CURRENT CONDITION AND 10-YEAR HISTORIC TREND ANALYSIS OF HYDROLOGIC HAZARDS IN THE KAMLOOPS TIMBER SUPPLY AREA

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B.C. Ministry of Forests, Lands and Natural Resource Operations

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Citation

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Executive Summary

A hydrologic hazard assessment was completed to evaluate watershed conditions in the Kamloops Timber Supply Area (Kamloops TSA). The assessment uses a GIS indicator-based assessment procedure to evaluate the likelihood of harmful or hazardous changes (hydrologic hazards) related to: streamflow, sediment generation and delivery, and riparian function. Hazard ratings for streamflow, sediment and riparian function are analyzed and reported using a hierarchical structure of assessment units (AUs) including: Sub-basins, Basins, Watersheds, Large Watersheds or Super-Watersheds. These hazard assessment results can be used as part of a risk-based approach to evaluate risk to downstream values such as fish habitat, water quality, people and property, infrastructure or aquatic biodiversity. The hazard assessment was completed for 2003 and for 2014 respectively using indicator data, and qualitatively discusses factors and uncertainties that may affect potential future hazards.

Historic 10-year trend and current condition results indicate an increase in the number of AUs with *High* and *Very High* hazard ratings for streamflow, sediment and riparian function from 2003 to 2014. The number of AUs with *High* and *Very High* Riparian hazard increases the greatest in this time period, followed by streamflow hazards. The primary factor contributing to elevated riparian and streamflow hazard is extensive Mountain Pine Beetle (MPB) induced mortality of pine-dominated forests and salvage of MPB-affected forests over the past decade in the middle to southern portion of the Kamloops TSA. These factors result in elevated equivalent clearcut area (ECA) and harvesting adjacent to streams in higher elevation Sub-basins, Basins and Watersheds. Upstream harvesting related effects on riparian buffers accumulate with livestock grazing and private land to contribute to increased likelihood of reduced riparian function in larger watersheds. The current streamflow and riparian hazards are expected to persist for the next 20-30 years at a minimum until regeneration of harvested areas occurs, and recovery of hydrologic function of forests and riparian vegetation returns.

These results suggest that unintended outcomes resulting from the cumulative effect of historic and current land use likely have occurred in the Merritt TSA. These outcomes may result in long standing ecologic consequences (impact to fish habitat, aquatic ecosystem health, and water quality) through a higher likelihood that harmful hydrologic changes could impact the provision of key ecosystem services important for human well-being (e.g. clean drinking water, flood regulation). These outcomes could also have direct, and potentially severe, socio-economic consequences to downstream values (e.g. injury and/or loss of human life, damage to property and/or infrastructure) through a higher likelihood of harmful hydrologic change (e.g. severe flooding or debris flow events).

To address these potential negative outcomes will require field-based assessment by qualified professionals in individual watersheds to support operational-level mitigation actions. Actual conditions in any given watershed can vary from those derived from this Strategic GIS-based assessment as a result of site-level factors not considered in GIS indicators and ratings. Although outcomes of this assessment are consistent with field-based monitoring of stream functioning condition completed throughout the Thompson-Okanagan Region over the past three years, the potential consequences to downstream values have not been assessed by qualified professionals in the field. Thus, further field-based investigation by qualified professionals to assess risk to downstream values and provide operational -level decisions and mitigation actions is recommended.

Table of Contents

1. Assessment Approach

This assessment of hydrologic hazard is part of a risk-based approach as described in Lewis et al. (2016), where risk is the product of hazard and consequence defined by the risk equation**: Risk = Hazard x Consequence.** In this assessment, only the hazard side of the risk equation is reported. These hazard ratings are then intended to be used with consequence ratings derived for downstream ecological and socio-economic values to derive risk ratings (Fig. 1). *Consequence* refers to the change, loss, or damage to a value(s) (e.g. human life, private or public property, water intakes, infrastructure, fish habitat etc.) that may result from hazardous occurrences. Consequence ratings are the measurement or expression of the potential loss or damage to downstream values, and the specific elements at risk comprising those values.

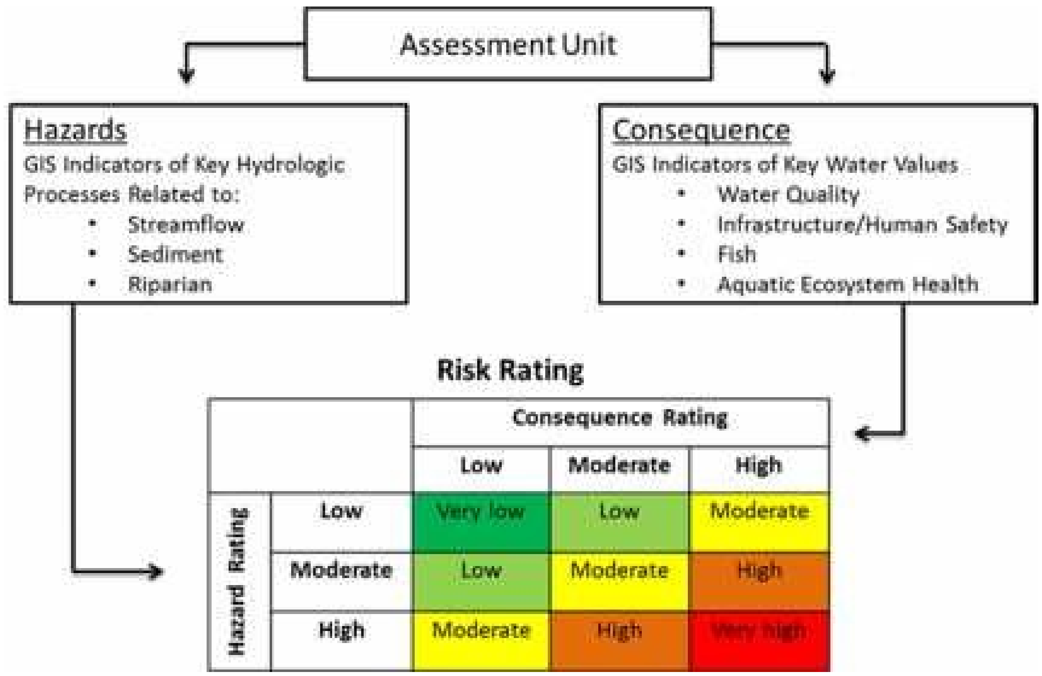

Figure 1. A qualitative risk matrix illustrating how hazard ratings from this assessment can be used with consequence ratings for both ecological and socio-economic values. From Lewis et al. (2016).

This assessment provides hydrologic **Hazard Ratings** as an expression of the likelihood of hazard occurrence. Three hydrologic hazards commonly used to evaluate watershed condition that are considered in this assessment include:

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

A five-class hazard rating scheme is used by applying the qualitative terms (*Very Low, Low, Moderate, High,* and *Very High*) to express the likelihood of a harmful event (hazard) occurring (Table 1). The five-class rating scheme can be adapted to a three-class rating scheme (*Low, Moderate, High*) by combining *Very Low* and *Low* into a single *Low* rating, and *High* and *Very High* in to a single *High* rating as applied in Figure 1.

Table 1. Terminology used to describe hazard ratings. From Lewis et al., 2016.

Rating	Definition	Probability of Occurring (%)
Very Low	Highly Unlikely	<10%
Low	Unlikely	<33%
Moderate	May	33-66%
High	Likely	>66%
Very High	Very Likely	>90%

1.1 Assessment Scenarios and Reporting

Hydrologic hazard ratings are reported for two time periods:

- **Historic condition to 2003** – historic condition includes existing levels of forest harvesting, road networks and other land use activities. Historic condition was re-created to 2003 using archived datasets.
- **Current condition (2014)** – current condition includes existing levels of forest harvesting, road networks and other land use activities. Current condition includes VRI information with updated consolidated cutblocks to January 2014.
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In addition to the historic and current condition, factors potentially affecting future condition are qualitatively discussed, but were not modelled at this time.

1.2 Confidence in the Assessment Outcomes

Strategic-level GIS indicator-based assessments, such as used in this report, have particular uncertainties inherent with human behaviour, the broad-scale of application, the generalizations and assumptions used to characterize the complex systems involved, and information and data limitations (Lewis et al. 2016). Thus, an estimate of the confidence in the assessment of historic, current and future condition is reported, as are sources of uncertainty potentially affecting the outcomes consistent with Lewis et al., (2016).

1.3 Assessment Units

This assessment uses a hierarchical reporting structure of Large Watersheds, Watersheds, Basins, Sub-Basins and Residual Units, collectively referred to as Assessment Units (AUs), following the methodology of Lewis et al. (2016). The assessment includes 401 AUs that cover most of the Kamloops TSA area (Fig. 2 Left) and extend beyond the TSA to include portions of Large Watersheds and Watersheds that flow into the TSA from the adjoining 100 Mile House TSA.

For reference, the assessment area includes a number of large watershed units that flow into Thompson River system. In the northern portion of the TSA, the Upper North Thompson, Raft and Barriere Rivers flow into the North Thompson north of Kamloops. In the southern portion of the TSA, the Adams River system flows into the South Thompson River east of Kamloops while the Deadman, Rayfield, Tranquille and Bonaparte Rivers flow into the Thompson River west of Kamloops (Fig. 2 Right).

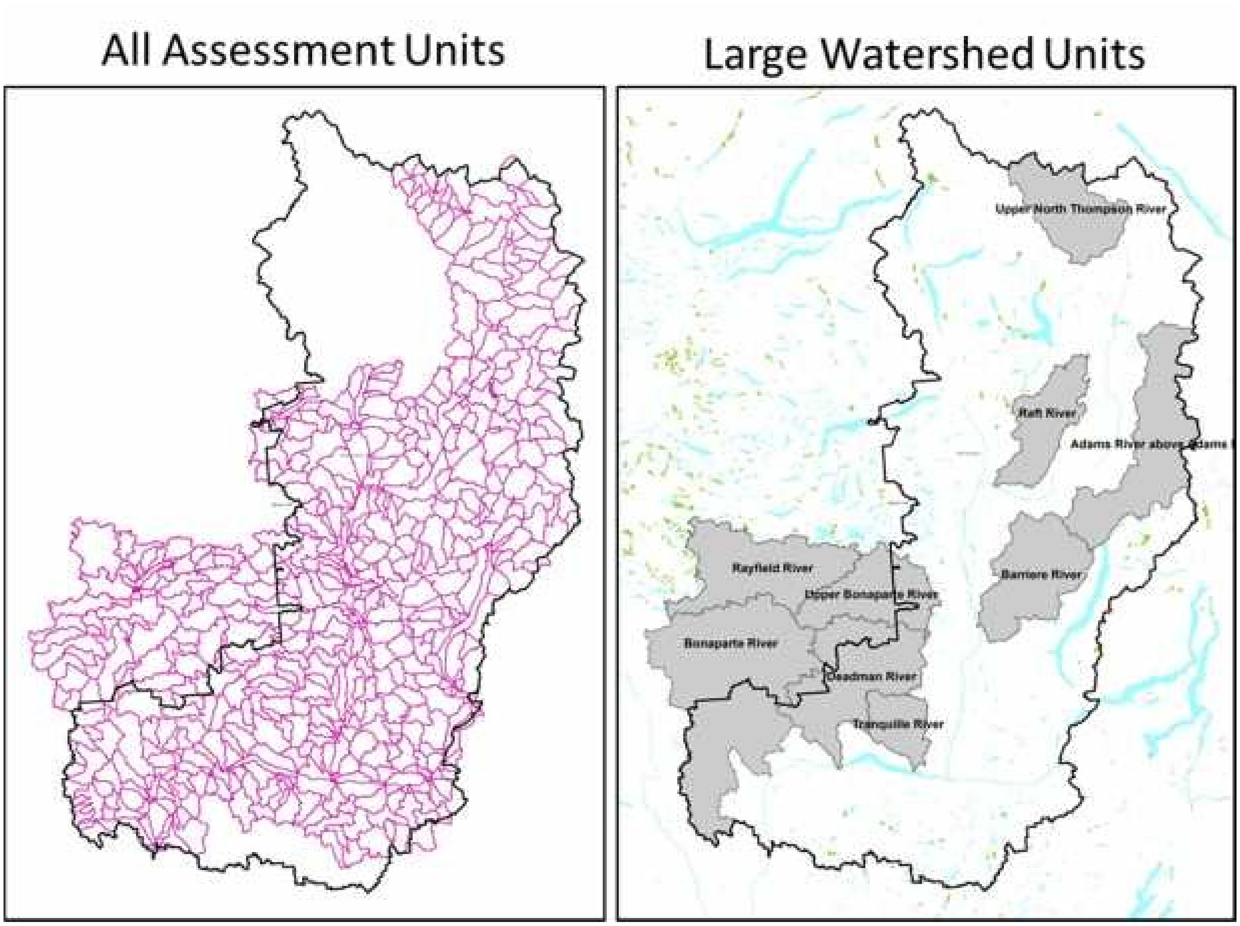

Figure 2. Map illustrating the extent of all Assessment Units (AUs) included in the Kamloops TSA Hydrologic Hazard Assessment (Pink outlines – left), and Large Watersheds (right) that are part of the AU reporting structure as reference for major systems included in the assessment.

2. Assessment Results

2.1 Current Condition and Historic Trend

2.1.1 Streamflow Hazard

The number of AUs with *Moderate*, *High* and *Very High* Streamflow hazard in the Kamloops TSA increased from 2003 to 2014, while the number of AUs rated *Very Low* declined (Fig 3; See Appendix 1). These results suggest more AUs are likely to experience an increased frequency and magnitude of potentially harmful hydro-geomorphic events (floods, bank erosion, channel instability, debris floods and debris flows). This change is due to an overall increase in equivalent clearcut area (ECA) following Mountain Pine Beetle (MPB) induced mortality of pine-dominated forests and extensive salvage of these affected forests over the past decade. The greatest increases between 2003 and 2014 occurred in upper elevation sub-basins, basins and watersheds in the southern portion of the TSA (See Appendix 1). The combined effects of extensive salvage logging across several smaller basins also accumulated to increase streamflow hazard in several larger watersheds.

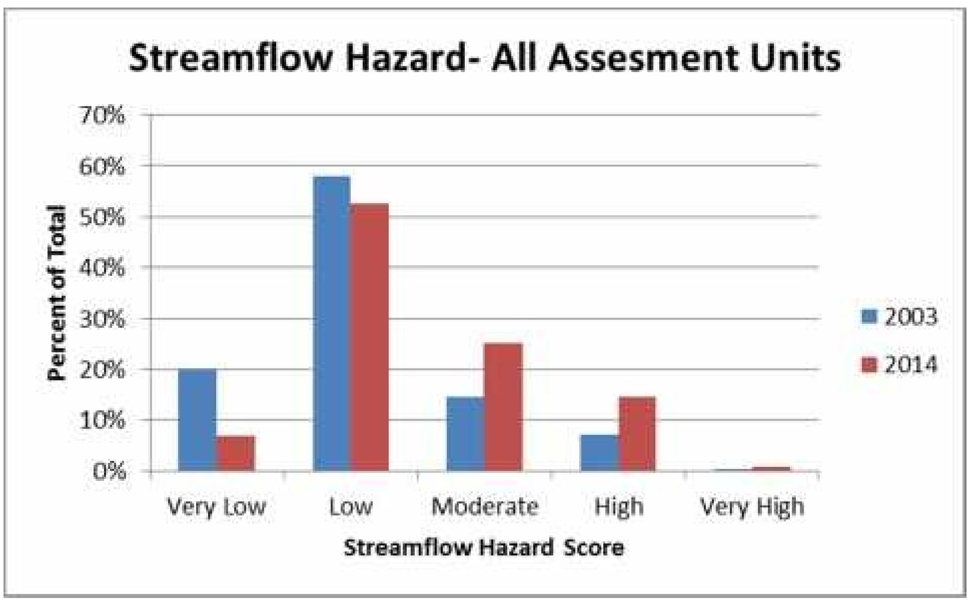

Figure 3. Change in streamflow hazard for all AUs (N= 401) in the Kamloops TSA from 2003 and 2014.

2.1.2 Sediment Hazard

The number of AUs with *Moderate*, *High* or *Very High* Sediment hazard in the Kamloops TSA showed a small increase between 2003 and 2014 (Fig 4, See Appendix 2). The results indicate that a small number of AUs are likely to experience potentially harmful levels of sediment. The results are due to an increase in roads close to water, roads on steep slopes (>50%) connected to water bodies and harvesting on gentle terrain over steep slopes connected to water bodies. These small changes are likely due to an expanding road network along small streams in upper elevation sub-basins, basins and watersheds associated with MPB salvage logging in the southern portion of the TSA rather than development of new major roads systems along low, valley-bottom rivers.

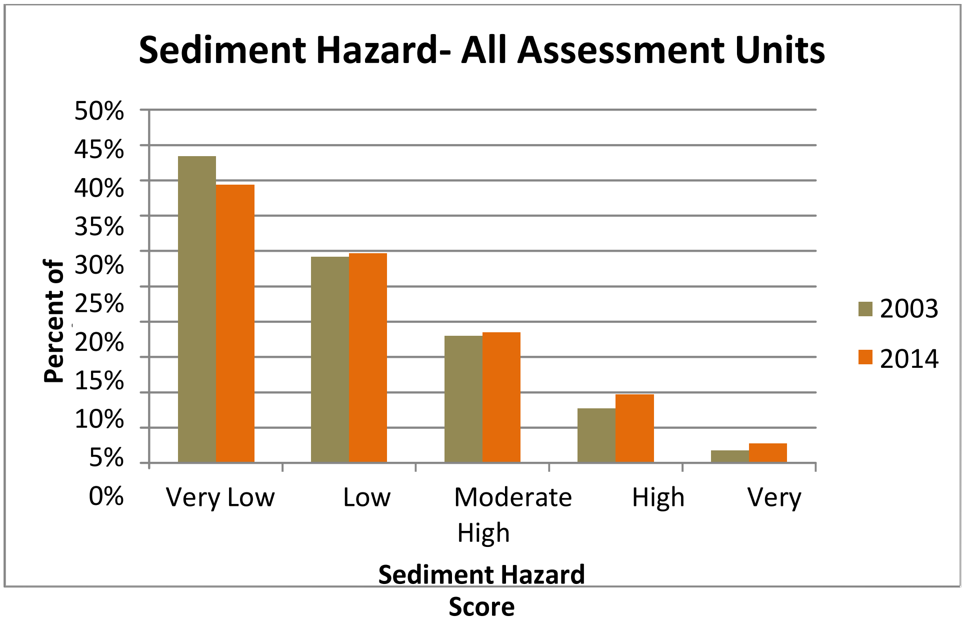

Figure 4. Change in sediment hazard for all AUs (N= 401) in the Kamloops TSA from 2003 and 2014.

The Kamloops TSA has an extensive, well-developed existing road network, so large changes in road-related sediment effects based on new road development were not anticipated. The increase in the amount of new roads measured in GIS may not reflect actual sediment generated and delivered in this time period because of changes in level of industrial use, road maintenance. Increased industrial use associated with MPB salvage during the past decade likely resulted in increased sediment generation and delivery. However, upgrading of old or existing (pre Forest Practices Code era) roads to improved current standards may have offset potential increases.

2.1.3 Riparian Function Hazard

The number of AUs with *High* and *Very High* Riparian function hazard in the Kamloops TSA increased from 2003 to 2014 with approximately 15% of AUs rated as *High* and *Very High* hazard in 2003 compared to close to 40% of AUs in 2014 (Fig. 5, See Appendix 3). The proportion of AUs rated *Moderate* or lower also declined in the same period. These results suggest a large portion of AUs are likely to experience loss of riparian function such as bank stability, stream shading or LWD inputs. This increase is driven by an increase in the proportion of total stream length with harvesting adjacent to streams (within 30 metres) particularly in Sub-basins and Basins where extensive salvage of MPB- affected forests occurred in the middle to southern (See appendix 3). This upstream harvesting combined with existing private land and livestock grazing effects in watersheds and large watersheds to result in significant increases in Riparian Function hazard at this scale.

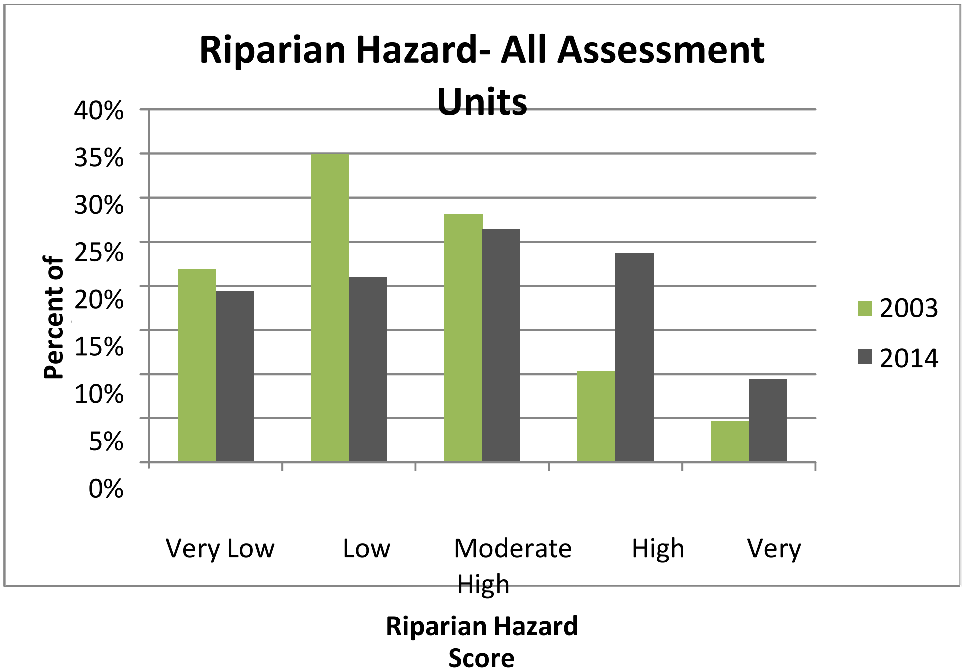

Figure 5. Change in riparian function hazard for all AUs (N= 401) in the Kamloops TSA between 2003 and 2014.

2.2 Projected Future Condition

2.2.1 Streamflow Hazard

Future changes in streamflow hazard will largely depend on the amount and spatial distribution of new forest harvesting or forest clearing associated with other resource sector activity or land use.

Future conditions that will contribute to a stable to declining streamflow hazard:

- The future average annual cut (AAC) is expected to decline as salvage of MPB-affected forests subsides(BC MFLNRO, 2016), and coupled with regeneration of existing harvested areas, should resulting in decreases in the rate of hazard experienced over the past decade.
- Harvesting directed into lower elevation Douglas-fir forests will have less effect on streamflow as these areas contribute less snowmelt to spring peak flow events.

The current streamflow hazard is expected to persist for a minimum of 20-30 years until forest regenerate and recover hydrologic function. Future conditions that will contribute to increasing streamflow hazard may include:

- Future harvesting directed into AUs with increased hydrologic response potential such as the interior wetbelt and wetbelt transition areas in the middle to northern portion of the TSA, could increase streamflow hazard.
- Uncertainty regarding the location, extent and severity of future natural disturbance, such as wildfire.

2.2.2 Sediment Hazard

Future sediment hazard as expressed using the GIS-based indicators used in the assessment procedure will depend on the spatial distribution of new road building associated with forest sector development and other resource sector or land use. However, actual sediment generation and delivery on the existing road network will likely have a greater effect across the TSA, and will depend on future use and road management practices.

Future conditions that will contribute to a stable to declining sediment hazard on the existing road network:

- Decreased industrial use of existing road networks.
- Deactivation or rehabilitation of existing roads.
- Opportunities to improve older road infrastructure (pre-FPC era) as forest harvesting directed into mid-term non-pine dominated forest types (dry Douglas-fir in the south and wetter ICH and ESSF forest in the northern portion of the TSA).

Future conditions that will contribute to increasing sediment hazard on the existing road network:

- New roads and harvesting in steeper more landslide probe terrain (wetter ICH and ESSF forest in the north of the TSA).
- Non-forest sector increase in industrial road use, and particularly in valley bottoms adjacent to major river corridors (e.g. pipeline expansions).
- Increased uncontrolled recreational (Off-Road Vehicle) use of existing road network.
- Increased uncontrolled livestock access to stream networks associated with existing expanded road networks.

2.2.3 Riparian Function Hazard

Future riparian hazard will depend on the amount and spatial distribution of forest sector development and other resource sector or land use in or adjacent to riparian areas.

Future conditions that will contribute to a stable to declining riparian hazard:

- Improved retention and protection of riparian vegetation during forest harvesting, particularly on small streams (S5-S6),
- Riparian restoration projects on private land,
- Improved livestock management practices to minimize uncontrolled livestock access and grazing in riparian areas,

Current riparian hazard is expected to persist for a minimum of 20-30 years until riparian vegetation in harvested areas regenerate and recovers hydrologic function. Future conditions that will contribute to increasing riparian hazard:

- Expansion of private-land clearing of riparian corridors or livestock grazing,
- Non-forest sector industrial expansion along valley bottoms riparian corridors (e.g. pipeline or highway expansions).
- Increased uncontrolled livestock access to stream networks due to loss of natural range barriers in areas where extensive MPB salvage has occurred.

2.3 Confidence in Hazard Ratings

2.3.1 Streamflow Hazard

A Moderate to High Confidence rating is applied to the results of the historic and current condition assessment for streamflow hazard.

The following factor contributes to increased confidence in the assessment results:

- Moderate to High confidence that model structure adequately captures both watershed characteristics and disturbance-related effects that contributes to an altered peak flow regime. High confidence is based on existing research, and recent validation of GIS-indicators with field- based monitoring.

The following source of uncertainty contributes to a reduced confidence in the assessment:

- Moderate certainty in vegetation resource inventory (VRI) data accurately capturing existing amount of forest harvesting and extent of hydrologic recovery of regenerating stands.

2.3.2 Sediment Hazard

A Moderate Confidence rating is applied to the results of the Sediment hazard rating used in the historic and current condition assessment of sediment hazard.

The following factor contributes to increased confidence in the assessment results:

- High certainty that model structure (indicators used to reflect road and harvesting related likelihood of sediment generation and delivery) adequately captures potential sediment sources

The following sources of uncertainty contribute to a reduced confidence in the assessment:

- Moderate certainty regarding actual impacts of roads on sediment generation and delivery to streams. The model currently assumes all roads equally contribute sediment; however sediment generation and delivery can vary depending on substrate, road location, construction, maintenance and use.
- Moderate – Low certainty in the erodible soils indicators (1:2 million coarse scale). Improved digital soil mapping can help capture locations of erodible soil types to improve information on sediment generation potential.

2.3.3 Riparian Function Hazard

A Moderate to High Confidence rating is applied to the results of the historic and current condition assessment of Riparian Function hazard.

The following factor contributes to increased confidence in the assessment results:

- High certainty in that the private land indicator reflects well-documented private land impacts in the literature and validation of private-land related effects from existing channel assessments and field-based monitoring in the Kamloops TSA.

The following sources of uncertainty contribute to a reduced confidence in the assessment:

- Moderate certainty related to the logging adjacent to streams indicator. Monitoring results from the Forest and Range Evaluation Program (FREP) show a high proportion of impact of forest and range practices on functioning condition of small streams (1-3 metres). These impacts are assumed to accumulate within a larger stream network based on the extent of harvesting adjacent to streams. However, actual knowledge is limited and will require further field-based investigations to corroborate this assumption,
- Moderate certainty in the livestock grazing indicator. Livestock related impacts can vary depending on livestock numbers, accessibility of streams and extent and type of management practices used to minimize livestock impacts to streams. However, field-based watershed assessments in the area have identified livestock impacts. Further field-based investigation and refinement of the indicator will improve accuracy.

3. Discussion and Conclusions

The increase in likelihood of harmful changes in all three hydrologic hazards suggests that unintended outcomes resulting from the cumulative effect of historic and current land use are likely to occur in the Kamloops TSA. The unintended outcomes of these changes may include increased frequency and magnitude of potentially harmful hydro-geomorphic events (e.g. floods, debris floods, flows, bank erosion) and harmful conditions (reduced water quality, loss of spawning and rearing habitat for fish).

These outcomes may have long-standing ecologic consequences (impact to fish habitat, aquatic ecosystem health, and water quality) impacting the provision of key ecosystem services important for human well-being (e.g. clean drinking water, flood regulation). These outcomes could also have direct, and potentially severe, socio-economic consequences to downstream values (e.g. injury to and/or loss of human life, damage to property and/or infrastructure) due to a higher likelihood of harmful hydro-geomorphic events (e.g. severe flooding or debris flow events).

To address the increased likelihood for harmful unintended outcomes to occur, as suggested by this strategic-level GIS assessment, field-based watershed-level risk assessments, completed by qualified professionals, are necessary to inform resource use and development decisions across multiple sectors. GIS indicator-based assessment procedures, as applied in this assessment, while useful for strategic level planning decisions in large management units (TSA's, Resource Districts), should not be used alone to make operational decisions or set management targets at the individual watershed level.

Outcomes of this strategic-level GIS indicator-based assessment are consistent with field-based monitoring of stream functioning condition completed throughout the Thompson-Okanagan Region over the past three years (Lewis, 2016), however the potential consequences to downstream values in specific watersheds have not been assessed by qualified professionals in the field. Actual conditions in any given watershed can vary from those derived from this procedure as a result of site-level factors not considered in GIS indicators and ratings.

The risk to ecological or socio-economic values (fish, fish habit, public safety, water quality, public and private infrastructure, etc.) resulting from hazardous changes in watershed processes can also vary based on spatial location and vulnerability (including any existing mitigation measures in place) of those elements. Thus, further field-based investigation by qualified professionals to assess risk to downstream values and provide operational -level mitigation recommendations is recommended. This strategic-level

GIS-based approach should not replace the use of qualified professionals and field-based assessments in individual watersheds to support operational-level decisions.

In the future, hydrologic hazard across the TSA may vary over time. The expected reduction in annual harvest in the Kamloops TSA, as salvage of MPB-affected stands subsides, is expected to mitigate some hazards with re-growth and recovery of hydrologic function in harvested or naturally disturbed forests. However, the spatial distribution of future harvesting and road building, particularly into non-pine dominated watersheds that may be more sensitive to forest harvesting, has the potential to maintain or elevate hydrologic hazards in some parts of the TSA.

Ongoing resource sector practices and land use may also prolong, increase or expand the existing hydrologic hazards and potential impacts to watershed condition, depending on the timing and spatial location of development activities and natural disturbances. Forward looking assessments that consider future land use, completed at both strategic levels, and within individual watersheds can be used to evaluate options to address and mitigate future unintended outcomes.

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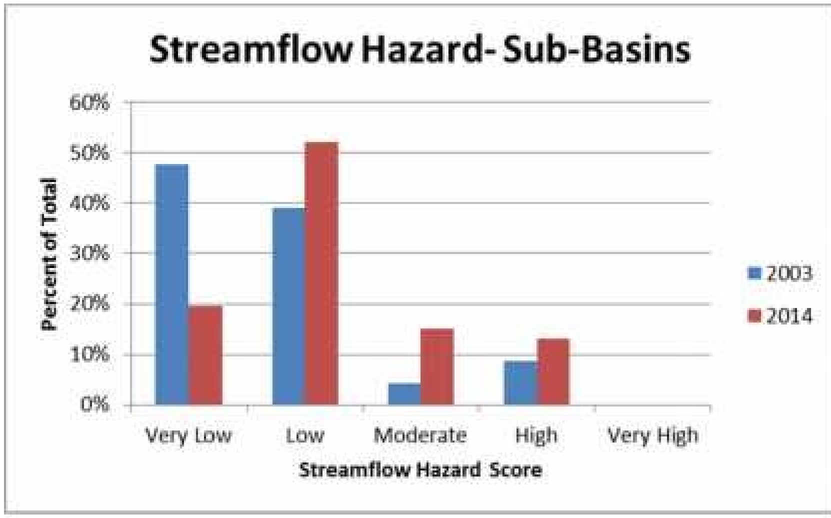
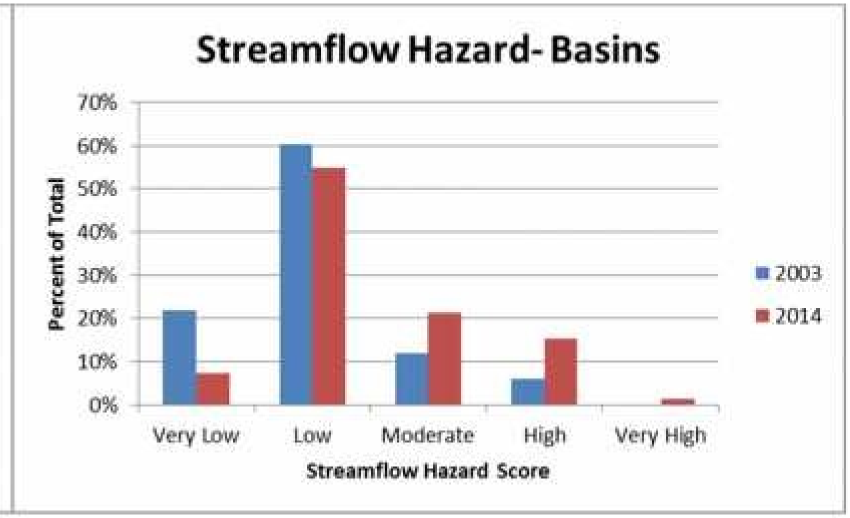
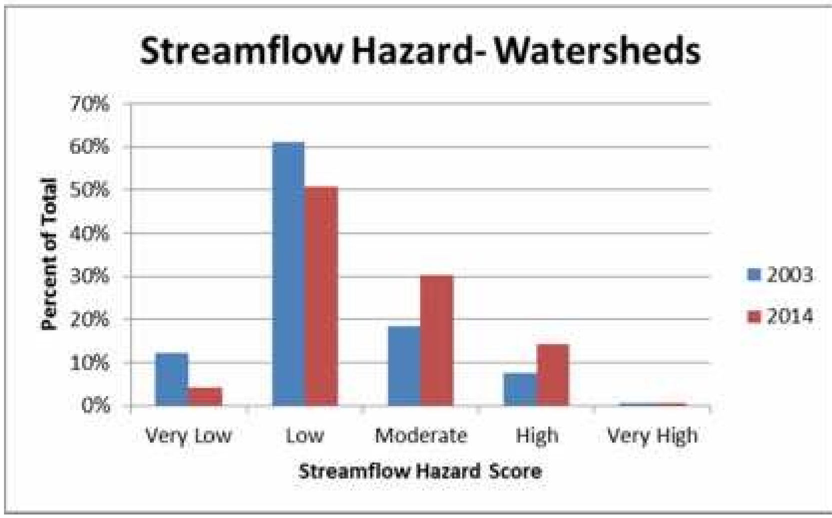
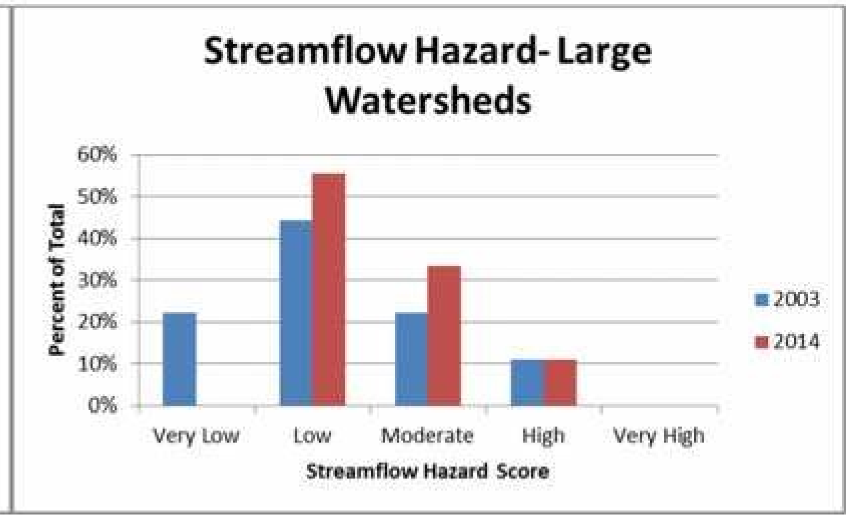
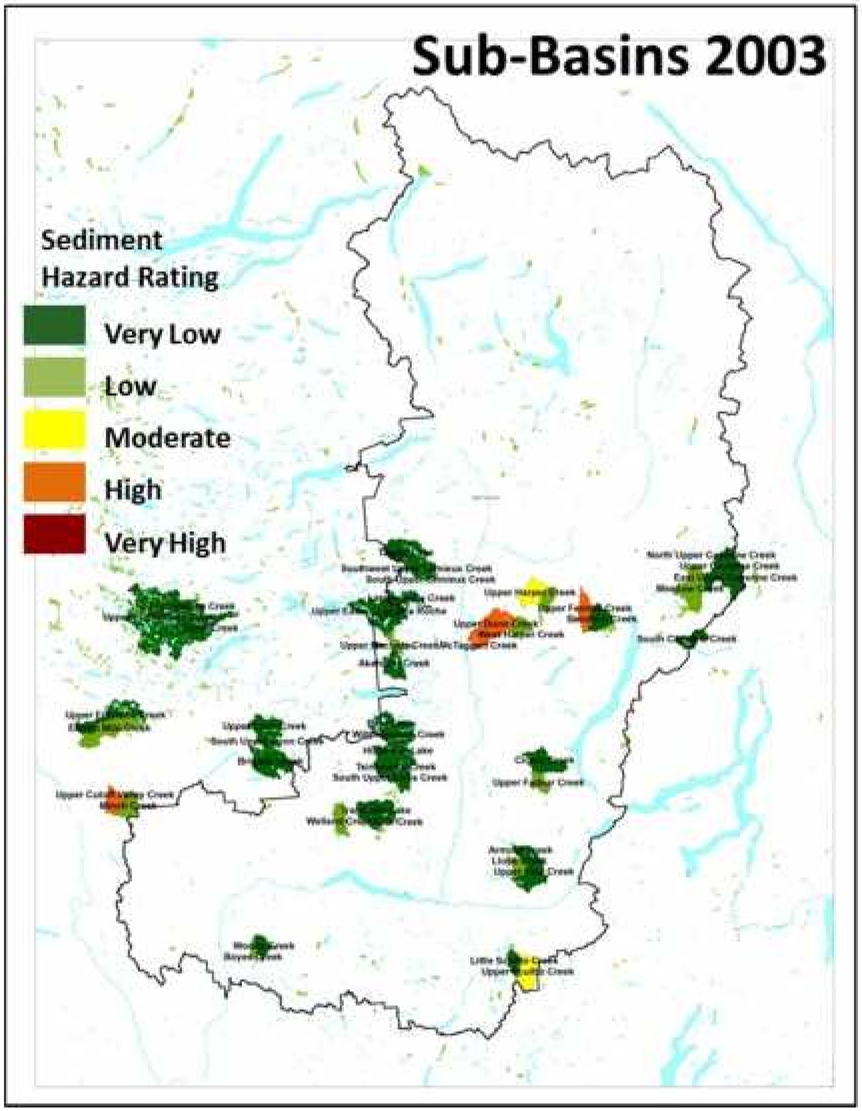
Appendix 1 – Streamflow Hazard Summary Statistics and Maps










Sub-Basins 2003
Sediment
Hazard Rating
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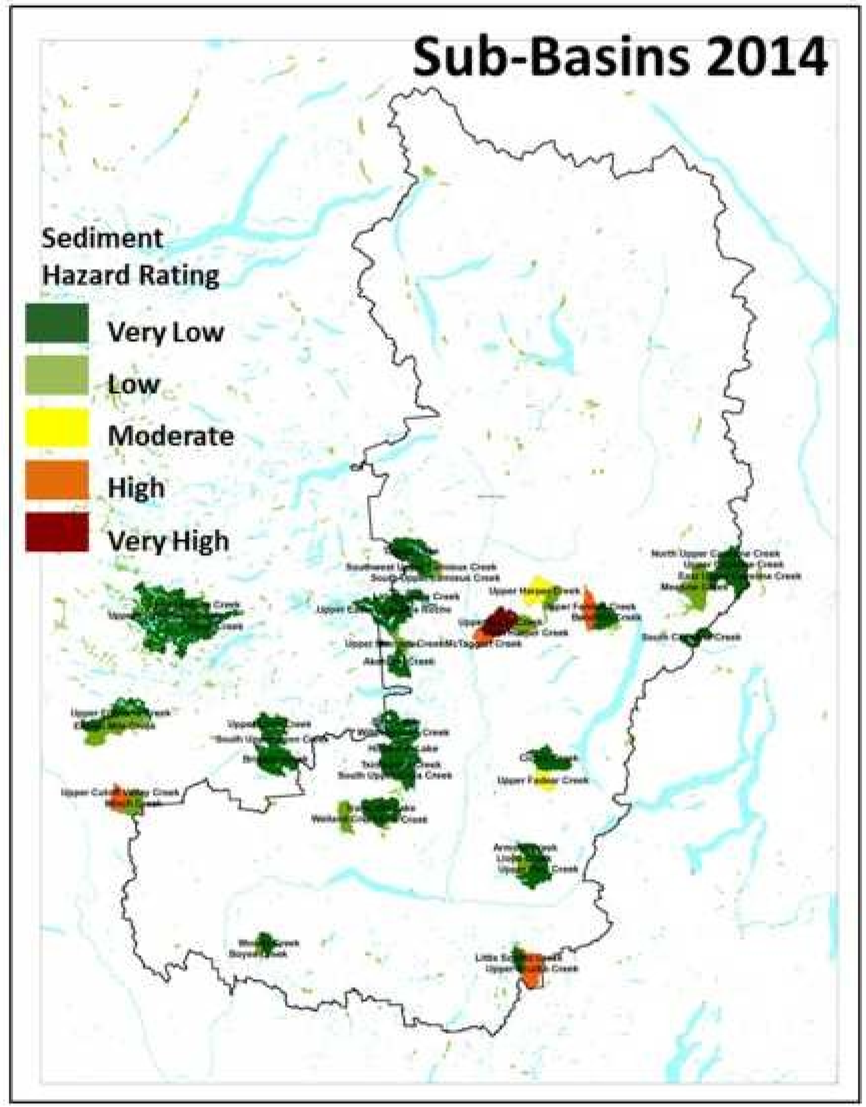
Moderate
High
Very High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Sediment
Hazard Rating
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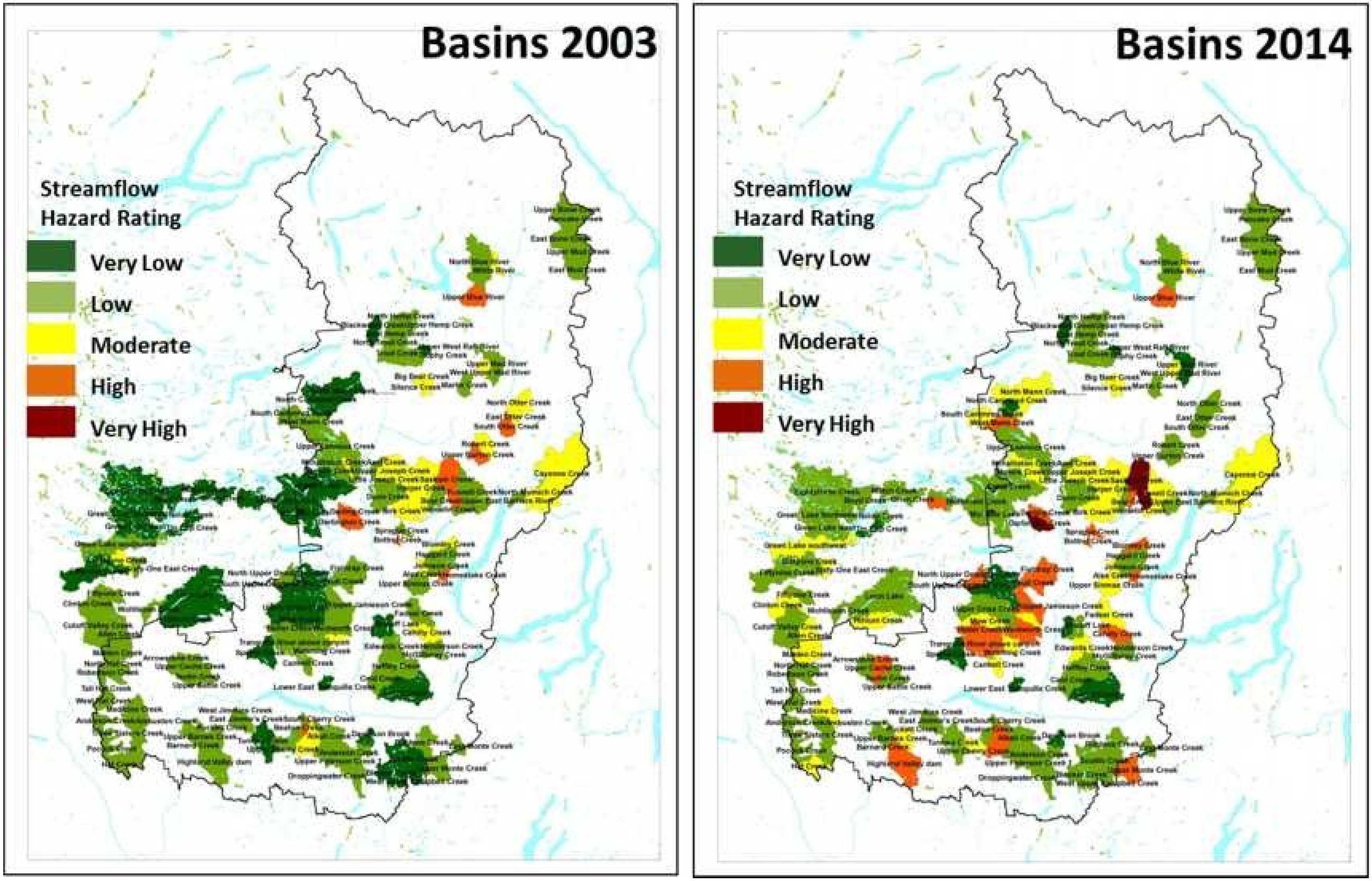
High
Very High


Basins 2003
Streamflow Hazard Rating
Very Low
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Basins 2014
Streamflow Hazard Rating
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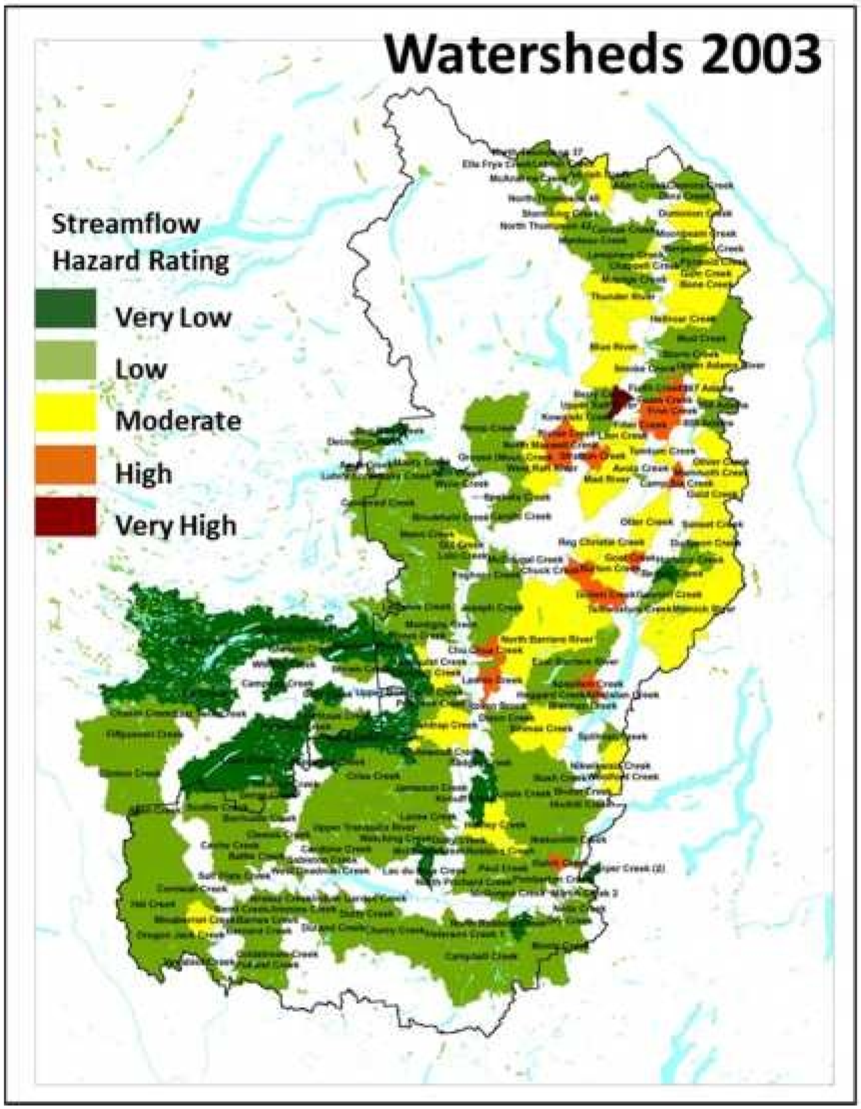
Watersheds 2003
Streamflow Hazard Rating
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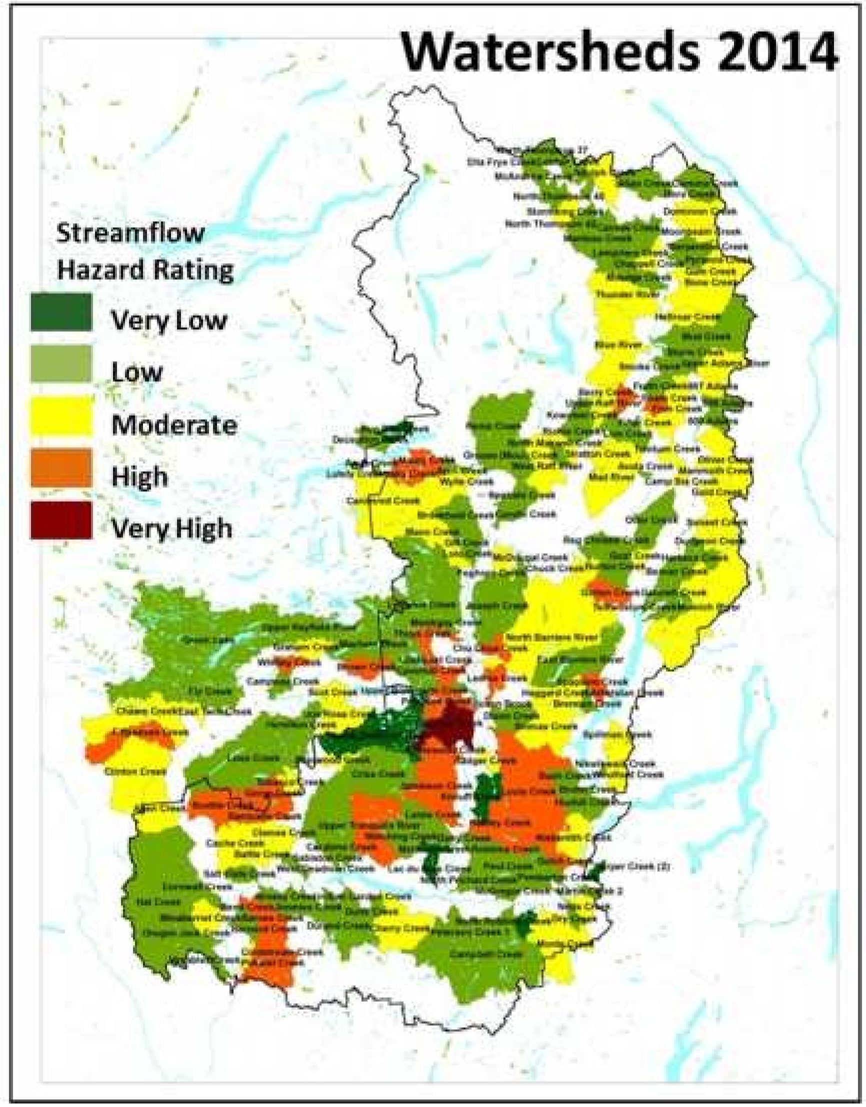
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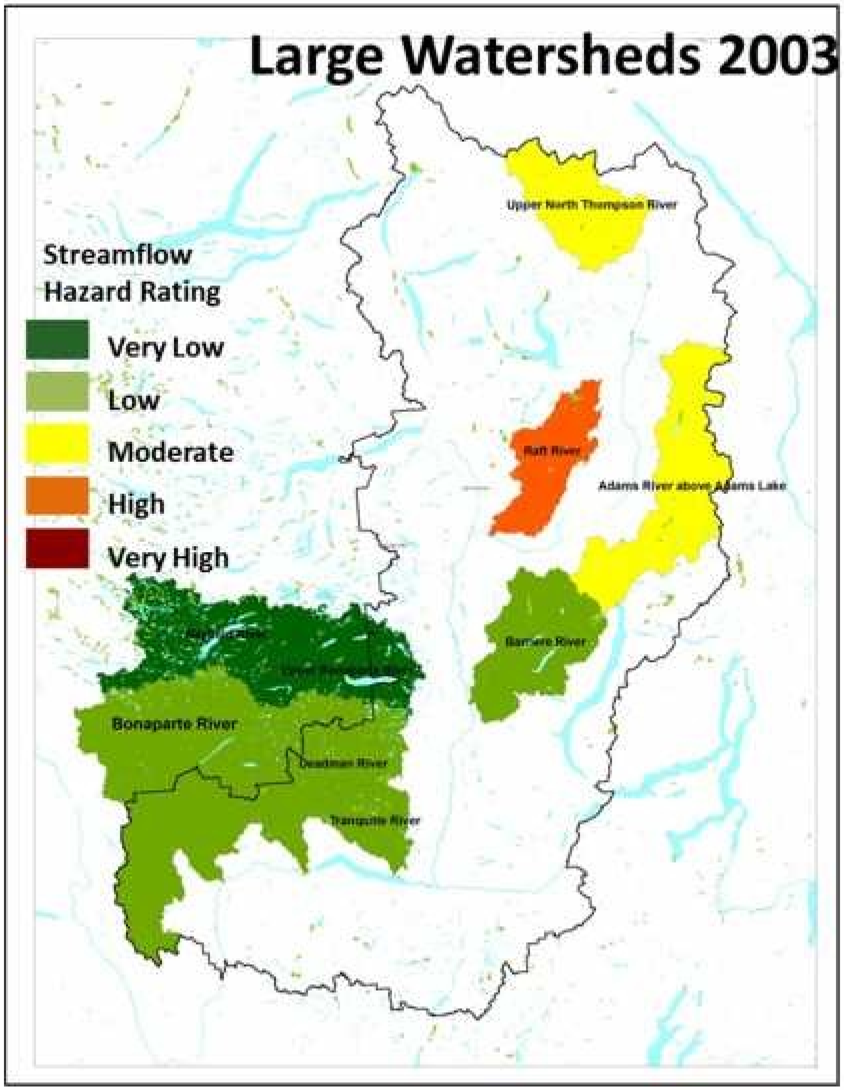
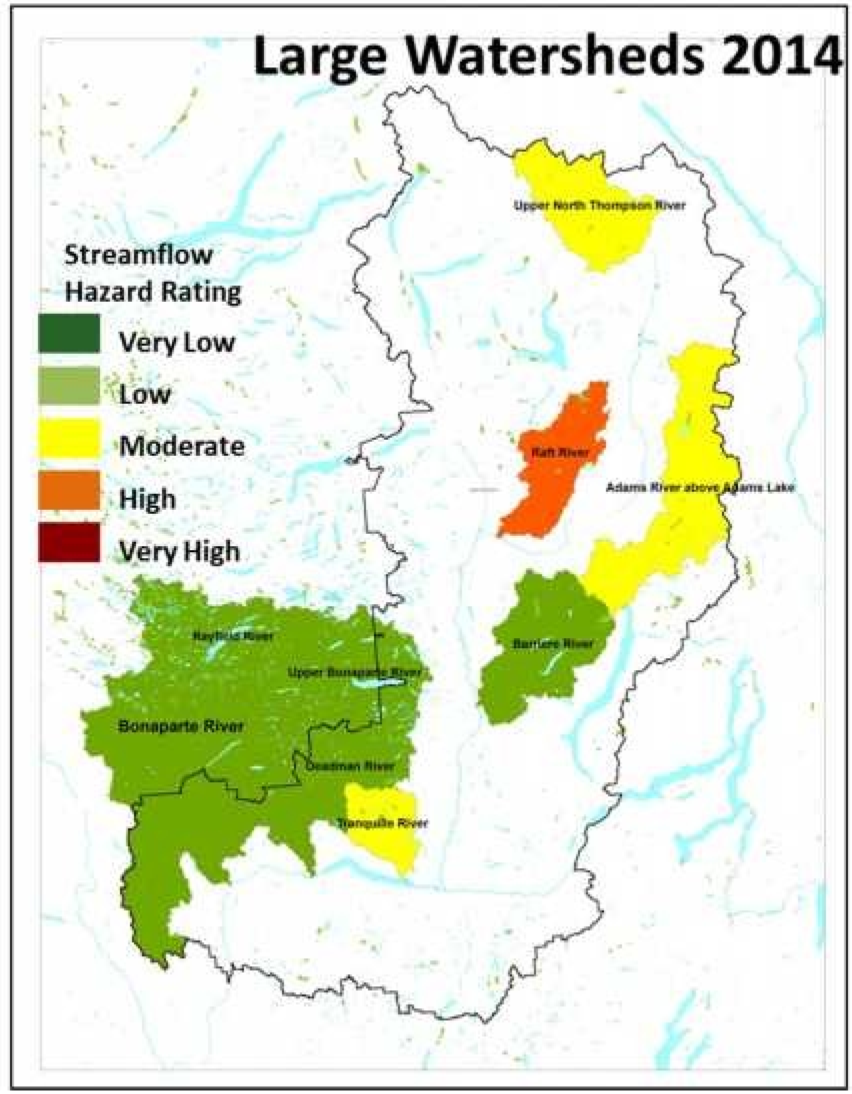


Large Watersheds 2003
Streamflow Hazard Rating
Very Low
Low
Moderate
High
Very High
Upper North Thompson River
Raft River
Adams River above Adams Lake
Barriere River
Bonaparte River
Deadman River
Tranquille River



Large Watersheds 2014
Streamflow Hazard Rating
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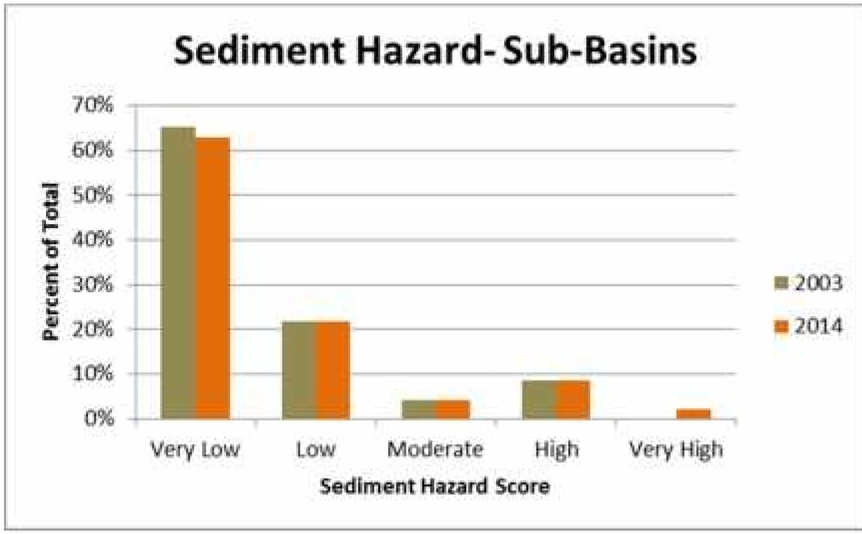
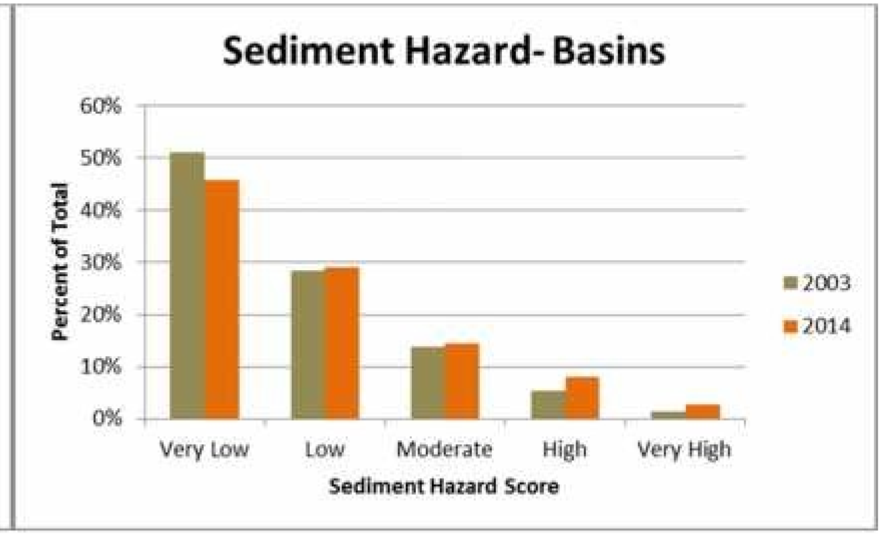
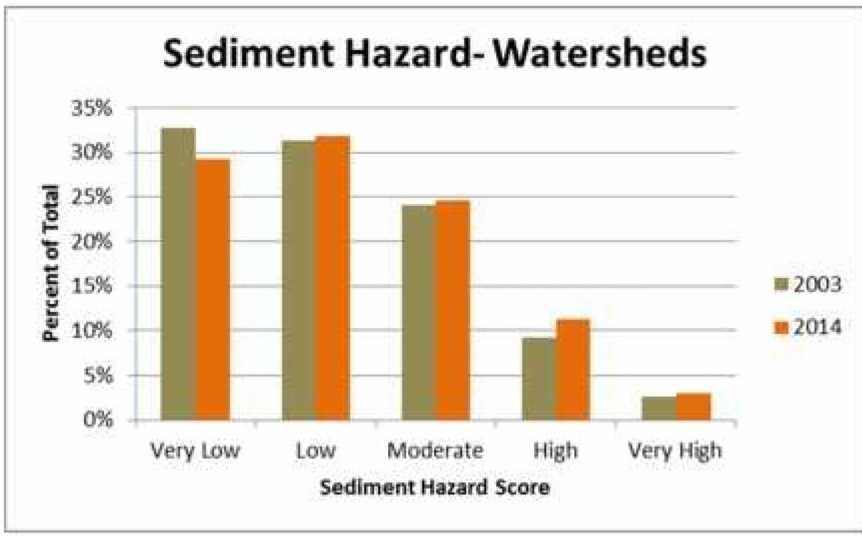
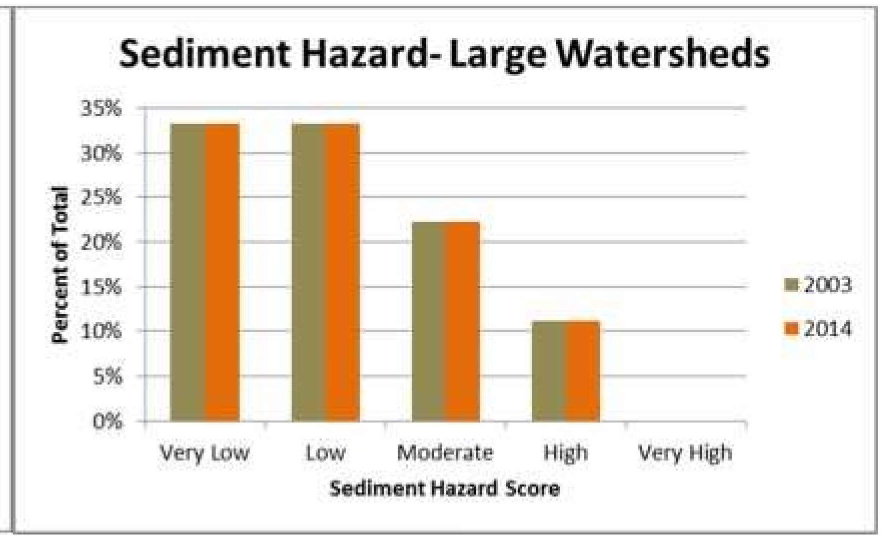
Very High
Upper North Thompson River
Raft River
Adams River above Adams Lake
Barriere River
Rayfield River
Upper Bonaparte River
Bonaparte River
Deadman River
Tranquille River

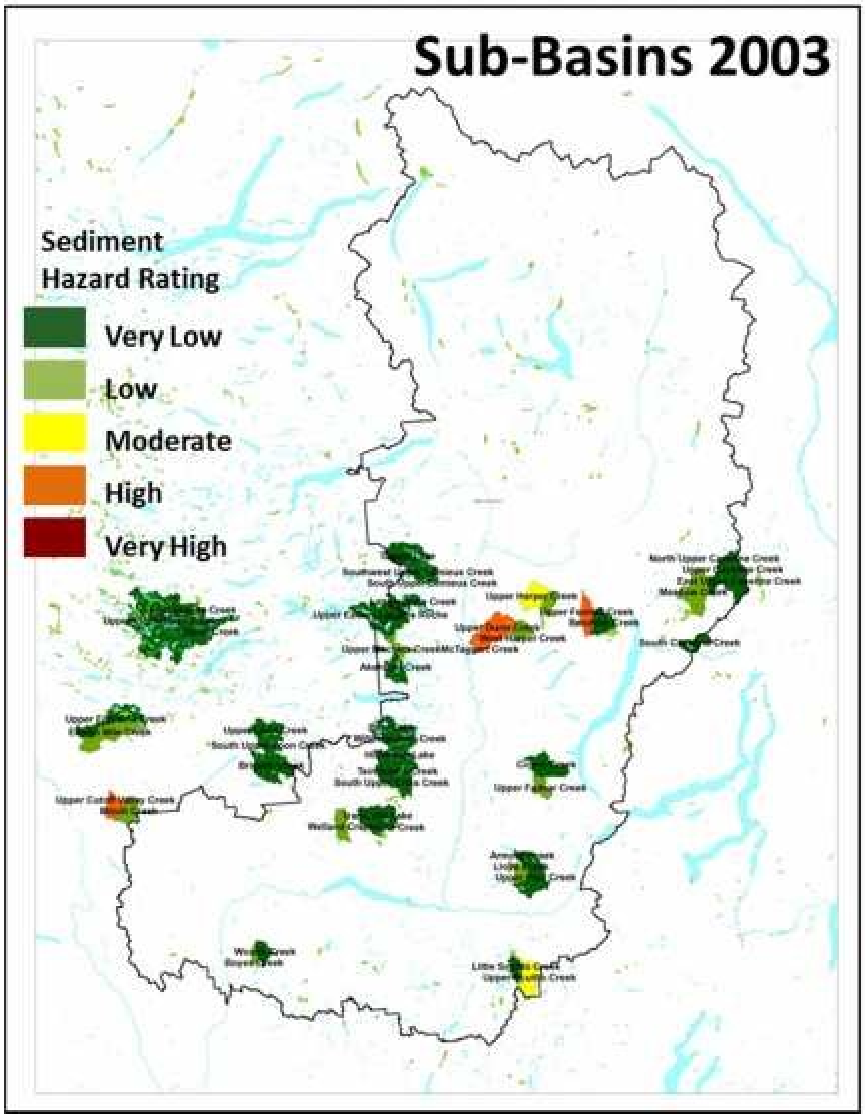
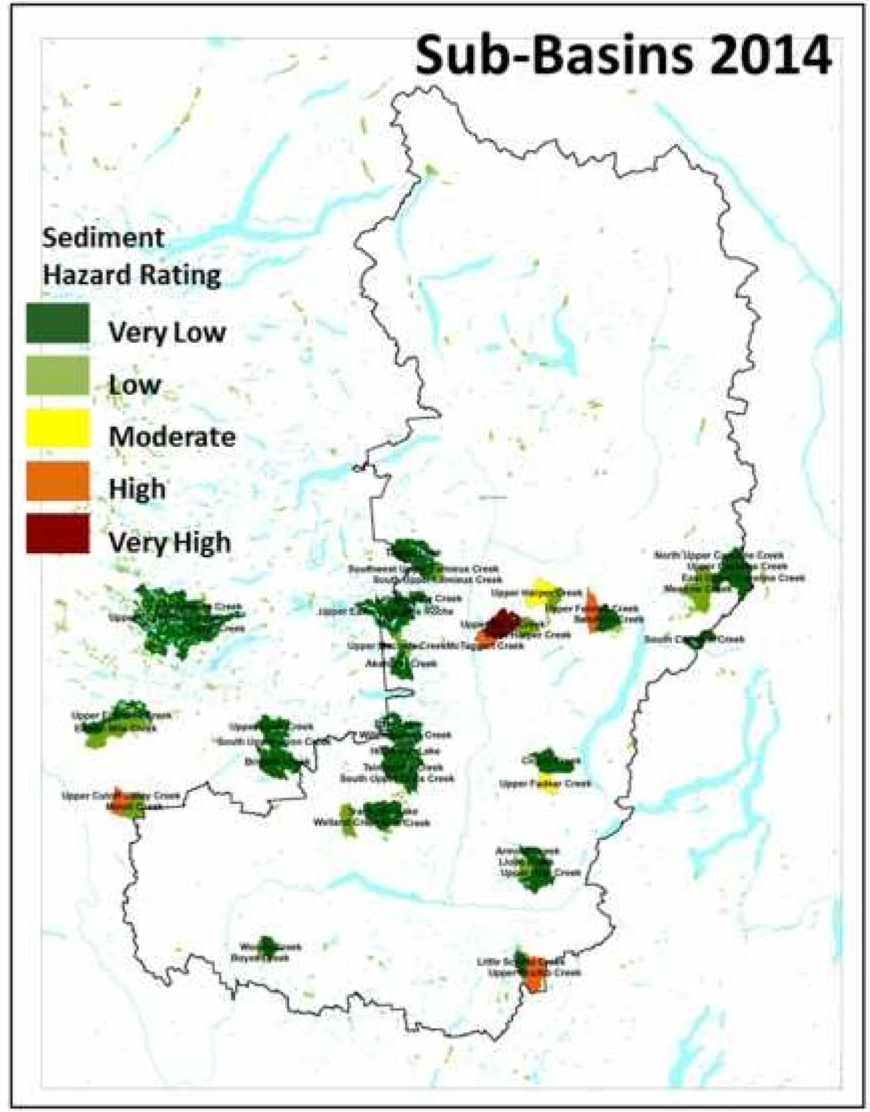
Appendix 2 – Sediment Hazard Statistics and Maps

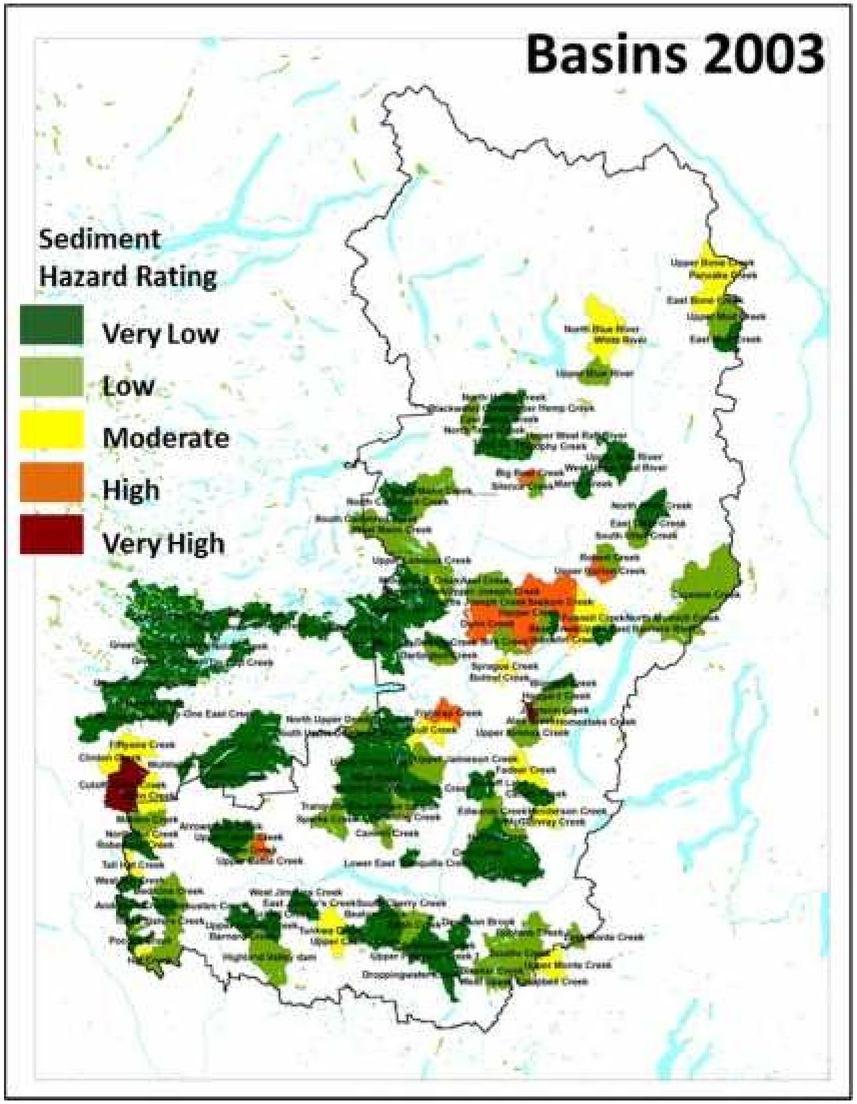


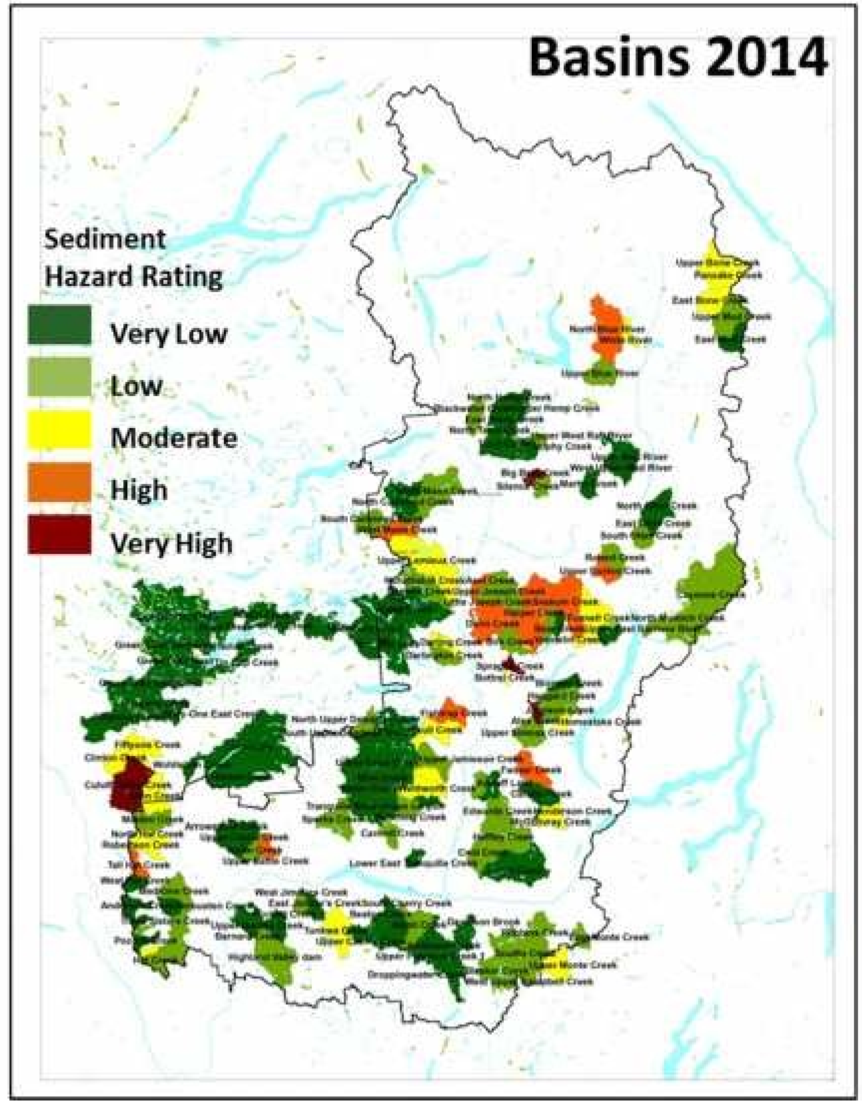


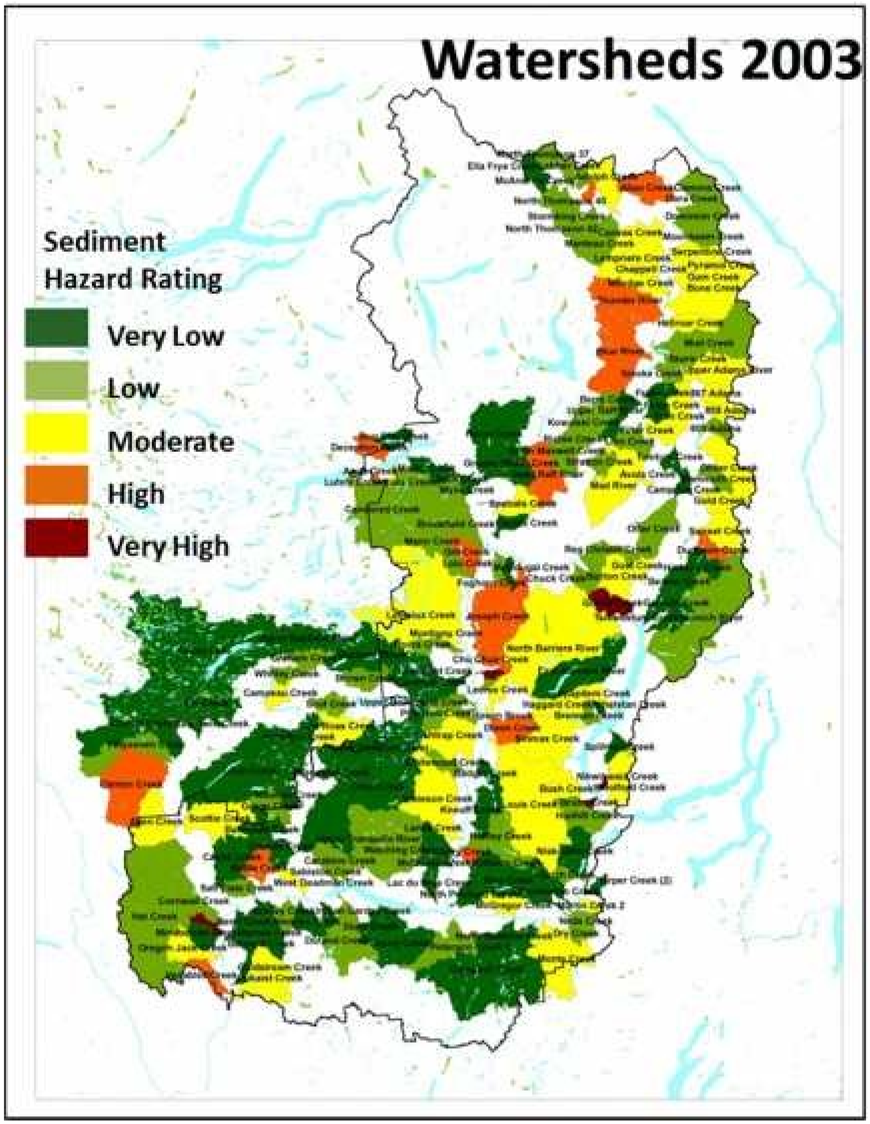


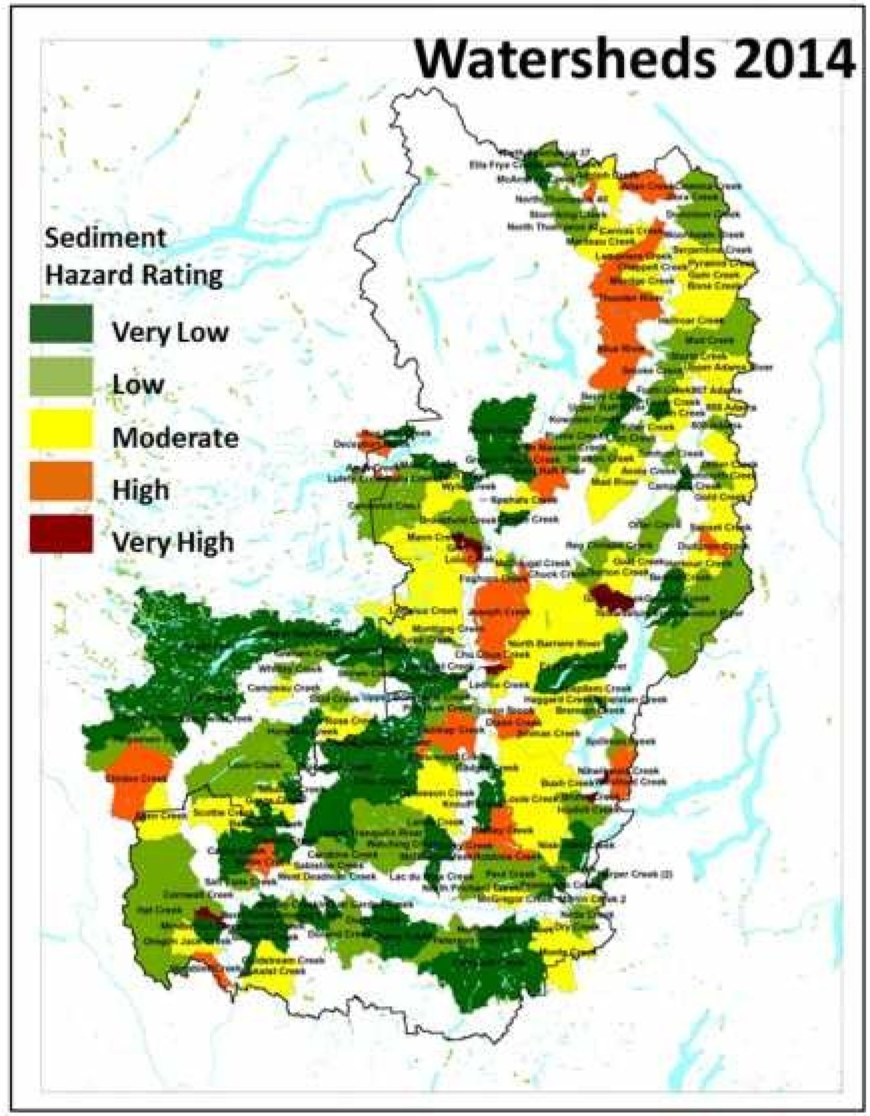


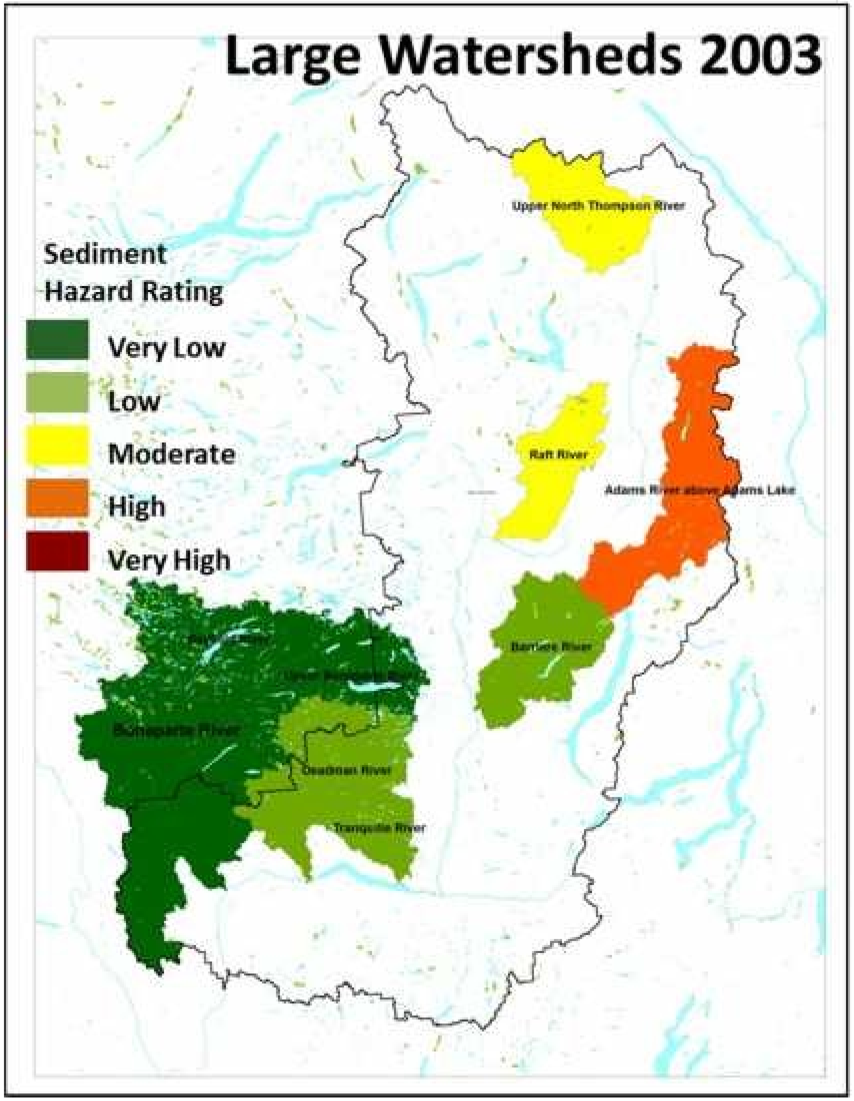

Sub-Basins 2003
Sediment Hazard Rating
Very Low
Low
Moderate
High
Very High

Sub-Basins 2014
Sediment Hazard Rating
Very Low
Low
Moderate
High
Very High

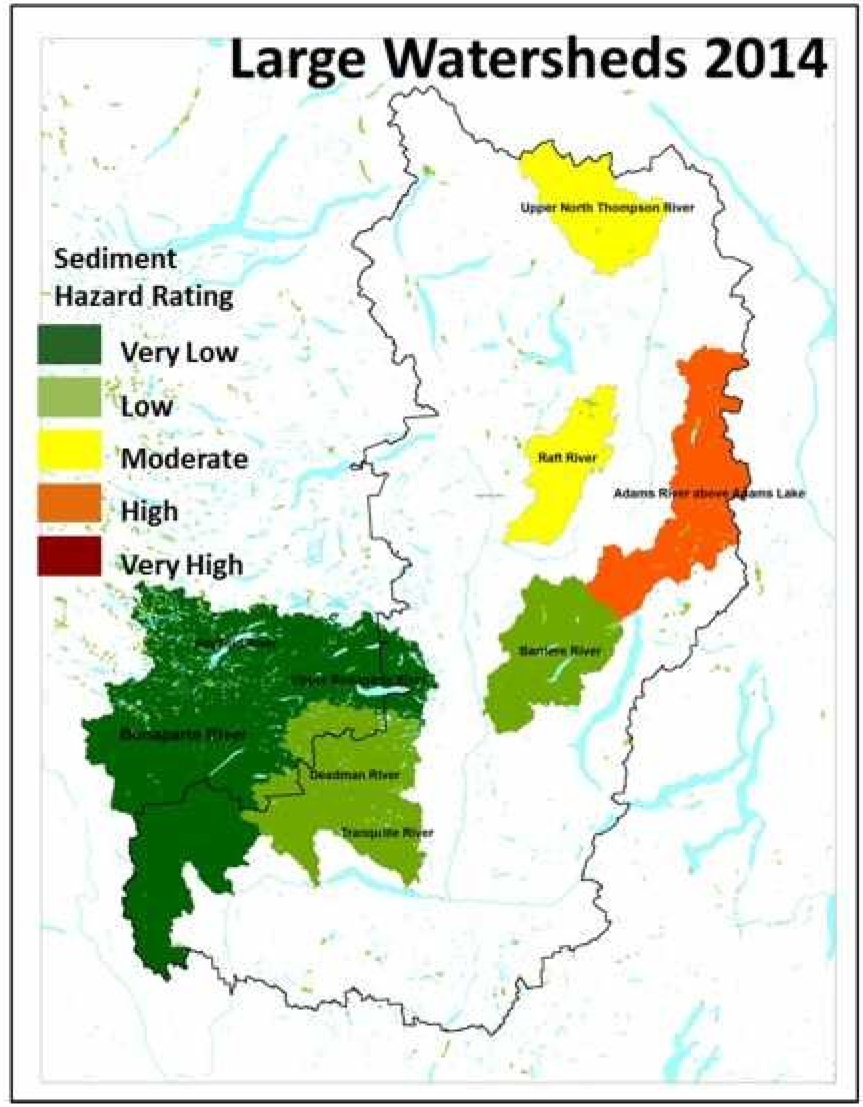

Basins 2003
Sediment Hazard Rating
Very Low
Low
Moderate
High
Very High


Basins 2014
Sediment Hazard Rating
Very Low
Low
Moderate
High
Very High

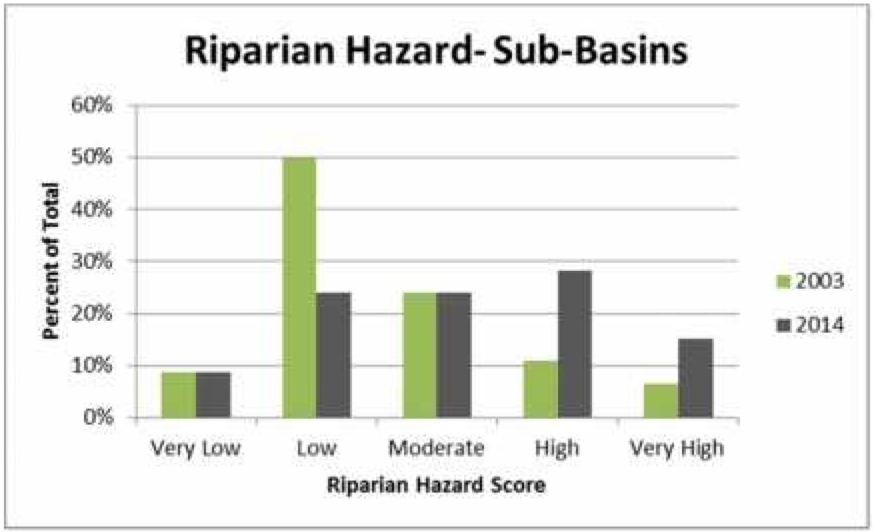

Watersheds 2003
Sediment
Hazard Rating
Very Low
Low
Moderate
High
Very High

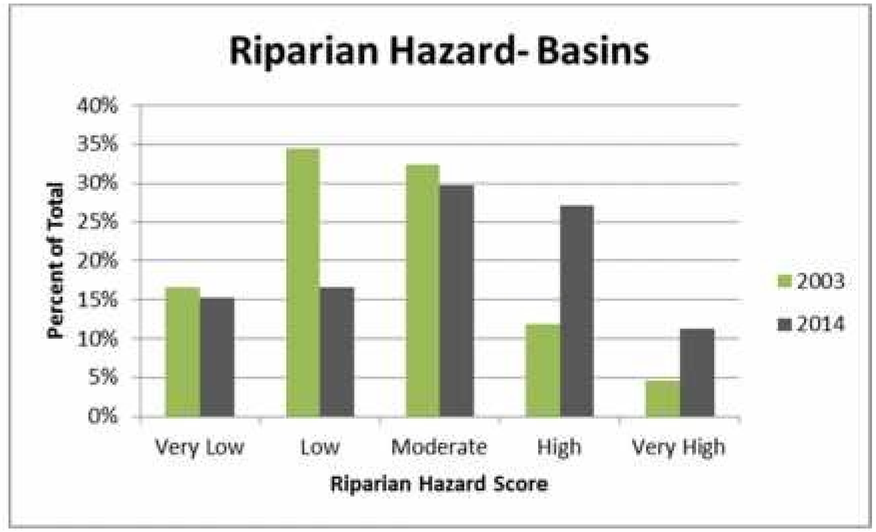

Watersheds 2014
Sediment
Hazard Rating
Very Low
Low
Moderate
High
Very High

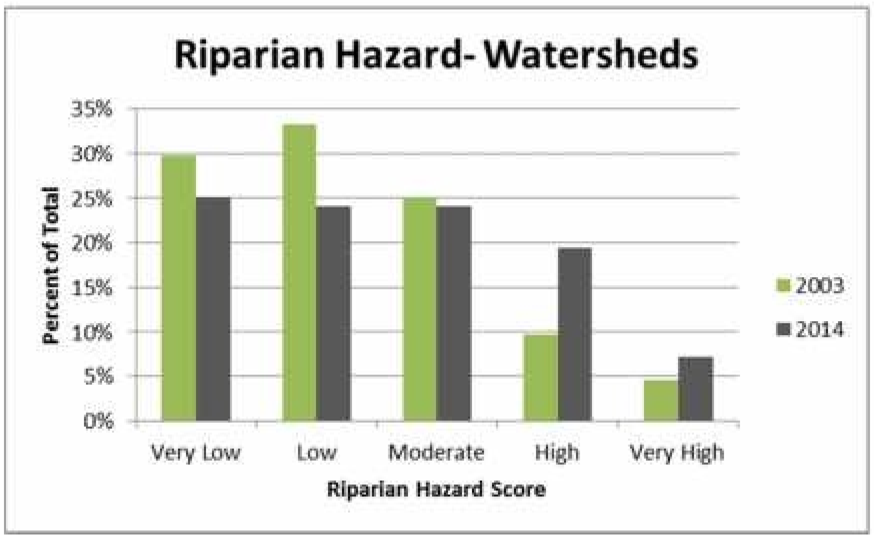

Large Watersheds 2003
Sediment Hazard Rating
Very Low
Low
Moderate
High
Very High
Upper North Thompson River
Raft River
Adams River above Adams Lake
Barriere River
Bonaparte River
Deadman River
Tranquille River

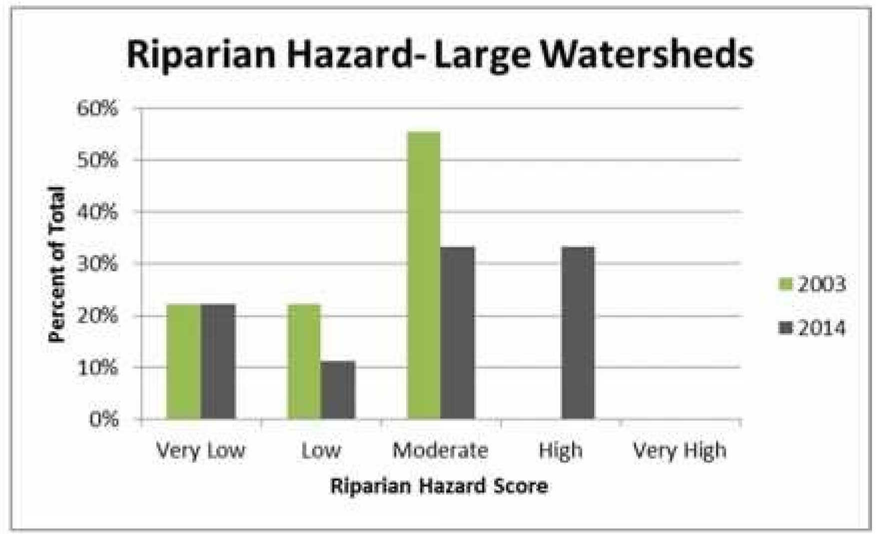

Large Watersheds 2014
Sediment Hazard Rating
Very Low
Low
Moderate
High
Very High
Upper North Thompson River
Raft River
Adams River above Adams Lake
Barriere River
Bonaparte River
Deadman River
Tranquille River

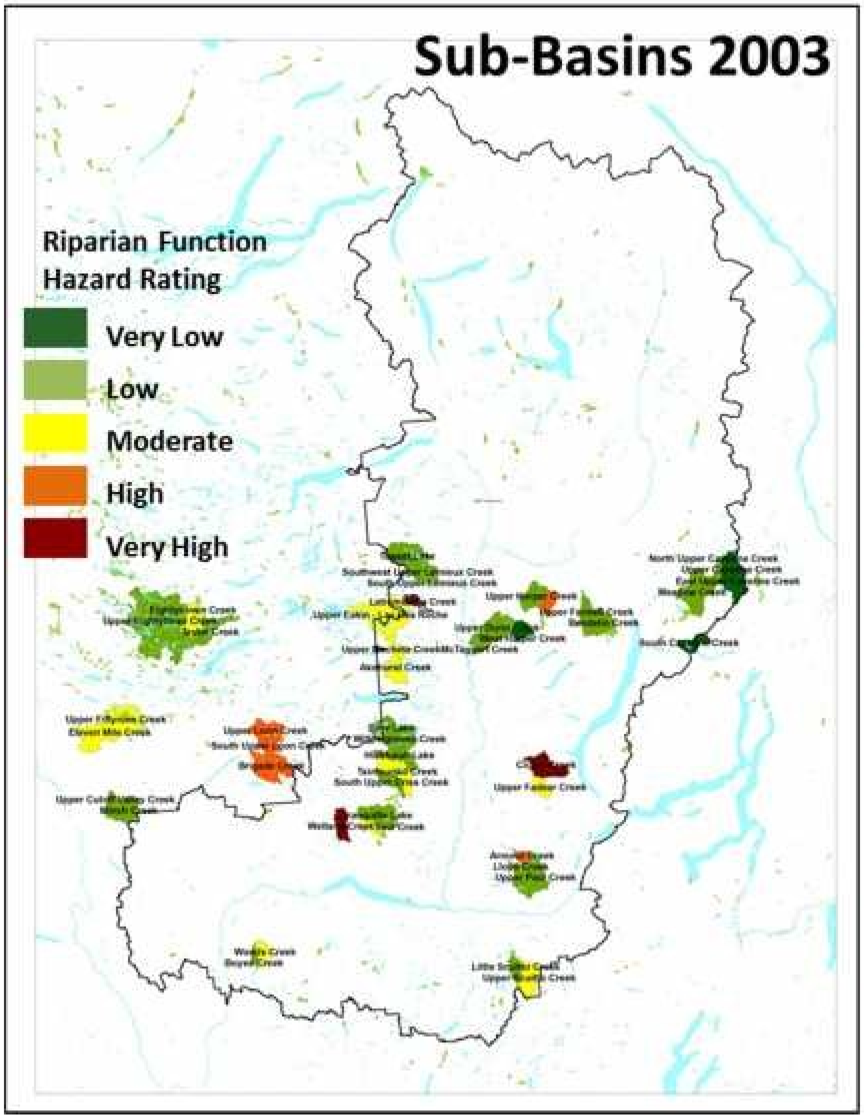
Appendix 3 – Riparian Function Hazard Statistics and Maps

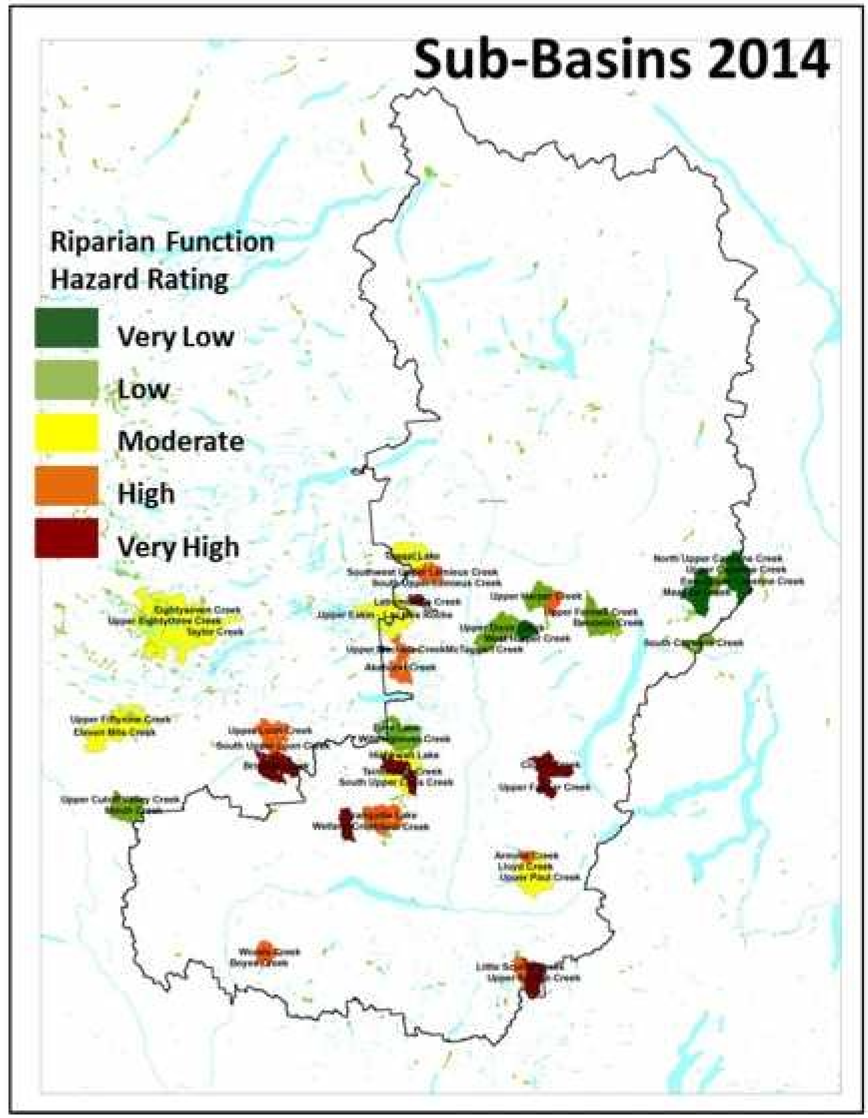


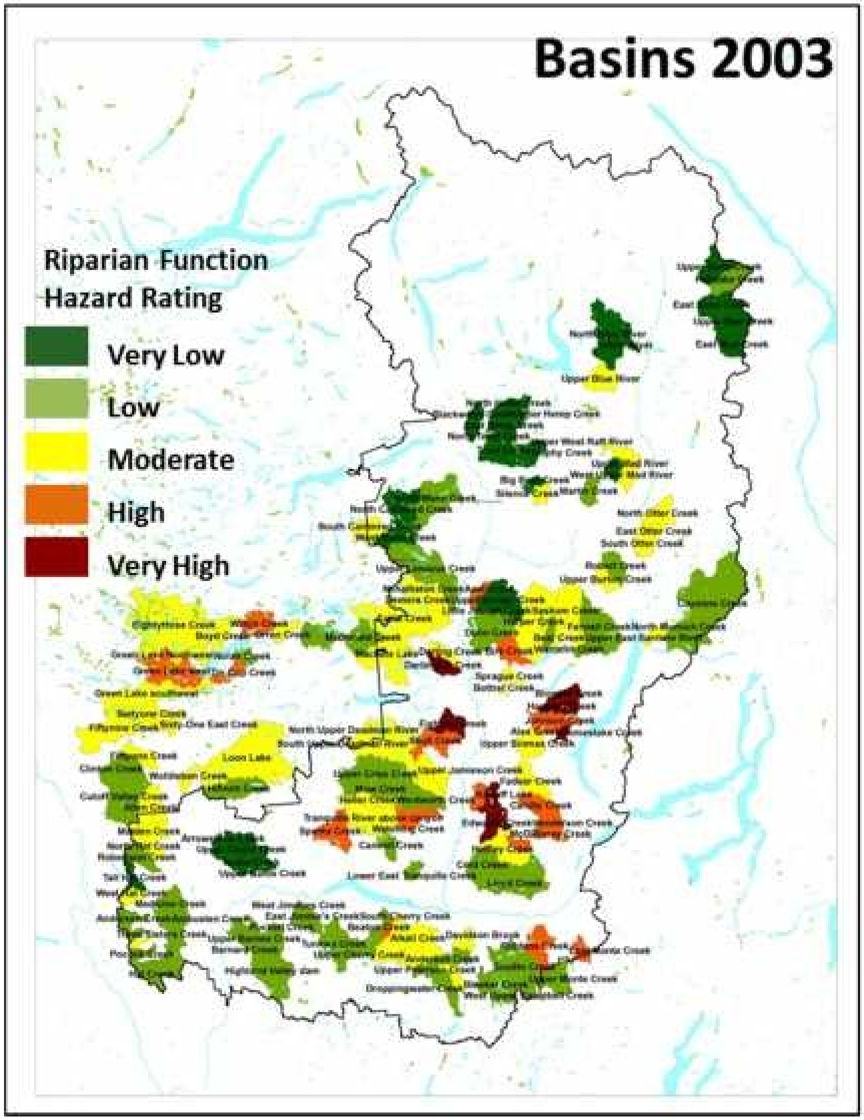


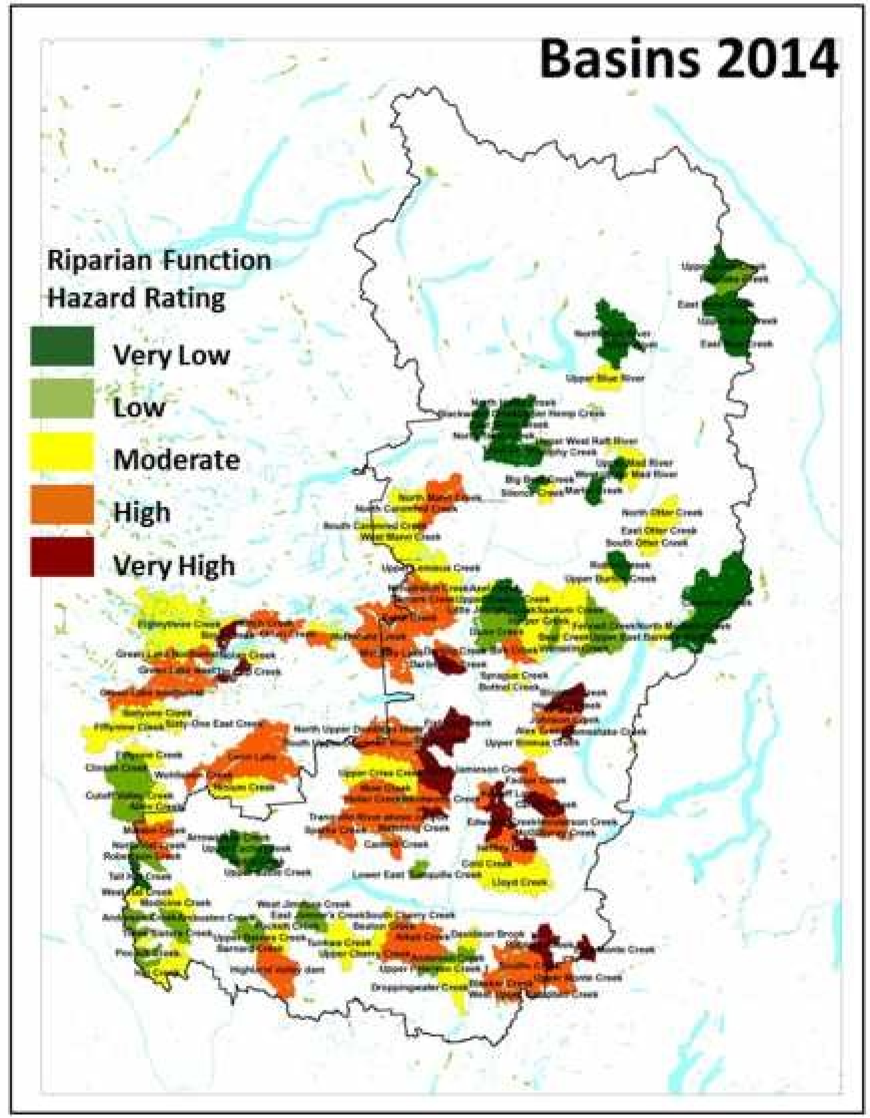


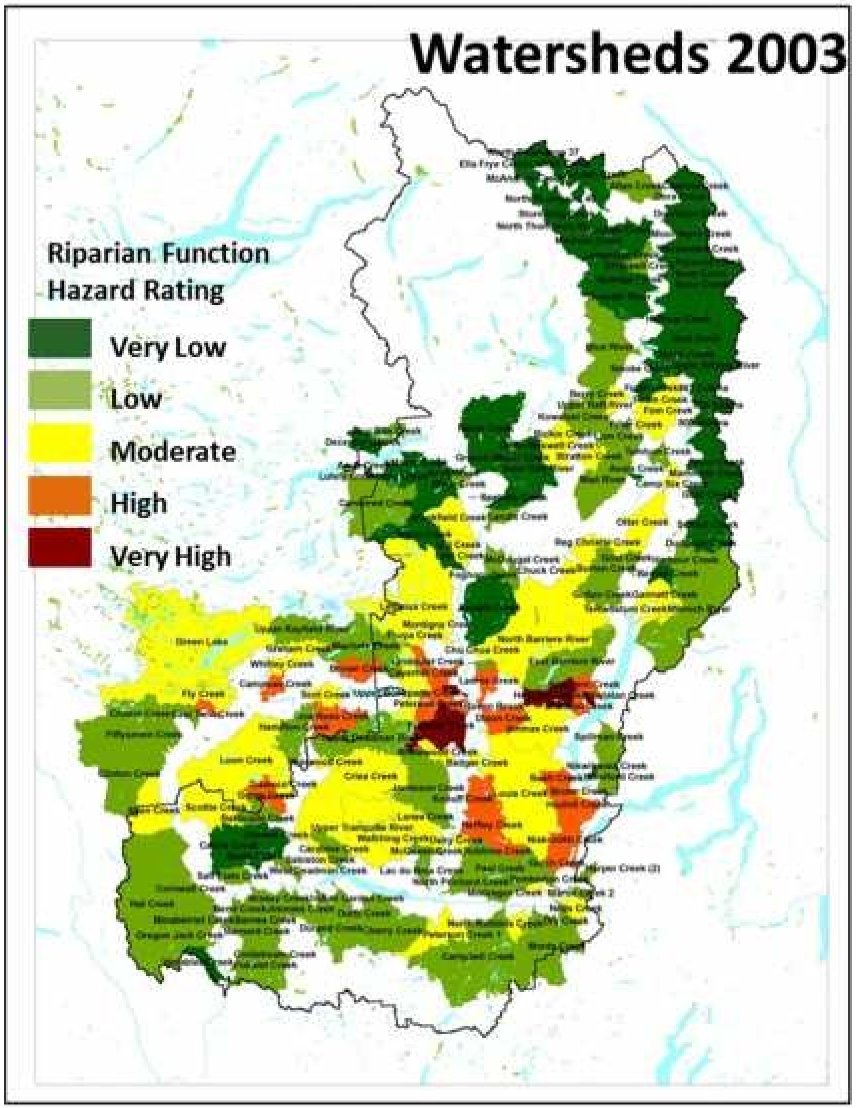


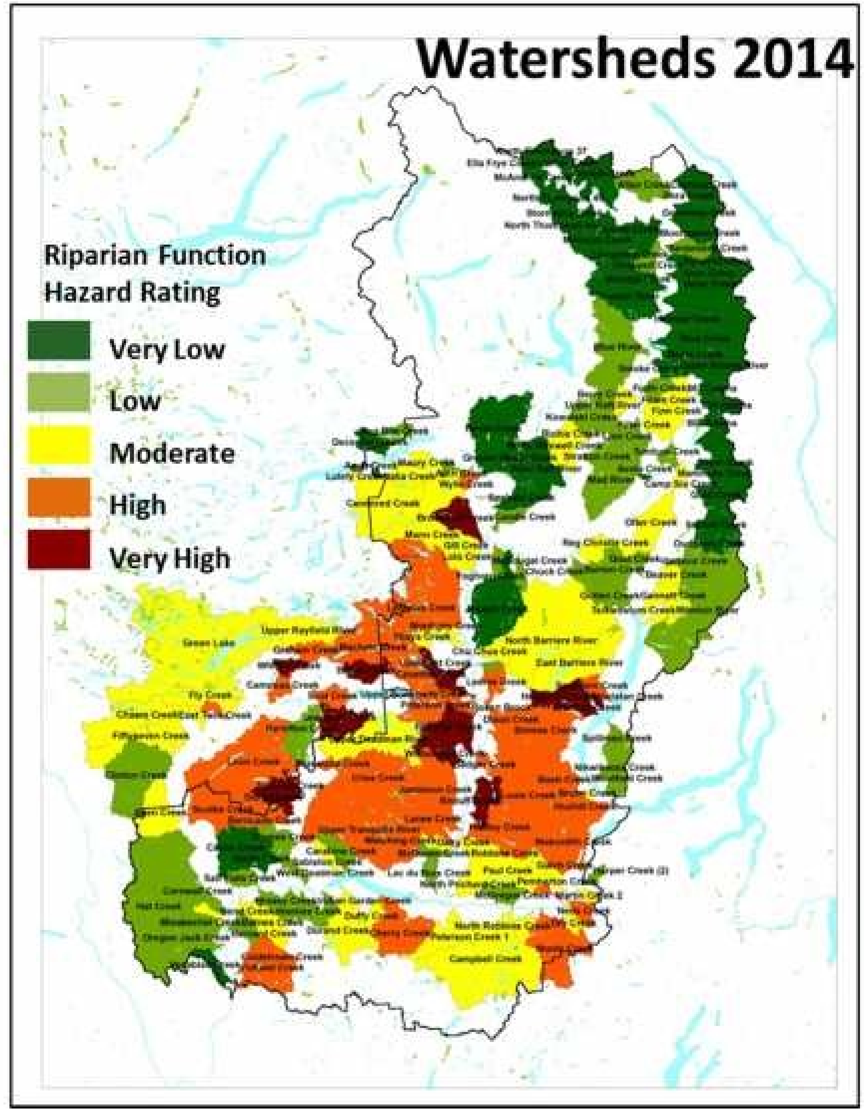

Sub-Basins 2003
Riparian Function
Hazard Rating
Very Low
Low
Moderate
High
Very High

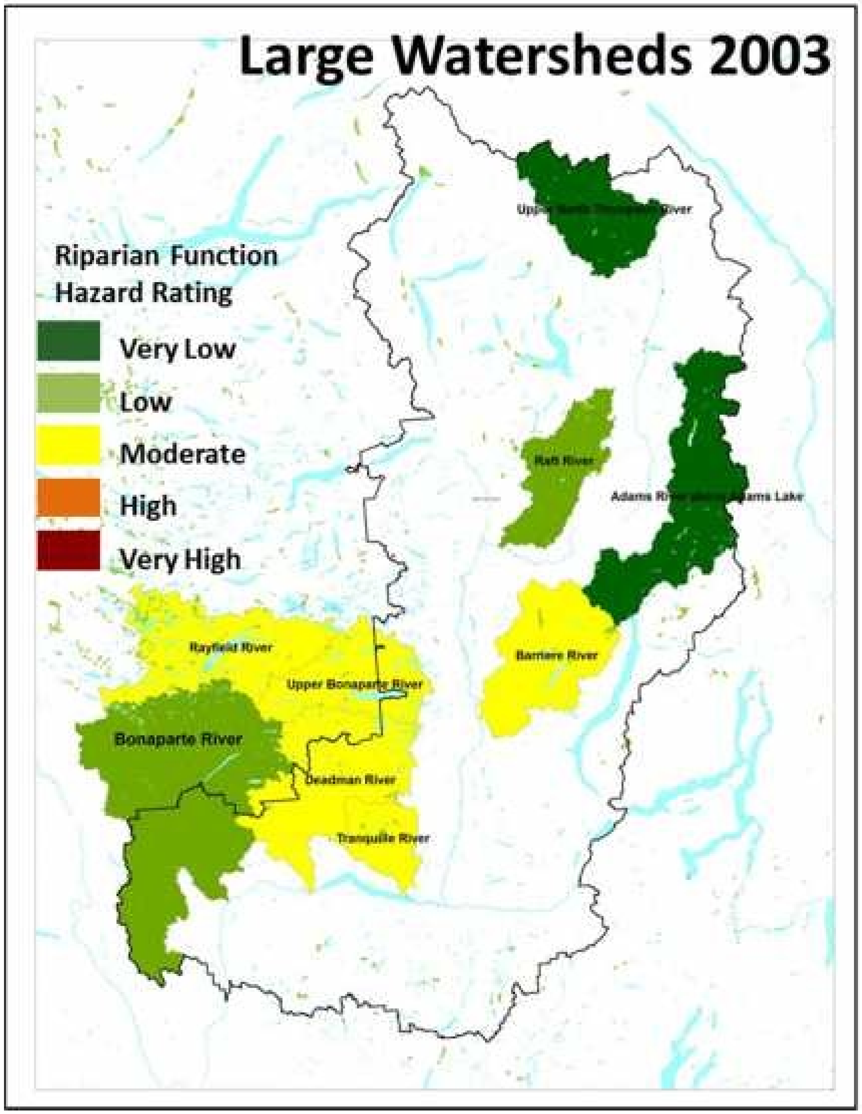

Sub-Basins 2014
Riparian Function
Hazard Rating
Very Low
Low
Moderate
High
Very High

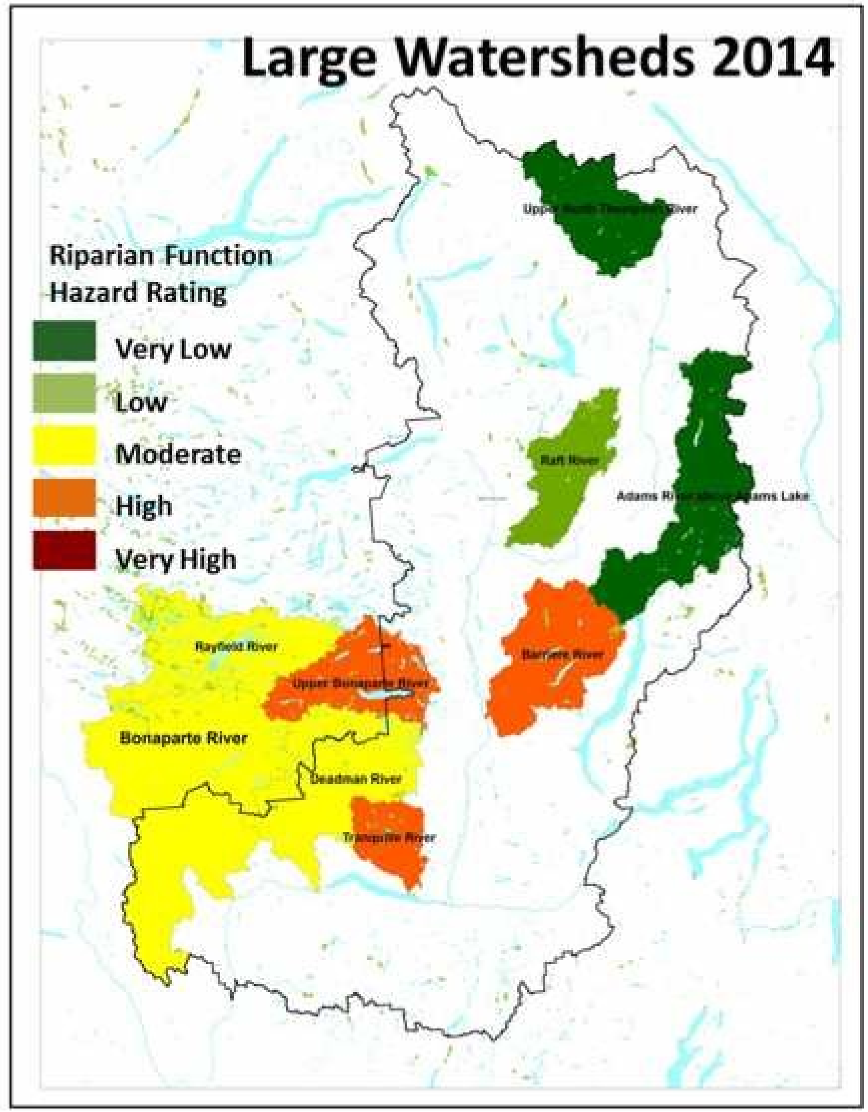

Basins 2003
Riparian Function Hazard Rating
Very Low
Low
Moderate
High
Very High


Basins 2014
Riparian Function Hazard Rating
Very Low
Low
Moderate
High
Very High


Watersheds 2003
Riparian Function
Hazard Rating
Very Low
Low
Moderate
High
Very High


Watersheds 2014
Riparian Function
Hazard Rating
Very Low
Low
Moderate
High
Very High


Large Watersheds 2003
Riparian Function
Hazard Rating
Very Low
Low
Moderate
High
Very High
Raft River
Rayfield River
Upper Bonaparte River
Barriere River
Bonaparte River
Deadman River
Tranquille River


Large Watersheds 2014
Riparian Function
Hazard Rating
Very Low
Low
Moderate
High
Very High
Raft River
Rayfield River
Barriere River
Bonaparte River
Deadman River