A GIS-based water quality risk assessment of Thompson Region watersheds

Samantha Cooper
Ministry of Environment
Thompson Region
January 2011

Acknowledgements

This project required extensive input from a number of people. I would therefore like to gratefully thank the following people for their assistance with this project:

- Chris Ens, Land Information Coordinator, ILMB, for all of his time, patience, and quality data analysis which formed the basis of this project;
- Bob Grace and Dennis Einarson (Environmental Impact Biologists, MoE) and Gabriele Matscha (Section Head, MoE) for their ideas, expertise, and feedback;
- Clayton Bradley and Morgan Rankin (Range Agrologists, MFR) for their technical expertise on range use;
- Kevin Murphy, Resource Stewardship Agrologist, MAL, for his timely feedback and comments;
- Alan Card (A/Timber Pricing Coordinator, MFR) and John McQueen (Stewardship Officer, MFR) for their expertise on riparian areas and forestry tenures;
- Colleen Dreger (Water Information Technician, MoE) and Duane Wells (Water Technical Officer, MoE) for their assistance in understanding water licenses; and,
- Rita Winkler (Hydrologist, MFR) and Tim Giles (Research Geomorphologist, MFR) for their comments on fire effects and forestry roads.

Abstract

Spatial data analysis of land use types, water users, and natural watershed characteristics was used to rank fourth and higher order watersheds in the Thompson Region from highest to lowest risk of anthropogenic effects on water quality and its designated users. The top three high risk watershed units were the South Thompson River from Shuswap Lake to Kamloops, Peterson Creek (Kamloops), and the North Thompson River from Barriere to Kamloops. These watershed units have high proportions of urbanization, agriculture, mining, and road and stream crossing densities. The main limitation to this approach was access to current spatial data.

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1.0 Introduction

Protection of surface water for the broad spectrum of resource users requires a thorough understanding of the watershed attributes that may cumulatively affect water quality. In 2009/10 staff in the British Columbia (B.C.) Ministry of Environment's (MoE) Thompson Region developed a watershed prioritization matrix to identify watersheds within the region at highest risk of anthropogenic effects on water quality and its designated users. The project output, namely a ranked list of all fourth order and higher watersheds in the Thompson Region, is a screening tool that will be used to focus regional monitoring efforts on areas of highest concern. Subject to an internal decision making process[1], the prioritized watersheds may be sampled for one year near their mouth. If this screening level sampling identifies water quality issues (e.g. water quality guidelines exceedances for one of the designated users in the watershed) a more intense monitoring program may be launched to confirm the issues and identify causes. Prioritizing monitoring activities based on outcomes of a risk analysis, followed by surveillance type monitoring, would enhance staff time and funding efficiency by focussing on watersheds of highest concern.

Watershed attributes with potential to impact water quality conditions that were considered in the risk rankings included a number of natural watershed characteristics and human land uses. The ranking process also included a multiplier based on the extent and sensitivity of water users in the watershed. All data were obtained through analysis of Provincial spatial data layers.

This report explains the process used to rank watersheds within the Thompson Region. Included are a brief overview of watershed attributes and their potential impacts on water quality, an explanation of methods used in the ranking process, and a discussion of ranking results. This initial snapshot is a starting point for the investigation of high-risk watersheds in the Thompson Region.

[1] The internal decision making process would take into consideration Ministry direction, Ministry biologists' expert opinion, existing data, resource availability, and additional ground truthing.

2.0 Study area

The area considered in this matrix was defined by the spatial boundary of the MoE's Thompson Region, shown in Figure 1. The Thompson Region encompasses thirteen biogeoclimatic zones. The four main zones are the Engelmann Spruce – Subalpine Fir (30%), Interior Douglas-fir (28%), Interior Cedar – Hemlock (16%), and Montane Spruce (11%) zones. The rest of the region is comprised of the Interior Mountain-heather Alpine (5%), Bunchgrass (3%), Ponderosa Pine (2%), Coastal Western Hemlock (2%), Sub-Boreal Spruce (1%), Sub-Boreal Pine-Spruce (1%), Mountain Hemlock (1%), Coastal Mountain-heather Alpine (1%), and Boreal Altai Fescue Alpine (<1%) zones. The mean, annual precipitation for these zones ranges from 280 to 5000 mm, 15 to 80% of which falls as snow (Meidinger and Pojar 1991, MacKenzie 2006). The mean annual temperature for these zones ranges from -4˚C to 27˚C.

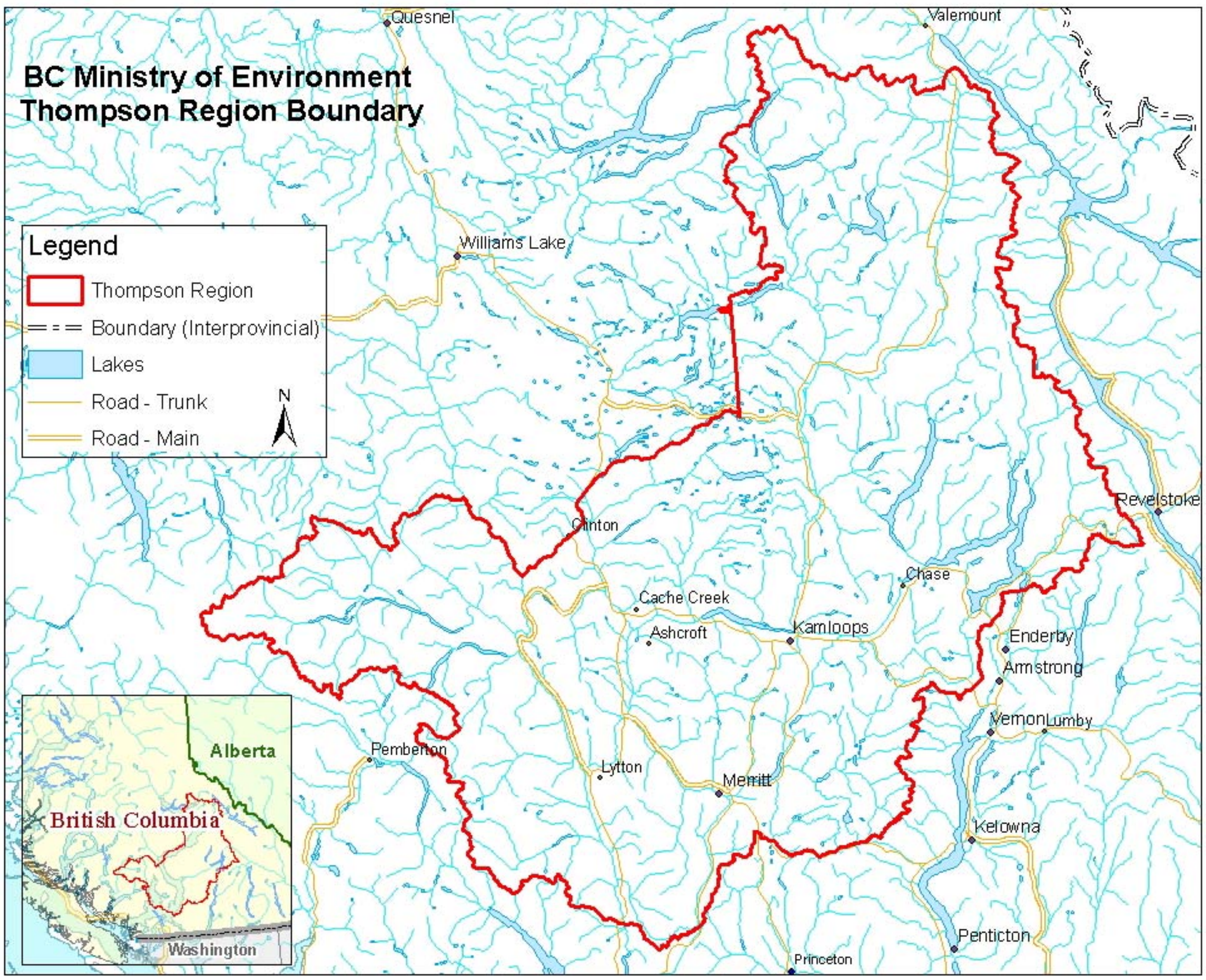

Figure 1. Project boundary as defined by the Ministry of Environment's Thompson Region.

3.0 Methods

A number of watershed risk matrices incorporating land use have been completed throughout the Province for other MoE regions[2]. These matrices were reviewed to help determine suitable methodology and criteria for the ranking process. Final criteria and watershed delineation methods for the Thompson Region's matrix were determined through internal discussions among regional water quality staff[3].

3.1 Watershed delineation

Within the Thompson Region rivers range in size from first order, headwater streams, to ninth order, main stem rivers, such as sections of the Fraser and Thompson Rivers. To make analysis feasible a target of 250 to 300 similar sized watershed units was set. Initial review of watershed data revealed over one thousand, third order watersheds in the region, a number which greatly exceeded our target. It was therefore decided that the smallest watershed unit would be fourth order, based on a 1:50,000 map scale. Third order and lower watersheds were merged with neighbouring watersheds[4] to create a watershed unit similar in size to others. Sixth order and higher watershed units with very large areas were subdivided into smaller sections. For this study sixth order and higher watershed units are referred to as 'large,' and the third, fourth, and fifth order watershed units are referred to as 'small.'

When sub-dividing the large watersheds into sections, first and second order streams that drained directly into the main stem were merged with that main stem section to ensure that all land area was accounted for. Based on this delineation, seventeen large and 216 small watershed units were considered. Watershed unit boundaries are shown in Appendices A and B, respectively.

Although these delineation and grouping methods allowed for manageable numbers and sizes of watershed units for comparison purposes, it is acknowledged that this does not accurately portray water movement across the landscape; water quality of a large river is highly dependent on the water quality of its tributaries. However, study limitations necessitated that tributaries and main stem sections be examined separately.

3.2 Establishing matrix criteria

Matrix criteria were determined by review of previous risk analyses completed by other jurisdictions. These reports were reviewed and discussed extensively by Thompson Region water quality staff to identify which criteria would be used in the spatial analysis. Two main criteria were decided upon: watershed attributes that influence water quality and extent and sensitivity of water users.

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[2] Omineca-Peace watershed prioritization report (Rex 2003), Ranking water quality risk in Cariboo Region watersheds (Hart 2004), Southern Interior Region forest water quality needs analysis summary (DAES 1996), Kootenay regional watershed assessment (McGregor 2003), A risk-based watershed screening procedure for the Kamloops Timber Supply Area (Forsite et al. 2007).

[3] In total there was 65 years combined experience between three water quality experts: Robert Grace, Environmental Impact Assessment Biologist, 25 years experience; Dennis Einarson, Environmental Impact Assessment Biologist, 30 years experience; Gabriele Matscha, Section Head, 10 years experience.

[4] Some third order streams were left un-merged due to their larger areas.

3.2.1 Watershed attributes that influence water quality

Watershed attributes that can influence water quality include human land uses as well as natural watershed characteristics. An assumption was made that as the total proportion of anthropogenic land uses within the watershed increases, so does the potential for contamination from non-point source (NPS) pollution. Unless otherwise stated, watershed attribute percentages were calculated using data at a 1:50,000 map scale and areas are in hectares. All data were obtained from the Provincial Land and Resource Data Warehouse (LRDW) and can be accessed through the GeoBC Data Discovery service (http://geobc.gov.bc.ca/). For more information on data layer location and accessibility please contact Samantha Cooper or Chris Ens.[5]

Watershed slope

Average watershed slope was considered because it provides a generalized indication of slope stability and potential for runoff; steep terrain increases the chance of landslides or debris flows and has potential to deliver more surface runoff to streams (Croke and Hairsine 2006, Rex 2003). Average watershed slope was determined from terrain resource information mapping and digital elevation model mapping data by the Integrated Land Management Bureau.

Drainage density

Drainage density is the total channel length divided by the watershed area (Knighton 1998). Water quality can be affected by drainage density by its linkage to surface runoff delivery; as drainage density increases, so should runoff delivery to streams (Rex 2003). It was calculated by adding up the total length of all streams at a 1:50,000 scale within the watershed unit and dividing by the total land area of the watershed unit.

Road density

Roads can be sources of NPS pollution by affecting water runoff and sediment yield. Storm water runoff, concentrated by roads, can contribute dust control and de-icing salts, sediment, and heavy metals to streams. Roads can increase sediment delivery to streams through road surfaces, ditches, cut banks, bridges and culverts (Forman and Alexander 1998). Herbicide and fertilizer use along roadsides may impact streamside vegetation and contribute nutrients into water courses. Hazardous materials from occasional spills during transport may also impact local water quality (Forman and Alexander 1998). Road density was calculated by dividing the total road length in the watershed in kilometres by the total land area in square kilometres. Data were obtained from the digital road atlas and forest tenure road layers.

Stream crossing density

Stream crossing density was considered because it accounts for locations where surface runoff or sediment may easily enter watercourses. Stream sections downstream of bridges may have altered sedimentation regimes, and road crossings may be sites of sediment and chemical entry (Forman and Alexander 1998). Stream crossing density was determined by dividing the total number of road crossings by the total stream length in kilometres. Analysis was based on 1:50,000 stream data and digital road atlas data.

[5] Samantha.Cooper@gov.bc.ca, 250-371-6200. Chris.Ens@gov.bc.ca, 250-828-4131.

Forest harvesting

Forest harvesting has potential to contribute to water quality degradation through erosion, sedimentation, surface runoff, increased risk of landslides, herbicide application, and altered water tables and stream flows (Croke and Hairsine 2006, Forman and Alexander 1998, NRCAN 2010, MHS and WLAP 2005). Harvesting within riparian zones can be particularly detrimental to water quality if it reduces the capability of the riparian area to maintain stream bank stability and filter sediment (Croke and Hairsine 2006, Kimmins 1997). For the purpose of this study a generalized assumption was made that the impacts to water quality from forest harvesting diminish as time since harvest increases due to vegetation recovery and road deactivation and rehabilitation. This assumption was applied through assigning higher scores (i.e. higher risk) to more recent harvesting than to historical harvesting (see Table 1).

Forest harvesting was divided into six categories: historical (1989-2004), recent (2004-2008), and planned (2009+) outside of the riparian area, and historical, recent, and planned within the riparian area. The riparian area was defined as all land within 100m of any water body or stream (based on a 1:50,000 scale)[6]. The extent of harvesting outside of the riparian area was calculated by dividing the total area harvested, or planned to be harvested, by the total land area of the watershed. Forest harvesting within the riparian area was calculated by dividing the total amount of forest harvested, or planned to be harvested, within 100m of any water body or stream by the total area within the 100m riparian zone.

Agriculture

A number of potential contaminants can enter water bodies as a result of agricultural activities including manure, fertilizers, pesticides, and soil particles (Ongley 1996, MoE 1999). These substances can contribute nutrients (including nitrogen, ammonia, organic carbon, and phosphorus), pathogens, endocrine disrupting compounds, hormones, sediment, salt, trace elements, and organics to water (Ongley 1996) which can negatively impact aquatic organisms and can degrade water used for human consumption. The amount of agriculture in each watershed was calculated by dividing the total area used for agriculture (as defined in the baseline thematic mapping layer[7] within the LRDW) by the total land area of the watershed unit.

Range

The use of rangeland for livestock forage is widespread across the Thompson Region. The Southern Interior Region of B.C. accounts for 79% of the province's total Crown range animal unit months (AUMs) (Fraser 2009). Livestock grazing can cause soil erosion, decreased stream bank stability, decreased water quality through inputs of manure, pathogens, nutrients and sediment, and increased stream

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[6] It is acknowledged that a 100m buffer on all streams and lakes is conservative; riparian management area widths in the Ministry of Forests and Range's Riparian Management Plan Guidebook range from 20m to 100m based on stream width, fish presence, and presence in a community watershed (MOF 1995). However, the United States Environmental Protection Agency's review of riparian buffer efficacy in removing nitrogen suggested that a buffer 112m wide should result in a 90% removal of nitrogen, although many other factors besides width must be considered (Mayer et al. 2006). Pike et al. (2009) states that, in general, the ability of a buffer to filter sediment and nutrients increases as the buffer strip width increases, and a buffer width of 100m or greater should remove 100% of excess nutrients. As such, a 100m buffer width was used for this study.

[7] The baseline thematic mapping layer was developed using a combination of analytic techniques, mostly using Landsat image mosaics. The intended purpose was a critical, comprehensive baseline inventory of human activity and natural resources which could be used to monitor land use activities.

temperatures (Belsky et al. 1999). Impacts may occur when animals graze in, around, and upland of streams and wetlands (Fraser 2009).

Range licenses usually include a maximum number of AUMs for an area of land. Ranchers are required to use 90% of their allotted AUMs (M. Rankin, B.C. Ministry of Forests and Range, personal communication). An AUM is generally defined as the amount of forage required by a cow, with or without a calf, for one month (Fraser 2009). To determine the degree of range use within watershed units the total number of permitted AUMs was divided by the total land area within the watershed.

Urban development

Urban development can have significant impacts on water quality. Runoff in urban areas generated from roofs, parking lots, and streets can contribute fertilizers, grease, organic contaminants, heavy metals, pesticides, antifreeze, salt, sediment, nutrients, pathogens, and fecal matter to receiving water bodies (Ongley 1996, MoE 1999, MHS and WLAP 2005). Urban areas may generate effluent from sewage treatment plants and industrial processes (e.g. pulp mills) which may be discharged directly into nearby rivers. The extent of urban development within each watershed unit was calculated by dividing the total urban area by the total land area. Urban development information was obtained from the baseline thematic mapping layer (see footnote 6).

Mining

Runoff from mines, quarries, well sites, and mine wastes have potential to contribute sediment, metals, acids, oils, organic contaminants and salts to water bodies (Ongley 1996). Metal mines have potential to generate acid rock drainage (ARD) based on the type of bedrock the mine site is located on. Where ARD is a problem there may also be issues with high levels of metals and sulphate. Gravel and sand pits may contribute sediments, salts, and other solid and liquid wastes into streams (MHS and WLAP 2005). Placer mines may contribute metals to, and cause increased turbidity in, streams that receive placer effluent (Bailey et al. 1998). Mining extent was determined by calculating the total number of hectares used for mining within the watershed unit (as defined by the baseline thematic mapping and terrain resource information mapping layers). Mines and areas known to produce ARD within the region were manually assigned the highest potential score for the category (see Table 1).

Forest fires

Forest fires have potential to affect water quality through erosion, debris flows, stream bank instability, and direct inputs of retardants. Following intense fires in the Pacific Northwest, debris slides, debris flows, and surface erosion may be observed as soils become saturated and unstable due to root decay (Wondzell and King 2003). Erosion may be increased if post-fire harvesting methods decrease infiltration and accelerate sedimentation (Beschta et al. 2004). Hydrophobic soils, which can develop in response to high or low intensity burns depending on the soil type and water content, can cause runoff and erosion of soil containing large quantities of nutrients. Hydrophobic effects may last up to six years post-fire (DeBano 1981).

In systems where fires cause mortality of riparian vegetation, sedimentation and erosion can occur within channels many years post fire due to bank instability likely caused by decaying root systems of riparian vegetation (Eaton et al. 2010). Fire retardant chemicals could affect water quality if they were applied close to streams (Pike et al. 2009). To be conservative, forest fire coverage was calculated by dividing the total number of hectares burned in the last ten years by the total land area. Fire data was obtained from the Provincial vegetation resource inventory.

3.2.2 Extent and sensitivity of water users

In addition to determining potential sources of NPS pollution, indicators for the extent and sensitivity of water users were also determined. This information helped further prioritize watersheds by adding a water use multiplier. Five water use indicators were considered including licensed allocation for potential human consumption, allocation for commercial, agricultural, and industrial purposes, allocation for fish and wildlife[8], presence of red listed fish species, and area designated as community watershed. Licensed allocation quantities were chosen because they indicate the extent to which users rely on the water resource. Presence of red-listed fish species and area designated as community watershed were chosen as indicators because they represent water users that may be more sensitive to water pollution. Data were obtained from the LRDW. Appendix C lists the water use purposes included in the three licensed allocation categories.

3.3 Collecting and analysing data

Once the matrix criteria were determined a geographical information systems (GIS) expert from the Integrated Land Management Bureau was contacted to extract the relevant spatial data from Provincial data warehouses. For each watershed unit the total extent[9] of each watershed attribute was calculated and stored in a spreadsheet. The proportion of watershed covered by each attribute was then calculated by dividing the parameter by the total watershed area. Proportions varied widely, so categories were devised to better compare between attributes. Categories ranged from zero to five and varied based on risk potential. (For example, the maximum category for range use was one and the maximum category for mining was five since mining was considered to have greater potential to impact water quality than range use).

To further highlight relative risk associated with watershed attributes water quality experts collaboratively assigned risk multipliers to each land use and natural watershed characteristic. These risk multipliers were based on the potential negative effects of the watershed attributes on water quality (in addition to their extent) and are illustrated in Table 1. For example, if there was a large mining footprint[10] in a watershed it received a maximum category value of five which was then multiplied by the mining risk multiplier of seven to give a maximum score of 35. All scores were summed for each watershed unit to give a total landscape score.

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[8] Conservation water licences may be obtained that allow the proponent to construct works, store water, and use water in order to protect fish or wildlife.

[9] Some criteria required that values other than area be used to illustrate the extent of the land use (e.g. range extent was calculated based on the number of AUMs per hectare; drainage density was calculated based on kilometres of stream).

[10] For the purposes of this matrix a large mining footprint was deemed to be greater than 100 hectares total mining area within the watershed unit. No differentiation was made between mine types as the data layers used did not include this information, and it was not within the project scope to apply data from other sources.

Table 1. Watershed attributes, multipliers, and highest potential scores.

Watershed attribute	Category	Category value	Potential score (range)	Risk multiplier	Highest potential landscape score
Agriculture (%)	0	0.00			
	>0	0.50			
	>1	1.00	0 to 4	*10	40
	>5	2.00			
	>10	3.00			
	>20	4.00			
Range (#AUM/ha)	0	0.00			
	>0	0.00			
	>0.02	0.10	0 to 1	*7	7
	>0.05	0.25			
	>0.10	0.50			
	>0.20	1.00			
Mining (hectares) (Note: if ARD is present, assign a value of 5.00)	0	0.00			
	>0	1.00	0 to 5	*7	35
	>50	3.00			
	>100	5.00			
Urban development (%)	0	0.00			
	>0	0.50			
	>0.5	1.00	0 to 3	*10	30
	>1	2.00			
	>2	3.00			
Urban development in riparian (%)	0	0.00			
	>0	0.25			
	>0.5	0.50	0 to 2	*10	20
	>1	1.00			
	>3	1.50			
	>5	2.00			
Planned future harvesting (2009+, %)	0	0.00			
	>0	0.10			
	>2	0.25	0 to 1	*4	4
	>5	0.50			
	>10	0.75			
	>20	1.00			
Recent harvesting (2004 - end of 2008, %)	0	0.00			
	>0	0.10			
	>2	0.25	0 to 1	*4	4
	>5	0.50			
	>10	0.75			
	>20	1.00			

Historical harvesting (1989 - 2004, %)	0 >0 >5 >10 >20	0.00 0.05 0.10 0.25 0.50	0 to 0.5	*4	2
Planned future harvesting in riparian (%)	0 >0 >2 >5 >7 >10	0.00 0.10 0.25 0.50 0.75 1.00	0 to 1	*4	4
Recent harvesting in riparian (%)	0 >0 >2 >5 >7 >10	0.00 0.10 0.25 0.50 0.75 1.00	0 to 1	*4	4
Historical harvesting in riparian (%)	0 >0 >2 >5 >7 >10	0.00 0.10 0.20 0.30 0.40 0.50	0 to 0.5	*4	2
Burned (1999-2009, %)	0 >0 >5 >10 >25 >50	0.00 0.00 0.05 0.10 0.50 1.00	0 to 1	*5	5
Slope (%)	0 >0 >2 >8 >15 >30 >50	0.00 0.00 0.20 0.40 0.60 0.80 1.00	0 to 1	*5	5
Drainage density (km/km2)	0 >0.0 >0.1 >0.5 >1.0 >1.5	0.00 0.00 0.10 0.50 0.75 1.00	0 to 1	*5	5

Road density (km/km2)	0 >0 >1 >2	0.00 0.10 0.50 1.00	0 to 1	*10	10
Stream crossing density (#/km)	0 >0 >0.25 >0.5 >0.75 >1.00	0.00 0.05 0.25 0.50 0.75 1.00	0 to 1	*10	10
		Highest potential score			187

3.4 Application of water use multipliers

Once total landscape scores were determined for each watershed unit a water use multiplier was applied. This multiplier was based on the assessment of extent and sensitivity of water users (see Section 3.2.2). The water use indicator values were summed for each watershed and then applied to the total landscape score to give a final watershed score. Table 2 illustrates the water use indicators and highest potential multiplier values.

Table 2. Water use indicators and highest potential multiplier values.

Water use indicator	Category	Category value	Potential score (range)	Highest potential multiplier value
Allocation for potential human consumption (gallons/second)	0 >0 >1000 >10000	1.00 1.10 1.50 2.00	1.0 to 2.0	2
Allocation for commercial, agricultural, and industrial (gallons/second)	0 >0 >1000 >10000 >100000	1.00 1.05 1.10 1.25 1.50	1.0 to 1.5	1.5
Allocation for fish and wildlife (gallons/second)	0 >0 >1000 >10000 >100000	1.00 1.05 1.10 1.25 1.50	1.0 to 1.5	1.5
Red listed fish species (presence)	N Y	1.00 2.50	1.0 to 2.5	2.5

Community watershed (% of land area)	0	1.00	1.0 to 1.2	1.2
	>0 - 30	1.10		
	>30	1.20		
	Highest potential multiplier value			8.7

Watersheds were ranked by final watershed scores from highest to lowest; high scores indicated high potential for anthropogenic effects on water quality and water users.

4.0 Results and discussion

The top ten highest risk large watersheds, and the top twenty highest risk small watersheds, are shown in Tables 3 and 4, respectively. Appendices A and B show the results for all large and small watersheds in the Thompson Region. The highest potential landscape score is 187.0, the highest potential water use multiplier value is 8.7, and the highest potential final score (which is the product of the landscape score and water use multiplier) is 1626.9.

Table 3. Thompson Region's top ten highest risk large watershed units.

Watershed name	Landscape score	Water use multiplier	Final score	Rank
South Thompson River 4 (Shuswap Lake to Kamloops)	122.2	6.6	806.2	1
North Thompson River 6 (Barriere to Kamloops)	119.3	6.6	787.1	2
Fraser River 10 (d/s Lytton)	93.7	8.1	759.0	3
Thompson River	104.5	7.1	741.6	4
South Thompson River 3 (Shuswap Lake)	88.0	7.1	624.8	5
North Thompson River 7 (Clearwater to Barriere)	68.6	6.6	452.8	6
Nicola River	61.3	7.0	429.1	7
Fraser River 11 (Lytton to Bridge River)	62.0	6.6	409.2	8
Bonaparte River	46.2	7.1	327.7	9
North Thompson River 5 (headwaters to Clearwater)	41.3	7.1	293.2	10

The highest ranked large watershed unit was the South Thompson River from Shuswap Lake to Kamloops. Its high landscape score (122.2 out of a possible 187.0) was due to high scores for road density, stream crossing density, urban, agriculture, and mining. Its moderate water use multiplier (6.6

out of 8.7) was driven by high licensed allocation for the purposes of human consumption and commercial/agricultural use and some area designated as community watershed. This section of the South Thompson River flows through a number of settled areas, including a portion of downtown Kamloops. There is a sewage treatment plant discharge at Pritchard. A number of working farms are located along this section of river, and the high mining values reflect the Lafarge gypsum mine and a number of sand and gravel pits scattered throughout the watershed unit.

The North Thompson River from Barriere to Kamloops was ranked second (119.3 out of 187.0) due to high road density, stream crossing density, urban, and agriculture scores. Its water use multiplier was the same as the South Thompson River from Shuswap Lake to Kamloops. The third ranked watershed unit was the Fraser River from Lytton to Hope (93.7 out of 187.0) due to high urban and mining scores. It also had a very high water use multiplier value (8.1 out of a possible 8.7) due to the presence of red-listed fish species in addition to high licensed allocations (human and agricultural/industrial/commercial) and some area designated as community watershed.

Table 4. Thompson Region's top twenty highest risk small watershed units.

Watershed name	Landscape score	Water use multiplier	Final score	Rank
Peterson Creek (Kamloops)	121.4	6.5	788.8	1
Coldwater River	89.1	7.1	632.6	2
Nicola 3	102.8	6.0	616.5	3
Sinmax Creek	87.6	6.5	569.4	4
Salmon River	77.7	7.1	551.3	5
Spahomin Creek	64.9	7.1	460.8	6
Cherry Creek	69.2	6.5	449.5	7
Guichon Creek	63.0	7.1	447.3	8
Dupuis Creek	73.6	6.0	441.3	9
Cutoff Valley Creek	64.2	6.6	423.7	10
Witches Brook	75.4	5.5	414.7	11
Louis Creek	57.0	7.1	404.7	12
Pukaist Creek	70.3	5.6	393.4	13
Heffley Creek	58.4	6.6	385.4	14
Barriere River	58.1	6.6	383.5	15
Eagle River	52.8	7.1	374.9	16
Clapperton Creek	62.0	6.0	372.0	17
Monte Creek	57.1	6.5	371.2	18
Meadow Creek	51.2	7.0	358.1	19
Gates River	49.2	7.1	349.3	20

The highest ranked small watershed unit was Peterson Creek (Kamloops) due to its high landscape score (121.4 out of a possible 187.0) and its moderate water use multiplier (6.5 out of a possible 8.7). The high landscape score was largely driven by high proportions of urban development (its lower reaches run through the City of Kamloops), mining, and agriculture. The Coldwater River, ranked second with a landscape score of 89.1 out of 187.0, had high scores for road density, stream crossing density, and mining. It also had a high water use multiplier (7.1 out of a possible 8.7) driven by high use by all three licensed allocation categories, the presence of red-listed species, and area designated as community watershed. Nicola 3, which is a combination of four smaller watersheds that drain into the Nicola main stem (Abbot Creek, Gordon Creek, Shackelly Creek, and Stumbles Creek), was ranked third with a landscape score of 102.9 out of 187.0. The high landscape score can be attributed to high urban, mining, road density, and stream crossing density scores.

The results for the large and small watersheds were reviewed by regional water quality experts (two Environmental Impact Assessment Biologists and the Water Quality Section Head) who agreed that the matrix results seemed accurate based on their knowledge of the region's watersheds and land use.

5.0 Conclusion and recommendations

Many watershed attributes contribute to water quality within a watershed, and many land uses have potential to degrade this precious resource. Conducting a risk assessment that considers watershed attributes that influence water quality as well as extent and sensitivity of water users can be a valuable tool for identifying areas at high risk of degraded water quality. The results could be used as part of a screening tool to prioritize watersheds for assessment, particularly on systems that lack recent water quality data. If issues are identified through the watershed assessment further monitoring and investigation could be undertaken to identify the sources of NPS pollution.

Future risk analyses should consider the following recommendations for improvement, if data are available: a category should be added that assesses the amount of agricultural activity within the riparian buffer zone; detailed mining data should be added so that mine types can be distinguished; point sources should be included, particularly if the data includes information on effluent quality and quantity; and recreation data should be included to identify areas that may be negatively impacted by off-road vehicle use. Essential to the effectiveness of this tool is current and detailed spatial land use data which, in this project, was a constraint. Limitations aside, this tool provides an initial snapshot of Thompson Region watersheds at highest risk of anthropogenic effects on water quality and its designated users.

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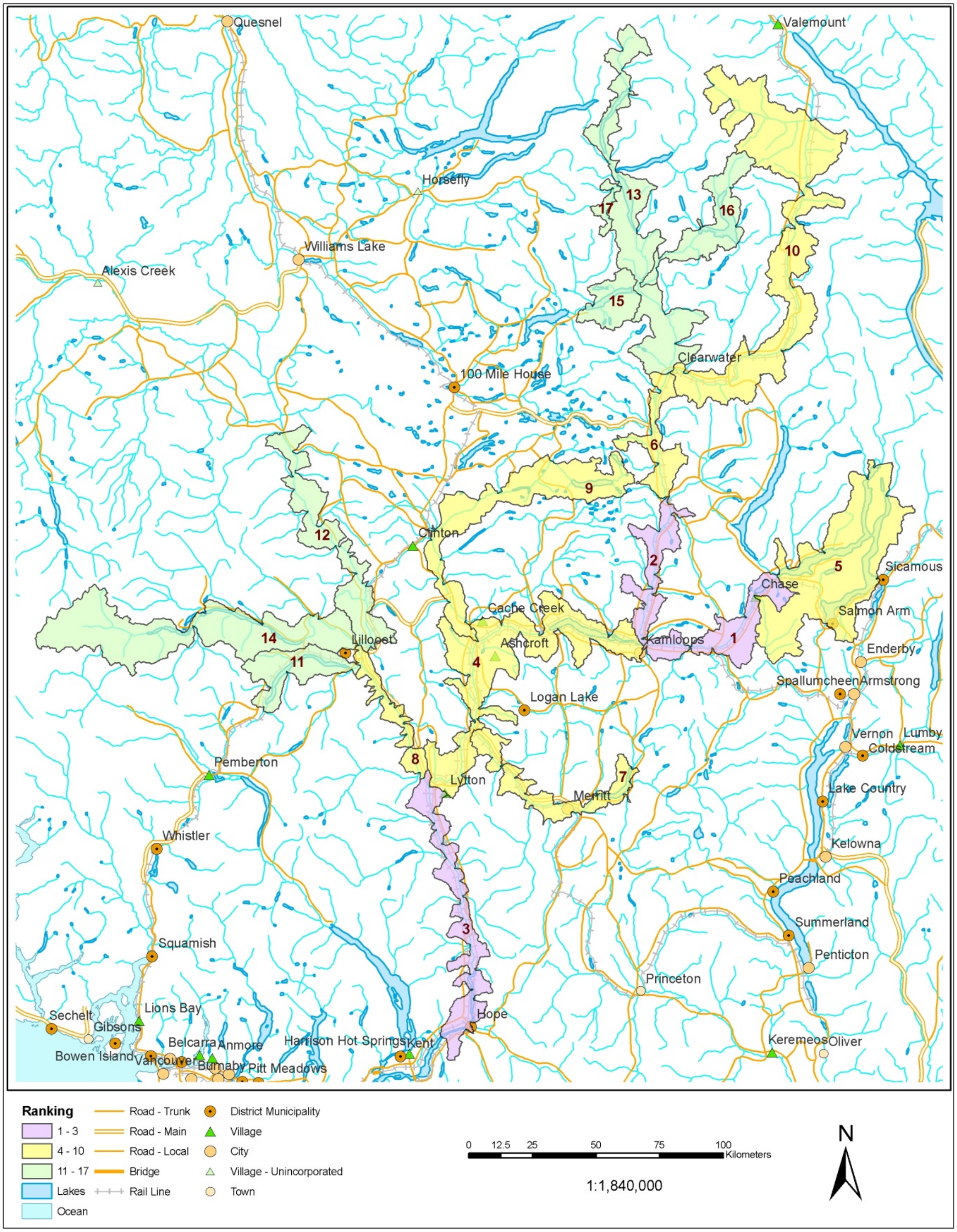
7.0 Appendices

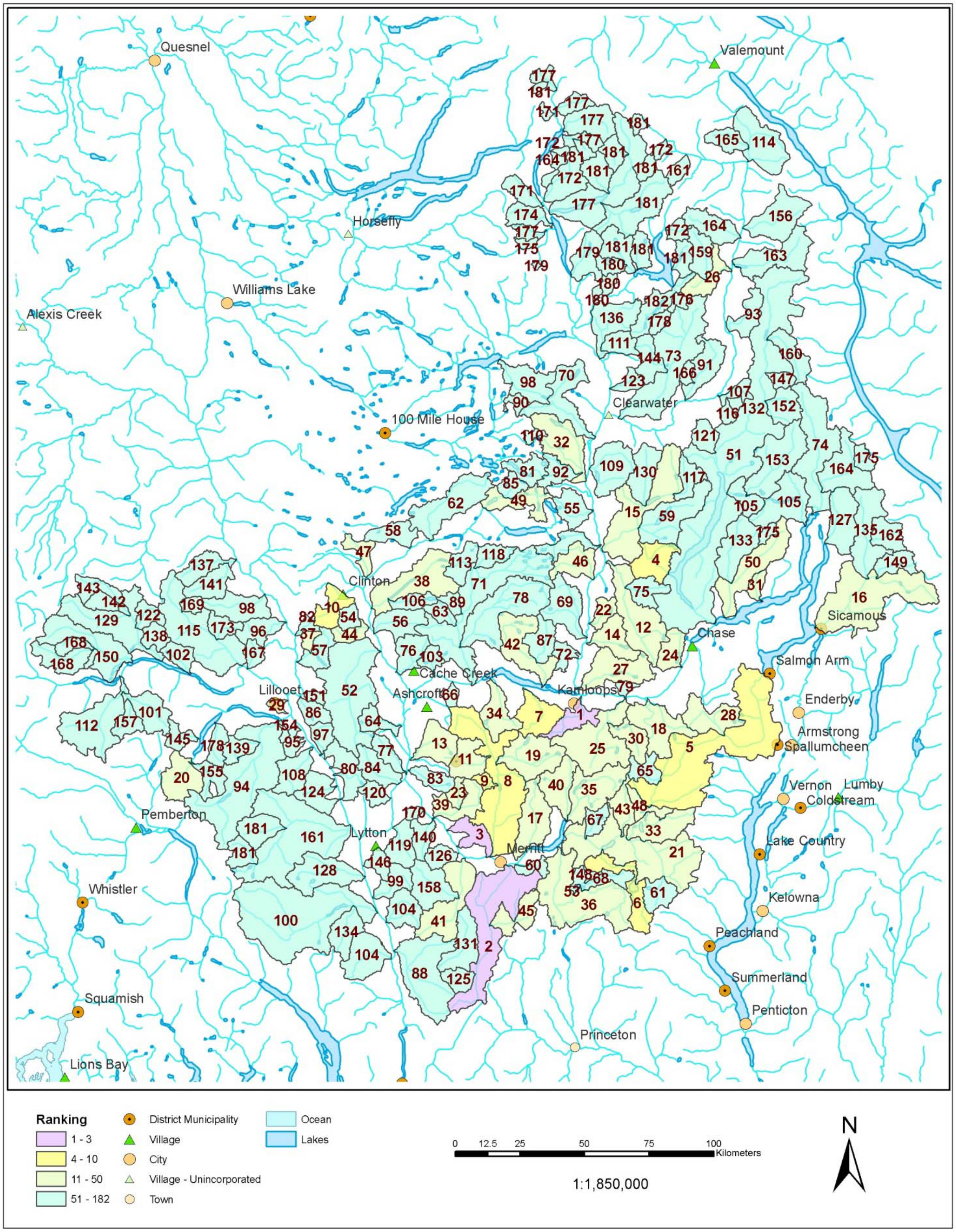
Appendix A. Large watershed boundary delineations and risk rankings



Appendix A. Large watershed risk rankings

Risk ranking	Watershed name	Resource use multiplier	Landscape score	Final score
		(sum of licensed allocation, community watershed, and red listed species scores; max 8.7)	(sum of all land uses; max 187)	(landscape score * resource use multiplier; max score is 1626.9)
1	SOUTH THOMPSON RIVER 4 (Shuswap Lk to Kamloops)	6.6	122.2	806.2
2	NORTH THOMPSON RIVER 6 (Barriere to Kamloops)	6.6	119.3	787.1
3	FRASER RIVER 10 (Lytton to Hope)	8.1	93.7	759.0
4	THOMPSON RIVER	7.1	104.5	741.6
5	SOUTH THOMPSON RIVER 3 (Shuswap Lk)	7.1	88.0	624.8
6	NORTH THOMPSON RIVER 7 (Clearwater to Barriere)	6.6	68.6	452.8
7	NICOLA RIVER	7.0	61.3	429.1
8	FRASER RIVER 11 (Lytton to Bridge R)	6.6	62.0	409.2
9	BONAPARTE RIVER	7.1	46.2	327.7
10	NORTH THOMPSON RIVER 5 (Clearwater to head)	7.1	41.3	293.2
11	SETON RIVER	7.1	36.0	255.6
12	FRASER RIVER 9 (u/s Bridge R)	6.5	34.6	224.6
13	CLEARWATER RIVER	7.0	27.9	195.3
14	BRIDGE RIVER	6.6	29.3	193.4
15	MAHOOD RIVER	6.0	13.4	80.4
16	MURTLE RIVER	5.0	7.0	35.0
17	ARCHER CREEK	5.0	6.8	33.8

Appendix B. Small watershed boundary delineations and risk rankings



Appendix B. Small watershed risk rankings

Risk ranking	Watershed name	Resource use multiplier	Landscape score	Final score
		(sum of licensed allocation, community watershed, and red listed species scores; max 8.7)	(sum of all land uses; max 187)	(landscape score * resource use multiplier; max score is 1626.9)
1	PETERSON CREEK	6.5	121.4	788.8
2	COLDWATER RIVER	7.1	89.1	632.6
3	NICOLA 3	6.0	102.8	616.5
4	SINMAX CREEK	6.5	87.6	569.4
5	SALMON RIVER	7.1	77.7	551.3
6	SPAHOMIN CREEK	7.1	64.9	460.8
7	CHERRY CREEK	6.5	69.2	449.5
8	GUICHON CREEK	7.1	63.0	447.3
9	DUPUIS CREEK	6.0	73.6	441.3
10	CUTOFF VALLEY CREEK	6.6	64.2	423.7
11	WITCHES BROOK	5.5	75.4	414.7
12	LOUIS CREEK	7.1	57.0	404.7
13	PUKAIST CREEK	5.6	70.3	393.4
14	HEFFLEY CREEK	6.6	58.4	385.4
15	BARRIERE RIVER	6.6	58.1	383.5
16	EAGLE RIVER	7.1	52.8	374.9
17	CLAPPERTON CREEK	6.0	62.0	372.0
18	MONTE CREEK	6.5	57.1	371.2
19	MEADOW CREEK	7.0	51.2	358.1
20	GATES RIVER	7.1	49.2	349.3
21	NICOLA 1	6.6	51.8	341.6
22	NORTH THOMPSON RIVER 3 (Knouff)	6.5	52.4	340.6
23	SKUHOST CREEK	5.0	65.7	328.5
24	SOUTH THOMPSON RIVER 2 (Niskonlith)	6.5	50.25	326.6
25	CAMPBELL CREEK	7.0	46.7	326.6
26	BLUE RIVER	6.0	53.4	320.4
27	NORTH THOMPSON RIVER 1 (Paul)	7.2	44.35	319.3
28	BOLEAN CREEK	6.6	48.2	318.1
29	FRASER RIVER 8 (Town and Dickie)	6.7	47.25	316.6
30	SCUITTO CREEK	6.0	52.0	312.0
31	ONYX CREEK	6.5	47.9	311.4
32	LEMIEUX CREEK	6.5	45.6	296.4
33	CHAPPERON CREEK	6.0	49.2	295.2
34	DURAND CREEK	6.0	48.0	288.0
35	STUMPLAKE CREEK	7.0	40.9	286.0
36	QUILCHENA CREEK	6.6	41.4	273.2
37	GILLON CREEK	5.5	48.9	269.0
38	LOON CREEK	6.5	40.8	264.9
39	SKUHUN CREEK	6.5	40.4	262.6
40	MOORE CREEK	6.5	39.8	258.7
41	SPIUS CREEK	6.6	38.6	254.8
42	TRANQUILLE RIVER	7.2	34.5	248.4

Risk ranking	Watershed name	Resource use multiplier	Landscape score	Final score
43	RANGE CREEK	5.6	43.1	241.1
44	MAIDEN CREEK	6.0	40.2	240.9
45	VOGHT CREEK	6.0	39.9	239.4
46	FISHTRAP CREEK	5.7	42.0	239.1
47	CHASM CREEK	6.0	39.8	238.8
48	MCINNIS CREEK	6.0	39.6	237.6
49	MACHETE CREEK	7.0	33.7	235.9
50	SCOTCH CREEK	6.1	38.4	234.2
51	ADAMS RIVER	6.6	35.3	233.0
52	HAT CREEK	6.6	35.2	232.0
53	WASLEY CREEK	5.0	46.0	230.0
54	ALLEN CREEK	6.0	38.2	228.9
55	NORTH THOMPSON RIVER 4 (Perterson and Darlington)	6.6	34.6	228.4
56	SCOTTIE CREEK	6.0	38.1	228.3
57	PAVILION CREEK	6.5	34.4	223.6
58	FLY CREEK	5.6	39.9	223.2
59	EAST BARRIERE RIVER	6.5	34.3	223.0
60	NICOLA 2	5.5	39.8	218.6
61		5.6	38.9	217.8
62	RAYFIELD RIVER	6.0	35.0	210.0
63	GORGE CREEK	6.0	32.7	196.2
64	OREGON JACK CREEK	6.0	32.5	195.0
65	WEYMAN CREEK	5.0	38.5	192.5
66		5.6	34.4	192.4
67	LAUDER CREEK	6.0	31.9	191.1
68		6.0	31.7	189.9
69	JAMIESON CREEK	5.7	33.3	189.5
70	MANN CREEK	6.0	31.5	189.0
71	DEADMAN RIVER	7.0	26.9	188.3
72	NORTH THOMPSON RIVER 2 (McQueen and Dairy)	6.1	30.1	183.6
73	RAFT RIVER	6.5	27.8	180.7
74	SEYMOUR RIVER	6.0	29.3	175.8
75	FADEAR CREEK	6.0	29.1	174.6
76	CACHE CREEK	6.0	28.7	172.2
77	TWAAL CREEK	6.1	27.4	166.8
78	CRISS CREEK	7.1	23.2	164.4
79	SOUTH THOMPSON RIVER 1 (McGregor)	6.1	26.1	159.2
80	FRASER RIVER 6 (Laluwisson, Lochore, McGillivray, Izman)	6.6	24	158.4
81	PHINETTA CREEK	6.5	24.4	158.3
82	KELLY CREEK	5.5	27.6	151.8
83	PIMAINUS CREEK	6.0	25.0	150.0
84	MURRAY CREEK	6.7	22.3	149.4
85	MCDONALD CREEK	5.0	29.7	148.3

Risk ranking	Watershed name	Resource use multiplier	Landscape score	Final score
86	FOUNTAIN CREEK	6.7	22.0	147.1
87	WATCHING CREEK	5.8	25.0	145.0
88	ANDERSON RIVER	7.2	20.1	144.7
89	TOBACCO CREEK	6.0	24.0	144.0
90		5.0	28.8	143.8
91	MAD RIVER	5.1	27.6	140.8
92	EAKIN CREEK	5.5	25.2	138.6
93	FINN CREEK	5.6	24.5	137.2
94	CAYOOSH CREEK	6.6	20.6	136.0
95	FRASER RIVER 7 (Towinock and Riley)	6.5	20.85	135.5
96	LEON CREEK	6.0	22.4	134.1
97	CINQUEFOIL CREEK	6.1	21.6	131.8
98	WATSON BAR CREEK	6.0	21.5	129.0
98	CANIMRED CREEK	6.0	21.5	129.0
99	MOWHOKAM CREEK	6.5	19.5	126.8
100	NAHATLATCH RIVER	8.5	14.8	125.8
101	CADWALLADER CREEK	6.6	18.8	124.1
102	MARSHALL CREEK	6.5	18.9	122.9
103	BATTLE CREEK	6.0	20.2	121.2
104	AINSLIE CREEK	7.1	16.8	119.3
104	SCUZZY CREEK	7.1	16.8	119.3
105	MOMICH RIVER	5.0	23.6	118.0
105	CELISTA CREEK	5.0	23.6	118.0
106	HIHIUM CREEK	6.0	19.6	117.3
107	OTTER CREEK	5.0	22.5	112.5
108	TEXAS CREEK	6.6	17.0	112.2
109	JOSEPH CREEK	6.1	18.1	110.4
110		5.0	22.1	110.3
111	TROUT CREEK	6.0	18.3	109.5
112	HURLEY RIVER	6.1	17.7	108.0
113	HAMILTON CREEK	5.8	18.8	107.8
114	ALBREDA RIVER	5.6	19.0	106.4
115	YALAKOM RIVER	6.0	17.6	105.6
116		5.0	21.1	105.5
117	FENNELL CREEK	5.0	21.0	104.8
118	JOE ROSS CREEK	5.0	20.8	103.8
119	NICOAMEN RIVER	5.7	17.8	101.5
120	SKOONKA CREEK	6.1	16.6	101.3
121	BURTON CREEK	5.0	20.2	101.0
122	NOAXE CREEK	5.0	20.0	99.8
123	SPAHATS CREEK	5.5	17.6	96.8
124	FRASER RIVER 5 (Intlpam, Inkoiko, Siwhe)	6.7	14	93.8
125	JULIET CREEK	5.0	18.7	93.5
126	NICOLA 4	6.0	15.1	90.6
127	ANSTEY RIVER	5.1	17.6	89.8
128	KWOIEK CREEK	7.2	12.5	89.6

Risk ranking	Watershed name	Resource use multiplier	Landscape score	Final score
129	TYAUGHTON CREEK	6.5	13.4	86.8
130	HARPER CREEK	5.6	15.3	85.7
131	MAKA CREEK	5.1	16.8	85.4
132		5.0	16.8	83.8
133	KWIKOIT CREEK	5.0	15.8	79.0
134	KOOKIPI CREEK	7.0	11.2	78.4
135	PERRY RIVER	5.0	15.7	78.3
136	HEMP CREEK	6.5	12.0	78.0
137	FRENCH BAR CREEK	5.0	15.4	76.8
138	LIZA CREEK	5.0	14.9	74.5
139	DOWNTON CREEK	5.0	14.8	74.0
140	SHAKAN CREEK	6.5	11.2	72.8
141	SOUTH FRENCH BAR CREEK	5.5	12.7	69.9
142	PARADISE CREEK	5.0	14.0	69.8
143	RELAY CREEK	5.0	13.8	68.8
144	WEST RAFT RIVER	5.0	13.7	68.3
145	MCGILLIVRAY CREEK	6.1	11.0	67.1
146	FRASER RIVER 4 (Siska)	8.1	8	64.8
147	GOLD CREEK	5.0	12.9	64.3
148	KAME CREEK	5.0	12.7	63.5
149	CRAZY CREEK	5.5	11.4	62.7
150	GUN CREEK	6.5	9.4	61.1
151	GIBBS CREEK	6.1	10.0	60.7
152	SUNSET CREEK	5.0	12.0	60.0
153	CAYENNE CREEK	5.0	11.8	59.0
154	ENTERPRISE CREEK	5.0	11.6	57.8
155	HAYLMORE CREEK	6.1	9.4	57.3
156	BONE CREEK	5.5	10.4	57.2
157	NOEL CREEK	5.0	11.4	57.0
158	PROSPECT CREEK	5.0	11.1	55.5
159	NORTH BLUE RIVER	5.0	11.0	55.0
160	OLIVER CREEK	5.0	10.8	54.0
161	STEIN RIVER	6.6	8.0	52.8
161		5.0	10.6	52.8
162	BEWS CREEK	5.0	10.5	52.5
163	MUD CREEK	5.0	10.2	51.0
164		5.0	10.0	50.0
164	RATCHFORD CREEK	5.0	10.0	50.0
164	THUNDER RIVER	5.0	10.0	50.0
165	ALLAN CREEK	5.5	9.0	49.5
166	MARTIN CREEK	5.0	9.9	49.3
167	ANTOINE CREEK	6.0	8.2	49.2
168	LECKIE CREEK	5.0	9.4	47.0
168	SLIM CREEK	5.0	9.4	47.0
169	YALAKOM CREEK	5.0	9.3	46.3
170	NICOLA 5	5.0	9.2	46.0

Risk ranking	Watershed name	Resource use multiplier	Landscape score	Final score
171		5.0	9.0	45.0
171	LICKSKILLET CREEK	5.0	9.0	45.0
172	TIGHE CREEK	5.0	8.8	43.8
172	GOAT CREEK	5.0	8.8	43.8
172		5.0	8.8	43.8
172		5.0	8.8	43.8
173	JUNCTION CREEK	5.0	8.6	43.0
174		5.0	8.3	41.3
174	BARELLA CREEK	5.0	8.3	41.3
175		5.0	8.0	40.0
175		5.0	8.0	40.0
175		5.0	8.0	40.0
176		5.0	7.9	39.3
177		5.0	7.8	38.8
177		5.0	7.8	38.8
177	HOBSON CREEK	5.0	7.8	38.8
177	EAST CREEK	5.0	7.8	38.8
177		5.0	7.8	38.8
177	AZURE RIVER	5.0	7.8	38.8
178		5.0	7.5	37.5
178	LOST VALLEY CREEK	5.0	7.5	37.5
179	FALLS CREEK	5.0	7.0	35.0
179		5.0	7.0	35.0
180		5.0	6.8	33.8
180		5.0	6.8	33.8
180		5.0	6.8	33.8
181		5.0	6.5	32.5
181		5.0	6.5	32.5
181	BRAITHWAITE CREEK	5.0	6.5	32.5
181	OVIS CREEK	5.0	6.5	32.5
181	KNUTSON CREEK	5.0	6.5	32.5
181	ANGUS HORNE CREEK	5.0	6.5	32.5
181	FILE CREEK	5.0	6.5	32.5
181	ANDERSON CREEK	5.0	6.5	32.5
181	STRAIT CREEK	5.0	6.5	32.5
181	SCUDAMORE CREEK	5.0	6.5	32.5
181	NORTH STEIN RIVER	5.0	6.5	32.5
181	ELLA FRYE CREEK	5.0	6.5	32.5
182	SNOOKWA CREEK	5.0	5.5	27.5

Appendix C. Licensed allocation categories and purposes included in each

Category	Purposes
Human consumption	Bottle sales
	Camps
	Churches and community halls
	Domestic
	Enterprise
	Exhibition grounds
	Institutions
	Mineral trading (bottled)
	Public facilities
	Waterworks (local authorities, other)
	Work camps
Agricultural, commercial, and industrial	Storage (conservation, power, storage)
	Ponds
	Cooling
	Dewatering
	Dust control
	Fire prevention and protection
	Fish hatchery
	Frost protection
	Landfill
	Greenhouses
	Heat exchangers
	Irrigation
	Land improvements
	Mining (equipment, hydraulic, placer, processing ore)
	Nurseries
	Power (commercial, general, residential)
	Processing
	Pulp mills
	Residential lawn/garden
	Sediment control
	Snowmaking
	Stock watering
	Swimming pool
	Truck washing
	Watering
	Wharf
Fish and wildlife	Conservation (construction works, stored water, use of water)