CEF Cumulative Effects Framework

BRITISH COLUMBIA

2019 Analysis of the Kettle River Watershed: Streamflow and Sedimentation Hazards

Kootenay Boundary Region

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

January 2021

Citation

Van Rensen, C.; N.N. Neumann; V. Young. (2021). 2019 Analysis of the Kettle River Watershed: Streamflow and Sedimentation Hazards. British Columbia Ministry of Forests, Lands and Natural Resource Operations and Rural Development.

Acknowledgements

The authors appreciate the information and technical support provided by Doug Lewis and Graham MacGregor in the Thompson Okanagan Region.

Table of Contents

Table of Contents 3
List of Acronyms 4
1 Introduction 5
2 The Kettle River Watershed 6
3 Assessment Methodology 8
3.1 Assessment Units 9
3.2 Indicators 10
3.3 Hazard Calculation 11
3.3.1 Streamflow Hazard 12
3.3.2 Sedimentation Hazard 12
3.4 Data 13
3.5 Assessment Limitations 14
4 Assessment Results 14
4.1 Streamflow Hazard Results 15
4.1.1 Runoff Generation Potential Rating 15
4.1.2 Runoff Attenuation Rating 19
4.1.3 Hydrologic Response Potential Rating 22
4.1.4 Equivalent Clearcut Area 23
4.1.5 Streamflow Hazard Rating 27
4.2 Sedimentation Hazard Results 29
4.2.1 Sediment Generation and Delivery Potential Rating 29
4.2.2 Land Use Disturbance Rating 33
4.2.3 Sedimentation Hazard Rating 38
5 Summary, Limitations and Next Steps 40
6 References 44
Appendix A *Streamflow Hazard* Indicator and Rating Maps 45
Appendix B *Sedimentation Hazard* Indicator and Rating Maps 68

List of Acronyms

AU	Assessment unit (includes headwaters and can be compiled at multiple levels)
AW	Assessment watershed (smallest units from BC Freshwater Atlas)
B.C.	British Columbia
BEC	Biogeoclimatic Ecosystem Classification
BEI	Broad Ecosystem Inventory
CEF	Cumulative Effects Framework
DDR	Drainage density roughness indicator
FWA	B.C. Freshwater Atlas
GIS	Geographic Information System
L1 AU	Level 1 Assessment Unit (single headwater AW)
TRIM	Terrain Resource Information Management
U.S.	United States of America

1 Introduction

The Government of British Columbia (the Province) is committed to sustainable resource management. As resource demands grow, we must be able to measure the combined effects of all resource development activities and natural disturbances, large and small, on the values important to the people of B.C. To meet this need, the Province established a Cumulative Effects Framework (CEF) in 2014 to guide the assessment of cumulative effects[1] across natural resource sectors and support the integration of assessment results in natural resource decision-making. Application of the CEF is underway in the Kootenay Boundary Region, led by the Ministry of Forests, Lands, Natural Resource Operations and Rural Development. Through this initiative, the Elk Valley Cumulative Effects Assessment and Management Report was completed which included an assessment of *Aquatic Ecosystems* as a valued component, and led to identification of priority management and mitigation actions (Elk Valley Cumulative Effects Management Framework Working Group 2018). Since completion of the Elk Valley project, the Kootenay Boundary Cumulative Effects (CE) team has expanded their CE initiatives to other areas in the region. For the new initiatives a watershed assessment procedure first designed by Thompson Okanagan Region was adopted (Lewis et al. 2016). Regional modifications were made to the assessment methods and are presented in Van Rensen et al. (2020). These new assessment methods were first applied to the Kettle River drainage basin and results are presented in this report.

The key objectives of the cumulative watershed effects assessment in the Kootenay Boundary Region are to assess the impacts of multiple disturbances on:

1. snowmelt-driven peak streamflow, referred to as the *Streamflow Hazard* in this analysis;
2. sediment generation and transport, referred to as the *Sedimentation Hazard*; and
3. riparian ecosystems, referred to as the *Riparian Hazard*.

At the time of writing this report, the protocols for assessing riparian hazard were under review by a CE working group and are therefore not included here. The Kettle River watershed assessment presented in this report is a strategic-scale geographic information systems (GIS) assessment that provides information on potential streamflow and sedimentation hazards at different scales in the watershed. The intention of this work is to provide tools for a wide range of management activities. For example, the results may inform land use activity management at the watershed scale, aquatic habitat protection and restoration and community development planning. The results presented in this report are considered a starting point for assessing hydrologic hazards resulting from the cumulative effects of multiple disturbances and activities on the landscape. While hazard rating results need to be validated with field work or modeling before being used for operational decision making, the patterns that emerge on the maps can be used as a first level of information for management planning. Ratings of potential hazard are derived from GIS data using our best understanding of hydrologic, climatic and geomorphologic processes occurring on the landscape; the procedures that are used to derive the hazard ratings will evolve and improve over time as new information is available.

[1] Under the Cumulative Effects Framework, cumulative effects are defined as changes to environmental, social and economic values caused by the combined effect of past, present and potential future human activities and natural processes.

This report provides a map-based overview of estimated streamflow and sedimentation hazards using data from 2019 in the Kettle River watershed. The Van Rensen et al. (2020) report which describes the assessment procedures should be referred to when interpreting the results presented here. In particular, this report includes:

- A brief overview of the indicators and methods used to assess the 2019 hazards to hydrologic and geomorphologic systems within the Kettle River watershed, including limitations of the assessment;
- Results for each indicator and hazard rating, including descriptive maps and initial interpretations (maps for each indicator and rating are provided in the appendices); and
- A summary of the results and key contributing factors influencing the results.

Where the 2019 hazard assessment indicates there may be a concern (i.e. higher hazard rating), additional examination, validation, analysis and management evaluation should occur to further determine the actual condition of, and hazard to, the value of interest.

As a start, it is hoped this report will inform collaborative discussions among government decision-makers, natural resource industries, First Nations and indigenous communities and local stakeholders, all of whom have a stake in ensuring natural resource decisions sustain B.C.'s natural resources and achieve the public interest.

2 The Kettle River Watershed

The Kettle River watershed is a tributary to the Columbia River. More than two thirds of the basin area lie within Canada (Figure 1); the river meanders south across the international boundary near the Village of Midway, returns to Canada near the City of Grand Forks and then flows south of the border again after receiving inflow from Christina Lake, entering the Columbia River near Boyds, Washington. The Kettle River watershed is approximately 9,945 km^2 in area (defined near where the Kettle River leaves Canada at Laurier, Washington) and falls within the traditional territories of the Ktunaxa, Okanagan, Sinixt and Métis peoples. Historic flood levels in the Kettle and Granby Rivers were recorded in 2018, causing extensive damage to homes and infrastructure in the City of Grand Forks and many rural areas. Concerns over the potential effects of forest harvest activities on this flood led to prioritisation of the Kettle River watershed for cumulative effects assessment.

Water quality and quantity are of critical concern for local communities and indigenous peoples to ensure adequate supplies of healthy drinking water, to practice traditional ways of life, to sustain fish, wildlife and biodiversity, and for recreational opportunities. Understanding the cumulative watershed impacts of both natural and anthropogenic disturbances can help reduce risks and hazards related to extreme flood events, landslides and drought. Across B.C., anthropogenic and natural factors are known to affect the integrity of watersheds, including, but not limited to, insect outbreak, fire, forestry, agriculture, ranching, mining, climate change and recreation.

Bark beetle infestations (with and without subsequent salvage logging), wildfire and forestry operations have all resulted in changes to forest stand age distribution, forest cover extent and stand characteristics

throughout the Kettle River watershed, especially at middle and high elevations. Most of the agricultural activity in the watershed is cattle ranching and production of forage crops (B.C. Agriculture and Food Climate Action Initiative 2019); extensive forest and brush removal for agricultural use has generally been limited to valley bottoms.

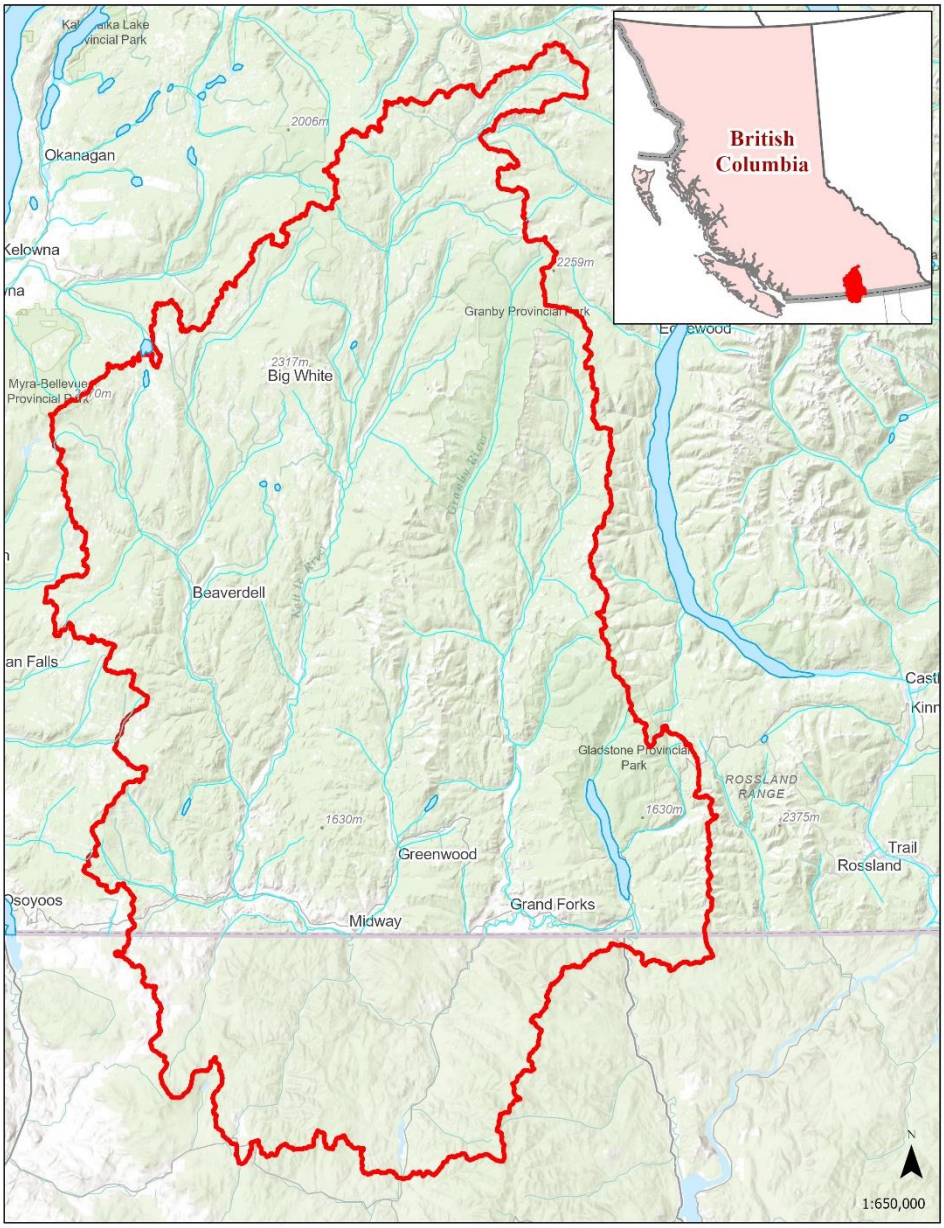


Figure 1. Location of the Kettle River watershed.

There is a legacy of mining and quarrying in the watershed, beginning with a series of gold rushes in the mid-19th Century. In the spatial land use data used for this analysis there are two relatively large mining footprints in Boundary Creek, but the remaining mines are either small in size or have been integrated

into a permanently disturbed landcover class in the same land use dataset. For example, modern gravel pits in the watershed are largely concentrated in the valley bottoms near major roads (Matheson et al. 1996) and are incorporated into a 'developed land' class rather than labelled separately as mining. There are extensive placer mine claims and leases in the northern portion of the watershed, in the Rock Creek sub-basin and west of Grand Forks. Although these activities often occur within the stream channel and can introduce significant amounts of sediment when poorly conducted, they are not currently addressed in the cumulative effects procedures.

Climate change models project warming in all seasons in the Boundary region, with slightly greater increases during the summer and in valley bottoms (B.C. Agriculture and Food Climate Action Initiative 2019). Most models project slight increases in average annual precipitation, with decreases during the summer and increases in spring, fall and winter. Of relevance to spring snowmelt-generated peak flows, winter snowpacks are expected to decline, especially at low elevations, but snowmelt will become more rapid (B.C. Agriculture and Food Climate Action Initiative 2019). Given this, climate change is expected to increase water temperature (especially when flows are low), to decrease low flows, to increase the potential for peak flows to occur earlier in the spring, and to increase the potential for peak flow events to occur in the fall due to rain events.

Other factors relevant to watershed functions in the Kettle River watershed include:

- The effects of recreational activities on aquatic ecosystems tend to be small or local in impact. One larger scale recreational activity in this watershed is development at Big White Ski Resort, which is included in the landcover disturbance indicators used. The potential effects of trail erosion are also included in the landcover disturbance indicator.
- The effects of low flows and fishing pressures on fish populations in the Kettle River have long been recognised, but because the methods used in this assessment focus on snowmelt-driven peak flows and sedimentation processes, they are not addressed here.
- The Kettle River watershed also includes portions of three large provincial parks (Graystokes, Granby and Gladstone) where industrial activities are restricted but where wildfire and insect outbreaks may be less stringently controlled compared to adjacent areas.

3 Assessment Methodology

This 2019 hazard assessment report is based on the methodology and assessment procedures outlined in Van Rensen et al. (2020). That report describes the procedures developed for a standard approach to region-wide assessment of cumulative watershed effects using GIS methodologies and consistent data sources.

The *Streamflow* and *Sedimentation Hazards* reported here indicate the potential for harmful hydrogeomorphologic conditions or events (e.g. floods, debris flows, bank erosion, reduced water quality, loss of fish spawning and rearing habitat). The impacts of these types of hazards can be immediate (e.g. public safety and damage to infrastructure or habitat) or persistent (e.g. in-stream habitat degradation, aquatic ecosystem health), and vary based on location and level of vulnerability. The assessment

procedures used a set of GIS indicators to estimate the natural sensitivity of a watershed to changes in (a) streamflow, specifically snowmelt-driven peak flow generation and (b) sedimentation (sediment generation and transport). Ratings of these natural sensitivities were then combined with indicators that reflect the effects of both natural and anthropogenic disturbance. This generated overall ratings of the estimated 2019 streamflow and sedimentation hazards. Details on the GIS indicators used and how they were combined to generate the final hazard ratings are provided in Section 3.3 and in Van Rensen et al. (2020).

This report summarizes the *Streamflow* and *Sedimentation Hazard* ratings assessed using GIS data from 2019. Details and modifications of the watershed assessment protocol specific to the Kettle River watershed are provided in the following subsections; further information on the indicators and ratings can be found in Van Rensen et al. (2020).

3.1 Assessment Units

The base units used in this analysis were the Assessment Watersheds (AWs) from the B.C. Freshwater Atlas (FWA) (Figure 2, left; Carver and Gray, 2010; https://catalogue.data.gov.bc.ca/dataset/freshwater-atlas-assessment-watersheds). While some AWs represent full drainage areas (i.e. a watershed), most represent partial drainage areas (i.e. discontinuous portions of a watershed) and so cannot be used for hydrogeomorphologic analysis. Instead, Assessment units (AUs) were defined using drainage patterns based on the FWA Stream Network (https://catalogue.data.gov.bc.ca/dataset/freshwater-atlas-stream-network). The AUs ranged in spatial scale from individual AWs to major sub-basins. The smallest AUs were headwater AWs that did not receive water from an adjacent AW. These were identified as Level 1 AUs (L1) since they only included one AW. From there, increasingly larger hydrologic units were created by combining AUs with adjacent AWs, with AUs that drain into each other, or with AUs that connect at a stream confluence; the resulting AU was named according to how many AWs were combined. The AU grouping continued in this nested fashion until the largest watershed areas of interest were defined (Figure 2, right). This nesting allowed results to be analyzed in a cumulative manner from the smallest L1 unit to the major sub-basins. For a more detailed description of the watershed delineation process refer to Van Rensen et al. (2020).

Due to data and analysis constraints the current assessments were only conducted for AWs that were entirely or primarily located in the Canadian portion of the Kettle River watershed (more details on the constraints are provided in Section 3.5). AWs with only a small area within the United States were still included in the analysis and assessment unit groupings (the U.S. portion was simply not included in the analysis). AWs and their subsequent AU groupings that were substantially or completely in the U.S. were not included in the assessment, with the result that only those AUs that lie entirely within Canada were analyzed. Therefore, results were only generated for the major sub-basins, not the entire Kettle River watershed. There were three large and three medium sized major sub-basins identified in the Kettle River watershed: West Kettle River, Kettle River mainstem or central, Granby River, Rock Creek, Boundary Creek and Christina Lake. These major sub-basins will often be referred to in the results section.

Results can be evaluated at any scale, from the smallest AU unit to the largest watershed, to help inform decision making across different scales. To use these results, first identify the point of interest (e.g. a bridge or culvert that may be damaged by peak flow); the relevant AU will be the drainage area upstream of that point.

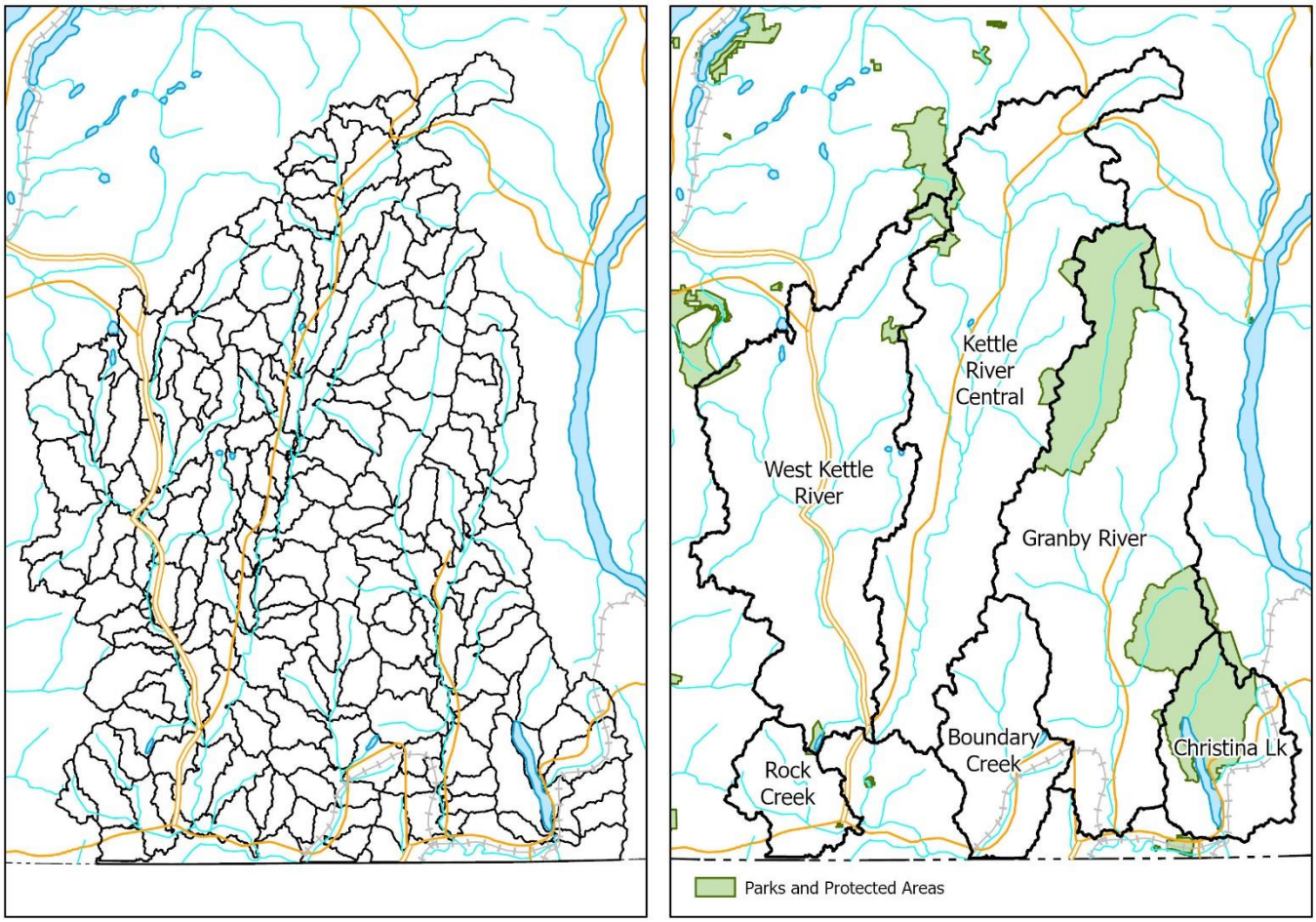


Figure 2. FWA Assessment Watersheds (AWs; left) were the base units used in the analysis, and for some headwater watersheds were the smallest Assessment Units (Level 1 AUs). The major sub-basins (right) were the largest watersheds used. The remaining assessment units (AUs) ranged between these two scales and were the result of a hierarchical nested grouping method that was based on streamflow patterns.

3.2 Indicators

The GIS indicators used to derive the *Streamflow* and *Sedimentation Hazard* ratings are summarised in Table 1. Benchmarks for aquatic ecosystem indicators evolved from a foundation of existing methodology and policy, namely the Watershed Assessment Procedure Guidebook (WAP) under the former *Forest Practices Code Act* (B.C. Ministry of Forests and B.C. Ministry of Environment, 1999). This guidebook has served as standard guidance and policy for the assessment of watersheds by watershed managers since its introduction. Both indicators and benchmarks from the WAP have been updated using current science and research, augmented with subject matter expert opinion to support assessment assumptions and

minimize uncertainty. Identified benchmarks are not limits or "thresholds" for disturbance but provide information and guidance to support management practices which maintain hydrologic, geomorphologic and aquatic ecosystem functions.

Table 1 Overview of GIS indicators used for watershed assessment; see Van Rensen et al. (2020) for more details, including how the indicators were derived.

GIS Indicator	Description
Streamflow Indicators	
Non-forested area	Estimate of naturally non-forested area; % of non-forested area relative to total AU area
BEC Unit Area	Indicator of precipitation, snowpack and forest cover density (score 0-3)
Absence of lakes and wetlands	Area weighted proportion (%) covered by lakes and wetlands
Drainage density ruggedness	Indicator of potential for rapid runoff; stream length (km)/area (km^2) x elevation range (km)
Equivalent Clearcut Area	The extent of disturbance (%), accounting for regrowth and relative hydrologic recovery compared to recent clearcut
Sedimentation Indicators	
Erodible soils	Extent of erodible soils and sediments (%)
Steep coupled slopes	Potential for sediment introduction into a stream from unstable terrain; % area of steep slopes with base 50 m from a stream
Absence of lakes and wetlands	Area weighted proportion (%) covered by lakes and wetlands
Roads close to water	Potential for sediment introduction from surface erosion or mass wasting events related to roads; road length within 50 m of a stream (km/km^2)
Roads on steep coupled slopes	Potential for sediment introduction related to roads on steep slopes; % total road length (km) on steep coupled slopes (km/km^2)
Disturbance on gentle over steep terrain	Extent of logging on gentle slopes (<50%) immediately above steep slopes (>50%) coupled to streams (%)

3.3 Hazard Calculation

Indicators of hazard are derived from GIS indicators using our understanding of hydrologic, climatic and geomorphologic processes occurring on the landscape. Details on the protocols used are available in Van Rensen et al. (2020).

3.3.1 Streamflow Hazard

Streamflow Hazard is the potential for forest disturbance to impact snowmelt-generated peak stream flow. This hazard is derived using a matrix combining the *Hydrologic Response Potential Rating* (an indicator of the natural sensitivity of an area to generate higher peak flows following disturbance) and *Equivalent Clearcut Area* (a disturbance indicator) as shown in Figure 3.

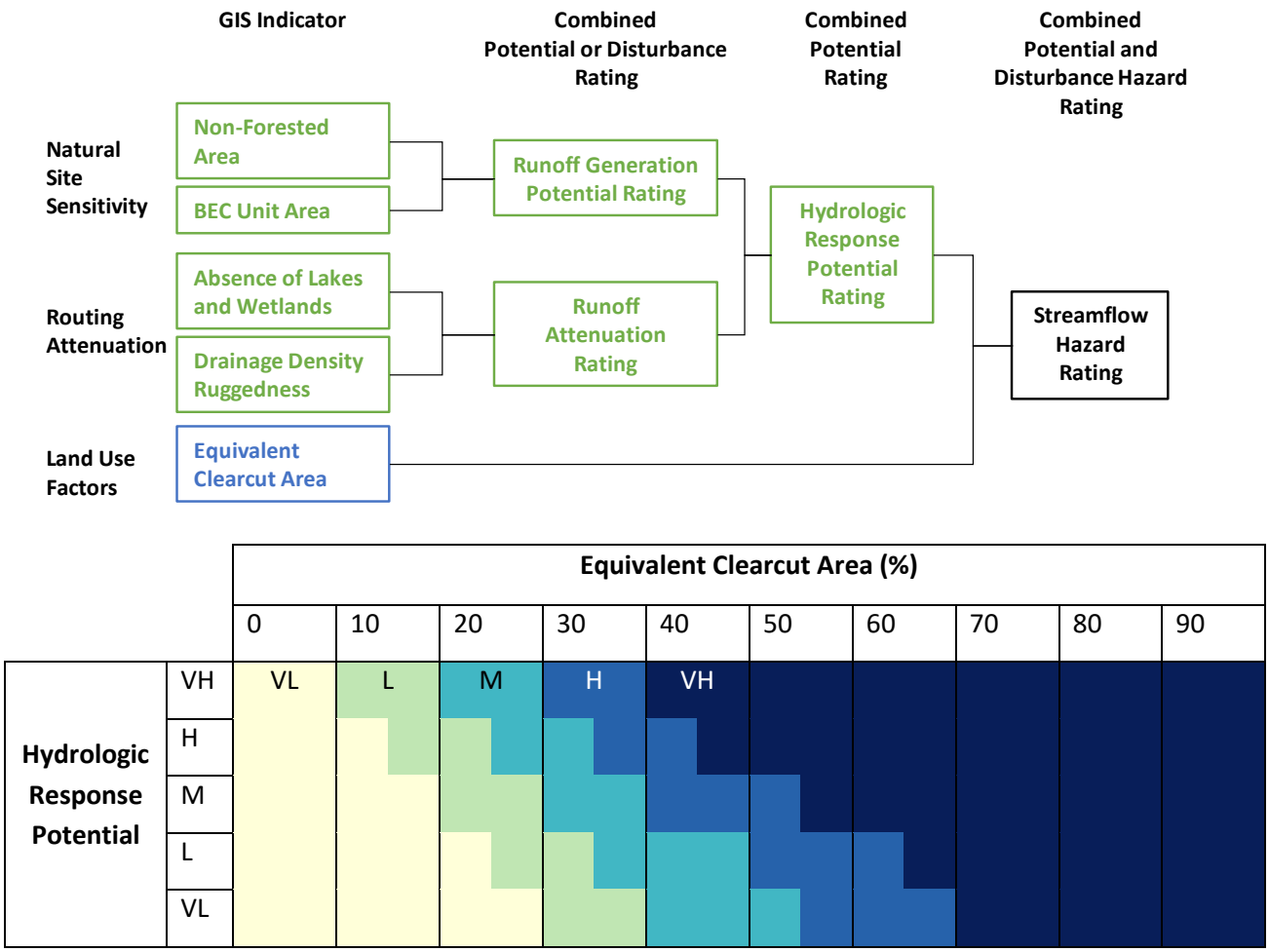
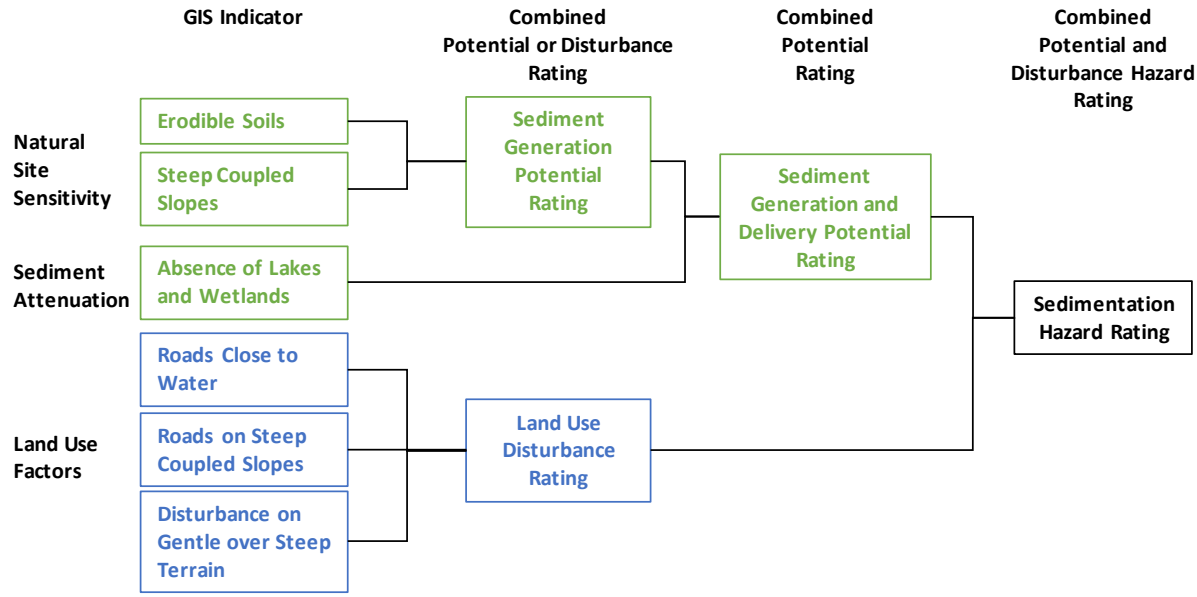


Figure 3. (Top) Flowchart showing GIS Indicators and intermediate ratings used to determine *Streamflow Hazard* ratings for snowmelt-generated peak flows. The procedures combine measures of the natural sensitivity of watersheds (in green) and land use disturbance factors (in blue) to derive the final streamflow hazard ratings. (Bottom) Rating matrix used to derive the *Streamflow Hazard Rating*. Ratings are identified as very low (VL), low (L), moderate (M), high (H) and very high (VH), represented by the gradient from cream to dark blue.

3.3.2 Sedimentation Hazard

Sedimentation Hazard reflects the potential for land use factors to increase the potential for erosion to introduce sediment to the stream channel network and the capacity to transport sediment downstream. The hazard is derived using a matrix that combines the *Sediment Generation and Delivery Potential* rating (an indicator of the natural capacity for erosion and the transport of sediment through the channel

network) and the *Land Use Disturbance* rating (reflecting the potential for impacts from land use and cover changes) (Figure 4).



		Land Use Disturbance Rating				
		Very Low	Low	Moderate	High	Very High
Sediment Generation and Delivery Potential Rating	VH	M	H	VH	VH	VH
	H	L	M	H	VH	VH
	M	VL	L	M	H	VH
	L	VL	VL	L	M	H
	VL	VL	VL	VL	L	M

Figure 4. (Top) Flowchart showing GIS Indicators and intermediate ratings used to derive the *Sedimentation Hazard* rating. The procedures combine measures of the natural sensitivity of watersheds (in green) and land use disturbance factors (in blue) to derive the final sedimentation hazard rating. (Bottom) Rating matrix used to derive the *Sedimentation Hazard Rating*. Ratings are identified as very low (VL), low (L), moderate (M), high (H) and very high (VH), represented by the gradient from cream to dark blue.

3.4 Data

This assessment used GIS data readily available through the B.C. Data Catalogue or products derived from those datasets. For a complete list of input datasets and their limitations, refer to Van Rensen et al. (2020).

3.5 Assessment Limitations

As with any model or GIS analysis, outputs are only as good as the quality and accuracy of the input data and how well hydrologic, biologic and geomorphologic processes are represented. Indicators and ratings are based on our best available knowledge and representation of streamflow/sedimentation response to an environmental or human factor. The land disturbance indicators used represent the major factors known to affect hydrologic and geomorphologic hazards in B.C. (i.e. forest disturbance and roads), which excludes other human activities and natural processes that can impact hydrologic and geomorphologic processes. Additional indicators may be added in the future to assess a wider range of activities if deemed appropriate or necessary.

The results and maps generated from this analysis provide estimates of potential hazards at relatively coarse resolutions. Importantly, conditions that may occur at discrete locations are sometimes integrated to represent conditions at watershed scales. These results can flag potentially high-risk areas to help prioritize projects and planning, but the results of this assessment should not be used alone for operational decisions or to set management targets without further investigation by qualified professionals, including field validation.

The assessment was limited to only the Canadian portion of the Kettle River basin. The assessment methods were designed to use B.C.-specific datasets and therefore were not compatible with readily available datasets from the U.S. Differences in available GIS datasets meant that the required indicators could not be properly derived. However, the analysis focusses on portions of the watershed where resource and restoration activities can practically be managed by the Province.

GIS based assessments are also limited by the input data used. The main input datasets for this analysis were the Vegetation Resource Inventory, a consolidated road dataset and a consolidated harvesting dataset. These datasets were either Provincial Open Data or were derived from them. Using readily available, open-source data allows for transparency and reproducibility of analysis, but the provincial datasets are limited in their scale of application and have some degree of uncertainty around them. The provincial scale of the data also means that more up-to-date regional or local information may not be captured.

More details on limitations to the assessment protocol can be found in Van Rensen et al. (2020).

4 Assessment Results

For each hazard rating, patterns in results are discussed and related to indicators and intermediate ratings. Assessment result maps are also included for each indicator and rating either in the main report or in the appendices and will be referred to in the text.

The appropriate location and size of AU at which to assess these results will vary by user and application; for example, an AU may be identified using a downstream point of interest such as a community or road crossing if the concern is peak flow impacts on infrastructure. Because the number of possible combinations of application and area of interest is so great, only general patterns in results will be discussed in the following sections.

4.1 Streamflow Hazard Results

In this section, patterns in the GIS indicators and the intermediate ratings that were used to derive the final *Streamflow Hazard* rating are discussed at two scales: the AWs and the major sub-basins. However, because the final *Streamflow Hazard* rating represents processes that accumulate across the landscape it can only be presented for assessment units (AUs), which are full watersheds (as opposed to most AWs which are not watersheds). This highlights the fact that flow at any point along a stream is affected by the total cumulative area of land that contributes water to that stream. The *Streamflow Hazard* rating results are reported at various AU levels to show the scaling effects of watershed nesting.

4.1.1 Runoff Generation Potential Rating

The *Runoff Generation Potential* rating is a qualitative indicator of the natural sensitivity of the peak flow generating processes of an area to forest disturbance (Figure 5), determined using the amount of non-forested area, and climate and natural forest density conditions (the latter two factors were represented using Biogeoclimatic Ecosystem Classification (BEC) units) (Figure 6).

The amount of non-forested area was low across the entire Kettle River watershed, with all AWs having less than 30% of their total area classified as alpine, rock, or unproductive brush landcover (Figures A2 and A3). The patterns seen in the *Runoff Generation Potential* rating for the watershed, then, were due to patterns in BEC Unit Area Scores (Figure 6).

The western half of the Kettle River watershed has a slightly drier climate (associated with Montane Spruce (MS) and Interior Douglas Fir (IDF) BEC subzones) compared to the eastern half (where Engelmann Spruce – Subalpine Fir (ESSF) and Interior Cedar Hemlock (ICH) subzones are more prevalent) (Figure 7), resulting in the lowest *BEC Unit Area* scores in the west (Figure 6). Because the amount of precipitation (especially snow) increases as elevation increases, there were a few AWs with high *BEC Unit Area* scores (and resulting high and very high *Runoff Generation Potential* ratings) in the headwaters of the Kettle River Central and Granby River sub-basins.

The effect of this east-west pattern was evident at the scale of the major sub-basins. The West Kettle River, Rock Creek and Boundary Creek sub-basins had a moderate *Runoff Generation Potential* rating, while the Kettle River Central, Granby River and Christina Lake sub-basins had a high rating (Figure 5).

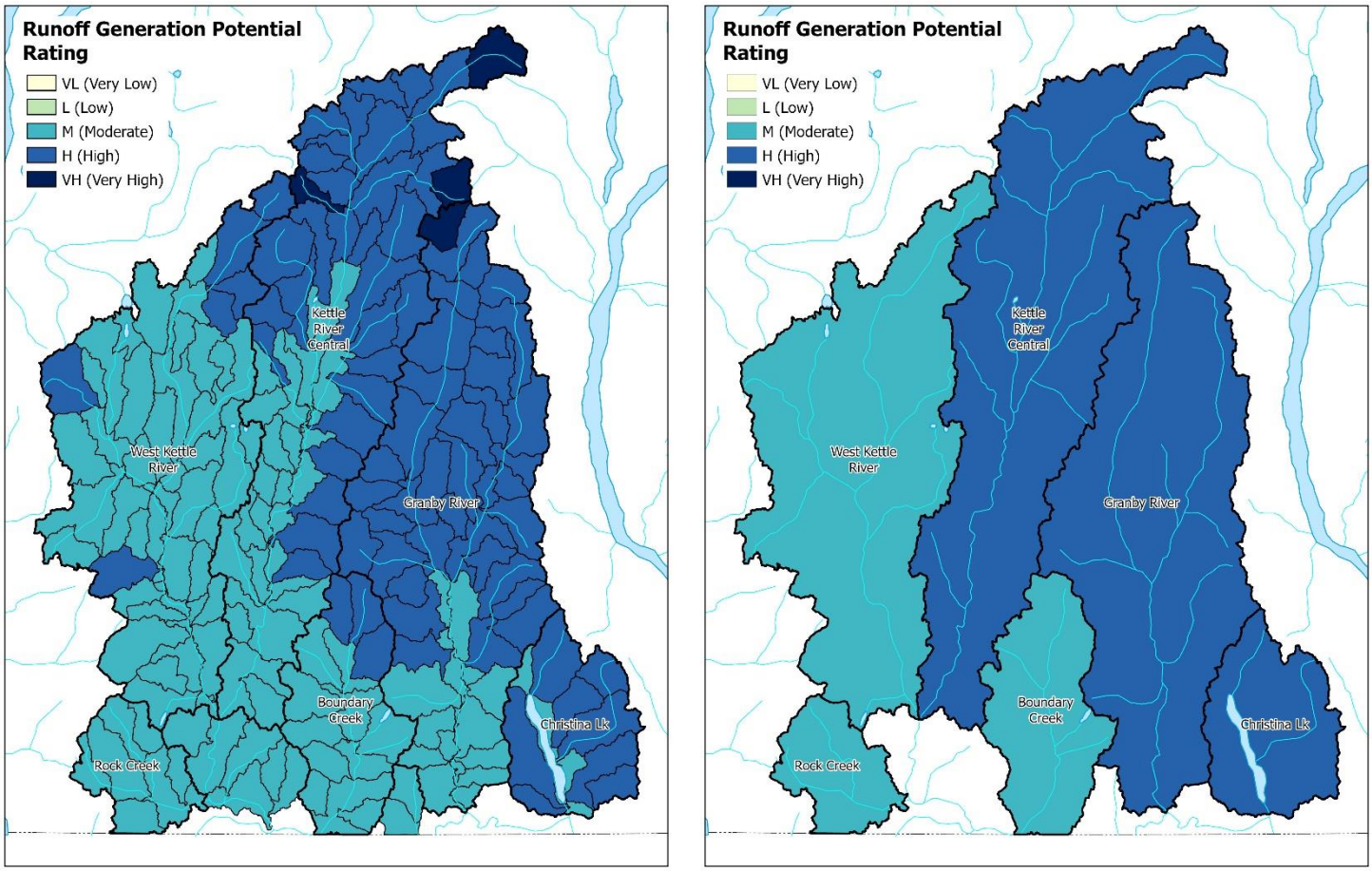


Fig 5. *Runoff Generation Potential* ratings for the base AWs (left) and major sub-basins (right) (See also Figures A12 and A13). Details on the rating can be found in Van Rensen et al. (2020).

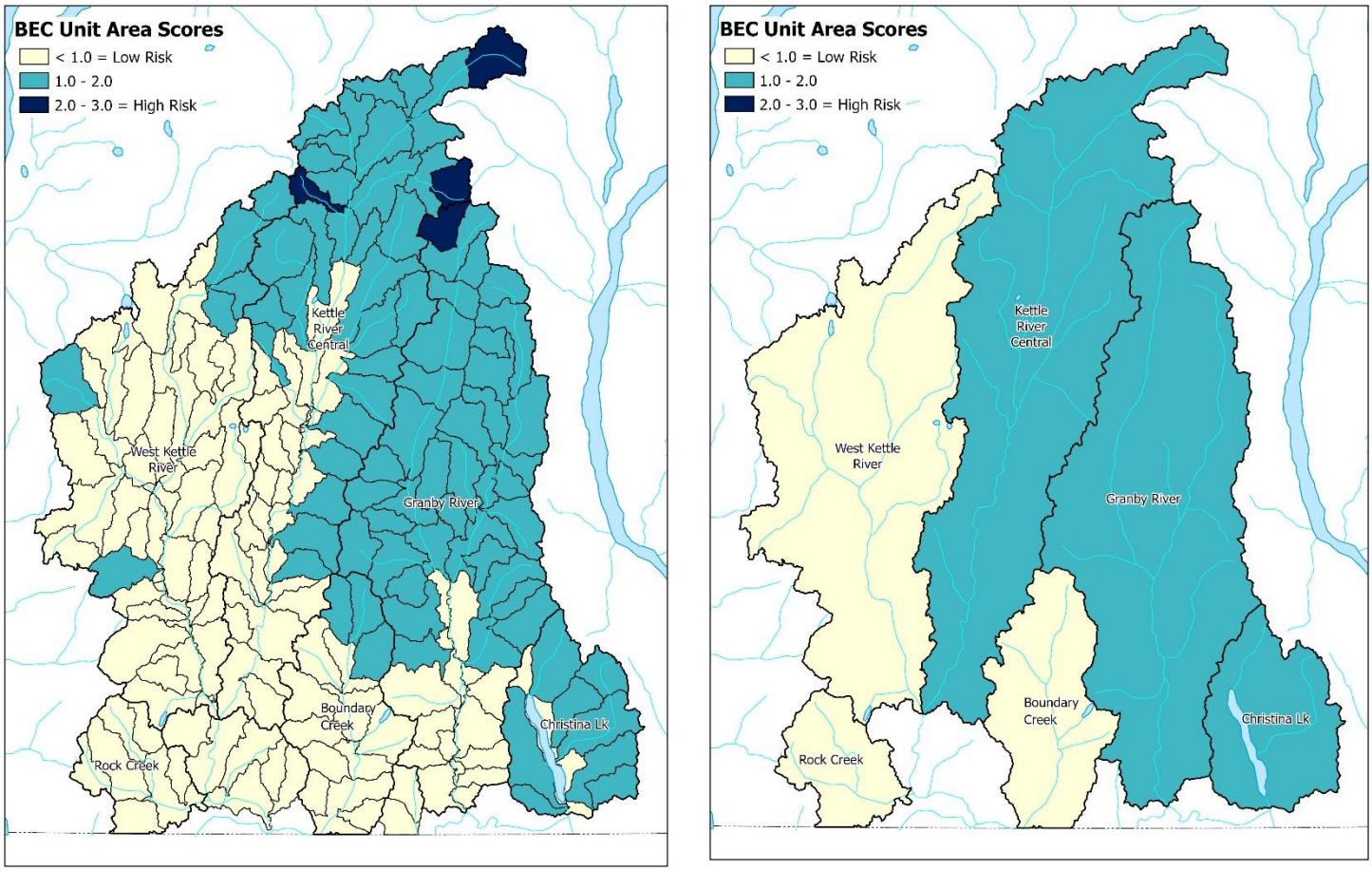


Figure 6. *BEC Unit Area* indicator values for the base AWs (left) and major sub-basins (right) (See also Figures A4 and A5). Details on the indicator can be found in Van Rensen et al. (2020).

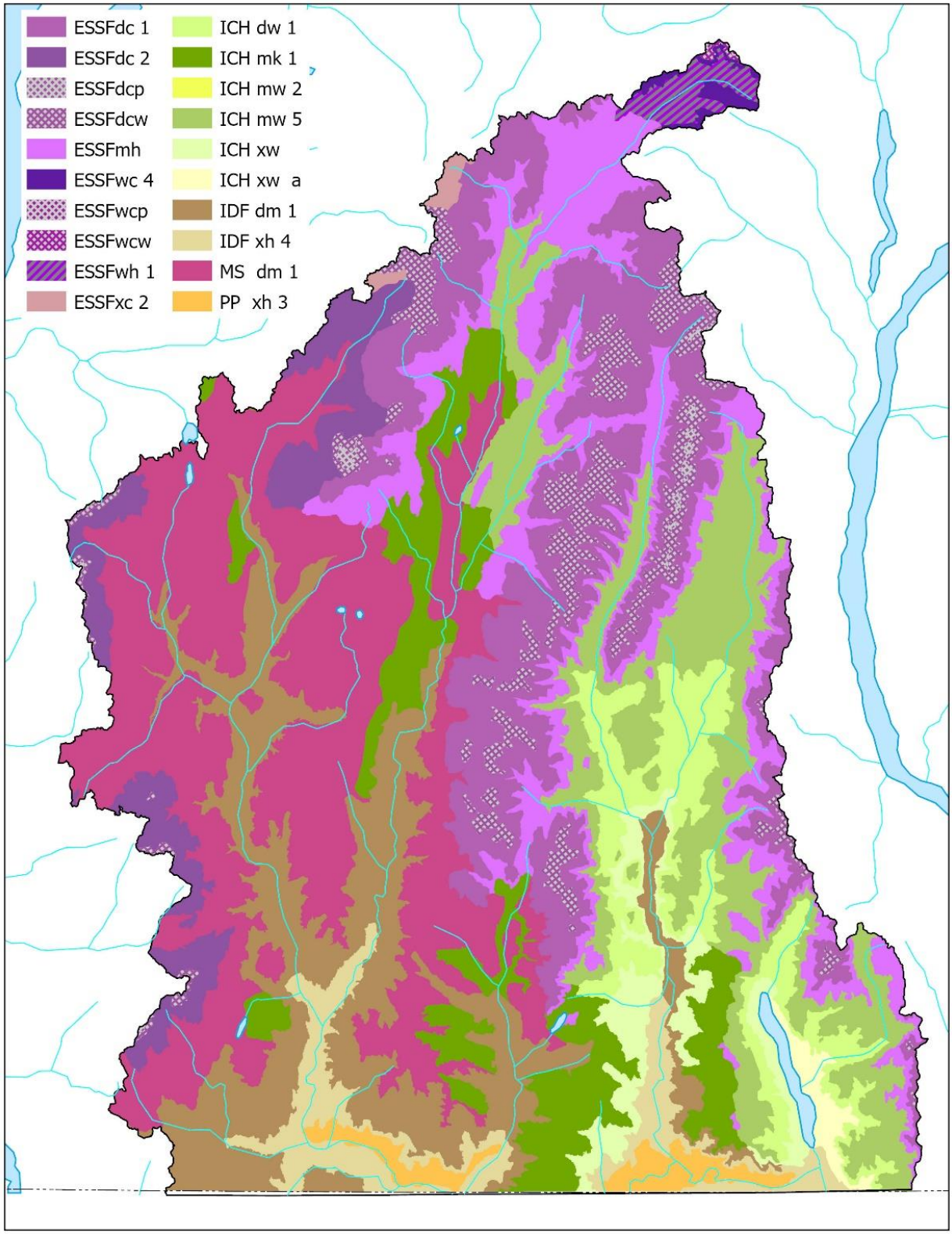


Figure 7. Biogeoclimatic Ecosystem Classification subzone variant classifications for the Kettle River watershed. For subzone definitions see MacKillop and Ehman (2016).

4.1.2 Runoff Attenuation Rating

Runoff attenuation refers to how efficiently hillslope and stream runoff is slowed, captured and stored as it is routed through the watershed (Figure 8). The potential for runoff attenuation was assessed using the *Absence of Lakes and Wetlands* indicator (which represents the lack of capacity for water storage in surface water bodies), the stream channel network density, and how steep the slopes are (the latter two metrics were combined in the *Drainage Density Ruggedness* (DDR) indicator).

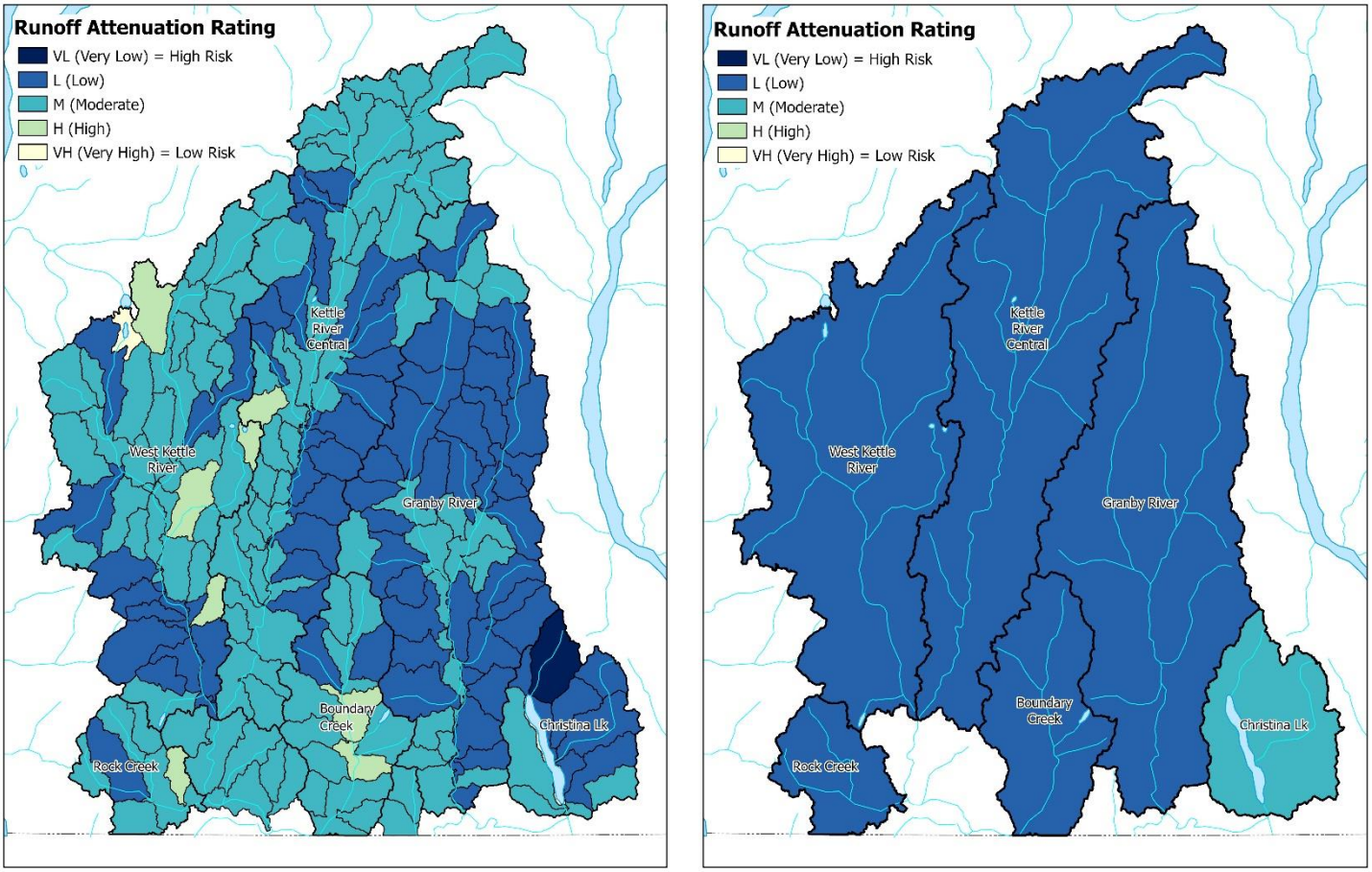


Figure 8. *Runoff Attenuation* ratings for the base AWs (left) and major sub-basins (right) (See also Figures A14 and A15). The colour scheme used reflects the potential for peak flow generation, where a low attenuation rating is associated with the potential for higher peak flows. Details on the rating can be found in Van Rensen et al. (2020).

There is relatively little capacity for surface water storage in the Kettle River watershed because there are few lakes and wetlands, especially at low elevation. One exception was Idabel Lake in the northern headwaters of the West Kettle River where the associated AW had an *Absence of Lakes and Wetlands* score of > 6 (indicating high attenuation capacity due to surface storage) (Figure 9). Fewer than a dozen of the AWs had moderate amounts of lakes and wetlands; the majority of the watershed had low levels of attenuation. The capacity for storage in Christina Lake caused the *Absence of Lakes and Wetlands*

indicator in its major sub-basin to be moderate. This indicator did not address the actual storage capacity of the lakes, wetlands or reservoirs, just their presence.

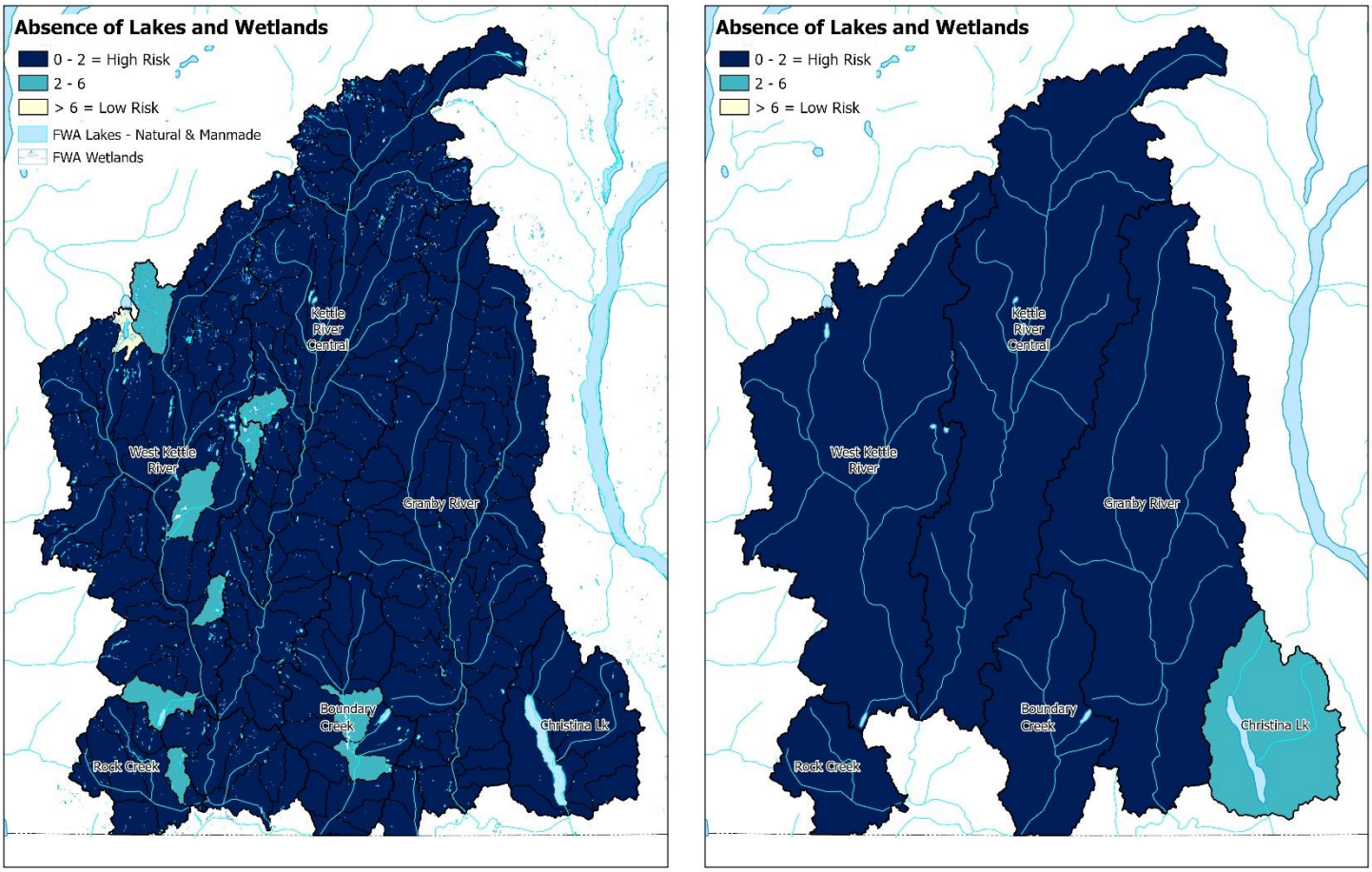


Figure 9. *Absence of Lakes and Wetlands* indicator for the base AWs (left) and major sub-basins (right). These results are based on the Freshwater Atlas natural and manmade lakes and wetlands (See also Figures A6 and A7). The colour scheme used reflects the potential for peak flow generation, where a low absence rating is associated with the potential for higher peak flows. Details on the indicator can be found in Van Rensen et al. (2020).

The relatively low relief of this area resulted in low scores for the *Drainage Density Ruggedness* indicator across more than half of the watershed (Figure 10). Most of the AWs in the West Kettle River sub-basin were scored as low (<2000), with the exception of the lowest elevations near the community of Westbridge. Much of the west-facing slope in the Kettle River Central sub-basin and the majority of the Granby River sub-basin had moderate DDR levels (2000-4000). The Sandner Creek L1 AU in the Christina Lake sub-basin had a high value (>4000) for the DDR indicator; the combination of relatively steep terrain and relatively dense stream channel network of Sandner Creek moved the indicator value over the 4000 threshold.

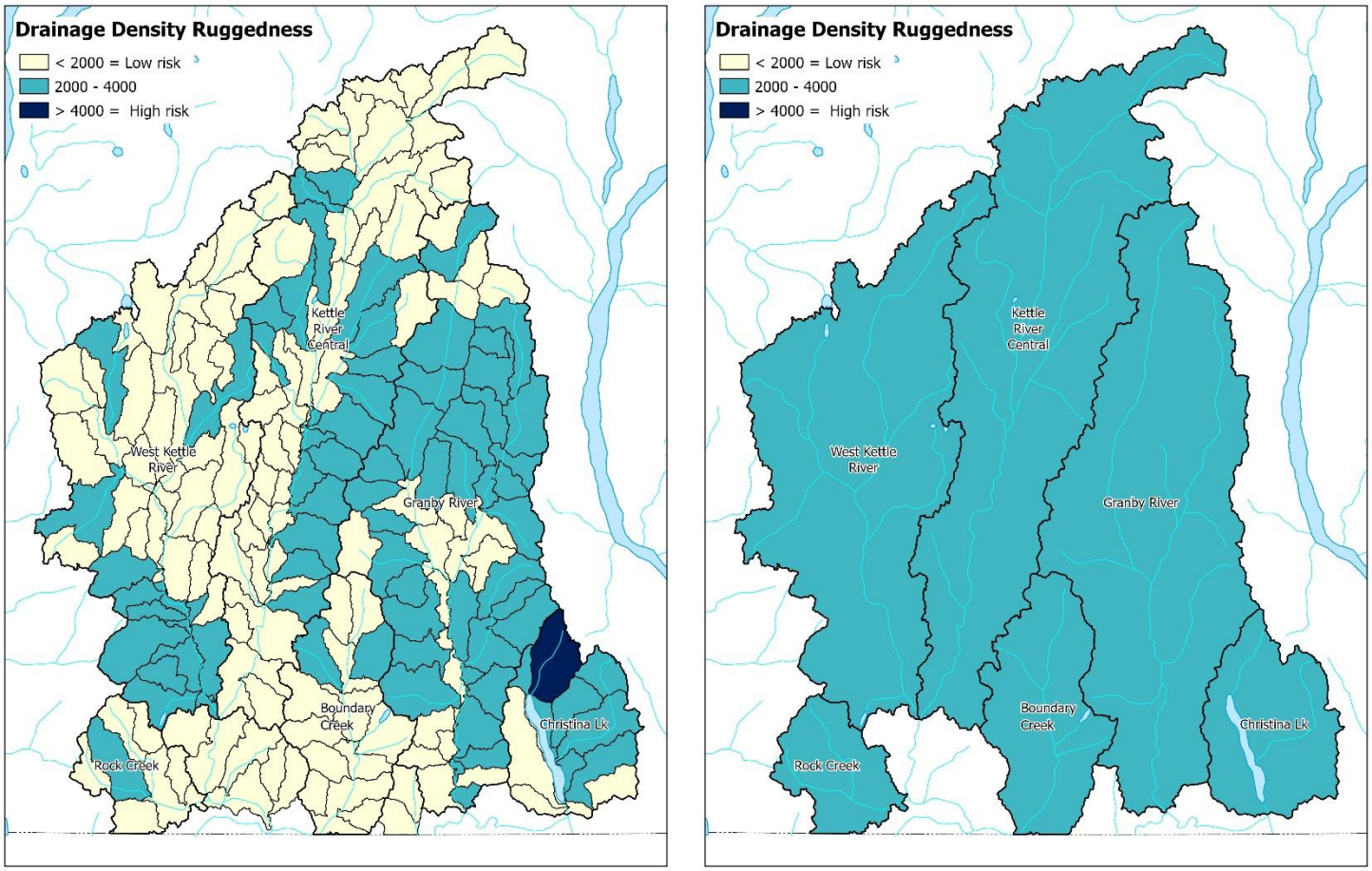


Figure 10. *Drainage Density Ruggedness* indicator at the AW scale (left) and the major sub-basins (right) (See also Figures A8 and A9). Details on the indicator can be found in Van Rensen et al. (2020).

Because of the relative uniformity of results for the *Absence of Lakes and Wetlands* indicator across the Kettle River watershed, the patterns seen in the *Runoff Attenuation* rating were strongly influenced by variability in the DDR indicator (Figures 8 and 10). The AWs with the greatest attenuation potential were concentrated in the western half of the Kettle River watershed, especially in the West Kettle River sub-basin. The low attenuation capacity in the eastern part of the Kettle River watershed, in the West Kettle River sub-basin near Westbridge, and across a wide swath of the Kettle River Central sub-basin make these areas more vulnerable to generating peak flows following forest disturbance.

The integrated effect can be seen when we look at the results for the major sub-basins. At these scales, all of the major sub-basins had small areas for surface water storage and moderate DDR values, which resulted in low overall attenuation capacities. The exception was the Christina Lake sub-basin, which had a moderate Runoff Attenuation rating because of moderate surface storage in lakes and wetlands, and moderate DDR indicator values (Figure 8).

4.1.3 Hydrologic Response Potential Rating

The *Hydrologic Response Potential* rating is a qualitative expression of the potential for increased runoff to be generated following forest disturbance and for it to be delivered downstream. It considers the natural conditions that lead to higher peak flow, specifically climatic and forest cover factors, hydraulic connectivity and streamflow attenuation. The *Hydrologic Response Potential* is a combination of the *Runoff Generation Potential* and *Runoff Attenuation* Ratings (Figure 3).

The generalised east-west pattern in climatic conditions (and therefore *BEC Unit Area* scores) was evident in the *Hydrologic Response Potential* rating results for the AWs and was superimposed with more localised variations in DDR and the potential for surface water storage in lakes and wetlands (Figure 11). At the scale of the major sub-basins, these spatial patterns were integrated so that all sub-basins had a high *Hydrologic Response Potential* rating.

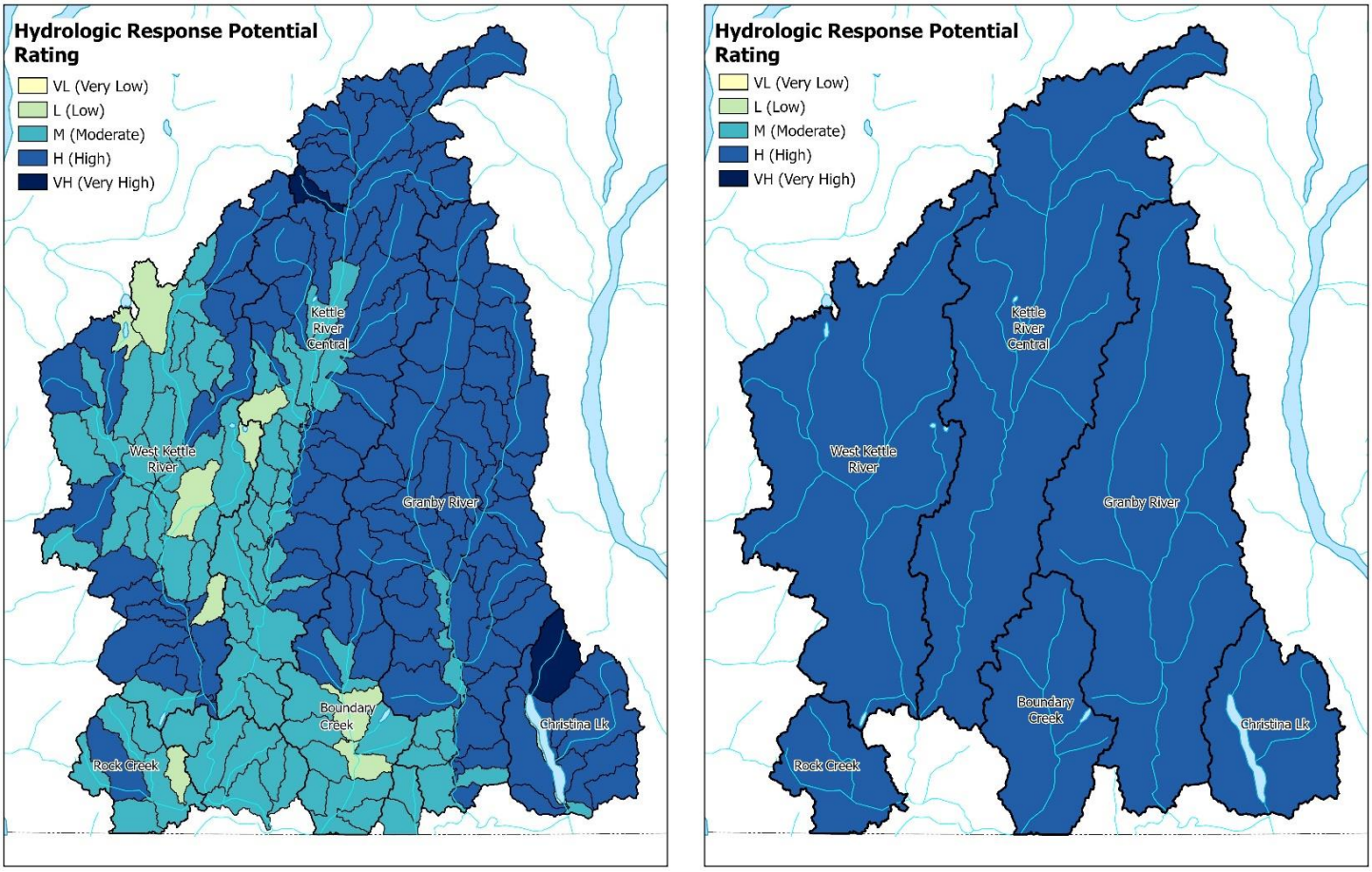


Figure 11. *Hydrologic Response Potential* ratings for the base AWs (left) and major sub-basins (right) (See also Figures A16 and A17). Details on the rating can be found in Van Rensen et al. (2020).

4.1.4 Equivalent Clearcut Area

Forest cover disturbance can have a strong influence on snowmelt-driven peak flows in most of B.C. and is represented in the assessment by the *Equivalent Clearcut Area* (ECA) indicator. ECA is used to determine the area over which a reduction in forest cover has occurred, expressed relative to the hydrologic impact of a recent clearcut or where land has been cleared of vegetation cover. Although streamflow response to forest disturbance varies between watersheds, in general there are measurable changes in streamflow at ECA values greater that 20-25% (Winkler and Boon, 2017).

Most of the AWs with very low ECA values in the east part of the Kettle River watershed were associated with larger parks and protected areas (i.e. Graystokes, Granby and Gladstone Provincial Parks), where anthropogenic disturbance is restricted but where natural disturbance may not be suppressed (e.g. wildfire, insect outbreaks) (Figures 12 and 13). Fire, insect outbreaks, and land development created the largest continuous disturbance areas.

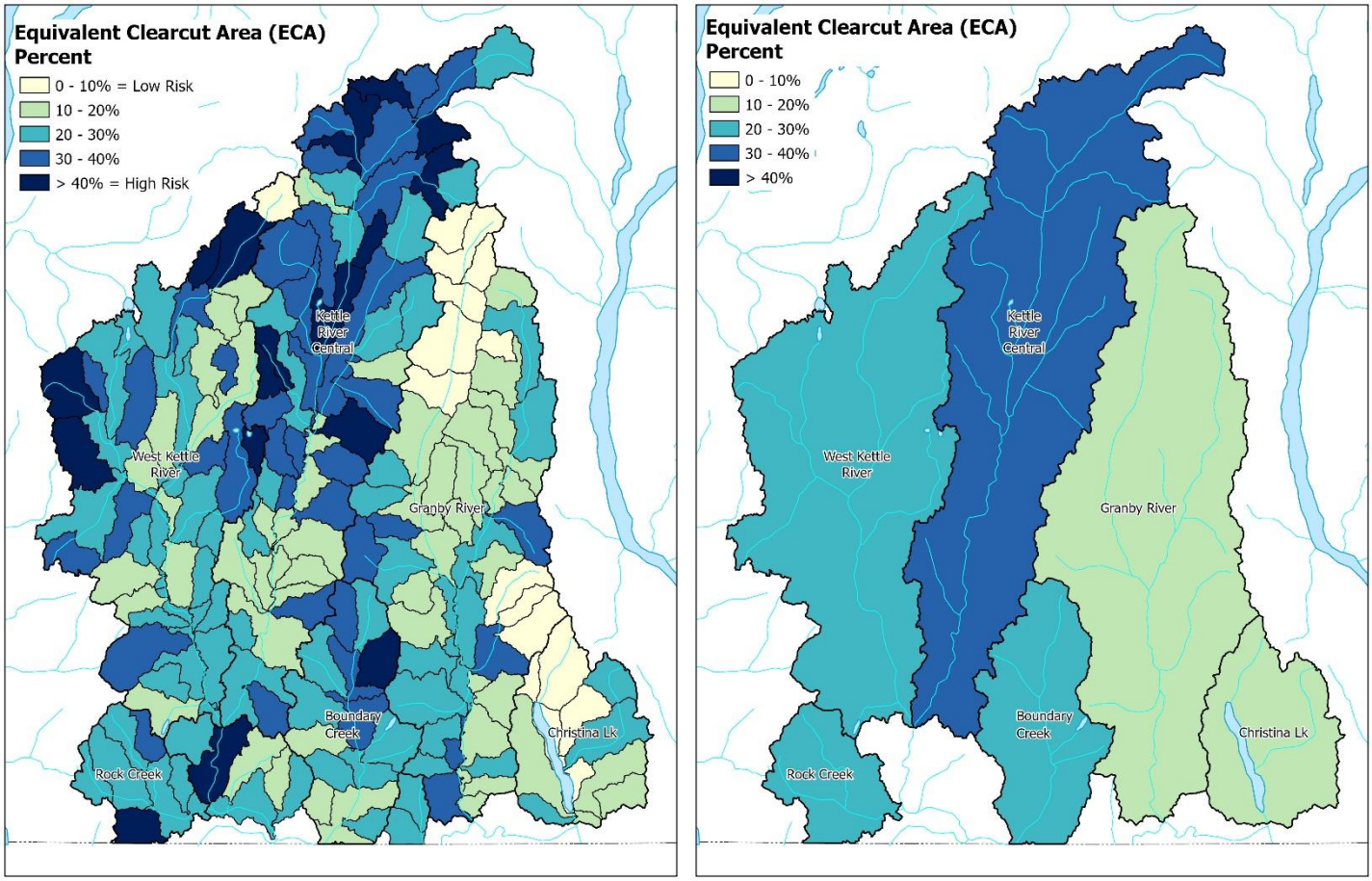


Figure 12. Equivalent Clearcut Area indicator values for the base AWs (left) and major sub-basins (right) (See also Figures A10 and A11). Details on the indicator can be found in Van Rensen et al. (2020).

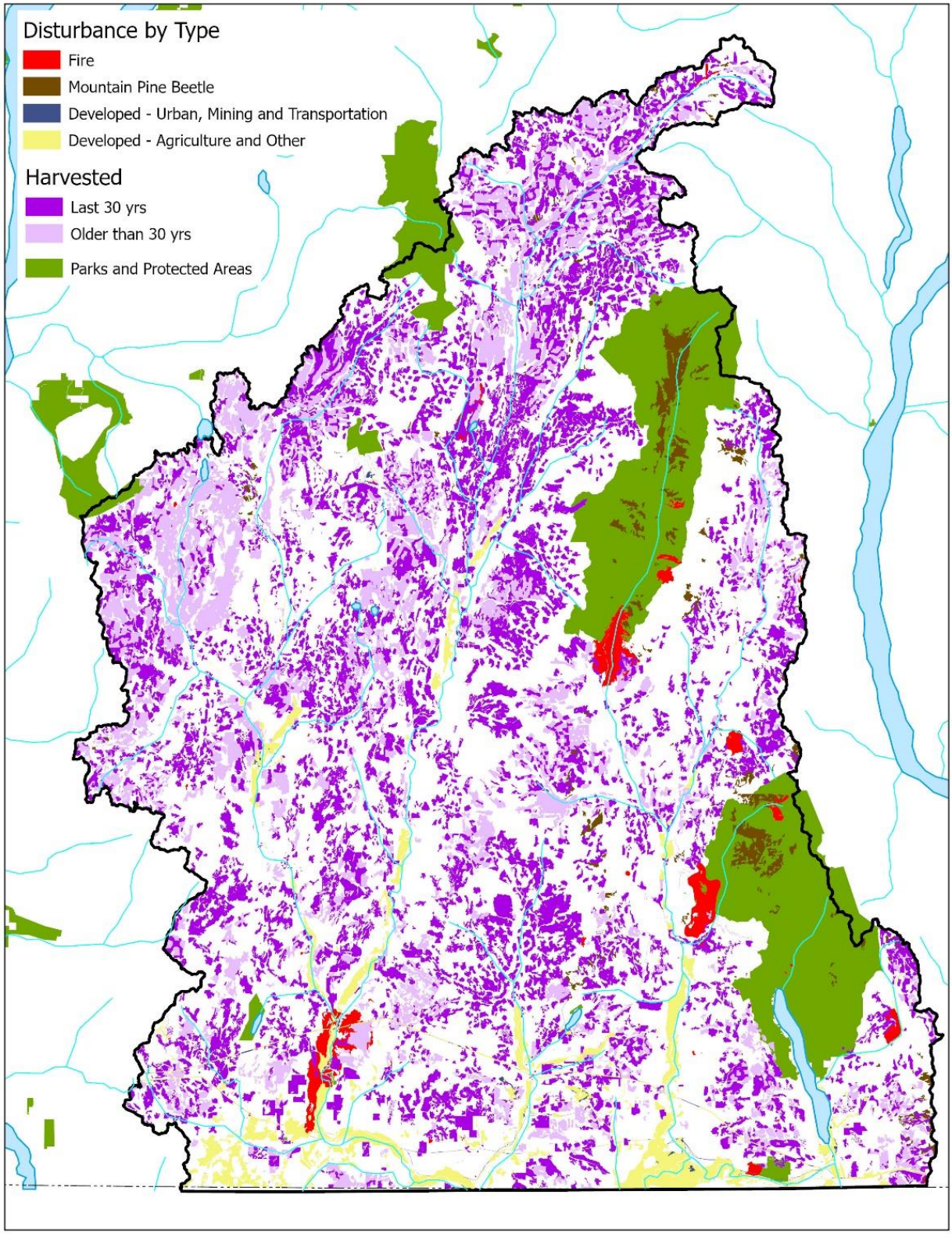


Figure 13. Land use factors and disturbances that influence ECA percentages across the Kettle River watershed. Logged areas on this map don't distinguish between harvest type (e.g. selectively logged vs. clearcut) but these distinctions were included in analysis. Figure 15 shows the ECA factors for these disturbed areas, which considers regrowth (tree height) and the presence of leave/seed trees.

Developed land, which includes land cleared for agricultural production, was largely concentrated in the southern part of the Kettle River watershed in the valley bottoms. Permanently developed land, which includes agricultural land, urban areas, mining operations and right-of-way features, were assigned a hydrologic recovery level of zero because they were assumed to have no tree or vegetation cover. The high ECA indicator value in the Baker Creek AW in southwestern Rock Creek was the result of this developed landbase. The combined influences of developed land and wildfire resulted in a high ECA value along Kettle River near the community of Westbridge. Other disturbance types were individually smaller in area and scattered across the landscape. The cumulative area classified as harvested far exceeded other types of disturbance in the Kettle River watershed.

The ECA indicator includes consideration of regrowth and the type of harvest activity (e.g. selective harvesting, clearcut logging) through the assignment of an ECA factor to each harvested or naturally disturbed area (Figure 14). The highest ECA factor scores (and therefore the highest level of disturbance) were assigned to recent clearcuts and high intensity fires. A forest stand was considered to be more than 90% recovered hydrologically when the mean tree height was 16-17m (Winkler and Boon 2015), which in this area would on average occur within 25-35 years of the disturbance; however, in less favourable growing conditions this estimated age would be higher.

It should be noted that areas where post-fire or post-insect outbreak salvage logging occurred were identified as harvested. These areas are identifiable only by magnifying the maps to see harvested polygons surrounded by fire or insect-affected forests (for example, around Nevertouch Lake in the central part of the Kettle River Central sub-basin, where salvage logging occurred following fire). Because standing timber is removed during these operations, it was appropriate to use the same hydrologic recovery curves as were used for conventional logging.

At the scale of the major sub-basins, the Granby River and Christina Lake sub-basins had ECA indicator values greater than 20%, while the Rock Creek, Boundary Creek, West Kettle River had ECA values between 20 and 30%. The Kettle River Central sub-basin had the highest ECA value between 30 and 40 percent (Figure 12).

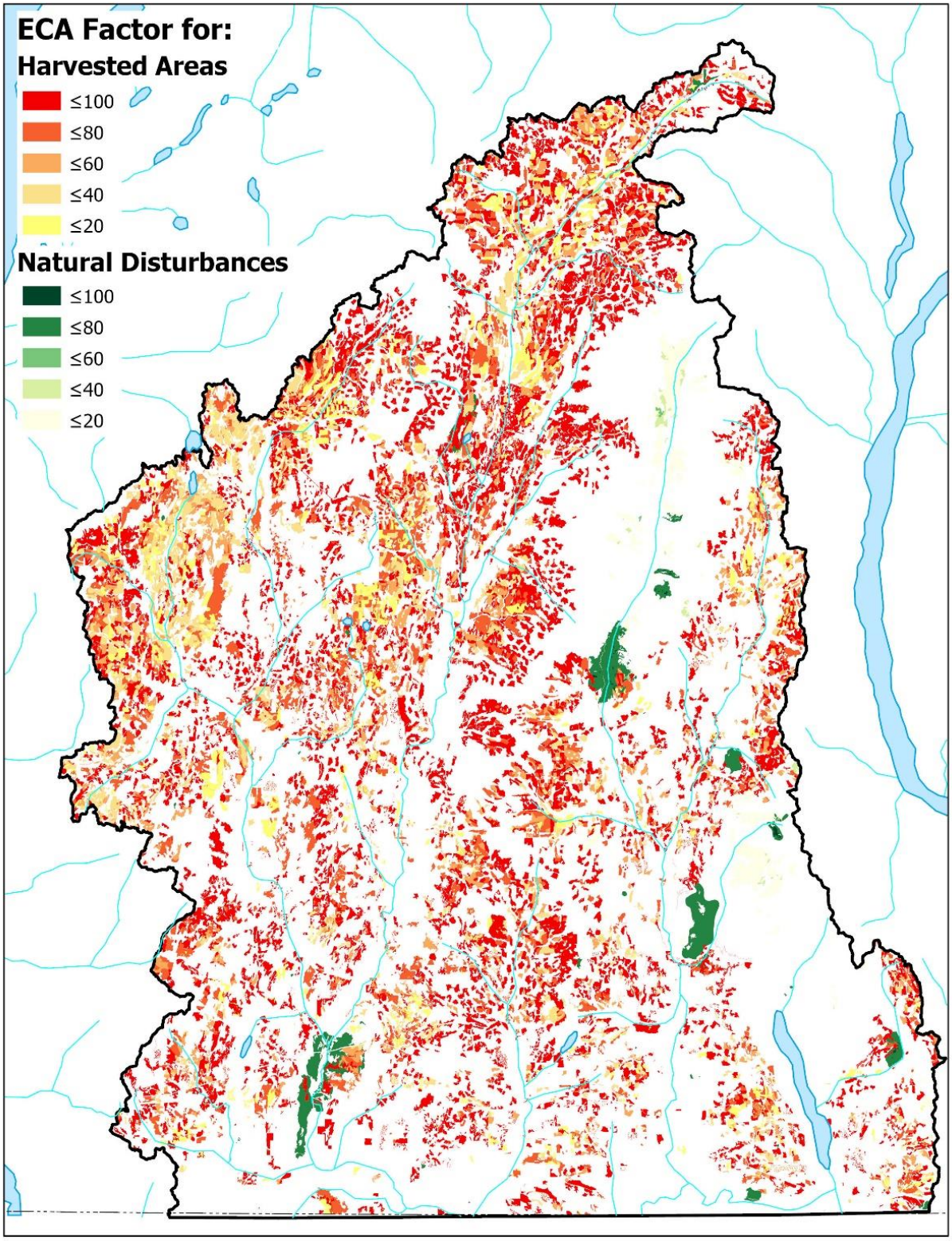


Figure 14. ECA factors for the harvested and naturally disturbed (insect and fire) areas. ECA factors were used to calculate the final ECA percent; the higher the factor, the higher the ECA. Details on the ECA factor can be found in Van Rensen et al. (2020).

4.1.5 Streamflow Hazard Rating

Wetter and more densely forested AUs that were steep and had little runoff attenuation were more likely to respond hydrologically to forest cover loss and have a higher *Streamflow Hazard* rating. Because this final hazard rating represents the effects of conditions and processes that accumulate within a watershed, the results for the *Streamflow Hazard* rating are only presented for the hydrologically-defined assessment units (AUs) (not for the individual AWs). Results are presented in a series of maps, showing ratings for the smallest watersheds (L1 AUs) and progressively larger watersheds (L2-L4, L7-L9, L14-L16 and L24, 29 and 39) up to the scale of the major sub-basins (Figure 15). This will allow the reader to see how the results progressively scale as watershed area increases.

At the scale of the major sub-basins, *Streamflow Hazard* was moderate in the West Kettle River, Kettle River Central, Rock Creek and Boundary Creek sub-basins, low in the Granby River sub-basin and very low in the Christina Lake sub-basin (Figure 15, bottom right). Looking at the Kettle River Central basin, the smaller AUs (L1 to L9) with High and Very High streamflow ratings that increased the hazard for the sub-basin are evident. These were mainly concentrated in the northern half of the sub-basin (Figure 15, top).

Insight into what influenced the *Streamflow Hazard* results for specific areas of interest can be gained by looking at the separate GIS indicators. For example, the AWs in the north part of the Kettle River Central sub-basin had similar climate and topography. The indicator results and ratings for *Hydrologic Response Potential*, which consider natural sensitivity to peak flow generation and routing attenuation indicators, were similar. The differences seen in the *Streamflow Hazard* rating, then, were driven by differences in *Equivalent Clearcut Area* (ECA). ECA was calculated using harvested and disturbed areas and estimates of hydrologic recovery. More recent harvest and permanently disturbed areas had a higher ECA factor (i.e. less hydrologic recovery) leading to a higher ECA percent. The higher ECA values calculated in the northern portion of the Kettle River Central sub-basin were the result of combined effects of timber harvest and natural disturbance with subsequent salvage logging, especially in the last 30 years.

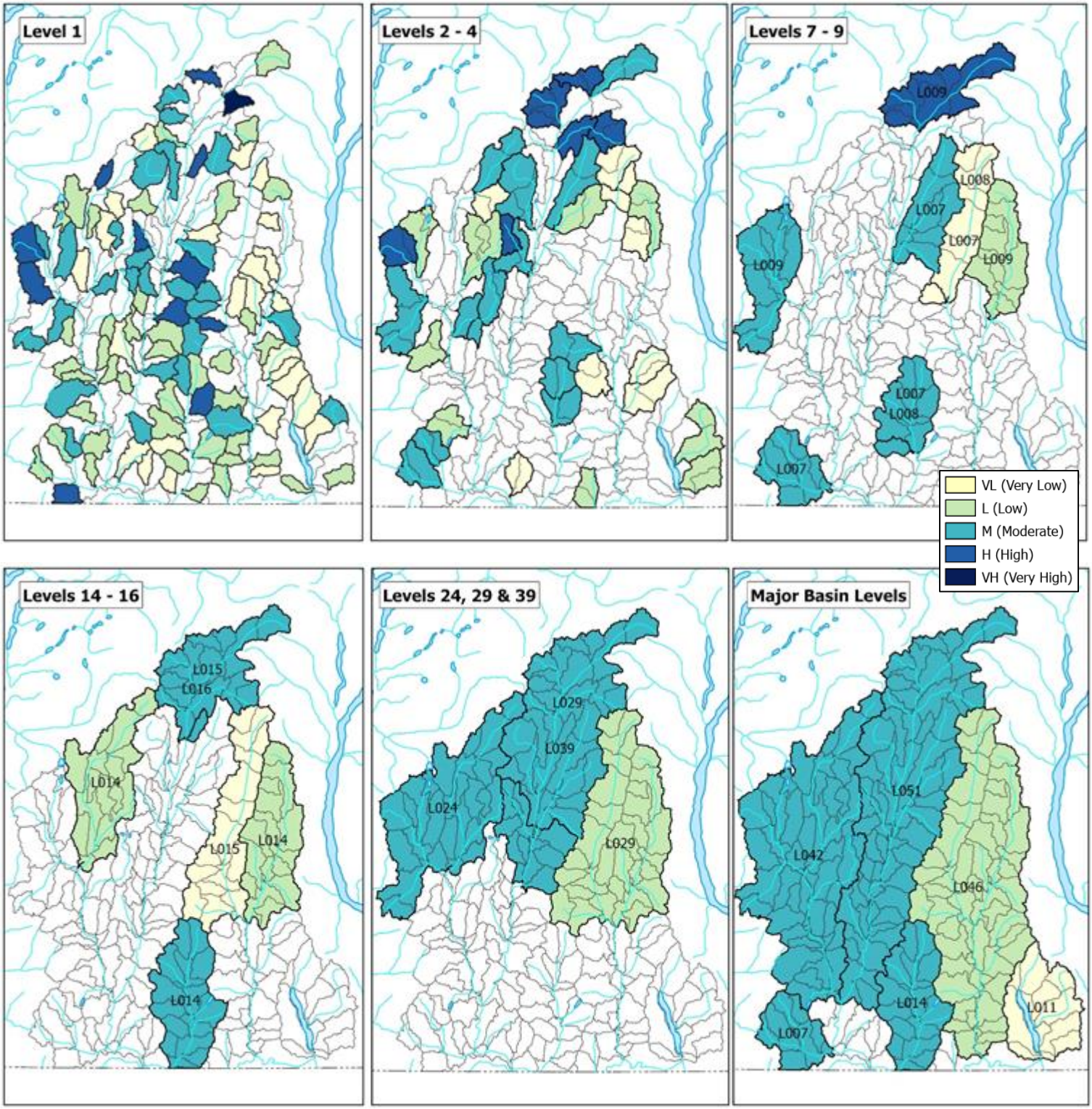


Figure 15. ***Streamflow Hazard*** **rating results at varying scales from smallest AU (L1, top left) to the major sub-basins (bottom right). AU levels are labelled. AWs are outlined, and a bolder line is used to outline the AUs (See also Figures A18-A23). Details on the rating can be found in Van Rensen et al. (2020).**

4.2 Sedimentation Hazard Results

The *Sedimentation Hazard* rating combines the natural sensitivity to erosion and sediment transport in a watershed with the potential impacts of road and forestry-related sources (Figure 4). As with the *Streamflow Hazard* rating, patterns in the GIS indicators and the intermediate ratings that were used to derive the final *Sedimentation Hazard* rating are discussed at two scales: the AWs and the major sub-basins. However, because the final *Sedimentation Hazard* rating represents processes that accumulate across the landscape it can only be presented for assessment units (AUs), which are full watersheds (as opposed to most AWs which are not watersheds). This highlights the fact that flow (and therefore sediment transport) at any point along a stream is affected by the total cumulative area of land upstream. The *Sedimentation Hazard* rating results are reported at various AU levels to show the scaling effects of watershed nesting.

4.2.1 Sediment Generation and Delivery Potential Rating

The *Sediment Generation and Delivery Potential* rating assessed the natural sensitivity to erosion and introduction of sediment into the stream channel network, and the ability of the stream network to transport sediment downstream. It combined an intermediate rating (the *Sediment Generation Potential*) and the *Absence of Lakes and Wetlands* indicator.

The GIS indicators used to determine the *Sediment Generation Potential* rating were the extent of erodible soils and the presence of steep slopes near streams. Most of the soils and sediments in Kettle River watershed were not considered to be highly vulnerable to erosion, with the exception of large deposits of glaciofluvial and glaciolacustrine sediments found in the West Kettle River and Rock Creek sub-basins and exposed deposits along some stream channels (Figure 16 and Figure B2). When the results were integrated at the scale of the major sub-basins, however, the total extent of erodible sediments was low, resulting in *Erodible Soils* indicator values of less than 10%. The exception was the Rock Creek sub-basin which had a value greater than 20% (Figure B3).

The generally gentle topography of this region produced few areas where steep slopes were near streams (Figure 17). There were a number of areas where steep coupled slopes were more common, notably in the Christina Lake sub-basin, across east-facing slopes in the upper Granby River sub-basin (mostly in Granby Provincial Park) and in the south-central portion of the Granby River sub-basin. When the assessment was done at the scale of the major sub-basins, the percent of the major sub-basin areas with steep coupled slopes was less than 10%, except Christina Lake which had 11-20%.

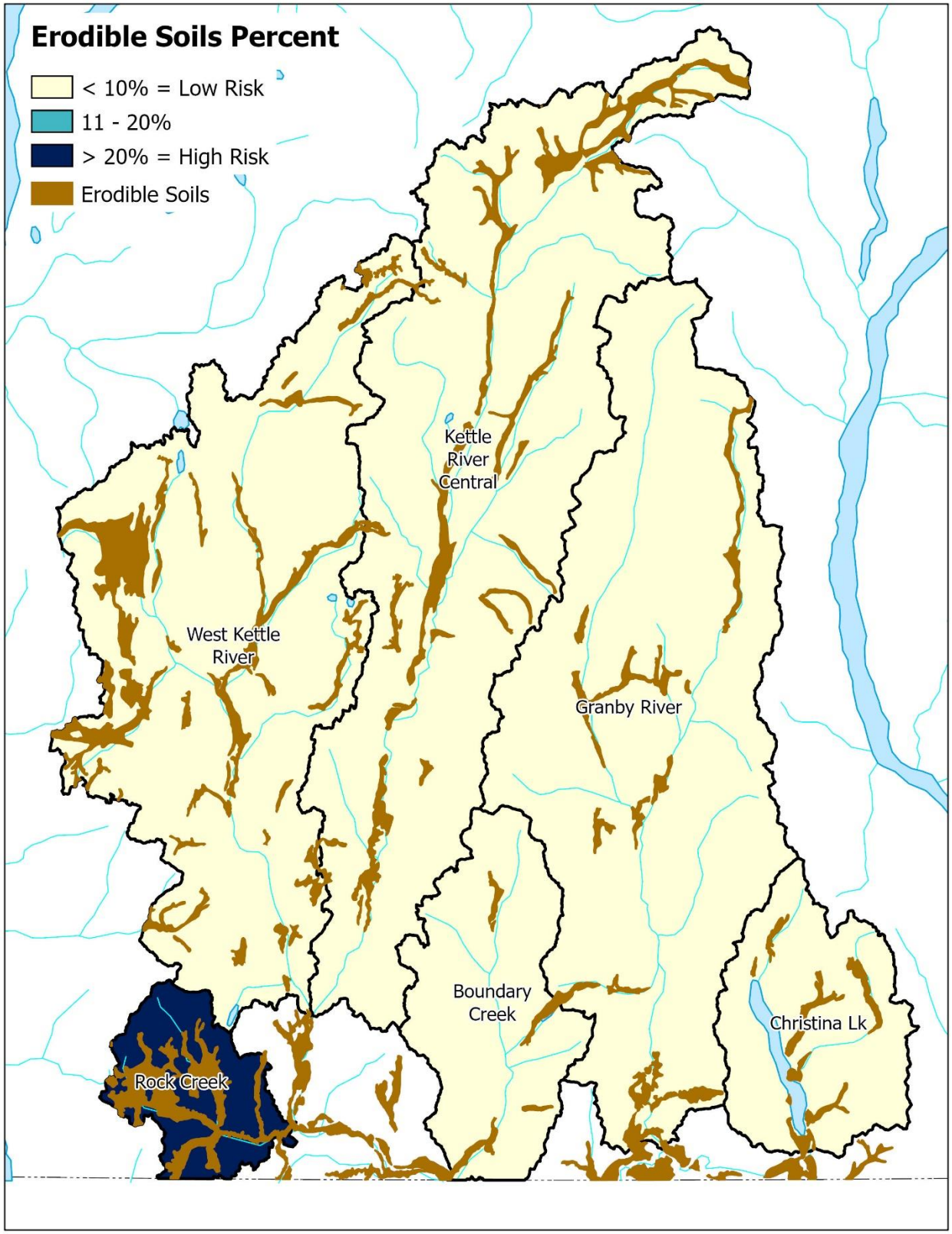


Figure 16. ***Erodible Soils*** **indicator results showing the distribution of erodible soils across the Kettle River watershed. Erodible soils include glaciofluvial and glaciolacustrine sediments.**

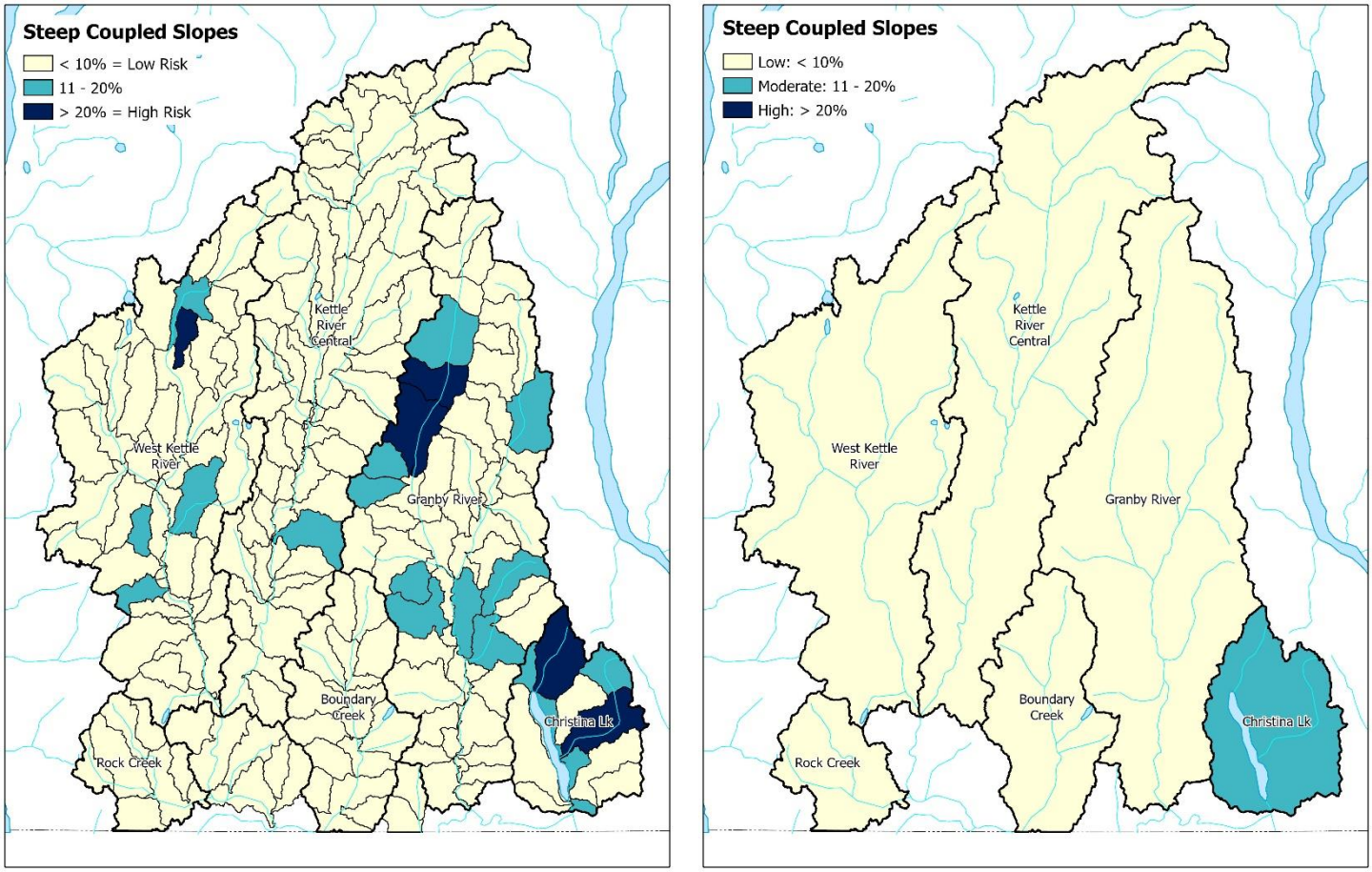


Figure 17. *Steep Coupled Slopes* indicator results for the base AWs (left) and major sub-basins (right) (See also Figures B4 and B5). Details on the indicator can be found in Van Rensen et al. (2020).

Patterns in the *Sediment Generation Potential* rating reflect the combined influences of the extent of erodible soils and the presence of steep coupled slopes (Figure 18). AWs with moderate *Sediment Generation Potential* ratings occurred throughout the Kettle River watershed, but there were clusters on the west side of the West Kettle River sub-basin and in the Rock Creek sub-basin. The upper Granby River and Christina Lake sub-basins had two or more AWs with moderate rating. At the scale of the major sub-basins, results indicated moderate ratings for the Rock Creek sub-basin but low or very low ratings for the remaining areas.

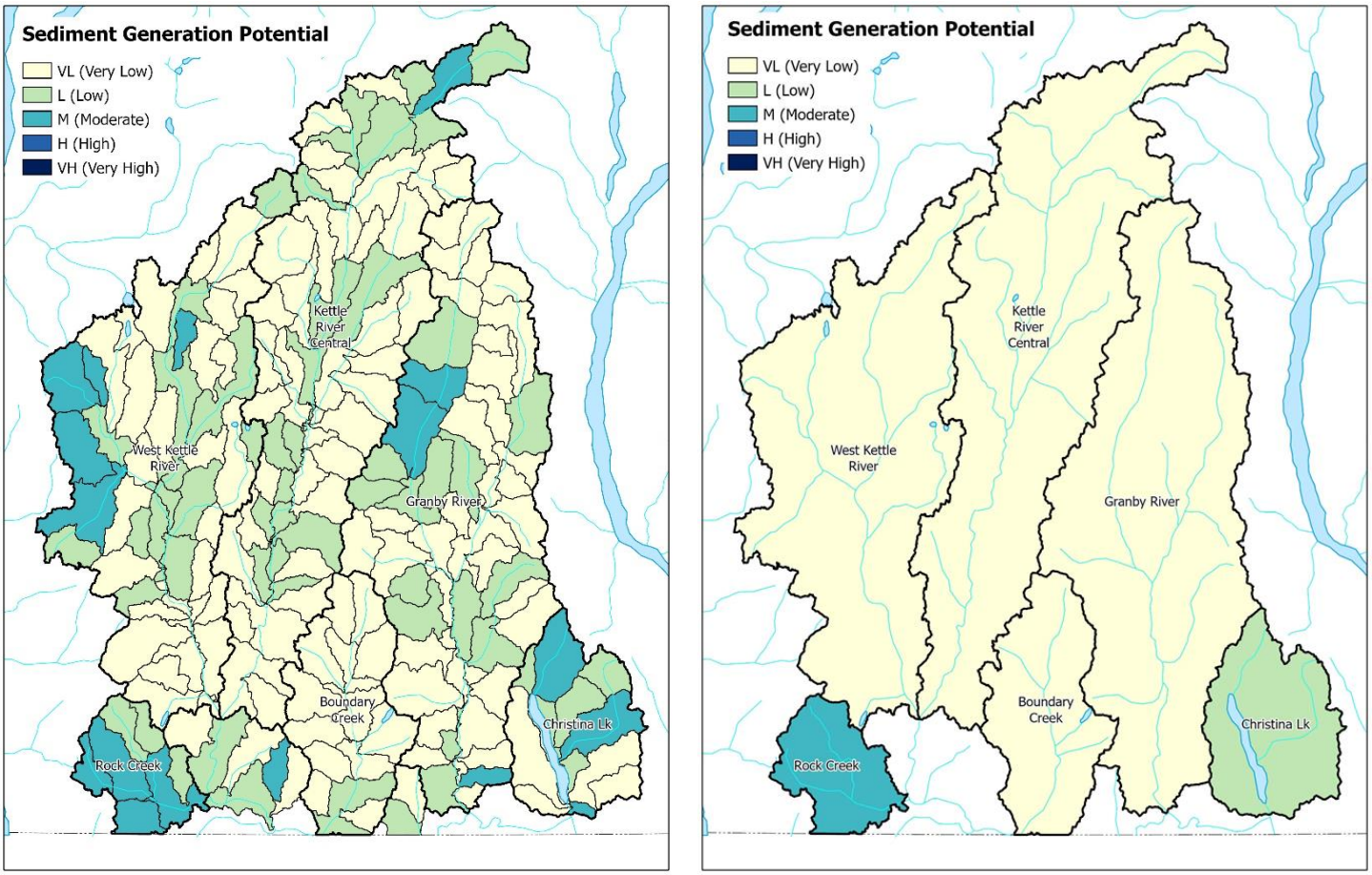


Figure 18. *Sediment Generation Potential* rating results for the base AWs (left) and major sub-basins (right) (See also Figures B14 and B15). Details on the rating can be found in Van Rensen et al. (2020).

As with streamflow, sediment movement in streams can be attenuated by lakes, ponds, wetlands and anthropogenic reservoirs. The same *Absence of Lakes and Wetlands* indicator values that were used in the *Streamflow Hazard* rating were adopted here to reflect the sediment transport attenuating characteristics of an area.

There are few lakes and wetlands across the Kettle River watershed that would slow streamflow and prevent sediment from being transported downstream (Figures B6 and B7). Exceptions are Christina Lake and Idabel Lake in the headwaters of West Kettle River, and a scattering of small lakes and wetlands in the western part of the watershed and in the valley bottoms of Boundary Creek. When the *Absence of Lakes and Wetlands* indicator was calculated for the major sub-basins, all had low attenuation potential. Only the Christina Lake sub-basin had moderate potential to attenuate sediment transport.

Most of the AWs in the Kettle River watershed had very low or low *Sediment Generation and Delivery Potential* ratings (Figure 19). Moderate ratings occurred where the extent of erodible soils was higher (in the western portion of West Kettle River sub-basin and the Rock Creek sub-basin) and where there were more steep slopes near streams (in the upper Granby River basin and northeast of Christina Lake). Only the Rock Creek sub-basin had a moderate rating when results were calculated for the major sub-basins, a

result of the large area of erodible sediments relative to the sub-basin area; all other major sub-basins had very low ratings.

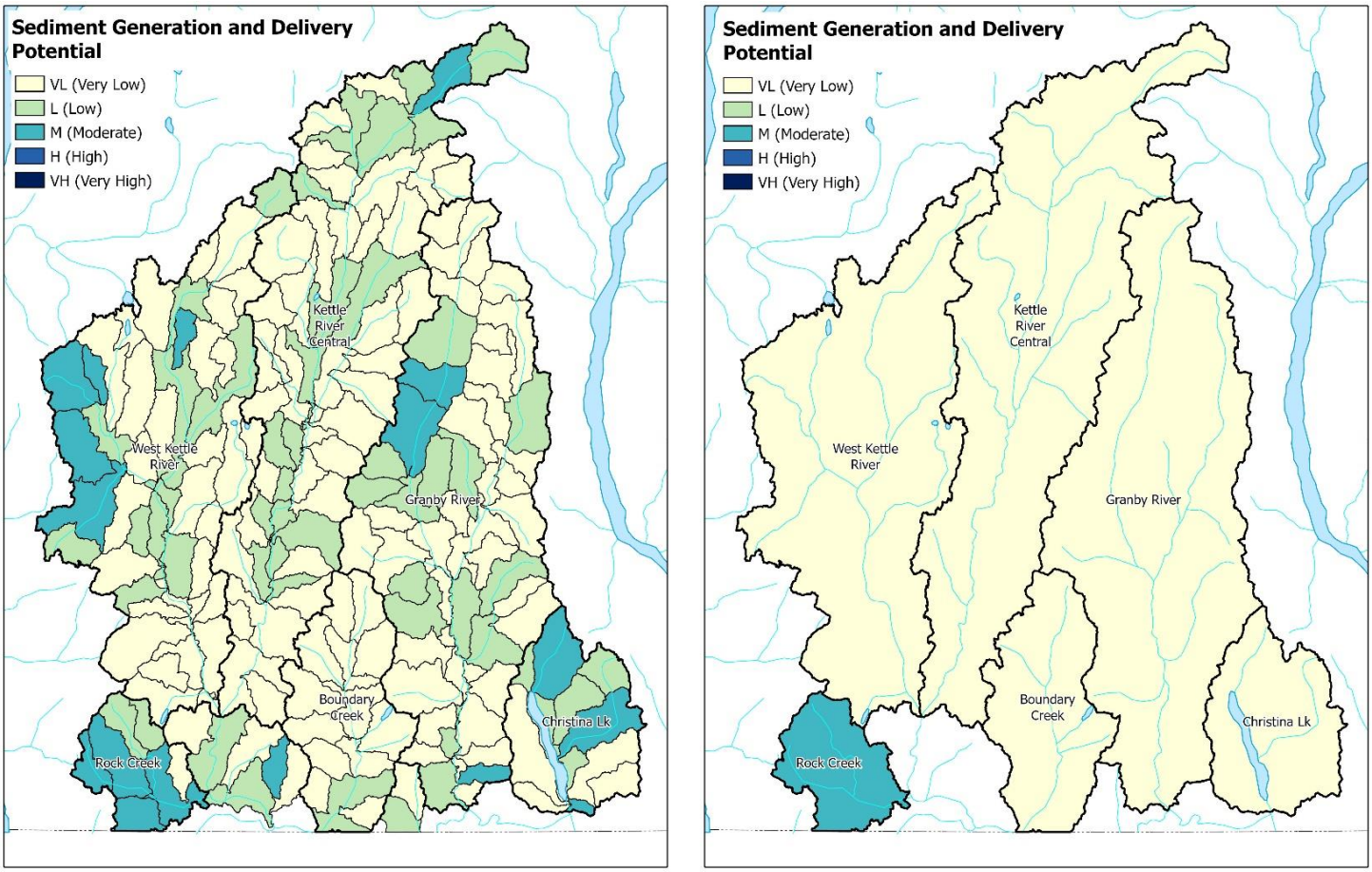


Figure 19. *Sediment Generation and Delivery Potential* rating results for the base AWs (left) and major sub-basins (right) (See also Figures B16 and B17). Details on the rating can be found in Van Rensen et al. (2020).

4.2.2 Land Use Disturbance Rating

Three indicators (*Roads Close to Water, Roads on Steep Coupled Slopes and Disturbance on Gentle Over Steep Terrain*) were combined into the *Land Use Disturbance* rating to represent the dominant types of landcover disturbance that introduce sediment into streams. The vast majority of roads in the Kettle River watershed are gravel and forest service roads (Figure 20). Large gaps in the road network are associated with provincial parks.

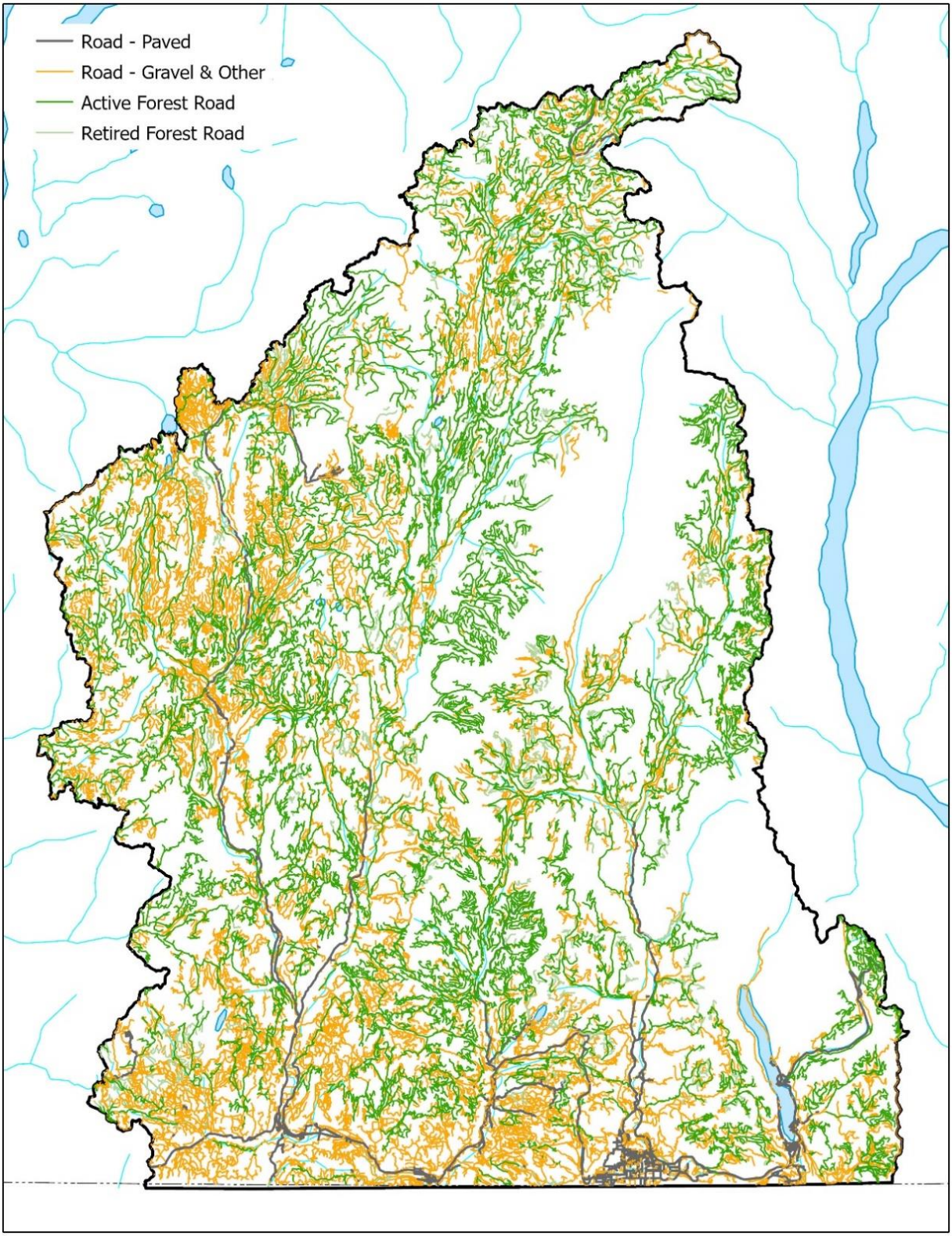


Figure 20. Distribution of roads within the Kettle River watershed. The road dataset is comprised of the Provincial Digital Road Atlas, the Forest Tenure road sections and TRIM roads. Large gaps in the road network are associated with provincial parks.

All areas in the Kettle River watershed except the provincial parks had moderate and high indicator values for *Roads Close to Water* (Figure 21). High values for total road length within 50m of a stream, expressed per unit area, were primarily concentrated in the western and southern parts of the watershed, as well as along the main valley of the Kettle River Central sub-basin. These patterns were evident when the results were integrated for the major sub-basins; the West Kettle River, Kettle River Central, Rock Creek and Boundary Creek sub-basins had high indicator values, and the Granby River and Christina Lake sub-basins had moderate values.

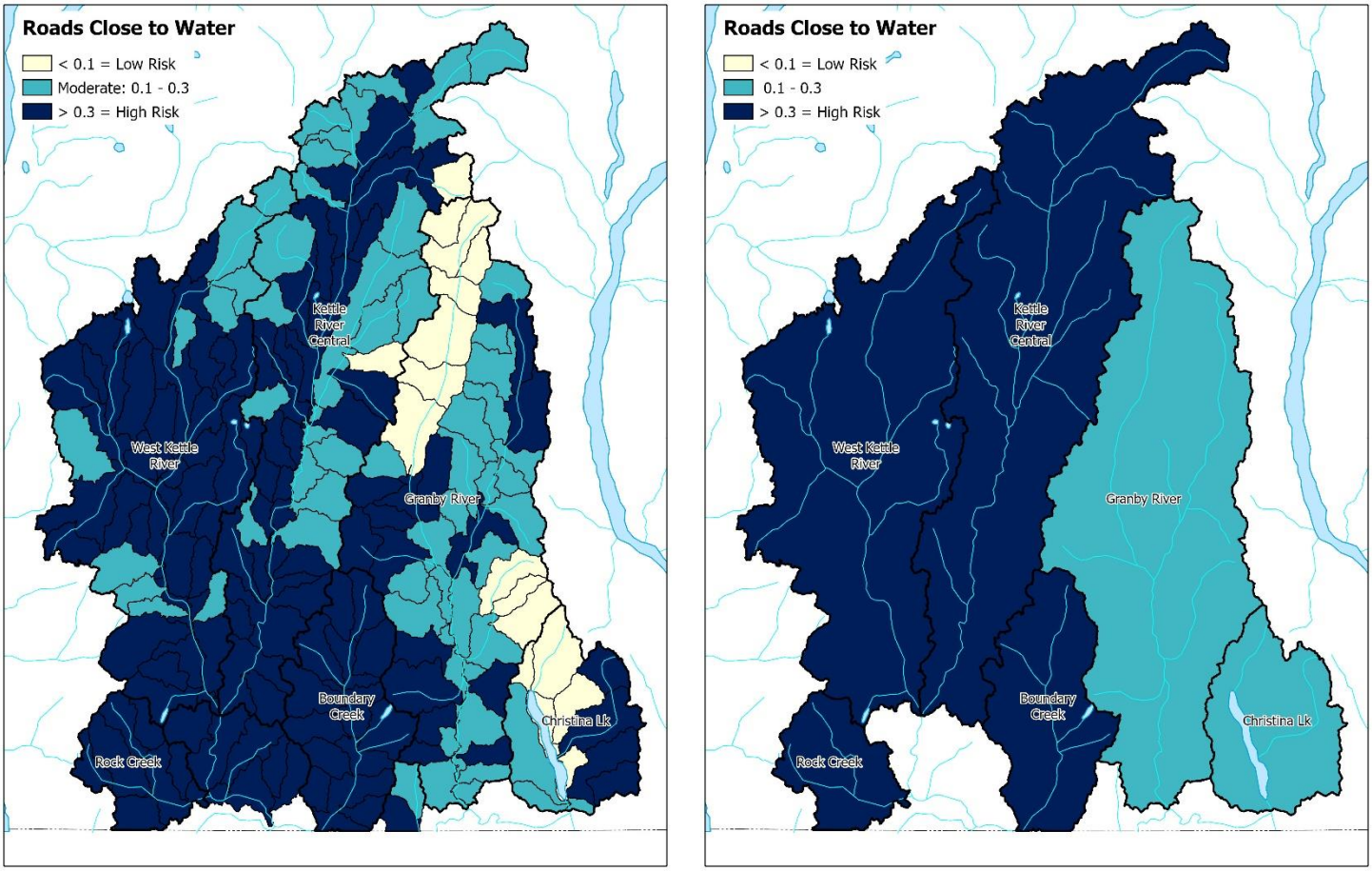


Figure 21. *Roads Close to Water* indicator results at the AW (left) and sub-basin level (right) (See also Figures B8 and B9). Details on the indicator can be found in Van Rensen et al. (2020).

Given the relatively gentle topography of the area not many of these roads were constructed on steep slopes (Figure 22). The vast majority of AWs in the Kettle River watershed had low *Roads on Steep Coupled Slopes* indicator values. The AWs for MacRae and Christina Creeks in the Christina Lake sub-basin, David Creek in the lower part of the Kettle River Central sub-basin, and the area adjacent to Kettle River immediately downstream (east) of Rock Creek had moderate values. The only AW with a high value was

Eugene Creek in the West Kettle River sub-basin. When the information was integrated at the scale of the major sub-basins, all areas had low *Roads on Steep Coupled Slopes* indicator values.

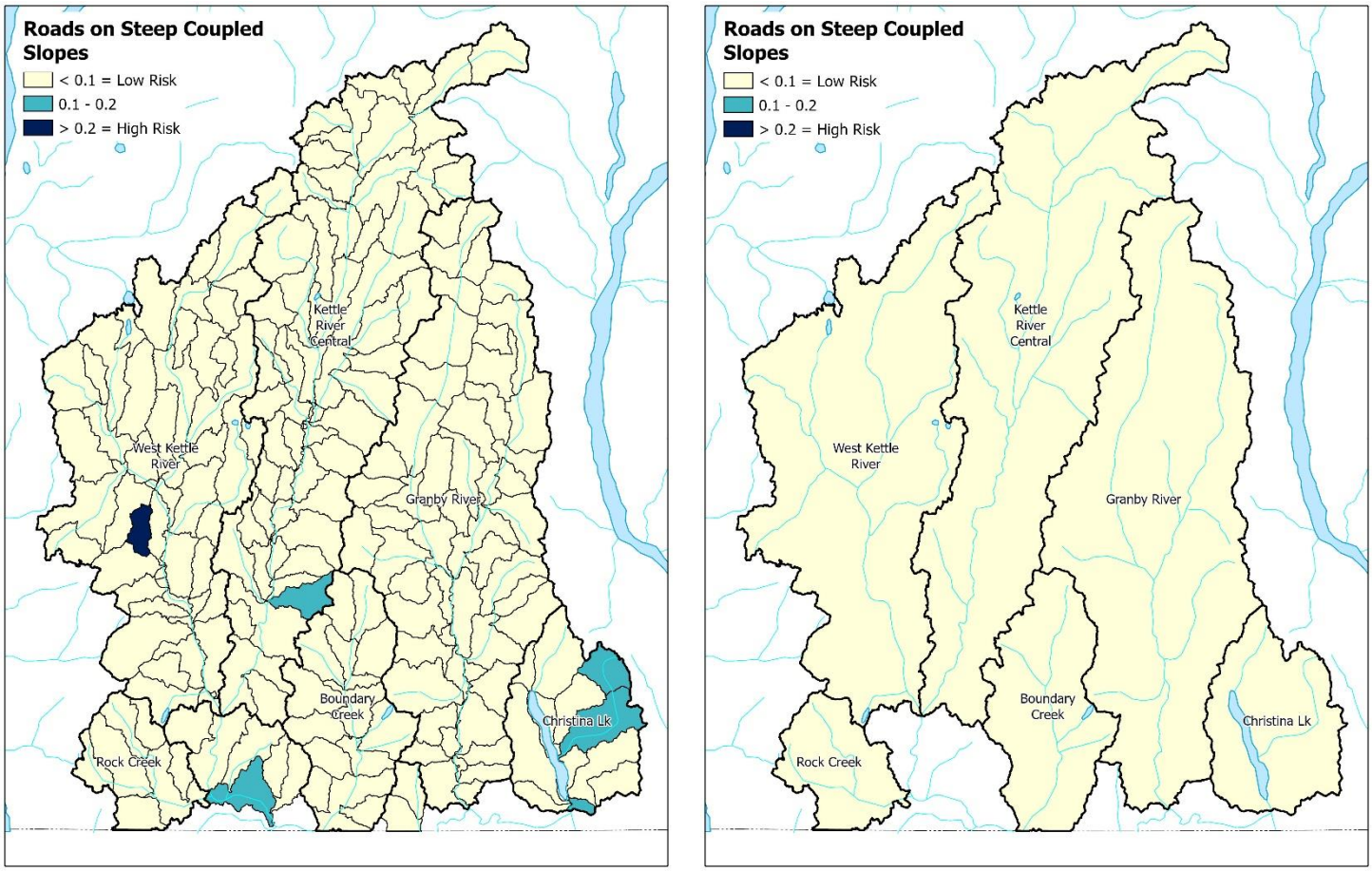


Figure 22. *Roads on Steep Coupled Slopes* indicator results at the AW (left) and sub-basin level (right) (See also Figures B10 and B11). Details on the indicator can be found in Van Rensen et al. (2020).

Results for the *Disturbance on Gentle Over Steep Terrain* indicator were almost homogenously low across the Kettle River watershed, with the exception of the AW for Eugene Creek which had a moderate value (10-20%) (Figure 23). At the scale of the major sub-basins, all had low indicator values.

When the three indicators were integrated into the *Land Use Disturbance* rating, the resulting patterns were primarily controlled by the *Roads Close to Water* indicator (Figure 24). Most of the western and southern parts of the Kettle River watershed, as well as areas in the main valley of the Kettle River sub-basin, had moderate ratings. Many AWs in the eastern half of the watershed, especially those in and adjacent to provincial parks, had low and very low ratings. Higher *Land Use Disturbance* ratings (high and very high) occurred for the AWs that had moderate *Roads on Steep Coupled Slopes* indicator results.

At the scale of the major sub-basins, the West Kettle River, Kettle River Central, Rock Creek and Boundary Creek sub-basins had moderate *Land Use Disturbance* ratings. The Granby River and Christina Lake sub-basins had low ratings.

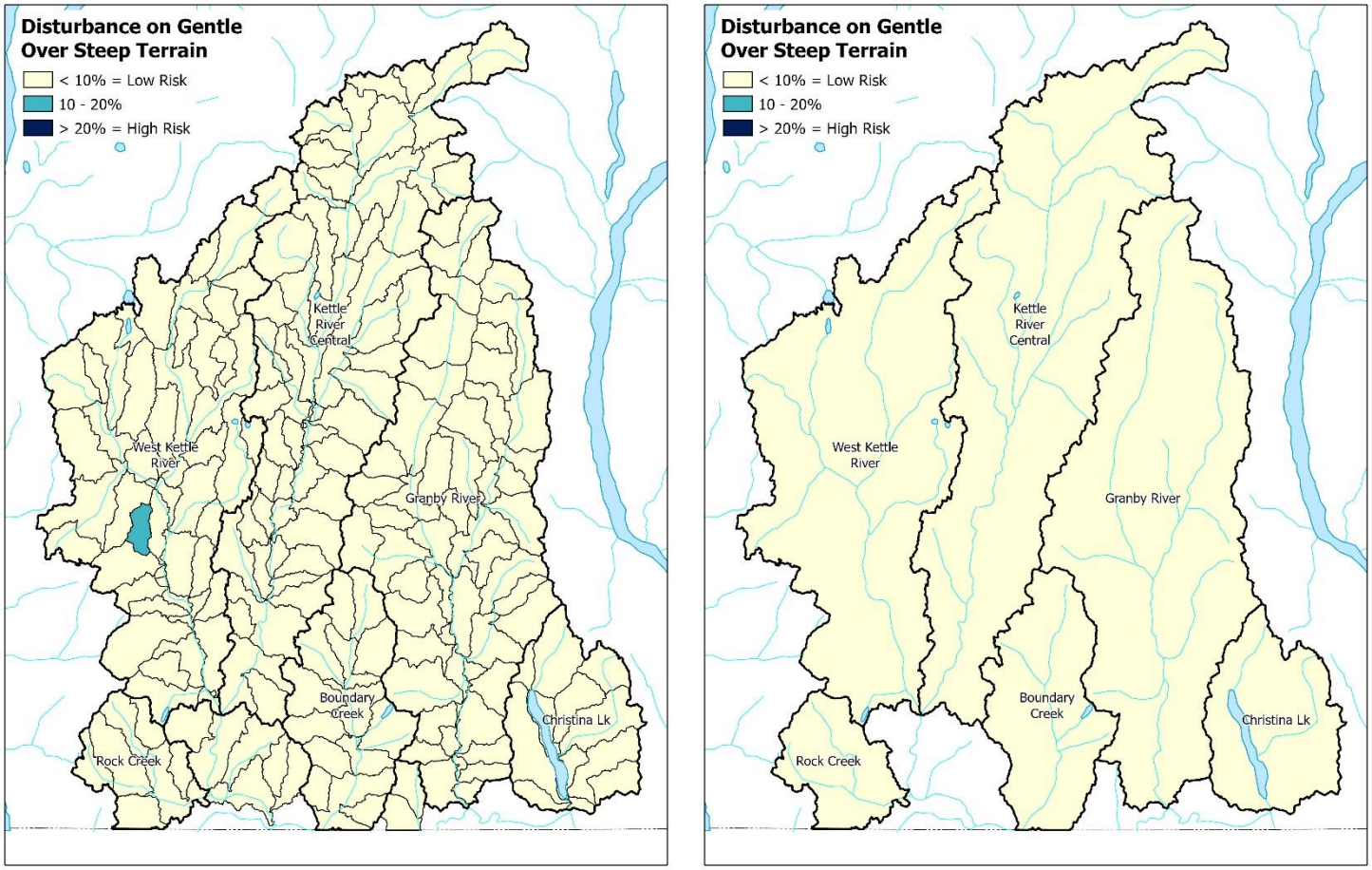


Figure 23. *Disturbance on Gentle Over Steep Terrain* indicator results at the AW (left) and sub-basin level (right) (See also Figures B12 and B13). Details on the indicator can be found in Van Rensen et al. (2020).

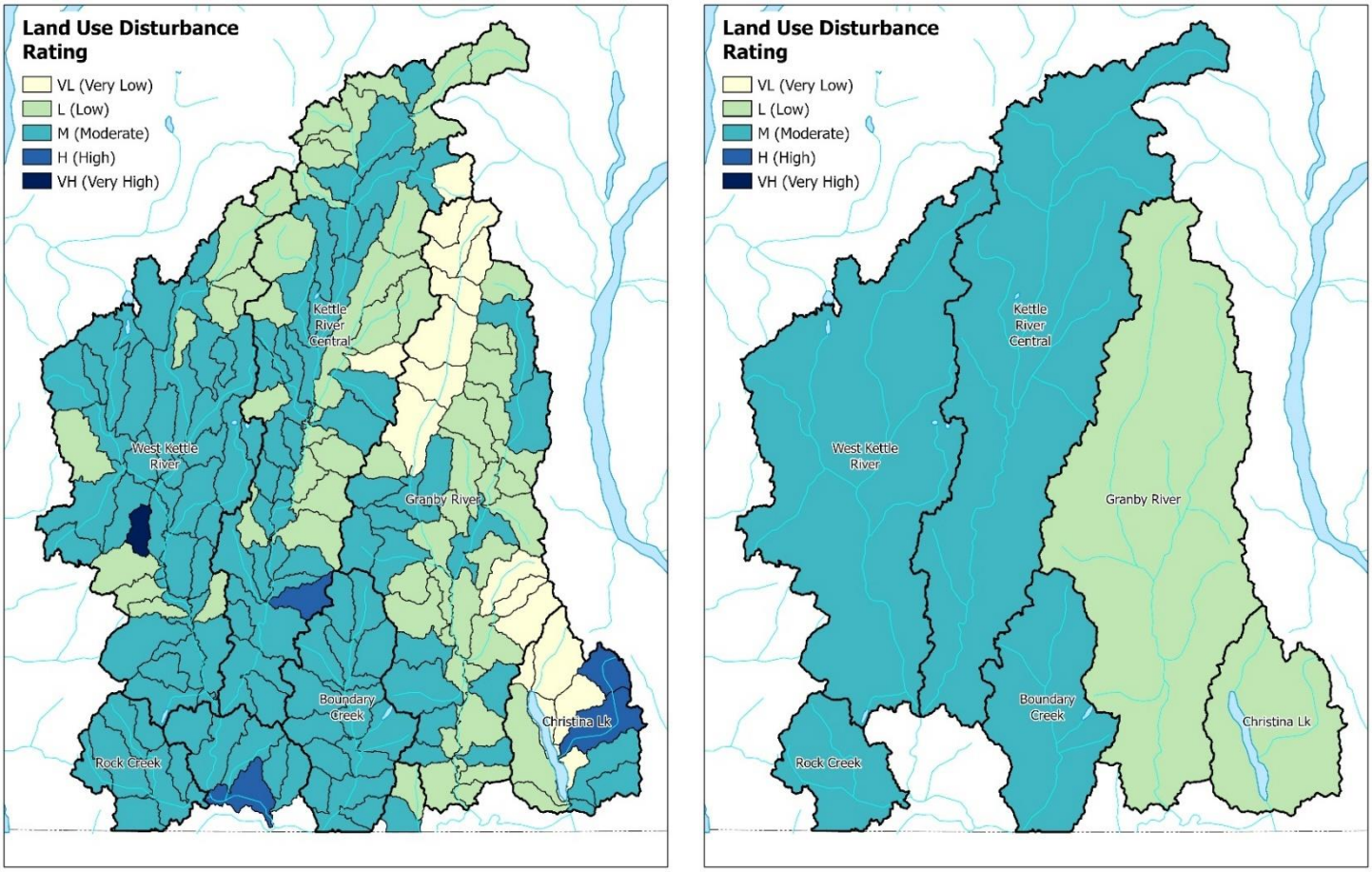


Figure 24. *Land Use Disturbance* ratings at the AW (left) and sub-basin level (right) (See also Figures B18 and B19). Details on the rating can be found in Van Rensen et al. (2020).

4.2.3 Sedimentation Hazard Rating

Results for the *Sedimentation Hazard* rating for most of the Kettle River watershed were very low and low (Figure 25). Because this final hazard represents the effects of conditions and processes that accumulate within a watershed, the results for the *Sedimentation Hazard* rating are only presented for the hydrologically-defined assessment units (AUs) (i.e. not for the individual AWs). Results are presented in a series of maps, showing ratings for the smallest watersheds (L1 AUs) and progressively larger watersheds (L2-L4, L7-L9, L14-L16 and L24, 29 and 39) up to the scale of the major sub-basins (Figure 25). This will allow the reader to see how the results progressively scale as watershed area increases.

Low level AUs (L1 to L3) in the west part of the West Kettle River sub-basin and most of Rock Creek sub-basin had moderate hazard ratings. These patterns were largely due to the influence of the *Erodible Soils* indicator. In the Christina Lake sub-basin, the L2 AU of MacRae Creek had a moderate hazard value due to the combined effects of the land use disturbance indicators (steep slopes near streams with roads). Eugene Creek (L1 AU) was the only AU with a very high hazard rating due to relatively high values for all three of the land use disturbance indicators used.

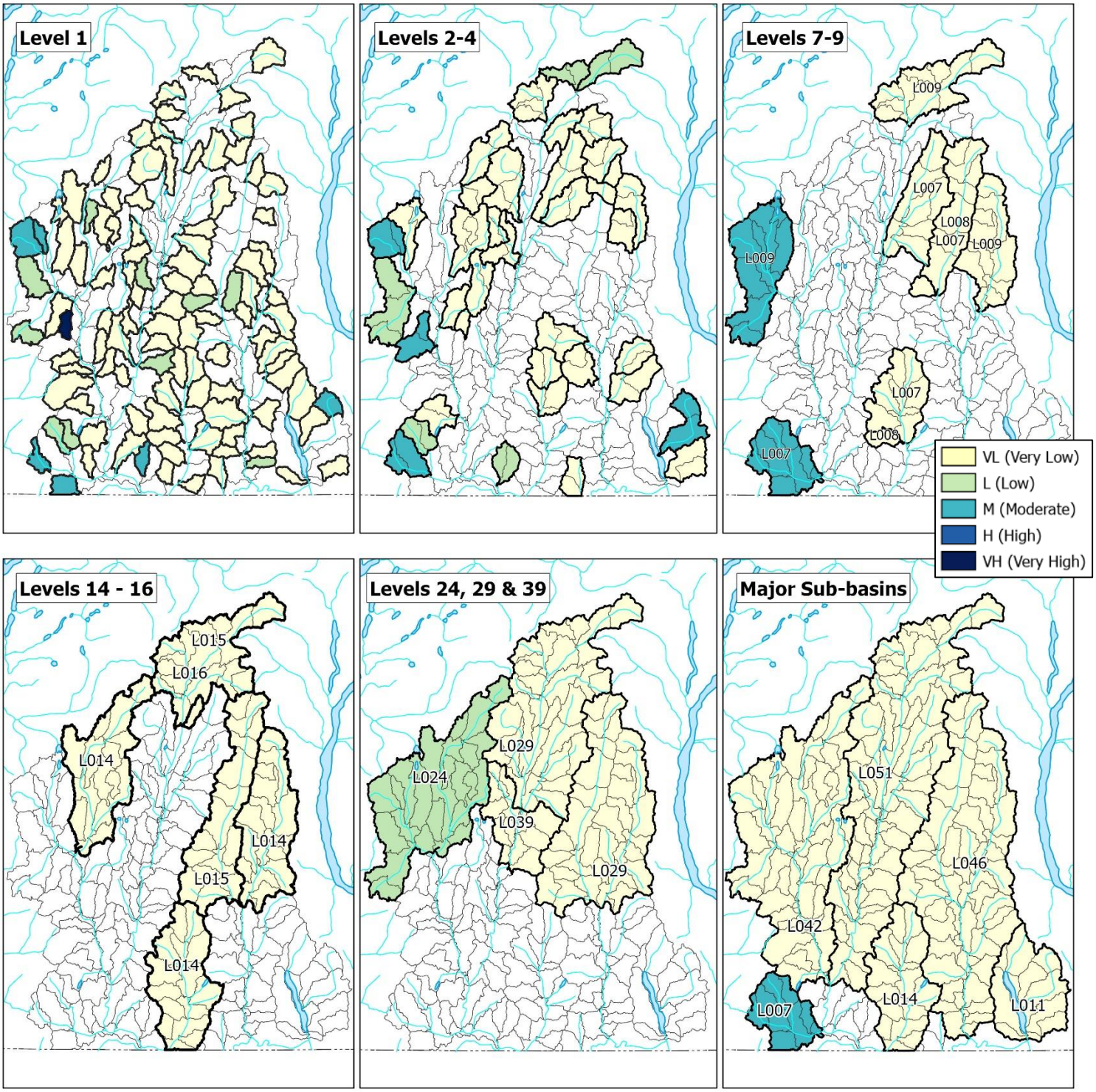


Figure 25. ***Sedimentation Hazard*** **rating results at varying scales from smallest AU (L1, top left) to the major sub-basins (bottom right). AWs are outlined, and a bolder line is used to outline the AUs (See also Figures B20-B25). Details on the rating can be found in Van Rensen et al. (2020).**

When the results were reported at the scale of the major sub-basins, all except Rock Creek had a very low *Sedimentation Hazard* rating. The moderate hazard rating for the Rock Creek sub-basin was due to an equal combination of its natural potential for erosion and capacity for sediment transport, and the effects of landcover disturbance.

Note that erosion and mass wasting events are generally local in extent, and in large basins it can take years to centuries for sediment to move downstream. This suggests that major basins may not be the appropriate scale to manage for sedimentation hazard. When using these results for management or operational applications, users should evaluate the appropriate scale(s) for their situation.

5 Summary, Limitations and Next Steps

The results of this assessment were intended to provide information at a coarse resolution for consideration in strategic, tactical and operational decision-making at all levels of governance and resource management. Management use of these results should be considered in a larger context of climate change, public safety, First Nations' interests, competing resource values and other relevant factors. They provide general insight into watershed and sub-watershed units that are potentially at higher or lower hazard, at least with regards to the indicators used and processes represented. It is important to note that the assessment procedures limited the types of disturbance indicators to anthropogenic and natural factors known to be the dominant causes of cumulative watershed effects in B.C. (i.e. forest disturbance, roads and logging activities), that the procedures represented our best current understanding of their hydrologic and geomorphologic effects on snowmelt-generated peak flow and sedimentation processes, and that the results have not been verified with field work or modeling. Field-based or model validation of assessment results should be conducted prior to operational application to verify/ground truth results to determine the actual hazard level and what type of management responses could be taken to reduce risks. These limitations should be kept in mind when looking at the resulting hazard ratings.

Results showed low *Streamflow Hazard* ratings in areas with limited anthropogenic disturbance (i.e. parks), indicating that, although much of the Kettle River watershed has a higher natural sensitivity to generate peak streamflow, disturbance was a key factor in increasing the calculated hazard rating. Results also indicated that, for the full Kettle River watershed, the higher potential hazard to generate high peak streamflows comes from disturbance in the central and western sub-basins, which includes Rock Creek, West Kettle River, Kettle River Central and Boundary Creek. A closer look at ECA values for these sub-basins, which drives the *Streamflow Hazard*, showed the Kettle River Central sub-basin to be particularly hazardous due to forest disturbance, with over 50% of AWs having an ECA greater than 30%. Given the moderate to high natural capacity to generate high peak flows based on topography, climate and low attenuation capacity, increased disturbance in this landscape has the potential to further exacerbate peak flows. Preventing additional disturbance in watersheds where ECA is high, particularly at mid- to high elevations, should be considered until recovery has advanced.

Both landcover change (i.e. forest disturbance) and weather conditions determine peak flow in any given year. This assessment focussed on the potential effects of forest disturbance on snowmelt-generated

peak flow. The specific factors that caused two consecutive years of flooding in the Kettle River basin (2017 and 2018) cannot be characterized using the methods described in this report. The effects of year-to-year variability in total winter snow accumulation and spring melt rates need to be considered and would best be explored using a hydrologic model. However, recognising that forest disturbance can impact peak flows, the hazard rating maps can be used for forest stewardship and landscape planning to help reduce further impacts and allow for forest recovery in the more heavily impacted areas.

Most of the Kettle River watershed had low ratings for sediment generation and delivery, but at the scale of the AWs there were some areas of concern within the Christina Lake and West Kettle sub-basins. Higher hazard ratings in these areas were due to the presence of roads close to water, especially on or adjacent to steep slopes. Results at the AW scale can help prioritize areas that may benefit from efforts to reduce erosion and sediment transport from roads (such as road deactivation and riparian wetland restoration).

The method used to calculate equivalent clearcut area was generally consistent with that used in the Provincial CEF, which has recognised limitations (Van Rensen et al. 2020). The current approach did not explicitly consider the potential for snowmelt synchronization between forests and disturbed areas at different elevations, which is known to increase peak flows. Research is currently underway to determine the best way to incorporate the potential for melt synchronisation. In addition, the hydrologic recovery rates used to calculate ECA are for pine dominated stands in climates that receive less snow than some parts of the Kettle River watershed. Field and modeling research projects are underway to determine hydrologic recovery curves in non-pine stands, on slopes with different aspects, and in areas that receive more snow. As this information is peer-reviewed and published, it will be incorporated into the watershed assessment protocol.

The ECA calculations also did not explicitly include resource roads. Resource roads that fell within cutblocks would have been treated the same as the adjacent harvested area, applying the same recovery rates. However, resource roads outside cutblocks which are not deactivated and replanted do not recover at the same rate. Incorporating roads in the ECA calculation (using appropriate buffers to reflect the width of natural landcover that was removed or disturbed for the road) would further increase ECA percent in most AWs. Given the relatively high density of resource and gravel roads in the Kettle River watershed and their persistent state of disturbance, the inclusion of roads in ECA calculations will be considered in the next version of the analysis.

The availability of data for private lands is often a problem for accurately calculating ECA. Most of the private land in the Kettle River watershed is located in the south near the international border and at low elevations in the main valleys. For the most part, these areas coincide with what is identified as ‘urban’ and/or ‘agricultural’ disturbances within the ECA Indicator and so are captured in the analysis.

Roads are the primary land disturbance indicator used for the *Sedimentation Hazard* rating. The assessment procedures used a CEF consolidated road dataset where there was no distinction made between older, and possibly overgrown, roads and newer or paved roads. Additionally, assignment of these road attributes was not done consistently throughout the consolidated product’s base road datasets. Therefore, all roads were treated equally in the rating calculations. Maintaining or adding certain road condition attributes and linking them back to a weighting factor would help refine road-related ratings. The Provincial CEF uses a road weighting scheme for their road density calculations while

acknowledging that the base road information is not always available or accurate (Provincial Aquatic Ecosystems Technical Working Group 2019).

The dominant forestry-related point source introduction of fine sediments to streams occurs where a resource or gravel road crosses a stream at a bridge, culvert or ford site (referred to as stream crossings). Artificial drainage patterns and exposure of erodible sediments at stream crossings increase the risk of sedimentation, which can be reduced through proper maintenance. In determining the *Sedimentation Hazard* rating, stream crossings are not explicitly considered but are included in the *Roads Close to Water.* This approach may under-represent their impact on fine sediment introduction and aquatic ecosystems. The interim assessment protocol adopted for the provincial-level cumulative effects assessment and the protocol used in Omineca Region include separate stream crossing indicators in addition to indicators of coupled road density (Provincial Aquatic Ecosystems Technical Working Group, 2019; John Rex, personal communication, 21 January 2021). The inclusion of a separate stream crossing indicator in the *Land Use Disturbance* rating will be explored in the next version of the analysis.

Roads and harvest on gentle-over-steep terrain are not the only type of land disturbance that have the potential to increase sediment introduction to streams. In the Kettle River watershed, past placer mining activity within stream channels may have destabilised banks, increasing their risk to unload sediment. Modern placer activities are limited in scale and are conducted with aquatic ecosystem health in mind; however, their potential impact on sediment mobilisation is not included in the current watershed assessment protocol.

The results from this streamflow and sedimentation hazard analysis for the Kettle River watershed may be used for a wide variety of applications (e.g. forest stewardship plans, land use planning, water authorizations); the demands from these types of applications will influence when and how often the analyses will be updated. Updates to the maps could occur at the same frequency that the input disturbance layers are updated, which is usually annually or bi-annually depending on capacity and demands from different partners and business areas. While the report may not be updated at this frequency, the resultant maps will be made publicly available.

Modifications to the hazard assessment procedures will occur over time as cumulative effects methods evolve and as research become available. The maps presented in this report should be considered a starting point for using watershed-scale hazard assessments to inform sustainable forested landscape management and activities affected by streamflow and sedimentation processes at that scale. It is the intention of the Kootenay Boundary Region Cumulative Effects Team to share and review these results with experts, First Nations, stakeholders and community groups for feedback and to work collaboratively to assess results and future analysis needs to help refine this iterative hazard assessment tool.

As time and capacity permits, the analysis will be expanded to the entire Kootenay Boundary region, largely guided by emerging pressures. In addition, procedures to derive a *Riparian Hazard* rating will be developed and included in the assessment protocols. Loss or alteration of riparian functions affects a wide range of hydrologic, geomorphologic and biological processes, and assessments of disturbances to this ecosystem are an important part of fully understanding disturbance impacts on watershed health.

Efforts are underway to use existing monitoring and modeling projects as means to validate the indicators and ratings. Field based monitoring programs such as the Forest and Range Evaluation Program (FREP), watershed assessment reports and hydrologic models are potential sources of information to help confirm or refine the protocols. The primary challenges in comparing results with previous reports and models is that (a) they may measure different things or be designed to meet different objectives, (b) measurements made at a single point can be difficult to extrapolate to the watershed scale, and (c) in order to use models for verification it must be known how well natural processes are represented.

Tools and processes are currently being developed by provincial staff to integrate and communicate resource value objectives, to assess how well these objectives are being achieved (including results from this report) and to respond with integrated resource management approaches to help achieve these objectives. In the spirit of the Declaration Act and UNDRIP, these assessments will be shared with key First Nations and indigenous community partners.

6 References

B.C. Agriculture and Food Climate Action Initiative. 2019. Regional adaptation strategies: Kootenay and Boundary. B.C. Agriculture and Food Climate Action Initiative.

B.C. Ministry of Forests and B.C. Ministry of Environment. 1999. Coastal watershed assessment procedure guidebook (CWAP), interior watershed assessment procedure guidebook (IWAP). 2nd ed. Forest Practices Branch, B.C. Ministry of Forests, Victoria, B.C.

Carver, M.; M. Gray. 2010. Assessment watersheds for regional application in British Columbia. Streamline Watershed Management Bulletin. 13(2): 60-64.

Elk Valley Cumulative Effects Management Framework Working Group. 2018. Elk Valley cumulative effects assessment and management report. Report prepared by the B.C. Ministry of Forests, Lands, Natural Resource Operations and Rural Development.

Lewis, D.; B. Grainger; M. Milne. 2016. A GIS indicator-based watershed assessment procedure for assessing cumulative watershed effects. Report prepared by the B.C. Ministry of Forests, Lands and Natural Resource Operations.

MacKillop, D.J.; A.J. Ehman. 2016. A field guide to site classification and identification for southeast British Columbia: The south-central Columbia Mountains; Also includes a supplement for four biogeoclimatic subzones/variants in the Boundary-Okanagan. British Columbia Ministry of Forests, Lands and Natural Resource Operations Land Management Handbook 70.

Matheson, A.; N.W.D. Massey; P.T. Bobrowsky; C.E. Kilby; G. Manson. 1996. Aggregate inventory of British Columbia: Private pits. B.C. Ministry of Energy, Mines and Petroleum Resources. Geological Survey Branch Open File 1996-5.

Provincial Aquatic Ecosystems Technical Working Group. May 2019. Interim Assessment Protocol for Aquatic Ecosystems in British Columbia. Report prepared by the B.C. Ministry of Environment and Climate Change Strategy and Ministry of Forests, Lands and Natural Resource Operations and Rural Development. Version 1.2.

Van Rensen, C.; N. Neumann; V. Young. (2020) A GIS indicator-based protocol for assessing cumulative watershed effects: Procedures adapted for the Kootenay Boundary Region. Report prepared by the B.C. Ministry of Forests, Lands, Natural Resource Operations and Rural Development. Version 1.0.

Winkler, R.; S. Boon. 2017. Equivalent clearcut area as an indicator of hydrologic change in snow-dominated watersheds of southern British Columbia. B.C. Ministry of Forests, Lands and Natural Resource Operations. Extension Note 118.

Appendix A *Streamflow Hazard* Indicator and Rating Maps

Maps are presented here for all of the GIS indicators, intermediate ratings and final ratings for the *Streamflow Hazard* rating. They are presented in the order indicated in the flowchart (Figure A1), from left to right (i.e. first the GIS indicators, second the combined potential or disturbance rating, third the combined potential rating and lastly the hazard rating) and from top to bottom.

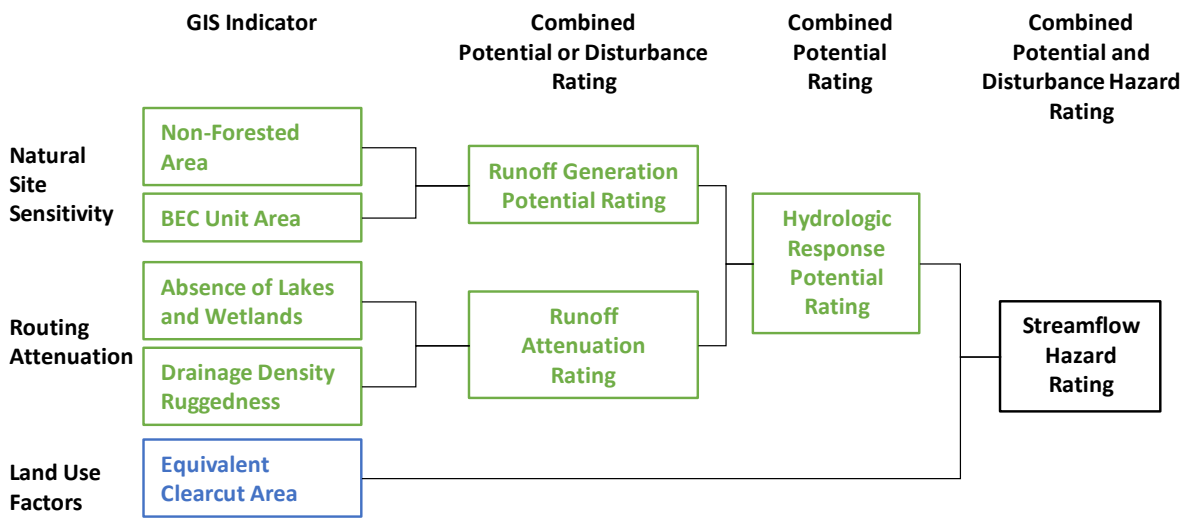


Figure A1. Flowchart used to derive the *Streamflow Hazard Rating.*

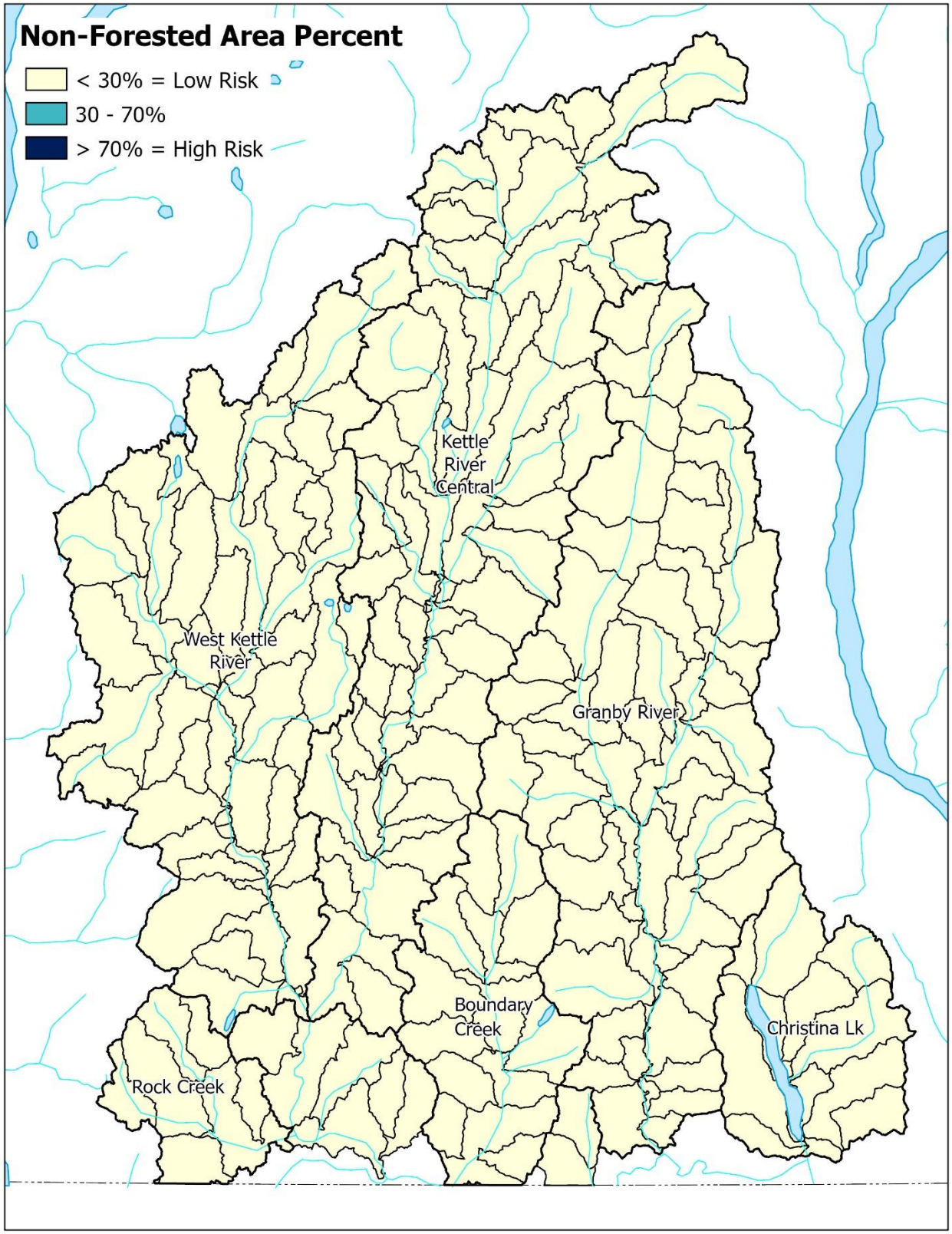


Figure A2. ***Non-Forested Area*** **indicator at the scale of the AWs. AWs are outlined in black, and the boundaries of the major sub-basins are indicated using thicker black lines. Results were not calculated for portions of the basin that are in the U.S.**

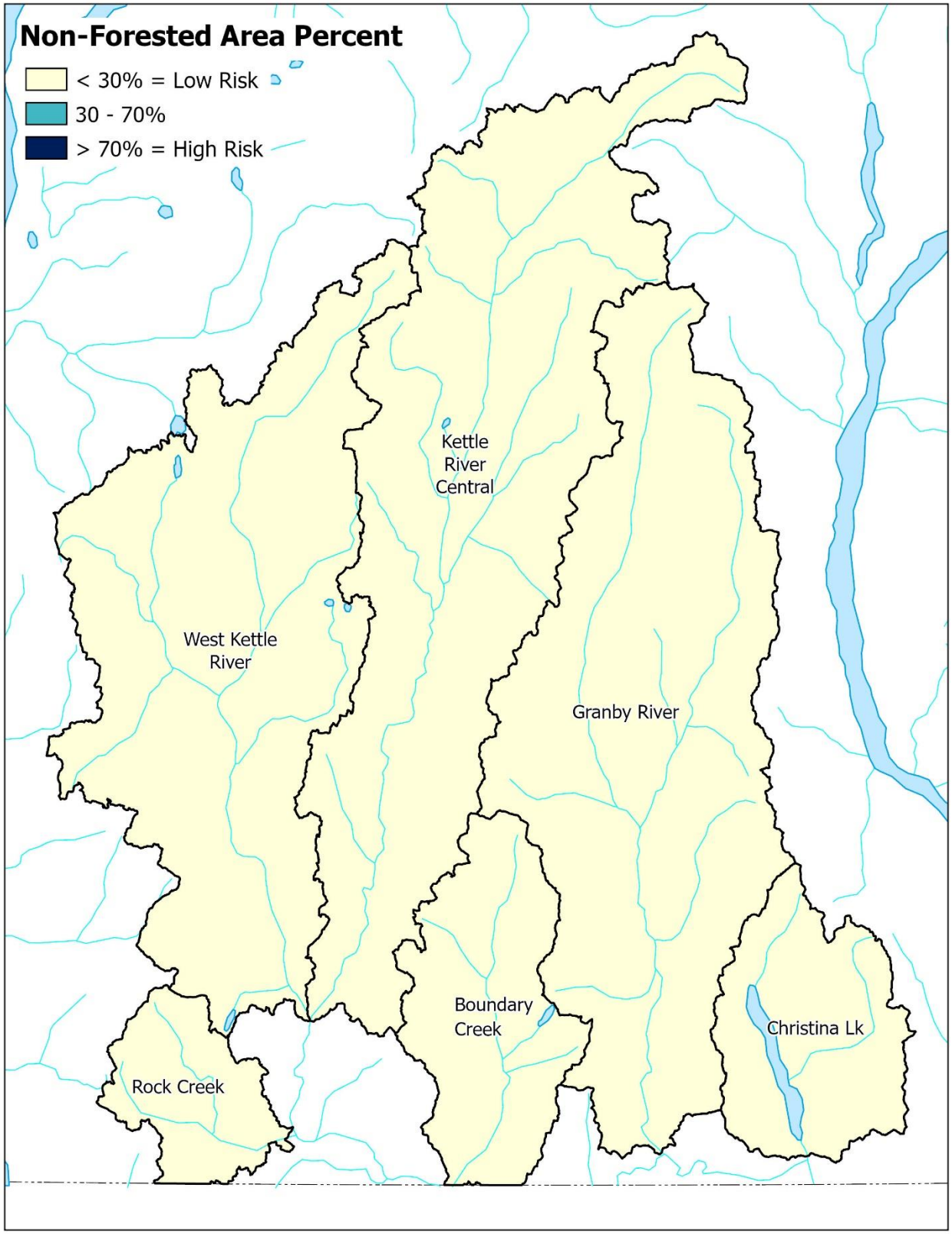


Figure A3. ***Non-Forested Area*** **indicator at the scale of the major sub-basins. Results were not calculated for portions of the basin that are in the U.S.**

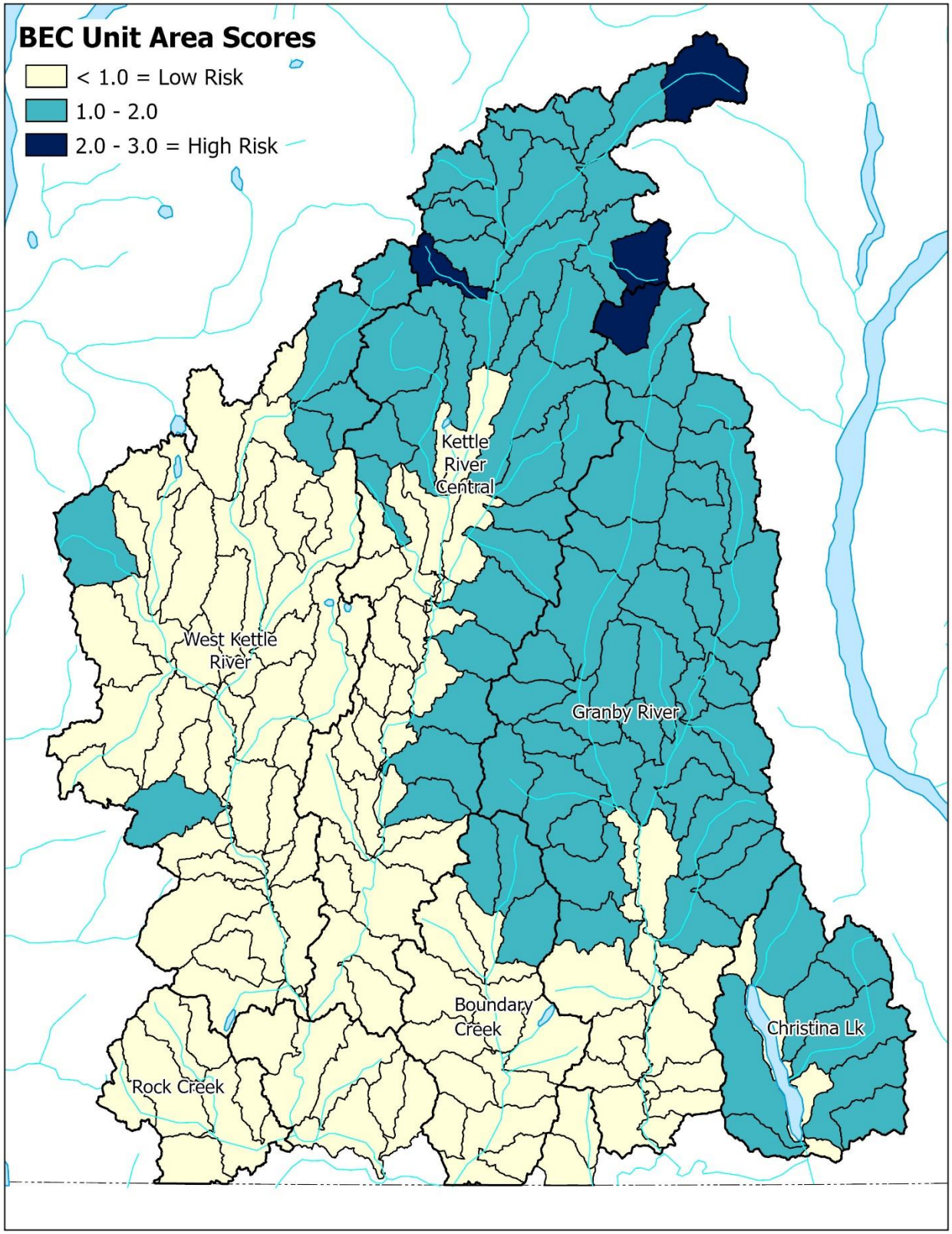


Figure A4. ***BEC Unit Area*** **indicator at the scale of the AWs. AWs are outlined in black, and the boundaries of the major sub-basins are indicated using thicker black lines. Results were not calculated for portions of the basin that are in the U.S.**

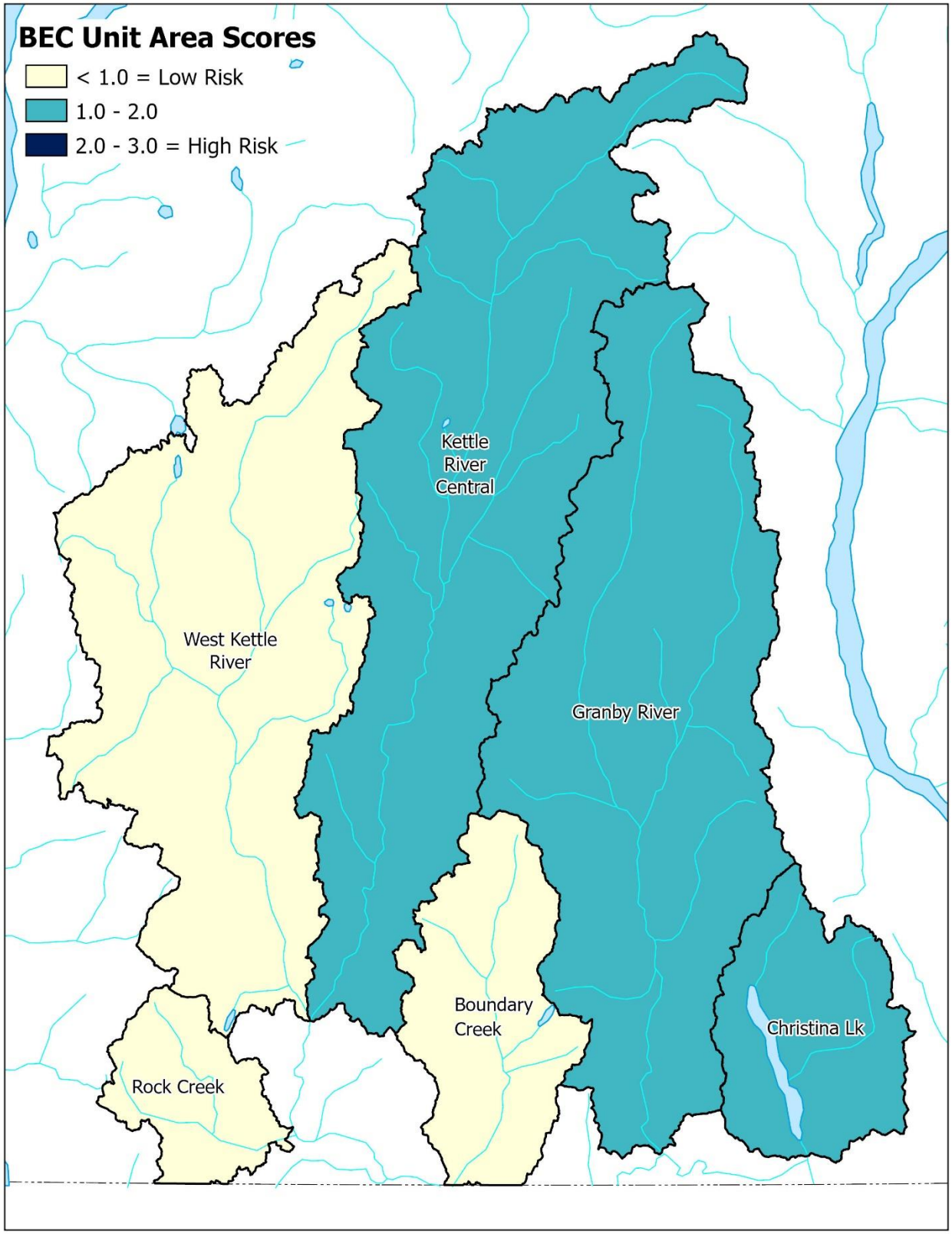


Figure A5. ***BEC Unit Area*** **indicator at the scale of the major sub-basins. Results were not calculated for portions of the basin that are in the U.S.**

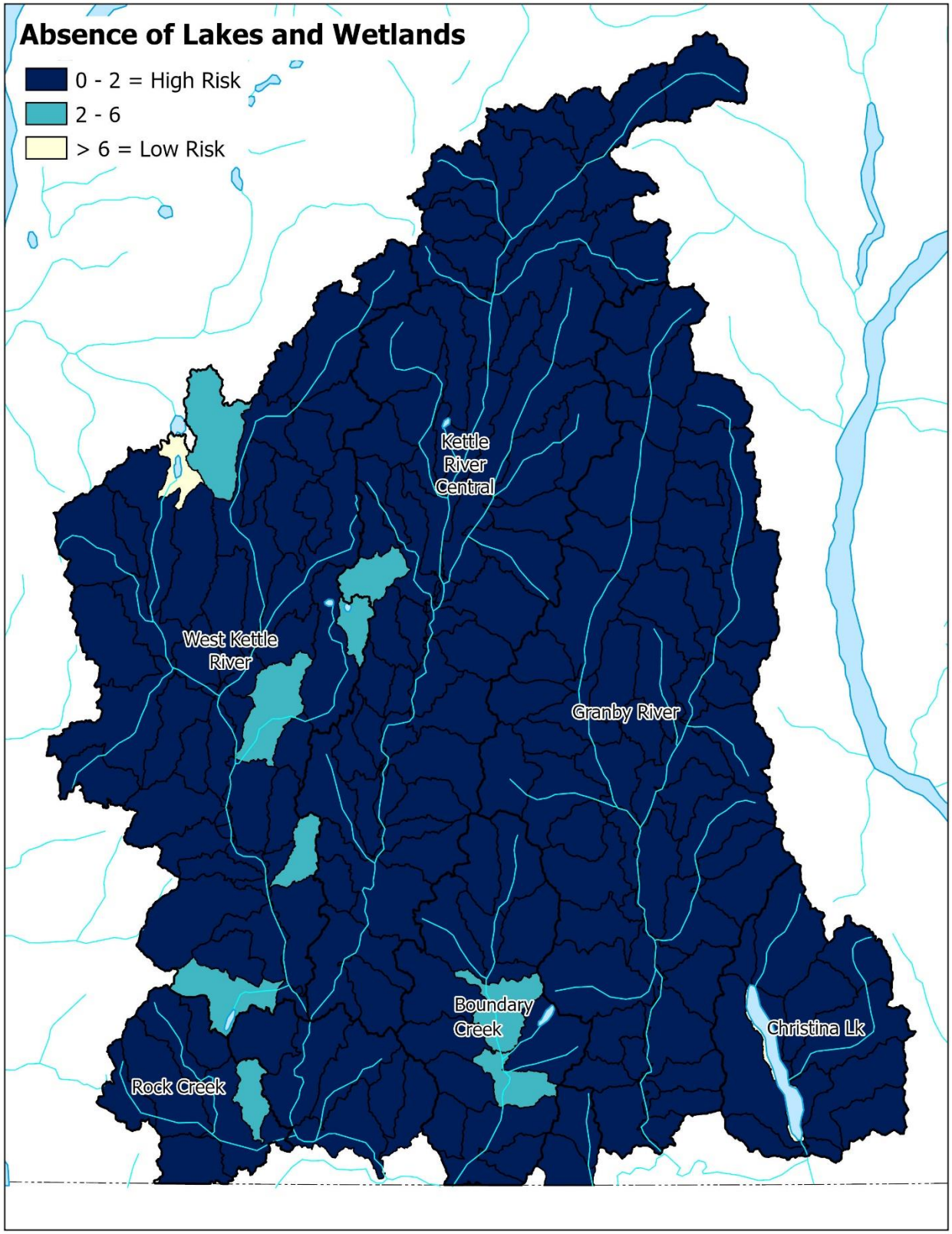


Figure A6. ***Absence of Lakes and Wetlands*** **indicator at the scale of the AWs. AWs are outlined in black, and the boundaries of the major sub-basins are indicated using thicker black lines. Results were not calculated for portions of the basin that are in the U.S.**

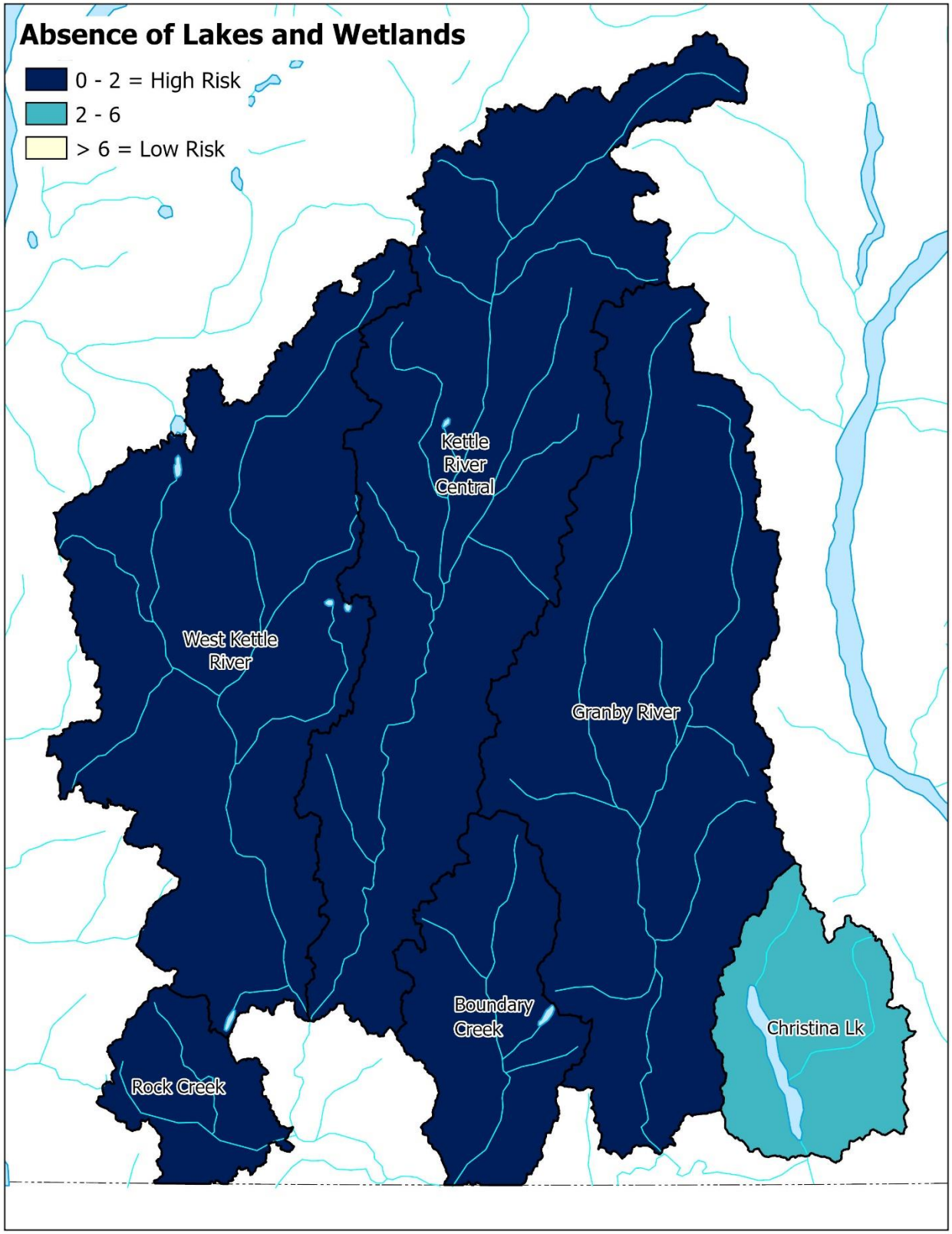


Figure A7. ***Absence of Lakes and Wetlands*** **indicator at the scale of the major sub-basins. Results were not calculated for portions of the basin that are in the U.S.**

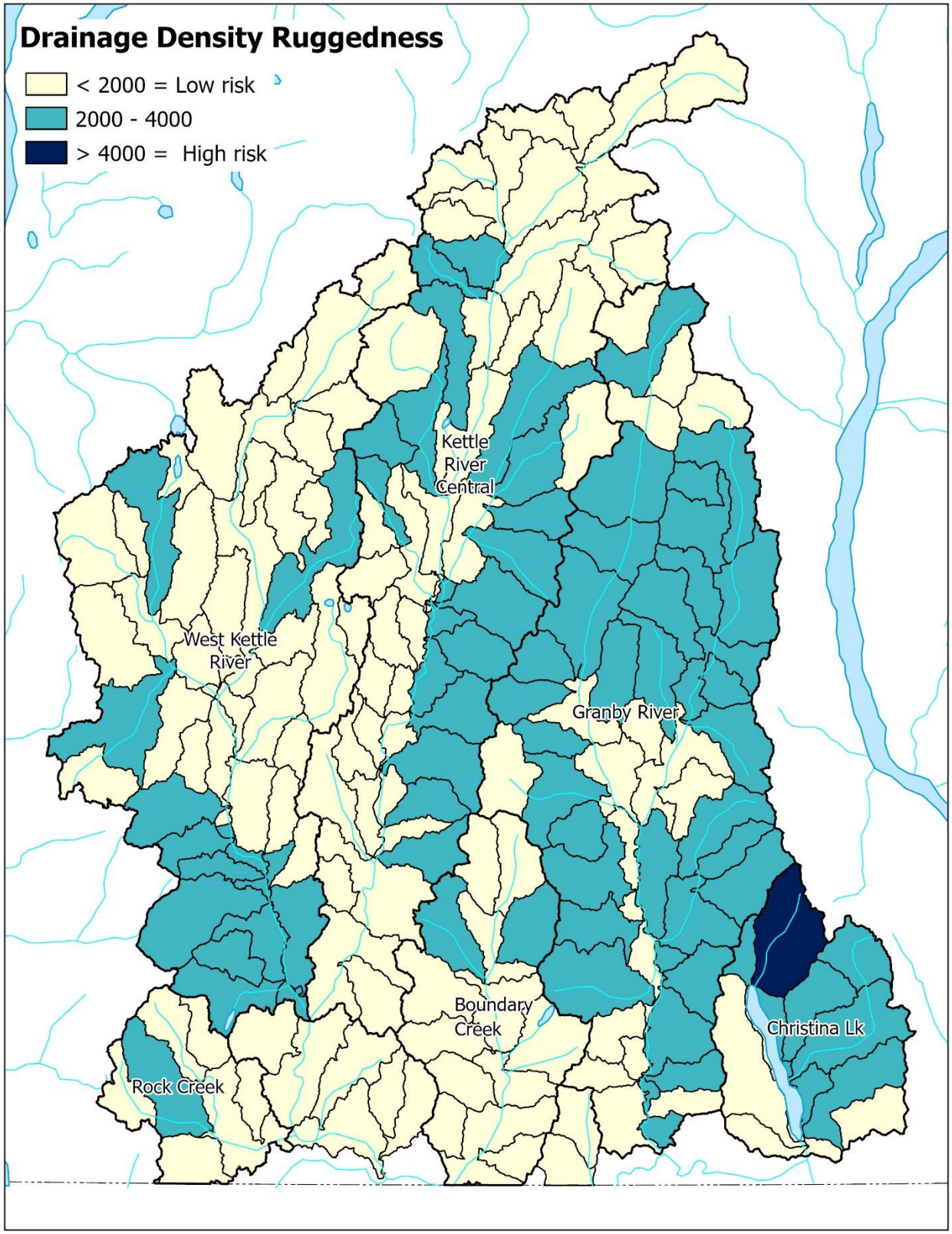


Figure A8. ***Drainage Density Ruggedness*** **indicator at the scale of the AWs. AWs are outlined in black, and the boundaries of the major sub-basins are indicated using thicker black lines. Results were not calculated for portions of the basin that are in the U.S.**

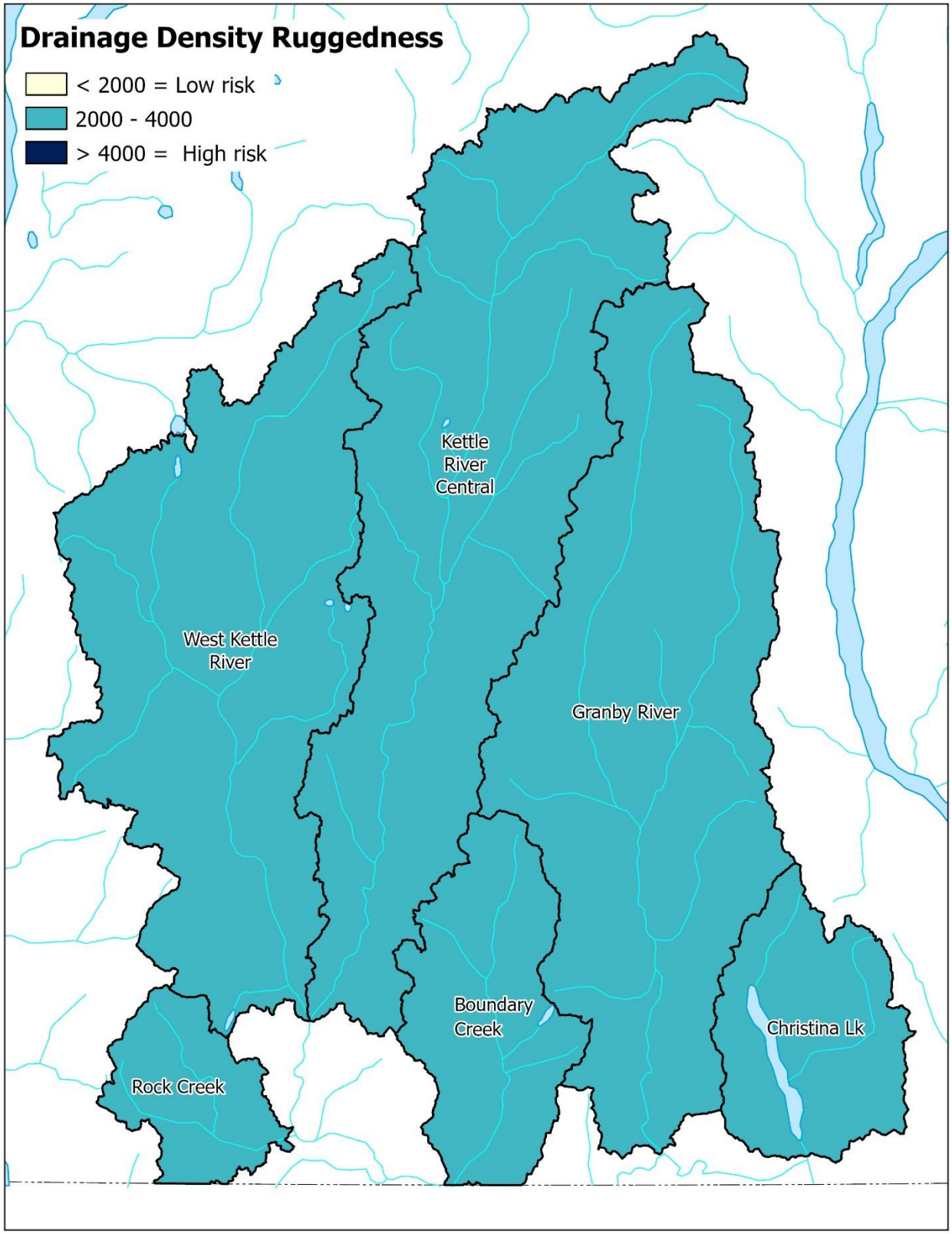


Figure A9. ***Drainage Density Ruggedness*** **indicator at the scale of the major sub-basins. Results were not calculated for portions of the basin that are in the U.S.**

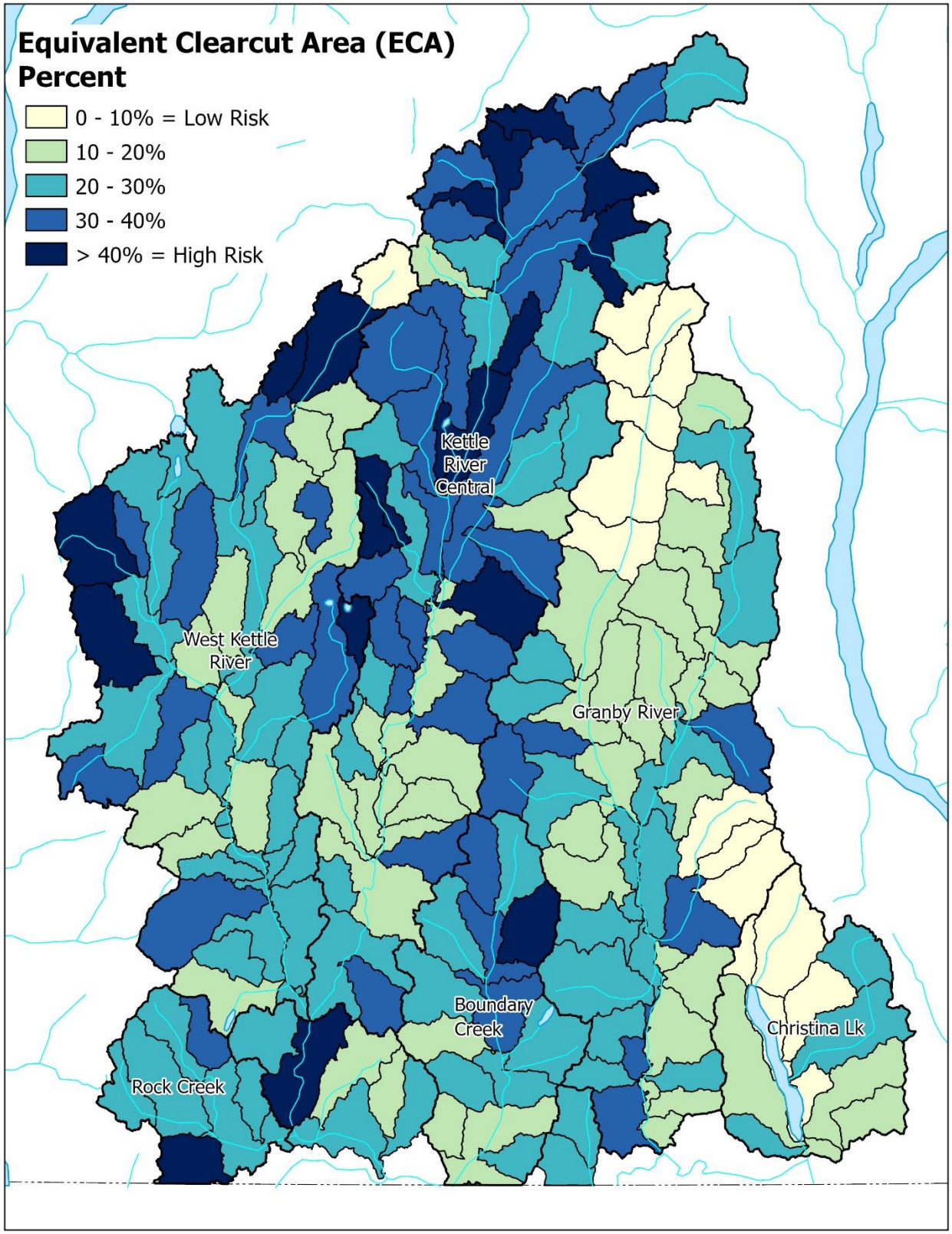


Figure A10. ***Equivalent Clearcut Area*** **indicator at the scale of the AWs. AWs are outlined in black, and the boundaries of the major sub-basins are indicated using thicker black lines. Results were not calculated for portions of the basin that are in the U.S.**

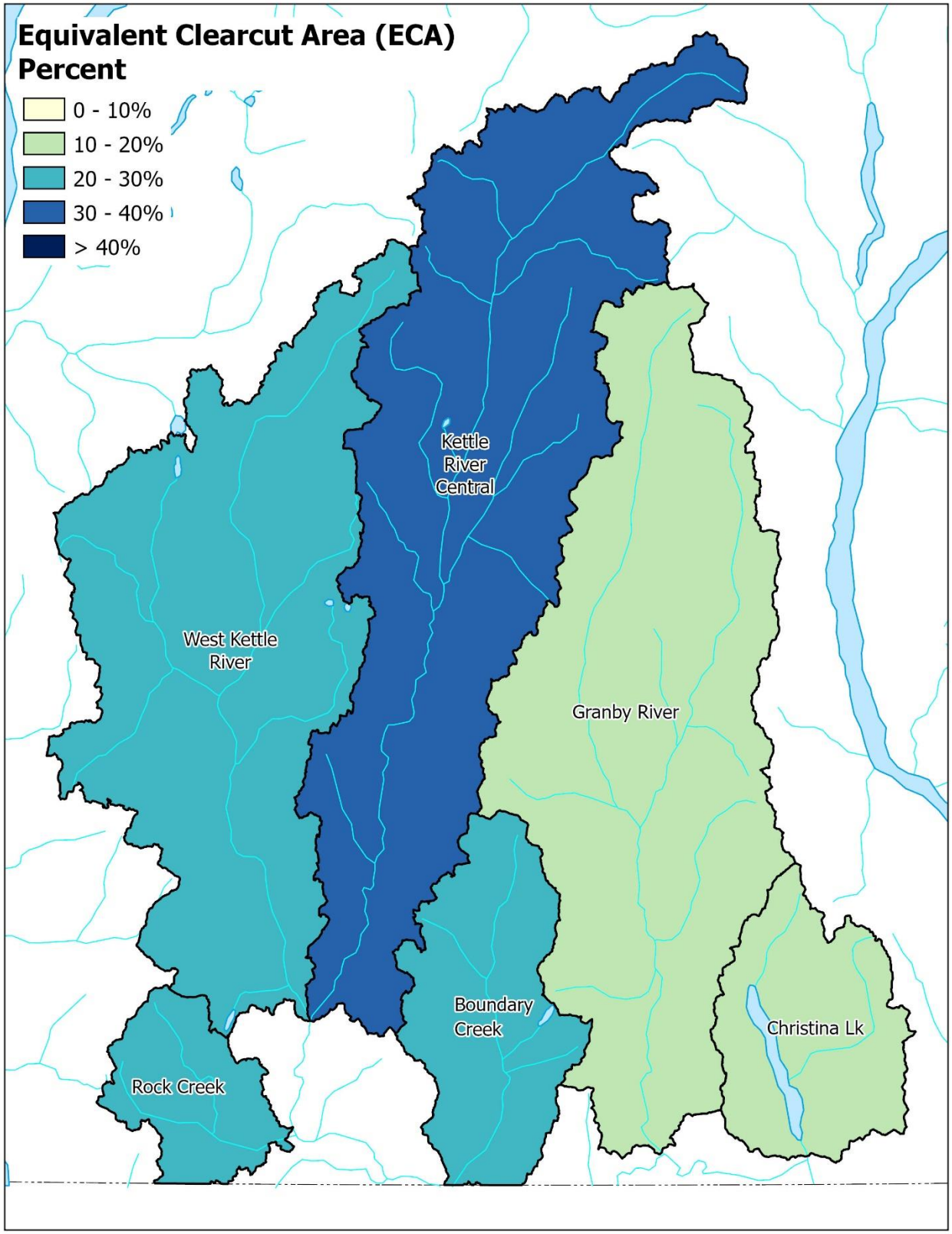


Figure A11. ***Equivalent Clearcut Area*** **indicator at the scale of the major sub-basins. Results were not calculated for portions of the basin that are in the U.S.**

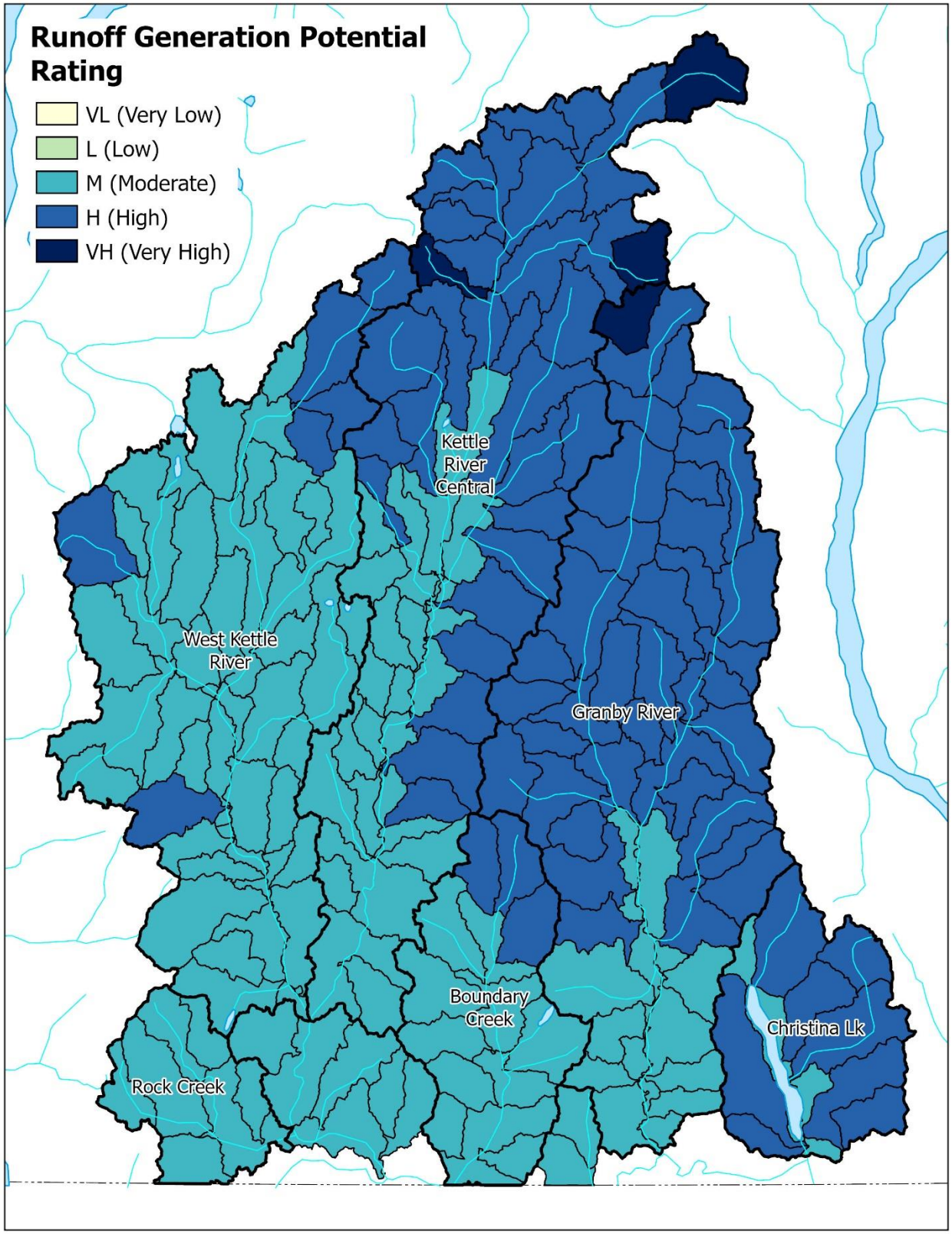


Figure A12. ***Runoff Generation Potential Rating*** **at the scale of the AWs. AWs are outlined in black, and the boundaries of the major sub-basins are indicated using thicker black lines. Results were not calculated for portions of the basin that are in the U.S.**

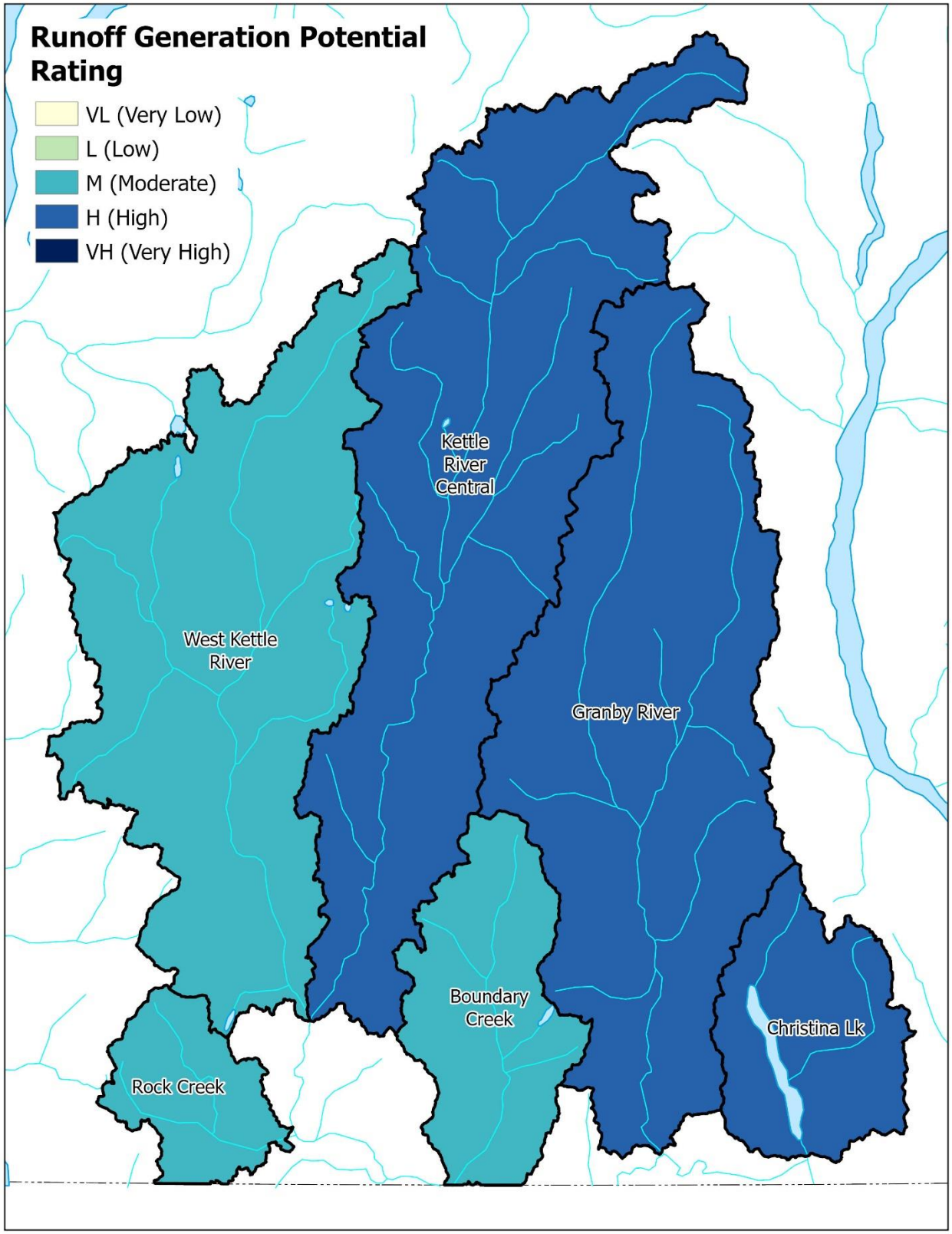


Figure A13. ***Runoff Generation Potential Rating*** **at the scale of the major sub-basins. Results were not calculated for portions of the basin that are in the U.S.**

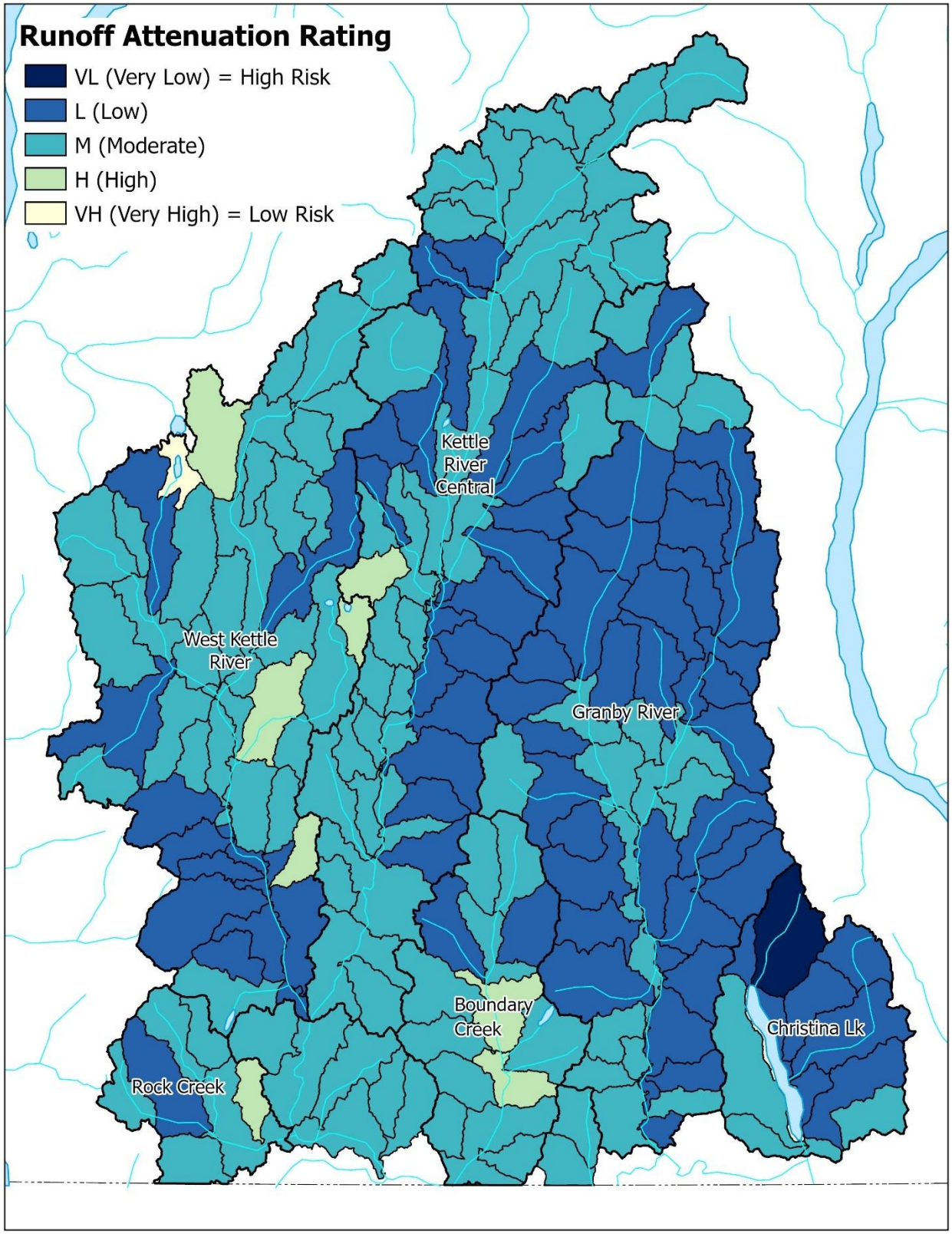


Figure A14. ***Runoff Attenuation Rating*** **at the scale of the AWs. AWs are outlined in black, and the boundaries of the major sub-basins are indicated using thicker black lines. Results were not calculated for portions of the basin that are in the U.S.**

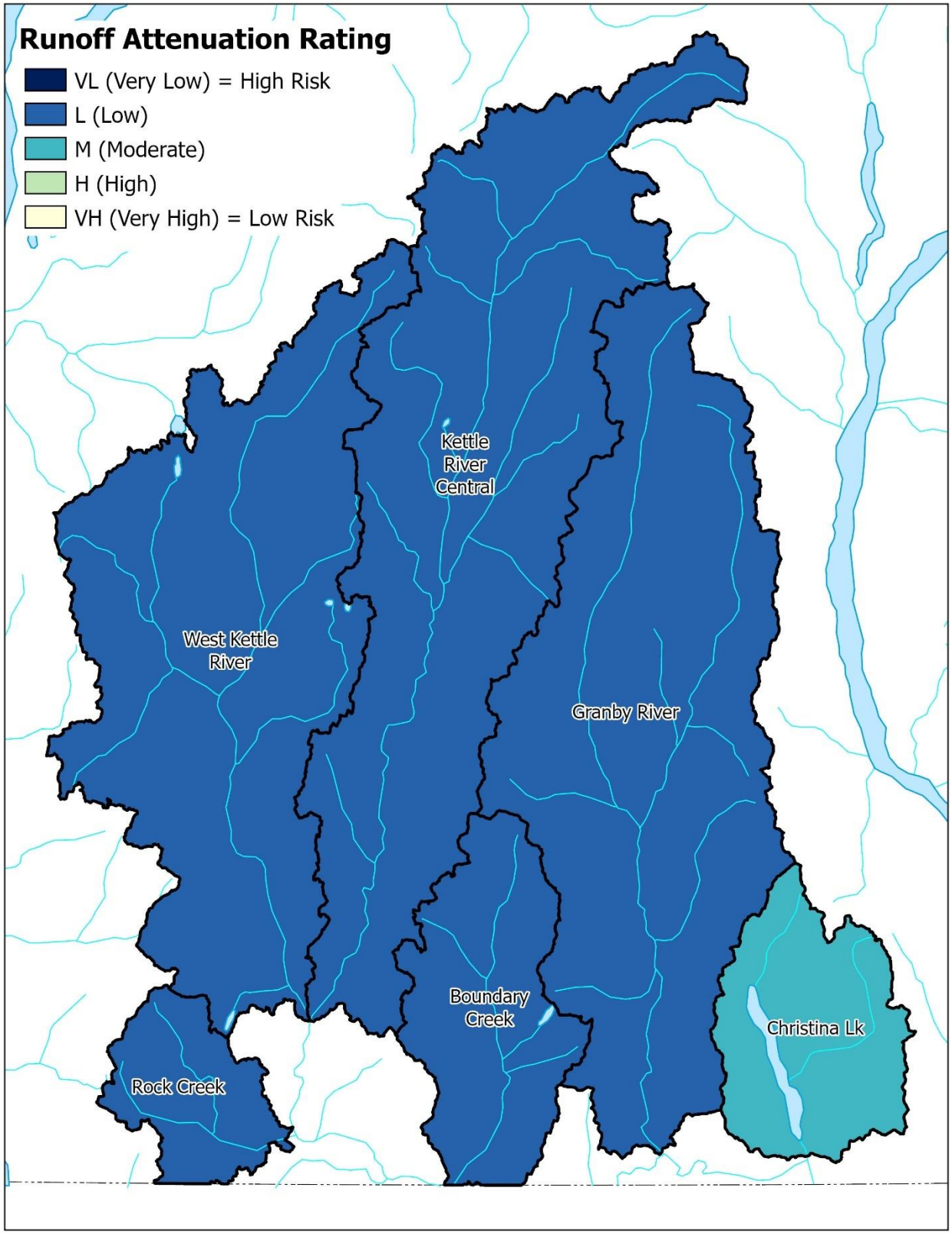


Figure A15. ***Runoff Attenuation Rating*** **at the scale of the major sub-basins. Results were not calculated for portions of the basin that are in the U.S.**

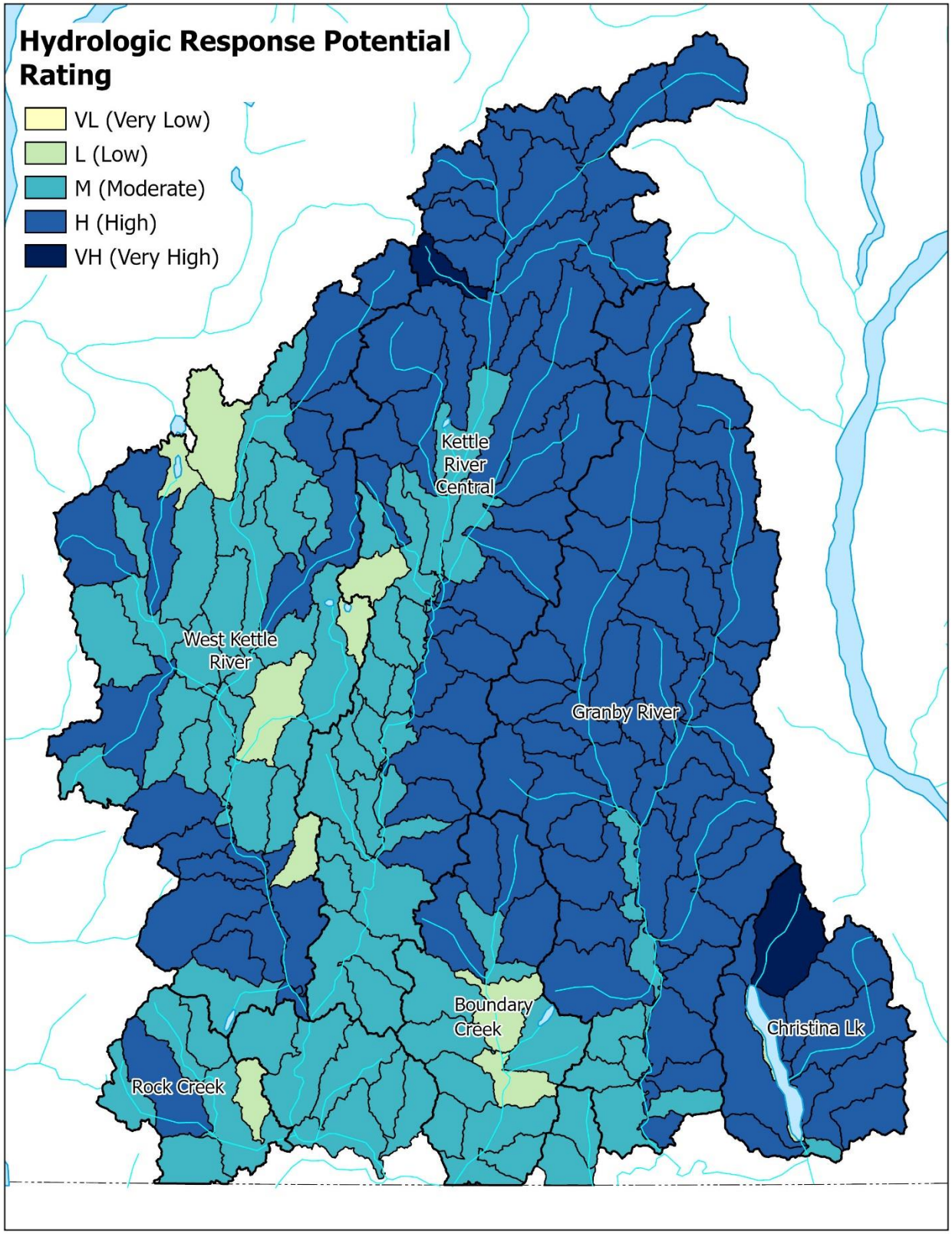


Figure A16. ***Hydrologic Response Potential Rating*** **at the scale of the AWs. AWs are outlined in black, and the boundaries of the major sub-basins are indicated using thicker black lines. Results were not calculated for portions of the basin that are in the U.S.**

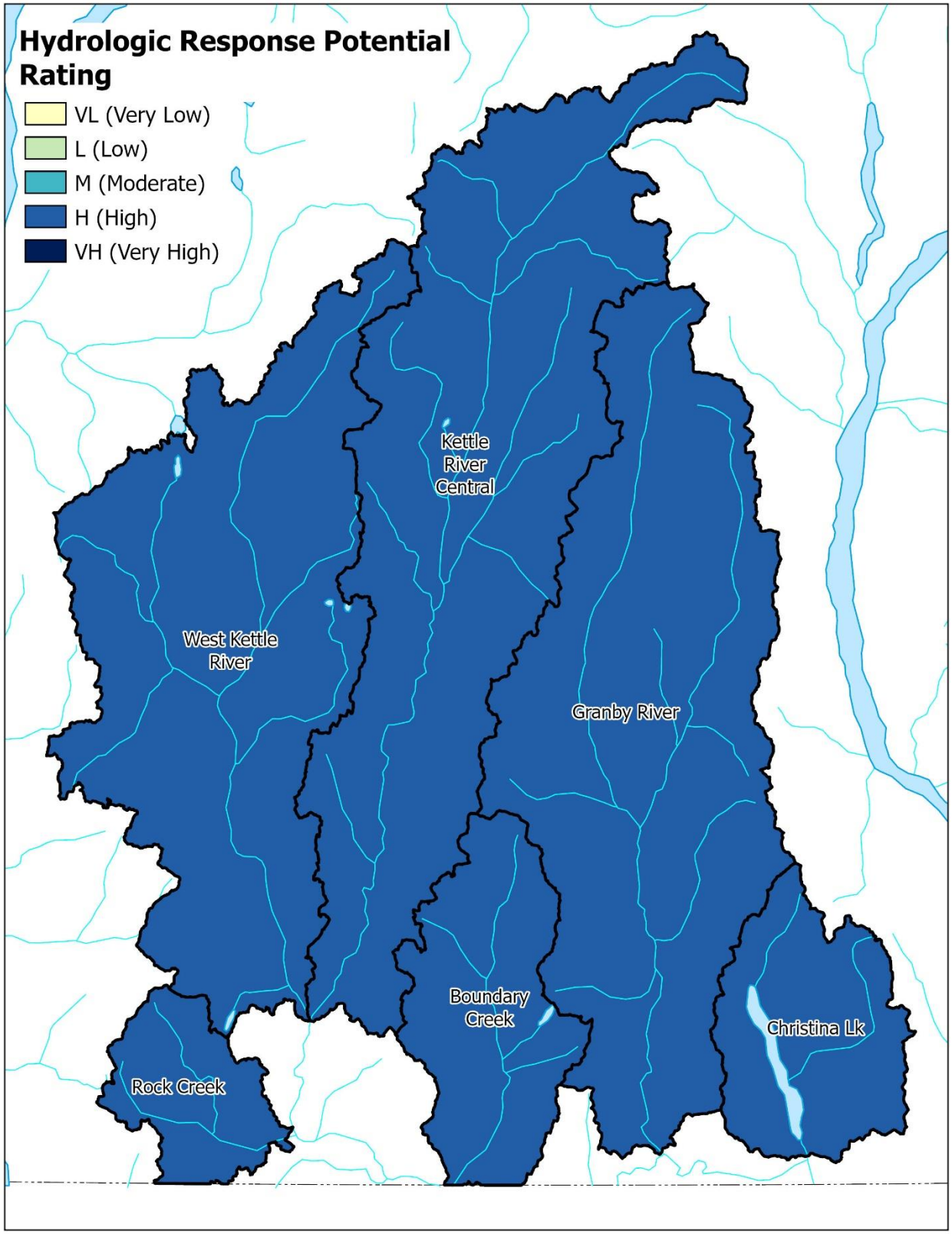


Figure A17. ***Hydrologic Response Potential Rating*** **at the scale of the major sub-basins. Results were not calculated for portions of the basin that are in the U.S.**

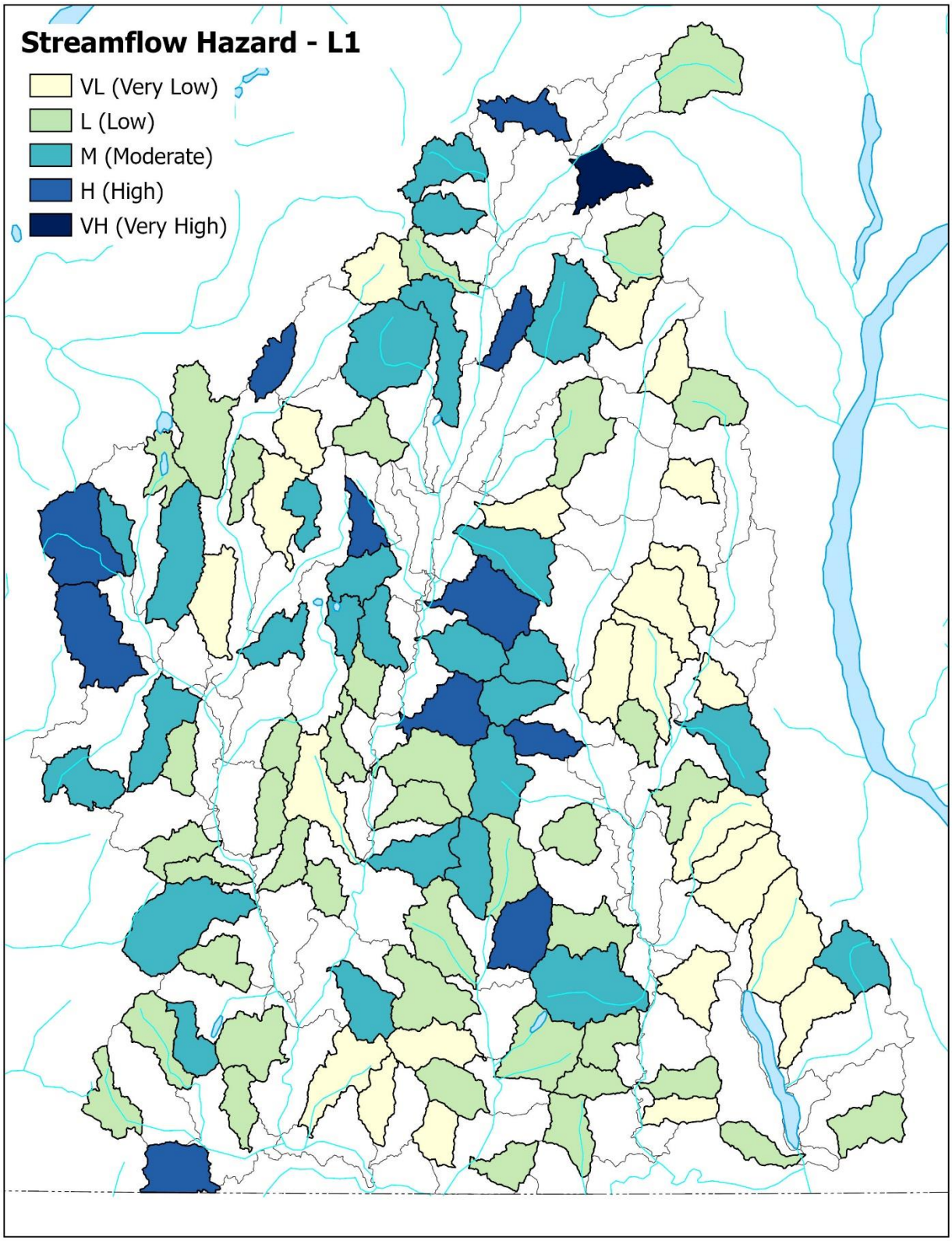


Figure A18. *Streamflow Hazard* rating at the L1 (headwater AW) scale. Results were not calculated for portions of the basin that are in the U.S.

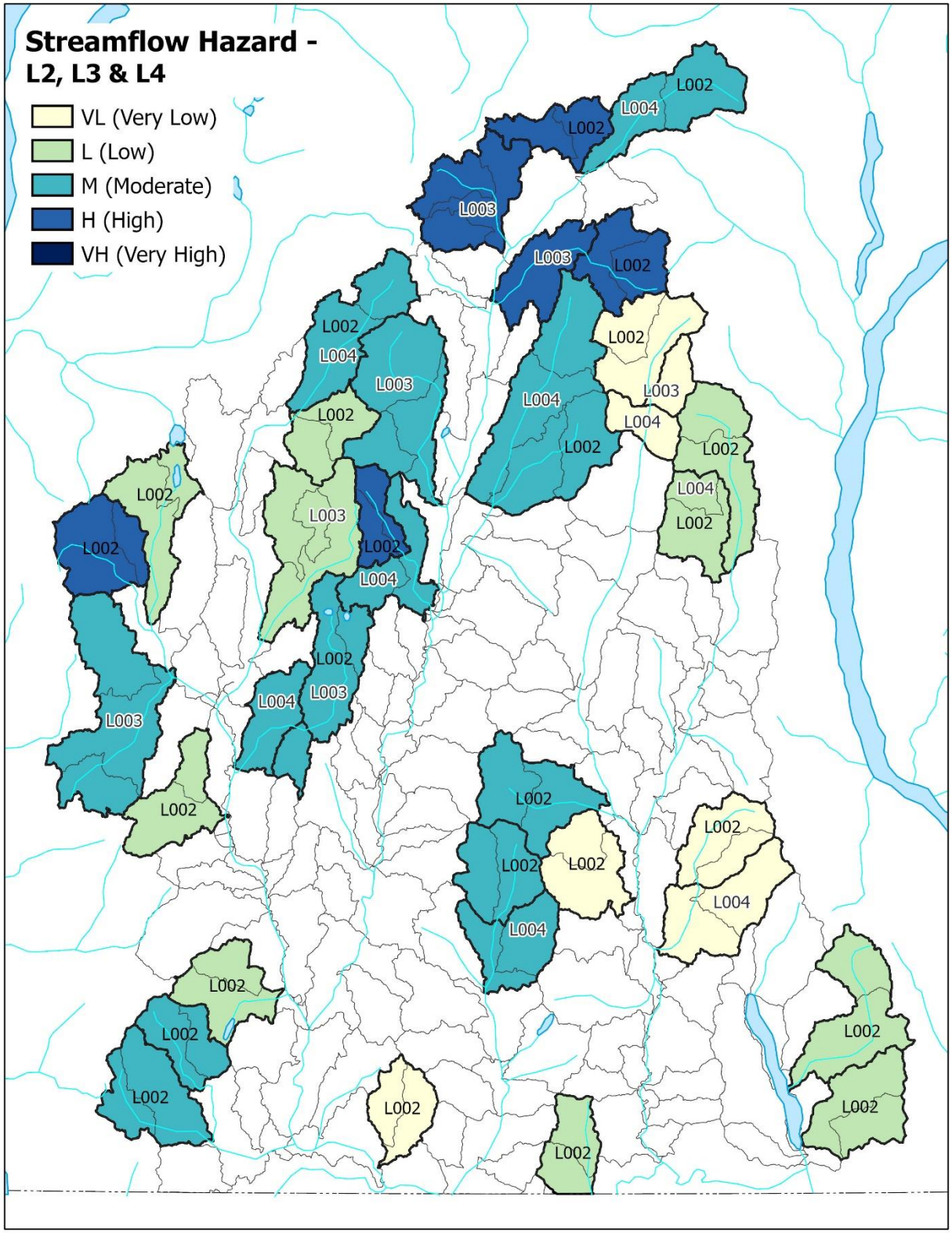


Figure A19. ***Streamflow Hazard Rating*** **at the L2, L3 and L4 scales. Results were not calculated for portions of the basin that are in the U.S.**

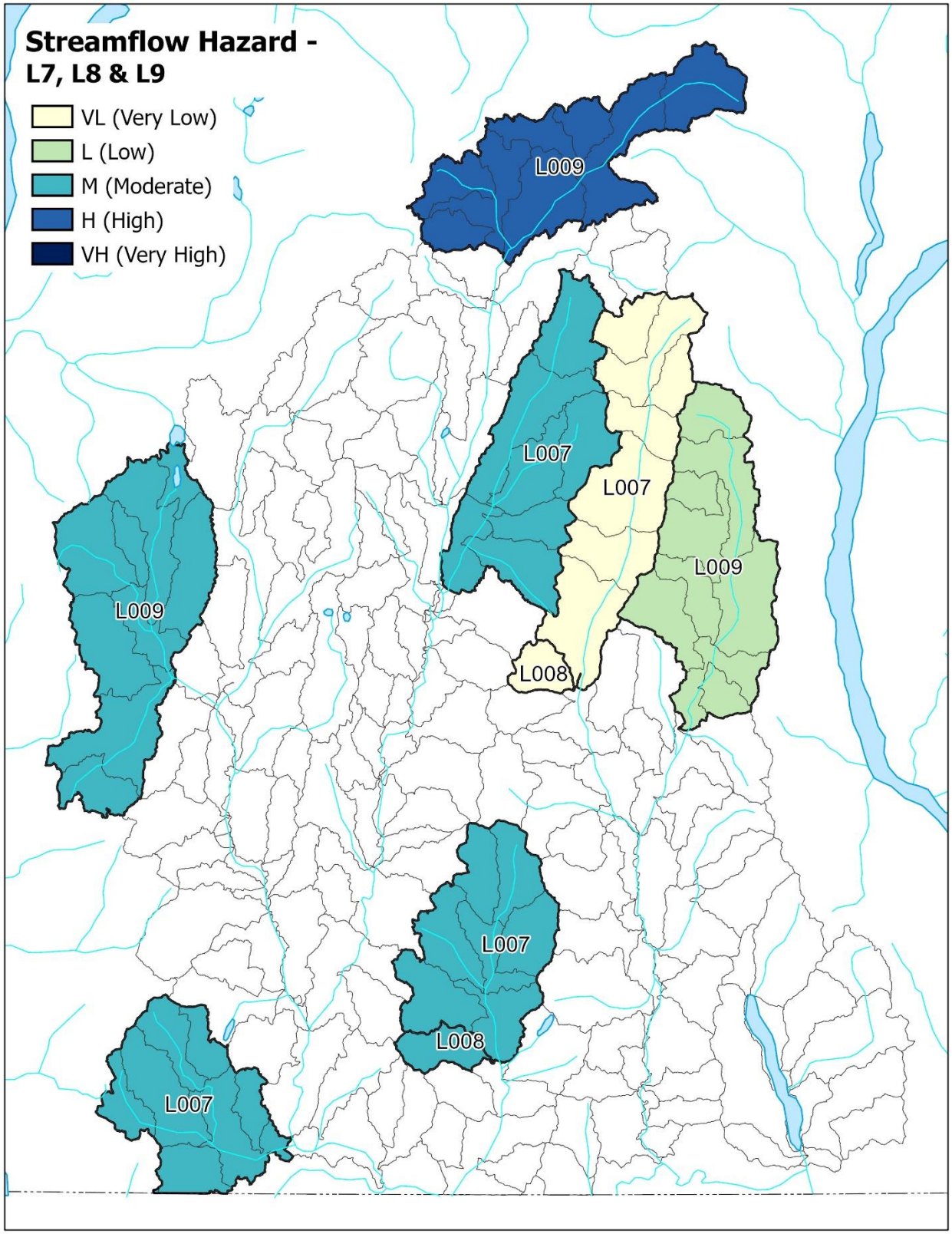


Figure A20. ***Streamflow Hazard Rating*** **at the L7, L8 and L9 scales. Results were not calculated for portions of the basin that are in the U.S.**

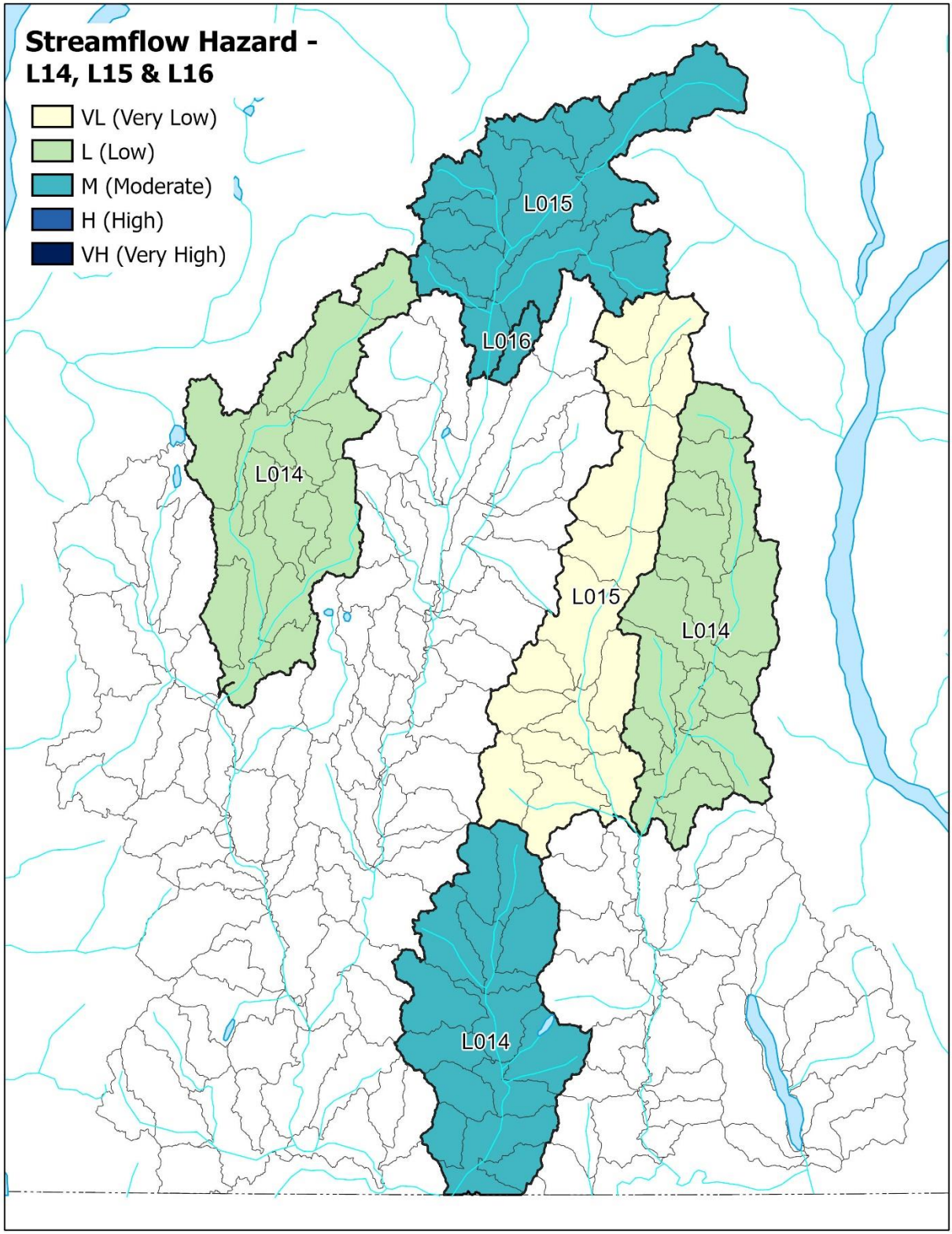


Figure A21. ***Streamflow Hazard Rating*** **at the L14, L15 and L16 scales. Results were not calculated for portions of the basin that are in the U.S.**

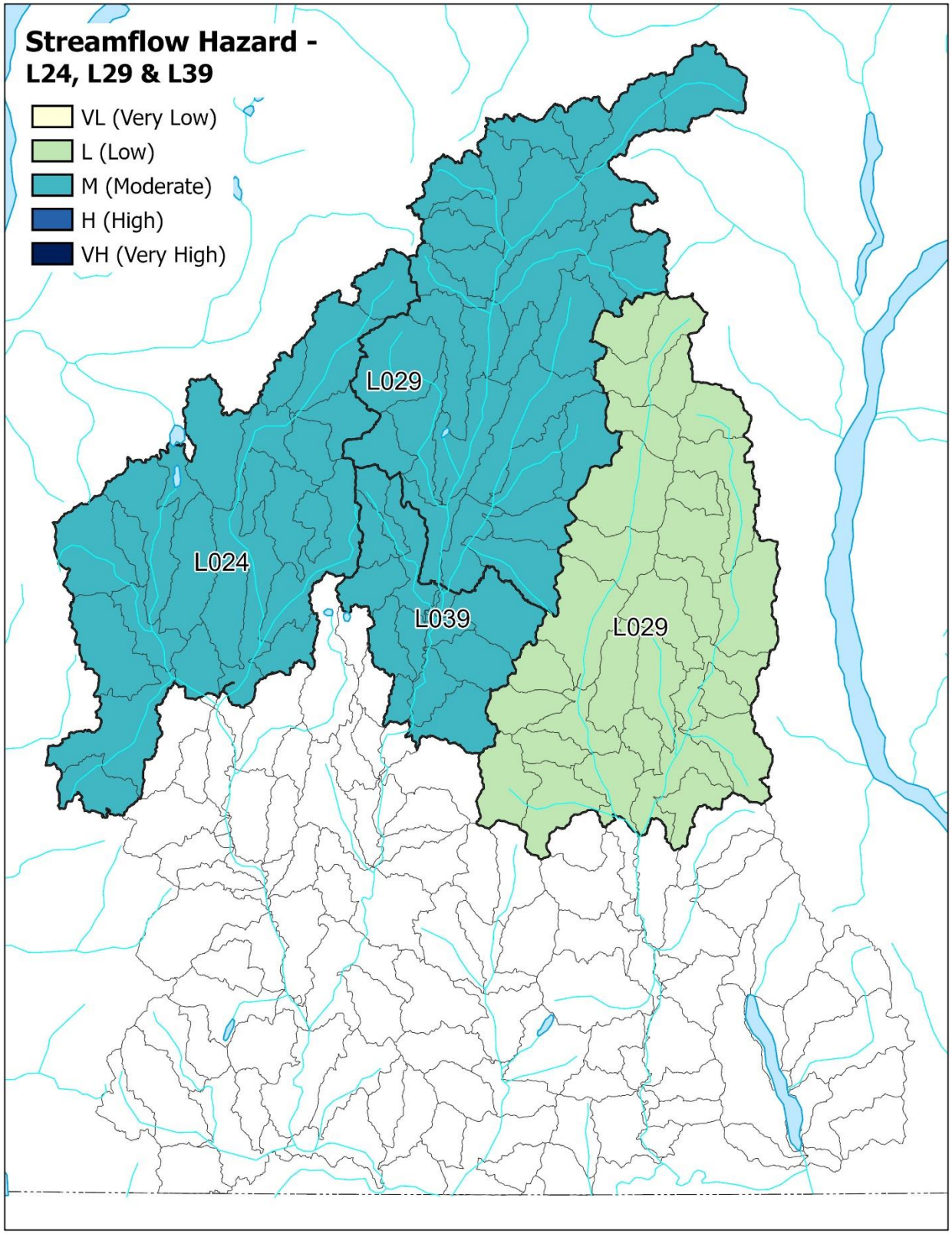


Figure A22. ***Streamflow Hazard Rating*** **at the L24, L29 and L39 scales. Results were not calculated for portions of the basin that are in the U.S.**

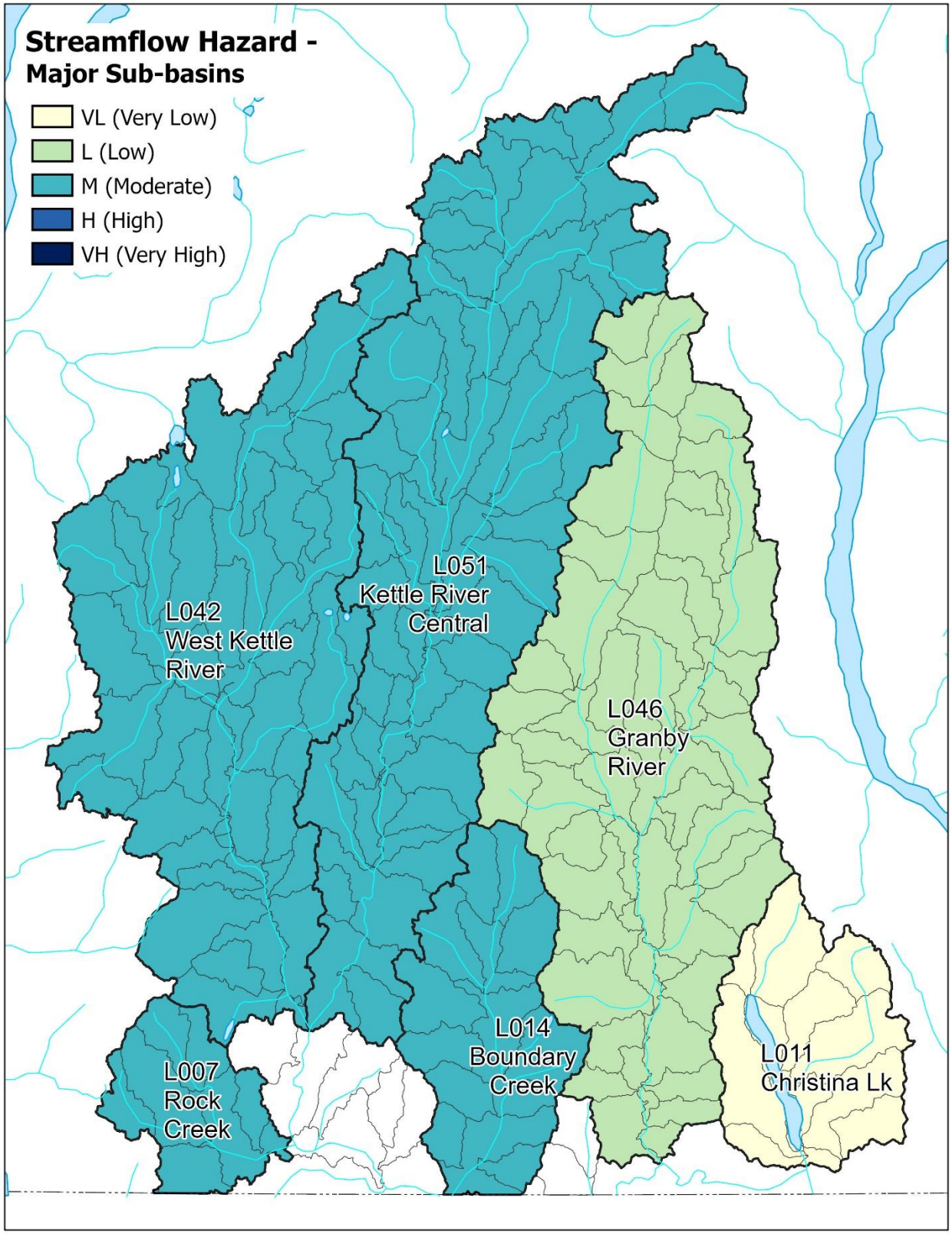


Figure A23. ***Streamflow Hazard Rating*** **at the major sub-basin scale. Results were not calculated for portions of the basin that are in the U.S.**

Appendix B *Sedimentation Hazard* Indicator and Rating Maps

Maps are presented here for all of the GIS indicators, intermediate ratings and final ratings for the *Sedimentation Hazard* rating. They are presented in the order indicated in the flowchart (Figure B1), from left to right (i.e. first the GIS indicators, second the combined potential or disturbance rating, third the combined potential rating and lastly the hazard rating) and from top to bottom.

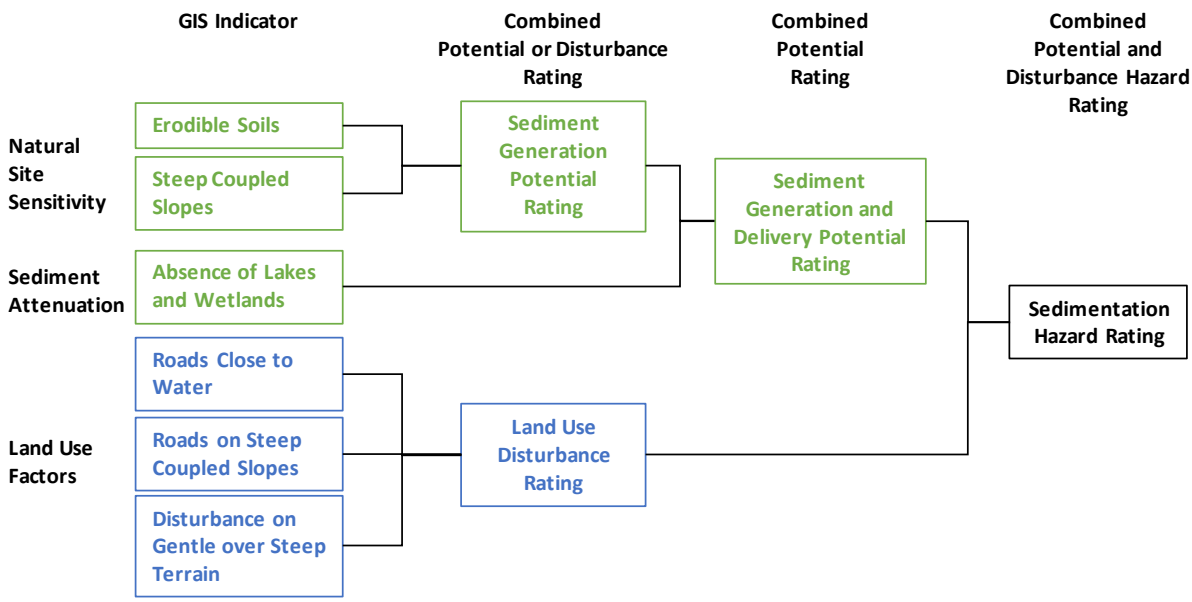


Figure B1. Flowchart used to derive the *Sedimentation Hazard Rating.*

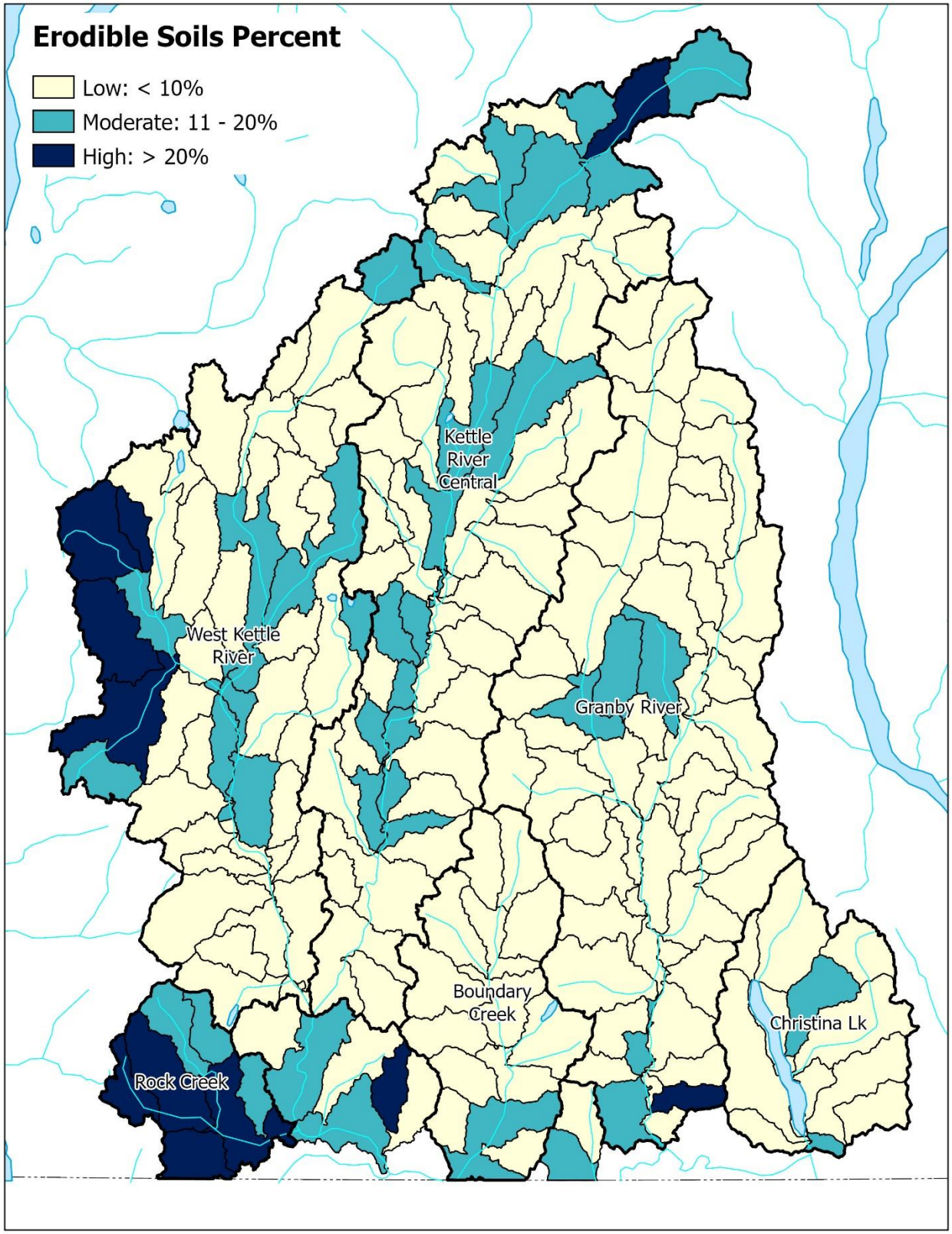


Figure B2. ***Erodible Soils*** **indicator at the scale of the AWs. AWs are outlined in black, and the boundaries of the major sub-basins are indicated using thicker black lines. Results were not calculated for portions of the basin that are in the U.S.**

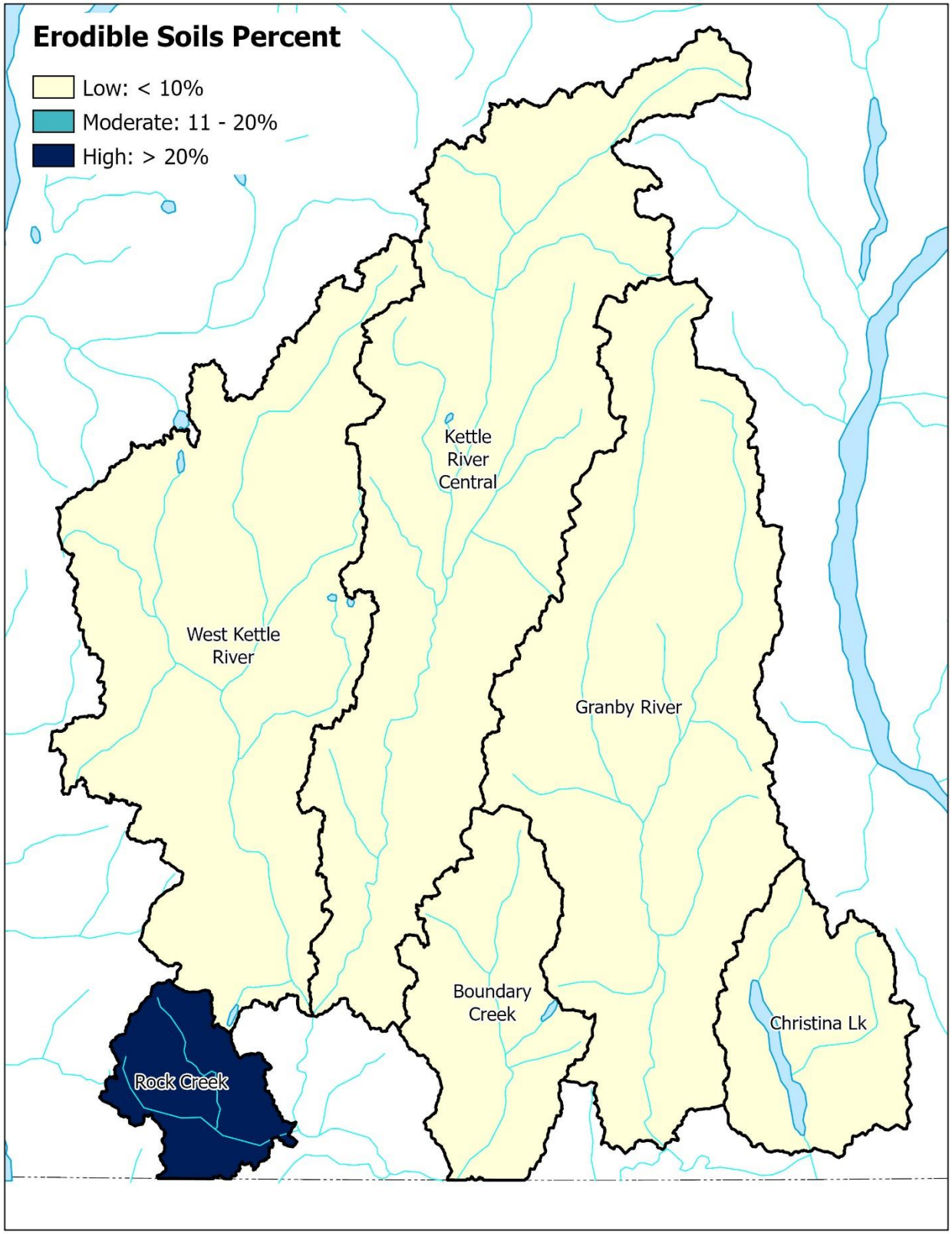


Figure B3. ***Erodible Soils*** **indicator at the scale of the major sub-basins. Results were not calculated for portions of the basin that are in the U.S.**

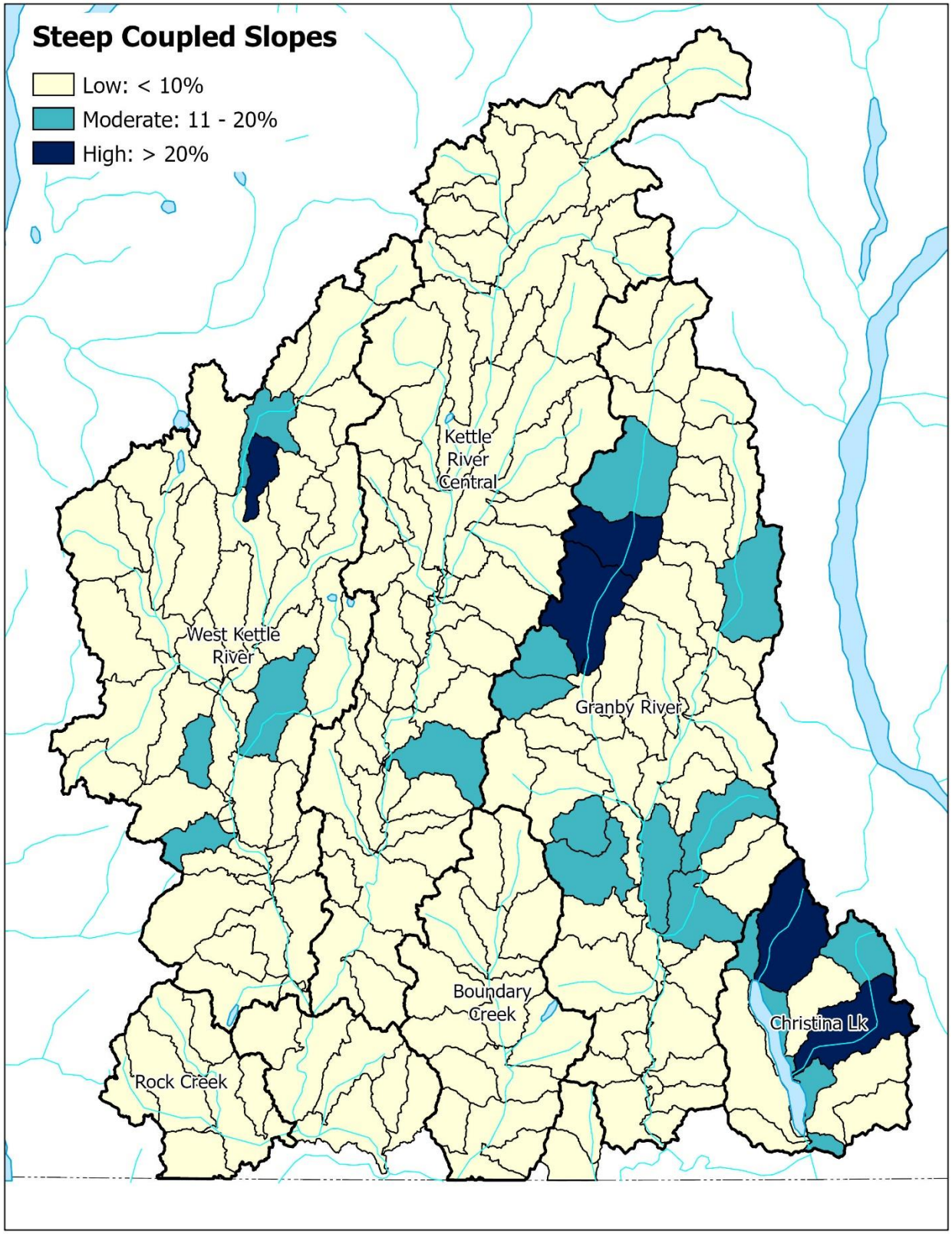


Figure B4. ***Steep Coupled Slopes*** **indicator at the scale of the AWs. AWs are outlined in black, and the boundaries of the major sub-basins are indicated using thicker black lines. Results were not calculated for portions of the basin that are in the U.S.**

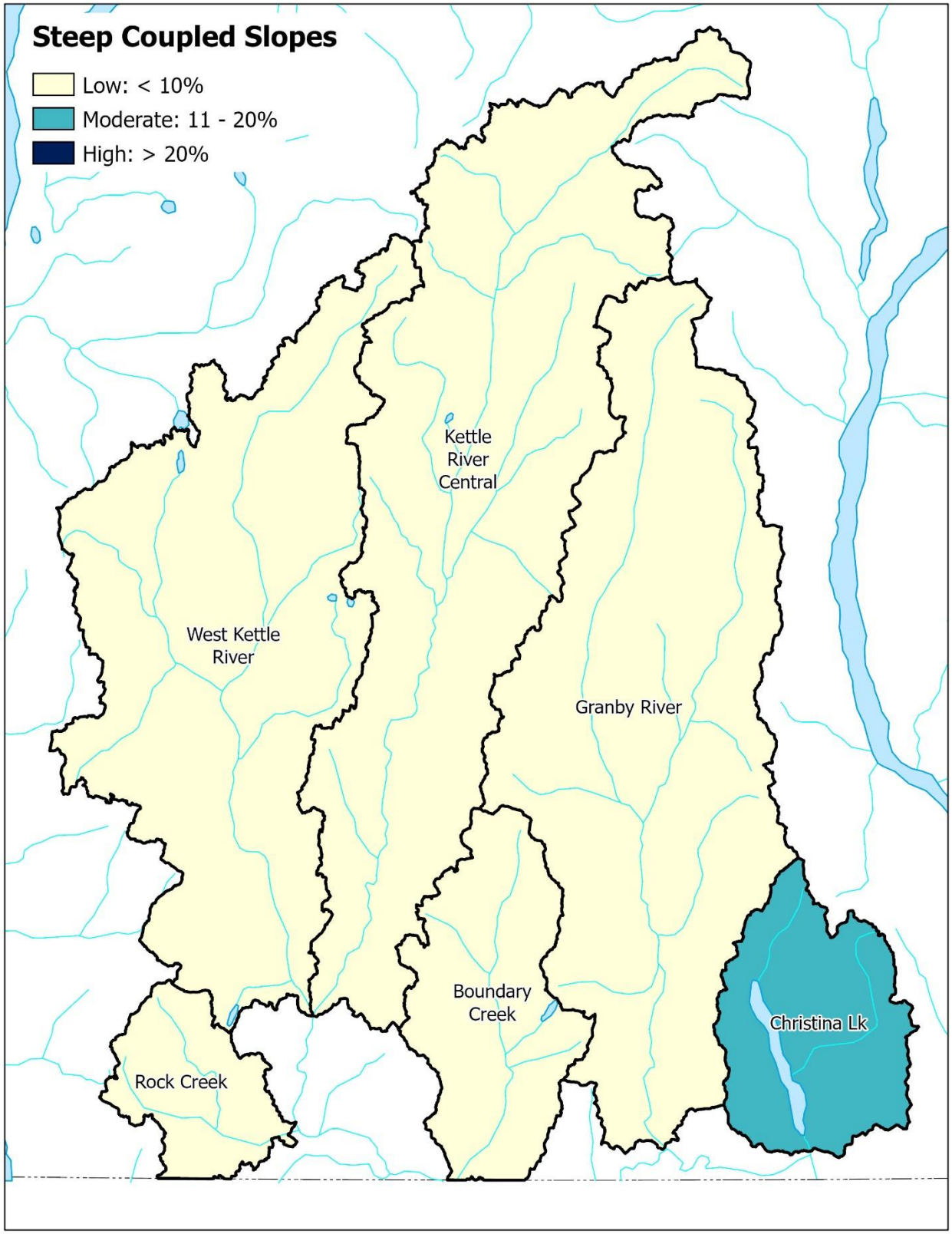


Figure B5. ***Steep Coupled Slopes*** **indicator at the scale of the major sub-basins. Results were not calculated for portions of the basin that are in the U.S.**

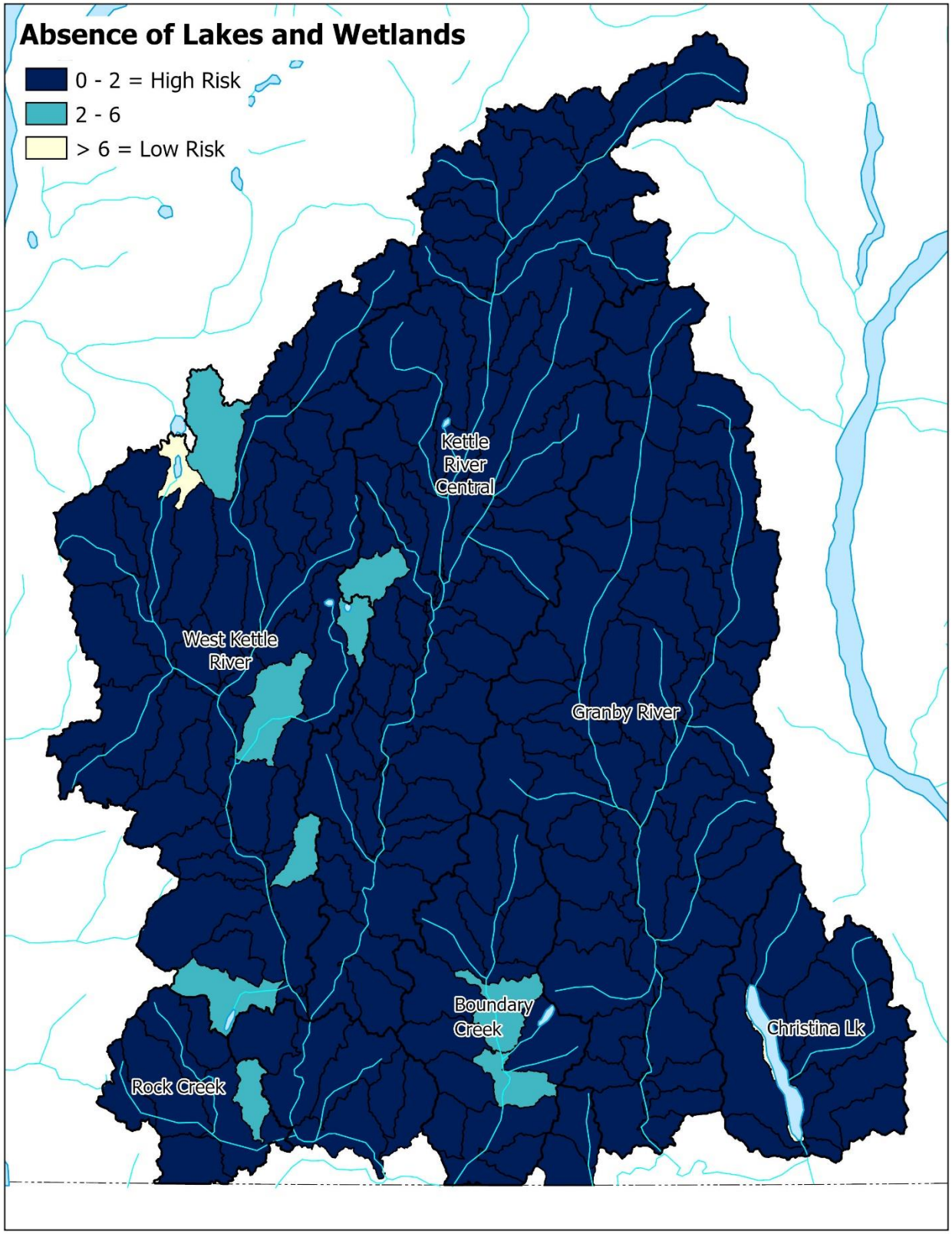


Figure B6. ***Absence of Lakes and Wetlands*** **indicator at the scale of the AWs. AWs are outlined in black, and the boundaries of the major sub-basins are indicated using thicker black lines. Results were not calculated for portions of the basin that are in the U.S.**

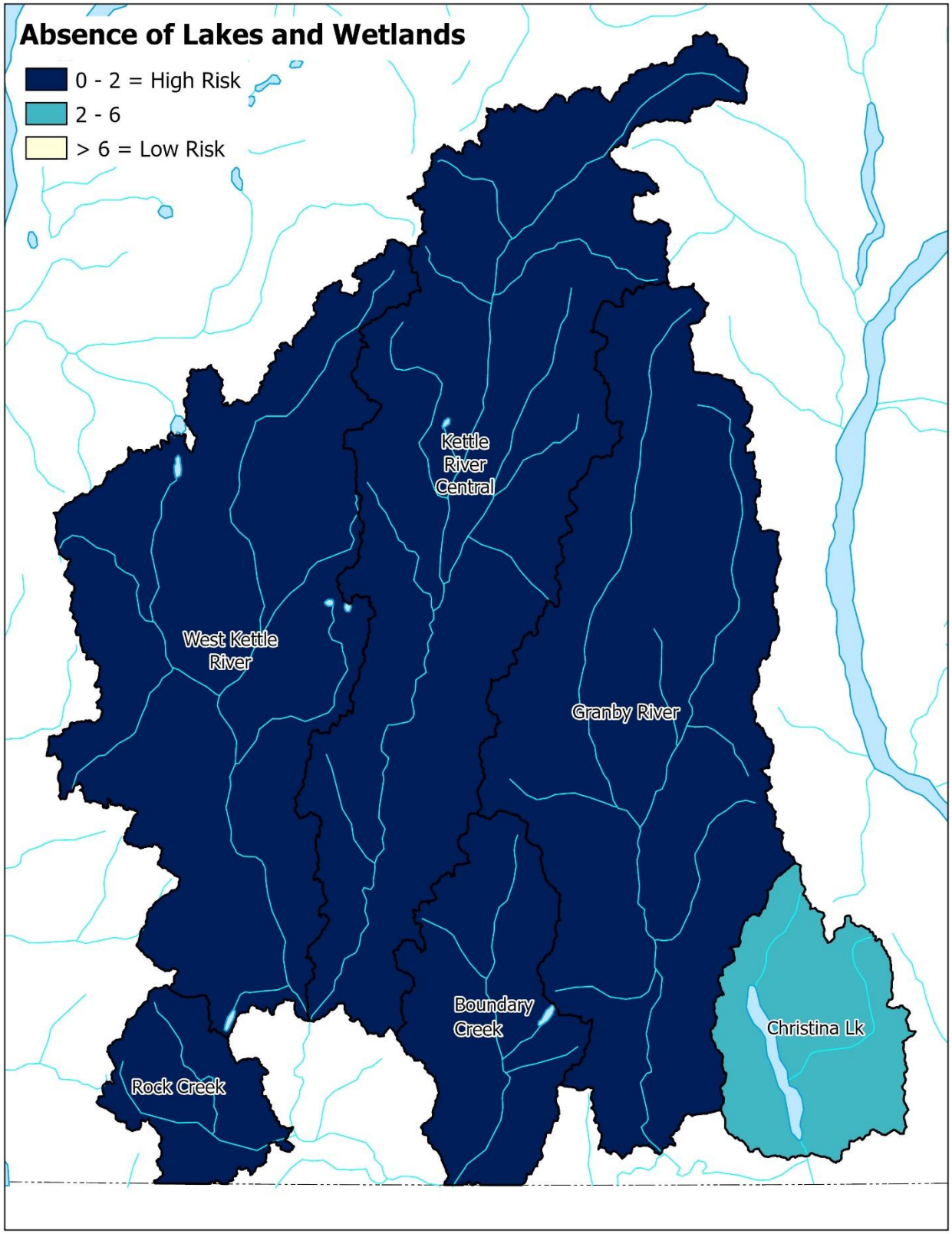


Figure B7. ***Absence of Lakes and Wetlands*** **indicator at the scale of the major sub-basins. Results were not calculated for portions of the basin that are in the U.S.**

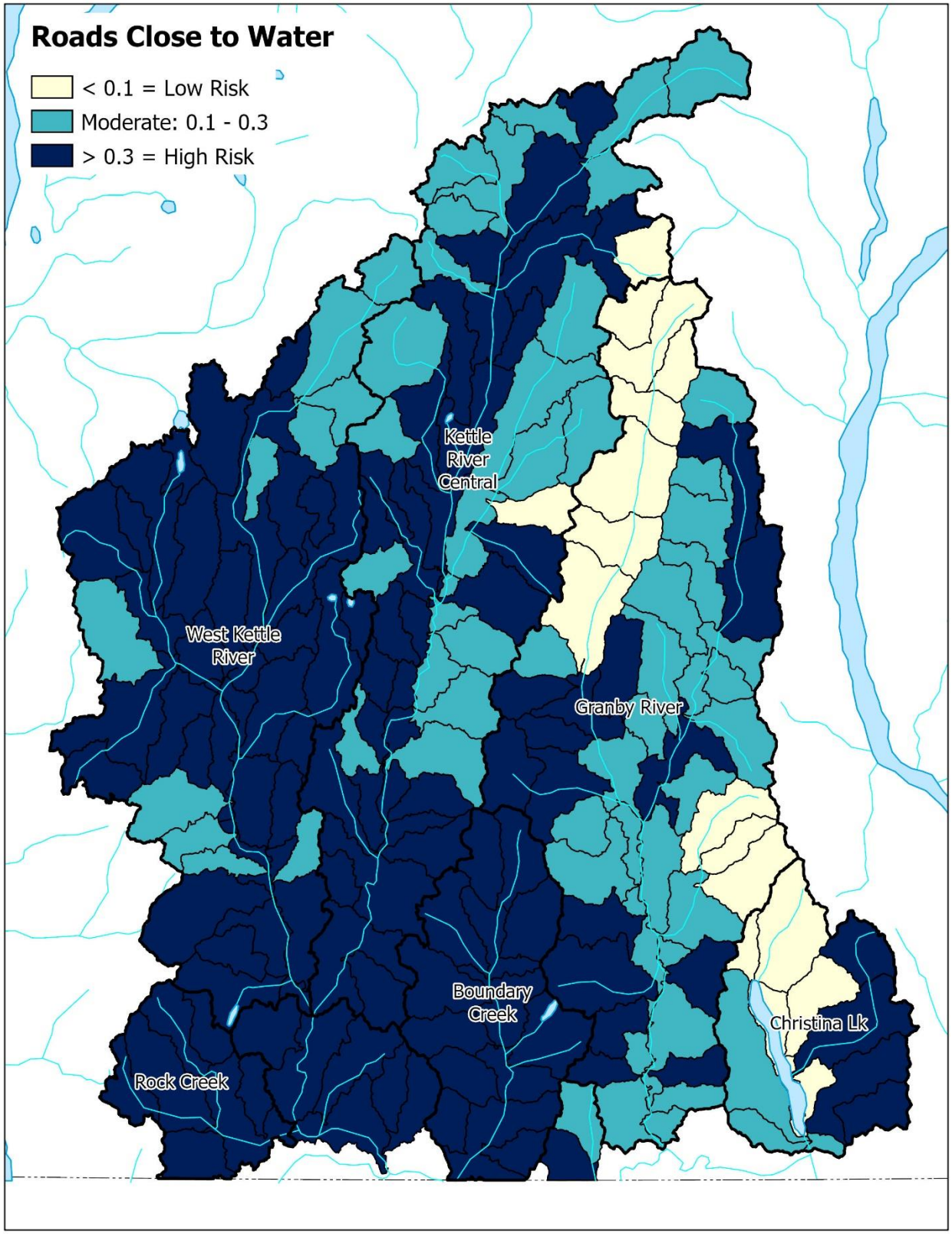


Figure B8. ***Roads Close to Water*** **indicator at the scale of the AWs. AWs are outlined in black, and the boundaries of the major sub-basins are indicated using thicker black lines. Results were not calculated for portions of the basin that are in the U.S.**

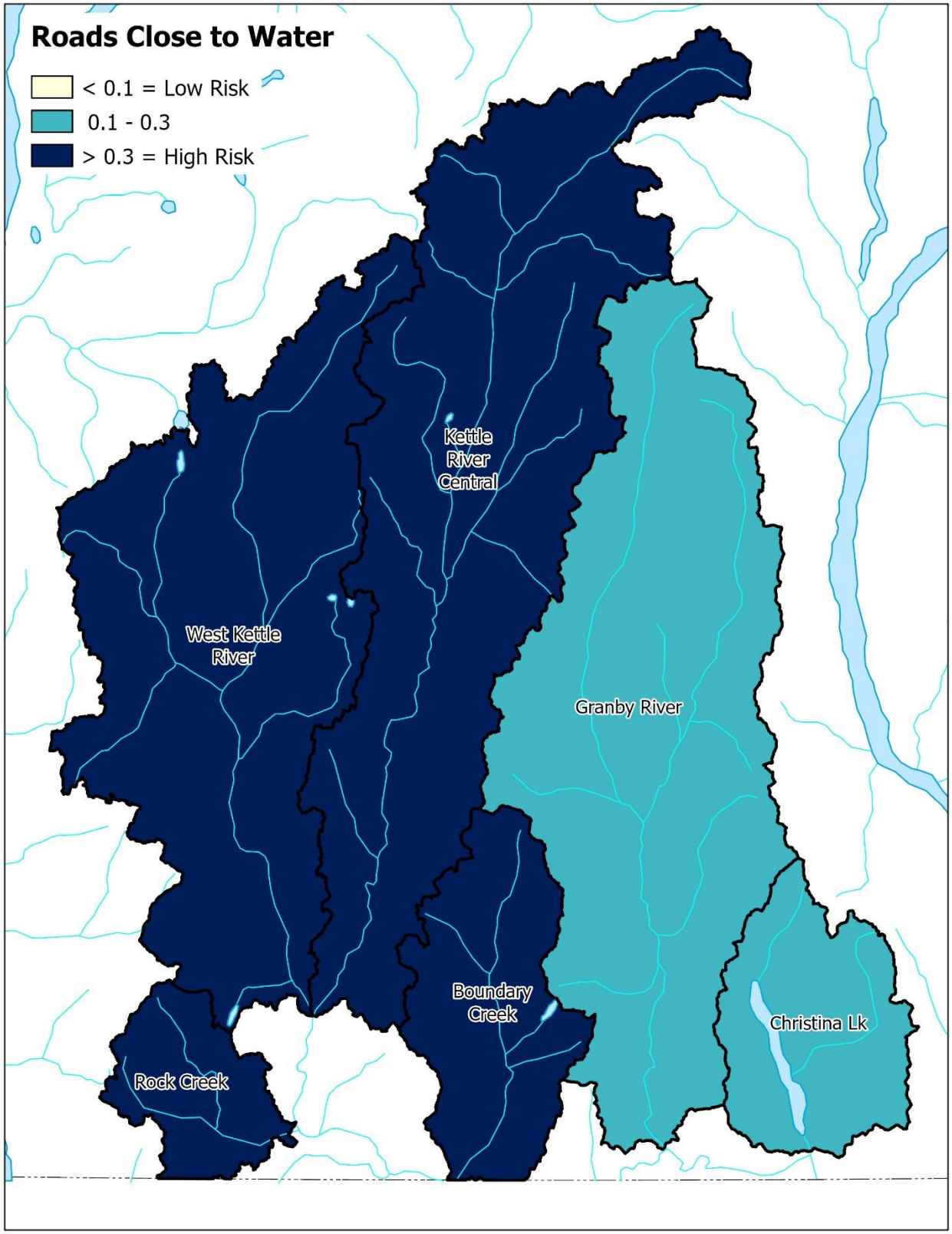


Figure B9. ***Roads Close to Water*** **indicator at the scale of the major sub-basins. Results were not calculated for portions of the basin that are in the U.S.**

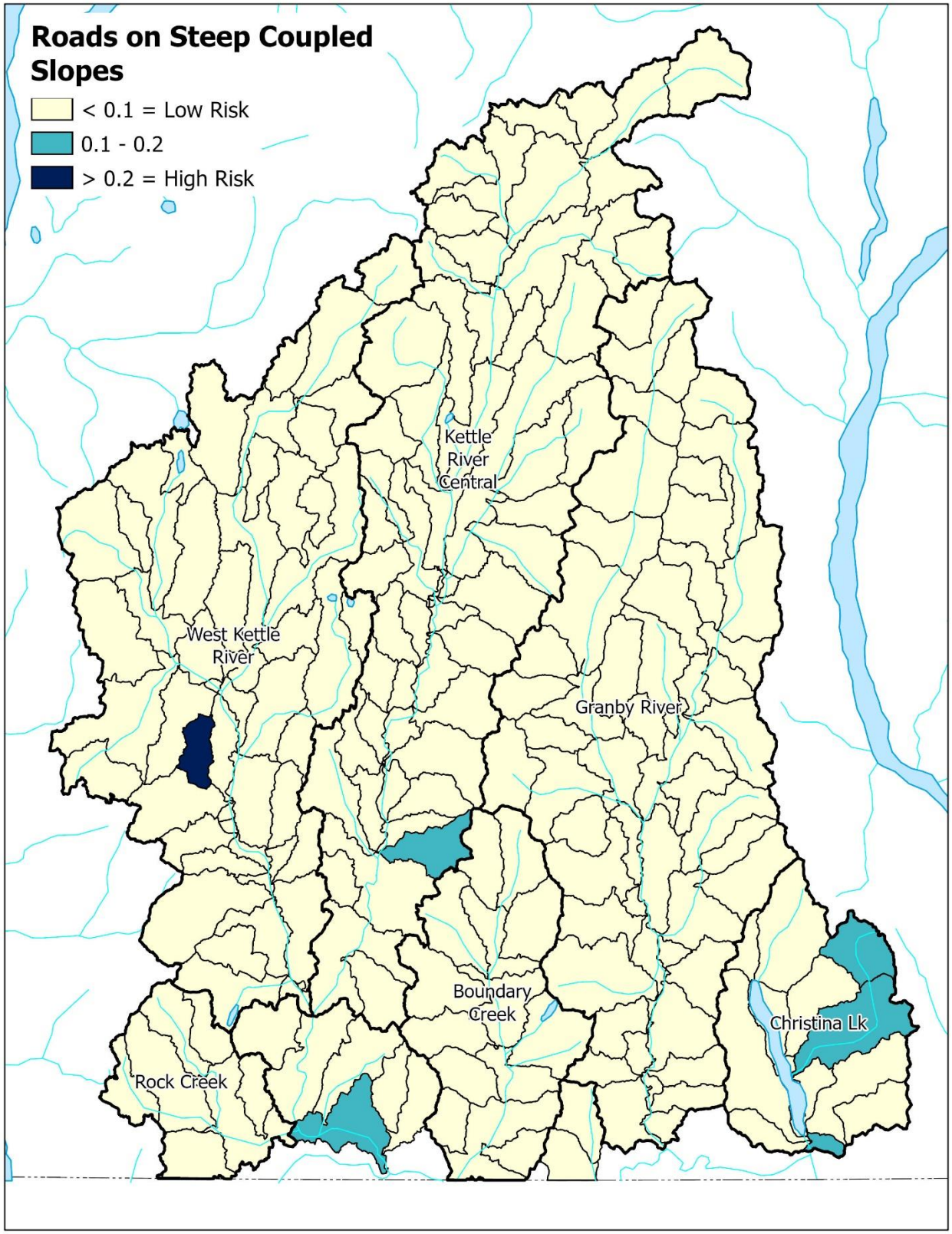


Figure B10. ***Roads on Steep Coupled Slopes*** **indicator at the scale of the AWs. AWs are outlined in black, and the boundaries of the major sub-basins are indicated using thicker black lines. Results were not calculated for portions of the basin that are in the U.S.**

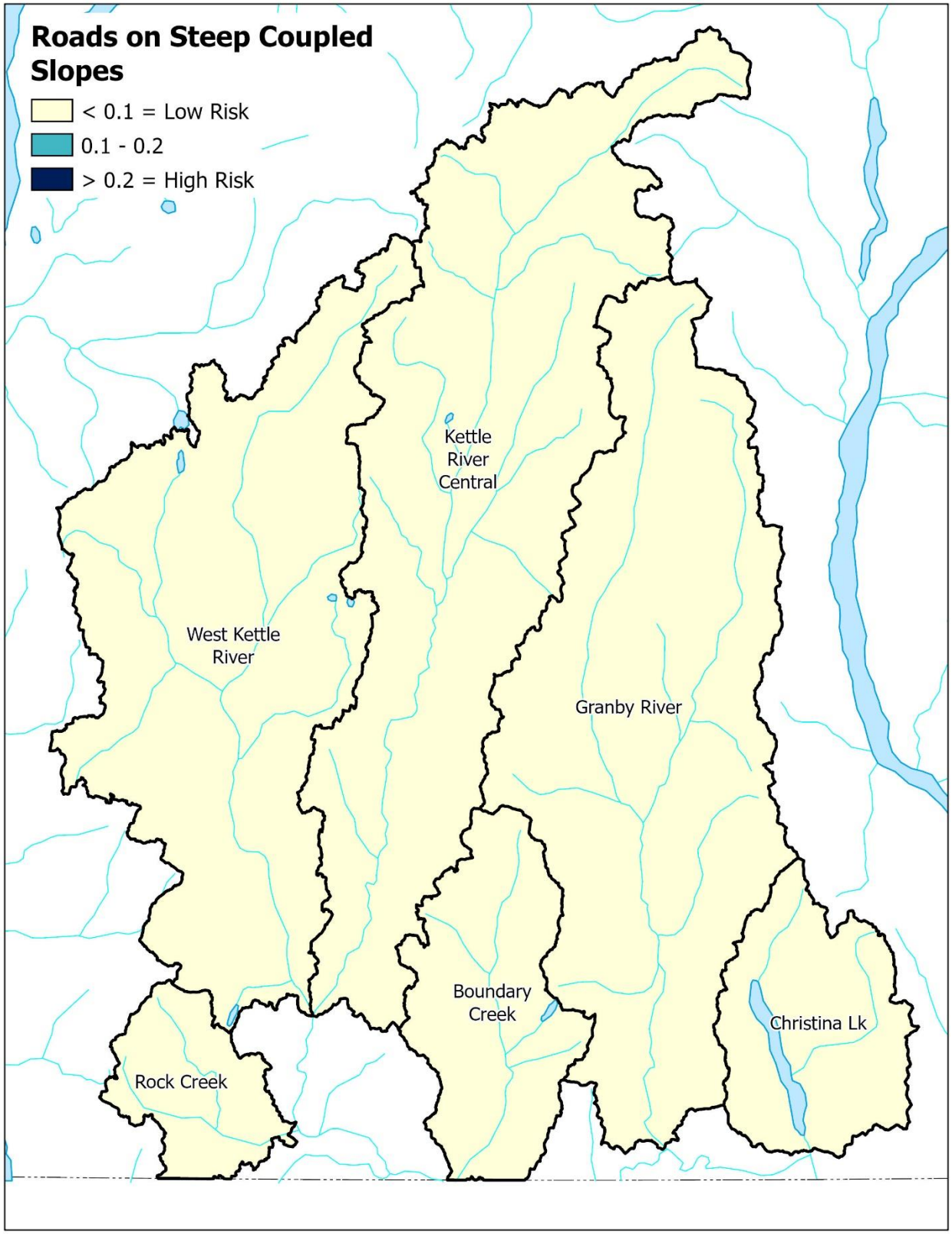


Figure B11. ***Roads on Steep Coupled Slopes*** **indicator at the scale of the major sub-basins. Results were not calculated for portions of the basin that are in the U.S.**

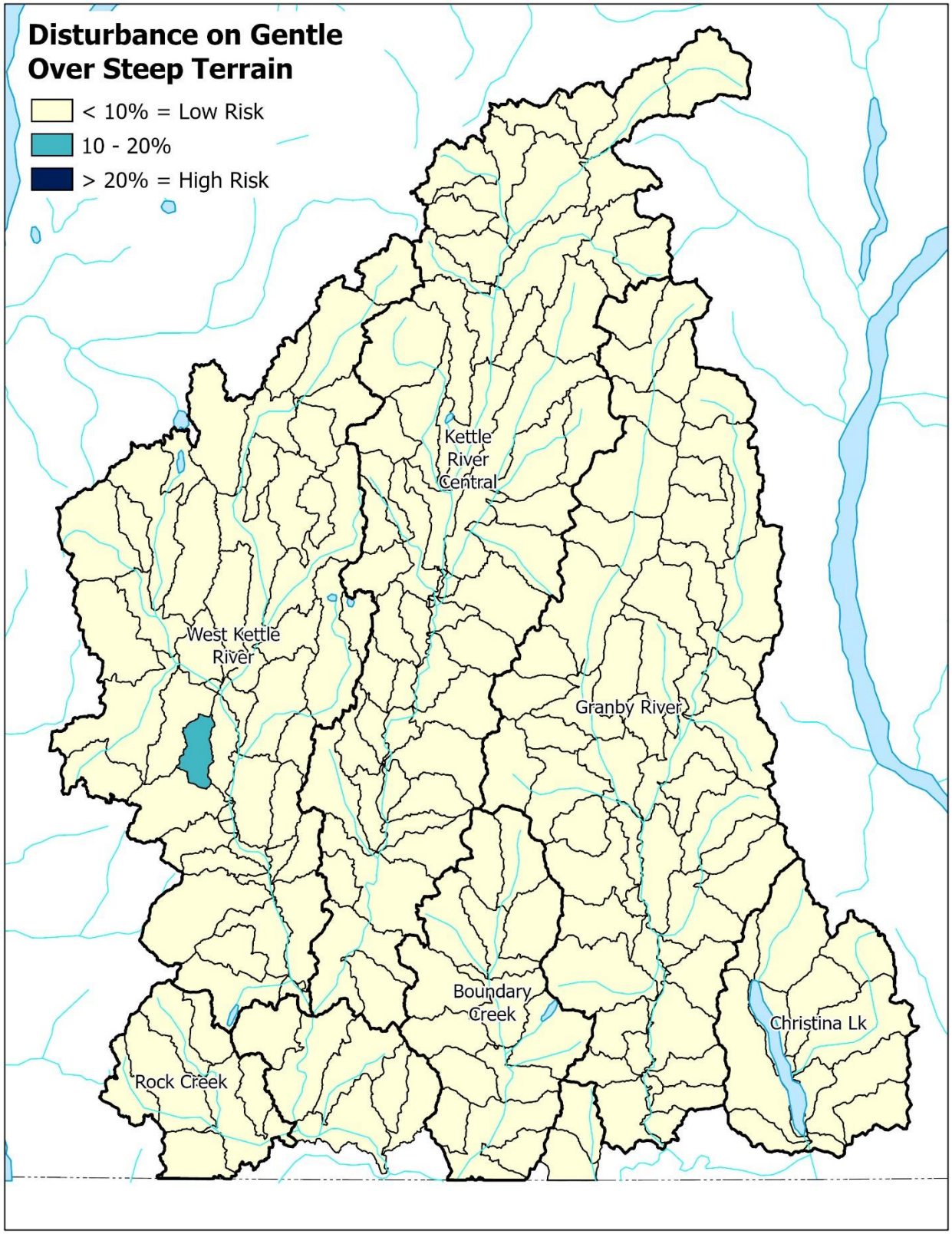


Figure B12. ***Disturbance on Gentle over Steep Terrain*** **indicator at the scale of the AWs. AWs are outlined in black, and the boundaries of the major sub-basins are indicated using thicker black lines. Results were not calculated for portions of the basin that are in the U.S.**

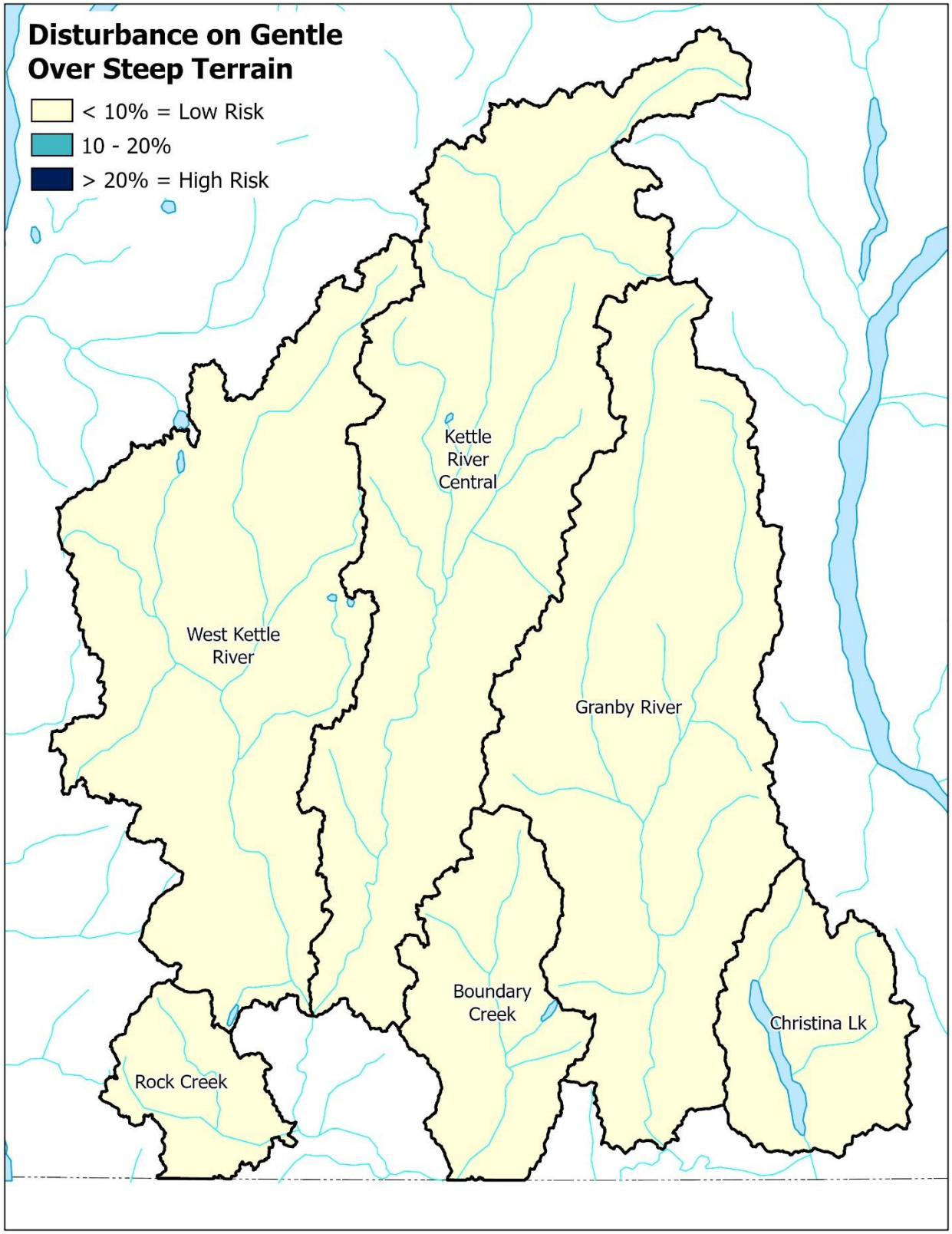


Figure B13. ***Disturbance on Gentle over Steep Terrain*** **indicator at the scale of the major sub-basins. Results were not calculated for portions of the basin that are in the U.S.**

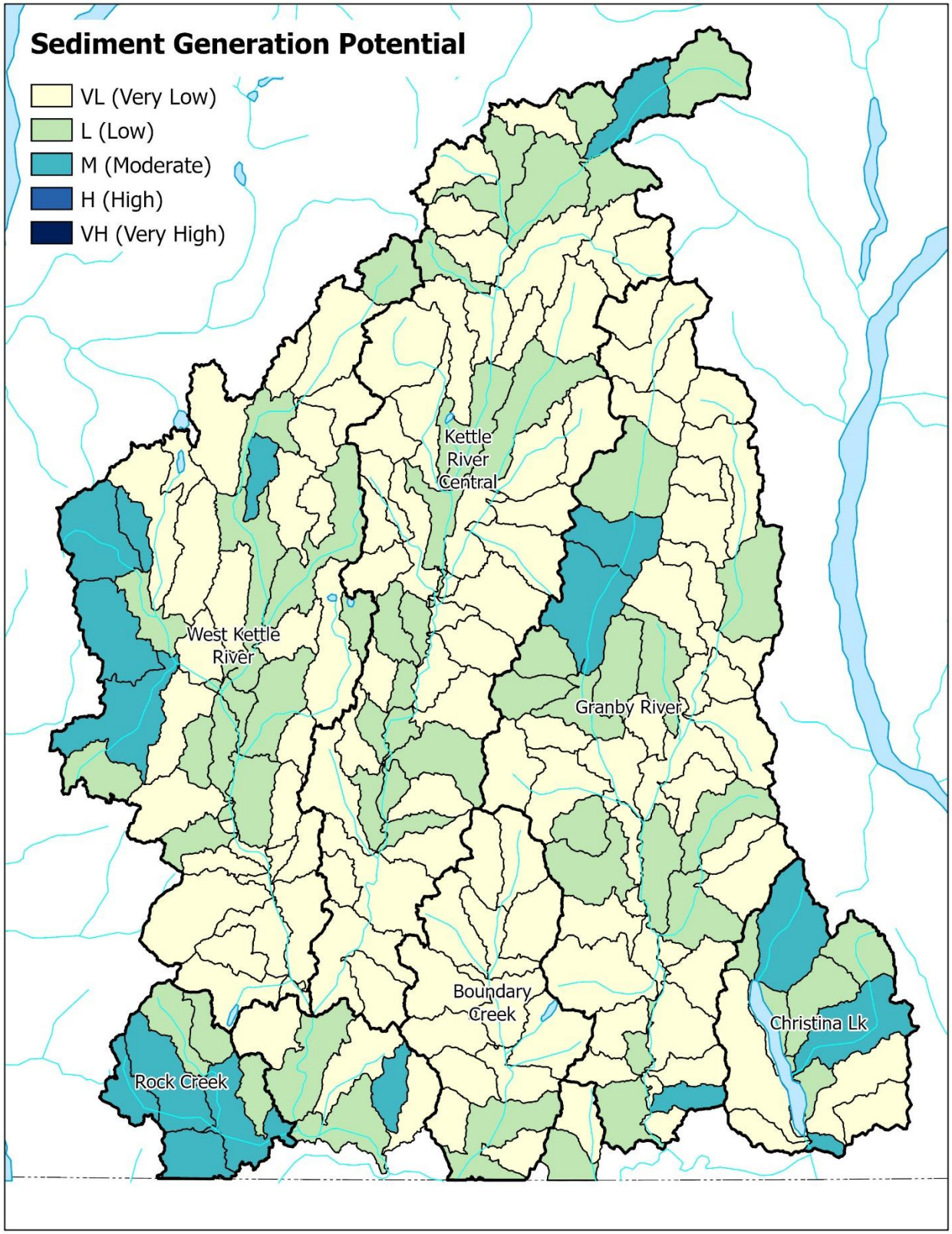


Figure B14. ***Sediment Generation Potential Rating*** **at the scale of the AWs. AWs are outlined in black, and the boundaries of the major sub-basins are indicated using thicker black lines. Results were not calculated for portions of the basin that are in the U.S.**

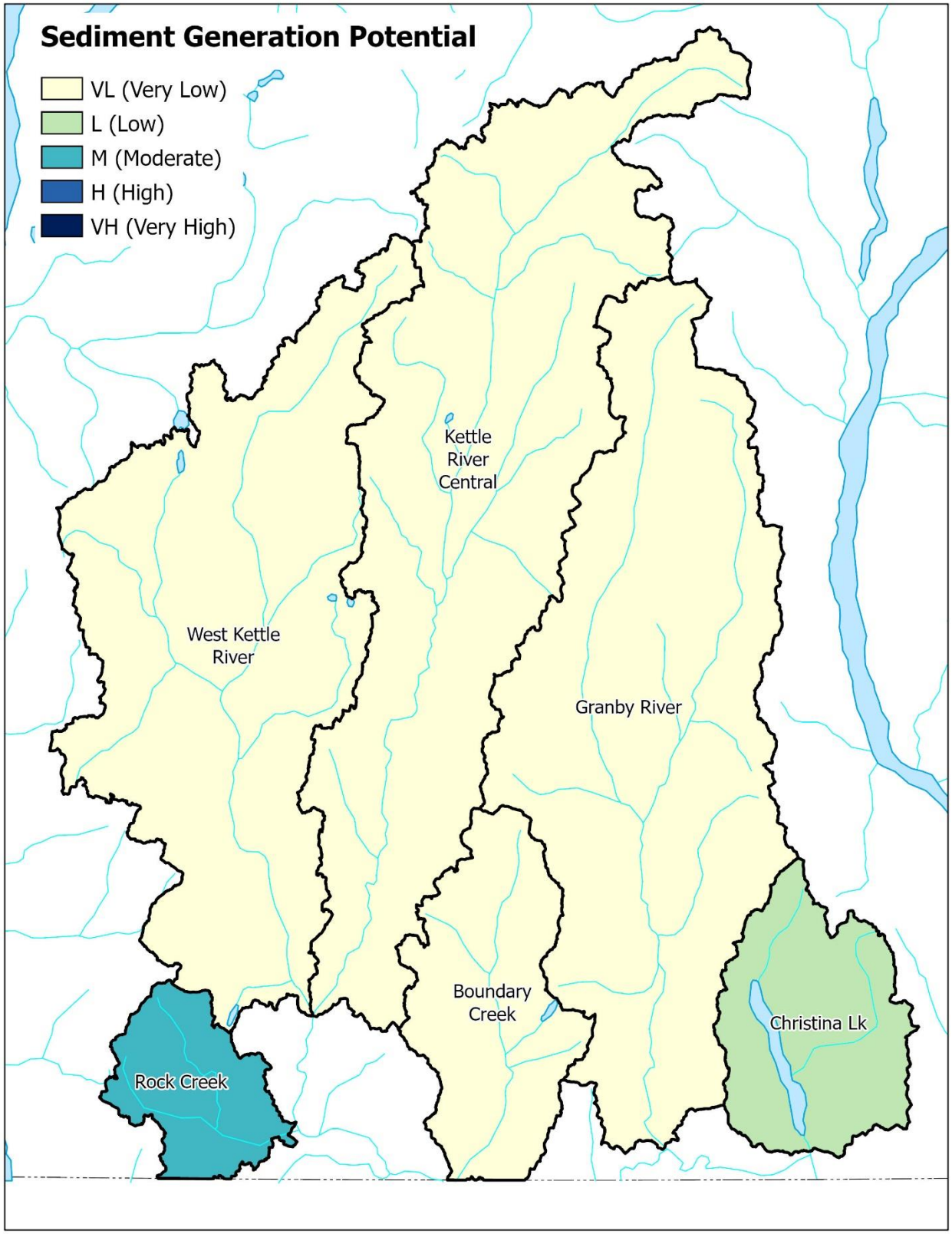


Figure B15. ***Sediment Generation Potential Rating*** **at the scale of the major sub-basins. Results were not calculated for portions of the basin that are in the U.S.**

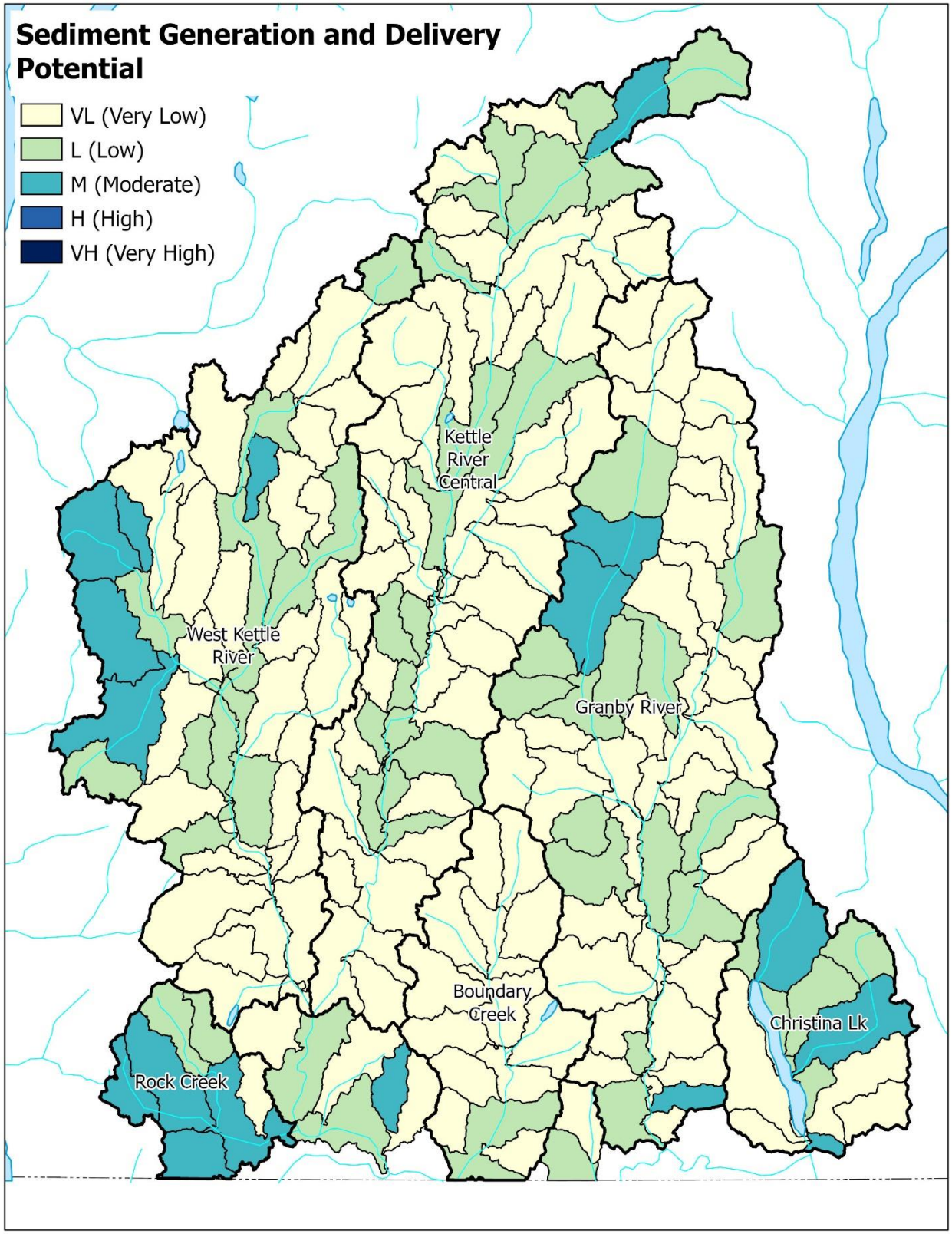


Figure B16. ***Sediment Generation and Delivery Potential Rating*** **at the scale of the AWs. AWs are outlined in black, and the boundaries of the major sub-basins are indicated using thicker black lines. Results were not calculated for portions of the basin that are in the U.S.**

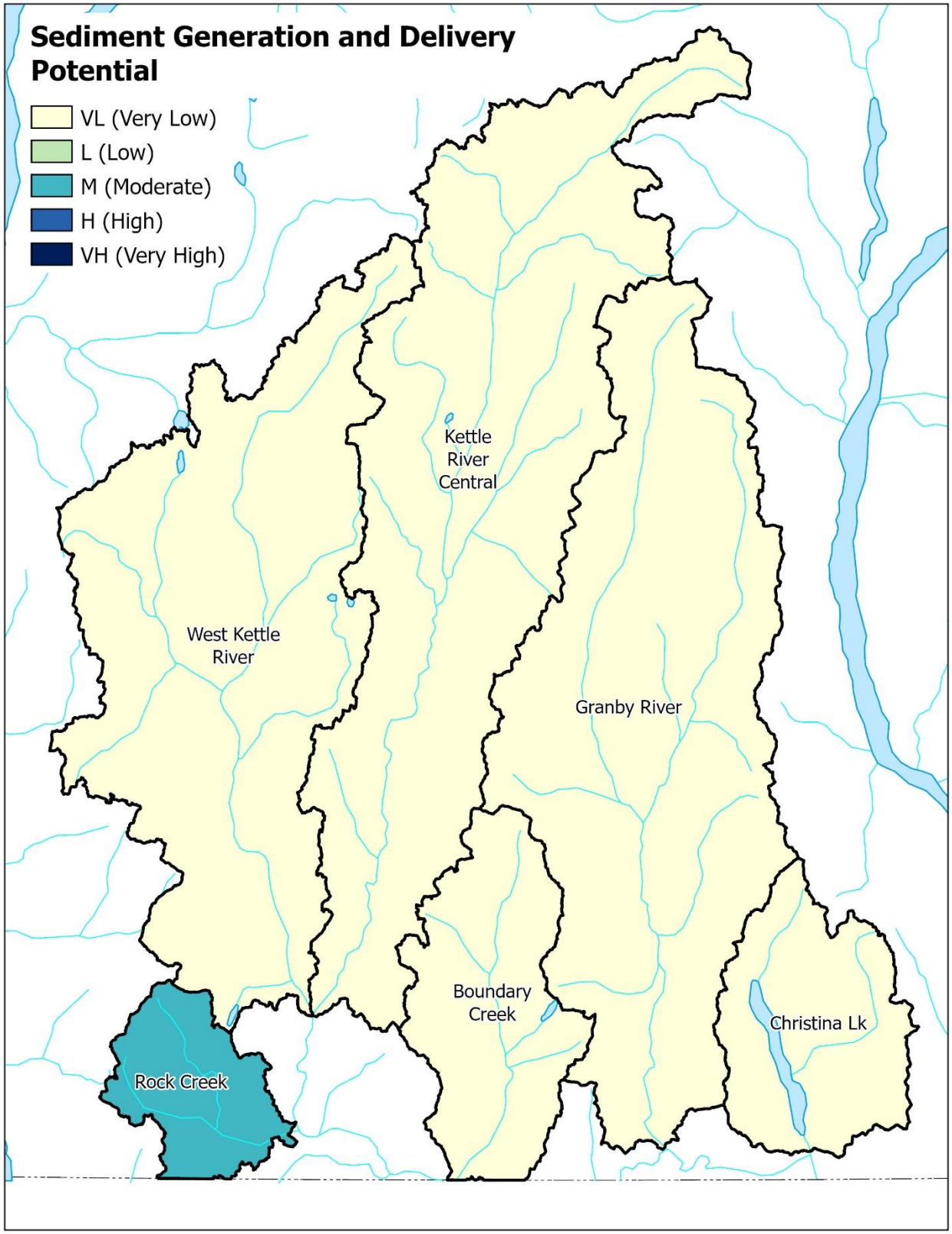


Figure B17. ***Sediment Generation and Delivery Potential Rating*** **at the scale of the major sub-basins. Results were not calculated for portions of the basin that are in the U.S.**

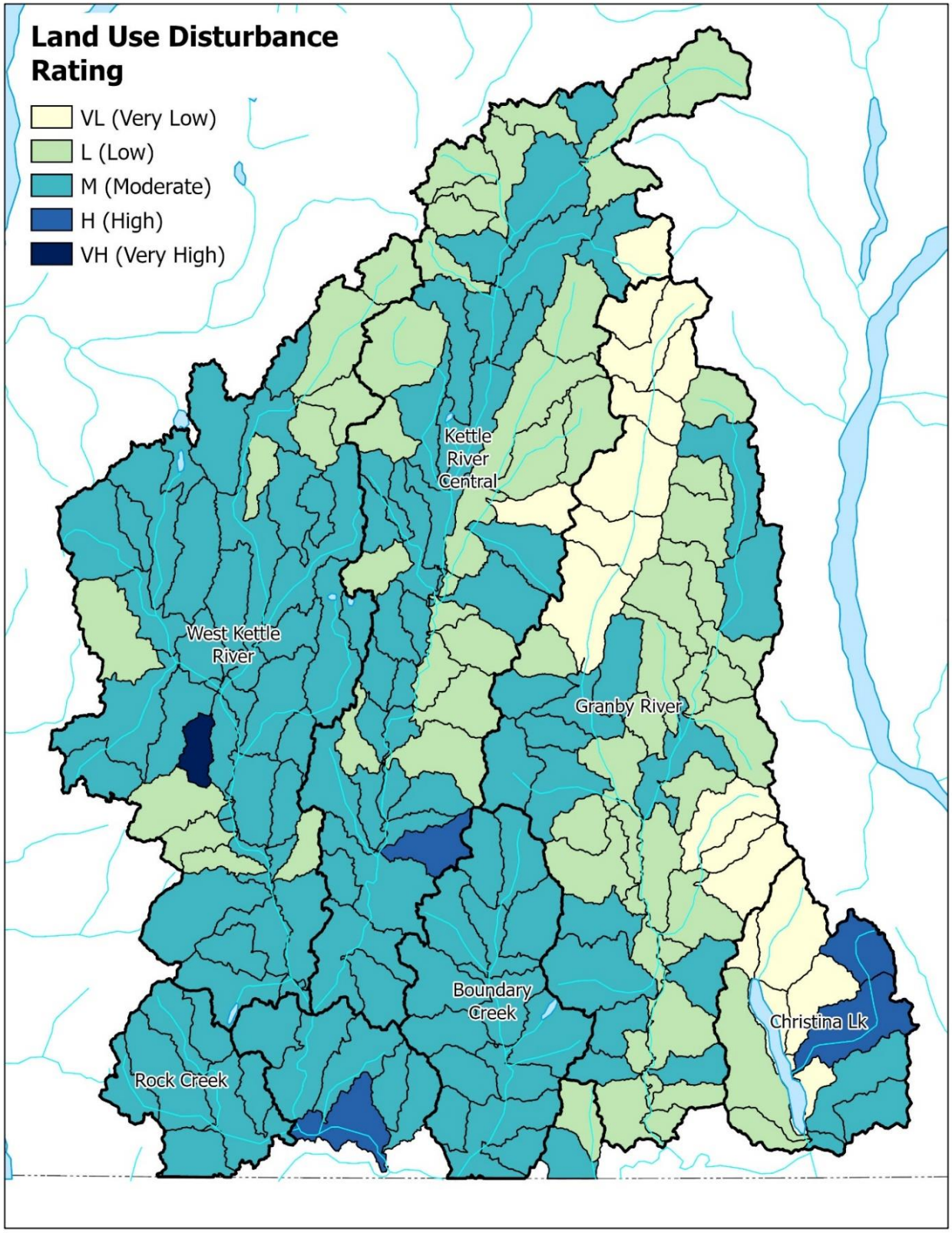


Figure B18. ***Land Use Disturbance Rating*** **at the scale of the AWs. AWs are outlined in black, and the boundaries of the major sub-basins are indicated using thicker black lines. Results were not calculated for portions of the basin that are in the U.S.**

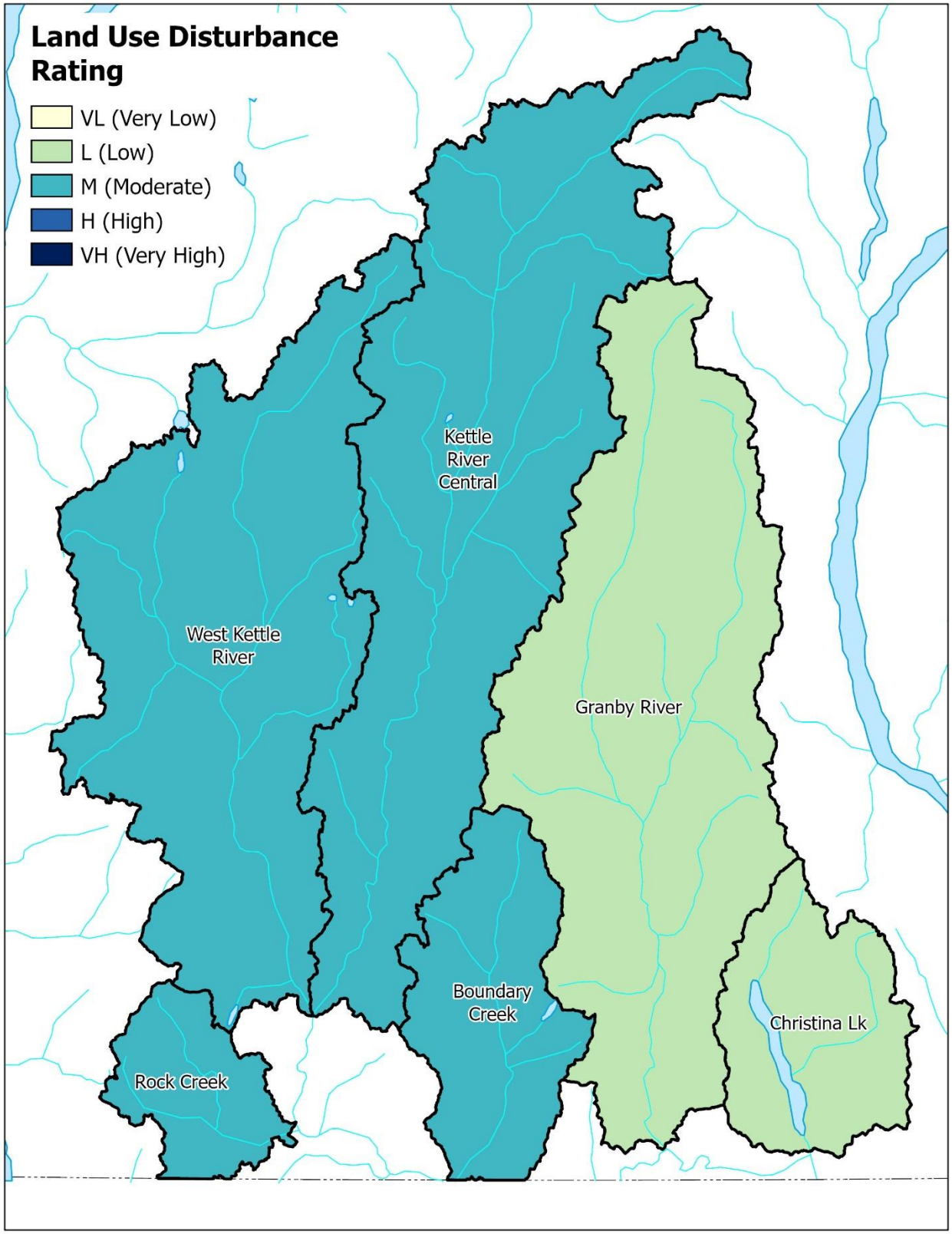


Figure B19. ***Land Use Disturbance Rating*** **at the scale of the major sub-basins. Results were not calculated for portions of the basin that are in the U.S.**

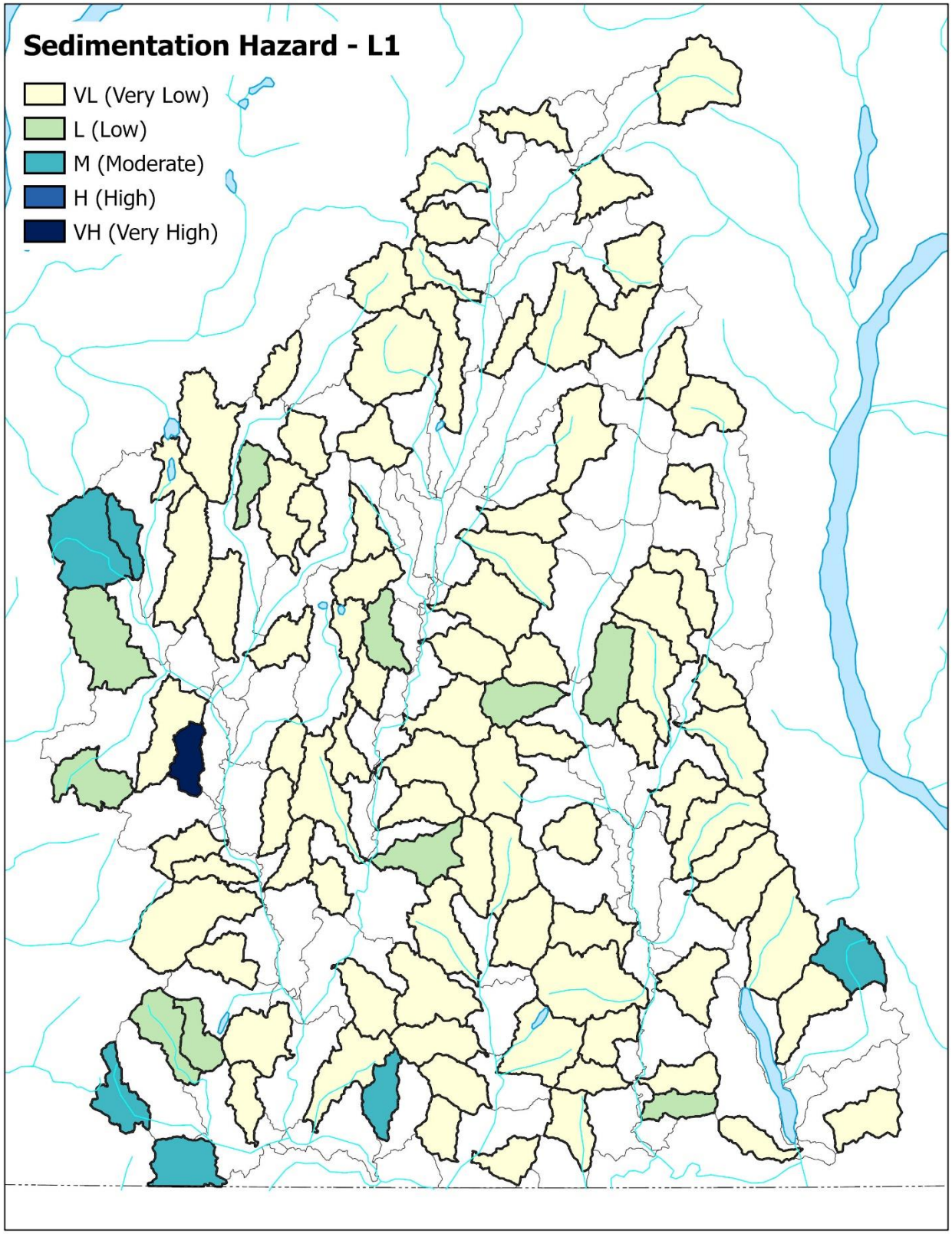


Figure B20. ***Sedimentation Hazard*** **rating at the L1 (headwater AW) scale. Results were not calculated for portions of the basin that are in the U.S.**

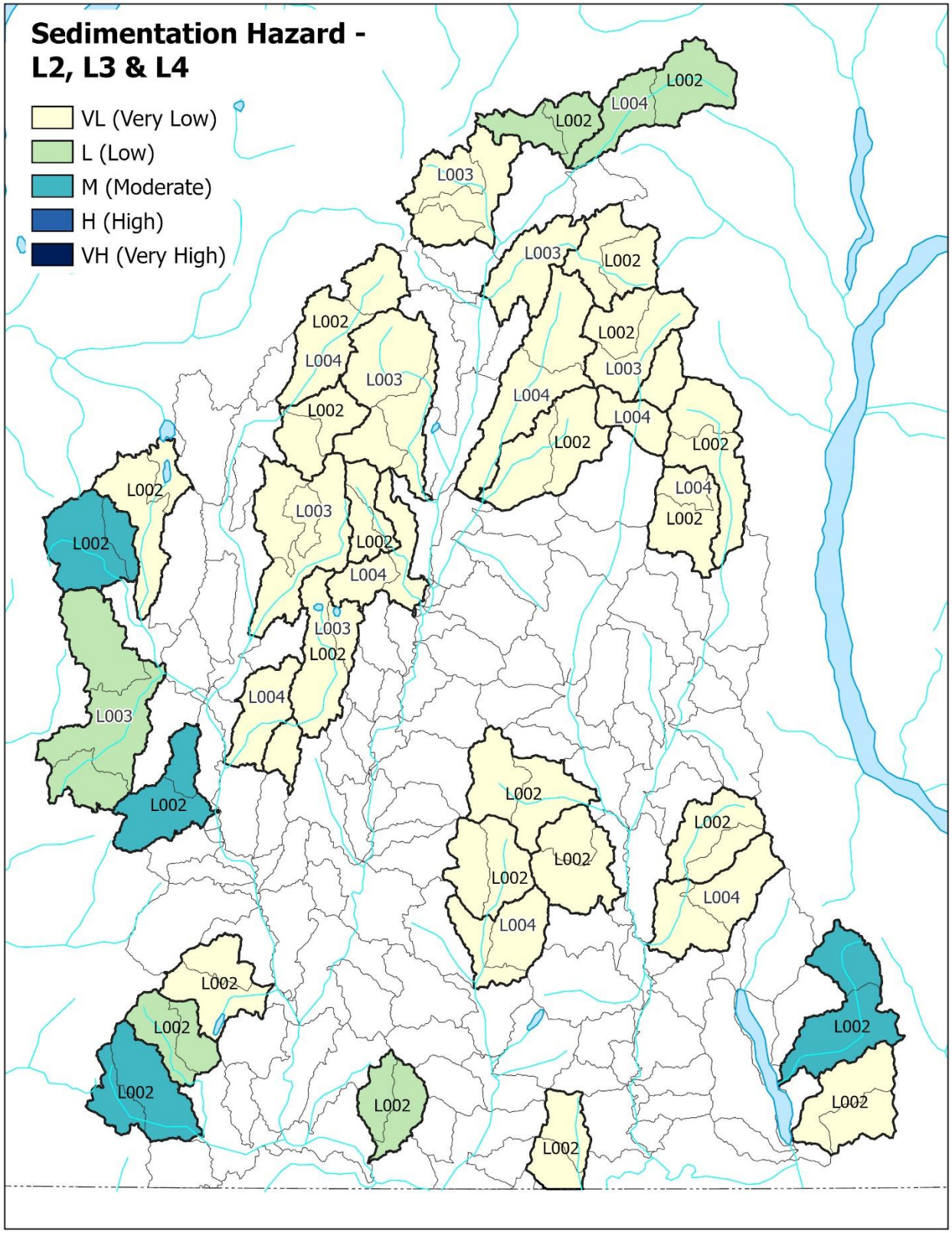


Figure B21. ***Sedimentation Hazard*** **rating at the L2, L3 and L4 scales. Results were not calculated for portions of the basin that are in the U.S.**

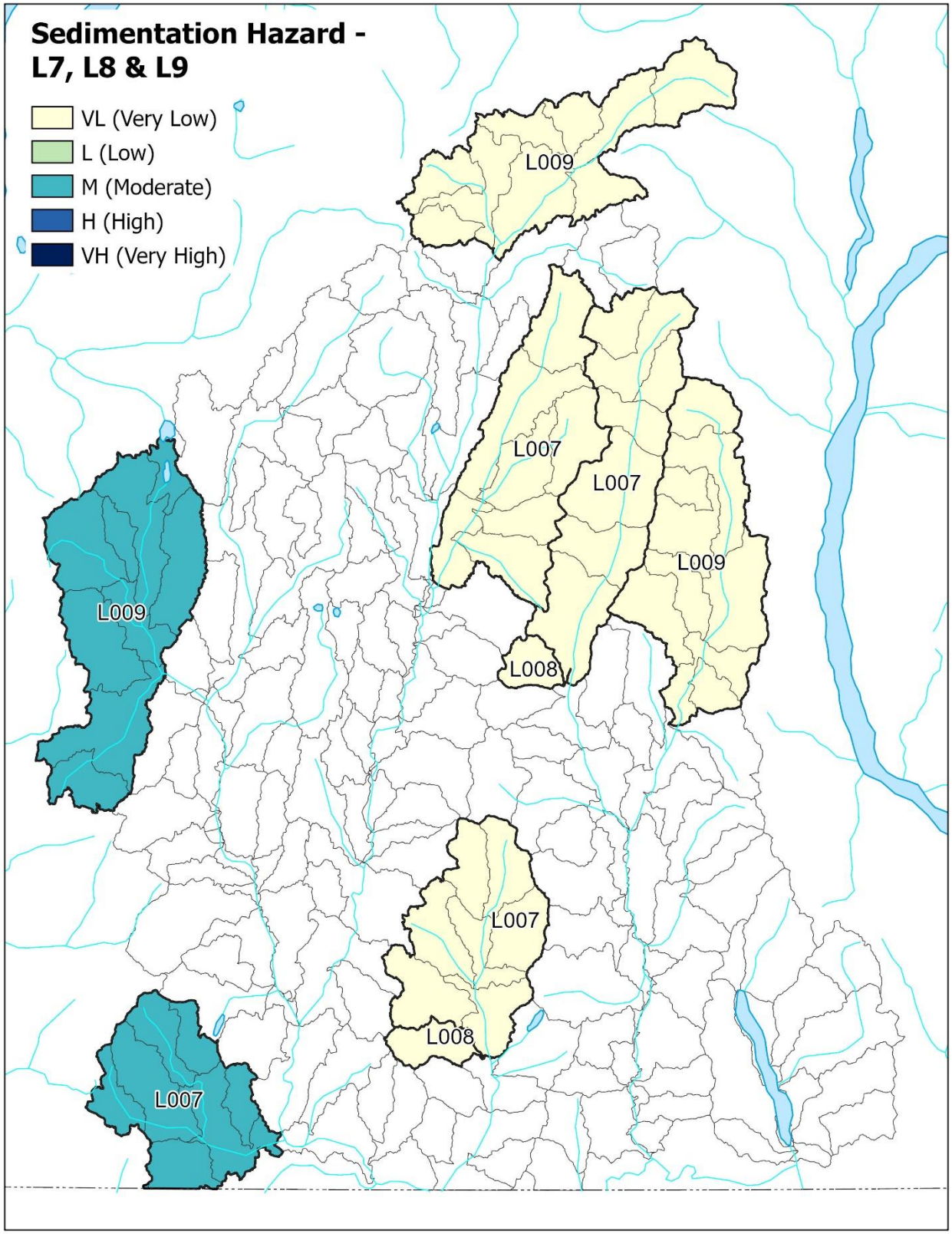


Figure B22. ***Sedimentation Hazard*** **rating at the L7, L8 and L9 scales. Results were not calculated for portions of the basin that are in the U.S.**

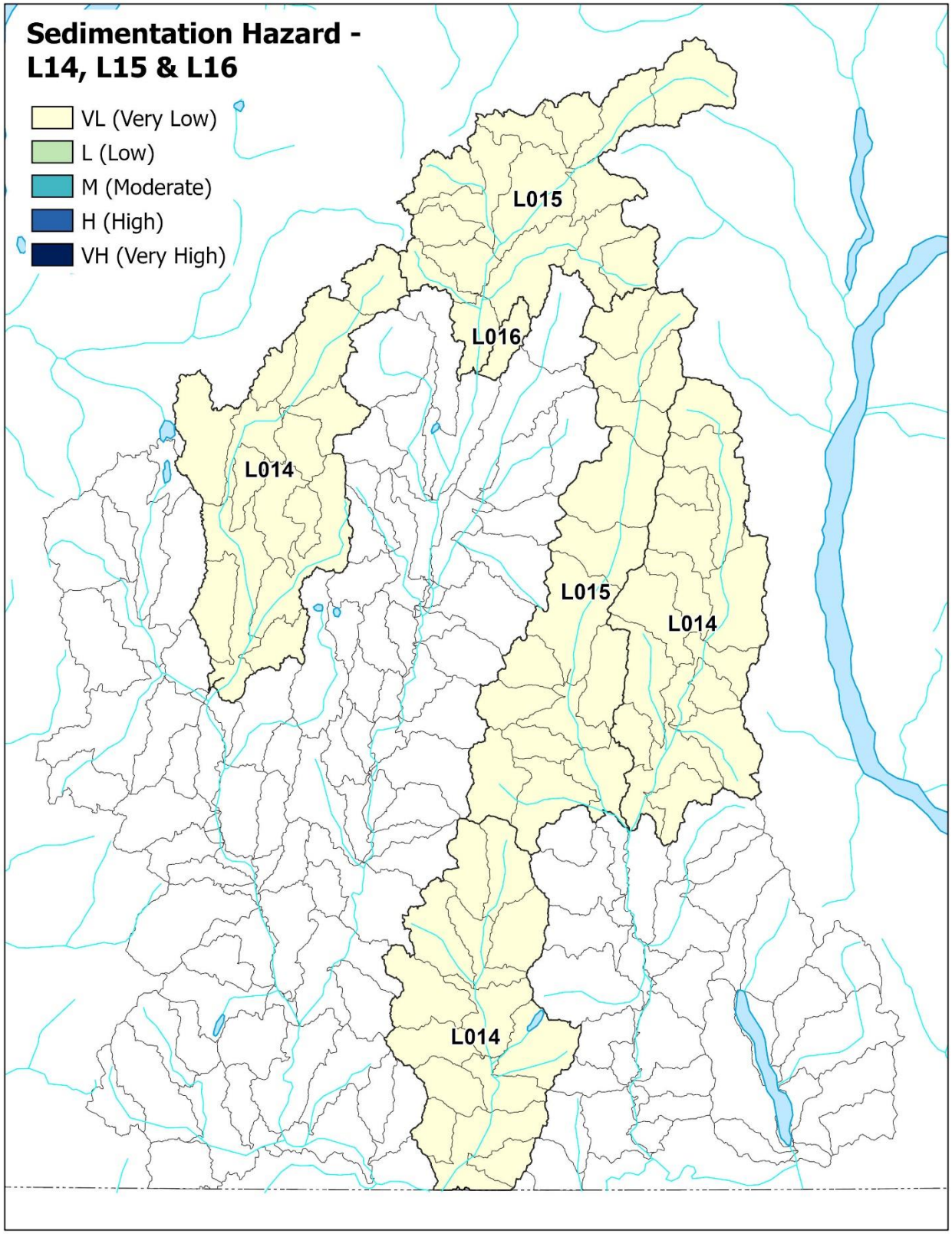


Figure B23. ***Sedimentation Hazard*** **rating at the L14, L15 and L16 scales. Results were not calculated for portions of the basin that are in the U.S.**

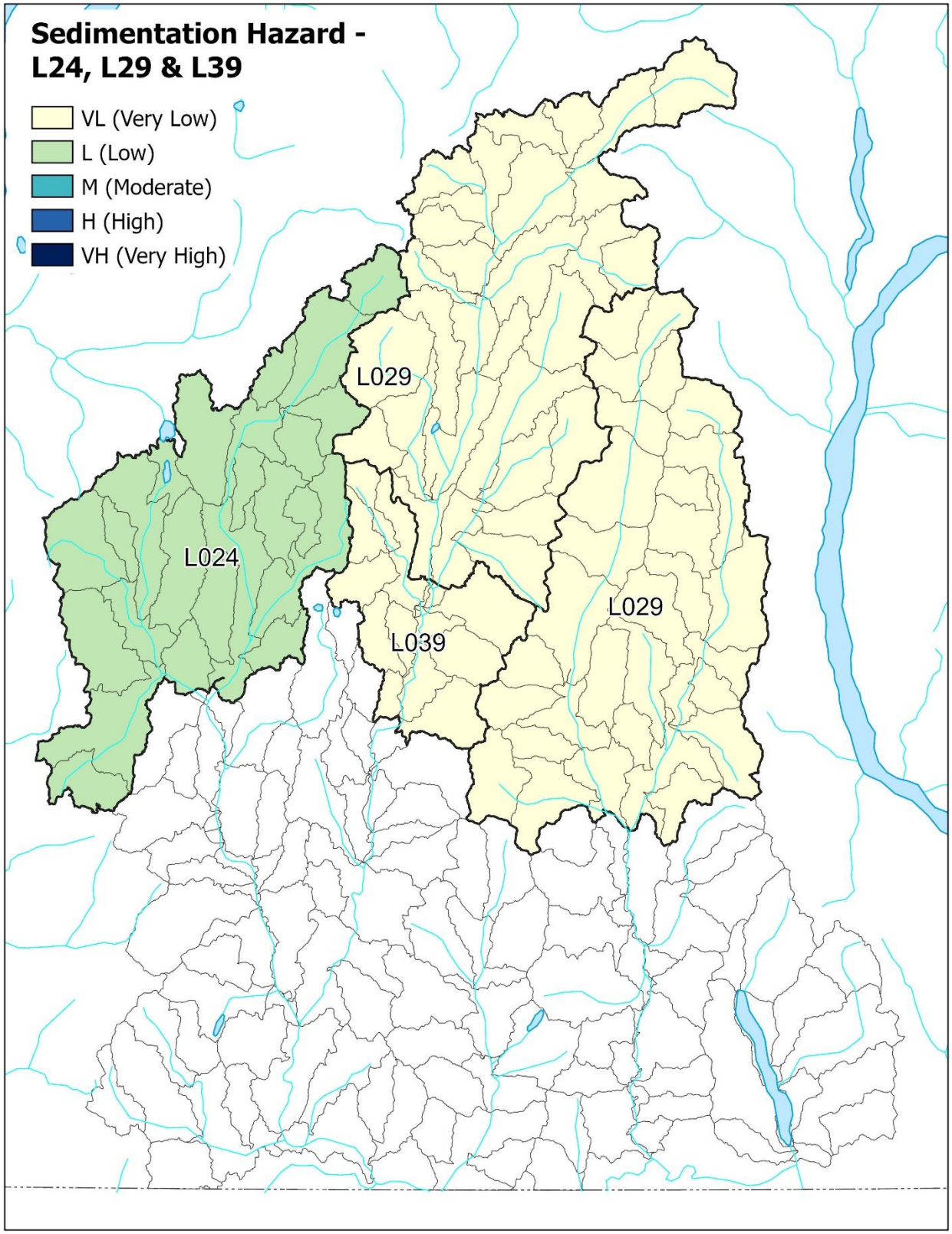


Figure B24. ***Sedimentation Hazard*** **rating at the L24, L29 and L39 scales. Results were not calculated for portions of the basin that are in the U.S.**

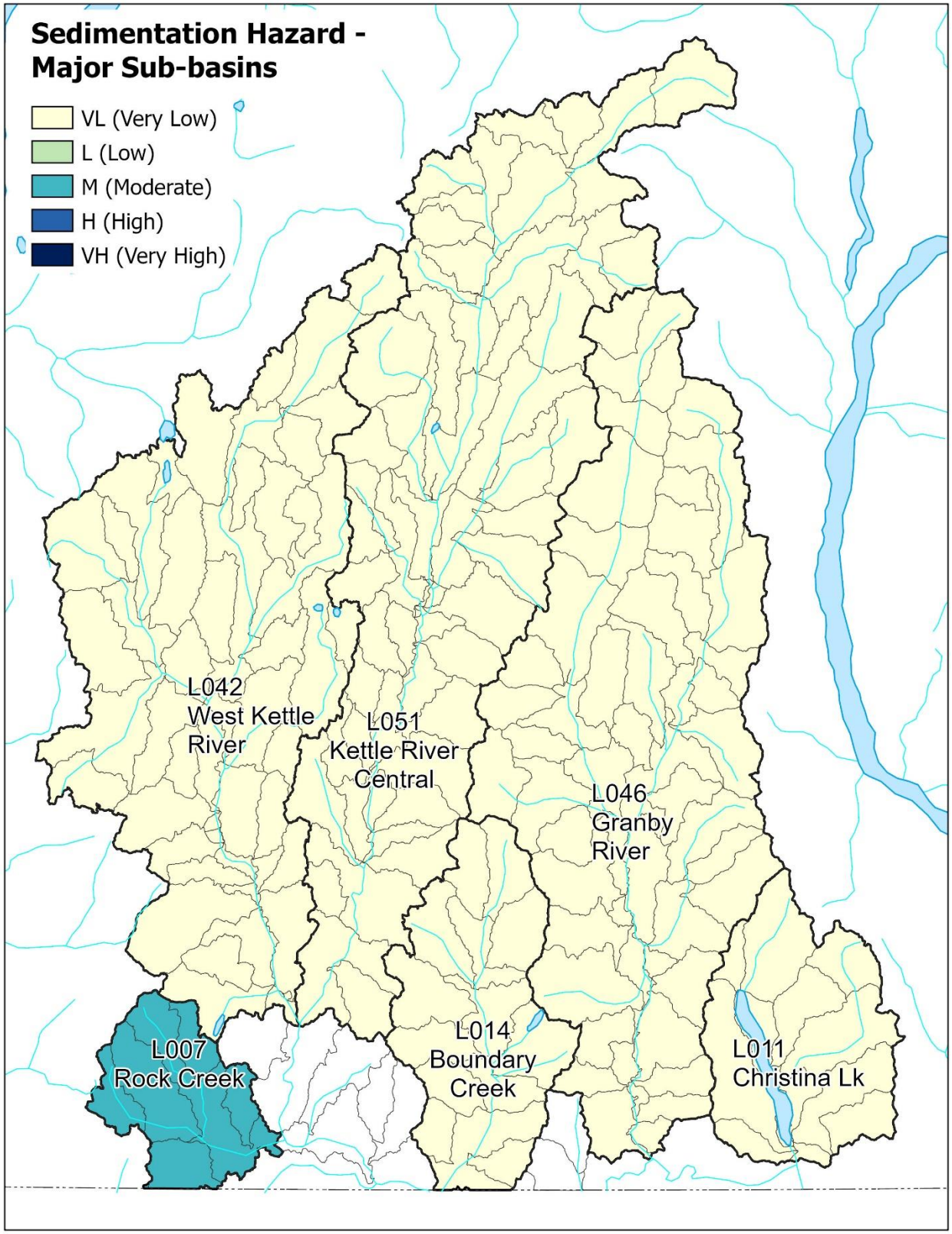


Figure B25. ***Sedimentation Hazard*** **rating at the major sub-basin scale. Results were not calculated for portions of the basin that are in the U.S.**