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1.0 INTRODUCTION

In November 1999 Summit Environmental Consultants Ltd. (Summit) was retained by Tolko Industries Ltd. - Louis Creek Division (Tolko) to conduct a hydrologic review of Tolko's proposed development plans for Cutting Permit (CP) 323 and a portion of CP 319. The two CPs were subsequently combined into a single plan under CP 323, which targets blowdown, snowpress (trees damaged by heavy snow loads), root disease, and trees damaged by mountain pine beetle. Comments on potential hydrologic impacts to Leonie and Bottrel Creeks associated with the development were provided in November 1999 (Summit, 1999a), and input into silviculture prescriptions for CP 323 was provided in December 1999 (Summit, 1999b). This preliminary review concluded that changes to the hydrologic regime would likely be minor based on the insensitivity of the watersheds to peak flow increases. However, the report suggested follow-up field verification to confirm channel and watershed conditions, stability, and sensitivity to future forest development. The watersheds of Leonie, Bottrel and Chip Creeks were subsequently examined in the field over a three-day period: November 26, December 1 and December 12, 1999.

Leonie, Bottrel, and Chip Creeks are each tributary to the Barriere River. Leonie Creek is a Community watershed, with a community intake situated at elevation 840 m, and several other intakes, both upstream and downstream of the community intake. Both Bottrel and Chip Creeks provide domestic water to several users in the lower reaches. Leonie Creek supports anadromous and resident fish, and the other two creeks are suspected to support anadromous fish in their lowest reaches.

This report summarizes the work completed to date, and provides recommendations to minimize potential aquatic resource impacts associated with forest management within the study area, in which natural factors (blowdown, snowpress, root disease, and mountain pine beetle) will necessitate some level of future management activity. This report will be updated in late 2000 as part of a reconnaissance watershed assessment currently underway for the entire Barriere River watershed.

The objectives of the study were to:

1. Assess sediment sources to the mainstems and significant tributaries of Leonie, Bottrel, and Chip Creeks.[1]
2. Assess the sources, nature, and degree of existing anthropogenic impacts on mainstem and tributary channels within each watershed, and identify means by which risks to water quality due to these impacts can be reduced.
3. Assess channel stability and sensitivity (the potential for channels to change in response to future forest management).
4. Provide strategies for forest management to mitigate potential risks to channels and water quality associated with future forest management, recognizing ongoing processes of forest change.
5. Review the specific forest management proposal associated with CP 323 and recommend mitigation strategies where necessary to reduce the risk of impacts on channels and water quality.

2.0 WATERSHED CONDITION

2.1 DATA

This section presents a summary of hydrologic conditions within each watershed. Table 2.1 presents a summary of basin characteristics, both for the existing (end-1999) condition, and assuming the development represented by CP 323 is completed (by end-2000).

CP 323 does not affect Chip Creek, therefore we do not present data for Chip Creek in Table 2.1. The Chip Creek watershed covers only 749 ha. Most prior harvesting has occurred in the upper elevations, and many blocks appear to be not yet hydrologically recovered. Due to

[1] The watershed condition for Chip Creek was assessed in reaches 1 and 3, however an detailed reconnaissance of the channel was not completed. ECA values were not determined as CP 323 does not directly affect Chip Creek watershed. Should future development plans include Chip Creek, a more detailed reconnaissance of watershed conditions is recommended.

20.5 km of road, the road density is relatively high (2.7 km/km^2). There are 10 stream crossings of the main channel and intermittent tributaries.

Table 2.1 Watershed report card for Leonie Creek and Bottrel Creek watersheds.

		Existing Condition (1999)		Impact of Forest Dynamics (1)		With Proposed Harvest of Standing Timber	
	Leonie Creek Watershed						
	Total watershed area (ha)	**3834**	N/A	N/A	N/A	N/A	N/A
	Total watershed area below H_{60} (ha) (H_{60}=1132m)	**1534**	N/A	N/A	N/A	N/A	N/A
	Total watershed area above H_{60} (ha)	**2300**	N/A	N/A	N/A	N/A	N/A
Extent of	Area of sub-basin harvested (ha, %)	1717	45	1785	47	1896	50
Harvesting	Equivalent clearcut area (ha, %)	757	20	832	22	954	25
	Equivalent clearcut area below H_{60} (ha, %)	333	22	335	22	348	23
	Equivalent clearcut area above H_{60} (ha, %)	424	18	490	21	606	26
Roads	Total length of road (km)	58.4	N/A	N/A	N/A	68.9	N/A
	Total road density (km/km^2)	1.52	N/A	N/A	N/A	1.80	N/A
Landslides	Total number of anthropogenic-related landslides entering streams (2)	7	N/A	N/A	N/A	N/A	N/A
Streams	Length of unstable or very unstable stream channel (km, %)	13.6	52	N/A	N/A	N/A	N/A
	Bottrel Creek Watershed						
	Sub-basin area (ha)	**571**	N/A	N/A	N/A	N/A	N/A
	Sub-basin area below H_{60} (ha) (H_{60}=1100m)	**228**	N/A	N/A	N/A	N/A	N/A
	Sub-basin area above H_{60} (ha)	**343**	N/A	N/A	N/A	N/A	N/A
Extent of	Area of sub-basin harvested (ha, %)	180	32	204	36	220	39
Harvesting	Equivalent clearcut area (ha, %)	180	32	204	36	220	39
	Equivalent clearcut area below H_{60} (ha, %)	84	37	92	41	100	44
	Equivalent clearcut area above H_{60} (ha, %)	96	28	112	33	123	36
Roads	Total length of road (km)	9.4	N/A	N/A	N/A	11.9	N/A
	Total road density (km/km^2)	1.65	N/A	N/A	N/A	2.08	N/A
Landslides	Total number of anthropogenic-related landslides entering streams	0	N/A	N/A	N/A	N/A	N/A
Streams	Length of unstable or very unstable stream channel (km, %)	0.9	16	N/A	N/A	N/A	N/A

ECA values include roads

(1) This column reports the ECA effect of natural processes in the study area.

(2) Reported by IWS, 1998.

Table 2.2 presents the characteristics of each reach of each of the three study area channels. The data include channel disturbance level, stability, and sensitivity.

Table 2.2 Channel characteristics: Leonie, Bottrel, and Chip Creeks.

Stream	Reach No.	Length (km)	Slope (%)	Confined?	Bankfull channel dimensions		Quantity of large woody debris[3]	Dominant bed texture[4]	Channel morphology[5]	Disturbance			Sensitivity[9]	Stability[10]	Riparian Condition[11]
					Width (m)	Depth (m)				level[6]	type[7]	cause[8]			
Leonie	1	3.5	6	N	19.7	2.5	2	c	RPc	5	1	S	3	5	4
Leonie	2	2.1	12-18	Y	--	--	--	b/R	SPb/B	1	--	--	2	2	1
Leonie	3	3.5	5-10	Y	7.0	1.2	3	c	RPc-w/CPb-w	1	--	--	3 (*2)	2	1
Leonie	4	Lake	N/A		No field inspection was completed								N/A		
Delta	5.1	0.4	6		No field inspection was completed								4 (*7)		
Delta	5.2	0.5	5		No field inspection was completed								4 (*7)		
Delta	6.1	1.5	6-8	N	6.5	1.2	3	c/b	CPc-w	3	3	B(*4)	3	4	LB=4, RB=1
Delta	6.2	3.4	10	Y	10.0	0.8	3	g/c	CPc-w	3	3	B(*4)	3	4	1
Nanak	trib	8.4	<5-8	N	1.0-3.6	0.4-0.6	2-4	g/c	RPg-w	2-4	1,2,3,4	B (*1,*4)	3	2-4	4
Willow	trib	2.9	12	N	3.5	0.7	2	c	CPc	2	--	--	2	2	1
Bottrel	1	0.9	11-14	Y	3.5	1.0-1.5	2	c	CPc	5	1	?(*3)	3	5	4
Bottrel	2	1.5	20-25	Y	2.0-5.0	1.0-1.5	3	b	SPb-w	2,4	--	--	2	2	1,3
Bottrel	3	3.1	5	Y	3.0	0.4	3	g/c	CPc-w	3	1	X(*6)	2	3	LB=1, RB=4
Chip	1	0.9	13	N	3.5	0.5	3	g/c	CPc-w	2	3	(*1)	4	3	4
Chip	2	0.7	23		No field inspection was completed								2 (*7)		
Chip	3	3.0	8	Y	3.0	0.6	5	g	CPc-w	4	1,2,3	B(*5)	2	3	5

Properties:
3: scarce (1), occasional (2), common (3), abundant (4), over-abundant (5)
4: sand (s), gravel (g), cobble (c), boulder (b), bedrock (R)
5: riffle-pool (RP), cascade-pool (CP), step-pool (SP), and bedrock (B); -w indicates LWD-related channel morphology
6: not detectable (1), slight (2), moderate (3), high (4), extreme (5)
7: bed aggradation (1), bed degradation (2), bank erosion/slumping (3), fine sediment input (4)
8: road crossing (X), culvert (C), slide (S), block (B), road (R), diversion (D)
9: none (1), slight (2), moderate (3), high (4), and extreme (5)
10: the classes are: 1 = very stable (immobile bed and banks)
2 = stable (cross-section, planform geometry and channel slope are relatively static)
3 = equilibrium (mobile bed and/or banks, but no long-term changes in cross-section or slope, channel may shift laterally but maintains form)
4 = unstable (channel pattern and/or cross-section and/or slope are changing by aggradation or degradation)
5 = very unstable (frequent and/or rapid and/or large changes in channel pattern and/or cross-sectional shape and/or slope)
11: natural (1), extensive buffer/selective logging (2), partial buffer/intact banks (3), logged to bank/substantial revegetation (4), logged to bank/no stabilizing vegetation (5)

Additional Comments:
*1 = very old selective logging, cattle access continues
*2 = due to erodible and high right bank
*3 = source was not identified
*4 = snowpress and SWD input
*5 = Blowdown, snowpress, slash
*6 = SWD input from fillslope
*7 Value estimated from a previous report (IWS, 1998), aerial photos and terrain maps (Terratech, 1998a).

Table 2.3 summarizes four "anthropogenic impact ratings" for each watershed: peak flow, channel stability, sediment, and riparian impact rating. Each rating is defined as the degree to which the natural regime has been altered by human activity. Table 2.4 summarizes channel sensitivity for each watershed. This table also presents a rating for "watershed routing efficiency" (how quickly the watershed routes precipitation and snowmelt into streamflow), and an assessment of the "potential for channel response due to ECA changes", which is derived by combining the channel sensitivity with the watershed routing efficiency.

2.2 DISCUSSION

Forest management in the study area is being driven largely by the need to manage forest health factors – the processes of blowdown, mountain pine beetle infestation, root disease, and snowpress damage. These processes have resulted in a natural increase in the ECA of about 2% since 1998 in the Leonie Creek watershed (Table 2.1), and 4% in Bottrel Creek (estimated from field information collected by Tolko on the extent of blowdown and snowpress damage). CP 323 is targeted at salvaging existing timber damaged by these processes, which are expected to continue to drive forest management decisions into the future.

Channel morphology and water quality are controlled primarily by the rate of sediment supply from a watershed surface to the channels, and by the hydrologic regime of the major channels. Forest degradation (either by natural or anthropogenic means) can affect both the sediment and hydrologic regimes. In general, forest management is more likely to impact channel morphology by affecting the sediment regime than by affecting the hydrologic regime (pages 316-320, Knighton, 1998).

Table 2.3 Summary of anthropogenic impact ratings for each watershed.

Impact Rating*	Leonie Creek watershed	Bottrel Creek watershed	Chip Creek watershed
Peak Flow	Low • potential disturbance from ECA effects is not detectable	Low • potential disturbance from ECA effects is not detectable	Low • no ECA-related effects were detected
Channel Stability	Moderate • reaches 1, 6.1, 6.2, and Nanak creek are either unstable or very unstable, due to both natural and human factors • Reaches 6.1 and 6.2 impacted by forest harvesting resulting in an increase in small woody debris, sediment, and log jams • cattle activity in Nanak has locally weakened banks and introduced fine sediment	Low • reaches vary in stability from stable to very unstable • a natural debris flow has disturbed reaches 1 and 2, resulting in instability in reach 1 as the stream downcuts through the deposited sediment lobe	Moderate • portions of the upper reaches are logged to bank and loaded with small woody debris, however disturbance is minor • cattle activity in reach 1 has weakened banks slightly and slightly decreased channel stability
Sediment	Low • seven small slides in reach 6.2 are attributed to their close proximity to forest roads, however the disturbance is localized • cattle disturbance in Nanak Creek has weakened banks and introduced fine sediment in localized areas • Leonie Slide has added large amounts of sediment to reach 1, however this is not anthropogenically-derived	Low • minor sediment contributed by cattle activity in localized areas • debris flow has deposited a sediment lobe in reach 1, channel is downcutting and transporting finer sediment Coarse sediment remains in-channel increasing bed-material particle size • no anthropogenic landslides were identified	Low • cattle activity has weakened banks slightly in reach 1, contributing fine sediment • no landslides were identified
Riparian Function	Low • reaches are natural or have substantial revegetation after harvesting	Low • reaches historically logged to bank have recovered with substantial revegetation	Moderate – High • reach 1 is logged to bank with substantial revegetation • reach 3 has portions that are logged to bank with no stabilizing vegetation

*Peak flow impact rating = the likelihood that peak flows (equal to or greater than the annual maximum daily discharge) have been increased by human activity.
Channel stability impact rating = the degree to which anthropogenic activity has affected channel stability.
Sediment impact rating = the degree to which human activity has increased the rate of sediment supply to the stream channel, relative to background rates.
Riparian function impact rating = the degree to which natural riparian function has been disturbed.

Table 2.4 Channel sensitivity, watershed routing efficiency, and potential channel response due to ECA for the study area

Watershed	Overall Channel Sensitivity	Watershed Routing Efficiency	Potential Channel Response due to ECA
Leonie Creek	Moderate	Low	Low
Bottrel Creek	Moderate	Moderate	Moderate
Chip Creek	Moderate	Moderate	Moderate

Anthropogenic impacts on the hydrologic and sediment regimes vary in degree throughout the study area (Tables 2.2 and 2.3), however overall effects have been minor. No channel changes attributable to ECA levels were identified in Leonie Creek (Table 2.3), and because of the relatively low ECA (20%), it is not likely that ECAs have altered the hydrologic regime of the creek. Data in Table 2.4 indicates that the response potential of Leonie Creek to **hydrologic changes** (in particular, increases in peak flows) associated with ECA is low. This means not only that a high value of ECA is needed to initiate detectable changes to channel characteristics (more than a threshold of approximately 50%), but also that the degree of channel impact beyond the threshold is not likely to be high. In addition, any such changes will likely remain overshadowed by the changes attributed to the naturally-occurring Leonie Slide.

Similarly, no channel changes attributable to ECA were detected in Bottrel or Chip Creeks. The Bottrel ECA is 32%, near typical rule-of-thumb thresholds for ECA effects (the ECA within the Chip Creek watershed is unknown). Table 2.4 indicates that both Bottrel and Chip Creeks have a moderate potential to show alterations associated with an increase in ECA. This can be interpreted to mean that the impact threshold is likely around 40%, and that the degree of impact above the threshold will be greater than for Leonie Creek. Based on the work conducted for this study, it is not likely that the existing ECA within Bottrel Creek has affected the peak flow regime, channel morphology, or water quality.

The two most notable **natural** sediment processes are the Leonie Slide, a large slump/earthflow (described by Terratech, 1998b) affecting reach 1 and the lower part of reach 2 of Leonie Creek, and a debris flow in Bottrel Creek, which originated in reach 2, and affects reaches 1 and 2. The sensitivity of the stream channel network to changes in the **sediment regime** (i.e. the rate of sediment supplied to the channel) is a function only of channel sensitivity (Table 2.4), which is moderate in all three watersheds. The lowest reaches are the most sensitive to changes in the sediment regime (Table 2.2). Leonie Lake substantially mitigates sediment transport through the lake into the lower reaches. In contrast, Nanak watershed and Leonie Creek below the lake are more susceptible to increases in inputs of fine sediment, which has the potential to degrade water quality at the community intake. Any introduced coarse sediment is likely to be eventually transported downstream, and contribute to the already moderately-sensitive reaches downstream of the Leonie Slide. Neither Bottrel nor Chip Creeks have a similar flat-gradient mid-elevation reach. Both have steep lower elevation reaches that efficiently transport sediment towards their respective fans (reach 1).

Future forest management is more likely to affect the sediment regime than the hydrologic regime of study area creeks. In addition, hydrologic changes could occur in future with or without any forest management (if ECAs get large enough), since blowdown, root disease, and beetle attack are ongoing processes. Under CP 323, ECA in Leonie Creek watershed will increase from 20% (18% above the H_{60} line) to 25% (26% above the H_{60} line). Natural processes (blowdown and snowpress) have already increased the ECA to about 22%, so harvesting of standing timber within CP 323 is responsible for an increase in ECA of only about 3%. The proposed blocks are located upslope of the flat-gradient mid-watershed elevations, and the increase to 25% is not likely to result in changes to the peak flow regime of the creek.

Under CP 323, ECA in the Bottrel watershed will increase from 32% (28% above the H_{60} line) to 39%. Blowdown and snowpress damage has already increased the ECA to 36%, so the ECA addition due to harvesting standing timber is only 3%. As indicated above, the threshold for ECA influence on the hydrologic regime is likely near 40%, so CP 323 will not likely have a noticeable effect on the peak flow regime. Any increases in ECA beyond CP 323 could potentially begin to affect peak flows in the creek, but any related channel changes will likely remain masked by the sediment aggradation and ongoing streamflow-induced downcutting associated with the existing debris flow. More so than limiting ECA to prevent changes to channel morphology, it is important to focus on minimizing any unnatural input of sediment and woody debris to the channel to avoid increasing the risk of debris flows in reach 2.

There is no proposed harvesting in the Chip Creek watershed. Recommendations for minimizing changes to the sediment regime in Leonie and Bottrel Creeks are provided in section 4.0.

3.0 CONCLUSIONS

On the basis of the investigation reported herein, the following conclusions are drawn:

- Anthropogenic disturbance in all three watersheds has only small, localized impacts.
- Sediment sources in Leonie Creek include landslides (including the natural Leonie Slide) and channel banks that have been disturbed by cattle activity (in the Nanak Creek tributary). Most landslides are attributed to natural factors, except those in reach 6.2, which can be linked to a forest road.
- Sediment sources in Bottrel Creek are limited to a single natural landslide and a sediment lobe in reach 1 from a recent natural debris flow.
- In reach 1 of Chip Creek, field evidence showed that cattle activity is increasing the rate of supply of fine sediment to the creek.
- The potential for future forest management to affect the sediment regime of study area channels is higher than the potential to affect peak flows.
- Changes to the hydrologic regimes are not likely to occur in Leonie Creek until ECA exceeds about 50%, and in Bottrel and Chip Creeks until ECA exceeds about 40%. Any

channel changes related to potential hydrologic changes in the lower reaches of Leonie and Bottrel Creeks will likely remain masked by existing natural sediment-related disturbances.

- Leonie Lake and surrounding flat-gradient areas at mid-elevations within the Leonie watershed substantially mitigate hydrologic or sediment regime changes initiated upstream of the lake.
- Natural factors such as blowdown, snowpress, mountain pine beetle infestation, and root disease have naturally increased the ECA within the study area and will continue to do so. About half of the ECA increase associated with CP 323 has already occurred due to natural processes.
- It is unlikely that CP 323 will alter the hydrologic regime or cause channel changes related to ECA levels. However, further increases in the Bottrel ECA (beyond CP 323) could begin to result in minor ECA-related channel changes, which will not likely be significant relative to the impacts of the existing (natural) debris flow.

4.0 RECOMMENDATIONS

The following recommendations are provided to guide future forest management:

- Forest management should focus on minimizing the introduction of fine sediment to all study area channels, since all three watersheds supply domestic water and fish presence is either confirmed (Leonie) or suspected (Bottrel and Chip).
- Management activities should avoid increasing the risk of debris flows in reach 2 of Bottrel and Chip Creeks, by ensuring natural drainage patterns are maintained and not concentrated onto sensitive slopes downslope of roads and blocks near these steep reaches, and that logging-related debris is not introduced to the channel.
- Road 3200 (Leonie Mainstem) is directly upslope of a raveling till bank adjacent to reach 3 of Leonie Creek (Map 1). This section of the road is scheduled for deactivation, and will be replaced by a road set 500m back from the Leonie Creek (indicated on Map 1).

Control of surface drainage across the deactivated road is recommended to prevent potential destabilization of the slope.

- Landslides in reach 6.2 are unstable due to undermining action by the stream channel. IWS assessed that in-stream stabilizing works would not be effective due to stream energy conditions during peak flows (IWS, 1998). These unstable sites should be left alone to stabilize and revegetate naturally. Future assessment of stability can determine if any remedial measures are necessary.
- Sections of reach 3 of Chip Creek have been logged to bank, and would benefit from riparian planting with appropriate species to re-establish a natural vegetation cover.
- Before future harvesting occurs in Chip Creek watershed, existing and future ECAs should be determined and advice provided on means to mitigate potential hydrologic and sediment changes.

Additional recommendations to mitigate past impacts on the sediment regime not related to forestry practices are as follows:

- Riparian planting will help re-establish functioning riparian vegetation in reach 1 of Bottrel Creek.
- Cattle fencing, control of cattle access, and riparian planting in lower Nanak Creek (Leonie Creek watershed) and in reach 1 of Chip Creek is recommended to reduce disturbance of the channel banks and re-establish functioning vegetation.

Specific recommendations for CP 323 are provided here. They are intended to provide objectives for specific blocks and roads, but not to constrain Tolko to specific strategies to achieve the objectives. The recommendations are based on the reconnaissance channel assessment reported herein, but proposed roads and blocks have not been inspected in the field.

- Proposed blocks 323-1, 2, 2.4, 2.5, and 3 border or cross Nanak Creek, and any introduced sediment has the potential to move downstream and affect the community water intake in reach 2 of Leonie Creek. To the extent possible (recognizing natural processes of forest degradation) maintaining riparian buffers and minimizing operations within the riparian management area will protect the functioning riparian vegetation and limit sediment introduction. Proposed roads to these blocks (such as 3225.20, 3225.70, and 3226) require drainage systems that will avoid disrupting the existing surface drainage patterns, and avoid introducing sediment. Roads should be at least seasonally deactivated (to control runoff) immediately following harvesting operations.

- Block 323-15.15 is located near an unstable section in reach 6.2 that has experienced several landslides initiated by forest development (IWS, 1998). Management of this area must include measures to ensure road and surface drainage is not concentrated to the unstable area, and vegetation is not removed at or closely above the unstable sites.
- Blocks 323-12.12, 12.2, and 12.3 border the channel in reach 3 of Bottrel Creek. Management strategies here should be designed to prevent the addition of sediment or logging-related debris to the channel, and thereby avoid increasing the risk of debris flows. In addition, block 323-12.2 is located upslope of road 3200 that parallels the channel, and concentration of flow that could destabilize the road prism or slope below should be prevented. If possible (recognizing natural factors) operations within the riparian zones should be minimized and trees should be felled away from the channel. Proposed roads 3232.20 and 3232.24 should be constructed to maintain surface drainage patterns (as per section 9.1.b of Forest Road Regulation, March 2000), and to minimize sediment being added to the channel. Roads should be at least seasonally deactivated (to control runoff) as soon as harvesting is completed.

5.0 REFERENCES

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