</td>
</tr>
</tbody>
</table>

- Since the 1960’s just over 595 hectares of land has been harvested (approx. 11%).
- When the regeneration of the forest is considered the area ‘acting’ as a clearcut (equivalent clearcut area) is about 534 hectares (10%).
Harvest distribution

- The majority of the existing cutblocks are situated in the lower one-third of the watershed (below 1400m) on northeast aspect slopes.
Current research indicates that harvesting situated on slopes that receive large amounts of direct solar radiation have the greatest influence on stand and watershed hydrology. Harvesting on slopes that receive minimal direct radiation have less of an influence.

Research also indicates that harvesting of up to 20% of the watershed area in the lower elevations of mountainous watersheds has minimal influence on watershed flood response. This is because these slopes are mostly snow free by the time the peak flows are occurring.
Assessed Change in probability of floods/debris floods due to development

Debris floods

- Less than 4% of Tributary 1 is disturbed by harvesting. All of this is situated at low elevations.
- There is no proposed harvesting in Tributary 1.
- There is no change in the existing probability of a debris flow in Tributary 1 associated with current or proposed harvesting.

Floods causing sedimentation

- The current cutblocks of less than 10% ECA, situated on slopes below 1350m will not change the natural probability of large flood events.
- 3 proposed blocks of CP 46 have a cumulative area of about 45 ha, increasing ECA to 579 ha or 10.4% of the watershed area above the uppermost intake. All blocks are situated below 1350m.
- The proposed harvesting will not change the natural probability of floods capable of increasing sedimentation events at the intake.
Recommendations for forestry

- To avoid increasing the frequency of larger floods, harvest levels in Duhamel Creek should be limited to less than 18% and any future blocks should be planned so as to balance the cut across aspects on slopes below 1350m elevation.

- Harvesting on the fans and cones of active debris flow/debris flood tributaries (such as Tributary 1) should be undertaken with exceptional care as harvesting in these areas can increase channel instability (See BC FLNRO, LMH 56).

- To avoid increasing the frequency of debris floods in Tributary 1 harvesting should be limited to less than 5% of the watershed area of Tributary 1 and should be limited to south aspect slopes or low elevation slopes (below 1100m). This recommendation also applies to the debris flow tributary directly south of Tributary 1 which shares the same fan and appears to carry debris flows with a similar frequency.

- Roads and trails on or above unstable or potentially unstable slopes must be designed and deactivated by a QRP to avoid concentrating and diverting surface and subsurface runoff. Drainage structures are to be sized to accommodate increased surface flows following harvesting.

- Harvesting and road building activities near water courses must consider information provided in Kalesnikoff’s Riparian Management Strategies (Apex, 2013) to determine best practices for forest harvesting adjacent to S2 to S6 streams to maintain channel and riparian integrity.
Acknowledgements

- Archive photos and historical information regarding flooding provided by:
  - Up the Lake website (upthelakehistory.wordpress.com, Randi Jensen coordinator)
  - Greg Nesteroff (Nelson Star Editor and History Buff)
  - Peter Jordan (Regional Geomorphologist, BC MFLNO

- Field assistance provided by Samuel Lyster P.Eng. And Will Halleran P.Geo., L.Eng.

- Presentation will be posted on Apex Website: www.apexgeoconsultants.com