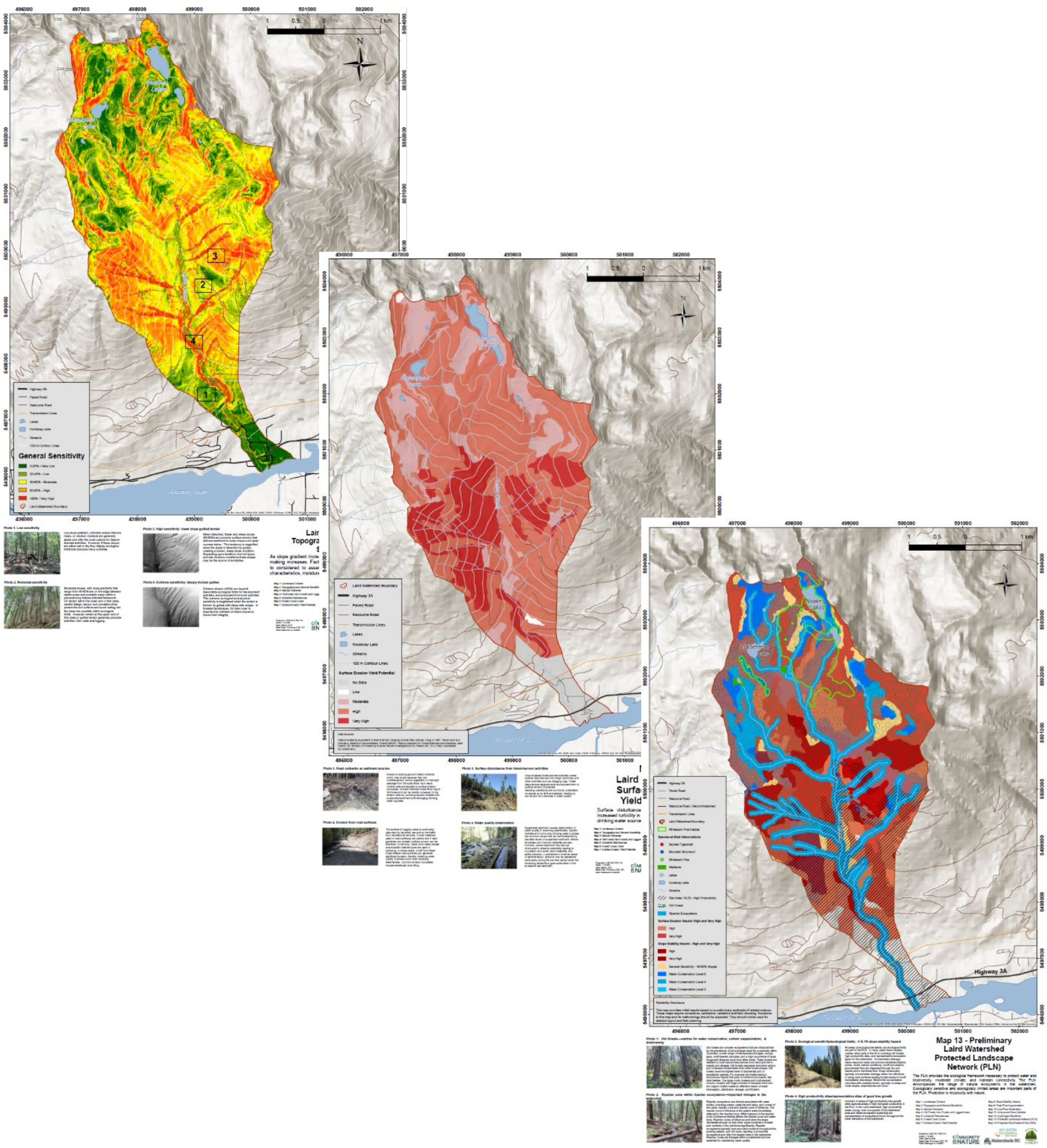
Preliminary Nature-Directed Stewardship Plans for Glade and Laird Watersheds



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- Herb Hammond – Sections 1.1-1.5, 2.1, 4.1, 4.3.3- 4.3.6, 4.3.11, 4.3-13, 7.1, 7.2
- Martin Carver – Sections 2.3, 2.4, 4.3.7-4.3.10, 4.3.12, 7.1
- Greg Utzig – Sections 2.4, 4.3.14
- Evan MacKenzie – Sections 3.1. 3.2, 3.3, Appendix A, B, and C.
- Arlo Bryn Thorn – Sections 2.2, 3.2
- Ryan Durand – Sections 4.2, 4.3.1, 4.3.2, 4.3.5, 4.3.6

LIMITATIONS

The project timeframe precluded the development of finished Nature-directed stewardship (NDS) plans. To create a NDS plan, a preliminary Protected Landscape Network (PLN) is designed, field verified, and revised before the final plan is prepared. At the heart of the process is active collaboration with both Indigenous and settler communities occupying the watersheds where the plan applies. This exchange of knowledge and revision to the interpretations of the plan needs to occur throughout the planning process. Project circumstances prevented this from taking place and were beyond the control of the key contributors to this report.

This report and its maps provide ***preliminary*** NDS plans. Limitations associated with these plans include the following:

- Collaboration with communities would be improved through additional iterative engagement should a second phase of the project be undertaken. The additional collaboration would also encourage wide community ownership of the NDS plans. Any subsequent development of these plans should be structured around this additional community collaboration as a priority activity.
- The results of these preliminary plans are based on a preliminary synthesis of related science and limited field verification of interpretations. Maps 9 to 13 require corrections, calibration, validation and field checking. Revisions to these maps and their methodology need to be expected. They should not be used for detailed layout and field planning.
- The variables used to derive hydrologic sensitivity synthesize a combination of well-accepted factors related to terrain stability and surface erosion and emerging hydrologic understanding related to the flow regime. The integration of these factors requires additional scientific input, review and field checking that was not possible within the constraints of this project.
- The Geographic Information System (GIS) capacity available in this project has resulted in gaps in map development as discussed in the report. These gaps can be resolved in future work.

The PLN provided in this report identifies a network of ecological reserves to provide a framework of ecological integrity and resilience for Glade and Laird watersheds. Although the plans are specific to these watersheds, as replicable models they may also be readily adapted to other watersheds. For the first time, the PLN incorporates unique hydrologic sensitivity interpretations as part of the reserves design. These preliminary plans may be used in future work to develop completed plans for protecting the ecological and hydrologic values of these watersheds. In the interim, the findings of these preliminary plans need to be respected and development activities in the watersheds paused, pending field verification and further analyses.

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1. INTRODUCTION

The creation of Nature-Directed Stewardship (NDS) plans for the Glade and Laird watersheds is a project of the West Kootenay EcoSociety. Located in the West Kootenay, along the Kootenay River (Glade) and Kootenay Lake (Laird) in the unceded territory of the Sinixt and Ktunaxa peoples, the two watersheds are small, relatively intact, and are important community drinking water sources for small residential areas. This project was initiated by residents and local elected officials who are concerned about industrial development within their watersheds, and the impact development will have on water and biodiversity.

Preliminary NDS plans were developed for Glade and Laird watersheds, using a combination of established processes developed over the last 25 years by the Silva Forest Foundation and novel approaches to incorporating hydrological modelling into the process. As a result, the map set produced for these NDS plans are preliminary and require additional field testing and calibration.

1.1 Introduction to Nature-Directed Stewardship

> *"Looking at life from a different perspective makes you realize that it's not the deer that is crossing the road, rather it's the road that is crossing the forest."*
>
> Author Unknown

Nature-Directed Stewardship (NDS)[1] is a system of ecosystem protection, maintenance, restoration, and human use. It was developed by the Silva Forest Foundation to protect ecosystem integrity and biodiversity at multiple spatial scales, while providing for Earth-centred human use of ecosystems (Silva Forest Foundation 1997). The first priority in NDS is maintaining (or restoring) natural ecological integrity — including biological diversity — across the full range of spatial (from very large to very small areas) and temporal (from short to long periods of time) scales.

NDS (otherwise known as "ecosystem-based planning", "ecosystem-based conservation planning", or "Nature-Directed Stewardshipping") is widely accepted by scientists and practitioners as the state-of-the-art approach to forest planning and use (Kaufmann et al. 1994). Indeed, NDS has also been successfully applied in many different types of terrestrial, aquatic, and marine ecosystems (Price, Roburn, & Mackinnon 2008).

[1] The expression *nature-directed stewardship* (NDS) is used interchangeably with *Nature-Directed Stewardship* (NDS), *ecosystem-based conservation planning* (EBCP) and *ecosystem-based planning* (EBP) and has the same meaning.

Nature-Directed Stewardship envisions people living as a respectful part of the ecosystems that sustain us. Our plans and actions are inclusive of the needs of all beings, all our relations. In this vision, ecosystems are seen as identities to be respected, not objects to be dominated, wisdom passed down by Indigenous elders and knowledge holders across Canada and elsewhere in the world. What people acquire from this relationship are clean air, pure water, climate moderation, healthy food and shelter, and respectful relationships with each other and Earth. People acquire well-being, while asking little from the ecosystems around them. Ecosystems are selfless—an important lesson for our species.

The vision of living as a respectful part of the ecosystems that sustain us is the starting point and constant touchstone for making ecosystem-based decisions or Nature directed decisions. Being a respectful part means recognizing that we are only one small, often ecologically insignificant part of the mosaic of natural ecosystems and learning from and protecting those ecosystems we inhabit. Being a respectful part means being Nature directed in our thoughts, plans, and activities.

Natural ecosystems function fully and flawlessly without industrialized human societies, but the converse is not true. Yet, from rural to urban landscapes, forest to grassland landscapes, and fresh water to marine landscapes, human beings have degraded and destroyed the very fabric of ecosystems.

Our ill-conceived actions have fueled climate change, water degradation, loss of biological diversity, and created many obstacles for human health and well-being. These results are not respectful of ecosystems and demonstrate the lack of a holistic, thoughtful, precautionary, and inclusive vision. NDS is rooted in a vision that avoids recreating these problems, while providing a system to restore natural ecosystem integrity and resilience. NDS asks that we use the vision of people living as humble, respectful parts of ecosystems to reach for an inclusive future that provides for the well-being of all—human and non-human. The NDS vision is achieved through a practical, tested system of planning and ecologically responsible human use of ecosystems i.e., home systems—our home. (Hammond 2015; Silva Forest Foundation 2004)

At the same time, it provides for ecologically and culturally sustainable communities and their economies. In other words, Nature-Directed Stewardship provides a picture of the ecological framework that is necessary to protect, and the ecological limits that constrain human uses in order for them to be sustainable. (Hammond 2009)

Ecologically and culturally sustainable management of ecosystems recognizes a hierarchical relationship between ecosystems, cultures, and economies. Economies are part of human cultures, and human cultures are part of ecosystems. Therefore, protecting ecosystem functioning provides for healthy human cultures, and the economies that are part of these cultures. This understanding is the foundation for and guides the planning and implementation of Nature-Directed Stewardship/Nature-Directed Stewardshipping/ecosystem-based conservation planning. (Hammond 2009).

NDS offers a way to plan and implement ecosystem-based use of forests, and ecological restoration of previously degraded forests and associated ecosystems. Given the extensive nature and long history of human-centred forest-based activities, applying NDS in these landscapes often focuses on ecological restoration.

In our rush to exploit "resources" found in forests, we have forgotten that we are part of ecosystems supported by a bigger ecosystem — the landscape. By forcing our will on forests, we have degraded those ecosystems and the watersheds and landscapes that support them.

We know enough to do better. We have workable methods for protection of Nature, and for assistance for Nature to restore (where necessary) fully-functioning ecosystems. This change begins with an Earth-centred approach rather than a human-centred approach: we are part of ecosystems, and what we do to ecosystems we do to ourselves. We must focus on needs, not on wants. Consumption must be replaced by conservation embedded in a steady state economy. We must act on the understanding that Earth sustains us, we do not sustain Earth.

1.2 THE CHALLENGE OF RESTORATION—HOW TO START AND MOVE TO NATURE-DIRECTED STEWARDSHIP

There is an inherent inertia in thinking about, let alone in undertaking, restoration of a reasonable semblance of nature—natural ecosystem functioning—to ecosystems and landscapes that have been degraded by industrial activities.

To avoid paralysis, we need to remember the wisdom of Lau Tzu: The journey of a thousand miles starts with a single step. That "first step" is changing our ways of thinking about the forest by adopting an Earth-centred, kincentric vision to guide our application of ecologically and socially responsible, practical planning and restoration activities.

In Nelson and Schilling's (2018) chapter, Dennis Martinez, O'odham/Chicano/Anglo, developed the term "kincentric" and describes it in this way:

> *"Kincentricity—Indigenous land care practices that entail reciprocal relationships laid out in "original compacts" between animals and human; way of life that includes relating respectfully to all life as kin and to the Earth as a nurturing mother. There are no "natural resources" when those beings are your kin who must be approached with respect before harvesting."*

Kincentric thinking and ways of being are the foundation for Nature-Directed Stewardship. Without adopting this thought process, we continue to be trapped in an anthropocentric way of being where ecosystems are seen as natural resources to be exploited for human wants, not identities to be respected in a regenerative, reciprocal relationship with Nature.

NDS is most effective when it begins from as large a landscape as possible. Landscapes hold watersheds, and watersheds hold patches—the multiple spatial scales of interconnected, interdependent ecosystems. Thus, the character of the landscape shapes its component watersheds, and the character of each watershed shapes the patches within it.

NDS provides a landscape vision that guides planning for smaller areas within the landscape in question. Integrated planning of this nature may be challenged by overlapping jurisdictions, the effects of past and ongoing development, and coordinating data analysis to synthesize a plan.

Just as large landscapes "hold" their component ecosystems, thereby influencing the character and condition of component ecosystems, a landscape may also be influenced, in part, from the bottom up. In other words, as the character and condition of component ecosystems change, so does the character and condition of the landscape.

Changing the character and condition of a single ecosystem within a landscape will not have as much overall influence as changing the broader character and condition of the landscape. However, working from the ecosystem, patch, or site toward the landscape may serve as an important catalyst for development of broad landscape visions and plans for protection and responsible use, and initiate important restoration activities.

Thus, starting with the restoration of a clearcut or road, a vision may be formulated for Earth-centred living that stimulates development and implementation of Nature-Directed Stewardship for a watershed or large landscape.

This approach offers a manageable, community-based way to initiate Nature-Directed Stewardship. In other words, start with the small, but manageable forest patch or site, and keep "walking up" the scale to expand site protection and restoration efforts to become watershed and landscape protection and restoration.

Whichever route we take, at the beginning of our walk, we need to consider what we are interacting with and what we need to protect and restore—ecosystems. Understanding ecosystems means understanding where we started in forest activities: the natural character that was degraded and replaced by an unnatural condition that has resulted from human activities. In most cases, current condition comprises a forest landscape only marginally capable of supplying the ecosystem benefits that it once did.

1.3 What is an Ecosystem?

An ecosystem is a community of interacting species, taken together with the physical environment within which it exists and within which the species composing the community also interact. Ecosystems have the following distinguishing characteristics:

- A web of interactions and interdependencies among the parts.
- Synergy, which is the "behavior of whole systems unpredicted by the behavior or integral characteristics of any of the parts of the system when the parts are considered only separately".
- Stability, a simple yet complicated concept that does not mean "no change" but rather is analogous to the balanced movement of a dancer or a bicycle rider.

Diffuse boundaries. Unlike an organism, an ecosystem does not have a skin that clearly separates it from the external world. Ecosystems are defined by connectance, and connections that extend through time and space, integrating every local ecosystem…within a network of larger and larger ecosystems that compose landscapes, regions, and eventually, the entire Earth (Perry 1994). Thus, ecosystems are interdependent, interconnected living systems. The linkages between the parts and processes of ecosystems are seldom obvious, but they are always there. Recognizing the interconnected, seamless linkages both from large ecosystems to small ecosystems and vice versa stimulates a large measure of humility about just how deep and far the impacts of our actions extend when we modify natural ecosystem composition, structure, and function—natural character. What we do to ecosystems, at any spatial scale, we do to ourselves.

Another way to look at an ecosystem is to consider the meaning of the first syllable of the term. Eco is derived from the Greek word oikos meaning the whole house or home (Boland 1997). Thus, ecosystem means home system. In other words, protecting and restoring the natural ecosystems that comprise a forest landscape or patch is protecting and restoring home—our home.

Interestingly, the word economy has the same first syllable, eco as the word ecosystem. However, the second syllable –nomy is derived from the Greek nomos "management" (Boland 1997). Thus, economy means home management, not the whole home system. Economies are therefore clearly part of ecosystems, and dependent upon the integrity of ecosystems for their survival.

1.4 KEY ELEMENTS OF NATURE-DIRECTED STEWARDSHIP

NDS means relating to and using the ecosystems we are part of in ways that ensure the protection, maintenance, and, where necessary, restoration of ecological integrity and biological diversity from the genetic and species levels to the community and landscape levels. An ecosystem-based perspective works at all scales, from the microscopic to the global. The priorities that guide ecosystem-based use of land, water, and air focus first on what to protect, and then on what to use:

- **First Priority:** Protect or restore ecological integrity… In other words, maintain and, where necessary, restore natural ecosystem composition, structure, and function at all spatial scales through time.
- **Second Priority:** Provide for balanced ecosystem use across the landscape… In other words, provide fair, protected landbases for all ecosystem users, both human and non-human. (Hammond 2009).

The methods and products of a NDS are a synthesis of Indigenous knowledge, shared by Indigenous knowledge holders, and scientific concepts developed by leading edge researchers and practitioners in ecology, conservation biology, landscape ecology, hydrology, and ecological economics. NDS not only provides for the maintenance and/or restoration of ecological integrity, but also for the development of diverse, sustainable steady state community economies.

Human uses are balanced, fairly distributed in a portion of the plan area, and carried out in ways that maintain ecological integrity. A significant portion of the plan area, usually 50% or more, is maintained as a natural ecosystem reserve. This part of the plan area is to provide for the needs of non-human beings and the processes that provide overall ecosystem benefits and support for the ecosystem as a whole. Ecosystem reserve areas may be used for Indigenous cultural and subsistence purposes, as guided by their leaders, and some non-consumptive activities, subject to the ecological limits specified in a particular plan.

Nature-Directed Stewardship is community focused, where communities are inclusive of many interests, share decision-making power, and take responsibility for their actions.

While NDS is rooted in science, it is not a new idea (Holt 2001; Kaufmann et al. 1994). An ecosystem-based way of relating to the land and water has its roots in Indigenous knowledge and management systems, which are the result of thousands of years of meticulous, repeated observations of how ecosystems function and their response to human activities (Finn et al. 2017; Gadgil et al. 1993). Considering the degradation throughout the world of natural ecological landscapes in the industrial age, Indigenous management systems have been the only management systems that have been proven to be sustainable in the long term.

Hence, NDS is grounded in both western science and Indigenous knowledge. Thus, when people develop and implement NDS, we are being ecologically responsible, and providing for both ecological and cultural sustainability.

1.4.1 Long-term Ecosystem Plans, Not Short-term Development Plans

NDS is built on ecosystem plans that have ecological timeframes that encompass full ecosystem cycles. The timeframe over which live and dead trees function and provide benefits in a forest, the ecological parts and processes develop that provide for water conservation, and soil development are examples of ecosystem timeframes. This is why plans for Nature-Directed Stewardship have timeframes of 250-500 years and beyond. Nature-Directed Stewardship provides plans with timeframes that generations of people will live through and modify as knowledge and needs change.

The timeframes for Nature-Directed Stewardship are significantly different than in most human endeavours, including forest management plans of 1-5 years, election cycles of 4-5 years, or annual budgets of corporations and non-profit organizations. In contrast, time cycles at the level of ecosystems range from very short to very long and are often hard to identify because ecosystems—forests, grasslands, savannahs—are continuums in time and space. Thus, Nature-Directed Stewardship needs to encompass the longest reasonable ecological timeframe, in order to maintain ecological integrity from the smallest site to the largest landscape.

Nature-Directed Stewardship furnishes an ecological picture that provides a baseline understanding of what is necessary to maintain and restore ecological integrity, without presupposing any particular type of human use. In Nature-Directed Stewardship, biology and ecology are put ahead of politics and short-term economic expediency.

Nature-Directed Stewardship commits human communities to a long-term, responsible, regenerative, and reciprocal relationship with Nature. Hopefully, application of this new relationship with Nature will, over time, serve as a catalyst for human beings to live as a respectful part of the ecosystems that provide for their well-being. Due to the extensive levels of restoration commonly needed to successfully implement NDS, ongoing restoration over extended time periods is a *keystone requirement* for success of a plan. Keeping the keystone in place will require lasting political and funding commitments.

1.4.2 Key Concepts

Four key concepts underlie development and implementation of Nature-Directed Stewardship:

1. ecological integrity,
2. character and condition of ecosystem composition, structure, and function,
3. ecological limits, and
4. multiple spatial scales and "nested" networks of ecological reserves.

Definition of each key concepts, along with an explanation of the context within which these concepts are applied in developing NDS are provided below.

1.4.2.1 Ecological integrity

Ecological integrity may be defined as, "A system's wholeness, including presence of all appropriate elements and occurrences of all processes at appropriate rates" (Angermeier and Karr 1994 in Franklin et al. 2000, p.1). A similar definition states: "the abundance and diversity of organisms at all levels, and the ecological patterns, processes, and structural attributes responsible for that biological diversity and for ecosystem resilience" (Coast Information Team 2004, p. 13).

A more detailed way to describe ecological integrity is through a set of goals for human use that would increase the probability of maintaining natural ecological integrity:

- maintain viable populations of all native species;
- represent, within protected areas, all native ecosystem types across their range of variation;
- maintain evolutionary and ecological processes—i.e., disturbance regimes, hydrological processes, and nutrient cycles;
- manage over periods of time long enough to maintain the evolutionary potential of species and ecosystems; and
- accommodate human use and occupancy within these constraints. (Mackinnon et al. 2003)

1.4.2.2 Character and Condition of Ecosystem Composition, Structure, and Function

Character and condition are closely related key concepts. Describing the **character** and **condition** of a landscape ecosystem or patches within the landscape is the starting point for development of NDS and for designing networks of ecological reserves at multiple spatial scales.

The **character** of ecosystems refers to the natural composition, structure, and function of the ecosystems included within a planning area at a particular scale. In other words, describing the ecological character of an area means describing what it is and how it works in the absence of modification by industrialized human societies, but including modification through Indigenous management systems. The character of ecosystems at all spatial scales is described using composition, structure, and function. (Silva Forest Foundation 2009)

The **condition** of ecosystems refers to how the *natural* ecological composition, structure, and function have been *modified* or impacted as a result of human activities, including resource exploitation, settlement, urbanization, tourism, and other human activities; but excluding pre-industrial Indigenous management systems. (Silva Forest Foundation 2009)

Within these two key concepts are three important ecological concepts:

- **composition**: the parts of an ecosystem, e.g., the types and numbers of species that occur in an ecosystem;
- **structure**: how the parts of an ecosystem are arranged e.g., the patterns of vegetation types across a landscape, and the frequency and distribution of live and dead trees (i.e., snags and fallen trees) within a site or patch; and
- **function**: the processes that occur within an ecosystem and between ecosystems that depend upon their parts and how they are arranged, i.e., their composition and structure. (Silva Forest Foundation 2009)

Character and condition are scale-dependent terms. For example, describing the character and condition of a site or patch involves different variables and considerations than describing character and condition in a watershed. That is why incorporating analyses of character and condition of ecosystems at multiple spatial scales into NDS is necessary to maintain ecological integrity of whole watersheds or landscapes.

The character of an ecosystem is a continuum in time and space. In other words, over time, an ecosystem is not static and unchanging. Natural disturbances constantly modify ecosystems as time passes. However, unlike disturbances from industrial activities, natural disturbances serve to maintain ecosystem function, enrich biological diversity, and provide biological legacies that connect one successional phase to another. The effects of natural disturbances maintain diversity while industrial resource extraction activities tend to simplify, homogenize, degrade, and often eradicate natural ecosystems. (Lindenmayer & Franklin 2002)

In a natural ecosystem, *natural disturbance regimes*, or the types of natural disturbances, may range from landscape level disturbances such as floods, fires and windstorms to the activities of insects and fungi at the site level. Large landscape level natural disturbances such as floods, insect epidemics, and windstorms are dramatic events; however, they are far less frequent in ecosystems than small site level events. (Perry 1994)

For example, in a natural forest ecosystem, the most frequent disturbance or agent of change is the death of an individual tree or a small group of trees. Death may be from a wide range of causes, including bark beetles, root decaying fungi, small wind events, patch fires, heavy snow accumulations, soil erosion, or combinations of these and other factors. (Perry 1994)

Thus, natural disturbance events result in changes to composition, structure, and function—different character of ecosystems/landscapes. In the time interval between successive disturbances, the character changes through a process referred to as succession. Unlike once thought, succession does not necessarily lead to a stable “climax” character. Succession is highly variable, stochastic, and complex (Christensen 2014). Describing the variability in ecosystem composition, structure, and function that occurs through the dynamic process of succession is often referred to as the “range of natural variability” (Landres et al*.* 1999)

As explained above, the condition of ecosystems refers to how the natural ecological composition, structure, and function have been modified or impacted as a result of human activities, including resource exploitation, settlement, urbanization, tourism, and other human activities (Silva Forest Foundation 2009).It is important to assess and incorporate ecological condition into Nature-Directed Stewardship, because the condition of an ecosystem:

- identifies areas in need of restoration (Eagan & Howell 2001),
- identifies the type and extent of restoration that is needed (Eagan & Howell 2001),
- helps to define areas that are more or less appropriate for networks of ecological reserves, and
- identifies limits for human economic development activities.

The condition of ecosystems is determined through analysis of maps, aerial photos, satellite imagery, LiDAR and other imaging data that show the location and characteristics of various activities or disturbances from human activities, excluding traditional Indigenous management systems.

Analysis of maps, aerial photos, LiDAR, satellite imagery, and/or other imagery data to describe condition, needs to be augmented by field assessments to accurately describe impacts to, and restoration needs of sites, watersheds, and landscapes modified by human activities, from urban development and manufacturing to timber and mineral extraction and agriculture.

Describing and comparing the character and condition — composition, structure, and function — of ecosystems at multiple spatial scales is the foundation for NDS. This aspect of NDS is illustrated in Figure 1.4-1.

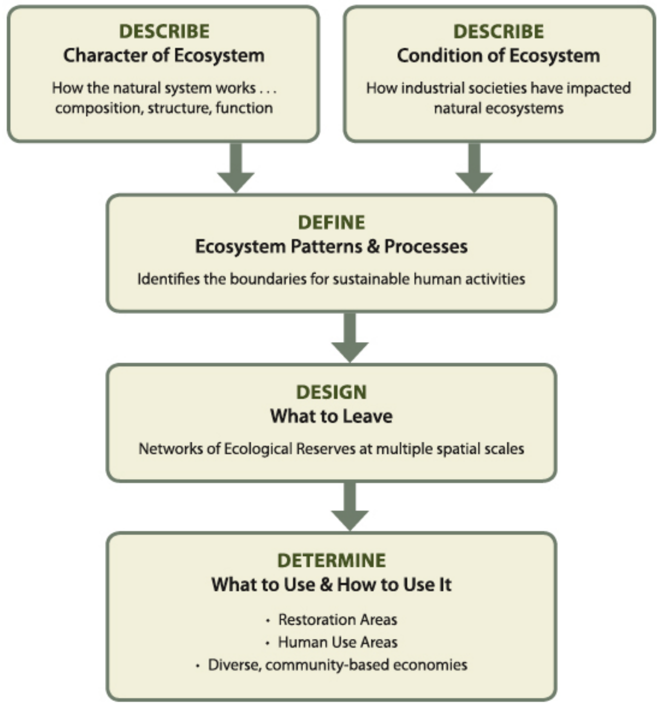

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Figure 1.4-1. General Process to Develop Nature-Directed Stewardship (Silva Forest Foundation 2009)

1.4.2.3 Ecological limits

Ecological limits provide boundaries for human activities under NDS. In other words, ecological limits to human activities define thresholds past which certain activities initiate fundamental, detrimental change to ecosystems, or thresholds beyond which ecological integrity is not maintained. Defining ecological limits is primarily a process of using scientific data with consideration of socio-political information. (Morgan 2015)

Changes to ecosystem composition, structure, and function that are beyond the range of natural variability of disturbances result in fundamental change to ecosystems, not fluctuation within the ecosystem such as those caused by natural disturbances (Holt & Sutherland 2003). The biophysical, climatic, or abundance thresholds past which species, ecosystems, and landforms suffer fundamental change, as opposed to natural fluctuations, are termed *ecological limits*.

The precautionary principle is applied to defining and respecting ecological limits in the process of developing NDS. Once defined in NDS, ecological limits prohibit development, or place constraints on development that err on the side of protecting ecological integrity. Both actions are taken to protect and/or restore ecological integrity. Through adaptive management applied over an adequate period of time, the results of ecological limits may be evaluated and refined as required.

Examples of major factors that define the ecological limits to human use of ecosystems include the habitat and reproductive needs of species, the shape of the terrain, the slope gradient, soil depth, soil texture, the amount of moisture available (both wet and dry conditions impose ecological limits), and local climatic conditions.

Disturbances are needed in ecosystems, but disturbances that exceed ecological limits result in degradation to ecosystem functioning, not fluctuations within natural ecosystem functioning. NDS is predicated on the premises that ecological limits will be respected, and that human uses will be designed to prevent, as opposed to mitigate, damage to the ecological integrity of ecosystems. Thus, identifying ecological limits is an important starting point for the development of Nature-Directed Stewardship at all spatial scales.

When ecosystem benefits, e.g., water, biodiversity, carbon sequestration and storage, and biological diversity become degraded, in most situations this means ecological limits have been transgressed. Thus, healthy ecosystem benefits are a good indicator that ecological limits are being respected.

An important ecological understanding that underpins NDS is that when ecosystems lose composition and structure from human modifications, they lose or significantly decline in their ability to function in natural ways.

Hence, whether or not managers are aware of the purpose(s) of particular arrangements of composition and structure, NDS approaches require that the natural range of composition and structure be maintained across spatial scales through time in order to ensure the maintenance of ecological integrity.

Hopefully, by maintaining the composition and structure that we can see, we will also maintain the composition and structure that we cannot see, particularly that found beneath the surface of the soil, and in the atmosphere. To respect ecological limits, there is a need for low risk management that sets cautious ecological limits in NDS.

1.4.2.4 Multiple Spatial Scales and "Nested" Networks of Ecological Reserves

One of the distinguishing characteristics of NDS is that plans are prepared, and activities carried out at multiple spatial scales. This characteristic of NDS is rooted in the sciences of landscape ecology and conservation biology, which explain that landscapes, both large and small, consist of interdependent, interconnected clusters of ecosystems. These clusters of ecosystems are found in repeated patterns across regions, subregions, landscapes, and watersheds. (Forman, Godron 1986)

The repeating pattern of interconnected clusters of ecosystems found in ecosystems of varying sizes (i.e., large landscapes to small sites) has two implications for NDS:

- the need for networks of ecological reserves across multiple spatial scales to maintain ecological integrity (Forman 1995);and
- the need for design of ecological reserves to start with as large an area as possible, such as subregions/territories and large landscapes. Planning then proceeds by designing ecological

> reserves for smaller areas and linking them to ecological reserves for progressively smaller areas, such as small landscapes, watersheds, and sites. (Primack 1995)

This approach to NDS ensures that ecological integrity is maintained across spatial and temporal scales. First, the ecological integrity of large areas, i.e., a watershed or multiple watersheds, in a planning landscape is provided for through designating large reserves. This design step is followed by the protection of the ecological integrity of the area outside of large reserves by establishing linked networks of ecological reserves that are nested within each other. (Soule & Terborgh 1999)

NDS is carried out across scales, not only for ecological factors, but also for cultural, social, and economic factors. For example, NDS recognizes and supports the interconnected, interdependent nature of various portions of a watershed to Indigenous and non-indigenous culture, alike. NDS also recognizes that healthy regional economies are dependent upon the development and maintenance of healthy community economies. Like ecosystems, the interdependence and interconnections between regional economies and community economies go both directions.

The general planning scales used in NDS are depicted in Figure 1.4-2. As shown in this diagram, networks of ecological reserves become finer and finer as planning moves from subregions and large landscapes to small landscapes, watersheds, and sites. Like “zooming in” on a telephoto zoom camera lens, increased detail and understanding of ecosystem composition, structure, and function is obtained as planning moves from large areas to small areas.

Watersheds ranging in size from approximately 100 to 100,000 ha are commonly mapped for use in defining NDS planning areas. The larger the planning area, the larger the watershed stratification that is appropriate. Small watershed units may be easily aggregated into large watershed units. Thus, stratifying a planning area by smaller watershed areas at the start of a NDS planning exercise both ensures that unique aspects of small watersheds are captured in reserve design, and provides an efficient way to define watersheds for a variety of NDS planning scales.

When one considers that every crease on the face of Earth is a small drainage basin or watershed that connects to adjacent creases to form slightly larger watersheds and so on, one realizes that watersheds are either tiny or all of Earth.

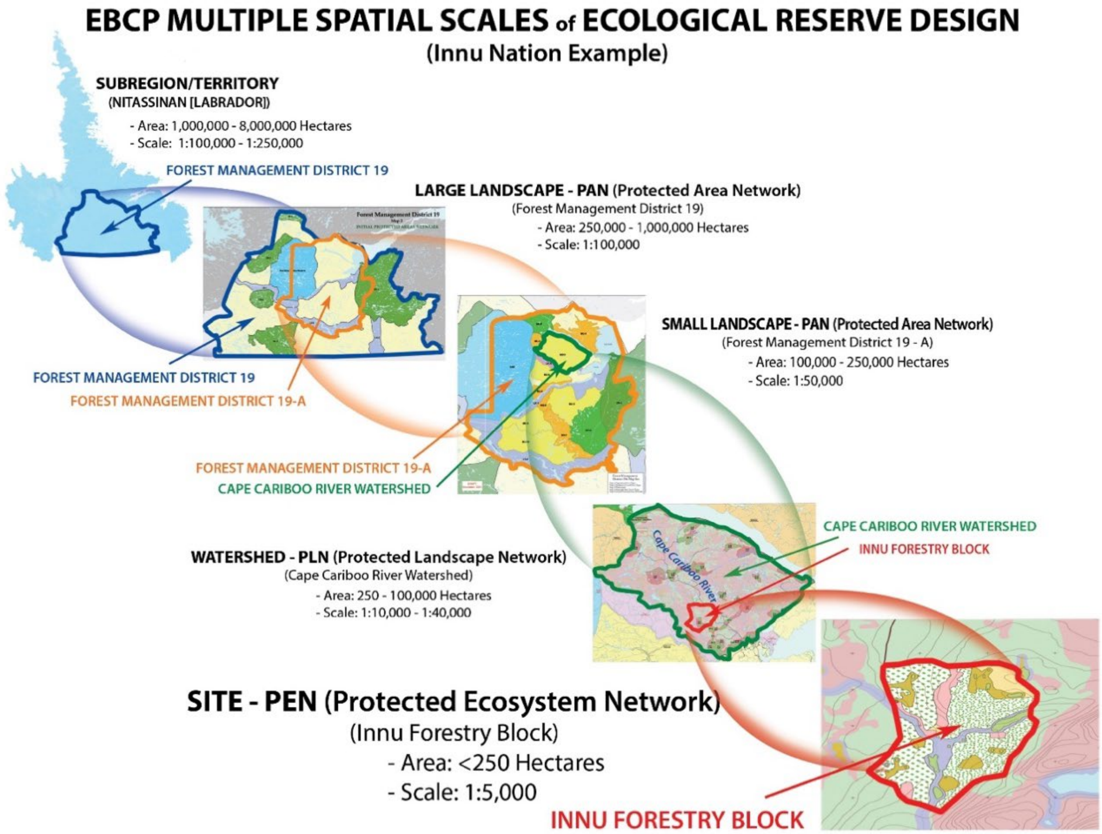

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Figure 1.4-2. Multiple Spatial Scales of Nature-Directed Stewardship (Silva Forest Foundation 2018)

1.4.3 Principles

NDS consists of seven interdependent, interconnected principles.

- *Principle 1:* Focus on what to *protect*, then on what to use.
- *Principle 2:* Recognize the *hierarchal relationship* between ecosystems, cultures, and economies.
- *Principle 3:* Apply the *precautionary principle* to all plans and activities.
- *Principle 4:* Protect, maintain, and where necessary, restore *ecological connectivity* and the *full range* of composition, structure, and function of enduring features, natural plant communities, and animal habitats and ranges.
- *Principle 5:* Facilitate the protection and/or restoration of *Indigenous land use*.
- *Principle 6:* Ensure that the planning process is *inclusive* of the range of values and interests.
- *Principle 7:* Provide for *diverse, ecologically sustainable, community-based economies.*
- *Principle 8:* Practice *adaptive management*. (Hammond 2009)

Each of these principles is discussed in more detail below.

1. **Focus on what to protect, then on what to use**

The first priority of a Nature-Based approach is to maintain and/or restore natural ecosystem composition, structure, and function across all spatial scales through time. That is, NDS protects ecological integrity (Franklin 1997). Biological diversity is protected, including genetic, species, community, landscape, and regional diversity. Natural ecosystems are maintained and/or restored, ranging from small patches of trees or individual wetlands to large river basins or regions. Ecological integrity includes maintaining natural assemblages of species, and ecosystem patterns and processes across spatial and temporal scales.

After protection of ecological integrity is provided for, Nature-Directed Stewardship provides for balanced, diverse human uses, which occur within ecological limits.

2. **Recognize the hierarchical relationship between ecosystems, cultures, and economies.**

Economies are part of human cultures and human cultures are part of ecosystems. Therefore, protecting ecosystem functioning or ecological integrity provides for healthy human cultures, and the economies that are part of these cultures.

This intuitive relationship between ecosystems, cultures, and economies, shown in Figure 1.4-3 is well grounded in both Indigenous knowledge and western science. (Daly 1991; Gowdy & O'Hara 1995)

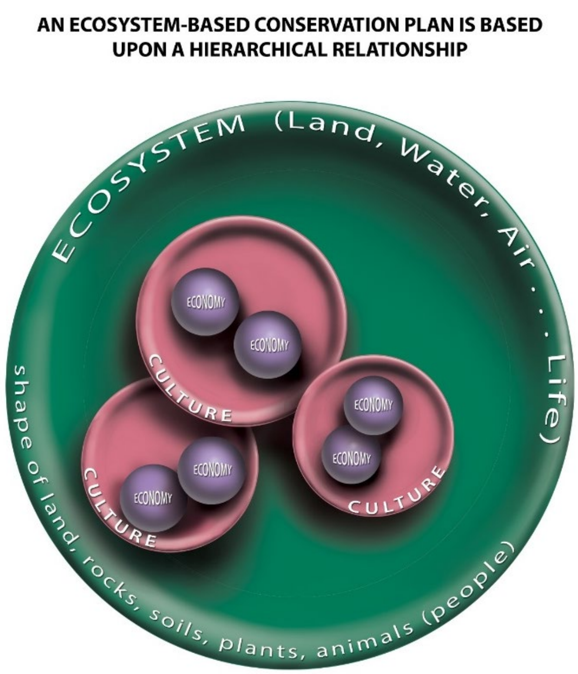

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Figure 1.4-3. The Hierarchical Relationship that underlies Nature-Directed Stewardship

In contrast to this hierarchical relationship, the "sustainable development" model portrays environmental, social, and economic factors as relatively equal. In the sustainable development model, where these factors "intersect" is where plans are considered to provide for sustainable activities (Flint 2013). I cannot think of any places where social factors are outside of the environment, or where economic factors exist outside of social factors.

From the standpoint of NDS, the sustainable development model is an *assumption of convenience* to maintain at least minimal levels of economic growth. In contrast, the NDS hierarchy constrains economic activities within the limits of ecosystems.

3. **Apply the precautionary principle to all plans and activities.**

The precautionary principle deals with uncertainties by specifying that decisions, interpretations, plans, and activities need to err on the side of protecting or restoring ecological integrity, as opposed to erring on the side of protecting resource exploitation (Keith 1994). In other words, if you're not sure that an activity will protect, maintain, or restore ecosystem integrity, then modify the activity so that it occurs within ecological limits, or do not do it.

Precautionary actions result from applying the precautionary principle. Precautionary actions are rooted in common sense (e.g., "look before you leap") and are taken where there is a lack of information or certainty about human impacts. They are cautious, conservative approaches and include leaving Nature untouched in the face of uncertainty. In order to prevent harm, precautionary actions are taken only after cautious evaluation and decision-making that focuses on intergenerational equity. The burden of proof rests with the proponent of disturbing Nature. A full range of alternatives must be considered – again, including doing nothing. And decision-making is participatory, meaning decision-making is open to all potentially affected parties, informed by best information, democratic and inclusive of all potentially affected parties.

Similar to the hierarchal relationship between ecosystem, cultures, and economies, applying the precautionary principle is one of the hallmarks of NDS. In order for plans to qualify as Nature-Directed Stewardship, they need to be developed and implemented using precautionary assumptions and actions in all aspects of planning and activities.

4. **Protect, maintain and, where necessary, restore ecological connectivity and the full range of composition, structure, and function of enduring features, natural plant communities, and animal habitats and ranges**

This principle is implemented by establishing nested networks of ecological reserves at multiple spatial scales.

Wholeness—ecological integrity—of ecosystems not only needs to be maintained across spatial scales, but also through time. This goal is achieved by incorporation of *ecological timeframes*, not human timeframes in NDS.

Ecosystems are timeless. Ecosystems are a continuum. Ecosystems do not "begin" or "end." Logical ecological timeframes include the functional roles of major components, e.g., a tree. Even in fire dominated forests, like the boreal, the functional lifetime of a tree, consisting of living tree, standing dead tree (snag), and decayed fallen tree may easily occupy 300 years or more. In a temperate rain forest this ecological timeframe may reach 2000 years.

5. Facilitate the protection and/or restoration of Indigenous land use

NDS encourages Indigenous people to map and describe their land uses and/or cultural activities. Under the guidance and control of Indigenous people, this information may be combined with ecological reserve design (see Principle 4) to ensure the protection and/or restoration of Indigenous land use through the establishment of *protected networks of cultural areas* or used in other ways specified by the Indigenous Nations(s) in the plan area. (Silva Forest Foundation 2009)

6. Ensure that the planning process is inclusive of the range of values and interests that fall within the definition of NDS

NDS provides for full discussion and debate of issues, based upon the best available information, by participants who represent the spectrum of values and interests that may be affected by the plan. Those representing various interests assume responsibility and accountability for accurately representing their interest, consulting with their constituencies, and assuming responsibility for the outcomes of NDS. Shared decision-making by all participants characterizes a NDS process and provides an egalitarian approach to planning.

An inclusive, community-based approach to planning ensures that people affected by the plan are active, full participants in the development and implementation of the plan (Maquire 1999; Owen 1995). The primary purposes of a NDS are to ensure the maintenance or restoration of ecological integrity and provide for healthy communities within the plan area. These goals can only be achieved when affected communities develop and take ownership of a plan. Because NDS, including the development of steady state, community economies, is often a shift from the status quo, public explanation, discussion, and community acceptance of the definition and principles of NDS are essential for the success of NDS.

7. Provide for diverse, ecologically sustainable, community-based economies

To be sustainable and provide for social equity, economies need to function within ecological limits, facilitate a diverse range of activities that focus on fulfilling individual and community needs, and protect and maintain ecological integrity (Jackson 2009). Healthy communities both depend upon and maintain healthy and diverse ecosystems.

A healthy global economy results from development of healthy regional economies maintained by healthy local or community-based economies. Hence, Nature-Directed Stewardship for local landscapes constitutes the foundation for healthy global economies by maintaining ecological integrity and providing for human well-being at local and regional scales. However, the reverse is not true. In other words, healthy global economies cannot be developed from the top down, because such plans are built upon centralized power structures that give first priority to maintaining the interests of power centers, as opposed to giving first priority to maintaining ecological integrity and developing healthy communities. (McKibben 2007)

The “healthy” economies referred to above recognize that economic growth is an anathema to the health of the biosphere and all who inhabit it. Thus, economies that arise from NDS may be seen as both *steady state* economies (Czech 2013) and as *regenerative* or *distributive* economies (Raworth 2017). In both cases, healthy economies respect the hierarchy explained in NDS Principle 2: economies are part of societies or cultures, which are part of, and dependent upon ecosystems. Therefore, maintaining the natural integrity of ecosystems provides for the health and well-being of human societies and the economies that are a part of these societies.

People are attracted to, and desire to live in beautiful, healthy environments. Economies thrive in healthy ecosystems, and through the protection of ecosystems by human communities (Power 1988; Power 1995). Once resources are depleted and all that remains is a degraded environment, the economy collapses, and people leave.

8. Practice adaptive management

Within the constraints of the precautionary principle and ecologically responsible actions, a variety of activities may be included as part of NDS. However, all activities are continuously evaluated for their success in maintaining or restoring natural ecological integrity, including biological diversity, and in providing for healthy communities, both human and non-human. The results of evaluations are incorporated into future modifications of NDS—adaptive management. (Noss & Cooperrider 1994)

Adaptive management is a systematic approach to improving management, including restoration, and accommodating change by learning from the outcomes of human activities. It involves gathering and incorporating new information. It is more than trial and error, or learning by our mistakes, because it involves careful design, monitoring, evaluation, and feedback in order to improve management (Gray 2000). Adaptive management can be practiced in a variety of ways, on a continuum from passive to active approaches, which differ in their intensity, commitment, and cost (Williams 2011).

Active adaptive management includes deliberate, carefully designed management experiments that have scientific rigor, including replicated treatments, rigorous data collection, and sound statistical analysis. Because active adaptive management is expensive and time consuming, this approach tends to be reserved for major questions that are not well-addressed through passive adaptive management. (Boesch et al*.* 2004)

Passive adaptive management involves careful monitoring of the effects and outcome of activities, and a subsequent comparison of these effects and outcomes to pre-activity predictions and conditions. Passive adaptive management, when well designed, is a practical, affordable way to learn from the results of management practices, including restoration activities. Examples of monitoring activities under passive adaptive management include photo points that are monitored through time, accompanied by careful measurements of the characteristics and condition of the ecosystems in question each time photo points are re-photographed. (Boesch et al*.* 2004)

The practice of adaptive management, both active and passive, is fundamental to NDS activities. Adaptive management provides for learning "what works and what doesn't," thereby encouraging design and implementation of a variety of approaches and techniques. Using a diversity of approaches and techniques that fit within the principles of NDS is necessary to protect and restore the *natural biological diversity* on which healthy ecosystem functioning depends. Thus, without the continual use of effective adaptive management, from planning through operations to monitoring, a plan and subsequent activities do not qualify as being NDS.

Where landscapes, watersheds, and sites have high degrees of degradation from resource development activities, adaptive management is even more vital than in areas with undisturbed or only partially disturbed natural ecological integrity. Applying NDS in degraded areas will be dominated by ecological restoration, which often brings with it many new situations, and/or infrequently encountered situations. Such circumstances mean that restoration treatments are breaking new ground, and evaluation of results is vital to successful restoration efforts.

Restoration goals will seldom be achieved with one or two treatments applied in a short time interval. Instead, ongoing restoration will be necessary to reach goals, often over extended periods of time. As the condition of watersheds and sites being restored changes, or does not change, with restoration activities, adaptive management to guide future activities becomes critical to the success of applying NDS.

1.4.4 Applying Nature-Directed Stewardship

NDS is most easily applied in relatively unfettered landscapes to maintain natural ecological integrity and biological diversity, while accommodating dynamic, often unpredictable natural processes of change that maintain diversity in a self-sustaining balancing act. Balance is the gift of diversity. However, without unpredictable change, diversity is not maintained. Without diversity, healthy ecosystems, from landscapes to small patches, do not exist. (Hammond 1992)

Ongoing and accelerating climate disruption challenges the integrity of all ecosystems and the validity of human planning processes that aim to provide human needs within ecological limits. As discussed in Section 4.1.5 of this report, identification of climate change refugia through NDS is a logical extension of the information and interpretation assembled in a plan for NDS. Maintenance of ecological integrity and biodiversity enable NDS to provide "stepping stones" to new socio-ecological regimes being forged by climate change.

1.5 Nature-Directed Stewardship and Economics—Management of Home

Note: Nature-Directed Stewardship includes a socio-ecological economic analysis of the current local economy with local communities as the referent group, and recommendations for the structure, both ecological and social, to facilitate the development of an ecological steady state economy. However, this *initial* Nature-Directed Stewardship plan does not contain either a socio-ecological economic analysis, or specific recommendations for an ecological steady state economy.

1.5.1 Introduction

The prefix “eco”, from the Greek “oikos” means home. Economics—management of the home—refers to activities carried out to meet the *needs* of individuals and society. Ecosystem means home system. In order to maintain ecosystem integrity, economics needs to be about protection and wise use of ecosystems in order to ensure their continued health and well-being. Ecosystems can then continue to protect our home and the home of all beings.

Good economics is rooted in a kincentric relationship with Nature—with ecosystems.

Good economics is based on reciprocity. Robin Wall Kimmerer (2014) explains this well:

> *“Reciprocity—returning the gift—is not just good manners; it is how the biophysical world works. Balance in ecological systems arises from negative feedback loops, from cycles of giving and taking: living and dying, production and consumption, biogeochemical cycles, water to cloud and back to water again. Reciprocity among parts of the living Earth produces equilibrium in which life as we know it can flourish. Positive feedback loops—in which interactions spur one another away from balance—produce radical change, often to a point of no return. We must understand that we, like every other successful organism, must play by the rules that govern ecosystem function. The laws of thermodynamics have not been suspended on our behalf. Unlimited growth is not possible. In a finite world you cannot relentlessly take without replenishment.”*

1.5.2 Ecosystems and Economies

NDS addresses the tension between human economies, which are open systems, and Earth, which is essentially a closed system. “An open system is any complex arrangement that maintains itself through an inflow and outflow of energy and material from and to its environment” (Victor 2008). Human beings are open systems. Economies are open systems.

The ecosystems that comprise Earth are open systems. However, Earth as a whole is a closed system. “A closed system exchanges energy with its environment but not material. The Earth receives solar energy and re-radiates an equal amount of energy to outer space, maintaining the planet’s temperature. The accumulation of greenhouse gases in the atmosphere from the operation of human-controlled open systems on the surface of the planet is disturbing this exchange of energy, causing the climate to change. Only insignificant amounts of material enter or leave the earth and that it is why it is a closed system.” (Victor 2008).

As open systems, living organisms, including human beings, are born, grow and develop, and then decline and die. When living organisms die, their energy and material are recycled, playing essential roles in ecosystem functioning. There are clear biological limits to growth for humans and all other organisms. Limits to growth enable open systems to not overtax Earth's finite materials, nor to encumber Earth with waste.

In contrast, today's economic systems, are predicated on perpetual growth (Raworth 2017). There are two primary problems with perpetual economic growth: depletion of Earth's finite materials and conversion of these materials to waste. Depletion is facilitated by classifying Earth's materials as "resources" (e.g., forest resources) to create the illusion that Earth's materials belong to us and have little value until turned into products important to human beings. Waste results because all material and energy used in economic activities, even with some of it being recycled, is degraded by the economic activity, and eventually ends up as environmental waste (Victor 2008). Thus, the modern economic imperative of perpetual growth depletes finite materials and increases environmental waste, thereby increasing the degradation of ecosystems and their essential benefits that life depends upon for survival.

Sometimes ecosystem benefits are referred to as "services." However, reference to ecosystem "services" also furthers the belief that Earth's bounty belongs to us, like electrical services, internet services, satellite TV services etc. This anthropocentric view has resulted in the commodification of ecosystem services. (Wall Street's Takeover of Nature Advances with Launch of New Asset Class, https://unlimitedhangout.com/2021/10/investigative-reports/wall-streets-takeover-of-nature-advances-with-launch-of-new-asset-class/).

By giving priority to the maintenance and/or restoration of natural ecological integrity, NDS facilitates the development of steady state economies that exist within ecological limits – within the closed system of Earth. Waste is reduced to manageable levels so that ecosystem benefits and the life dependent upon these benefits are maintained.

The Center for the Advancement of the Steady State Economy (CASSE) defines a steady state economy as:

> *"A steady state economy is an economy of stable or mildly fluctuating size. It is ideally established at a size that leaves room for nature and provides high levels of wellbeing. The term typically refers to a national economy, but it can also be applied to a local, regional, or global economy. An economy can reach a steady state after a period of growth or after a period of downsizing or degrowth. To be sustainable, a steady state economy may not exceed ecological limits.*
>
> *A steady state economy aims for stability or mildly fluctuating levels in population and consumption of energy and materials. Minimizing waste allows for a steady state economy at higher levels of production and consumption.*
>
> *All else equal, the steady state economy is indicated by stabilized (or mildly fluctuating) gross domestic product (GDP). GDP is not a good indicator of well-being, but is a solid indicator of economic activity and environmental impact.*

> *A steady state economy is the only type of economy that is sustainable over the long term. It is an economy that meets people's needs without undermining the life-support services of the planet. It represents the ultimate social movement toward a better world for all. Life is downshifted as overconsumption, congestion, sprawl, and unfair trade practices fade away. People instead focus on community, relationships, sufficient consumption, and the things that really matter in life."* (CASSE 2022a; CASSE 2022b)

Brian Czech (2018) adds important aspects of a steady state economy in a Post in the Daly News, CASSE:

> *"Steady state economics centers around the themes of sustainability, distribution of wealth, and allocation of resources. When asked for advice, the steady state economist will prescribe stabilized GDP (for sustainability), an equitable distribution of wealth, and efficient allocation of resources using a variety of approaches. In contrast, conventional economics deals almost entirely with the allocation of resources by prescribing especially the "free market"."*

From the mid-1800s to the present, industrial activities, including forestry, mining, roads, and residential development have caused and continue to cause serious losses in ecosystem integrity and biological diversity within the forest landscape and elsewhere across Earth. Timber extraction in forests, particularly clearcutting, exacerbates climate disruption. These losses bring with them many costs that range from human health problems and air/water pollution to floods and landslides, intense storms, drought, and temperature extremes. Many of the human costs and monetary losses associated with these events may be avoided through maintenance of natural ecological integrity, which provides, at no charge, ecological benefits that purify air and water, conserve and manage water, moderate climate, provide healthy human environments, reduce extreme events, and efficiently sequester and store carbon to mitigate climate change.

1.5.3 An Economy of Reciprocity

Some further thoughts about economics of abundance from Robin Wall Kimmerer (2020):

> *"I don't think market capitalism is going to disappear anytime soon; the faceless institutions that benefit from it are too entrenched. But I don't think it's pie-in-the-sky to imagine that we can create incentives to nurture a gift economy that runs right alongside the market economy, where the good that is served is community. After all, what we crave is not trickle-down, faceless profits, but reciprocal, face-to-face relationships, which are naturally abundant but made scarce by the anonymity of large-scale economics. We have the power to change that, to develop the local, reciprocal economies that serve community, rather than undermine it.*
>
> *Continued fealty to economies based on competition for manufactured scarcity, rather than cooperation around natural abundance, is now causing us to face the danger of producing real scarcity, evident in growing shortages of food and clean water,*

breathable air, and fertile soil. Climate change is a product of this extractive economy and is forcing us to confront the inevitable outcome of our consumptive lifestyle, genuine scarcity for which the market has no remedy. Indigenous story traditions are full of these cautionary teachings. When the gift is dishonored, the outcome is always material as well as spiritual. Disrespect the water and the springs dry up. Waste the corn and the garden grows barren. Regenerative economies which cherish and reciprocate the gift are the only path forward. To replenish the possibility of mutual flourishing, for birds and berries and people, we need an economy that shares the gifts of the Earth, following the lead of our oldest teachers, the plants."

We all need to work towards the development of ecologically-based steady state economies. These will be community economies that radiate to regional economies and beyond.

The corporate, growth oriented economy is a major part of the problem that faces forests and all ecosystems. As Kimmerer points out above, the corporate market economy, based on perpetual growth will not go away easily. However, ignoring the problem by continuing the current economic way of being only increases the downward spiral. This initial NDS plan supports the development of ecological steady state economies that support the transition for forest workers from timber extraction and plantation management to ecological restoration and regenerative activities, like proforestation—growing existing forests intact to their ecological potential (Moomaw et al. 2019).

How is this transition supported financially? Currently the timber industry, which accounts for approximately 2% of GDP and is responsible for less than 2% of the jobs in BC is subsidized by at least $1 million/day. Instead of spending $365 million/year and more in perverse subsidies for the timber subsidies, that money needs to be redirected to ecologically and socially responsible subsidies in support of forest worker transition.

Robin Wall Kimmerer (2020) gets the last word:

"The natural world itself is understood as a gift and not as private property, as such there are ethical constraints on the accumulation of abundance that is not yours. Well known examples of gift economies include potlatches or the Kula ring cycle, in which gifts circulate in the group, solidifying bonds of relationship and redistributing wealth.

The question of abundance highlights the striking difference between the market economies which have come to dominate the globe and the ancient gift economies which preceded them. There are many examples of functioning gift economies—most in small societies of close relations, where community well-being is recognized as the "unit" of success—where the interest of "we" exceeds that of "I." In this time when the economies have grown so large and impersonal that they extinguish rather than nurture community well-being, perhaps we should consider other ways to organize the exchange of goods and services which constitute an economy."

2. SCIENTIFIC BACKGROUND

2.1 Forestry Effects on Watershed and Ecosystem Functions

2.1.1 Intact Natural Forests

To understand the effects of forestry, i.e., timber extraction and tree plantation management on water and watershed functions, we need to start with how intact, natural forests provide water and watershed functions. Our discussion focuses on the benefits that intact, natural forests provide for water quality, quantity, and timing of flow.

Intact, natural forests are also referred to as primary forests. All forests that have not been significantly altered by industrialized society's activities are referred to as primary forests. A hiking trail through a forest does not constitute significant alteration. A road and clearcut do constitute significant alteration.

Intact natural forests provide high quality water in moderate amounts throughout the year. Water management by intact, natural forests improves as the forest ages. Thus, old-growth primary forests provide the best water. Why?

During a rainstorm, millions of liters of water fall on a forest canopy from a great height. During a snowstorm, hundreds of thousands of tonnes of snow collect in a forest canopy. The forest absorbs this energy and releases it, one drop at a time. Old and old-growth forests do this best because they have multiple canopy layers. When water falls on an old forest canopy, the rain or snow is first intercepted by large, tall, old trees with millions of leaves. As the water in the form of rain or snow gently falls through the forest canopy, intermediate and shorter trees, shrubs, and herbs, and eventually mosses and lichens catch the water and slowly release it to the absorbent forest floor – soil, streams, ponds, and wetlands. This function regulates both the energy and volume of water released into the forest.

In the case of snow, which applies to both the Glade and Laird watersheds, the multi-layered canopy and canopy gaps of old, intact forests collect and store snow through the winter. Once the warmth of spring returns, the forest canopy regulates the melting of snow and the corresponding gradual release of water by partially shading the snowpack. In this situation, the multi-layered canopy and canopy gaps of old, intact natural forests "meter" the release of water in the spring and summer, conserving water to provide for late summer and early fall flows.

During precipitation events, both rain and snow, a significant amount of the precipitation is intercepted by the tree canopy, sublimated or evaporated back into the atmosphere, and moved to another location. This occurs when snow or rain is caught in the canopies of large trees and multi-layers of vegetation in the old forests and is sublimated/evaporated by exposure to the energy of sun and/or wind. In a snow dominated older forest, 40% to nearly 70% of the snow is intercepted by the canopy, with a large portion of that precipitation returned to the atmosphere through the actions of sun and wind (Helbig 2020).

This function of old and old-growth forests is not only important for local and regional distribution of water, but also for regional and continental distribution of water (Creed & van Noordwik 2018; FAO 2019).

An old forest canopy slows the force of water falling during a rainstorm to maintain order and balance in the ecosystem. This means that during rainfall, soils are able to partially drain, giving them an ability to absorb the storm water as it falls and avoid surface runoff and erosion.

Large fallen trees decaying on the forest floor are characteristic structures in primary forests, particularly old and old-growth forests. Decayed wood is the natural water storage and filtration system in forest ecosystems. Decayed wood holds many times more water than a given volume of most mineral soils (Isaacson 1985). These large dead tree structures found in intact natural forests function as "water storage and filtration systems" for hundreds of years.

Water storage and filtration in the decayed wood of an old forest is particularly vital for "late-season," or late summer and fall water. Therefore, even small first and second order streams need millions of tonnes of decayed wood distributed throughout their watershed to provide for healthy water quality, quantity, and timing of flow — flow that meets ecosystem and human needs throughout the seasons.

The multilayered canopies of intact old and old-growth forests, together with their large supplies of decayed wood, have an additional hydrological function. Cool temperatures and humid air, found from the upper canopy to the forest floor slow the evaporation of water, thereby conserving the release of water from the forest so that flows are moderate and dependable throughout the year. This hydrological role of natural, intact old forests will increase in importance as global warming increases.

In contrast, young forests that have many fewer leaves to intercept water, smaller crowns, single-layer canopies, higher air temperatures, less humid air, and declining supplies of decayed wood. These factors mean that young forests do not conserve water well. Forest landscapes dominated by young forests tend to have more frequent floods during storm events, faster and higher runoff periods in the spring, and more frequent and severe droughts, particularly in the fall (Segura et al. 2020).

Maintaining the natural character of intact primary forests, particularly old and old-growth forests throughout the forest landscape is important to not only maintain today's water supplies but will be even more important with the moisture stresses that grow as global warming increases.

Primary forests are commonly embedded in a matrix extensively modified by activities of industrial societies, like forestry, mining, and urban development. In this context, the word matrix refers to the dominant patch type in the landscape (Lindenmayer & Franklin 2002). In most landscapes dominated by industrialized human societies, the matrix is highly modified by their activities. This condition creates urgency to protect remaining primary forests and other intact natural ecosystems, and to re-establish connectivity between these patches to restore ecological integrity and resilience.

Applying the concept of the matrix to watersheds, forest ecologists David Lindenmayer and Jerry Franklin (2002) explain the connections between natural, intact forests and water:

> *"As the dominant patch type in most temperate landscapes, the matrix strongly influences the condition of aquatic ecosystems and water quality. Vegetation conditions in a watershed, especially the type and density of forest cover, directly influence the structure, environment, and diversity of associated aquatic ecosystems. Terrestrial vegetation also regulates the paths and rates of water movement, erosion, and sediment transport through a watershed.*
>
> *Natural forests typically provide a stable landscape context for the development of aquatic ecosystems and organisms. Forest cover mutes environmental extremes, such as in-stream temperature fluctuations; provides energy and nutrient inputs; filters sediments; and provides large woody debris which is an essential structural element of many aquatic ecosystems. Forest cover can influence storm response such as by reducing peak flows. Forests can also extend runoff in watersheds, such as those dominated by spring snowmelt. Erosion is also minimized in natural forest landscapes, resulting in high-quality water with low levels of sediment and dissolved and suspended materials.*
>
> *A central goal of matrix management is preserving aquatic ecosystem integrity and the hydrologic and geomorphological processes upon which much biodiversity depends. Given its fundamental importance to human societies, the maintenance of a well-regulated, high-quality water supply is (or should be) one of the chief objectives in the management of forest lands."* (pp.12, 13, 49)

2.1.2 Intact Natural Forests and Carbon

Carbon sequestration and storage are critical functions of forested watersheds. Sequestration is the capture of carbon from the atmosphere through the process of photosynthesis. Storage of carbon occurs in leaves, twigs, branches, and main stems of woody plants. Because of their size, trees obviously sequester and store the largest amount of carbon in a forest, compared to other plants. Long-term storage of carbon occurs both in the limbs and trunks above ground, as well as below ground in the roots. Approximately 50% of the carbon stored in forests is found in the soil, including decayed organic matter, plant roots and the mycorrhizal fungal network that connects all plants. The older and more complex the forest structure and the larger the trees, the greater the amount of carbon that is captured and stored in the forest. Thus, intact primary forests, particularly old-growth forests are our most important terrestrial carbon sink. Moomaw, Masino, and Faison (2019) describe this concept in the following:

> *"Climate change and loss of biodiversity are widely recognized as the foremost environmental challenges of our time. Forests annually sequester large quantities of atmospheric carbon dioxide (CO_2), and store carbon above and below ground for long periods of time. Intact forests — largely free from human intervention except primarily*

for trails and hazard removals — are the most carbon-dense and biodiverse terrestrial ecosystems, with additional benefits to society and the economy. Internationally, focus has been on preventing the loss of tropical forests, yet US temperate and boreal forests remove sufficient atmospheric CO_2 to reduce national annual net emissions by 11%. US forests have the potential for much more rapid atmospheric CO_2 removal rates and biological carbon sequestration by intact and/or older forests. The recent 1.5 Degree Warming Report by the International Panel on Climate Change identifies reforestation and afforestation as important strategies to increase negative emissions, but they face significant challenges: afforestation requires an enormous amount of additional land and neither strategy can remove sufficient carbon by growing young trees during the critical next decade(s). In contrast, growing existing forests intact to their ecological potential — termed proforestation — is a more effective, immediate, and low cost approach that could be mobilized across suitable forests of all types. Proforestation serves the greatest public good by maximizing co-benefits such as nature-based biological carbon sequestration and unparalleled ecosystem system services such as biodiversity enhancement, water and air quality, flood and erosion control, public health benefits, low-impact recreation, and scenic beauty." (p. 1)

Moomaw and his colleagues clearly support the need to protect forested watersheds, particularly those with intact forests, as carbon sinks that play an essential role in mitigating climate disruption and assisting to keep global warming below 1.5° C. This essential benefit of intact forested watersheds supports the protection of both Glade Creek and Laird Creek watersheds as carbon sinks, particularly given their context within a landscape of clearcuts and other developments that are carbon sources.

2.1.3 Forestry Effect on Water and Watersheds

As used in this context, "forestry" means conventional industrial forestry as practiced widely across BC. While forest professionals and timber companies widely tout their protection of biodiversity, water, and the myriad of ecosystem benefits provided by intact, natural forests, these claims are not borne out in examination of the results of forestry. Clearcuts and tree plantations, based upon short rotations, or the periods between logging and logging plantation trees, dominate the practice of forestry. The result is the virtual exclusion of "kinder, gentler" forestry practices, where maintenance of ecological integrity and resilience are the priorities through the establishment of networks of ecological reserves. And, in some areas between ecological reserves, partial cutting is used to remove a modest amount of timber at periodic intervals to meet human needs.

Clearcuts degrade water (Yu & Alila 2019). Clearcuts degrade biodiversity (Jilia 2020). Clearcuts degrade ecological resilience (Thompson et al. 2009). Clearcuts exacerbate climate disruption (Weiting 2019; Pojar 2019). Then, why are they sanctioned by forest professionals in the employ of timber companies. Two reasons: clearcuts are the cheapest and fastest way to turn trees, seen as "logs standing vertically," into monetary profits; and the private control of forests on alleged public forests in BC gives the timber industry the power to decide how forest management occurs. De facto privatization of forests is the result of tenure arrangements between timber companies and the BC government. These tenures provide timber companies the means to define what is “good” for BC forests and the public interest.

2.1.3.1 Removal of Forest Canopy—Forestry Effects

Clearcut forestry completely removes the multi-layered canopies that intercept precipitation, redirect some of the precipitation to other locations, and reduce the amount that reaches the forest floor. When it comes to the direct release of energy from a storm event, the energy from rain is significantly dampened as it drips through the canopy. In a snow storm, the canopy collects a large amount of the snow fall and releases it to the atmosphere to avoid development of snow packs that will overload the watershed during spring runoff.

In all places where intact forests have been removed, these water buffering effects are lost.

In the case of rain, the energy of falling water is released immediately during the storm. This often results in high levels of water saturation of soils, which may lead to erosion, including landslides, and floods.

In snow dominated portions of a watershed, openings like clearcuts and road corridors collect approximately 40% + deeper snow packs than are found under the multilayered canopies of intact old and old-growth forests. In the spring and summer, the deeper snow packs in openings melt approximately 30% faster than the snowpack shaded by an intact, old natural forest. This process releases a large pulse of water in the spring and reduces the water available from a watershed in the late summer and fall. Thus, the absence of forests can result in spring floods and fall droughts, particularly in watersheds that depend upon snowpacks for water. (Yu & Alila 2019; Wood 2021)

Replacing the multi-layered canopy of large, dense foliage forest crowns is a slow process that requires decades of forest growth and development (Owen 2022). In the case of the Laird and Glade forests, this process will require in order of 100 years or more, which is well beyond the intended rotation length when plantation trees are scheduled to be logged. Thus, forestry does not intend to ever replace the canopy of trees that once functioned so well in the conservation and management of water.

2.1.3.2 Loss of Decayed Fallen Trees—Forestry Effects

Protection of existing dead trees (snags and fallen) coupled with continuous replacement of dead standing (snags) and fallen trees are essential processes related to water conservation and overall health of a watershed. In natural forest ecosystems that are not disturbed by logging or other forms of clearing these processes function relatively smoothly through time, even with natural disturbance regimes changing the structure of the forest.

However, replacing large dead tree structures is absent from most approaches to “sustained yield” forest management, particularly those that employ clearcutting and short rotation plantations. Large living trees are all removed as logs. Even smaller trees beneath the size to qualify for a log are cut down in order to “efficiently” remove merchantable trees.

Clearcut forestry either removes snags as merchantable logs or fells the snag to avoid dangerous working conditions. When trees are yarded or skidded from the forest to landing areas where logs are loaded on trucks, many fallen tree structures are broken apart and lose their water storage and filtration function. These fallen trees fall victims to a well understood principle of forest ecology: loss of the composition and/or structure results in loss of function.

The loss of a multi-layer forest canopy with large tree crowns able to intercept water, and the loss of the benefits of decayed wood from a continuous supply of large fallen trees, leads to decline of the water storage and filtration capacity of watersheds. The end result of this ecological degradation is overall loss of watershed integrity, including loss of water quality and timing of flows that vary from spring floods to fall droughts.

2.1.3.3 Concentration of Water—Forestry Effects

In an intact, natural forested watershed, water is dispersed through the vegetation cover of the forest, absorbed and transmitted through permeable soil, eventually emerging as surface water in springs, seeps, wetlands, intermittent creeks, year round creeks, ponds, lakes, and rivers. However, when forestry occurs in a watershed much of the water changes from being dispersed throughout the system to concentrated in particular locations, which often results in erosion, landslides, and siltation of water supplies.

By removing the forest canopy, forestry subjects the forest floor to being overloaded with precipitation in rain events and overly deep snow packs that melt rapidly in the spring. In both of these situations, the concentration of water on the forest floor may lead to degradation of soil and water. The chance for these effects to occur may increase with the intense storms and drought that accompany climate disruption. Prolonged drought may result in the development of hydrophobic soils that in intense storms may cause concentration of runoff, overland flow, and associated soil and water degradation. (Hewelke et al*.* 2018; Gimbel et al*.* 2016)

Other than in the infrequent situation of aerial removal of logs, forestry operations require the construction of access roads to reach areas that are scheduled to be logged. Many of these areas that are logged also require the construction of skid trails, or low quality roads through the logging area to drag logs to a road or log landing area, where logs are loaded on trucks. These roads and trails have compacted, water-impermeable surfaces, across the direction of slope, thereby intercepting downslope movement of water, and concentrating water on their surface. Prior to forestry operations, this water was dispersed throughout the soil and moved down the slope to nourish plants, animals, microorganisms, and maintain ecosystem processes. Dispersed movement of water is the natural way of water in forests and does not cause detrimental effects to the forest.

However, water is concentrated by road surfaces, ditches, and cross drains. Under circumstances of intense rainfall and/or rapid snow melt, both more common with climate change, road surfaces and the fill slope on which roads are constructed may become saturated with water, resulting in erosion and landslides. Fill slopes are at a steeper angle than the angle of the underlying natural topography and consist of unconsolidated material, both of which make them more subject to failure when saturated with water than the underlying natural soil profile. In situations where the fill slope fails, the natural soil profile beneath the fill slope usually becomes part of the landslide. Such events associated with roads often result in direct siltation of surface water supplies.

Forestry operations attempt to manage the concentration of water on roads by constructing ditches on the upslope side of roads and draining the ditches through culverts beneath the road at intervals along the road. Notably this type of water management does not occur on skid trails.

While ditches reduce water concentration on road surfaces, they also result in greater concentration of water that accumulates along the length of the ditch. That water is funneled through culverts onto slopes below the road, resulting in saturation of the fill slope or natural slope, soil erosion and potential mass movement of soil.

Overall, the concentration of water that results from forestry operations poses many risks to both the integrity of the ecosystems that comprise the sites modified by forestry, and ecosystems that are down slope, and downstream from the forestry operations.

2.1.3.4 Decayed Roots and Slope Instability—Forestry Effects

After an area is logged in forestry operations and time passes, the roots that formerly anchored the trees on the slope and contributed to the movement of water and nutrients from the soil up into tree crowns begin to decay. As the roots decay and are incorporated into the rhizosphere, they leave behind hollow “pipes” where the roots were once found. These hollow pipes have cemented, water impermeable sides due to pressure from the growth of living roots. These hollow pipes become filled with water and form another situation where forestry concentrates water to the detriment of the stability of ecosystems and topography.

As water pipes beneath the stumps in a clear-cut spread across an area, the likelihood of soil erosion and landslides increases. The effect of water pipes concentrating water is most pronounced on moderate to steep slopes. Thus, precautionary forestry planning for moderate to steep slopes assesses the likelihood of concentration of water from roads, skid roads, and water pipes following logging and may preclude forestry operations in these areas.

2.1.3.5 Loss of Carbon Sequestration and Storage—Forestry Effects

Logging intact forests in watersheds removes the carbon sequestration and storage function of the area where forestry operations occur. The trees extracted from the area logged are responsible for the largest loss of carbon conservation in forestry operations. In addition, clearcut forestry warms and dries out the soil and fallen trees, which results in an increase in the decomposition of these structures, and a corresponding rapid release of carbon from dead fallen trees and soil organic matter. (Pojar 2019; Weiting & Leversee 2019)

More than 60% of the carbon stored in the logs that are removed is back in the atmosphere within five years (Hammond, 1992). Thus, long-term storage of carbon in wood products is an inaccurate justification for logging. Even with the less than 40% of a log that reaches “long-term” storage, the length of that storage seldom exceeds 50-70 years, a much shorter lifetime than that found in the trees that once occupied the forest that was destroyed by forestry (Pojar 2017). Thus, as roads and logging progress through watersheds, the ability of the watershed declines to serve as a carbon sink and mitigate the climate emergency and biodiversity crises.

Roads are permanently lost to carbon sequestration and storage. Forestry in BC results in a high density of roads. In his research, Younes Alila, UBC hydrologist, documented 18,000 km of logging roads in one watershed of 8,000 square kilometres in size. “That density of road network is all over B.C. This watershed is no exception,” Alila explains (Brenna 2022). Current BC legislation permits up to 7% of clearcut blocks to be occupied by roads and landings. So, significant areas in the managed plantation “forests” created after logging are permanent carbon dead zones (Pojar 2019).

In the case of clearcut areas, it takes 13 years or more for the planted trees to absorb more carbon than is being released from the area due to decomposition of organic material. During that time the “managed forest” is a carbon sequestration dead zone. The forest has been converted from a carbon sink to a carbon source. That carbon source will last for a long time. (Weiting & Leversee 2019)

In the order of 150-250 years of forest growth and development will be necessary to restore the level of carbon sequestration and storage that existed in the intact, natural forests before they were logged. This period of time is based on the past growth patterns of interior wet-belt forests. Research in coastal temperate rain forests indicates that 250 years and more is necessary to restore the level of carbon sequestration and storage that existed before logging in these forests (Harmon 1990).

However, climate change calls into question whether forests in the future will follow past growth patterns. The growing stressors associated with climate disruption, like drought, insect epidemics, and extreme weather, may prevent natural forest development as existed in the past, and further reduce carbon sequestration and storage in managed forests.

Barry Saxifrage (2020) documents clearly that Canada’s forests have moved from being important carbon sinks that reduce greenhouse gases to large carbon sources that exacerbate climate disruption:

> *“My first chart (Figure 2.1-1) shows the overall trend. The green area means the forests are gaining carbon; the red area means they are emitting it. And the bold black line shows the net carbon balance of our managed forests. As you can see, these forests reliably gained carbon in the past. They were critical CO_2-absorbing sinks. But not anymore.*
>
> *Now they've flipped to emitting CO_2. Lots of it. In 2017, they lost 230 million tonnes of CO_2 ($MtCO_2$). Driving this trend is an un-natural surge in native insect outbreaks and wildfires. Humans are turbocharging both. Our relentlessly high levels of fossil fuel*

burning are rapidly altering the climate in favour of more insects and infernos. In addition, decades of poor land use practices have produced unfit, vulnerable, monoculture forests.

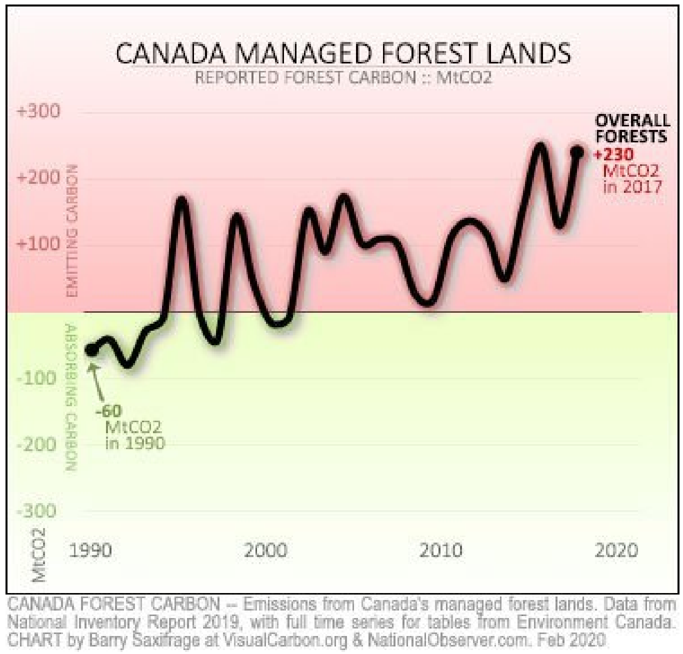
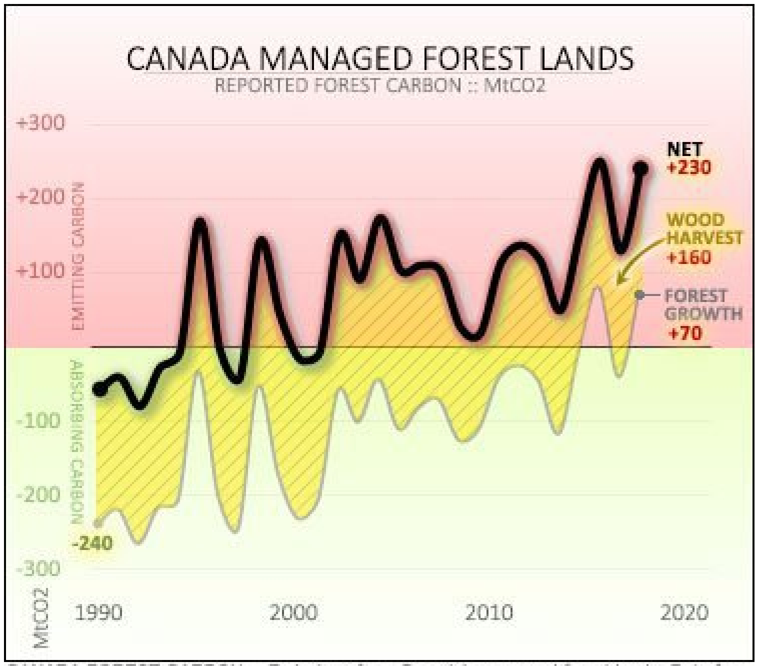


Figure 2.1-1. Carbon in Canada's Forests

As our managed forests have weakened under the strain, they are no longer replacing the amount of carbon that logging is taking out of them. My second chart (Figure 2.1-2) breaks this down. Canada reports forest carbon in two parts: ***forest growth*** *(grey line) and* ***harvested wood*** *(yellow area). Harvested wood volumes have averaged 185 MtCO_2 worth per year, since 1990. In recent years, it's been around 160 MtCO_2 worth.*

All that extracted forest carbon used to be replaced each year as new growth pulled even more CO_2 out of the air. But our faltering forests can't keep up anymore. Now logging is pushing our forests over the edge from absorbers to emitters. And all the excess logged carbon is accumulating in our atmosphere -- just like CO_2 from fossil gas, coal and oil." (n.p.)



CANADA FOREST CARBON -- Emissions from Canada's managed forest lands. Data from National Inventory Report 2019, with full time series for tables from Environment Canada. CHART by Barry Saxifrage at VisualCarbon.org & NationalObserver.com. Feb 2020

Figure 2.1-2. Carbon in Canada's Managed Forests

In their report for the Sierra Club BC, "Clearcut Carbon," Weiting and Leversee (2019) documented Saxifrage's findings for BC:

> *"The latest provincial data show annual emissions from logging as 42 million tonnes of carbon dioxide. Temperate forests capture about 2 tonnes of carbon per hectare per year. This analysis suggest that in BC, in addition to emissions from logging, clearcutting also prevented trees from removing at least 26.5 million tonnes of carbon dioxide per year from the atmosphere. This amount of carbon capture that cannot occur because the forest has been logged is known as foregone carbon sequestration.*
>
> *For comparison, BC's officially reported emissions (primarily from burning fossil fuels, not counting forest emissions) were about 65 million tonnes of carbon dioxide in 2017. Considering the 42 million tonnes of carbon dioxide emissions caused annually by logging and the 26.5 million tonnes of foregone capture of carbon dioxide per year together, their combined impact on our climate exceeds the impact of BC's officially counted emissions. This means reforming forestry to avoid emissions from logging and loss of carbon capture is as important for provincial climate action as phasing out fossil fuels.*
>
> *Overall, BCs growing forest emissions from destructive logging, wildfires and beetle outbreaks are now three times greater than official provincial emissions. Yet these forest emissions are largely ignored because they are not counted as part of BCs official emissions in provincial greenhouse gas inventories."* (p. 3)

2.1.3.6 Irrecoverable Carbon—Watershed Forests

The carbon stored in intact forested watersheds may be classed as “irrecoverable carbon”. That is to say that the carbon lost during logging activities, the manufacture of short and relatively short life cycle (<70 years) products, and the transportation of logs and wood products cannot be recovered within timescales relevant to avoiding dangerous climate impacts (Goldstein et al. 2010). For example, growing trees to replace the 150 year old trees that were cut and removed during logging will require at least 150 years and assumes that replacement trees will survive the ongoing impacts of climate change. Goldstein et al. (2010) describe the importance of ecosystem integrity:

> *“Overall, Earth’s ecosystems contain vast quantities of carbon that are, for the time being, directly within human ability to safeguard or destroy and, if lost, could overshoot our global carbon budget. Protecting these biological carbon stocks is one of the most important tasks of this decade.”* (p. 293)

From many directions, there are clear indications that forestry exacerbates climate change through the large increases in greenhouse gas emissions that accompany conversion of intact, natural forests. Forestry is responsible for converting forests in BC and across Canada from carbon sinks to carbon sources. As forest management continues to be dominated by short rotation, clearcut logging and the establishment of tree plantations, one questions the dedication of forest professionals and the Association of BC Forest Professionals to the protection of the public interest.

2.2 BIODIVERSITY

Biodiversity is defined through taxonomic (species) or functional (niche) terms. Both taxonomic and functional diversity are important components of a healthy ecosystem. Taxonomic diversity is often measured as species richness, quantified by the number of species present in a community or ecosystem (Battles, Shlisky, Barrett, Heald, & Allen-Diaz 2001). High species richness means that multiple species achieve specific duties within an ecosystem, providing redundancy within each role, achieved through multiple pathways (Cornwell & Ackerly 2009). Functional diversity is measured by a metric associated with the number of functional groups present in an ecosystem, relative to the local functional group pool (Mouchet et al. 2010). High functional diversity provides ecosystems assurance that there are many different roles within an ecosystem being filled, and therefore a high variation of niches being filled – regardless of species achieving the role (Tilman et al. 1997).

Old-growth forests are filled with great diversity (Keeton et al. 2007). Heterogeneity in vertical and horizontal structure creates a structural variation where numerous microsites each produce small unique habitats. Little microclimates are filled by specialists that become targets of generalists. Old-growth forests are structurally and/or biologically different to their adjacent forest (Blasi et al. 2010).

Indicators that relate to old-growth health in terms of functional and taxonomic diversity include high basal area, proportion of large basal area stems, large volume of coarse woody debris, and high structural complexity (Martin et al. 2018). High basal area refers to a high proportion of forested area covered by tree stems, when large trees dominate the basal area, the forest has a high proportion of high basal area stems. Large amounts of coarse woody debris means that there are many pieces of fallen trees that are providing habitat for many taxa, some of whom are old-growth obligates (Ettwein et al. 2020). These characteristics are decreased in forest stands managed for timber (Martin et al. 2018).

Since ecological function and timber profitability directly conflict as objectives, forests managed for timber often are lacking sufficient protection for ecosystems (Krumm et al. 2020; Larson & Lohrengel 2011). Forests with interventions from human disturbance have numerous responses, many of which are detrimental to ecosystem function (Likens, Bormann, Johnson, Fisher, & Pierce 1970). Management history can impact forest plant dynamics that result in the loss of vegetation function (Minami, Oba, Kojima, & Richardson 2015), increased opportunity for invasive species, and reduce carbon stocks (Trofymow et al. 2008). When altered, these forests no longer provide stable riparian corridors (Oldén et al. 2019), which can change the temperature and moisture regimes (Moore et al. 2005), thus changing the viability of habitat across trophic levels (Kominoski et al. 2013; Wipfli et al. 2007). The result is shifts in both the plant and animal communities that involve different ecological processes and therefore create different ecosystem functions than that found in riparian areas of old-growth forests (Frady et al. 2007).

The spatial arrangement of old-growth forests are diverse in inter-tree distance, which enables a more varied composition of habitat conditions, thus supporting a wider variation of species than in harvested landscapes (Fraver et al. 2014). Primary old-growth forests hold more canopy cover and more seedling density than harvested sites, thus providing higher carbon storage networked and locked into the structural complexity of many species (Menge & Hedin 2009). The resulting combination of structural and taxonomic diversity through complex species and age distributions may provide the necessary ecosystem resilience for facing climate change (Nagel et al. 2014). Through the continued provision of wildlife habitat, carbon sequestration, and riparian functions, diversity of old-growth forests will continue to host numerous important functions that are essential for nature and humans alike – especially in times of environmental degradation and uncertainty (Keeton 2006).

2.3 HYDROLOGIC FUNCTION

Watershed hydrology can be described scientifically in relation to three of its components: water, sediment, and stream channels. In the snow-dominated watersheds of Canada's Upper Columbia Basin, the flow regime can be characterized in terms of the annual hydrograph at the watershed outlet which is shaped by the processes of snow accumulation, snow melt, and runoff and how they vary and interact across the watershed throughout the year including its groundwater and opportunities for water and sediment storage. The sediment regime involves the erosion and transport of soil and sediment throughout a watershed, occurring at widely contrasting rates and scales of movement. These two broad aspects of watershed hydrology integrate in stream systems where channel form and stability are a focus from the perspective of hydrology (and fluvial geomorphology). This section summarizes current hydrologic science in these disciplines with an emphasis on the flow regime.

2.3.1 Flow Regime

The annual hydrograph of the Glade and Laird watersheds is shaped by the accumulation and melt of snow and its subsequent runoff across the watershed. The form of the hydrograph at the watershed outlet is the net result of a complex of surface and subsurface processes interacting throughout the watershed. The seasonal availability of water fundamentally shapes the watershed's aquatic ecosystems and human communities. Two characteristics of this hydrograph of particular importance are the maximum annual flow, the "peak flow", and the minimum annual flow, or "low flow". For example, channel form is to some degree determined by the frequency of these high flows and the opportunities for aquatic communities are limited by the annual periods of greatest water restriction. These requirements are generally referred to as environmental flows (or instream flows). Human communities have developed similar dependencies aligned with the annual cycle of water availability.

The 2007 Brisbane Declaration and Global Action Agenda on Environmental Flows is an official global pledge to work together to protect and restore aquatic systems and has led many countries to adopt environmental flow policies. The original statement was updated by Arthington et al*.* (2018) to define the environmental flow of a stream as "the quantity, timing, and quality of freshwater flows and levels necessary to sustain aquatic ecosystems which, in turn, support human cultures, economies, sustainable livelihoods, and well-being". A plethora of proposals exist on how to establish environmental flow requirements for waterbodies (e.g., Jowett 1997; Bradford 2008; Arthington et al. 2006; Acreman and Dunbar 2004; Richter et al. 2003). Its definition also provides an appropriate context for the activities of the present NDS project.

2.3.1.1 Low-Flow Regime

Diminished input to a watershed's overall water balance, sustained over a long period, will lead to a recession in watershed discharge and, ultimately, to a period of low flow. Meteorologically, low flow may occur in response to an extended period of dry weather or prolonged cold weather causing storage of precipitation as snow and ice. However, annual low flows occur in the late-summer and fall In the lower Kootenay River valley and along the West Arm of Kootenay Lake. Here they are called warm-season low flow, or just low flow. Winter temperatures tend to be warm and are rising with climate change. The summer period is becoming increasingly characterized by hotter droughty conditions.

In comparison with the short-duration dynamics associated with the peak-flow regime, the relative scarcity of water associated with the low-flow period highlights enduring storage and runoff processes. Undisturbed, this region's forest cover moderates winter precipitation inputs and subsequent melt rates. Runoff is further moderated by intact soils that promote seepage to subsurface flow pathways and potentially to longer-term groundwater storage. The type and age of the forests affect transpiration rates which affect groundwater storage. Soil moisture mediates the influence of transpiration on streamflow (Moore et al. 2011). Within this overall framework, the specific characteristics of a given watershed engage with meteorological inputs in any given year to determine the low flow based on the balance of inputs, outputs, and storage components of the water budget. How this balance plays out when disturbed can be described in terms of the watershed-level role of vegetation and soils in shaping low flow.

Vegetation has a strong control over hydrologic inputs to the basin water balance and the pace at which introduced water migrates to the outlet to contribute to low flow. The coniferous forest canopy intercepts snow, leading to significantly reduced inputs (30-40%) to the basin due to subsequent sublimation (Winkler et al. 2010). Forests reduce melt rates and surface evaporation leading to enhanced infiltration of runoff into surface soils. In addition to modifying snow dynamics, trees transpire throughout their life cycle, particularly during periods of rapid canopy development when their transpiration rates may exceed that of old-growth forests (Segura et al. 2020). In the short term, significant forest removal typically leads to an increase in basin water yield due largely to the loss of transpiration (Coble et al. 2020). While this initially translates into increased baseflow, it is followed by a general decrease, thereafter, depending on the rate of vegetation regrowth (Johnson 1998) and the nature of the disturbance (Goeking & Tarboton 2020). Section 2.1.3 provides additional background on the role of intact forests in the water cycle and how processes change with disturbance.

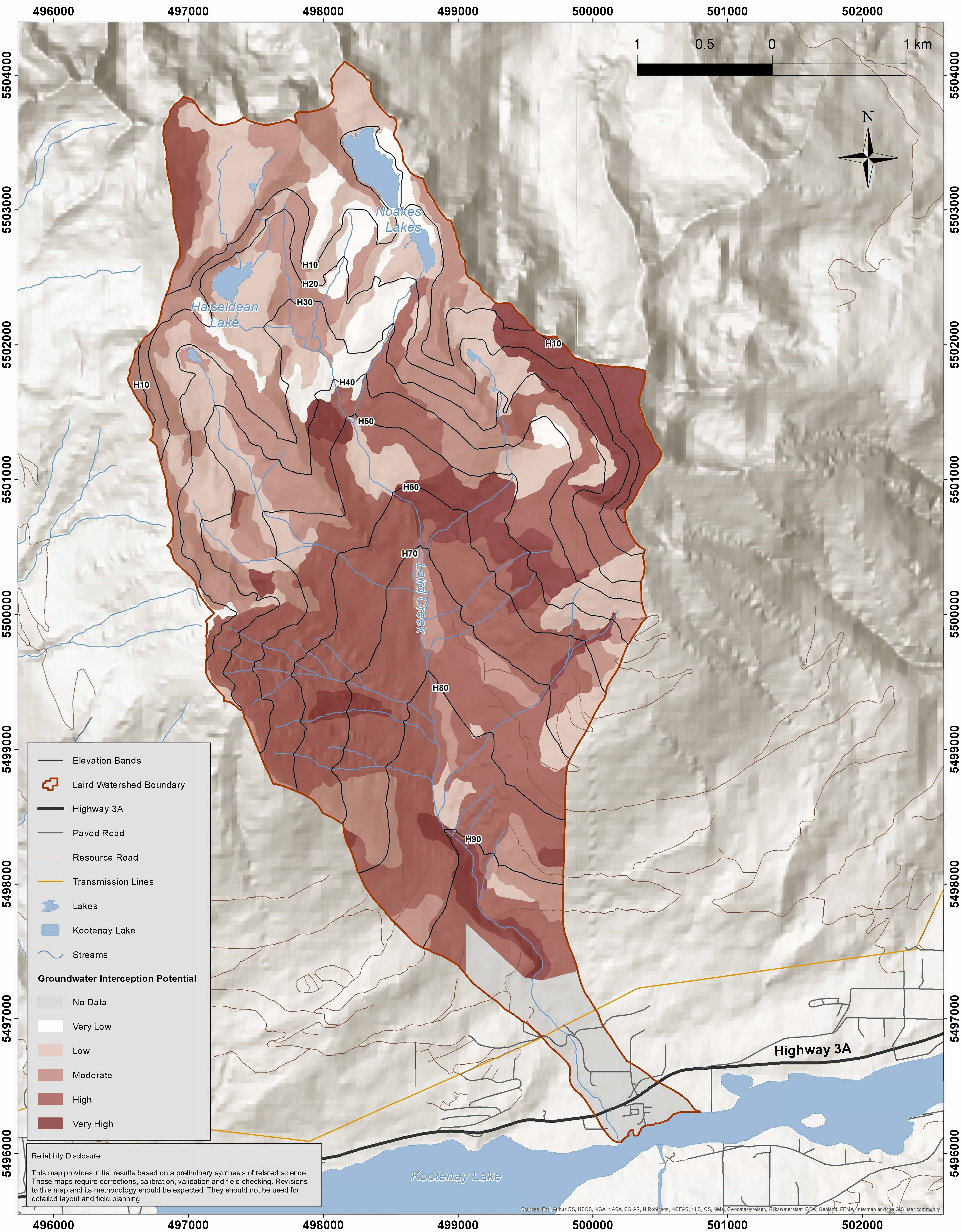
Only the portion of snow melt and rainfall that is in excess of the infiltration capacity of surface soils becomes hillslope runoff. The relative proportion of the inputs that typically infiltrates into the soil mantle depends on the infiltration properties of the surface in addition to its moisture levels at the time of infiltration. Surficial materials are shaped by glacial processes which have left behind preferential pathways, impermeable layers, variable infiltrability, and other characteristics which shape the behaviour of subsurface flow. The condition of surface soils plays an important role in determining the extent to which inputs to the basin water budget go into short- and long-term storage or are advanced toward the watershed outlet. Roads are important in the basin water budget because those built on steep terrain typically involve interception of subsurface moisture and flow paths, conveying that stored water to ditchlines and to the stream network, thereby bringing that water more quickly to the watershed outlet (Moore et al. 2020; Wemple & Jones 2003). These accelerated runoff processes alter basin water budgets, generally decreasing low flows through reductions in the portion of water moving through slower groundwater pathways.

2.3.1.2 Map 10 – Low-Flow Moderation

The Low-Flow Moderation (LFM) map developed in this study assembles key available data and interpretations related to factors supportive of long-term moderation of warm-season low flows. See Map 10 in Sections 5 and 6. Four factors are brought together in the map. For Laird watershed, a supplementary map includes a fifth factor, groundwater interception, created from data available from terrain mapping.

- Areas Significant for Slow Groundwater Recharge and Late-Summer Snow Melt. It is recognized that precipitation stored as snow plays a significant role in maintaining low flows and that its value in augmenting groundwater is sensitive to changes in the timing of melt (Jefferson et al. 2008; Scibek et al. 2007). Locations with the highest snow accumulation and the lowest natural melt rates under forest cover are identified as areas significant for slow groundwater recharge through prolonged snow melt. These areas emphasize cool aspects at high elevation because it is known that snowfall increases with elevation and melts more slowly when out of reach from the sun. A precautionary interpretation is followed with respect to the net effect of forest cover on snow accumulation and melt, suggesting that forest cover is best maintained on those areas of highest rating in terms of their potential as refuge for slow groundwater recharge. Section 4.3.10 discusses how forest openings modify the LFM ratings.

- Old Forests. In general, old forests have characteristics that should support late-summer low flows due to the typical water-holding capacity of these forest ecosystems. Forests over 140 years of age are shown on the map as additional priority areas to be maintained in their natural state to support late-summer low flow. Teich et al. (2022) conclude that shading from the canopies of widely-spaced, large-diameter single trees in post-fire environments may prolong snow duration over larger areas because they intercept snow and, while they emit longwave radiation accelerating local melting, they also shield the snowpack from solar radiation.
- Wetlands and Lakes. Wetlands and lakes provide direct contributions to baseflow, often sustained throughout prolonged dry periods. (Baseflow is defined here as streamflow primarily sourced from deep and shallow subsurface storage. Baseflow is a component of the annual low flow and in extreme years, baseflow and low flow could be almost the same.)
- Riparian Areas. Although riparian trees consume water and transpiration fluctuations occur on a daily basis due to riparian vegetation (Bond et al. 2002), they also provide shading and bank protection to streams thus moderating low flows, particularly during periods of extreme heat which are projected to be more common under future climates (see Section 2.4).
- Groundwater Interception. In Laird watershed, available terrain mapping is sufficient to provide a preliminary approach to assessing the relative likelihood of subsurface flow interception. See Figure 2.3-1. These ratings offer the potential to prioritize soil disturbance away from locations where subsurface flow is most likely to be intercepted.



Projection: NAD 83 UTM 11N
Scale: 1:15,000
Date: March 2022
Base Data: Province of BC; BC Data Catalogue & LidarBC

Figure 2.3 1. Preliminary Map of Groundwater Interception Potential for Laird Watershed

2.3.1.3 Peak-Flow Regime

Flood flows from forested watersheds have been recognized scientifically back to at least the 1800s (Neary et al. 2012). In forested snow-dominated watersheds, the annual peak flow normally occurs as a result of the freshet, driven by spring heating of a snowpack accumulated over the winter period and typically increasing in depth with elevation. Stand-level studies have shown the critical importance of the forest canopy in reducing snow accumulation and melt rates in comparison with clearcuts (examples - Parajuli et al. 2019; Schelker et al. 2013; Whitaker & Sugiyama 2005; Winkler 2001; Kittredge 1953). In BC forest industry practice, changes in snow accumulation and melt have long been operationalized (simplistically) in terms of tiered limits to Equivalent Clearcut Area (ECA) as a primary strategy to limiting changes to peak flows and following increments in likelihood (Winkler & Boon 2017). Despite this well-established recognition that forest-cover loss can exacerbate peak flows, it is also commonly and simultaneously held that the largest floods are generated independently of forest cover (Calder et al. 2007):

> *"Now forest hydrologists generally agree that, although forests mitigate floods at the local scale and for small to medium-size flood events, there is no evidence of significant benefit at larger scales and for larger events."*

This contradiction has been sustained for decades despite the lack of evidence or a physical basis to maintain it. Schnorbus and Alila (2003) used numerical modelling in Redfish Creek to show how peak flows were augmented by forest loss across the range studied. As forest harvest reaches ever higher levels in watersheds across BC including numerous watersheds in the lower Kootenay River valley and along the West Arm of Kootenay Lake and as climate disruption brings greater extremes in heating and precipitation – dramatically altering patterns of accumulation and melt – the potential for calamitous flood outcomes is growing. It is more essential than ever that the findings of stand-level science be reconciled with this assumption often held regarding watershed-level outcomes for the largest floods.

Progress in this field has been held back by the selection of methods used and an inadequate understanding and recognition of the probabilistic nature of flood flows. Although frequently applied to assess the effect of forest loss on flood flows, the assumptions of the paired-watershed method[2] are often violated while the findings of studies employing this method are taken as reliable. The approach assumes that the factors affecting streamflow can be controlled so that the experimental effect of changing forest cover can be quantified. However, the opportunity to control these factors is weak and poorly evaluated and becomes effectively impossible for large watersheds. Application of this method is also a time-consuming approach because calibration (Bren & Lane 2014) and subsequent

[2] In the paired-watershed method, control and treatment watersheds are monitored prior to the implementation of forest harvesting, then empirical relationships are developed, usually in the form of simple linear regressions referred to as calibration equations, using pre-treatment measured peak flows of the control and treatment watersheds. The calibration equation is used to estimate the expected peak flows of the treatment watershed had the treatment not occurred.

experimentation each takes years (or even decades) to yield meaningful results, particularly for the infrequent larger floods typically of greatest interest. The approach has led to the effort of understanding hydrologic responses of watersheds being called “enigmatic” (Eisenbies et al. 2007), when it is more likely the result of the application of deterministic logic at inappropriate scales and frequencies, necessitating the recruitment of methodological alternatives.

Recent scientific progress in this field has emphasized the probabilistic nature of flood flows. For smaller floods (higher frequency) and in smaller watersheds, the paired watershed approach may provide sufficient experimental control to yield reliable results. However, as the floods get less frequent and as the watershed scale grows, it can’t effectively work as an appropriate scientific tool because of the lack of control that can be achieved in these situations. Yu and Alila (2019) provide the reasoning:

> *“Using the case of snow environments for illustration, the magnitude of a peak flow event of the same watershed, in either forested or harvested conditions, is controlled by several hydro-meteorological factors: snow accumulating on the ground, energy creating the melt, occasional rain falling on melting snow, and antecedent moisture condition in the soil. Many combination scenarios of these four factors, which all occur randomly, could generate the same peak flow event magnitude. Hence, every peak flow event occurs with a certain frequency, and disproving such a peak flow event has not changed in magnitude as a result of harvesting ought to be conducted simultaneously for every one of these combination scenarios.”*

Frequency and magnitude of flood flows are two sides of the same coin. Where changes in magnitude cannot effectively be studied directly, they can alternatively be studied through analysis of flood frequency which inherently integrates processes at a watershed level.

In light of the potential for forest and soil disturbance to augment the peak flow regime of floods of all sizes (including the largest floods), a methodology is needed to estimate and/or rank the potential effect of disturbance on peak flows across a watershed of interest. Given the topographic complexity of Laird and Glade watersheds – and most watersheds in the lower Kootenay River valley and along the West Arm of Kootenay Lake – and given the growing extremes in meteorological drivers possible in any given spring, simulation modelling (if supported by sufficient calibration data) may be the only approach currently able to provide accurate assessments of flooding response to changes in forest cover and soil disturbance. In the absence of a calibrated and validated model able to provide this information, other approaches to translating stand-level studies to the watershed level are needed. The potential connections between peak flow and low flow lend further importance to this call for new practical applications: in many cases, a higher (and earlier) peak flow may also contribute to a lower low flow later in that year’s hydrograph (all things being equal). Tools are urgently needed to assist managers in moderating peak flows and particularly under the framework of NDS. An approach is described below to initiate development of such a procedure.

2.3.1.4 Map 9 – Peak-Flow Augmentation

A Peak-Flow Augmentation (PFA; Map 9) rating system has been developed to provide a preliminary ranked spatial layout of watershed area in terms of their relative sensitivity to augment peak flows if its forest cover were removed. See Map 9 in Sections 5 and 6. While many factors influence the flow measured at a watershed outlet, and some interact, a subset of the key spatial factors is assembled in the rating system. The map concept is built upon findings reported in Whitaker et al. (2002). That work was undertaken partly to "test" the H60[3]-concept assumptions of the Interior Watershed Assessment Procedure (IWAP) – namely, that cutblocks above the H60 should be weighted 50% more than those below because of their added potential effect in raising peak flows. The Whitaker et al. (2002) study was carried out adjacent to Laird watershed in a very similar mountainous setting (Redfish watershed), so its conclusions are highly relevant to Laird Creek (and should be applicable to Glade watershed). That study assessed five standardized elevation bands in its physically-based spatially-explicit modelling analysis: outlet-H80, H80-H60, H60-H40, H40-H20, H20-peak. It finds that "Increasing harvest levels in the bottom 20% of the watershed caused little or no change in current peak flow magnitudes." In addition, they state the following (page 11):

> *"The IWAP assumes that snow typically covers the upper 60% of a basin at around the time of peak streamflow and that timber harvesting above this H60 line will have a significantly greater impact on peak flows than logging in lower portions of the basin. While the first of these assumptions was reasonably confirmed for Redfish Creek, the second notion is not supported by the simulation results. Instead, the H80 elevation line was found to be important, while cut block elevation was found to be relatively unimportant above this line."*

Building on these modelling results and given the strong role of elevation, Map 9 uses the simple quintile classification from Whitaker et al. (2002), namely, five groups of equal watershed area, with the lowest and highest of these five groups assigned as equally low. As areas identified to have a strong potential to affect the peak-flow regime if they were harvested, the watershed's critical central zone is distinguished as having the highest likelihood of modifying the peak flow if the forest cover were removed. To evaluate the scope of this critical zone, the approach takes into account the following:

- Whitaker et al. (2002) concluded that harvest levels within the H80 to H40 band leads to "significant impacts on annual maximum flows".
- Based on results across dozens of measurement sites, Toews and Gluns (1986) found mean snow water equivalent (SWE) to increase with elevation by 11-15 mm/100-m in forested sites and 21-27 mm/100-m in open sites. Presumably, H40-H20 would also have been important in the work of Whitaker et al*.* (2002) if those areas were well forested in the Redfish watershed,

[3] The H60 is the contour line above which lies 60% of the watershed area. The "H" refers to the hypsometric curve that shows how watershed area varies with elevation.

given the additional SWE present at higher elevations in comparison with the mirrored lower portion within the H80-H60 band.

- Although the IWAP augmented all areas above the H60, the uppermost areas should actually be excluded because - in a manner similar to the lowermost areas – they would have limited effect on the peak.
- Gluns (2000) provides the results of five years of snowline observations showing that the mean snowline sits at the H65 (not the H60) when the peak flow is occurring. At this point in the freshet, flow pathways are saturated and incremental runoff inputs are readily conveyed to the stream system and able to influence the peak flow. Additional snow and/or higher melt rates on either side of the H65 would increase the peak flow directly – in addition, in this zone there may be a preference for a higher rating above the H65 due to the higher SWE expected there.
- Changes to the first half of the rising limb likely have a greater opportunity to affect peak flows than changes to the second half of the recession limb. Also, forest canopies are generally less effective in snow interception at elevations where subalpine occurs.

Based on these additional findings and considerations, a central band of H70-H60 is identified as the most significant to the magnitude of the peak flow, tapered asymmetrically on each tail. See the inherent ratings provided in Table 4.3-1 (Section 4.3.9).

Whereas elevation is influential in determining snow dynamics, this powerful factor is modified by other topographic variables. Based on results from nine independent studies spanning five decades, Varhola et al. (2010) highlight the strong role that aspect plays in shaping melt rate both during the freshet and during the winter period of snow accumulation. They report a comparable result across these studies: forested south-facing sites can show higher melt rates than otherwise equivalent north-facing openings. Although empirical generalizations were difficult, based on their field measurements, Jost et al*.* (2010) found aspect and forest cover to have comparable effects on melt rate. It is expected that melt rates on south aspects increase at a higher rate when their forest cover is removed in comparison with their cool-aspect counterparts (Ellis et al*.* 2011). On the other hand, added snow is generally present on north aspects (due to lower within-winter melt) at the end of the accumulation period. For the map, it is estimated that these may balance out and that intermediate aspects (east and west) are also intermediate in the balance between these factors.

Hillslope gradient plays an additional role in modifying snow accumulation and melt rates. According to Varhola et al*.* (2010), the "overall impact of increasing slope is to reduce snow accumulation due to snow moving downhill, exposure to wind and higher temperatures in sunnier aspects during the accumulation period." Steeper southern slopes will melt faster than gentle ones. On north aspects, increased slope angle works in the opposite direction by sheltering the snow from the solar radiation to increase within-winter snow accumulation then reducing melt rates during the spring freshet. Thus, the rating is reduced for steep cool aspects given their reduced ability to melt quickly when the forest cover is removed. The opposite is done for warm aspects, understanding that the relative effect (absolute value) may be greater on the cool aspects.

To incorporate an adjustment for hillslope gradient into the map, ratings are adjusted for selected aspects with slope gradients above 70%. Warm aspects (SE/S/SW: 120-240˚) are given a rating one step higher (L->M; M->H) for their potentially enhanced melt while cool aspects (NW/N/NE: 300-60˚) with slope gradients above 70% are given a rating one step lower (H->M; M->L) for their potentially inhibited melt. The intermediate easterly and westerly aspects remain unchanged. Gluns (2000) echoes this influence of slope and aspect in reporting that the snowline – though consistent from year to year – was not found to follow a specific contour at any one time but was variable depending on the aspect and position in the watershed and, not surprisingly, being lower in sheltered areas and higher in exposed areas.

Other inherent factors that can influence the peak flow include wind (Anderton et al. 2004) which works in combination with slope gradient and opening size (where they occur), specific weather conditions (e.g., rain-on-snow events) which can shape the processes dominant in the energy balance during the freshet, and interactions of factors whereby some work to increase and others decrease the peak flow. These remaining factors are excluded from this simple map-based rating because they can't readily be spatialized and generalized and likely don't compete in magnitude for the effect of the other factors, especially elevation.

Forest disturbance plays a significant role in modifying the inherent PFA ratings including the size, shape, and orientation of openings. In addition, roads add considerably to the potential to augment the annual peak flow particularly when they are situated in the mid-to-upper areas of the watershed. Although a quantitative treatment of disturbance is beyond the scope of this preliminary Map 9, some aspects are introduced in the map and in the discussion of Sections 4.3.9 and 4.3.10.

2.3.2 Sediment Regime

The watershed sediment regime is commonly understood in terms of two components, distinguished based on the size of the material in question. The fine-sediment regime involves the portion of soil and surficial material that is normally transported through suspension in water. In general terms, this includes sands, silts, and clays. In contrast, dynamics of material transported largely by gravity are included in the coarse-sediment regime. This component is generally focused on material sizes greater than coarse sands, including large car-sized boulders.

Similar to an analysis of the flow regime, understanding the components of the sediment regime involves examining flows of materials in terms of inputs, storage, and outputs within a sediment budget. However, unlike the flow regime, soil and sediment moves at a much slower pace and can remain in storage for very long periods – decades, centuries, and longer. Before European contact, the sediment regimes of the Glade, Laird, and surrounding watersheds were relatively inactive with the vast quantity of potential material blanketing the mountainsides immobilized by the stabilizing influences of trees and forest ecosystems. Additional general background on sediment regimes of forested watersheds can be found in Geertsema et al. (2010).

Disturbance is an integral part of the sediment regime. It occurs both naturally and due to human activities. It can occur directly due to the consequence of an activity such as a road (e.g., the May 11, 2011, debris flow that occurred in the Laird watershed below a new road segment; Wemple et al. 2001) or indirectly through changes to the flow regime that come about usually due to cumulative activity (e.g., instream erosion due to a modified flow regime – see McEachran et al., 2020). Forests play an outsized role in moderating the effects of natural disturbance and have been a major stabilizing force in the sediment regime following deglaciation into the Holocene Epoch. In contemporary terms, although anthropogenic disturbance originates from many sectors, disturbance due to forestry activities (Jordan et al. 2010) is the most widespread and persistent agent of human disturbance of the sediment regime in the lower Kootenay River valley and along the West Arm of Kootenay Lake.

Accelerated soil erosion and downslope sediment movement typically decreases water quality and can destabilize channels, leading to a multitude of negative outcomes for aquatic ecosystems, species, and human communities that depend on stable stream systems. Furthermore, once disturbed, it can take significant time periods to restabilize the sediment regime by reducing the magnitude of the sediment sources and the stabilizing or removing excessive sediment put in motion, for example, mobilized in channel systems. As a result, disrupting the natural sediment regime should be avoided when undertaking human activities. Climate disruption underscores this principle because extreme weather is challenging thresholds for erosion and instability that previously were rarely or never exceeded.

Maps 7 and 8 (Sections 5 and 6) provide key data required to avoid disturbing the sediment regime when undertaking human activities. Map 7 indicates the relative likelihood of erosion by surface erosion processes when surface soils are disturbed. Map 8 indicates the relative likelihood of slope instability ("landsliding") occurring due to disturbance activities. Due to the more detailed terrain mapping available in Laird watershed, these primary hazards are augmented in that watershed with the likelihood that eroded material will be delivered to the stream network. These maps provide core tools for spatially identifying hazards related to the sediment regime, hazards which imply constraints to human activities if hydrologic function is to be fully maintained. Given the changes in erosion and stability that projected climates are expected to bring, it is growing increasingly important that management practices not only avoid direct and indirect disruption of the sediment regime, but also actively create resilience to thereby support and encourage stability in watershed hydrologic processes.

2.3.3 Hydrologic Sensitivity

The high-sensitivity areas of each hydrologic component are presented together in the Hydrologic Sensitivity maps. See Map 12 in Sections 5 and 6. Achieving proper hydrologic function at the watershed-level depends upon satisfactory performance within each hydrologic component which is driven by the respective priority areas. The hydrologic sensitivities are broadly distributed across each watershed while also having areas of overlap. For example, the peak-flow sensitivity is driven largely by snow melt and accumulation in the upper centre (by elevation) of the watershed whereas low-flow sensitivity focuses on snow dynamics at higher elevations. Sedimentation sensitivities depend on soils and terrain constraints which are largely independent of flow-regime requirements and can occur anywhere in the watershed. Some high-hazard sediment regime areas overlap spatially.

The integration provided by Map 12 indicates that maintenance of proper function of the hydrologic and geomorphic regimes of the watershed involves site protection or low-risk management over the vast majority of the watershed area. Table 2.3-1 suggests activities that are potentially compatible with the overall sensitivity of each Water Conservation Level (WCL). If these (maximum) activities are followed in one WCL, they must be followed in all WCLs. Management activities pursued should also be nested within a Protected Ecosystem Network (see Section 4.3-14). In this Table 2.3-1, whatever is permitted at a particular level is also permitted at levels lower to it; the opposite is not true. In consideration of climate disruption, permitted activities can be scaled back to focus exclusively on resilience objectives over a wider range of Water Conservation Levels (WCLs).

Table 2.3-1. Potential Compatible Activities by Overall Level of Hydrologic Sensitivity

Water Conservation Level	Potentially Compatible Low-Risk Management Activities
1	Opportunities exist for potential activities. Examples include: • Long-term forest management within protected ecosystem networks and continuous forest cover with full-cycle trees • Low-density roads and trails All development must meet basic environmental standards.
2	Activities must be tightly controlled, meeting high environmental standards. Examples include: • Partial cutting within protected ecosystem networks and with well-distributed full-cycle trees • Minimal soil disturbance • Low-impact tourism and recreation
3	Minimal development is permitted and must maintain the priority for water protection above other objectives. Activities must be tightly controlled, well managed and meeting high environmental standards. Examples include: • Back-country recreation (e.g., hiking and other ecotourism) • Low-impact tourism and recreation in specified areas • Wildcrafting; gathering of food and medicinal plants
4 and 5	No disturbance permitted except to meet ecosystem restoration and resilience objectives. All activities must be low impact and explicitly prioritize water protection. Examples include: • small openings to increase snow accumulation and limit melt • harvesting on (only) snow; essentially no soil disturbance • winter roads and drainage restoration Activities in WCL5 should be limited to stable areas and activities with only a very high likelihood of success.

An overarching objective of Map 12 and its associated guidance is to maintain a long-term stable channel with required environmental flows, i.e., streamflow in the appropriate quantity, quality, and timing to sustain the stream's aquatic ecosystems and adequately support the downstream dependent human communities. The flow and sediment regimes depend upon different parts of the watershed to differing degrees to maintain full function. However, the consequences of diminished function are felt most acutely in the channel system. It is in the streams and riparian areas where vulnerabilities compound. For example, regardless of whether sediment transport is initiated by slope instability or waterborne erosion processes, delivered material eventually pools together in the channel network, affecting water quality and aquatic habitat. During periods of extreme low flows or during periods of extreme heating, water quality is challenged further when the coniferous riparian vegetation is absent. Excessive peak flows can destabilize channels, causing bank and channel degradation leading to channel sedimentation incremental to hillslope sources. It is to avoid this integration of consequences that Map 12 is developed.

2.4 Climate Disruption – Impacts on Hydrology and Ecosystems

The hydrologic dynamics discussed in the previous section have developed over millennia, operating within a steady-state climate, generally changing only slowly. In the past few decades, this region's climate has entered a period of non-stationarity (Milly et al. 2008), disrupted by warming due to emissions of greenhouse gases (GHGs). These continued and escalating changes are disrupting the familiar hydrologic behaviour of the Glade and Laird watersheds, and the entire Upper Columbia Basin. Every aspect of the ecosystems within the watersheds are also changing. Past behaviour is no longer a reliable measure of the future – for hydrology and ecosystems.

2.4.1 Climate Disruption and Hydrology

As would be expected with ongoing increases in GHG emissions and CO_2 concentrations in the atmosphere, and broadly consistent with projected patterns of change in other parts of the Columbia Basin (CBT 2017), temperatures are projected to increase in the West Arm area. Annual temperatures have been increasing over the past century, by about 0.7°C from the early 1900s to the 2010s. They are projected to increase by a further 3.4 to 5.6°C in the coming decades, depending on the trajectory of GHG emissions. The projected increases extend across all seasons. All the projected seasonal temperatures are outside of anything experienced in the previous century, and summer temperatures are potentially increasing at a more rapid rate than the other seasons (Figure 2.4-1).

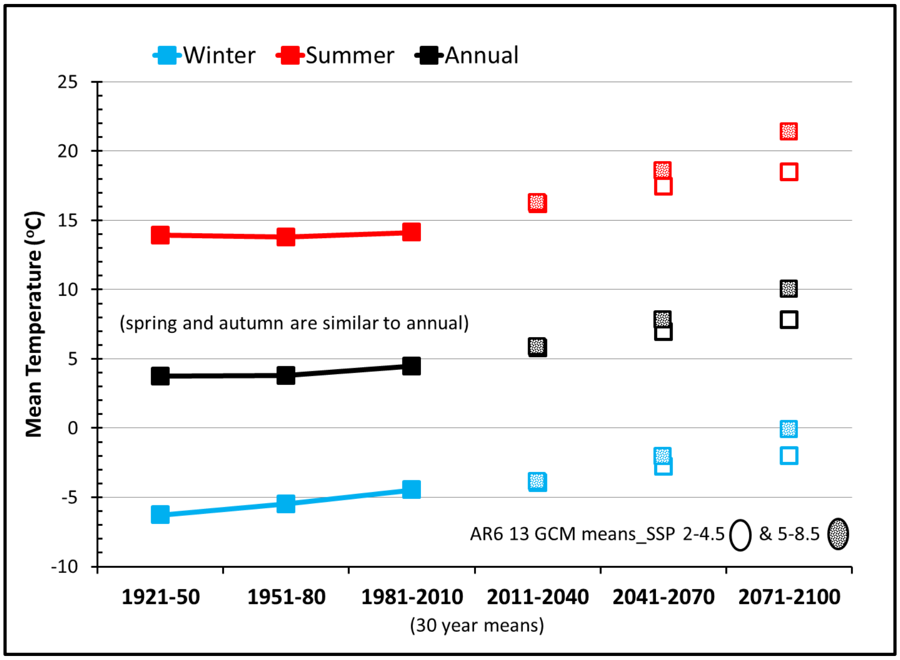


Figure 2.4-1. Historic and Projected Seasonal and Annual Temperature Changes for the West Arm Area

Seasonal precipitation patterns are significantly more variable than temperatures. Summer, spring, and fall precipitation has been increasing over the past century. In contrast, winter precipitation has increased mid-century and then decreased in the last few decades of the last century (Figure 2.4-2). Future projections indicate declines in summer precipitation and continued increases in the other seasons. While projected spring, fall, and winter precipitation levels are greater than experienced in the last century, summer levels are within the range of what has been experienced sometime in the past.

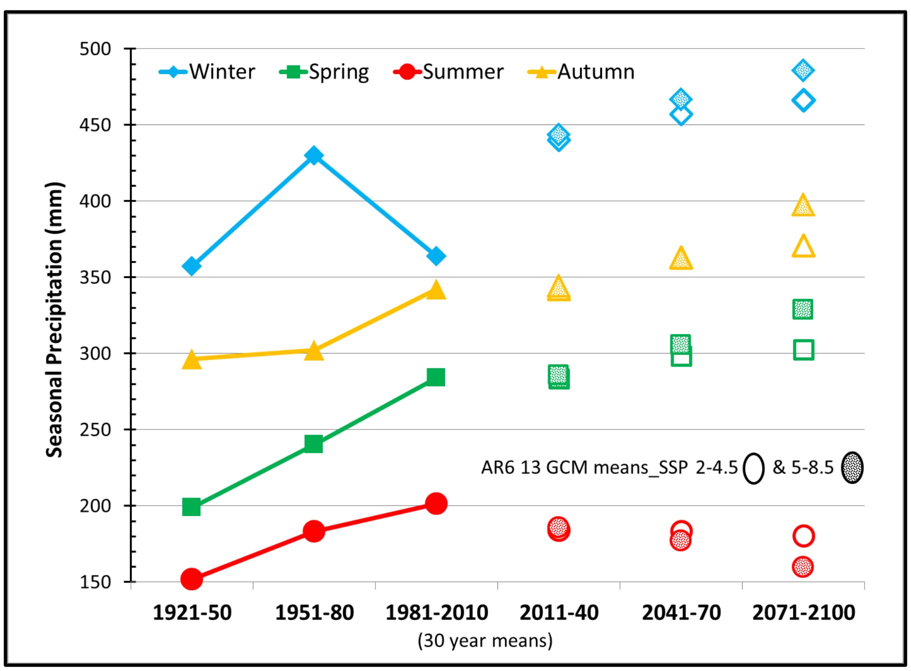


Figure 2.4-2. Historic and Projected Precipitation Seasonal Changes for the West Arm Area

Although total annual precipitation is projected to increase in the coming decades, the form of much of that precipitation will shift from snow to rain due to increased temperatures, especially at lower elevations (Figure 2.4-3). The percentage of precipitation that falls as snow in the West Arm has already decreased across all elevations, from about 65% to 60% at higher elevations, and 30% to 20% at lower elevations. It is projected to decrease to as low as 5-10% by the end of the century at the lowest elevations (Figure 2.4-3). This may lead to increased winter runoff, and further drought conditions in the warmer seasons.

Projected decline of snow under future climates in the mountains of western North America has been widely investigated (e.g., Barnett et al. 2005) and documented to have been occurring since the 1970s (Dongyue et al. 2017; Dye et al. 2002). In snow-dominated watersheds, reductions in winter snowfall (Mote et al. 2006, 2018) drive declines in water availability while an increase in winter snow melt contributes further to the decline (Musselman et al. 2021; Xiao 2021). Combined climate and hydrologic modelling in southern British Columbia show that the low-to-mid elevation watersheds (e.g., Glade and Laird) are where the loss of snow cover have the greatest impact under future climates (Islam et al. 2017) – though the pace of change may be uneven.

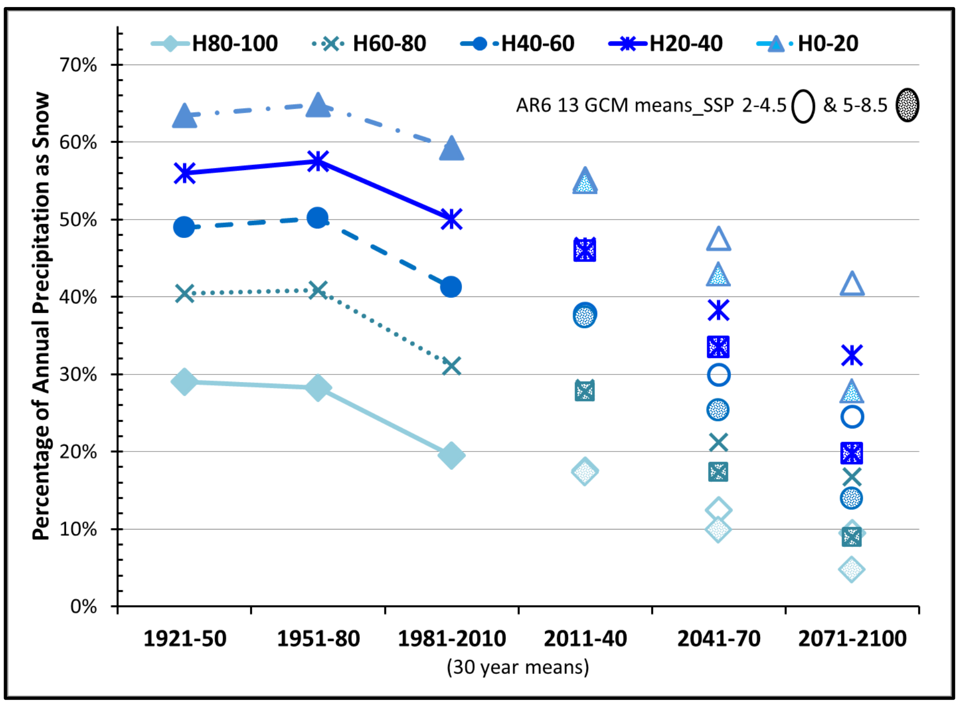


Figure 2.4-3. Historic and Projected Changes in Percentage of Precipitation as Snow for Various Elevation Bands of the West Arm

In addition to changes in season precipitation and snow, rainfall patterns are also changing. Heavy precipitation at scales ranging from hours to days to weeks is already occurring due to intensified atmospheric activity (Kirchmeier-Young & Zhang 2020; Fowler et al. 2021). Atmospheric rivers are of particular concern because they are strongly associated with high rainfall intensities in British Columbia and can cause flooding due to the runoff volume and because of the potential for occurrence of rain-on-snow which can melt accumulated snowpacks often at very high elevation (Sharma & Dery 2020b). During 1979-2012, landfalling atmospheric rivers increased over British Columbia (Sharma & Dery 2020a). In 2013, an atmospheric river crossed the Columbia Basin from the prairies bringing heavy rainfall, rain-on-snow, and extreme flooding to many basins in the East and West Kootenays (Figure 2.4-4).

Increased heating can lead to summer drought particularly if combined with earlier spring warming which advances the freshet. In the Fraser basin, Kang et al. (2016) document a ten-day advance in timing of the spring freshet from 1949 to 2006 and Islam et al. (2017) identify a 25-day freshet advance by the 2050s compared with historic levels. Short-term intensive heating over days and weeks is of notable concern during the late spring when the snowpack (in terms of snow water equivalent, SWE) is at its peak because severe flooding can result. Prolonged summer heating, particularly if combined with early spring heating, can lead to depressed baseflows and drought. Dierauer et al. (2020) have shown that below-normal snowpacks caused by above-normal winter temperatures are associated with decreased summer runoff, decreased summer groundwater storage and extreme summer low flows. Using groundwater models, their results show the effect growing through the 2050s and 2080s. For three streams near Glade and Laird watersheds, Figure 2.4-5 plots recent monthly streamflow falling well outside of previous norms including depressed baseflow in the late summer. Examples of abrupt change in other streams are evident across spatial scales.

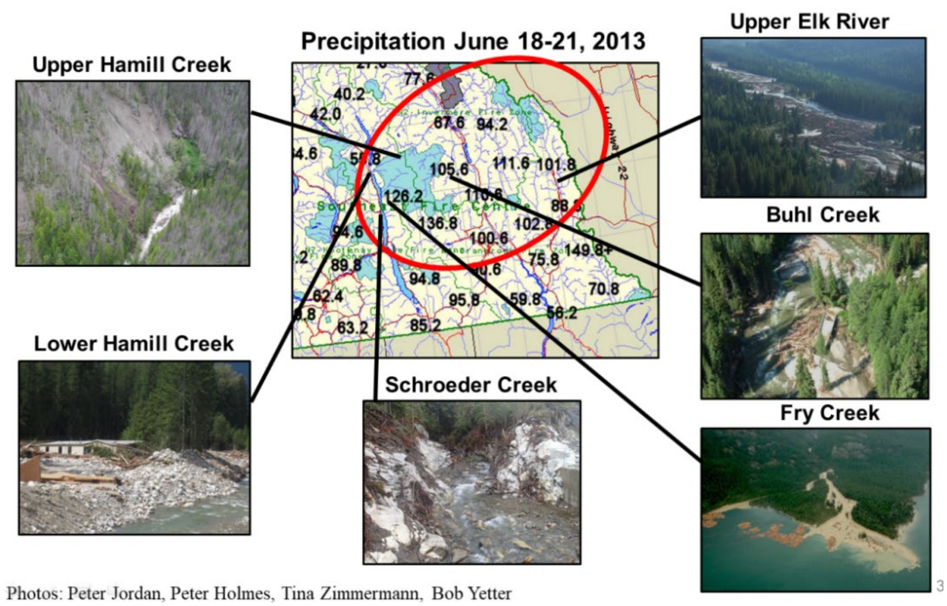
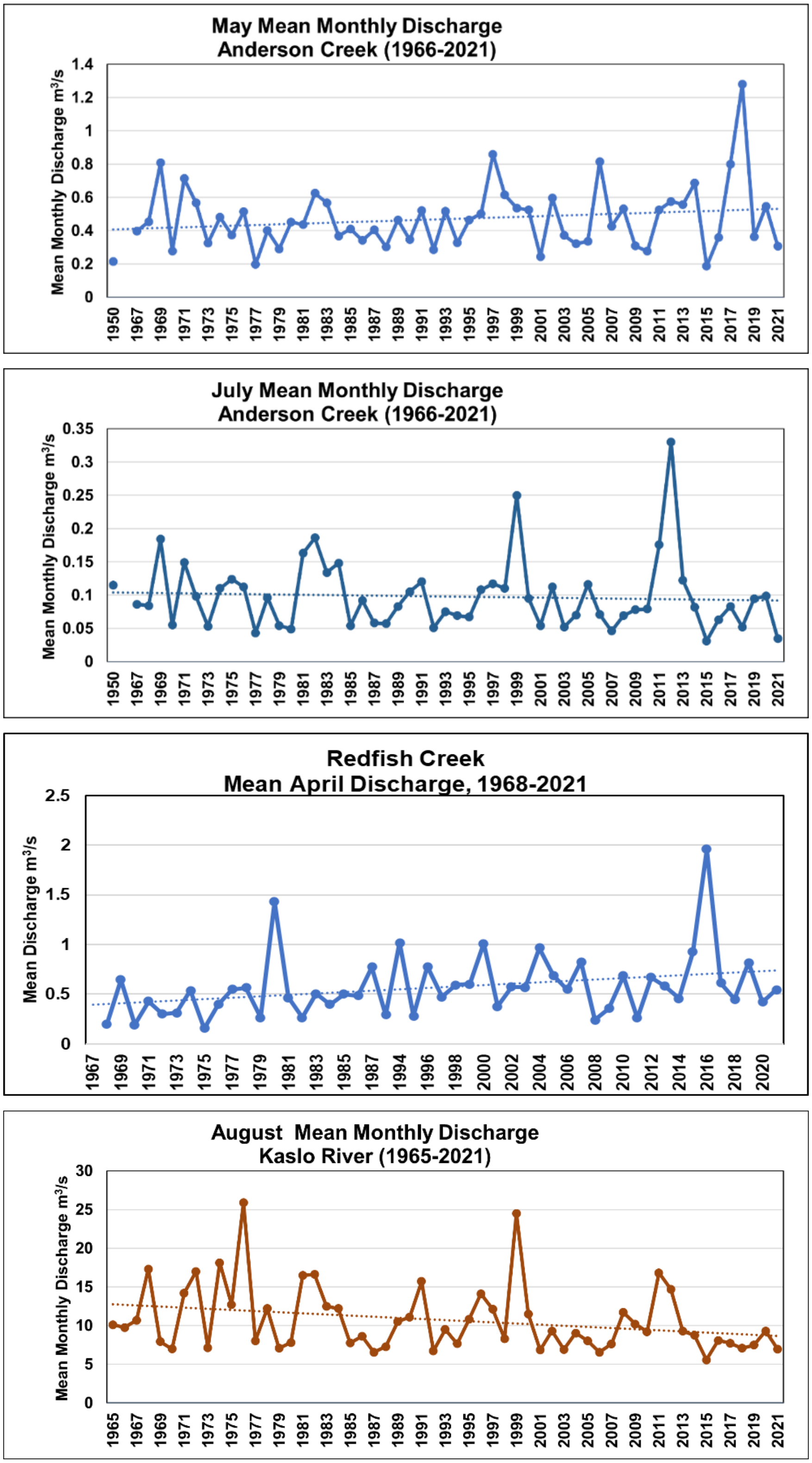


Figure 2.4-4. Extreme Precipitation and Peakflow Event from 2013

The changes described above lead to secondary changes in hydrology and geomorphic conditions. These changes and feedbacks can lead to an intensification of the hydrologic effects of climate change. For example, where drought leads to intense wildfire and hydrophobic soils, runoff changes can accelerate causing landslides and enhanced flooding. Where extensive forest cover is lost to wildfire or insect infestation, rates of snow accumulation and melt may be affected leading to additional hydrologic change. Declines in water quality are expected. Where channels are destabilized, further sedimentation and water quality declines may occur.

Climate disruption is bringing hydrologic unpredictability to the annual progression of snow accumulation, freshet runoff, and late-summer and winter baseflow and releasing soil and sediment into stream systems. Although the changing hydrology manifests in terms of both trends and extremes, it is the extreme events and their increasing frequency and intensity that will be most strongly noticed by communities because how they affect annual peak flows and baseflows relates strongly to society's infrastructure and expectations (Siirila-Woodburn et al. 2021). Where water is not available to ecosystems at the required and appropriate quantity, quality, and timing of flow, this gap in environmental flows can lead to improper function of ecosystems and potentially ecosystem changes.



a) May and July, Anderson Creek (9.1 km²; 1966-2021), b) April, Redfish Creek (26 km²; 1968-2021) and c) August, Kaslo River (442 km²; 1965-2021)

Figure 2.4-5. Long-term Mean Monthly Discharge

2.4.2 Climate Disruption and Ecosystems

The steady increases in summer temperatures and potential decreases in summer precipitation will have dramatic impacts on the ecosystems in the lower elevations of the West Arm. Wildfire risk will increase significantly, and moisture deficits will also increase. Moisture deficits and increased frequency of fire will likely result in a major shift in vegetation.

Climatic Moisture Index (CMI) is an indicator of available moisture based on the difference between annual precipitation and annual potential evapotranspiration (Hogg 1997). CMI has been used as an indicator of forest productivity and risks related to drought, as well as an indicator of the transition from grasslands to boreal forests in central Canada (Hogg and Schwartz 1997). More recently it has also been used with GCMs to assess future forest risks from drought across northern Canada (Wang 2014). Analysis of CMI values for southern BC Biogeoclimatic Ecosystem Classification (BEC) units have shown that it roughly correlates with the closed forest/open forest transitions shown on the right of Figure 2.4-6.

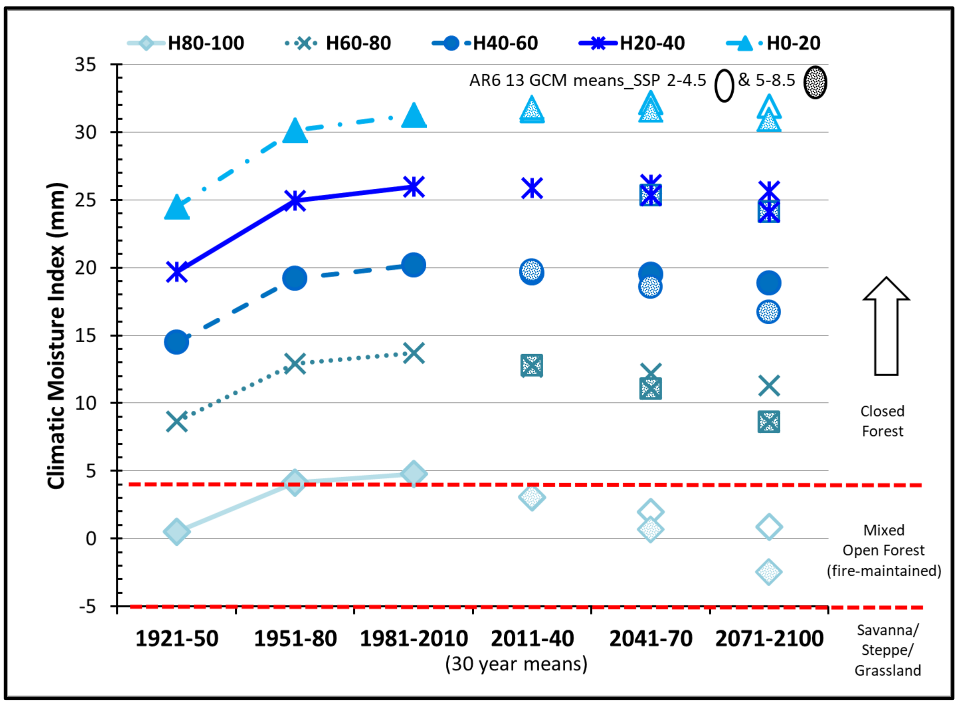


Figure 2.4-6. Historic and Projected Changes in Climatic Moisture Index for Various Elevation Bands of the West Arm

CMI calculations and projections indicate that decreased summer precipitation and increased evaporation will shift the environment at the lowest elevations of the West Arm from climates that have supported closed forests to savanna type environments of mixed grasslands and scattered trees. The upper elevations will still be capable of supporting closed forests, but they will likely have a more frequent stand-replacing disturbance regime.

Analyses of projected shifts in bioclimates are shown on Map 14 for the 2080s, demonstrating three potential futures based on three GCM and emission scenarios (Utzig 2012). See Section 4.3.14 for further discussion.

All the historic and projected climate values presented in Section 2.4.2 are from ClimateNA v7.10 (Wang et al. 2016), with outputs averaged from individual point data extracted from a 1-km grid for the area around the West Arm of Kootenay Lake (Figure 4.3-1), including both Glade and Laird Creek watersheds. All data are interpolated between individual climate stations and General Circulation Model (GCM, or Global Climate Model) outputs using the Parameter Regression of Independent Slopes Model (PRISM) interpolation method. Projections are taken from the mean of an ensemble of 13 GCM scenarios from the Coupled Model Intercomparison Project phase 6 database (CMIP6), corresponding to the Intergovernmental Panel on Climate Change Assessment Report 6 (AR6, IPCC 2021). Two emissions scenarios were considered: Shared Socioeconomic Pathway (SSP) 2-4.5 represents a moderately-low emissions scenario consistent with intermediate mitigation of GHGs; SSP 5-8.5 represents a high GHG emissions scenario that would result from continued development of fossil fuel resources. The differences between the outcomes for SSP 2-4.5 and 5-8.5 indicate the extent to which impacts could be reduced if serious GHG reductions were to be pursued in the coming years. More information on the models and projected data is available at: https://bcgov-env.shinyapps.io/cmip6-BC/ (see also Mahony et al. 2021). For simplicity, the data is summarized by 30-year intervals. The bioclimate shifts presented in Map 14 are based on outputs from AR4, rather than AR6. For associated methods for those projections refer to Utzig (2012).

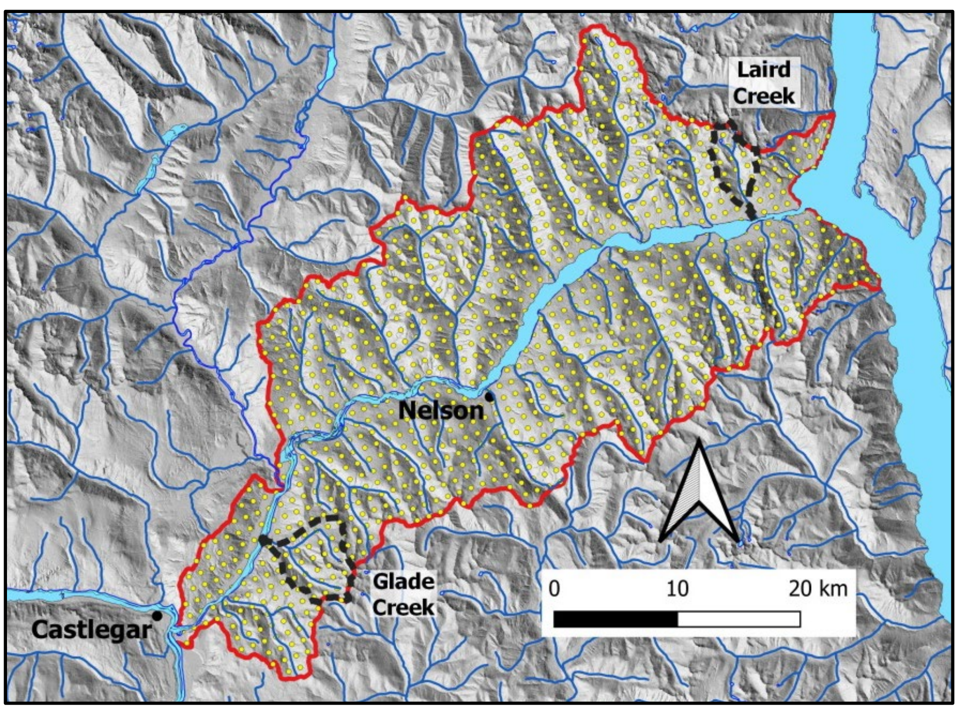


Figure 2.4-7. The West Arm Area with Glade and Laird Creeks. Grid Used to Extract Climatic Information from ClimateNA

3. STUDY AREAS

Glade and Laird watersheds are located in the West Kootenay (Figure 3-1). Glade is located on the Kootenay River, about 10 km east of Castlegar. Laird is located on the west arm of Kootenay Lake, near the community of Balfour, to the east of Nelson.

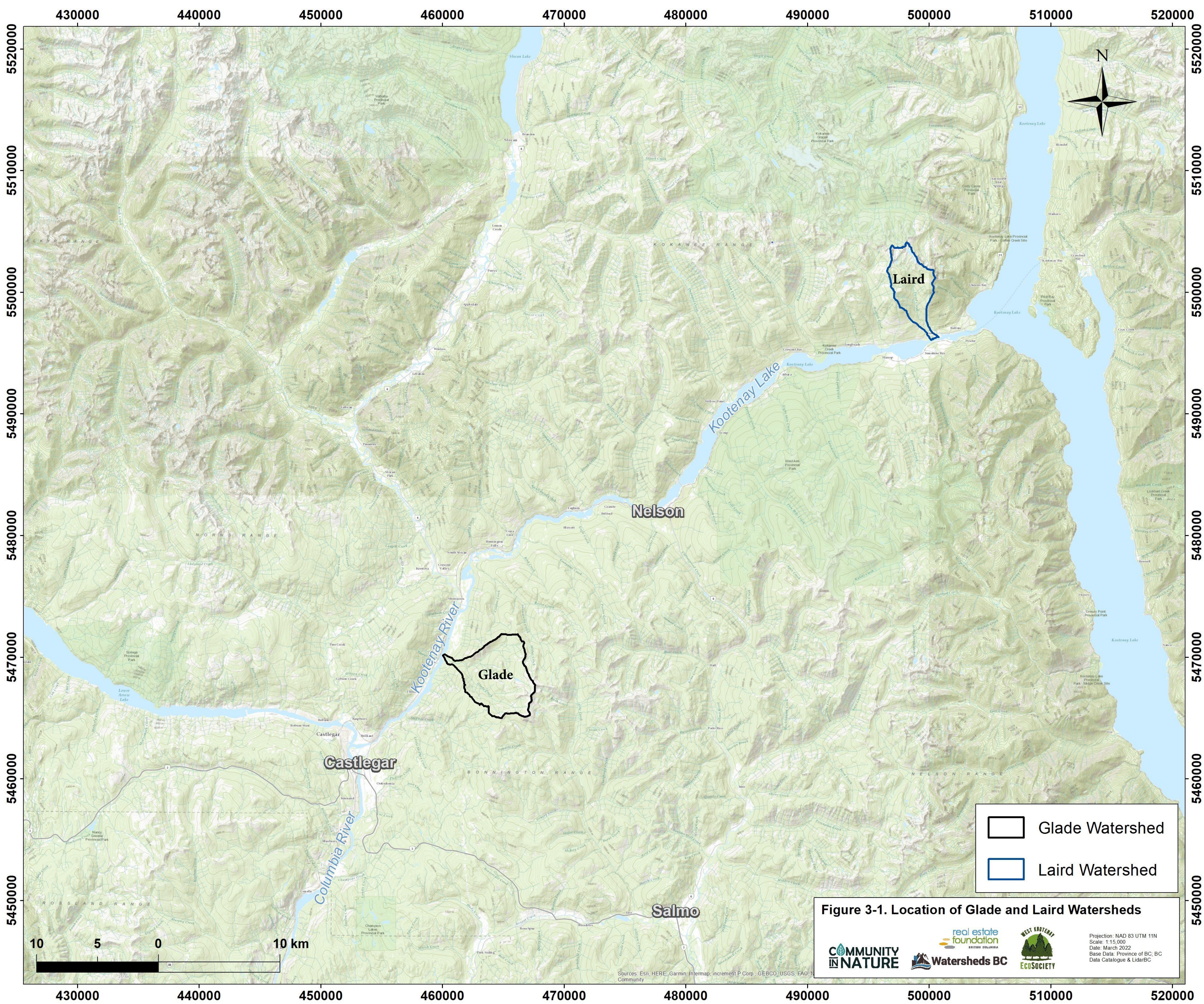


Figure 3-1. Location of Glade and Laird Watersheds

3.1 Geology, Landforms, and Soils

The following sections provide an overview of the watersheds' bedrock geology, surficial geology, and soils. Detailed information for the region and Glade and Laird watersheds can be found in Appendix A.

3.1.1 Physiographic Setting

Physiographic regions are unique assemblages of bedrock geology, landforms, surficial materials, and soils that together with climate influence the distribution of ecosystems across geographic areas. The project area is located within the Selkirk Range of the Columbia Mountains physiographic region that includes the north-south trending Monashee, Selkirk, and Purcell mountain ranges from west to east, and the Cariboo Mountains to the north. The Selkirk Mountains are bound by Kootenay Lake and River, the Duncan River and Reservoir, and the Beaver River to the east, and the Columbia River and Lower and Upper Arrow Lake Reservoirs to the west. The range is underlain by igneous intrusive, sedimentary, and volcanic bedrock types in the south and central portions, and mainly sedimentary and metamorphic rocks to the north. It includes rugged mountains that increase in elevation from south to north and deeply-incised valleys with steep sidewalls. The project area is situated in the south portion of the Selkirk Mountains and includes creek drainages on both sides of the West Arm of Kootenay Lake and on the south side of the lower Kootenay River between Nelson and Thrums.

3.1.2 Bedrock Geology

The nature of bedrock strongly influences landscapes and site conditions. The physical properties of rock such as hardness and resistance to weathering influence the steepness and complexity of terrain. Both physical and chemical properties affect the sensitivity of the bedrock to geological processes such as mass wasting, erosion and redistribution of materials, and site characteristics including the depth, texture, coarse fragment content, and nutrient status of the surficial materials and associated soils (MacKillop et al. 2018). Therefore, bedrock can also strongly influence vegetation composition, site productivity, and ecosystem distribution.

Granodiorite is the dominant bedrock type occurring along the north side of the West Arm and lower Kootenay River. Therefore, within the RDCK Area E project area, Laird Creek watershed as well as the Kokanee and Redfish drainages are dominated by the coarse-grained intrusive rock. Finer-grained rock types including limestone, slate, siltstone, and argillite also underlie low elevation areas from the lower Laird Creek drainage to north of Queens Bay. In the portion of Area E located south of the West Arm and Kootenay River, the bedrock geology is more complex with a mix of granodiorite and finer-grained sedimentary and volcanic rocks, but in the Glade Creek watershed, granodiorite is also the dominant rock type. An area of limestone, slate, siltstone, and argillite also occurs between the big bend in the north fork of Glade Creek and the north boundary of the watershed.

3.1.3 Surficial Geology

Surficial materials include the unconsolidated mineral and organic deposits that overlie bedrock. They form the parent materials of soils and thus influence the physical, chemical, and biological nature of ecosystems. The materials can be closely related to the underlying bedrock, or they can have properties that don't reflect the local bedrock geology when they've been transported long distances by glaciers, gravity, water, and wind. Surficial materials can be highly modified during transport and also after deposition by living organisms and natural or anthropogenic disturbances (MacKillop et al. 2018).

In the Laird Creek watershed, colluvial veneers and blankets are the most common surficial deposits and occur on moderately steep to steep terrain from valley bottom to the highest mountain ridges. Colluvial veneers dominate at mid to upper elevations, but colluvial blankets are also very common on lower to mid slopes in the central part of the watershed. The deeper deposits extend from the valley bottom at lower elevations to the upper subalpine on the east side of the drainage. Talus deposits and exposed bedrock are common at high elevations in the vicinity of Noakes Lakes and Balfour Knob.

Morainal (basal till) deposits are common on more moderate sloping terrain at lower to mid elevations along the west side of the valley and at mainly lower elevations on the east side of the creek. The areas are dominated by morainal blankets but also include some shallow till and colluvial veneers. Another area of morainal deposits occurs on moderate slopes in the valley bottom of the upper west fork of Laird Creek located south of the fork draining Haiseldean Lake. The area is situated at mid to upper elevations. Morainal veneers and blankets are less common on upper slopes at higher elevations. Almost all of the morainal and colluvial deposits in the watershed are derived from coarse-grained intrusive rocks and are mainly coarse-textured.

A glaciofluvial kame terrace overlies the finer-grained sedimentary bedrock where Laird Creek enters the West Arm. The gravelly sandy deposits may be capped by eolian materials. A small fluvial fan at the mouth of Laird Creek overlies the east side of the terrace and consists of gravelly, coarse-textured materials. Anthropogenic materials are associated with roads and settlement in the lower part of the creek drainage.

In the Glade Creek watershed, colluvial veneers on steep terrain are the most common landforms. The deposits occur from lower slopes in the drainage to upper slopes and crests at high elevations. Colluvial blankets occur with the veneers on steep slopes along the south side of the south fork of the creek. Talus deposits and exposed bedrock are common at high elevations in the areas around Siwash Mountain and the creek headwaters.

Morainal deposits are very common on lower to mid slopes in the south fork valley and on the northeast-facing terrain between the north and south forks of the creek. The area includes some colluvial blankets on the steeper slopes and the deposits occur mainly at mid elevations. Basal tills with minor glaciofluvial kame deposits also occur on moderate slopes at mid elevations in the area between the big bend in the north fork and the north watershed boundary. Most of the till and colluvial deposits in the drainage are derived from coarse-grained granodiorite and are coarse-textured. The morainal deposits located along the north boundary of the watershed are derived from finer-grained bedrock types and have medium textures.

Coarse-textured glaciofluvial materials are dominant in the bottom of the lower creek valley and sloping kame deposits extend a short distance up the south fork and up the north fork into the lower subalpine zone, about three quarters of the way to Siwash Lake. A small fluvial fan deposit occurs at the mouth of Glade Creek and anthropogenic materials are associated with settlement and farming in the vicinity of the fan.

3.1.4 Soils

Soils are important for providing the physical medium for plant rooting and the cycling and storage of water, nutrients, and gases that are necessary for plant growth. Soils are formed through the effect of climate (moisture and temperature), topography, and biota (organisms and vegetation) acting on geological parent materials over time (Jungen 1980). Therefore, the types of soils that develop in an area are closely tied to physiography, bedrock and surficial geology, regional climate, and vegetation patterns. For example, warmer and wetter climates tend to result in stronger soil development than cooler, drier climates. With respect to geology, soils that develop in parent materials derived from finer-grained, softer, darker-colored bedrock types (mudstone, shale, siltstone) have finer textures and higher nutrient status than soils that form in parent materials derived from coarse-grained, hard, lighter-colored rocks such as granodiorite, granite, and quartz sandstones (MacKillop et al. 2018). The soil characteristics associated with different soil types determine ecosystem characteristics.

Soil types vary by elevation, climate, parent materials, and vegetation. As elevation increases in the mountains, climatic conditions become cooler and moister affecting soil development processes and vegetation. Parent materials also change from the valley bottom to the high elevation ridges and summits. Within mountainous regions, climate, soils, and associated vegetation can be stratified by elevation bands or zones. In BC, the BEC system classifies ecosystems within zones and subzones with similar climate, soils, and vegetation characteristics. The zones and subzones correspond to elevation bands in the mountain landscapes.

3.2 Regional Ecology

Many of the forests in the study area have a long legacy of timber harvest and fire disturbance. These events have occurred across multiple ecosystems within this area, resulting in areas having multiple regeneration scenarios occurring within small areas. Some factors that influence the various ways in which the forests have re-established over the past century include the original species present, environmental conditions before and after the event, time since event, climate, geology, topography, proximity to development, and restoration and conservation efforts (Pojar, Klinka, & Meidinger 1987). The severity and uniformity of the disturbances (fire, disease, insect infestation, etc.) also influence the type and availability of regeneration materials present and the recovery strategy of the communities following the event (Carbone & Aguilar 2016). The landscape reflects the combination of primary and secondary successional development that has resulted in a mosaic of various tree species, forest density, vertical structure, and health conditions.

In early successional forests of the West Kootenays, there are often single and two-tiered canopies dominated by seral (early development) coniferous species. Seral deciduous species also occupy these early successional stands until they are outcompeted by the coniferous species, which develop into the main canopy and eliminate the direct light necessary for the deciduous species to thrive. These young forests usually have very low ground cover in the shrub, herb, and bryophyte (mosses and liverworts) layers due to canopy shading. The tree layer is typically dense with a closed canopy.

After canopy closure occurs, forests of this region transition towards their more mature stages, starting with stem exclusion. This successional stage is when the density of early seral species is higher than the carrying capacity for the system (given finite growing space), thus the strong survive and outcompete the individuals with less effective strategies, physiology, and/or ecology. At this point, the canopy begins to open up, allowing for increased growing space and more light to reach the ground. In the understories, the next cohort of shade-tolerant seedlings of the climax (late development) species has already been established. This creates a three-or-more tiered tree canopy wherein three or more distinct vertical layers exist. The shrub and herb layers also develop from the newly accessed light on the ground. With this increase in growing space, the tree seedlings in the understory will continue to grow and slowly recruit into the intermediate and, eventually, the co-dominant and dominant canopies.

As succession progresses, the early seral species will be outcompeted by the climax species. These shade-tolerant climax species will continue to grow from the understory into the dominant canopy, and outcompete the seral species for space, light, soil moisture, and nutrients. Often this process can take many decades, as seral species such as Douglas-fir and western larch can maintain dominance in the canopy for long periods of time before being outcompeted by western hemlock and western redcedar.

In the south Selkirk Mountains, lower to mid elevation areas are classified as the Interior Cedar Hemlock (ICH) biogeoclimatic zone. The lowest elevations, mainly in the main valley bottoms, correspond to the very dry, warm Interior Cedar Hemlock (ICHxw) subzone. Lower elevations above the ICHxw are classified as the dry warm ICHdw subzone, and the moist warm ICHmw subzone occurs at mid elevations. Areas at mid to upper elevations are classified as the Engelmann Spruce – Subalpine Fir (ESSF) zone. The transition area between the ICH and the ESSF zones at mid elevations is classified as the wet hot Engelmann Spruce – Subalpine Fir (ESSFwh) subzone and is considered to be a lower subalpine unit. The “wet hot” modifiers are relative to other ESSF subzones in the province. Upper elevations above the transition area are classified as the wet mild ESSFwm unit, with the wet mild woodland (ESSFwmw) and parkland (ESSFwmp) subzones occurring at higher elevations. The highest elevation areas above the parkland that don’t support tree growth are included in the Interior Mountain-heather Alpine (IMA) zone.

In the lower elevations of the ICH zone in the West Kootenays, Douglas-fir (*Pseudotsuga menziesii*), western larch (*Larix occidentalis*), western white pine (*Pinus monticola*), grand fir (*Abies grandis*), paper birch (*Betula papyrifera*), and trembling aspen (*Populus tremuloides*) are the early seral species on zonal sites, associated with intermediate moisture and nutrient regimes. Soil moisture regime (SMR) is the capacity of soil to hold moisture and supply it to plants, whereas soil nutrient regime (SNR) is the relative concentration of essential soil nutrients available to vascular plants over several years (Pojar et al. 1987). Mature stands are composed mostly of western hemlock (*Tsuga heterophyla*) and western redcedar (*Thuja plicata*), but mesic (moderate moisture) sites with high exposure and dry sites can include Douglas-fir and western white pine.

In the ESSF zone, early and late seral and climax successional stages are less distinct with respect to species composition. Both Engelmann spruce (*Picea engelmannii*) and subalpine fir (*Abies lasiocarpa*) can dominate in various successional stages of forest regeneration. Variable amounts of lodgepole pine can also occur in earlier successional stages of forests in the ESSF zone. Western hemlock, western redcedar, western white pine, Douglas-fir, and western larch are often found in ESSF forests at lower elevations in the transition zone between the ICH and ESSF units, while whitebark pine (*Pinus albicaulis*) and subalpine larch (*Larix lyallii*) can occur in ESSF forests on dry sites, usually at higher elevations.

It's important to note that the distribution of BEC zones and subzones on the landscape reflect current climatic conditions. The composition and distribution of biogeoclimatic units are projected to significantly change in the future due to climate change. The elevation bands will remain the same but climatic conditions, soils, and vegetation within those bands will change as the climate changes.

3.3 Unique and Rare Habitats and Vascular Plants

Many of the unique and/or rare habitats and species in the project area occur on dry or wet sites on the landscape. Dry sites are associated with open forests on very shallow soils with exposed bedrock or talus, shrub-dominated ecosystems on steep, warm-aspect slopes with shallow soils, small pocket grasslands, bedrock-controlled meadows, and cliffs and bluffs. Wet sites include wet forests and wet meadows in areas with seepage or high water tables, and wetlands in wet depressions and basins. The wet forests and meadows often occur in riparian areas along creeks and around lakes, ponds, and wetlands. The dry and wet ecosystems are typically uncommon on the landscape, provide important habitat for many species, including species of conservation concern (at-risk), and are very sensitive to disturbance.

3.3.1 At-risk Ecological Communities

A search of the BC Conservation Data Centre (CDC) database identified ten ecological communities considered to be at-risk within the RDCK area and that could potentially occur in the Laird Creek and Glade Creek watersheds. The ecosystems have a status of extirpated, endangered, or threatened (red list) or of special concern (blue list) indicating that they are vulnerable to becoming threatened, endangered, or extirpated in BC. The ten at-risk ecological communities are shown in Appendix B which includes notes on the potential for the ecosystems to occur in the watersheds. The table also includes a shrub-dominated brushland community that is uncommon in the southern Columbia Mountains. It is currently not listed, but the CDC is in the process of ranking the community and it may be designated as at-risk in the near future.

One of the at-risk ecological communities is known to occur in the Glade Creek watershed. The *ICHdw1/02 Douglas-fir/tall Oregon-grape/parsley fern* very dry forest ecosystem occurs at low elevations (ICHdw) and is found on dry, steep, warm-aspect slopes with very shallow soils and an abundance of exposed bedrock. It can also occur on blocky talus slopes. It has been identified on the dry ridge and upper slopes located above the lower north fork of Glade Creek. The ecological community often provides habitat for at-risk and other sensitive plant and animal species. Due to its very shallow and/or coarse-textured, dry soils, it is very sensitive to disturbance including to degradation by invasive plant species. The ecosystem may also occur on similar sites at lower elevations in the Laird Creek watershed. It correlates to the *ICHdw1/102 FdPy – Pinegrass – Rock-moss* site series described in MacKillop and Ehman (2016).

The *Gb03 ninebark – oceanspray – bluebunch – wheatgrass* brushland community is a potentially at-risk ecosystem that appears to occur (based on air photo interpretation) in the Glade Creek watershed, but its occurrence has not been confirmed by field surveys. It occurs on dry, steep, warm-aspect slopes with shallow soils and minor amounts of exposed bedrock. The ecosystem can occur at low to mid elevations (ICHxw, dw, mw) and is often associated with open dry forests of the listed *ICHdw1/02* ecosystem at lower elevations. The brushland community also provides important habitat for a high diversity of plant and animal species, including at-risk species and is very sensitive to disturbance by invasive plants as well as to conifer encroachment due to fire suppression. It is not currently designated as an at-risk ecological community, but the CDC is in the process of ranking the ecosystem due to its limited distribution, sensitivity to disturbance, and potential threats to the habitat. The community is described as the *Gb03* brushland site association in Section 6.4 of MacKillop and Ehman (2016).

The red-listed *Gg11 Idaho fescue – bluebunch wheatgrass – junegrass* grassland could possibly occur in small, exposed openings interspersed with areas of *ICHdw1/02* very dry forest and *Gb03* brushland located on the dry ridge and upper slopes above the lower north fork of Glade Creek. The *Gg11* grassland can occur in the ICHdw and at lower elevations in the ICHmw, but the ecosystem is very uncommon in the ICH, particularly at elevations above the ICHxw.

Another at-risk ecological community that occurs on dry sites at upper elevations is the red-listed ecosystem *timber oatgrass – grouseberry – thread-leaved sandwort – compact selaginella*. The alpine grassland is more common in the East Kootenays but also occurs very infrequently at high elevations in the south Columbia Mountains on dry, neutral to warm, moderate to steep upper slopes. It can also occur in gentle depressions with cold air accumulation that inhibits tree growth. The grassland could possibly occur in small pockets at high elevations (ESSFwmw, wmp) in the Glade Creek and Laird Creek watersheds but doesn't appear to be, based on air photo interpretation. It is described as the *Ag01* site association in MacKillop and Ehman (2016).

Other ecosystems that provide important habitat for plant and animal species, are sensitive to disturbance, and are uncommon on the landscape but are not ranked as at-risk ecological communities include wet forests, wet meadows, and wetlands.

Wet forests in riparian areas are important for providing cover, forage and travel corridors for wildlife and are particularly uncommon at lower elevations. Wet forest ecosystems that occur in the ICHxw and dw subzones are as follows:

- *112 CwHw – Horsetail – Lady fern* site series
- *113 CwSxw – Skunk cabbage* site series

Both site series (ecosystems) occur on gently sloping to level areas with water tables at or near the surface, and they are often associated with riparian areas. Old and mature forests in these ecosystems are rare to very rare in the ICHxw and ICHdw1. The 113 site series can also be classified as the *Ws10 Western redcedar – Spruce – Skunk cabbage* forested swamp (MacKillop and Ehman 2016).

Horsetail-dominated sites are also uncommon on the landscape at mid and upper elevations (ICHmw, ESSFwh, wm). They include the following ecosystems:

- *ICHmw4/114 SxwCw – Horsetail – Lady Fern* site series
- *ESSFwh3, ESSFwm3/112 SeBl – Horsetail – Canby's lovage* site series

The 112 sites series in the subalpine typically occurs on high bench flood sites in riparian areas (112a riparian phase), but it can also be a treed swamp (112b swamp phase) classified as the *Ws08 Subalpine fir – Sitka valerian – Horsetail* forested swamp. The wet forest ecosystems are described in more detail in MacKillop and Ehman (2016).

Wetlands are also uncommon in the mountainous terrain of the project area. They are restricted to very poorly-drained sites in small wet depressions and basins, on level areas and gentle toe slopes with high water tables, and in riparian areas adjacent to rivers, creeks, ponds, and lakes. Despite their small size and limited distribution, they play a very important ecological role on the landscape. They support unique plant communities, including at-risk species, that in turn provide habitat for a variety of wildlife species that depend on them for food, water, and cover. Wetlands also provide water storage and slow release that helps control flooding and erosion, and they filter out sediments for improved water quality.

The wetland ecosystems that occur in the project area include marshes, fens, swamps, and shallow water. Due to the steep terrain in the Glade and Laird Creek watersheds at low and mid elevations, wetlands are more likely to occur on gentle terrain in the upper valleys and basins. Marshes, swamps, and shallow open water wetlands may be more common than fens that are associated with organic deposits.

A number of different marsh ecosystems occur at lower elevations (ICHxw, dw, mw) with the most common being the *Wm01 Beaked sedge – Water sedge* and the *Wm05 Cattail* site associations. The *Wm01* ecosystem and the *Wm16 Bluejoint – Arrow-leaved groundsel* association, dominated by bluejoint reedgrass and subalpine forbs, are the most common marsh types at upper elevations (ESSFwh, wm, wmw).

Swamp wetlands include tall shrub swamps and treed swamps. The tall shrub swamps that could occur at lower elevations in the watersheds are *Ws06 Sitka willow – Sitka sedge, Ws01 Mountain alder – Skunk cabbage – Lady fern*, and *Ws02 Mountain alder – Pink spirea – Sitka sedge* ecosystems. The *Ws10 Western redcedar – Spruce – Skunk cabbage* site association is the only treed swamp ecosystem that occurs at lower elevations in the south Columbia Mountains and is likely rare to absent in the watersheds. At upper elevations, the *Ws13 Barclay's willow – Common horsetail – Arrow-leaved groundsel* shrub swamp can occur on a variety of wet sites, and the *Ws08 Subalpine fir – Sitka valerian – Horsetail* association is the only treed swamp that occurs very infrequently at mid to high elevations in the south Columbia Mountains.

Fen wetlands are very uncommon at lower elevations in the watersheds. The *Wf01 Water sedge – Beaked sedge* fen is more likely to occur than *the Wf05 Slender sedge – Common hook-moss* ecosystem in the ICHdw and mw subzones. Fens might be slightly more common in the subalpine areas and there are a number of different types that develop at upper elevations. The *Wf03 Water sedge – Peat-moss* fen and the *Wf13 Narrow-leaved cotton-grass – Shore sedge* site association are the most common fens in the subalpine subzones (ESSFwh, wm) while the *Wf04 Barclay's willow – Water sedge – Glow* moss ecosystem is more common at higher elevations in the woodland (ESSFwmw).

Alpine wetlands also occur on seeps and saturated flats at high elevations in the alpine and subalpine. Due to the constraints of the colder climate, they differ from swamp and marsh wetlands with similar site conditions at lower elevations by being dominated by low-stature vegetation including black alpine sedge, forbs, dwarf willows, and/or mosses. Some alpine marshes can also have permafrost, particularly those at higher elevations. In the southern Columbia Mountains, the alpine wetland type that occurs in the ESSFwmp, wmw and wm subzones is the *Wa02 Alpine sedge – Bog-laurel – Peat moss* site association. It is uncommon in the subzones but may occur on wet sites at high elevations in the two watersheds.

Shallow water wetlands are dominated by submerged and floating-leaved aquatic plants. The aquatic wetlands occur from low to high elevations but are more likely to occur at upper elevations in the watersheds. They have been divided into two subgroups including yellow pond lily types and pondweed types, but no site associations have been described to date. The wetland ecosystems listed above are further described in MacKillop and Ehman (2016).

Wet meadows often occur around wetlands, ponds, and lakes, on seepage sites adjacent to or within wet forests, and in avalanche run-out zones at higher elevations. The sites lack trees due to excessive moisture, cold air accumulation, late snow melt at high elevations or avalanching. They are often small in size and can support a high diversity of herbaceous species.

3.3.2 At-risk Vascular Plant Species

A search of the BC CDC database was also conducted to identify at-risk plants that occur in the RDCK area and could potentially occur in the Glade Creek and Laird Creek watersheds. A total of 27 red- or blue-listed vascular plant species were identified by the search. The plants are listed in Appendix C, which also includes information on the types of habitats where each species occur on the landscape.

Whitebark pine (*Pinus albicaulis*) is a provincially blue-listed species that is known to occur in both watersheds. The Committee On the Status of Endangered Species In Canada (COSEWIC) and SARA (Species At Risk Act) both rank the species as Endangered (a species facing imminent extirpation or extinction). The seeds of the high elevation species provide an important food source for Clark's nutcrackers, grizzly bears, red squirrels, and other mammals. The tree also has cultural significance for First Nations people who harvested the seeds for food. They also used the fibrous roots of the trees to sew bark together and to weave watertight containers and canoes (Parish et al. 1996). Whitebark pine stands have been devastated in some areas by blister rust, the mountain pine beetle, and wildfire. The trees frequently grow on dry, warm-aspect slopes and exposed windswept ridges with very shallow soils. Areas of whitebark pine habitat at upper elevations have been identified in both watersheds.

There are several other at-risk species that were identified by the CDC that could possibly occur in the watersheds. Heart-leaved springbeauty (*Claytonia cordifolia*) grows in a wide range of habitats in the ICHmw including moist/wet and riparian coniferous forests, mixed forests and rock-dominated sites and it has been found in the vicinity of Nelson. Dwarf hesperochiron (*Hesperochiron pumilus*) grows at lower elevations on sites with seasonal seeps and is known from Beavervale Creek, west of Salmo and near Castlegar. Least bladdery milk-vetch (*Astragalus microcystis*) occurs in dry coniferous forests in the ICHdw and has been found in the Pass Creek area. Mountain moonwort (*Botrychium montanum*) grows in coniferous forests in the ICHmw on mesic (average moisture) sites and is known from the Laird watershed and several areas in the Slocan Valley. Wild licorice (*Glycyrrhiza lepidota*) occurs in riparian forests and riparian herbaceous habitats at lower elevations. There are old occurrence records for the species from Queens Bay and it has been found more recently at Tulip Creek near Castlegar. Other at-risk species are unlikely to occur in either watershed based on preferred habitat types and occurrence locations (Appendix C). The species are associated with habitats that likely don't occur in the watersheds, and/or the closest occurrences of the species are located a long distance from the project area.

A species that is not at-risk but provides a unique habitat at high elevations is subalpine larch (*Larix lyallii*). It occurs on cool, exposed slopes often with very rocky, coarse-textured soils. Due to its hardiness, it can tolerate high altitude, north-aspect sites that are too cold for most other tree species. As a result, it often forms pure stands on those sites. Mountain goats, bighorn sheep, and grizzly and black bears all feed in subalpine larch stands and blue grouse feed on the tree needles (Parish et al. 1996). The species also has a high aesthetic value for recreationalists. Stands of subalpine larch occur in the upper woodland areas between Haiseldean and Noakes lakes in the Laird Creek watershed. It is unknown how common the species is at upper elevations in the Glade watershed.

4. NATURE-BASED PLANS FOR LAIRD AND GLADE WATERSHEDS

This document provides two draft interpretive map sets for NDS for Laird Creek and Glade Creek watersheds in Area E, RDCK. Interpretive maps that provide an ecological story are the core of an NDS. The maps are arranged in logical sets, and not only convey technical information about the ecosystems comprising the plan area, but also include photos and plain-language descriptions of the content of the maps and their “take home” messages. In this way the interpretive map set is the plan.

4.1 GLADE AND LAIRD WATERSHEDS—THE CONTEXT AND CONSERVATION

The context of the Glade Creek and Laird Creek watersheds within the broad ecological, climatological, and social landscapes in which they are found provides important guidance for protection, through conservation activities, and human use of the watersheds.

4.1.1 Ecological context

As shown on Map 1: Landscape Context in the interpretive map set that forms a part of this Initial NDS Plan, both the Glade Creek (Glade) and Laird Creek (Laird) watersheds exist within a landscape fragmented by roads, clearcuts, and other forms of development.

This condition is particularly noticeable in the landscape that surrounds the Glade watershed, while the fragmentation of the landscape that surrounds Laird watershed is partially buffered by its proximity to protected areas, West Arm Park, and Kokanee Glacier Park. However, large areas in the landscape adjacent to Laird watershed have been fragmented by roads, clearcuts, and urban development. Habitat loss for a variety of species and exacerbation of climate disruption accompany these human disturbances both within the watersheds and in the landscape surrounding Glade and Laird.

The ecological features within each watershed provide factors to consider in deciding how to protect, restore, and conduct precautionary uses of the watershed.

Laird Creek drains a deeply incised, predominantly south-facing watershed with a very high risk for ecosystem and water degradation from road and logging development. In some areas, very steep slopes run virtually unchanged from the watershed height of land to Laird Creek. Overall, the watershed contains extensive areas with past and ongoing instability issues.

The steep slopes of Laird Creek are made more sensitive and complex by regular gullies that have been carved along, or parallel to the slope direction of the steep terrain. Ecologically sensitive, gullied terrain makes up much of the watershed. This terrain complexity results in complex water movement patterns. Water not only moves down main slopes, but also down the sides of gullies in directions approximately perpendicular to water movement along the main slope. Gullied terrain increases slope sensitivity, may be easily degraded by roads and logging, and complicates drainage control.

Glade Creek drains a “funnel” shaped watershed with the upper part of the watershed being the wide portion of the funnel that tapers to a narrow outlet where Glade Creek empties into the Kootenay River. There are two forks of Glade Creek, with the North Fork joining the Main Fork of Glade Creek just above where the basin narrows to meet the Kootenay River.

The upper part of the watershed, north and south of Siwash Lake contains significant areas of low and moderate slope terrain that in some areas is punctured by high and extreme slope terrain. However, below the upper portion of the watershed, slopes are dominated by a mixture of high- and extreme-slope terrain. This terrain is frequently crossed by steep, deeply incised small tributary streams. The result is that gullied terrain, like that found in Laird Creek, covers the majority of the watershed. This portion of the watershed contains complex water movement patterns and is highly sensitive to disturbance from roads and forest removal by logging or other development activities.

While both Glade and Laird watersheds contain areas of intact forests, both watersheds have also been degraded by logging roads and clearcuts. In Glade Creek, these types of disturbances started approximately 100 years ago. In that era, logging used flumes from water diverted from the Creek to transport logs downslope. In Laird Creek, road and logging disturbance is more recent, having started in 2005. This road development and logging in Laird Creek caused a major landslide in May 2011 that filled the Creek with approximately 2,000 m^3 of mud, gravel, rock, and shattered trees. The Laird Creek residents were forced to rely upon bottled water into July 2011, while remedial measures were taken in the Creek and slopes above.

There are remnant old-growth forests in the upper portions of the Glade Creek watershed. Some of those upper elevation forests, particularly important for snow management, have been recently logged. However, most of the watershed is a young to early mid-age, recovering forest. Significant portions of the watershed were logged in the 1920s, using limited roads and flumes. In some cases, the flumes were directly adjacent to, or in creek channels.

A major forest fire occurred in much of the watershed in 1934. These fires left scattered remnant old/old growth trees, singly and in small patches. There was erosion, landslides, and debris torrents in portions of the Glade Creek watershed following the fires. These events have largely ceased as the forest ages from young to early, mid-age, 80 years and beyond. A major utility corridor passes through the lower portion of the watershed and has completely removed the benefits of the forest in that portion of the watershed.

There are active plans to log portions of the early, mid-age forest in the lower watershed. These plans will also remove remnant old/old growth trees and patches. From the standpoint of water, this planned logging is very ill-timed. The forest in the mid and lower portions of the watershed is nearing full recovery from logging in the 1920s and the 1934 fire and entering the stages of forest development where the important co-benefits of high quality water in moderate flows, and high levels of carbon sequestration and storage, are being provided.

Extensive areas of intact forests greater than 140 years of age are found in the upper half of the Laird Creek watershed. Some of these areas will have old-growth forest attributes. Most of these forests are on steep unstable slopes and many comprise parkland ecosystems, where deep snow packs are the major influence on forest cover, and result in open forest canopies of scattered trees and clumps of trees interspersed with openings of shrub dominated vegetation. Parkland ecosystems are ecologically very sensitive and generally not economical to log.

There are also large areas of intact forests greater than 80 years of age found in the lower half of the Laird Creek watershed. While only a small portion of this area has been logged, there are pending plans to log more areas, some of which are in close proximity to the 2011 landslide and have resulted in reconstruction of the road that triggered the landslide.

As explained in Section 4.3-10, clearcuts and roads pose significant negative effects to water, impacting the quality, quantity, and timing of flow of water. The same may be said for the utility corridor in Glade.

Protection of the Glade and Laird watersheds to maintain and restore natural water quality, quantity, and timing of flow is an important ecological and social decision. Part of this protection and restoration will rely upon encouraging the development of older intact forests, with the objective that over time these forests will become old-growth forests. With this approach, both water and biodiversity will improve over time. Implementing a designation of protection is both consistent with our scientific understanding of how watersheds work and forms a critical part of a socially responsible and ecologically enlightened approach to mitigating and adapting to global climate disruption.

4.1.2 Climatological and Hydrological Context

Like the rest of Earth, the climate crisis affects both Glade and Laird watersheds. The stresses on water, ecological resilience, and natural ecological integrity will only grow in coming years in concert with humankind's ongoing lack of effective action to reduce greenhouse gases in the atmosphere.

Both Glade and Laird are within the Lower Columbia-Kootenay hydrological region, as described in the Columbia Basin Trust's *Water Monitoring and Climate Change in the Upper Columbia Basin* (CBT 2017).

This hydrological region is among the warmest and driest hydrological regions within the Canadian portion of the Columbia Basin. The Lower Columbia-Kootenay hydrological region has the following existing and projected[4] climate conditions compared to the other hydrological regions found in the upper Columbia Basin (CBT 2017):

- Summer precipitation predicted to be amongst the lowest in the region as climate change proceeds.

[4] Based on an average of emissions scenarios for RCP4.5 and RCP8.5.

- Amongst the highest summer climatic moisture deficits, along with the Upper Kootenay and Columbia Kootenay Headwaters regions.
- Moisture deficit is a measure of evaporative loss compared to precipitation inputs, which is a practical integration of temperature and precipitation effects. Moisture deficit provides a useful measure of moisture needed for vegetation growth that must be met from sources other than rain, e.g., soil moisture, irrigation, to avoid impacts from drought. Water shortages for domestic and agricultural use, vegetation stress, increased wildfire risk, and wetland decline are all impacts from drought.
- Winter and summer temperatures are both increasing.
- The mean annual temperature has already increased by 1°C and is projected to increase by 4°C by 2100.
- Lower elevations already experience less than 50% of the winter precipitation as snow and this is expected to fall below 15% by the end of the century.
- The percent of precipitation falling as snow above the H60 line is projected to drop to nearly 50% by the end of the century (from the 1961-1990 baseline of 85%). In contrast, this metric is projected to decline to 80% in the cooler regions of the Columbia Basin during the same period. The H60 line is the elevation in a watershed above which lies 60% of the watershed's area.
- Snowfall/snowpacks at high elevations provide critical support for late-summer low flows. The more winter precipitation shifts from snow to rain provides a measure of the vulnerability of annual low flows to decline, and eventually fail to meet the needs of existing ecosystems, which will likely result in an ecosystem regime change.

With the acceleration of climate change, both Glade and Laird face warmer winters, with precipitation increasingly occurring as rain. This trend means lower snow packs to support summer and fall water supplies. Hotter, drier springs, summers, and falls will stress the maintenance of current forest vegetation cover and reduce water availability for ecosystem function and human use. Heat waves and accompanying drought bring with them water shortages for all beings, higher fire risk and loss of ecological resilience that may lead to ecological regime change (Thompson et al. 2009; Walker 2012). Intense storms at all times of the year will become more common, due in part to increased water vapor in the atmosphere (O'Malley 2019).

For both Glade and Laird, these climate change effects may be heightened by being situated in the Lower Columbia-Kootenay region. Baseline conditions for this region start at a warmer level, and therefore cross thresholds for climate disruption earlier than most other locations within the upper Columbia River basin (CBT 2017). Thus, maintaining natural ecological integrity in these watersheds is important to the maintenance of ecological resilience and key ecosystem benefits, like dependable water supplies and adaptation to climate change (Thompson et al. 2009).

4.1.3 Social Context

Both Glade and Laird watersheds are consumptive use watersheds that depend upon the maintenance of natural levels of water quality, quantity, and timing of flow to support their populations, both human and non-human.

The ecological condition of both watersheds has been disturbed by past roads and logged areas, and there are further roads and logging planned in each watershed. Thus, water supplies in both areas are threatened by changes to hydrological function that will accompany planned forestry operations (Yu & Alila 2019). If this occurs, there is no guarantee that alternative water supplies, suitable to meet ongoing community needs, will be available, particularly with the hydrological and ecological stresses from climate change. The communities of Glade and Laird cannot realistically move to a new location to meet their needs.

Another aspect of the social context of Glade and Laird watersheds is that they are found within Forest License tenures of three timber companies and one government-owned logging entity: Kalesnikoff Lumber Company and Atco Wood Products in Glade, and Cooper Creek Cedar (for Porcupine Forest Products) and BC Timber Sales (BC government) in Laird. These timber/logging organizations all claim sustainable forestry operations and operate in large landscapes well beyond the Glade and Laird watersheds. They can move to a new location to meet their needs.

A problem arises for the timber companies in that they have been active participants through industrial lobbies and input from their forest professionals in changing forest legislation and policy to suit their profit-oriented objectives. The result has been the establishment of a non-sustainable cutting rate across their operating areas and throughout BC (Broadland 2020; Broadland 2022).

At one time, the Ministry of Forests acknowledged that “fall down” would occur with the disappearance of old/old-growth forests, and that there would need to be a reduction in the allowable annual cut to account for logging younger forests with lower timber volumes. However, this understanding and accompanying policies regarding fall down disappeared with the implementation of the *Forest and Range Practices Act* and Professional Reliance, which turned over the management and decision-making authority from government to timber companies and forest professionals in their employ.

The end result is that British Columbia’s forests—public forests—are being logged at a non-sustainable rate. Supported by a sympathetic bureaucracy that:

- determines cutting rates based upon assumptions developed from inadequate, timber biased data,
- does not factor in climate change or biodiversity loss,
- places timber extraction as the priority use of public forests, and
- limits any allowable cut reductions to small amounts that will not impact the economy.

Over-cutting of forests continues with the false assurance provided by forest professionals that BC is the location of "world leading sustainable forestry." The absence of an accurate, field-based forest inventory makes it difficult to determine the actual level of over-cutting and enables the timber industry to obfuscate the problem with assumptions of convenience about what the real ecological, social, and economic impacts of industrial forestry are.

The mismanagement of BC's forests by timber companies, forest professionals, and the Ministry of Forests exacerbates climate change (Weiting 2019) and degrades biological diversity (Della Sala et al. 2021). Industrial timber extraction poses a threat to the Glade and Laird watersheds in a variety of ways. Those threats, include exacerbation of climate change and accelerated loss of biodiversity both within and well outside of the watersheds.

Thus, industrial forestry as practiced and proposed in Glade and Laird does not protect the public interest. Continuing to deny that reality simply increases the risk to water and the other forest benefits that come from intact forest ecosystems and watersheds (Watson et al. 2018).

There is a pressing need for a new relationship with forests to replace the forestry/industrial paradigm that continues to cause the degradation of BC's forests and threatens the integrity of Glade and Laird watersheds.

4.1.4 A New Relationship with Forests

A complete "rethink" is needed for what we euphemistically refer to as *forestry*. As currently practiced in the vast majority of cases, forestry is little more than a front for logging, for degrading, and in many cases destroying forests. Forestry gets off the hook of public scrutiny by many because the timber industry is constantly reassuring the public that "new forests" are quickly planted following logging. You can plant a tree, but you cannot plant a forest. Therein lies the fundamental disconnect between *forests* and *forestry*.

Society has always needed forests for their essential ecological benefits of air and water purification; interception and storage of water by tree crowns; storage and movement of water across continents; climate moderation; carbon sequestration and storage; biological diversity; spiritual renewal; and food and shelter, to name the big benefits. Cultures that co-existed with forests recognized and protected these ecological benefits in their interactions with the forest. These cultures were rooted in a kincentric/Earth-centred ethic, not the destructive anthropocentric ethic that drives today's society, a society controlled and directed by corporate capitalism (Martinez 2018):

> *"Kincentricity—Indigenous land care practices that entail reciprocal relationships laid out in "original compacts" between animals and humans; a way of life that includes relating respectfully to all life as kin and to the Earth as a nurturing mother. There are no "natural resources" when those beings are your kin who must be approached with respect before harvesting."*

In this definition, Dennis Martinez is describing a regenerative approach, as opposed to a production, technology dependent approach like that employed in industrial forestry. The failure of the later approach in forest management's attempt to "control forests" has never been more evident than in the climate and biodiversity crises, and the lack of equity in society.

In another example of kincetric thought and action, Robin Wall Kimmerer (2015) explains the *honorable harvest* through the Potawatomi way of relating to Nature—to forests:

- Ask permission of the ones whose lives you seek. Abide by the answer.
- Never take the first. Never take the last.
- Harvest in a way that minimizes harm.
- Take only what you need and leave some for others.
- Use everything that you take.
- Take only that which is given to you.
- Share it, as the Earth has shared with you.
- Be grateful.
- Reciprocate the gift.
- Sustain the ones who sustain you, and the Earth will last forever.

Kincentricity and the process for the honourable harvest need to be the foundation for a new relationship with forests. As forestry, read timber extraction and growing replacement trees (if planted trees survive climate change), approaches critical levels of forest removal and degradation of essential ecological benefits of forests, the need to redefine our relationship with forests takes on urgency. A new relationship with forests needs to focus on protection of remaining intact natural forests—primary forests, particularly old-growth, coupled with restoration of ecological integrity, biodiversity, and overall ecological resilience in forests degraded by forestry and other human exploitation.

These changes will not be made by following the path of today's timber-biased forestry analyses and planning. We need to put concepts like AACs (allowable annual cuts), rotation ages, second-growth, commercially valuable trees, free to grow, etc. aside and focus on forests. This may be achieved by developing NDS that provide networks of ecological reserves connected by linkages across landscapes, watersheds, and sites. Produced at multiple spatial scales, these networks use a precautionary approach to define what needs to be protected and where restoration needs to occur. Once these networks are identified, we can talk about how to fit us into the forest picture in ways that protect the ecological integrity of forests. The locations where we fit are termed "human use areas."

Some of those human use areas will be for the removal of timber through a process that maintains continuous forests through the use of ecologically-based partial cuts. When human use areas for timber extraction are defined, we can talk about how much we may periodically cut (i.e., AAC) and how long trees need to be grown to provide their full ecological benefits (i.e., rotation age).

NDS is not to be confused with land use planning, where people negotiate how to divide up the forest pie for human uses. NDS is first about protection and restoration of natural ecosystem composition, structure, and function, and secondarily about human uses that are carried out in ecologically responsible ways. NDS may be defined as forest conservation.

NDS provides for as many, and often more meaningful, jobs in forest protection and restoration, and in partial cuts compared to jobs found in industrial forestry in today's failing timber economy. An additional economic benefit of NDS is that it facilitates the development of diverse, community-based economies, where high levels of employment may be developed and sustained.

In order to develop a new relationship with forests, we will need transformational change. This will include shifting control of forests from private corporations to control by Indigenous Nations and settler government through a co-management arrangement that is governed by the philosophy, principles, and process of NDS.

As we make that shift, we need to constantly remind ourselves that being captured by today's forestry theory, concepts, and jargon limits our creativity and abilities to change. If bound by the prevailing theories of forestry, we will not solve the problem, because we are treating symptoms not dealing with the problem. The problem is our misguided relationship with forests. Forestry as currently practiced is an outdated construct, defined and promoted by industrial interests through government, education, research, and effective lobbies.

A new relationship will emerge when we embrace a kincentric relationship with forests and implement the honourable harvest. NDS plans will move us along the path to that new relationship with forests.

4.1.5 Climate Change Refugia—a Conservation Opportunity

The context of Glade and Laird watersheds may be summarized as:

- Both watersheds contain significant areas of intact forests. In the case of Glade, a large area of young to mid-age diverse healthy forests is just entering the phase in their development where they provide high levels of benefits for water, biodiversity, and carbon management.
- Both watersheds exist in a large landscape fragmented by roads and clearcuts that contribute to climate disruption and biodiversity loss (Pojar 2019; Price et al. 2020; Wood 2021).
- Recent road construction and logging, coupled with imminent plans for additional roads and logging threaten the ecological integrity and resilience of both watersheds, particularly in the climate emergency.
- Forestry and associated logging activities in the watersheds are part of a non-sustainable cutting rate that exacerbates climate change and biodiversity loss.
- Their location in the Lower Columbia-Kootenay Region of the Upper Columbia River Basin results in both watersheds starting from a warmer baseline than other parts of the Basin. This means

that projections for future climate disruption reflect that this Region is likely to cross undesirable thresholds more quickly than other Regions.

- Rural communities in both watersheds depend upon high quality, dependable water supplied by both watersheds.

Given their ecological, climatological, and social contexts, both Glade and Laird watersheds play important roles in mitigation and adaptation to climate disruption. These climate change related roles are the most important benefits provided by the watersheds in support of the broad public interest to reduce the effects of climate change and provide important forest benefits, particularly high quality water supplies and reduction of greenhouse gases in the atmosphere.

To protect the important roles of Glade and Laird watersheds in the climate change era, the areas may be designated as *climate change refugia*.

Climate change refugia is described by Morelli et al*.* (2016) as:

> *"areas relatively buffered from contemporary climate change over time that enable persistence of valued physical, ecological , and socio-cutural resources."* (p. 2)

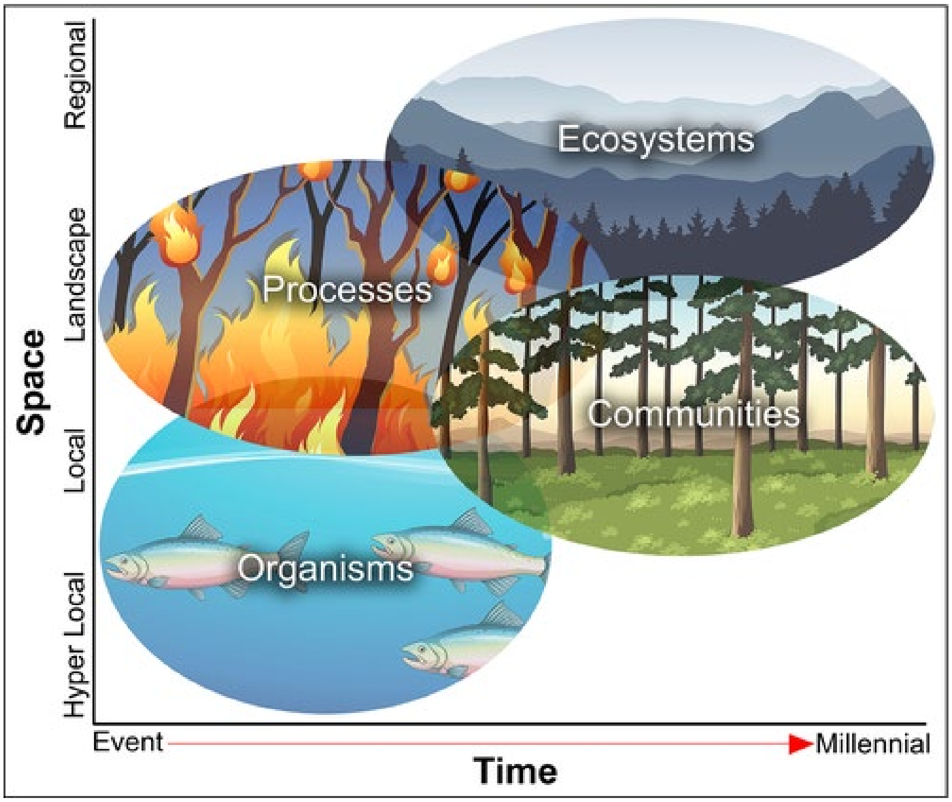
While the climatological context of these watersheds would seem to limit their designation as climate change refugia, their ecological context within a severely fragmented landscape and the presence of intact forests support their value as refugia. The dependence of rural human communities on the forest benefits from these watersheds also is a nod towards their designation as refugia.

One might argue that ultimately most, if not all climate change refugia will fail to maintain current ecosystem composition, structure, and function. This conclusion arises from the relatively static definition of refugia. A broader interpretation of refugia is more nuanced and attempts to accommodate ecosystem complexity, while providing protection for sociocultural and physical resources (Morelli et al*.* 2020).

The reality is that refugia will have varying lifetimes, or periods within which they are effective, and will serve different purposes. Thus, refugia have both a spatial and temporal aspect. Classification of refugia by how long they are predicted to play a chosen refugium function(s) leads to identification of refugia as "micro" or "macro" refugia, relating to the continuums of refugia, described here by Morelli et al*.* (2020):

> *"Climate-change refugia exist along spatial and temporal continuums (Figure 4.1-1; Keppel and Wardell-Johnson 2015), ranging from regional scales (where macro refugia can facilitate ecosystem persistence over centuries and even millennia), to landscape and local scales (where micro refugia can maintain particular species and communities for years and decades), to "hyper- local" scales (where refuges can provide temporary shelter for individuals) (Fey* et al*. 2019). In addition, disturbance refugia (Web Panel 1)*

can delay ecosystem transitions for decades or longer." (Carlotta Chuck at al. 2020) (p.229)



(Morelli et al. 2020)

Figure 4.1-1. At regional scales, macro refugia can facilitate ecosystem persistence over centuries and even millennia. At landscape and local scales, micro refugia can maintain selected species and communities for similar lengths of time. At shorter timescales (days to years), hyper-local refuges can provide temporary shelter for individual organisms.

Climate change refugia are established in locations with ecological integrity, biological diversity, and ecological resilience. These types of complex ecosystems rely on their integrity and resilience to provide options for change to accommodate the stressors of climate change. By comparison, the degraded, simplified ecosystems that result from logging, tree plantations, and other forms of development have very limited resilience and options for change as climate change progresses.

A critically important function of climate change refugia is that they will provide for the persistence of important forest and other ecosystems benefits as climate changes progresses. The length of time persistence occurs will depend on the speed and types of change wrought by climate change. Changes will occur within the natural range of variability from natural disturbances for the ecosystems in the refugia. If changes from climate change reach points beyond the natural range of variability, the refugia will provide stepping stones to a new socio-ecological regime. This will result a more orderly transition to a new ecosystem form and, hopefully, bring with it some of the benefits from the previous ecosystem composition, structure, and function.

In these ways, designation of the Glade and Laird watersheds as climate change refugia will assist persistence of the natural ecosystem, and their inherent resilience for as long as possible. As refugia these watersheds will meet community needs for as long as possible in the face of yet unknown changes in climate. The surrounding landscapes will also benefit from the maintenance of ecological integrity and resilience in the Glade and Laird watersheds. This is important to the overall mitigation of, and adaptation to, climate change in the larger landscape that holds the two watersheds.

The composition and structure that support designation of Glade and Laird watersheds as climate change refugia will be explained more fully in the rationales for the interpretive maps that show hydrologic sensitivity (Section 4.3.12) and the Protected Landscape Network (Section 4.3-13).

4.2 Data Sources

Data used for this project were primarily obtained from publicly available provincial government sources as there are limited watershed-specific data sets for the study areas. Primary data included:

Provincial government (Data BC) is the primary source, including:

- Freshwater atlas (streams, rivers, lakes),
- Wetlands,
- Roads,
- Transmission lines,
- Forest harvest polygons (results),
- Contours,
- Biogeoclimatic units,
- Vegetation Resource Inventory (VRI), and
- Fire history.

Other data from:

- Terrain Mapping,
    - Glade – Digitized from Apex Geoscience (Halleran 2007) Terrain Stability Mapping for Kalesnikoff Lumber for the western portion of the Glade Watershed.
    - Glade – Digitized from Apex Geoscience (Halleran 2000) Detailed Terrain Stability Mapping of the Glade Project area for the eastern portion of the Glade Watershed.
    - Laird – Terrain and Soil Inventory, West Arm Demonstration Forest (Utzig 1997).
- LiDAR (LiDAR BC – Province of BC),
- Canada wide digital elevation models (CDEM) from Natural Resources Canada,

- ESRI and Google imagery servers, and
- 2021 field studies (tree age, height and species, disturbances, channel width and morphology, species-at-risk observations).

4.3 METHODOLOGY

4.3.1 Map 1 Landscape Context

The landscape context map is a simplistic representation of the two study areas within the larger region. The map uses satellite imagery to illustrate the high level of disturbance and fragmentation in the West Kootenays outside of parks and protected areas. Provincial base data were used to label communities, roads, parks, and the main rivers.

The intent of this map is to illustrate that Glade and Laird watersheds are relatively intact within a largely fragmented landscape, providing opportunity for landscape level protected area and climate change refugia.

4.3.2 Map 2 Topography and General Sensitivity

The topography and general sensitivity is a representation of the main slope (gradient) classes of each watershed. These maps were generated using 1 m LiDAR bare earth data, and classified as:

- <20% low sensitivity
- 20-40% moderate sensitivity
- 41-60% high sensitivity
- >60% extreme sensitivity

As slope gradient increases, the need for caution in decision making increases. Factors additional to slope gradient that need to be considered to assess terrain sensitivity include landform, soil characteristics, moisture, etc.

4.3.3 Map 3 Natural Character

Natural character shows the predicted distribution of old forest and other primary forest in the watershed prior to modification by industrialized human societies. In the cases of Glade and Laird watersheds, natural character would be an estimated depiction of the forest cover prior to the large settlement fires in the late 1800s and early 1900s. This depiction of natural character is important as it provides a “natural baseline” against which today’s condition may be assessed. The difference between character and condition is termed the “restoration deficit.”

These maps are intended to provide a baseline of the natural character of these forest landscapes/watersheds under natural disturbance regimes and Indigenous management. The natural character map was made using VRI data to differentiate between forested and non-forested areas of the watershed.

4.3.4 Map 4 Old Forest, Non-Forest, and Logged Areas

These maps present the age of forest cover, along with riparian ecosystems and non-forested ecosystems. Modelled from the VRI, the forest age shows the stark difference between Glade and Laird watersheds, with Glade containing mostly mid-aged forests as a result of large fires and logging around 100 years ago. Old forests are largely limited to the higher elevations of the watershed, although ecologically valuable old veteran trees can be found sporadically throughout the watershed. The Laird watershed, on the other hand, contains a significant amount of old forest in the mid to upper elevations. Laird has much less disturbance history than Glade, including a lack of large stand-replacing fires in the last century, and forestry activities generally restricted to the lower elevations. Riparian ecosystems are also represented on these maps, using a width that is 1.5x the average tree height in which the watercourse passes through. The riparian ecosystems layer only covers the larger mapped streams based on limited available data; both watersheds have a much larger number of un-mapped small watercourses than is shown on the maps.

4.3.5 Map 5 Industrial Disturbance

Industrial disturbance maps include the main anthropogenic modifications present within the focal watersheds. The primary layers included:

- Roads (from the provincial road atlas),
- Trails (from various sources, or digitized),
- Transmission Lines (from provincial base data), and
- Cut blocks (from the provincial RESULTS layer and from tenure holders).

Layers were modified as needed for the analysis. Specifically, old overgrown roads were classified as such so they could be removed from the zones of influence analysis. As there are limited data on the type, condition, and age of older roads, a visual analysis of ortho imagery was used to distinguish between road types, combined with the 2021 field data. Transmission line rights-of-way were also assessed, and the areas where the lines spanned valleys, and therefore no vegetation management occurs, were removed from the analysis.

Each feature was buffered by 50 m, 150 m, and 500 m to represent different levels of influence. Timber management activities affect ecological processes and population dynamics well beyond the apparent physical boundaries of access roads and clearcut blocks. This zone of influence, or “edge effect,” extends much farther into the surrounding landscape than is often realized. Impacts found in the zone of influence include:

- habitat loss for species from microscopic soil organisms to large mammals, like grizzly bears,

- fragmentation of habitats and loss of connectivity,
- increased air and soil temperatures,
- reduced interception and conservation of water,
- drying winds,
- spread of invasive plants,
- loss of soil moisture,
- decrease in nutrient value of forage species, and
- decreased benefits from the forest canopy.

Effects from the zones of influence are long lasting. Some habitat loss may last for a century or more, particularly where old-growth forest habitat is necessary for persistence of species. The forest canopies of intact, old forests are complex creating a variety of habitats in the soil, along the forest floor and up through the canopy. The forest canopies of tree plantations are very simple and lack the biological diversity and physical complexity needed for intact, healthy forests. This is part of the reason that tree plantations are more flammable and less resilient to climate change than intact natural forests.

4.3.6 Map 6 Forest Crown Cover

The Forest Crown Closure map shows the forest age and crown closure of each watershed. The maps were created using VRI data, with the crown closure corrected from LiDAR data. Each map show the following age and crown closure classes:

- Forest Age Classes
  - 0-40 years (non-forest, shrub, and early successional forests)
  - 40-80 years (young forest)
  - 80-140 years (mature forest)
  - 140-250+ years (old forest)
- Crown Closure Classes
  - <25%
  - 25-50%
  - >50%

Crown cover reflects the crown mass of living leaves, which intercept, distribute, store, and conserve water, both rain and snow. The denser the crown cover and the older the trees the better the conservation of water. Vegetation cover affects rain and snow interception, snowmelt, evapotranspiration, and hydrologic response. Interception is important here, not only for evaporation/sublimation, but also to give soils and partially disturbed surfaces a chance to drain and recover, thereby avoiding overland flow.

4.3.7 Map 7 Surface Erosion Hazard and Surface Erosion Yield Potential

The Surface Erosion map provides a relative rating of the potential across the watershed for soil erosion due to waterborne processes. It is provided in five classes – VH, H, M, VL, and L. The specifics of what is presented in the map varies between the two watersheds due to differences in the available terrain mapping.

Available terrain mapping for Glade watershed is at the reconnaissance Terrain Survey Intensity Level (TSIL) C with limited field checking (Halleran 1999; Halleran 2007). Available terrain mapping for Laird watershed is at Survey Intensity Level (SIL) 3 for the operable areas and TSIL 4 for the inoperable areas (Utzig 1997). These earlier SIL mapping standards require >60% and >30% of the map polygons to be field checked, respectively, and are roughly equivalent of TSIL B and TSIL C (Greg Utzig personal communication, 2022). Province of BC (1999) estimates that TSIL C has 20-50% of polygons field checked and that the TSIL B has 50-75% field checked. In addition to the differences in reliability of the terrain mapping in the two watersheds, Utzig (1997) provides more detailed descriptions and interpretations of soil properties, hillslope characteristics, and potential instream yield of eroded materials. Utzig (1997) also provides planning guidance for reducing risk.

4.3.7.1 Laird Watershed

Terrain mapping for Laird watershed provides two surface erosion potentials along with sediment yield ratings. The surface erosion hazard expresses the likelihood of soil erosion at the surface. The road and ditchline erosion hazard provides the likelihood for waterborne erosion from road surfaces, cutbanks, and ditchlines. This Laird map integrates these two hazards and further combines their integration with the site's sediment delivery potential which provides the likelihood that the eroded material will reach the stream network. As a result, this map provides surface erosion yield potential ratings following the information provided in the available terrain mapping (as per Table 2.11, Utzig 1997).

4.3.7.2 Glade Watershed

Terrain mapping for Glade watershed provides only the surface soil erosion potential, without further erodibility data about the subsurface soils. Only a handful of polygons are assessed for the delivery of soil erosion to the stream network. As a result, this map provides only the potential for surface erosion at a particular site. This hazard rating follows the four classes provided in both Table 3 of Halleran (2000) and Table 5 of Halleran (2007).

4.3.8 Map 8 Slope Stability Hazard

The Slope Stability Hazard map provides a relative rating of the potential across the watershed for soil erosion due to processes related to slope instability. It is provided in five classes – VH, H, M, V, and VL.

The specifics of what is presented in the map varies between the two watersheds due to differences in the available terrain mapping.

4.3.8.1 Laird Watershed

Terrain mapping for Laird watershed provides terrain stability hazard following BC's standard system of terrain stability hazard assessment. In addition, landslide-induced stream sedimentation hazard is provided in four classes. Both these hazard ratings are presented on the map. The colour presents the likelihood of a landslide (as per Table 2.1 in Utzig 1997) whereas the stippling indicates the likelihood that a landslide would reach the stream network should it be initiated (as per Table 2.3 in Utzig 1997) - "landslide induced sedimentation" (LIS). Together, these two ratings provide the likelihood of causing sedimentation in streams due to slope instability.

4.3.8.2 Glade Watershed

Available terrain mapping for Glade watershed provides terrain stability hazard across the watershed. In the available information, only a handful of polygons are assessed for the delivery to the stream network. As a result, this map provides only the potential for initiation of a landslide. These ratings follow the four classes provided described in Table 2 of Halleran (2000) and Table 3 of Halleran (2007).

4.3.9 Map 9 Peak-Flow Augmentation

The Peak-Flow Augmentation (PFA) map portrays the potential of watershed areas to augment the hydrograph's peak-flow during the annual freshet and does this using five classes (VL-L-M-H-VH). In general, the middle of the watershed has the greatest ability to increase the peak flow and this potential drops off above and below this (more-or-less) central band. However, aspect and slope contribute to this potential by modifying snow accumulation and its melt in relation to the timing of the hydrograph's peak flow. Forest and soil disturbances further modify the potential due to associated changes in site-level snow accumulation and melt and subsequent runoff dynamics.

The map provides a preliminary approach to apportioning, across the watershed, potential impacts to the peak flow. The methodology is rooted in applying elevation as a primary determinant. A hypsometric curve is first used to establish nine contour lines that divide the watershed area into ten equal parts. As provided in Table 4.3-1, a basic rating is given to each elevation band. These Basic Inherent Ratings have been developed based on a synthesis of snowline research and distributed physically-based modelling, as discussed in Section 2.3. They are provided here as preliminary values, subject to revision and field verification in future work.

Table 4.3-1. Preliminary Potential Ratings for Augmentation of the Hydrograph's Peak Flow in Relation to Topographic Attributes

Elevation Band (by area)	Basic Inherent Rating (Natural Forest Cover)	Adjustments for certain aspects				Adjustment for slope gradient >70% (half this if 30-70% slope)			
	Mixed aspects (E/W) AND gentle slopes (<30%)	Hot	Warm	Cool	Cold	Hot	Warm	Cool	Cold
		S	SE/SW	NW/NW	N	S	SE/SW	NW/NW	N
Outlet-H90	0	0	0	0	0	0	0	0	0
H90-H80	5	-4	-2	+2	+4	-2	-1	+1	+2
H80-H70	20	-10	-5	+5	+10	-6	-3	+3	+6
H70-H60	30	-5	-2	+2	+5	-4	-2	-2	+4
H60-H50	25	+5	+2	+2	+5	+3	+2	-2	-3
H50-H40	20	+10	+5	-5	-10	+2	+1	-1	-2
H40-H30	15	+5	+5	-5	-5	+1	+1	-1	-1
H30-H20	10	+5	+5	-5	-5	+1	0	0	-1
H20-H10	5	+4	+2	-2	-4	0	0	0	0
H10-peak	0	0	0	0	0	0	0	0	0

Other factors in addition to elevation influence the magnitude of snow accumulation and the pace of its melt. Aspect plays a strong role in shaping melt rate both during the freshet and during the winter period of snow accumulation. Warm aspects enhance melt rates and cool aspects slow them down. The consequences vary by elevation band and preliminary estimates are provided in Table 4.3-1 where aspect is grouped according to the following classes:

N – 270-30	SE – 120-150	E – 60-120	NW – 300-330
S – 150-210	SW – 210-240	W – 240-300	NE – 30-60

Hillslope gradient further modifies the ratings by changing melt rates and exposing sites to sun during the accumulation period and potentially modifying wind interactions. On north aspects, increased slope angle works to shelter the snow from the solar radiation thereby increasing within-winter snow accumulation and reducing melt rates during the spring freshet. The opposite occurs on hot aspects. These influences are grouped and quantified as shown in Table 4.3-1.

Using these topographic attributes, the adjustment ratings in Table 4.3-1 are applied to the inherent ratings of each site to provide a final rating regarding the potential to augment the hydrograph's peak flow. Within the elevation bands, these ratings are applied across the watersheds to polygons of relatively uniform slope and aspect resulting in a spatial distribution of adjusted ratings. Polygons from the Vegetation Resource Inventory (VRI) are used as a base, split by the elevation bands shown in Table 4.3-1. Polygon aspect is generated from the Digital Elevation Model (DEM) using a spatial join. Manual corrections to polygons were performed by overlaying the data on the LiDAR bare earth hillshade and LiDAR elevation model, splitting as needed when the polygons contained more than one dominant aspect. The resultant polygons then had the average slope calculated from the DEM using the functional surface tool. Slivers resulting from the processes were cleaned by merging them with neighbouring polygons.

Due to the preliminary nature of these ratings, they are further grouped into five classes (VH-H-M-L-VL) as shown on the map. The individual polygon areas are distributed into these classes following the adjusted ratings and with a 20% allocation of watershed area within each class. In subsequent work, changes in how elevation, aspect and slope are quantified and grouped can be considered to improve the spatial distribution of the adjusted ratings. Such methodological enhancements can follow potential advances in integration of the science of watershed-level snow accumulation and melt.

Disturbance modifies the inherent PFA ratings shown on Map 9. Forest loss increases snow accumulation and melt rate and roads create openings and enhance runoff efficiency. The effect of forest loss can be quantified in terms of Equivalent Clearcut Area (ECA) reflecting the level of hydrologic recovery of a disturbed stand. Based on revised curves developed in the southern Interior of British Columbia (Winkler and Boon, 2015), Table 4.3-2 indicates how ECA varies in relation to hydrologic recovery, expressed as a function of tree height. Roads and clearings for transmission lines present permanent ECA of 100%. On Map 9, only openings due to roads, cut blocks and transmission lines are shown. At a future version of the map, openings can be shown due to fires, insects, and other causes and a detailed ECA analysis included.

Table 4.3-2. Disturbance Reductions for Forest Openings due to Hydrologic Recovery

Tree Height (m) (average dominant/codominant)	Hydrologic Recovery[1] (%)	Equivalent Clearcut Area[2] (%)
< 4.3	0	100
4.3	10	90
5.6	20	80
6.7	30	70
7.6	40	60
8.6	50	50
9.8	60	40
11	70	30
12.9	80	20
15.8	90	10
> 25.0	100	0

1 – Rates of hydrologic recovery based on Winkler and Boon (2015).

2 – Small openings (under three tree heights – Golding and Swanson, 1978) may have reduced ECA due to modified rates of snow accumulation and melt.

Disturbances may reduce or increase the PFA rating depending on the type of disturbance (shape/size) and its topographic location in the watershed, as introduced in Section 4.3.10 and in Table 4.3-4 in the context of moderating low flows. Future versions of this map may provide additional tools to interpret the effects of disturbance relative to the inherent PFA rating.

4.3.10 Map 10 Low-Flow Moderation

The Low-Flow Moderation (LFM) map shows watershed areas expected to be important for supporting late-summer low flow. Four elements are shown on the map.

4.3.10.1 Areas Significant for Slow Groundwater Recharge and Late-Summer Snowmelt

Table 4.3-3 provides ratings of the relative potential of sites to provide slow groundwater recharge and to act as refuge sites for late-summer snow melt. These basic inherent ratings have been developed based on professional judgment of a synthesis of scientific findings related to snow accumulation and melt, as discussed in Section 2.3. They are provided here as preliminary values, subject to revision and field verification in future work. Locations with a higher rating are assessed to be of higher value in supporting delayed snowmelt, thereby promoting late-summer low flow. Also, the higher the rating, the more important it is that the areas should remain forested (especially under old forests), and without blading of the soil surface. Roads and skid trails intercept and concentrate the downslope movement of water, causing it to leave the watershed more rapidly than where water movement occurs on natural, undisturbed slopes. Compacted surfaces of roads and skid trails also concentrate water and hasten its exit from the watershed.

Table 4.3-3. Basic Inherent Ratings of Low-Flow Moderation Potential

	Basic Inherent Rating (Natural Forest Cover)	Adjustments for certain aspects				Adjustment for slope gradient >70% (half this if 30-70% slope)			
Elevation Band (by area)	Mixed aspects (E/W) AND gentle slopes (<30%)	Hot S	Warm SE/SW	Cool NW/NW	Cold N	Hot S	Warm SE/SW	Cool NW/NW	Cold N
Outlet-H90	0	0	0	0	0	0	0	0	0
H90-H80	0	-3	-2	+2	+3	-1	-1	+1	+1
H80-H70	5	-4	-3	+3	+4	-2	-1	+1	+2
H70-H60	10	-7	-4	+4	+7	-3	-2	+2	+3
H60-H50	15	-10	-6	+6	+10	-4	-3	+3	+4
H50-H40	20	-13	-8	+8	+13	-5	-3	+3	+5
H40-H30	30	-16	-9	+9	+16	-6	-4	+4	+6
H30-H20	40	-19	-11	+11	+19	-7	-4	+4	+7
H20-H10	50	-22	-13	+13	+22	-8	-5	+5	+8
H10-peak	65	-25	-14	+14	+25	-10	-6	+6	+10

Disturbance modifies the inherent LFM ratings shown on Map 10. Forest loss increases snow accumulation and melt rates and roads create openings and enhance runoff efficiency. The effect of forest loss is quantified partially on the map in terms of ECA reflecting the level of hydrologic recovery of a disturbed stand. Based on revised curves developed in the southern Interior of British Columbia (Winkler and Boon 2015), Table 4.3-2 indicates how ECA varies in relation to hydrologic recovery, expressed as a function of tree height. Roads and clearings for transmission lines present permanent ECA of 100%. On Map 9, only openings due to roads, cut blocks, and transmission lines are included. In a future version of the map, openings can be shown due to fires, insects, and other causes.

On balance, disturbances only decrease the LFM ratings because they reduce the opportunity to sustain low flows over the long-term and in the greatest number of circumstances, depending on the type of disturbance and its topographic location in the watershed. Table 4.3-4 illustrates an exception to this whereby small openings of the appropriate shape and orientation may provide improved conditions for low flow. Future versions of this map may provide additional tools to interpret the effects of disturbance relative to the inherent LFM rating. For example, Table 4.3-4 could be used to provide a preliminary estimate of how the ratings change when openings are created.

Table 4.3-4. Disturbance Adjustments for Ratings of Low-Flow Moderation Potential

Elevation Band (by area)	Disturbance Adjustments[1] (openings[2] due to cutblocks, roads, insects, fire, wind, etc.) (subject to % recovery for disturbed stands, based on tree height)	Disturbance Adjustments for Small Openings[1] (subject to % recovery for disturbed stands, based on tree height)	
		1-3 H[2]	<1 H[2]
Outlet-H90	0	0	0
H90-H80	0	0	0
H80-H70	-5	0	+2
H70-H60	-10	-5	+5
H60-H50	-15	-8	+8
H50-H40	-20	-10	+10
H40-H30	-20	-10	+10
H30-H20	-20	-10	+10
H20-H10	-20	-10	+10
H10-peak	-20	-10	+10

[1] Following Golding and Swanson (1978), disturbance adjustments are reduced for small openings (under 3 ha) with an E-W dimension of under one tree height.

[2] H = prevailing tree height of canopy in adjacent stands.

4.3.10.2 Wetlands and Lakes

Lakes and wetlands contribute directly to baseflows and need to be protected from disturbance and from extreme summer heating. These areas appear on the map along with a 50-m buffer to provide shading of the edges of lakes and wetlands, and to support them with important nutrient inputs. Where known, the source areas for these waterbodies should also generally remain undisturbed.

4.3.10.3 Riparian Areas

Riparian vegetation is important for many reasons, including maintaining connectivity, protecting significant areas of high biodiversity, and protecting important ecosystem processes. Riparian areas are also potentially important for moderating low flows. The borders of waterbodies protect the waterbody itself and protect its banks from disturbance and erosion thereby helping to reduce dewatering (and surface low flows) and shading the waterbody surface, thereby reducing evaporation. Moisture from transpiration moves around in intact riparian forests, keeping the humidity up and slowing evaporation, both in the forest and from the adjacent stream. Waterbodies need protection from disturbance and from extreme summer heating so that they can contribute the maximum possible to low flows. Riparian trees also transpire, potentially reducing baseflow.

Riparian buffers are established on all the streams to protect low flows and general water quality when flow is at its lowest. Until appropriate field data are available on stream size, the buffers are established according to stream order as follows:

- Third and fourth order streams – 50 m buffer (on each side)
- Second order streams – 30 m buffers (on each side)
- First order streams – 15 m (on each side)

Although set as a fixed buffer on the map, these can instead be used as a general budget for riparian reserves, with the actual width at any specific location established in relation to site characteristics for each reach (e.g., floodplain width, gully presence, bedrock banks, etc.). Some areas may require 100 m and others 10 m. As necessary, it is proposed that the buffer requirements be refined through field work before activities can proceed according to the above table.

4.3.10.4 Old Forests

Open stands with large trees are more likely to accumulate and maintain more snow for longer periods (Teich et al. 2022). Older stands are more likely to possess this structure, thereby providing additional water storage and release properties supportive of baseflows. As the climate warms and the higher elevations (where most precipitation inputs occur) are increasingly subject to warm-weather events, forest crowns may intercept moisture and help retain it for absorption by the forest floor. Older forests also tend to have larger reservoirs of decayed wood able to store and filter water, cool temperatures, and shade slow evaporation. Biological legacies, like large old trees and large fallen trees, in young, natural forests also play important water conservation roles.

4.3.10.5 Potential Groundwater Interception (Laird)

Shallow subsurface flow can be intercepted through construction of roads and trails, potentially never returning to the groundwater. Where terrain mapping is sufficiently detailed, it may be possible to provide a preliminary assessment of the relative likelihood of cutbanks intercepting shallow subsurface flow through construction of roads and trails. In this context, roads and trails are assumed to have a combined width of the running surface and ditchline of 3-6 m in mineral soil (narrow out-sloped roads may decrease the potential impact). Where surface soils are thin and coarse, where cutslopes are constructed on steep uniform slopes, and in various other circumstances, a high proportion of shallow horizontal flow may be intercepted by roads and trails. Conversion of subsurface flows to surface flows in ditchlines increases the speed of runoff, reducing the contribution of groundwater to late summer low flows, thereby reducing the capacity of the watershed to moderate low flows.

The likelihood for intercepting subsurface water depends on a range of factors provided in the terrain mapping available for Laird watershed. To map this vulnerability, relevant factors are assembled in a preliminary rating system as shown in Table 4.3-4. Each factor is assessed then summed up using the indicated weightings. Groundwater interception potential is rated using the following classes: 0-19 (VL), 19-32 (L), 32-38 (M); 38-44 (H); 44-60 (VH). The low, moderate, high, and very high classes are shown on the map (stippling and hatching on top of the shading). The preliminary result illustrates the relative vulnerability across the watershed of intercepting subsurface flow when disturbing the surface soils. (This map remains preliminary because it requires further consideration and revision within the GIS and potentially field reviewed/verified.) Where roads and trails are considered within areas of high and very high vulnerability, they should be built with minimal soil disturbance (e.g., temporary roads on compactible snow).

Table 4.3-4. Factors Related to Interception of Shallow Groundwater Flow

		Rating					
Site Factors	**Weight**	**0**	**1**	**2**	**3**	**4**	**5**
Moisture regime	3	VX	SX	SM	M	SHG	HG,SHD
Slope Gradient (%)	2	<20	20-30	30-50	50-60	60-70	>70
Depth to restricting layer (cm)	2	>150	120-150	90-120	60-90	30-60	0-30
Slope length and uniformity	2	Short broken		Long broken	Short uniform		Long uniform
Meso slope position	2	Crest	Upper	Toe		Mid	Lower
Slope length up (m)	1	0-200	200-400	400-600		600-800	>800
Coarsest texture across all depths	1	C,SC,SiC	CL,SCL,SiCL		L,SiL,Si,FSL		S,LS,SL

4.3.11 Map 11 Unique and Rare Habitats

Unique and rare habitats are small portions of a watershed but are essential to protect in order to maintain biodiversity and species-at-risk. As comprehensive surveys for at-risk species and ecological communities have not been completed in the focal watersheds, these maps identify the known and potential unique and rare features. Mapped features include:

- Potential at-risk ecological communities modelled using the VRI mapping and a search of the BC CDC for listed communities in the Bioegeoclimatic Units that the maps cover.
- Critical habitat mapping for the endangered Whitebark pine (*Pinus albicaulis*) was obtained from the Whitebark Pine Ecosystem Foundation (2014) and modified using occurrence data collected during the 2021 field season.
- Wetlands, as per provincial data sets. As wetlands are uncommon and not extensive in these watersheds, they are important habitat features to protect.
- Species-at-risk observations made during the 2021 field season included three blue-listed species; banded tigersnail (*Anguispira kochi* ssp. *occidentalis*), mountain moonwort (*Botrychium montanum),* and scaly chanterelle (*Turbinellus floccosus*).
- In the Glade Watershed, moderate and high productive forests are relatively uncommon. The VRI Site Index was used to indicate the location of the most productive forests in the watershed.

4.3.12 Map 12 Hydrologic Sensitivity

The Hydrologic Sensitivity map assembles information from the four hydrology maps (7-10) into a set of ranked Water Conservation Areas. The five areas reflect graded priorities for protection resulting from the sensitivity of the watershed's hydrologic regime to disturbance in these areas. Table 4.3-5 lays out the components of each map that contribute to each Water Conservation Level. As the Water Conservation Levels rise from 1 through 5, the hazards to water in that area increase as do the limitations on development in order to maintain full hydrologic function. Equivalently, from levels 1 to 5, development costs rise, and opportunities decline. See Section 2.3.3 for further discussion.

Table 4.3-5. Composition of Water Conservation Levels Shown in Map 12

	Map 7		Map 8			
HPLN Groupings	**Laird**	**Glade**	**Laird**	**Glade**	**Map 9**	**Map 10**
Water Conservation Level 1	SEYP – L,VL	SEH – L,VL	TSH-VL (all) TSH-M with DP-VL	SSH[1] – VL	PFA–VL	LFM-VL
Water Conservation Level 2	SEYP – M	SEH – M	TSH-L (all) TSH-M with DP[1] – L	SSH[1] – L	PFA–L	LFM-L
Water Conservation Level 3	SEYP – H	SEH[1] – H	TSH-M with DP[1] – M TSH-H with DP L,VL	SSH[1] – M	PFA–M	LFM-M
Water Conservation Level 4	SEYP – VH	SEH[1] – VH	TSH-M with DP[1] – VH,H TSH–H with DP1 – M	SSH[1] – H	PFA–H	LFM-H
Water Conservation Level 5			TSH–H with DP[1] – VH, H TSH[1] – VH (all)	SSH[1] – VH	PFA–VH	LFM–VH; wetlands Riparian buffers

[1] *SEYP=Surface Erosion Yield Potential; SEP = Surface Erosion Hazard; TSH=slope stability hazard; DP-delivery potential*

4.3.13 Map 13 Protected Landscape Network

An explanation of the reasoning behind the *preliminary* protected landscape network (PLN) design is contained in this section. The PLN design is considered to be preliminary for three reasons:

- overlapping components of the PLN need to be checked with a GIS analysis to be sure that each component is adequately covered by the PLN, and the GIS hierarchy provides the best map presentation,
- components of the PLN need to be field checked, and
- the PLN needs to be checked for adequate inclusion of components of the Hydrologic Sensitivity (Map 12). Protection of hydrologically sensitive areas is an overarching need for the PLN, both because both watersheds are community water sources, and the imminent threat of climate disruption to water conservation.

Within the process of nature-directed planning, protected landscape networks are a mid-spatial scale network of ecological reserves. PLNs are situated spatially between protected area networks (PANs) for multiple watersheds and large landscapes, and protected ecosystem networks (PENs) for sites and patches that comprise a watershed.

Protection of water is the priority in this PLN design. This means protection for both water quantity, quality, and timing of flow (especially at the outlet) AND the maintenance of all the species and communities that depend on intact aquatic ecosystems and natural environmental flows. In this way, the PLN reflects both hydrology and ecology because, ultimately, they are inseparable.

Overall, the design and implementation of a PLN is needed to protect and maintain ecological integrity and resilience throughout the watershed. These functions are particularly important to mitigate and adapt to the climate emergency and biodiversity crises. As such, PLNs offer a buffer against the effects of climate disruption, and potential climate change refugia.

PLNs provide the *ecological framework* necessary to protect, maintain, and, where necessary, restore:

- natural water quality, quantity, and timing of flow,
- a diversity of habitats for both species and ecosystems,
- the full range of ecosystem function and processes,
- connectivity throughout the PLN and between adjacent PLNs and/or PANs,
- unique and/or rare habitat types,
- ecologically limited, ecologically sensitive sites, and
- representative ecosystem types found throughout the area encompassed by the PLN.

Within the framework of protection afforded by the PLN, ecologically responsible human activities may occur within the finest scale network of ecological reserves—PENS. The location and types of activities are decided by a process that selects *human use areas*. This process is community-based, informed by the PLN, and constrained by the overarching requirement to protect ecological integrity. A human use area selection process was not carried out in this initial NDS plan. Thus, the plan does not contain specific recommendations for the locations of human uses. Before that step is taken, uncertainties about the PLN, described earlier, need to be clarified and the PLN revised accordingly.

4.3.13.1 Protected Landscape Network - Glade

The components of the preliminary PLN are shown on Map 13 in the GIS hierarchy used in their depiction on the map. That same GIS hierarchy is reflected in the order of the list below, and in the Map 13 legend. The components of the preliminary PLN for the Glade watershed and the general reasons for their inclusion are:

- species at risk observations for Banded Tiger Snail, Scaly Chanterelle, and Whitebark Pine—unique and rare habitats,
- moderate productivity (site indices 17-19)—representative ecosystems for watershed. Needs to be checked with species and age strata to be sure that representative ecosystems are fully captured by the PLN, including those found in “other components”,

- high productivity (site indices 19-23)— rare ecosystems found only in the extreme lower portion of the watershed, just above and below where Glade Creek crosses under the powerline,
- whitebark pine habitat—unique and rare habitats, upper elevation water conservation,
- open, dry site Douglas-fir and Ponderosa pine—unique and rare ecosystem type,
- potential blue-listed brushlands (low elevation: *Gb03 Ninebark—Oceanspray—Bluebunch wheatgrass*)—unique and rare ecosystem type,
- old forest—highest quality water, conservation of water, highest levels of biodiversity, and largest stores of carbon,
- riparian ecosystems—water quality, connectivity throughout watershed, biodiversity hot spots,
- very high and high surface erosion hazard—ecological limits, ecological sensitivity, and contributes to hydrologic sensitivity,
- very high and high slope stability hazard—ecological limits, ecological sensitivity, and contributes to hydrologic sensitivity,
- general sensitivity, 40-60% slopes—ecological limits and ecological sensitivity on moderate to steep slopes. Steeper slopes greater than 60% are included within the *high and very high slope stability hazard* classes,
- water conservation level 5—highest level of hydrologic sensitivity to development,
- water conservation level 4—high level of hydrologic sensitivity to development, and
- water conservation level 3—moderate level of hydrologic sensitivity to development.

The PLN needs to be checked with species and age strata to be sure that representative ecosystems throughout the watershed are fully captured by the PLN, including those found in “other components”.

Many of the components of the PLN overlap, which reinforces their need to be part of the framework for ecological protection of the watershed. By reviewing the percent coverages for the watershed (Table 4.3-6), the broad extent of the overlap becomes clear.

4.3.13.2 Protected Landscape Network - Laird

The components of the preliminary PLN are shown on Map 13 in the GIS hierarchy used in their depiction on the map. That same GIS hierarchy is reflected in the order of the list below, and in the Map 13 legend. The components of the preliminary PLN for the Laird watershed and the general reasons for their inclusion are:

Table 4.3-6. Components of the Protected Landscape Network for Glade

PLN Components	Hectares	% of Watershed (3,018 ha)
SI 19-23 Moderate Productivity	644	21%
SI 17-19 High Productivity	23	1%
Whitebark Pine Habitat	59	2%
Open Douglas-fir, Ponderosa Pine Nutrient Poor (ICHdw1/102)	27	1%
Potential Blue-listed Brushland: Gb03 Ninebark—Oceanspray—Bluebunch wheatgrass	165	5%
Old Forest	606	20%
Riparian Ecosystem	958	32%
Surface Erosion Hazard—very high and high	916	30%
Slope Stability Hazard—very high and high	1,218	40%
General sensitivity 40-60% slope	1,051	35%
Water Conservation level 5 (Low Flow Moderation, Peak Flow Augmentation, Slope Stability Hazard)	1,248	42%
Water Conservation level 4 (Low Flow Moderation, Peak Flow Augmentation, Slope Stability Hazard, Surface Erosion Hazard)	2,449	81%
Water Conservation level 3 (Low Flow Moderation, Peak Flow Augmentation, Slope Stability Hazard, Surface Erosion Hazard)	2,931	97%

- whitebark pine habitat—unique and rare habitats, upper elevation water conservation,
- species at risk observations for Banded Tiger Snail, Mountain Moonwort, and Whitebark Pine—unique and rare habitats,
- wetlands—carbon storage, water quality and conservation, biodiversity hot spots,
- high productivity (site indices 19-23)— representative ecosystems for lower half of watershed,
- old forest—highest quality water, conservation of water, highest levels of biodiversity, and largest stores of carbon,
- riparian ecosystems—water quality, connectivity throughout watershed, biodiversity hot spots,
- high and very high surface erosion hazard—ecological limits, ecological sensitivity,

- high and very high slope stability hazard—ecological limits, ecological sensitivity,
- general sensitivity, 40-60% slopes—ecological limits and ecological sensitivity on moderate to steep slopes. Steeper slopes are included within the *high and very high slope stability hazard* classes,
- water conservation level 5—highest level of hydrologic sensitivity to development,
- water conservation level 4—high level of hydrologic sensitivity to development, and
- water conservation level 3—moderate level of hydrologic sensitivity to development.

The PLN needs to be checked with species and age strata to be sure that representative ecosystems throughout the watershed are fully captured by the PLN, including those found in "other components".

Many of the components of the PLN overlap, which reinforces their need to be part of the framework for ecological protection of the watershed. By reviewing the percent coverages for the watershed (Table 4.3-7), the broad extent of the overlap becomes clear.

Table 4.3-7. Components of the Protected Landscape Network for Laird

PLN Components	Hectares	% of Watershed (1,698 ha)
Whitebark Pine Habitat	147	9%
Wetlands	3	<1%
SI 19-23 High Productivity	439	26%
Old Forest	998	59%
Riparian Ecosystems	369	22%
Surface Erosion Hazard—very high and high	628	37%
Slope Stability Hazard—very high and high	1,329	78%
General sensitivity 40-60%	542	32%
Water Conservation Level 5 (Terrain Stability Hazard, Landslide Induced Sediment, Low Flow Moderation, Peak Flow Augmentation)	1,257	74%
Water Conservation Level 4 (Terrain Stability Hazard, Landslide Induced Sediment, Low Flow Moderation, Peak Flow Augmentation, Sediment Yield Potential)	1,436	84%
Water Conservation Level 3 (Terrain Stability Hazard, Landslide Induced Sediment, Low Flow Moderation, Peak Flow Augmentation, Sediment Yield Potential)	1,798	106%

4.3.14 Map 14 Projected Bioclimates in the 2080s

Analyses of projected shifts in bioclimates, are shown in Section 2.4 for the 2080s, demonstrating three potential futures based on three GCM and emission scenarios (Utzig 2012). **The bioclimates shown are broad groupings of vegetation zones – NOT individual BEC units; the names and abbreviations are indicated in the discussion below.**

Map 14 presents three scenarios to emphasize that there is considerable uncertainty in how climate disruption will manifest. As illustrated in the graph in the upper right of Map 14, these scenarios were selected[5] to represent the outer limits of over 40 scenarios run for BC as a whole. The variability in the outcomes of the scenarios result from differences in individual GCMs, differing assumptions about how Earth systems will respond to increased GHGs in the atmosphere and assumptions about the rate of GHG emissions over the coming decades. Using the 1961-90 normals as a baseline, the vertical axis of the graph is the projected increase in annual BC temperature in °C and the horizontal axis is the projected change in annual precipitation in percent. Note that all the scenarios project an increase in temperature, and almost all project an increase in annual precipitation (but not necessarily summer precipitation). The actual outcome is likely to be somewhere between these three scenarios.

Current Mapping: The "Current Mapping" in the upper left of Map 14 (in both Sections 5 and 6) shows the present distribution of broad vegetation zones across the West Arm region based on Biogeoclimatic Mapping (BEC) by BC MFLNRORD (Mackillop et al*.* 2018). In the latest BEC mapping, the lowest elevations of the West Arm and lower Kootenay River is dominated by Grand Fir (GF) bioclimates (ICHxw). The mid elevations grade into Dry and Moist Interior Cedar Hemlock (DICH – ICHdw1, MICH – ICHmw4) bioclimates as the climate becomes wetter and cooler with elevation. In the upper elevation the bioclimates change to Wet Subalpine Forest (WSF – ESSFwh3) and Alpine Parkland types (AP – ESSFwhp) at upper elevations.

The following sections summarize projected bioclimate shifts for the West Arm region:

> **Warm/Moist Scenario:** This scenario shown in the lower left portion of Map 14 represents modest increases in annual temperature and precipitation. In this scenario the lower elevations generally shift Ponderosa Pine (PP) bioclimates, except for the lowest elevations west of Nelson where the valley bottom shifts to Grassland/Steppe (GS) bioclimates. The mid and upper elevations of Glade Creek are mainly Dry Interior Cedar-Hemlock (DICH). The mid elevations of Laird Creek include a mix of Dry Interior Cedar-Hemlock (DICH) and Transitional Coast-Interior Hemlock (TCH). The uppermost elevations of Laird include areas of Wet Interior Cedar-Hemlock (WICH).

[5] The scenarios were recommended by the Pacific Climate Impacts Consortium (PCIC) for use in exploring the range of potential climate outcomes for BC, for further information on the scenarios and modelling see Utzig (2012).

Hot/Wet Scenario: With this scenario, shown in the lower right section of Map 14, larger increases in annual precipitation and moderate increases in temperature, lead to a different mix of projected bioclimates for both Laird and Glade Creeks. The lowest elevations of both creeks shift to Grand Fir (GF) bioclimates, while the mid elevations shift to Dry Montane Spruce (DMS) types. The upper elevations in both cases become dominated by Transitional Coast-Interior Hemlock (TCH).

Very Hot/Dry Scenario: Large increases in temperature and little change in annual precipitation cause this scenario to result in major shifts in bioclimates (upper right of Map 14). The lower elevations shift to non-forested Grassland/Steppe (GS) bioclimates, while the mid and upper elevations are dominated by Ponderosa Pine (PP) bioclimates, with minor areas of Wet Douglas-fir (WDF).

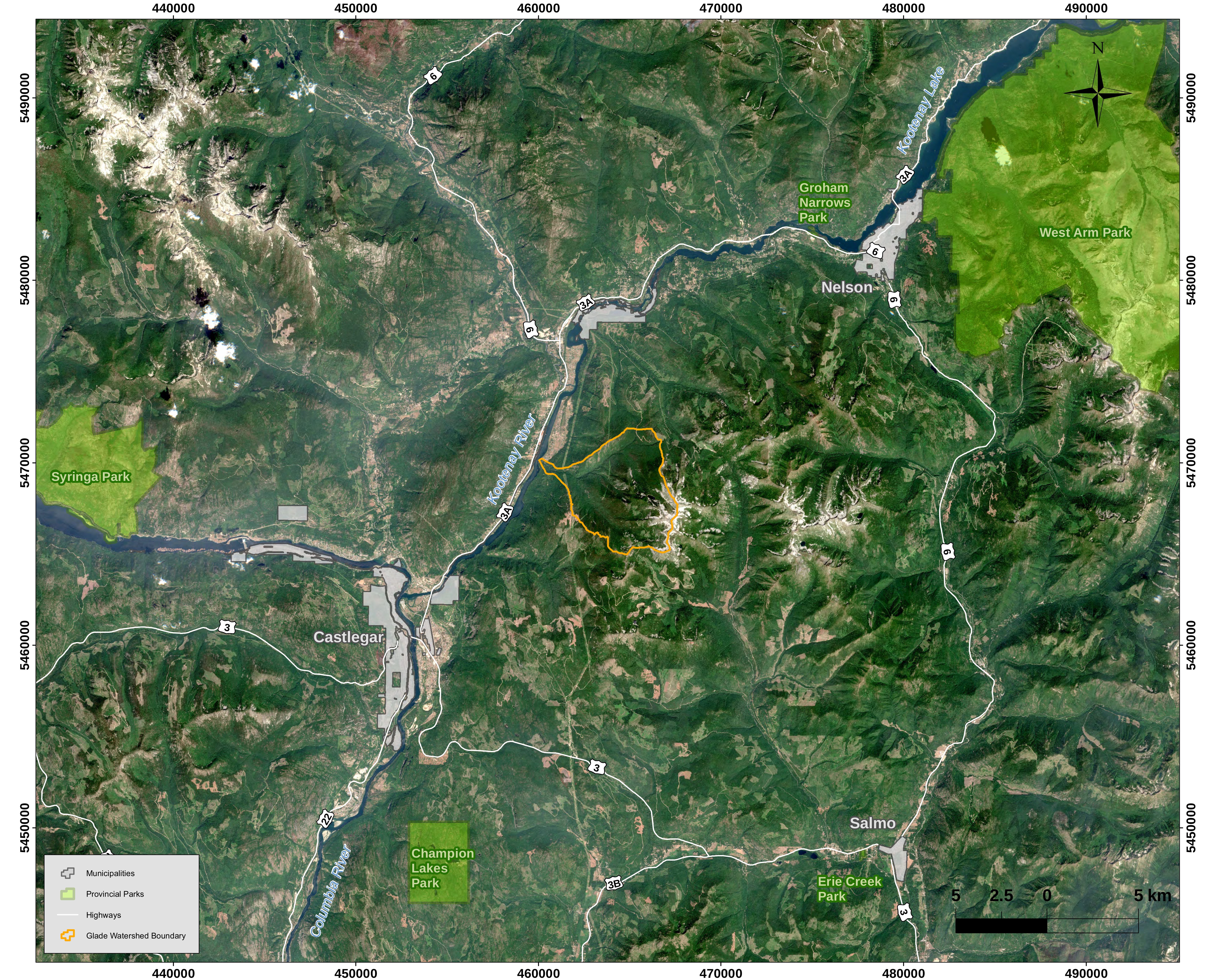
Although there are significant differences between the scenarios, there are also areas of agreement. The areas of agreement are projections that can be assumed to have a high likelihood of occurrence, given that all scenarios point in that direction. The projected convergent outcomes include bioclimate shifts where:

- the lower and mid elevations generally shift to warmer drier bioclimates ranging from Grassland/Steppe to Grand Fir forests – the main difference being how hot and dry;
- ESSF subzones generally disappear; upper elevations shift from Wet Subalpine Forest to some type of cedar-hemlock forest (Wet Interior Cedar/ Hemlock or Transitional Coastal Interior Hemlock), or possible Ponderosa Pine savanna with the Very Hot/Dry scenario.

These shifts in vegetation communities are unlikely to be a smooth transition but are more likely to occur after a stand-replacing event such as wildfire, windthrow, drought, or pest infestation. Following the stand-replacing disturbance, conditions may not be suitable for re-establishment of historic vegetation and new species will begin to establish – **IF** there is a suitable seed source. Many of the projected bioclimates are located hundreds or even thousands of kilometres from the West Arm, so there is not a high likelihood of species in those areas shifting their ranges to the West Arm in the next six decades. Without a suitable seed source, the present vegetation shift may be stalled, leading to a prolonged period of invasive species or weedy shrub/herb early-seral communities. Reductions in stand density, removal of ladder fuels, and reforestation with fire-resistant tree species will help to reduce forest vulnerabilities and increase ecosystem resilience to drought and fire (Utzig 2019) but eliminating GHG emissions as soon as possible is the only real alternative for limiting impacts of climate disruption.

The projected bioclimate shifts presented in Map 14 are based on climate projections applied to the same grid points as in Section 2.4.2 (Figure 2.4-7), but with outputs from the IPPC AR4 rather than AR6. The data originates from older versions of GCMs than those used in Section 2.4.2, but represent a comparable range of outputs to those of the 13 GCM ensemble used in Section 2.4.2. For a detailed discussion of the methods for creating the maps refer to Utzig (2012).

5. GLADE WATERSHED MAPS



Map 1
Glade Watershed Landscape Context

Relatively intact watershed in a fragmented landscape provides opportunity for landscape level protected area and climate change refugia. Full protection of the watershed is encouraged because it is part of the red-listed Interior Wet Belt ecosystem.

Photo 1. Intact older forests

The Glade watershed contains large areas of relatively intact forests, including older forests and old veterans. Contiguous forest stands and intact watersheds are essential for providing habitat to a wide range of flora and fauna, along with the plethora of ecosystem benefits they provide, including pure water in moderate flows throughout the year; and carbon sequestration and storage.

Photo 2. Clear-cuts and tree plantations within watersheds

The landscape around the watershed is highly fragmented by logging, roads, transmission lines and other human developments. A large portion of the regional landscape's forest cover includes historic logged areas that naturally regenerated, and more recent clearcuts that were converted to tree plantations, which have a significantly different composition and structure than natural forests.

Photo 3. Intact forests and habitat

Intact, natural forests are also referred to as primary forests. All forests that have not been significantly altered by industrialized society's activities are primary forests. Intact natural forests provide high quality water in moderate amounts throughout the year. Water management by intact, natural forests improves as the forest ages. Thus, old-growth primary forests provide the best water.

Photo 4. Creeks and water quality

Intact watersheds are essential for pure and abundant water supplies. Natural ecosystem processes help to regulate water flow, capturing early season snow melt and slowly releasing it through the watershed in summer and fall. Intact systems also provide high quality water, buy naturally filtering it through decayed fallen trees and natural soil profiles.

Projection: NAD 83 UTM 11N
Scale: 1:15,000
Date: March 2022
Base Data: Province of BC; BC Data Catalogue & LidarBC

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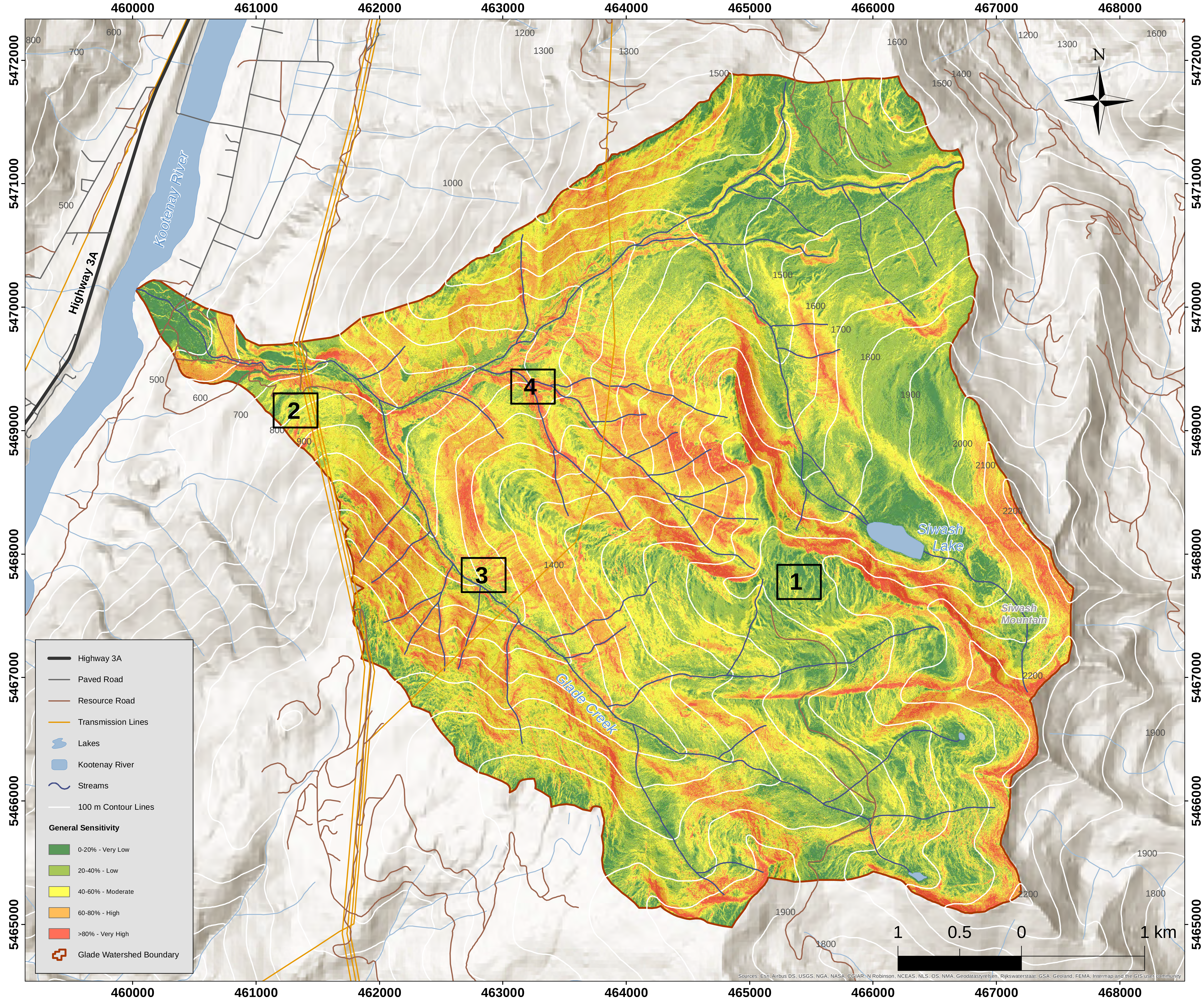


Map 2
Glade Watershed Topography and General Sensitivity

As slope gradient increases, the need for caution in decision making increases. Factors additional to slope gradient need to considered to assess terrain sensitivity - landform, soil characteristics, moisture, etc.

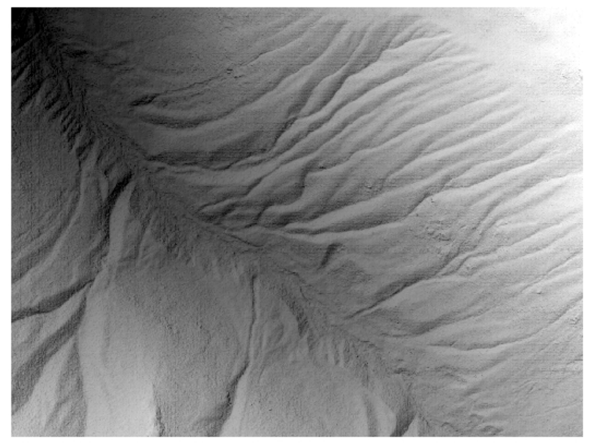
Photo 1. Low Sensitivity: Gentle Subalpine Slope

Low slope gradient, unbroken slopes that are mesic, or medium moisture are generally stable and offer the most options for Nature-directed activities. However, if these slopes are either wet or dry they display ecological limits that preclude many activities.

Photo 2. Moderate Sensitiviety: Mid-slope Forested Gully

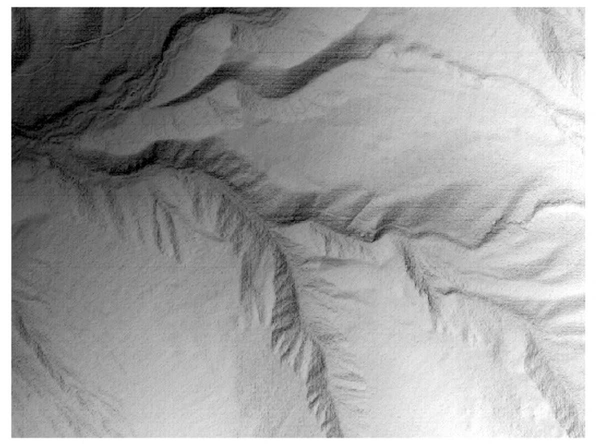
Moderate slopes, with slope gradients that range from 40-60% are on the edge between stable areas and unstable areas within a precautionary Nature-directed framework. On terrain within the lower end of this class, careful design, layout, and operations that protect the soil surface and avoid cutting into the slope are possible within ecological limits. However, terrain at the upper end of this class or gullied terrain generally preclude activities, like roads and logging.

Photo 3. High Sensitivity: Lower Slope Gullied Terrain



When disturbed, these very steep slopes (60-80%) are prone to surface erosion that delivers sediment to lower slopes and water courses below. This tendency is magnified when the slope is dissected by gullies, creating a broken, steep slope condition. Depending upon landform and soil types, and site moisture conditions these slopes may be the source of landslides.

Photo 4. Extreme Sensitivity: Deeply Incised Gullies



Extreme slopes (>80%) are beyond reasonable ecological limits for development activities, and precluded from such activities. This extreme ecological and physical sensitivity is heightened when the terrain is broken by gullies with steep side slopes. In forested landscapes, full tree cover is important to maintain on these slopes to insure their integrity.

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Map 13: Protected Landscape Network (PLN)
Map 14: Projected Bioclimates for the 2080s

Projection: NAD 83 UTM 11N
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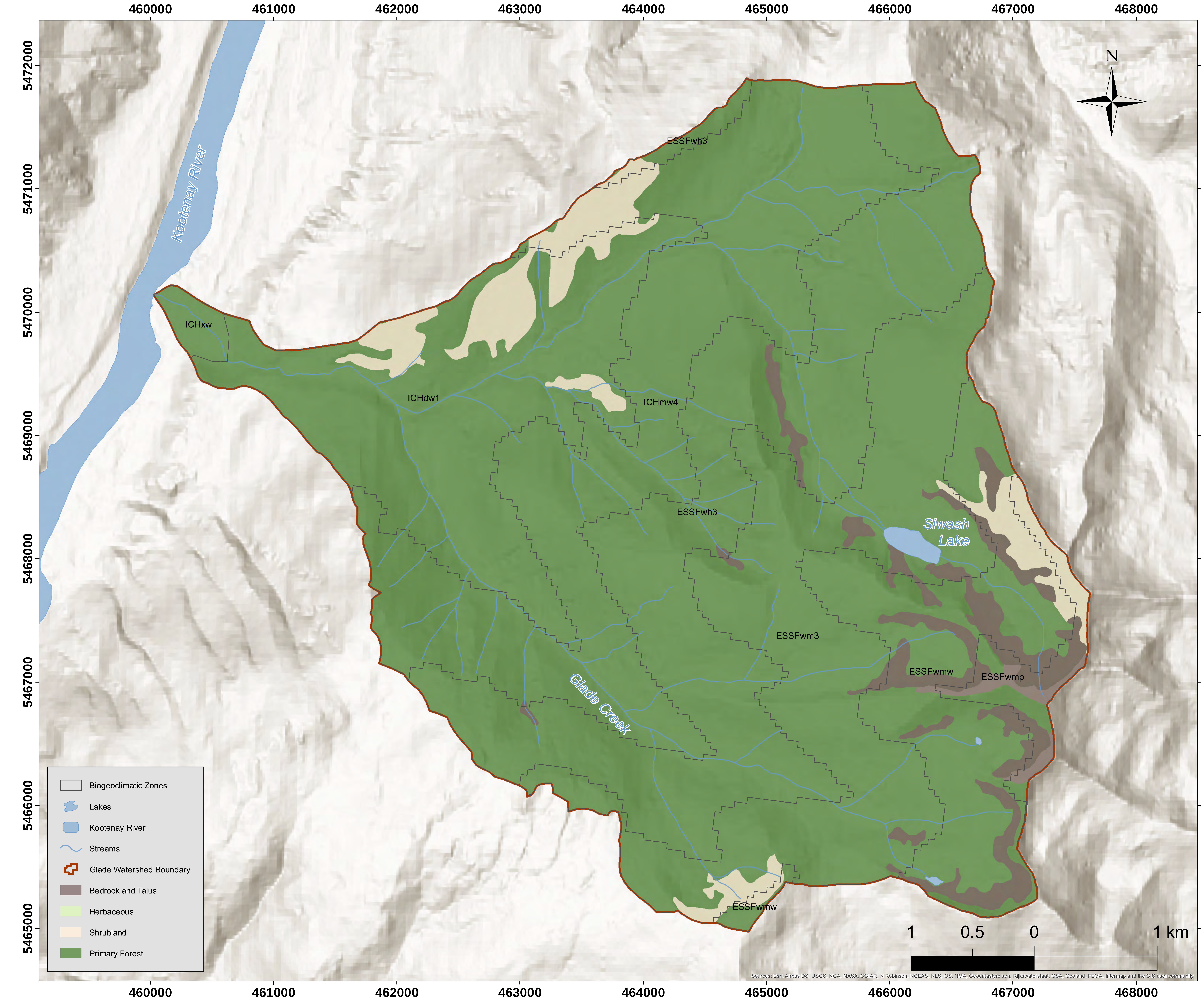
Map 3
Glade Watershed Natural Character



Primary forests, particularly old-growth forests, conserve and manage water far better than second-growth forests. Plantation "forests" from logging are ineffective in water conservation. These forests need to be grown well past their rotation age in order to adequately conserve water, particularly in the climate

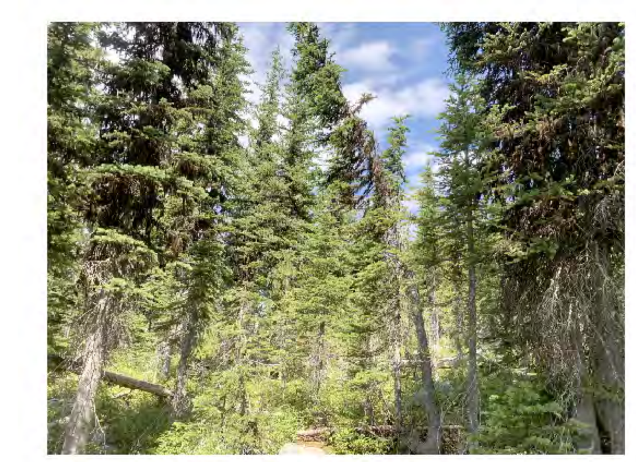
Photo 1. Younger forests

Without human intervention, younger forests would be expected to occupy small portions of most of the watershed. Natural disturbances such as fire, landslides, and insect outbreaks in a healthy natural ecosystem typically result in small areas of disturbance that enhance and maintain bodiversity. The large even age young to mature stands that dominant a large portion of the landscape are a reflection of the massive modification and interruption to natural process that have occurred since the advent of industrial forestry.

Photo 2. Mature forests with old vets

Early industrial era logging was limited by the available technology and restricted by difficult terrain. As a result, much of the 100+ year old forestry was focused on high-grading, i.e. removal of the largest and best quality trees. Since this work was mainly done by hand, a large portion of the smaller trees and saplings were not cut and were free to grow into the mature forests we have today. These older logged areas frequently have large old trees, termed veterans or vets, that were not cut and now have a significant ecological value.

Photo 3. Old subalpine forests



The remnant older high elevation forests in the Glade watershed represent the natural character, or expected pre-industrial condition of the watershed. Aside from large stand replacing fires and other natural events, the majority of the higher elevations of the watershed would look similar to these remnant stands before modern forestry and other resource development occurred.

Photo 4. Sparsley vegetated ridges, talus slopes and rock outcrops

In a natural watershed, there are areas where forests do not become established, or forests are limited to small stunted trees due to site conditions. Rocky ridges, steep slopes with coarse rocky material or thin soils, and areas with high wind exposure or cold air drainage, limit the ability of forests to develop. These non-forested areas contain important habitat for many species that are adapted to those specific conditions.

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Scale: 1:15,000
Date: March 2022
Base Data: Province of BC; BC Data Catalogue & LidarBC

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Map 4
Glade Watershed
Old Forest, Non-Forest, and Logged Areas

The majority (75%) of the watershed is mid-age forest, recovering from fire and 100-year0old logging. These forests are only just becoming effective water managers, biodiversity sources, and climate regulators. Recent logging in reducing remnant old-growth forests, heightening the need to protect mid-

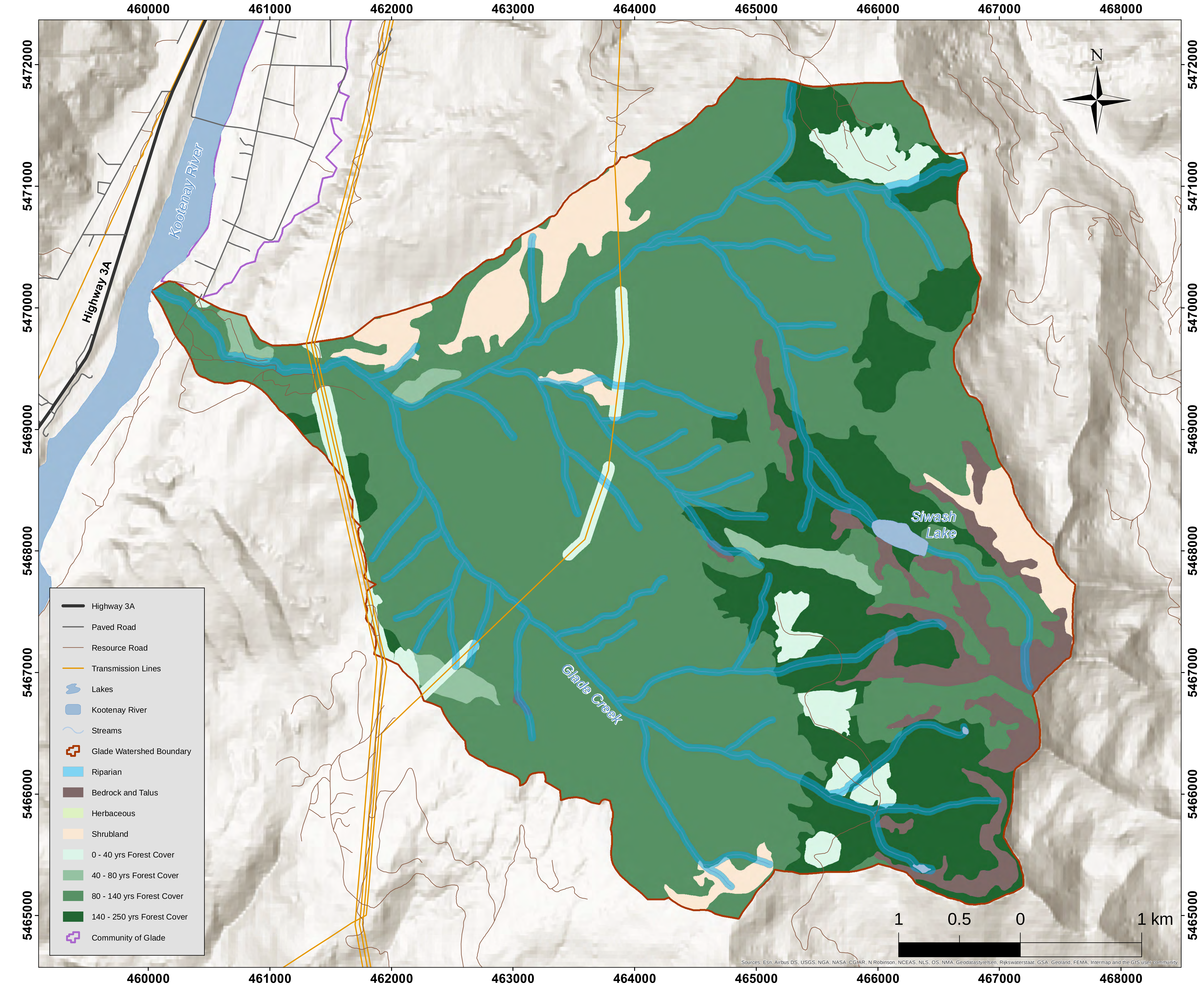


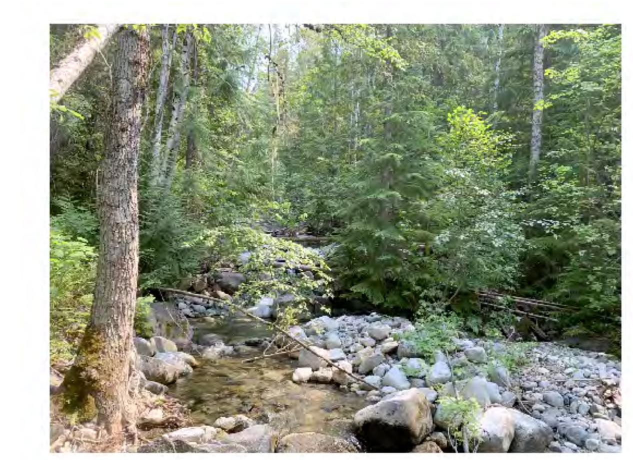
Photo 1. Old forests

In the Glade Watershed, older forests are restricted to higher elevations that did not historically burn and were not logged. As these areas represent some of the last remaining old, high quality trees in the watershed, they are now being targeted for logging. High elevation forests are essential for maintaining summer and fall water flows, as their dense canopy cover and complex structure are effective at capturing and slowly releasing water from a melting snowpack. One logged, these areas lose most of their water retention functions, resulting in higher freshet flows and reduced summer low flows in the watershed.

Photo 2. Mid-aged forests

Maturing forests are the future old forests for a watershed. Justifiably, much attention is given to protecting the older forests in a watershed. However, protection of mature forests is equality important to ensure that mature forests are allowed to naturally age. As this process takes hundreds of years, proper planning is required to ensure that the old growth of the future has the opportunity to develop, and that the many different types of forested ecosystems are represented, including the full range of tree species, and site conditions (wet, dry, poor rich, etc.).

Photo 3. Riparian ecosystems—riparian zones & riparian zone of influence



Riparian ecosystems are directly associated with water, including creeks, wetlands and lakes, and consist of two parts: riparian zone and riparian zone of influence. The riparian zone of influence is the upland area immediately adjacent to the riparian zone. What happens in the riparian zone of influence directly affects the riparian zone and water body. Riparian zones of influence end when the slope decreases enough so that down slope movement of water and nutrients in the soil slows significantly. In deeply incised valleys the riparian zone of influence can run all the way to the top of the ridge that bounds a watershed. Riparian ecosystems typically have abundant moisture throughout the growing season, and rich soils, resulting in productive ecosystems and often the larger trees in the watershed. Riparian zones are linkages within a watershed and are essential for maintaining water quality, providing shade that cools the water in creeks, and contributing food and nutrients to the aquatic ecosystems

Photo 4. Logged areas

Logged areas effectively re-set the ecological development of an ecosystem. Current industrial logging strips all trees from a site, creates extensive soil disturbance, and removes or burns the majority of the carbon from a site. Given the inhospitable conditions that follow logging, forest regeneration is slow. Management of logged areas attempts to exclude non-tree plants that heal the disturbed sits and usually plant the area with a limited number of commercially desirable tree species, often with limited genetic diversity and not from local genetic material. The future tree plantations that grow on these sites are very different from natural forests, and typically lack the diversity and complexity that is inherent in a natural system, making them much less resilient to fire, insects, disease, and climate change.

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Scale: 1:15,000
Date: March 2022
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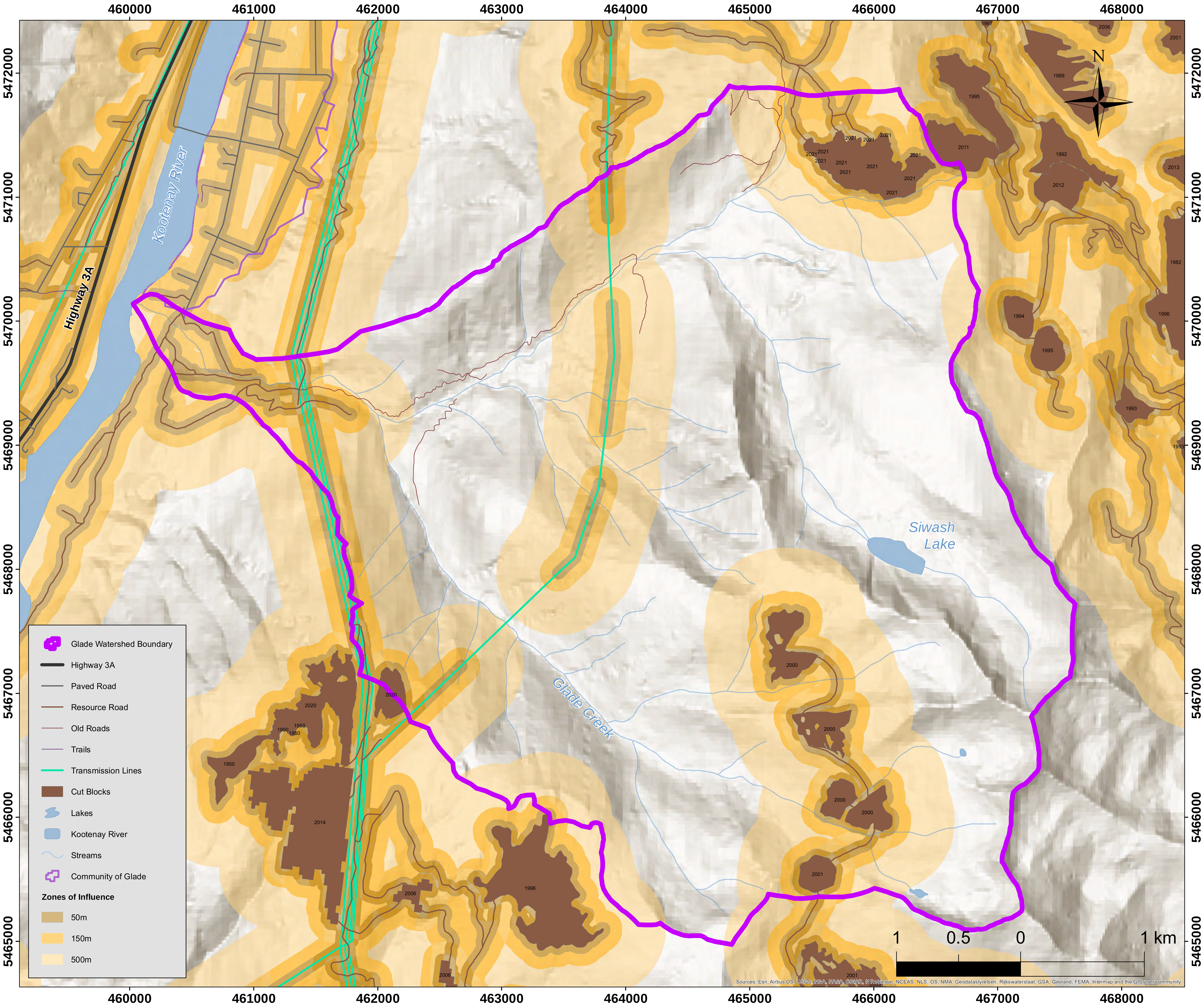
Map 5
Glade Watershed Industrial Disturbance



With consideration of cautious zones of influence, the actual footprint of roads, transmission lines and clearcuts is significantly larger than the actual opening created by each type of disturbance. In the Glade watershed 22 kilometres of road cover about 11 hectares of land, with zones of influence up to 623 hectares of land. Existing clearcuts of cover 81 hectares of land, with zones of influence clearcuts cover about 748 hectares of land. The 10 kilometres of maintained transmission line right of ways, affect about 623 hectares of land.

Photo 1. Roads

The construction of roads throughout a watershed often results in many long-lasting impacts. The physical disturbance caused by the road is significant, particularly as slope gradient increases. Roads result in modifications to surface water flow via interception and concentration of water in ditches and culverts, create increased potential for erosion and landslides, and provide a pathway for the introduction of invasive species. Where roads modify topography, the original natural ecosystems, cannot be restored to its original condition after resource development is done. Partially restored roads are used for years after for recreation, hunting and other purposes, effective extends the disturbance of the road to degradation of wildlife populations.

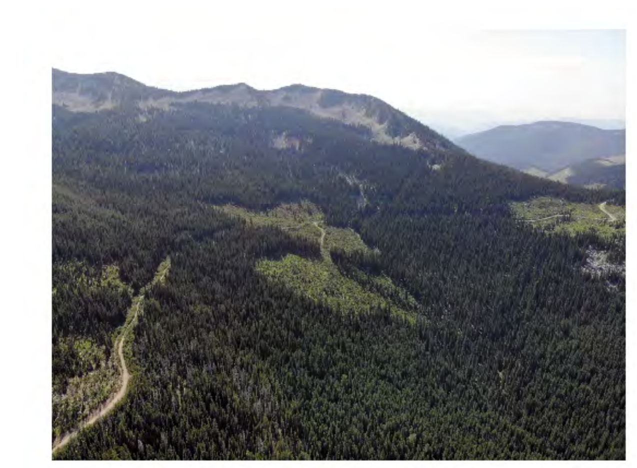
Photo 2. Clear cut logged blocks

Timber management activities affect ecological processes and population dynamics well beyond the apparent physical boundaries of access roads and clearcut blocks. The zone of influence, or "edge effect," created by roads, logging, and other disturbances extends much farther into the surrounding landscape than is often realized. Impacts within these zones of influence include habitat loss, fragmentation, increased air and soil temperature, increased wind and drying influences, and much more.

Photo 3. Transmission line right-of-ways

The right-of-ways for transmission lines are periodically cleared, resulting in a permanent shrub and herb dominated community. These modified ecosystems contain very different habitat and biodiversity values compared to the natural communities they replaced. Right-of-ways also contain access roads, and are often used by recreationalists such as off road vehicles, resulting in additional disturbance to wildlife, sources of erosion and sedimentation, and a vector for the introduction and transmission of invasive species.

Photo 4. Clearcuts With Moderate Height Regeneration



The forest canopies of tree plantations are very simple and lack the biological diversity and physical complexity needed for intact, healthy forests. This is part of the reason that tree plantations are more flammable and less resilient to climate change than intact natural forests. Moderate height trees in a plantation, also lack the structure to effectively conserve and manage water

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Scale: 1:15,000
Date: March 2022
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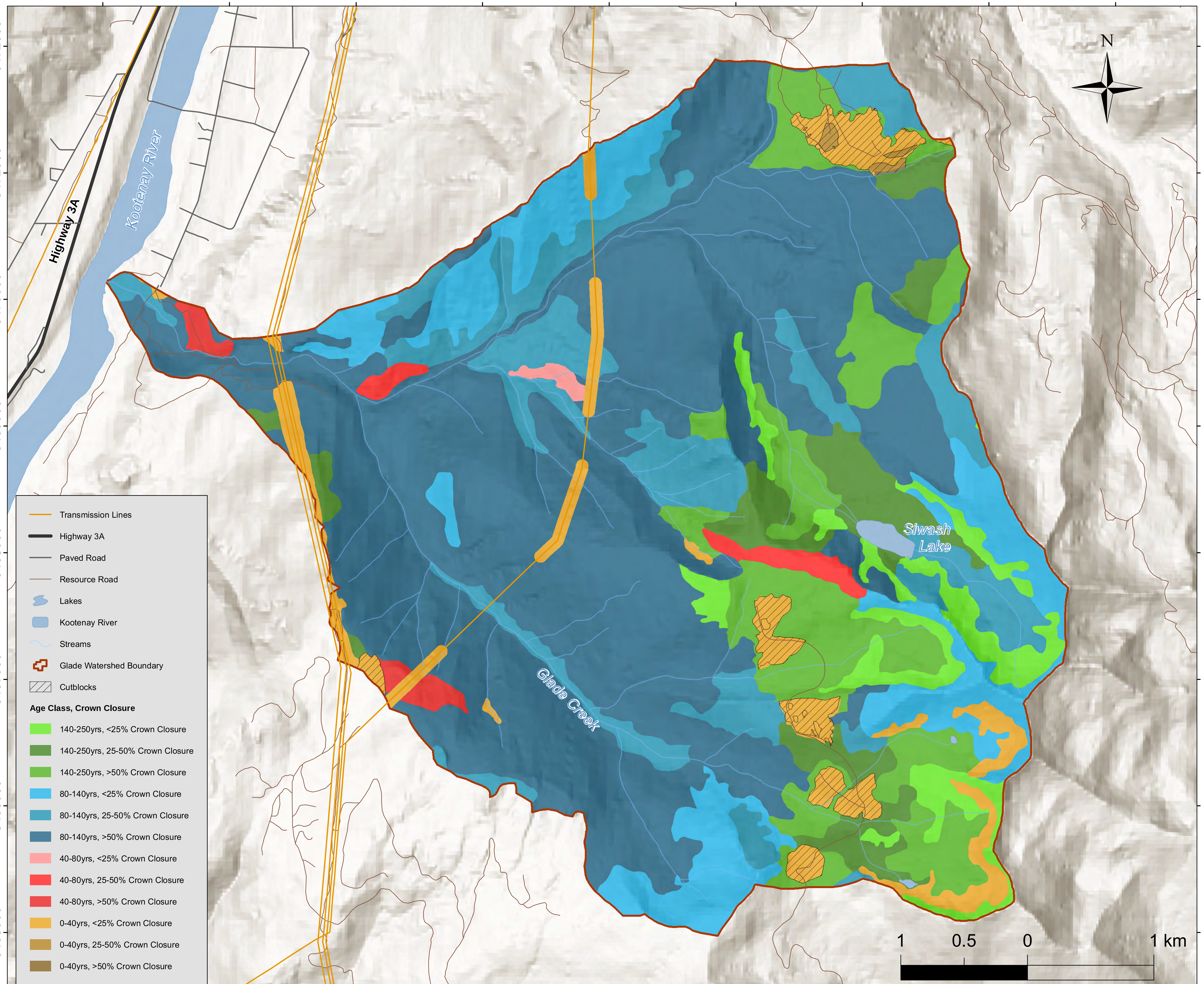


Map 6
Glade Watershed Forest Crown Cover

Crown cover reflects the crown mass of living leaves, which intercept, redistribute, store, and conserve water, both rain and snow. Older trees with dense crown cover provide the best water conservation benefits.

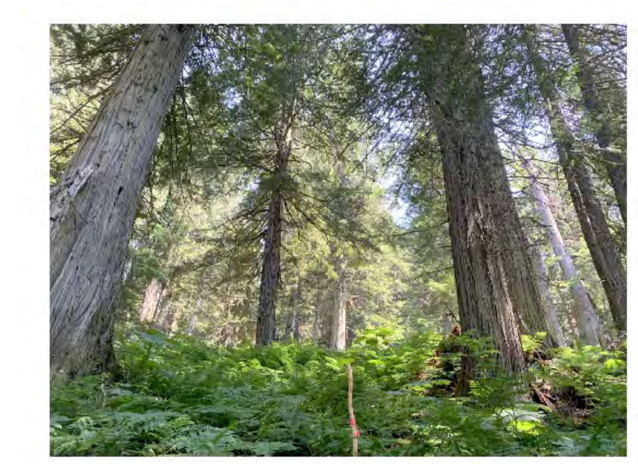
Photo 1. Young forests

Young forests are often even-aged, tightly spaced trees with small crowns. These forests have limited diversity in composition and structure, especially on the forest floor which is often missing decayed wood and deep organic layers. Only a small number of plant and lichen species are found in these conditions. These forests have yet to undergo natural self thinning that reduces density, creates openings, and gradually increases structural diversity and complexity as the forest ages.

Photo 2. Mature forests

Mature forests, in the 80-140 yr range, are starting to develop the vertical and horizontal complexity that is so important for biodiversity and habitat. They often have multiple layers of tree canopies, with shade intolerant trees occurring as a subdominant canopy. Mature forests generally lack the old trees, snags, and large fallen trees of an old forest.

Photo 3. Old forests



Old forests are complex ecosystems that are characterized by the prevalence of old and (typically) large trees, a wide range of tree species and ages, canopy gaps, multi-layered canopies, and a high occurrence of large snags and decayed wood from fallen trees. These forests are naturally resilient to many natural disturbances from wind and fire to insects and disease. Young trees and sapling become established in openings created by canopy gaps. Species diversity is high, and specialised habitat for many old-growth dependant specialists occurs. The large crown masses and multi-layered, coupled with large volumes of decayed wood and soil organic matter create an effective method of water interception, distribution, storage, and filtration. Old forests conserve and manage water better than any other forest phase.

Photo 4. Tree plantations

Logged areas are replanted with a variety commercially desirable conifer species at a high density. As the plantation establishes, a very dense canopy cover of closely spaced trees forms, and encroachment of natural regeneration increases both crown and stem density. Plantations conserve and manage water poorly, and have also been described as "biological deserts," owing to their lack of species and ecosystem processes. Without careful management, tree plantains often result unhealthy, poor quality stands of trees. This poor quality extends to the wood products generated from plantation trees, because the trees largely consist of juvenile wood that is a poorly suited for both structural lumber and pulp.

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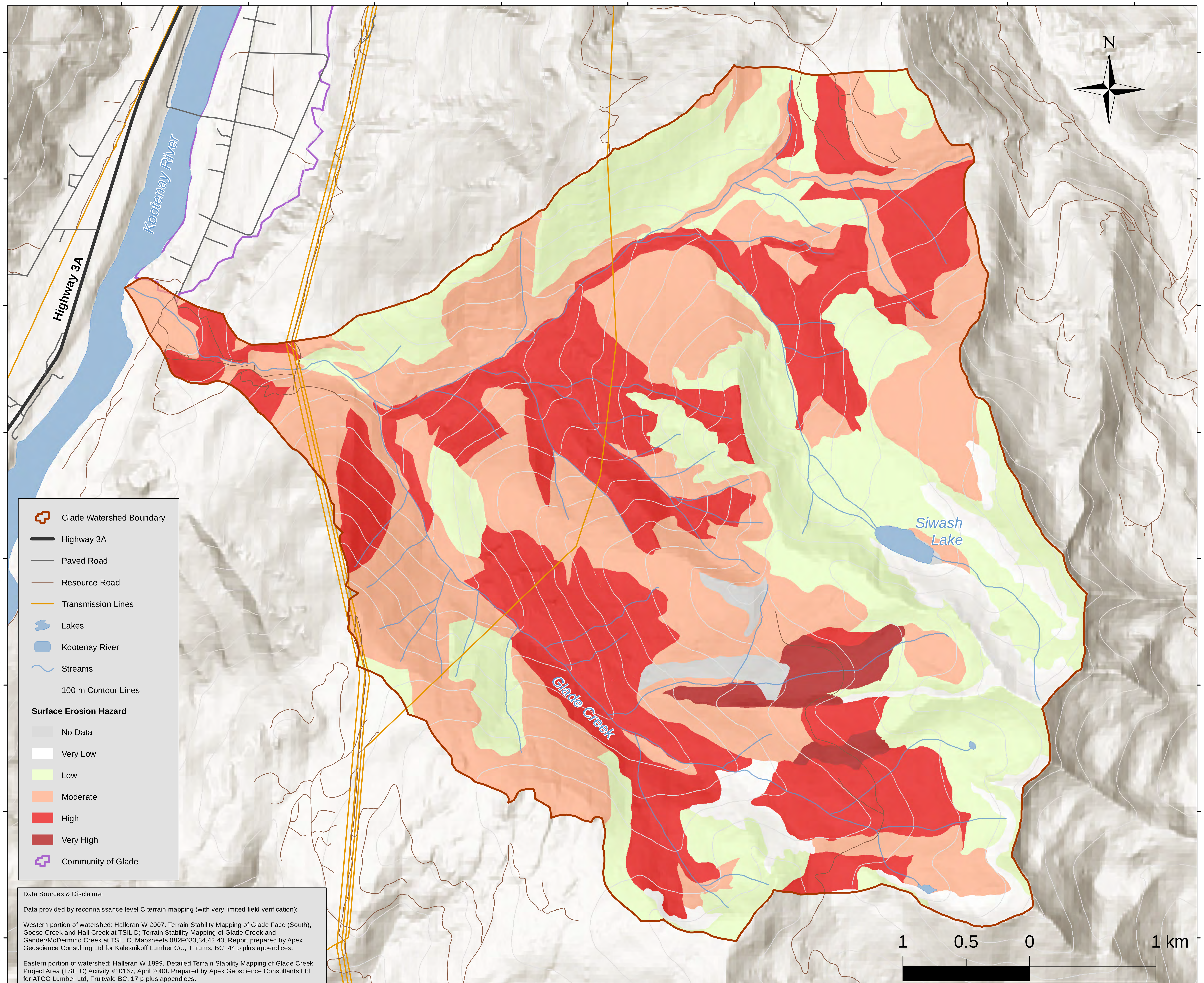
Map 7
Glade Watershed
Surface Erosion Hazard



Surface disturbance on erodible soils can cause increased turbidity in waterbodies and potentially impair drinking water sources and aquatic habitats.

Photo 1. Road cutbanks as sediment sources

Roads on sloping ground create cutbanks which may erode because they are oversteepened, poorly vegetated, or intercept seepage from the subsurface. As a result, mineral soils are exposed to surface erosion processes. Eroded materials make their way to ditchlines and can be readily conveyed to the stream network, polluting aquatic habitats with suspended sediment and damaging drinking water supplies.

Photo 2. Erosion from road surfaces

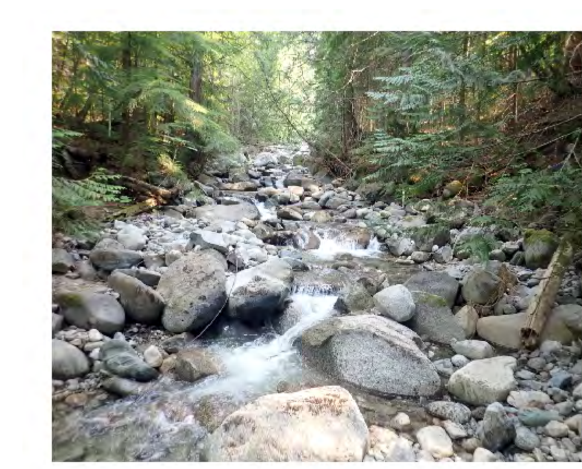
The surface of logging roads is continually disturbed by industrial use and by the traffic from recreational vehicles. If local materials used in road surfacing are coarse and if road gradients are modest, surface erosion can be tolerable. Commonly, roads climb steep slopes and erodible material types are used in surfacing. In these cases, runoff from these impermeable road surfaces can generate significant erosion, thereby impairing water quality of streams and other receiving waterbodies. Common erosion processes include sheetwash and rilling.

Photo 3. Surface disturbance from forest-harvest activities

Ground-based forest-harvest activities create surface disturbances from large machinery and other activities such as dragging logs. These disturbances degrade soils and expose them to surface erosion processes.

Skidding operations are commonly undertaken on slopes up to 40% and steeper, leading to soil erosion and declines in water quality.

Photo 4. Water quality deterioration



Suspended sediment causes deterioration of water quality in receiving waterbodies. Aquatic habitats and community drinking water supplies are common values that can be threatened by elevated levels of suspended sediment. Where landslides and channel instability are also involved, coarse sediment may also be introduced to streams potentially leading to inundation and burial, bank instability, and safety hazards. In persistent or extreme cases of sedimentation, streams may be dewatered particularly during the low-flow period when the remaining streamflow goes subsurface in the excessive bed sediment.

Projection: NAD 83 UTM 11N
Scale: 1:15,000
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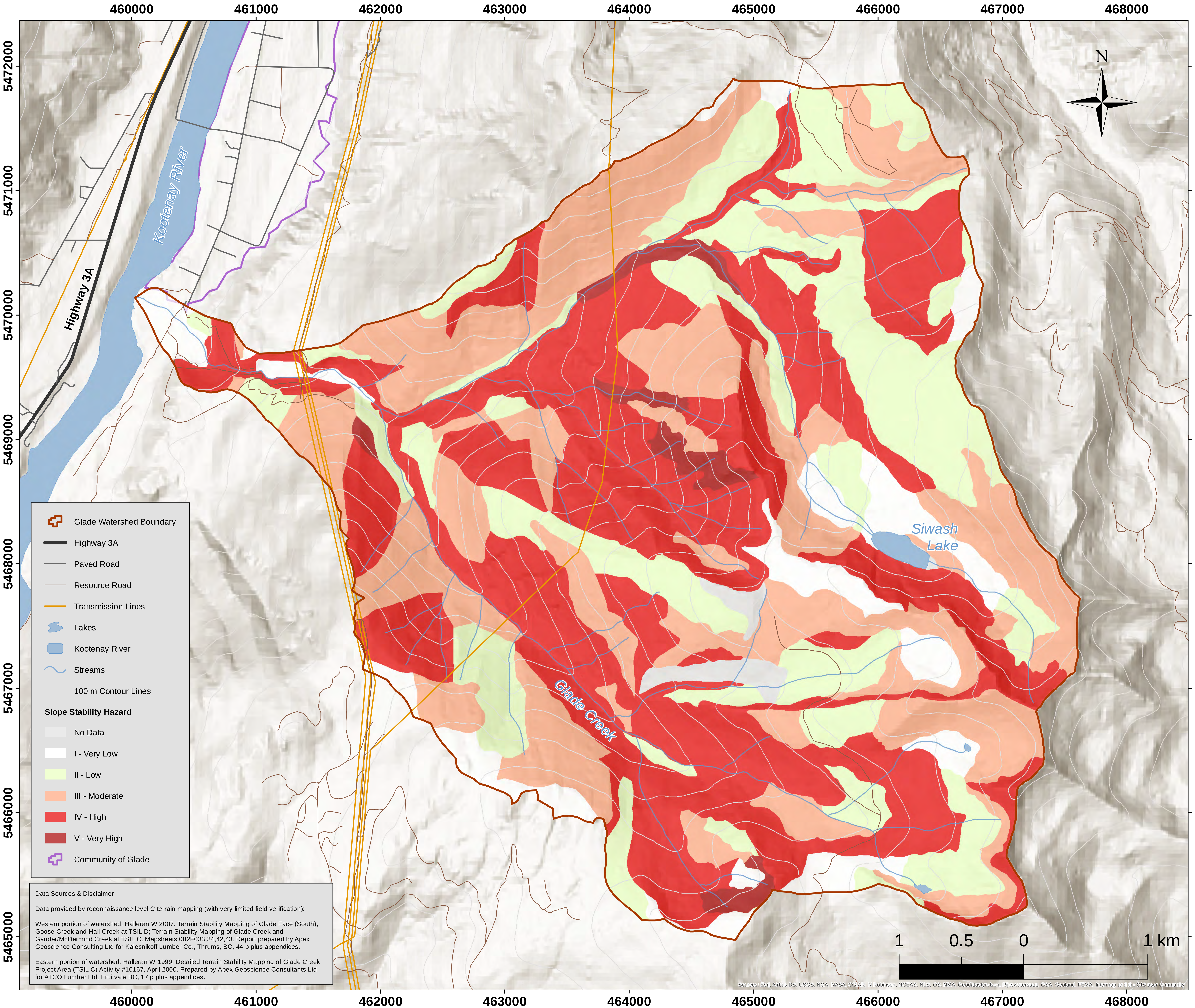
Map 8
Glade Watershed
Slope Stability Hazard



Data Sources & Disclaimer

Data provided by reconnaissance level C terrain mapping (with very limited field verification):

Western portion of watershed: Halleran W 2007. Terrain Stability Mapping of Glade Face (South), Goose Creek and Hall Creek at TSIL D; Terrain Stability Mapping of Glade Creek and Gander/McDermind Creek at TSIL C. Mapsheets 082F033,34,42,43. Report prepared by Apex Geoscience Consulting Ltd for Kalesnikoff Lumber Co., Thrums, BC, 44 p plus appendices.

Eastern portion of watershed: Halleran W 1999. Detailed Terrain Stability Mapping of Glade Creek Project Area (TSIL C) Activity #10167, April 2000. Prepared by Apex Geoscience Consultants Ltd for ATCO Lumber Ltd, Fruitvale BC, 17 p plus appendices.

Many watershed locations are vulnerable to slope instability, which can lead to downslope ecological harm and hazards to human values due to landslides.

Photo 1. Drainage from roads on steep ground

Concentrated drainage below resource roads are common landslide initiation points. Under natural conditions, runoff and shallow groundwater flow are dispersed through the soil mantle and in the forest floor. Road construction typically concentrates drainage either into ditchlines or along road surfaces leading to high levels of runoff immediately downslope. Where this concentration coincides with unstable terrain, typically on steep and moist slopes, slope failures can occur. These can form open-slope failures or debris flows where they enter steep streams and possess sufficient momentum.

Photo 2. Landslide paths below resource roads

Forestry and other resource activities carried out in steep terrain may require road construction on potentially unstable slopes. Depending on the quality of construction, the approach to drainage management and long-term maintenance efforts, drainage pathways can be readily altered leading to downslope instability and, potentially, landslides.

Photo 3. Slope failures from concentrated drainage

Roads on steep slopes typically dispose of excavated material as sidecast, forming fillslopes. Often oversteepened, these are typical initiation sites of slope failure. Culverts receive drainage concentrated from upslope areas and ditchlines and provide discharge points that present hazards to downslope stability. Routine drainage management from resources roads on steep ground can lead to debris slides.

Photo 4. Disrupted drainage from resource roads

Resource roads are generally built to be wide so as to sustain large industrial trucks and promote safety for those travelling along the road. However, wide roads on steep terrain require careful drainage systems including cutbanks shedding into ditchlines which in turn may carry the runoff long distances to the next suitable discharge point. Cutbank erosion may quickly lead to blocked ditchlines involving random discharge of concentrated drainage down potentially unstable slopes. Once initiated, landslides can travel long distances and potentially reach important aquatic habtiats, and human infrastructure such as drinking water intakes.

Projection: NAD 83 UTM 11N
Scale: 1:15,000
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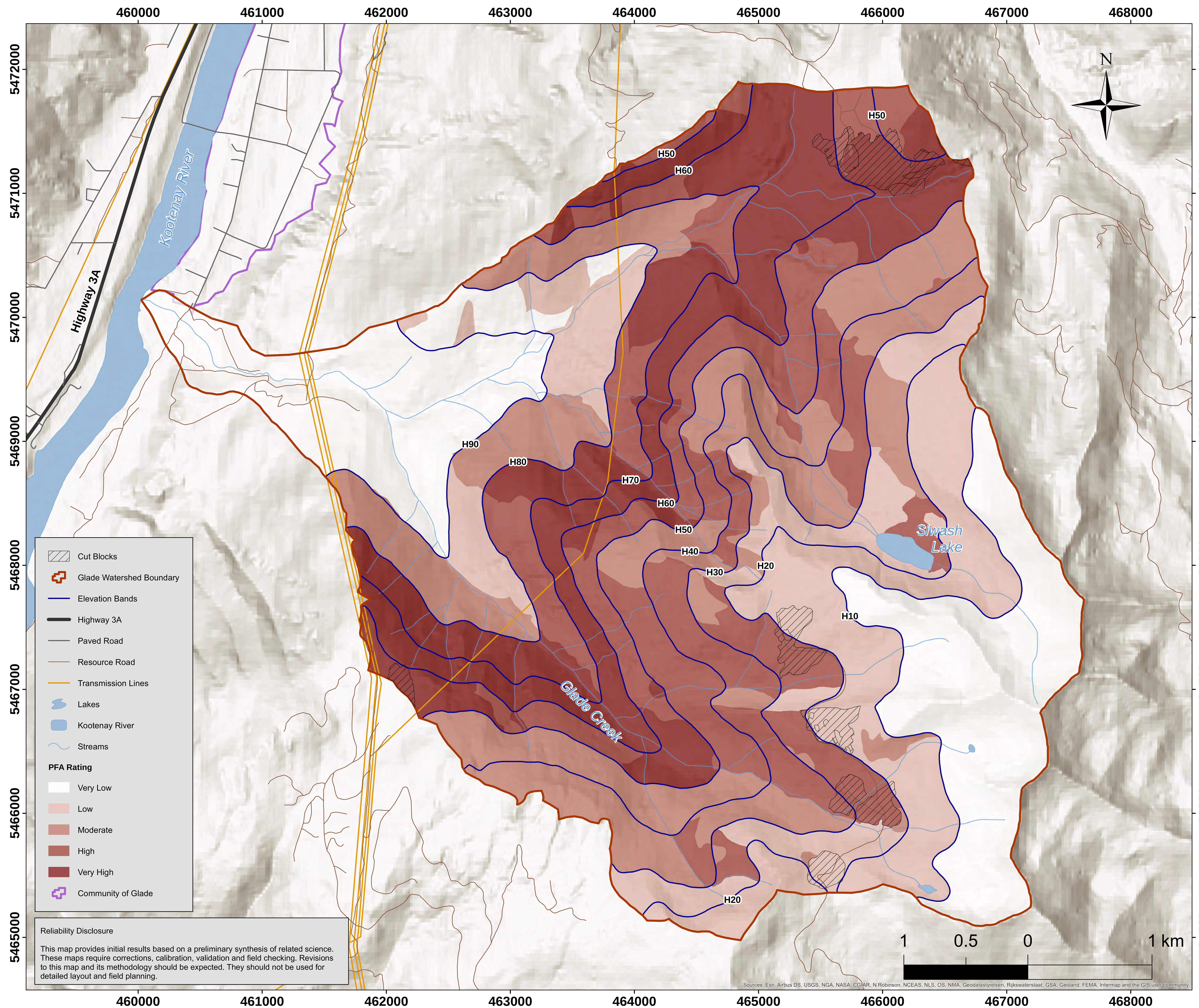
Map 9 - Preliminary Glade Watershed Peak-Flow Augmentation

Calibration, Validation & Revision Required

Certain watershed locations have a higher effect on the freshet's peak flow due to changes in snow accumulation and melt. Disturbances in these locations may lead to higher peak flows and damaging floods and channel instability.



Reliability Disclosure

This map provides initial results based on a preliminary synthesis of related science. These maps require corrections, calibration, validation and field checking. Revisions to this map and its methodology should be expected. They should not be used for detailed layout and field planning.

Photo 1. Forests moderate snow dynamics

In the Interior Wet Belt, forest cover intercepts falling snow, preventing it from reaching the ground surface. While suspended in the forest canopy, a large proportion (30-40%) of the total snowfall at a site is evaporated back into the air ("sublimated") before it ever reaches the ground surface. Forests also limit snowpack melt rates thereby reducing the pace at which runoff is formed during periods of heating.

Photo 2. Clearcuts affect snow accumulation and melt

In snow-dominated watersheds, clearcuts increase snow accumulation and enhance melt rates. In clearcuts, sunny aspects (orientation to the sun) and steeper ground promote rapid melt whereas north aspects reduce melt both in clearcuts and under the forest canopy. Precipitation (including snowfall) rises with elevation in the Interior Wet Belt. As a result, the consequences for runoff of removing forests may be amplified with elevation.

Photo 3. Peak flow integrates melt and runoff processes across watershed

During the spring freshet and other periods of heating, watershed snowmelt concentrates in complex ways to form a hydrograph typically with a peak flow and/or a period of very high flow. The magnitude and timing of the peak flow is greatly influenced by snow accumulation and melt across the watershed. Melt dynamics are greatly influenced by forest removal and road construction which modify snow accumulation/melt and patterns of runoff. A lot is at stake for downstream regions where aquatic ecosystems, stream channels and human values are sensitive to runoff magnitude.

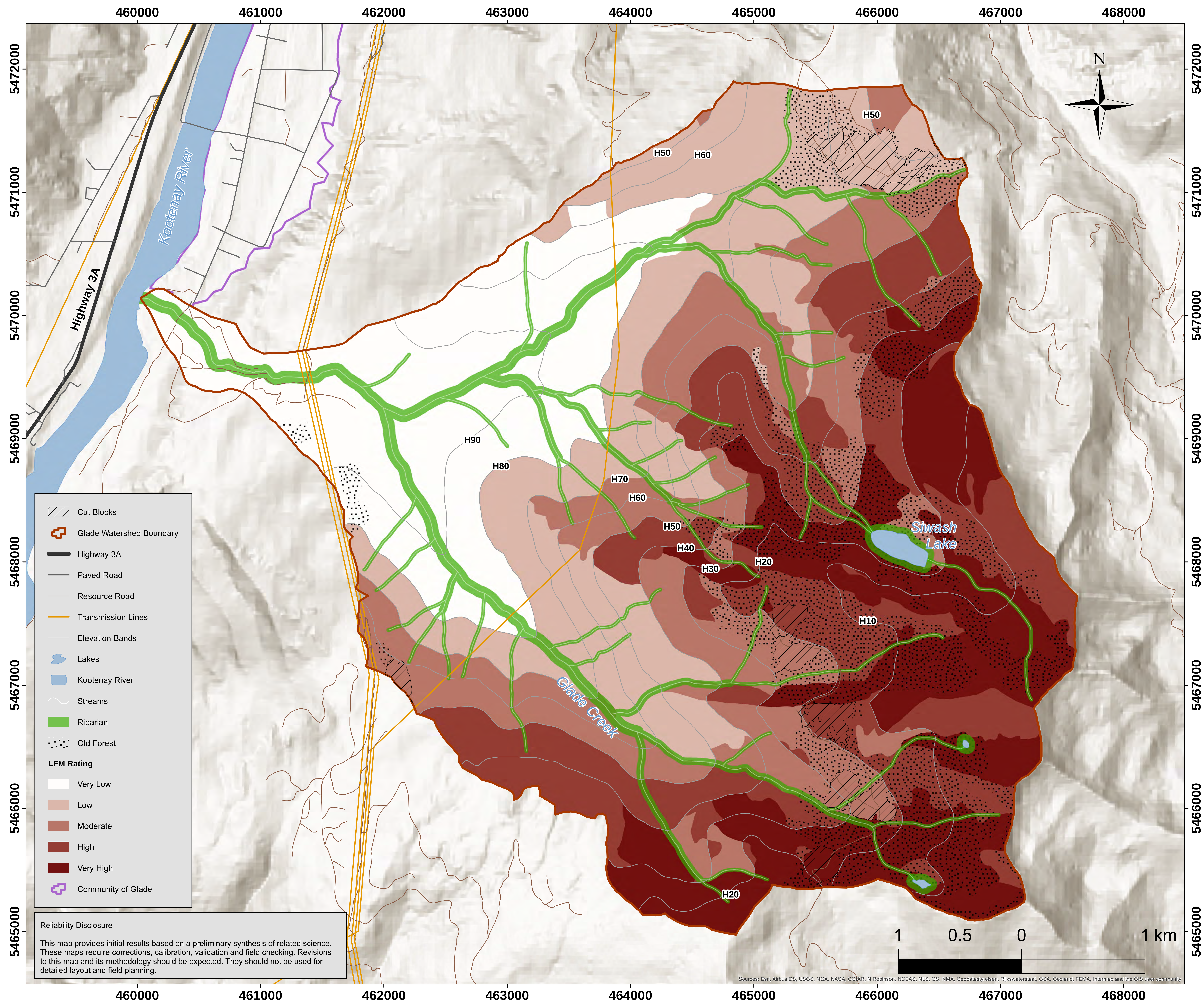
Photo 4. Roads and ditchlines accelerate runoff

Roads and ditchlines concentrate drainage and modify runoff dynamics. Active road surfaces are impermeable and prevent infiltration, leading to enhanced runoff in adjacent areas. Ditchlines transport water, often long distances, across hillslopes to discharge points that, depending on the stability of downslope areas, may or may not be suitable to receive the concentrated drainage.

Projection: NAD 83 UTM 11N
Scale: 1:15,000
Date: March 2022
Base Data: Province of BC; BC Data Catalogue & LidarBC

Map 10 - Preliminary Glade Watershed Low-Flow Moderation

Calibration, Validation & Revision Required



Certain locations and components in the watershed are more effective than others in raising and maintaining baseflows, especially in the face of prolonged summer heating. Disturbances in these locations may undermine reliability of baseflows for ecosystems and water supplies.

Photo 1. Forest wetlands

Wetlands, including forested wetlands, provide direct support to baseflows especially during periods of sustained summer heating. They represent locations where water is typically found year-round. They are associated with a slow release of drainage and often support rare and unusual species. Forest cover may also provide shading to the wetland to protect its moisture regime during periods of summer heating. This is expected to be of particular importance given the heating and heat waves associated with climate change projections.

Photo 2. Snow in small openings is not like in clearcuts

Small forest openings alter snow accumulation and melt in ways quite different than that of larger clearcuts. Depending on the size of the opening, snow accumulation can increase relative to forested sites while melt rates may remain unchanged or change only slightly (depending on the topography). If forest openings are designed carefully and respect the site's energy dynamics, it should be possible to use them to improve groundwater recharge thereby potentially providing opportunities to improve baseflow.

Photo 3. Road cutbanks intercept shallow groundwater flow

Road cutbanks intercept shallow groundwater flow which may otherwise have been available to support late-season baseflow. Once in the ditchline, this water is routed to drainage structures which are frequently connected to the stream network. As road densities grow higher in an industrialized watershed, the extent of loss to baseflow grows thereby contributing to the decline in late-summer low flow. Minimising blading and reducing road widths provide strategies to reduce the impact of roads on baseflow.

Photo 4. Late-freshet snowmelt supports low flow

In snowmelt-dominated watersheds, like those of the Interior Wet Belt, slow snowmelt into surface soils provides significant proportions of annual groundwater recharge. It is this below-surface water storage that supports warm season lowflows which aquatic ecosystems and human communities depend on critically. These "environmental flows" are particularly dependent on late-freshet snow melt which can last well into the summer, for high-elevation watersheds with limited exposure to the sun.

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Map 13: Protected Landscape Network (PLN)
Map 14: Projected Bioclimates for the 2080s

Projection: NAD 83 UTM 11N
Scale: 1:15,000
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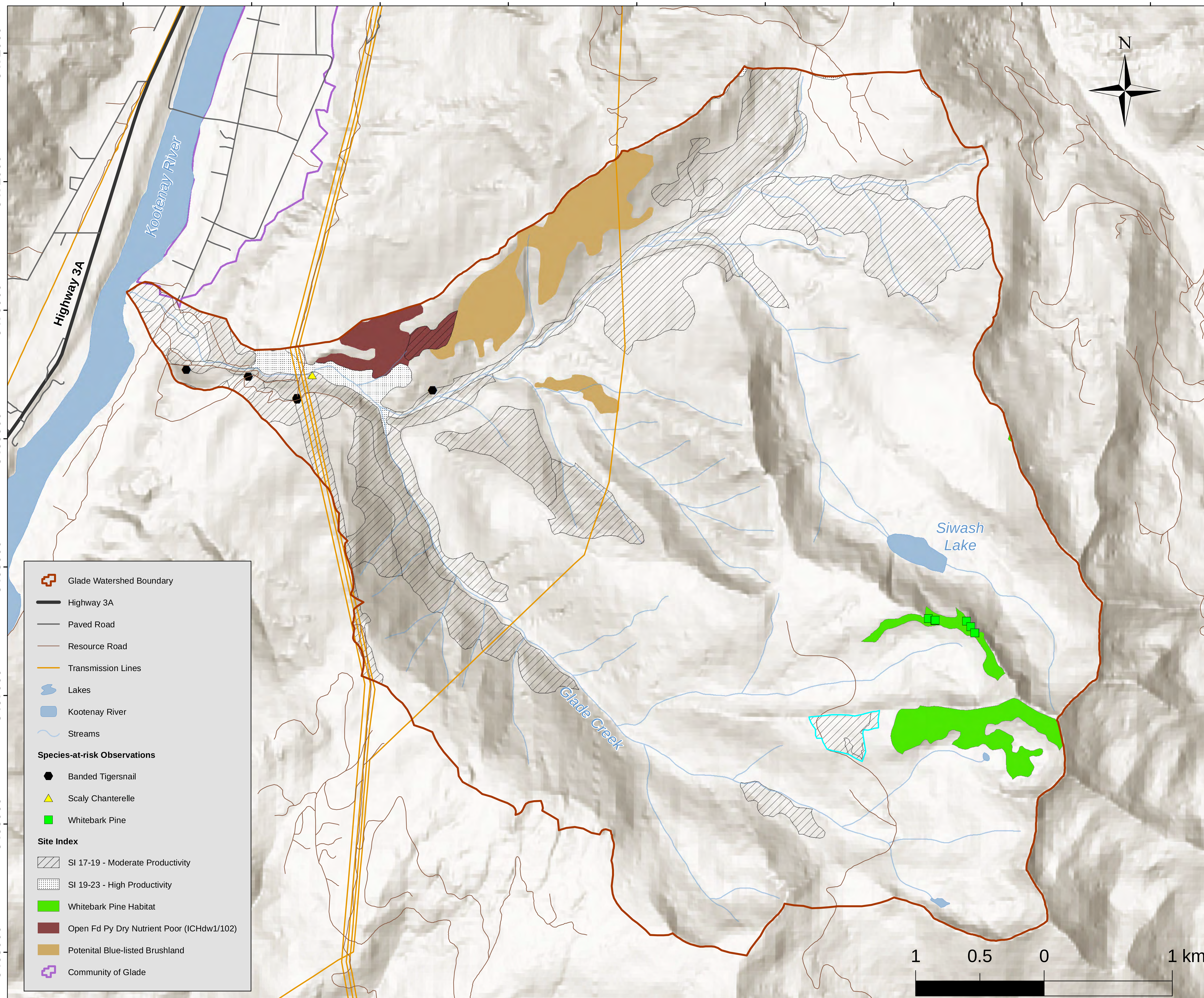
Map 11
Glade Watershed
Unique and Rare Habitats



Unique/rare habitats are small portions of the watershed but are essential to protect, because they are infrequent and critical to the persistence of key species. Habitats for threatened and endangered species are considered unique/rare habitats.

Photo 1. Banded Tigersnail

The banded tigersnail (Anguispira kochi ssp. occidentalis) is a blue-listed snail that only occurs in the Columbia and Kootenay River watersheds. While it is a threatened species, it is locally abundant in areas along Kootenay River. The banded tigersnail lives in a variety of forested habitats, most commonly occurring in moist areas with high canopy cover and generally adjacent to riparian areas. As with most gastropods, it is very susceptible to forestry and other activities that reduce the forest cover and disturb litter, woody debris or soil. It is likely abundant in the lower elevations of the Glade watershed.

Photo 2. Scaly Chanterelle

Scaly chanterelle (Turbinellus floccosus) is a blue-listed mushroom that occurs in mixed coniferous forests of western North America. It is uncommon in the interior of BC, with most known populations occurring in coastal regions. The scaly chanterelle is dependant on mycorrhizal connections with a variety of coniferous tree species.

Photo 3. Whitebark Pine habitat

Whitebark pine (Pinus albicaulis) is blue-listed in British Columbia and an Endangered species nationally. It is restricted to upper elevation subalpine forests, typically along ridge crests, rocky ridges and slopes. Whitebark pine populations are decreasing due to white pine blister rust, a very damaging non-native fungi that is widespread in the province. Whitebark pine seeds are critical food source for grizzly bears, particularly as a late season pre-hibernation energy source. Whitebark pine stands play important water conservation roles in the upper portions of watersheds.

Photo 4. Open Douglas-fir Ponderosa Pine ecosystems

A small patch of red-listed Douglas-fir / tall Oregon-grape / parsley fern (ICHdw1/02) ecosystem was identified in the Glade watershed on the steep south facing slopes above the waterfalls. This forested community is very uncommon in the Interior Cedar Hemlock zone, as it occurs on warm aspects with dry, poor soils, which are infrequent.

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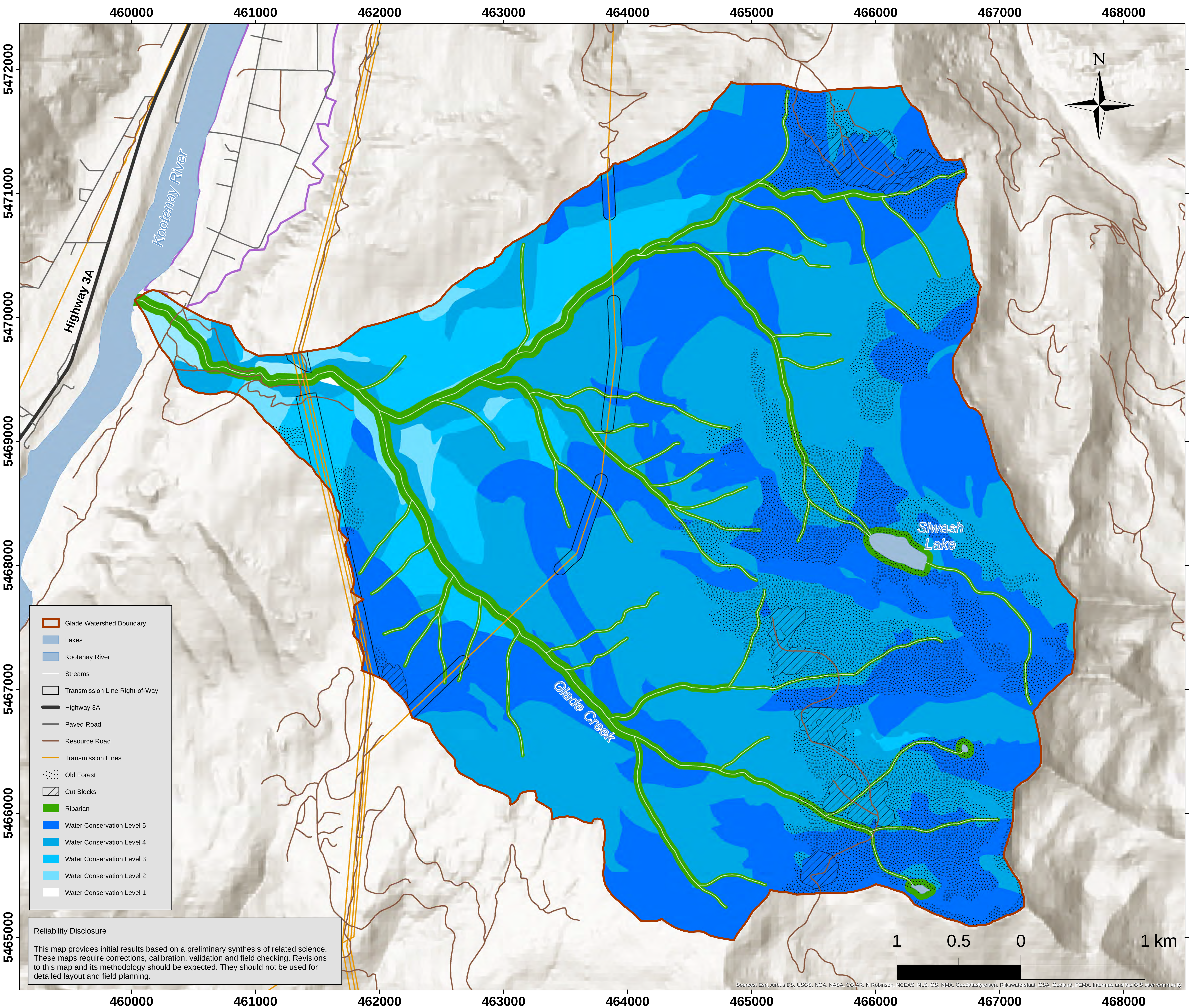
Map 12 - Preliminary Glade Watershed Hydrologic Sensitivity

Calibration, Validation & Revision Required

Clean water, healthy aquatic ecosystems, and stable channels require forest and soil protection widely distributed across the watershed to maintain the natural flow regime and minimize stream sedimentation. Few locations in the watershed are not involved in some capacity in maintaining a positive hydrologic function.



Reliability Disclosure

This map provides initial results based on a preliminary synthesis of related science. These maps require corrections, calibration, validation and field checking. Revisions to this map and its methodology should be expected. They should not be used for detailed layout and field planning.

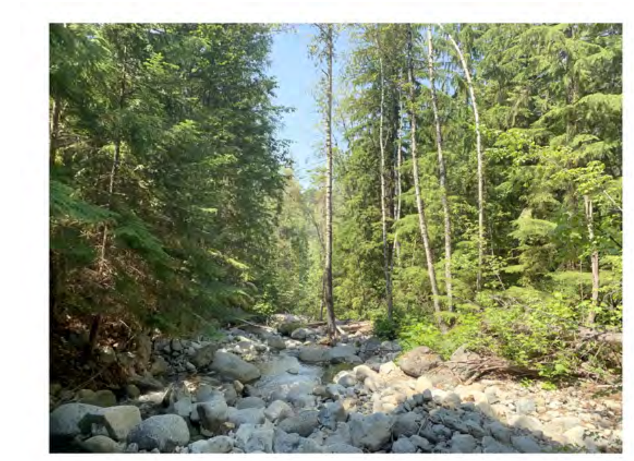
Photo 1. Old forests support positive water outcomes

Old forests provide a range of positive benefits to hydrologic function at both site and watershed levels. Rainfall and snow interception due to the forest canopy and tree trunks reduce the amount and/or pace at which incoming precipitation moves toward the watershed outlet. Old forests typically promote groundwater recharge. Deadfall and other decaying materials associated with old forest types store water, releasing it slowly and support baseflows. A multi-layered forest canopy provides valuable shade to ground-level forest ecosystems which is particularly valuable during periods of intense heating associated with climate disruption.

Photo 2. Wetlands

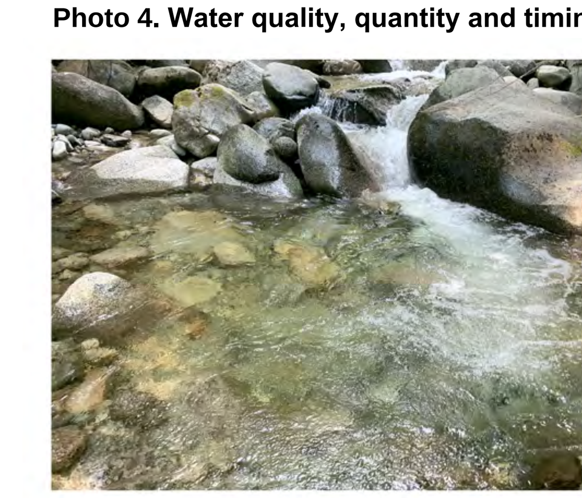
Forested wetlands provide a range of positive benefits to watershed hydrology as well as providing rich points of ecological diversity. Wetland typically support late-season baseflow by releasing water slowly to shallow groundwater and to streams. Wetlands also store water both from the freshet period and from rainfall events, making it available later. Depending on their location in the watershed, they also serve as important storage sites for sediment thus contributing to improvements in downstream water quality. Where they are able to survive future increases in temperature, wetlands of any size provide critical watershed elements to sustain beneficial function during periods of hydrologic disruption.

Photo 3. The water benefits of riparian vegetation



The riparian zone is the strip of land adjacent to a waterbody with different characteristics due to its proximity to water. Riparian vegetation plays a large role in maintaining proper hydrologic function in a watershed across scales. Undisturbed riparian vegetation protects banks thereby promoting channel stability. In addition to its many essential habitats, riparian areas shade streams reducing summer water temperatures. This protection of aquatic habitats from temperature extremes is expected to be of growing importance as disruption escalated due to climate change. Whereas riparian vegetation transpires, it limits evaporation and reduces sedimentation in streams. The role of riparian vegetation changes greatly from headwater to watershed outlet.

Photo 4. Water quality, quantity and timing of flow



High quality water in the right amount and at the right timing is a foundation to watershed hydrology supportive of species, habitats, ecosystems and human uses. Within the smaller catchments that drain toward the West Arm of Kootenay Lake and to the downstream Kootenay River, every location within these watersheds contributes in some way to the water quality, quantity and timing of flow at the outlet. Some areas play an oversized role in comparison with others. Both the flow and sediment regimes should be moderated to maintain resilience in aquatic habitats and for human water uses, particularly during this ongoing period of climate disruption.

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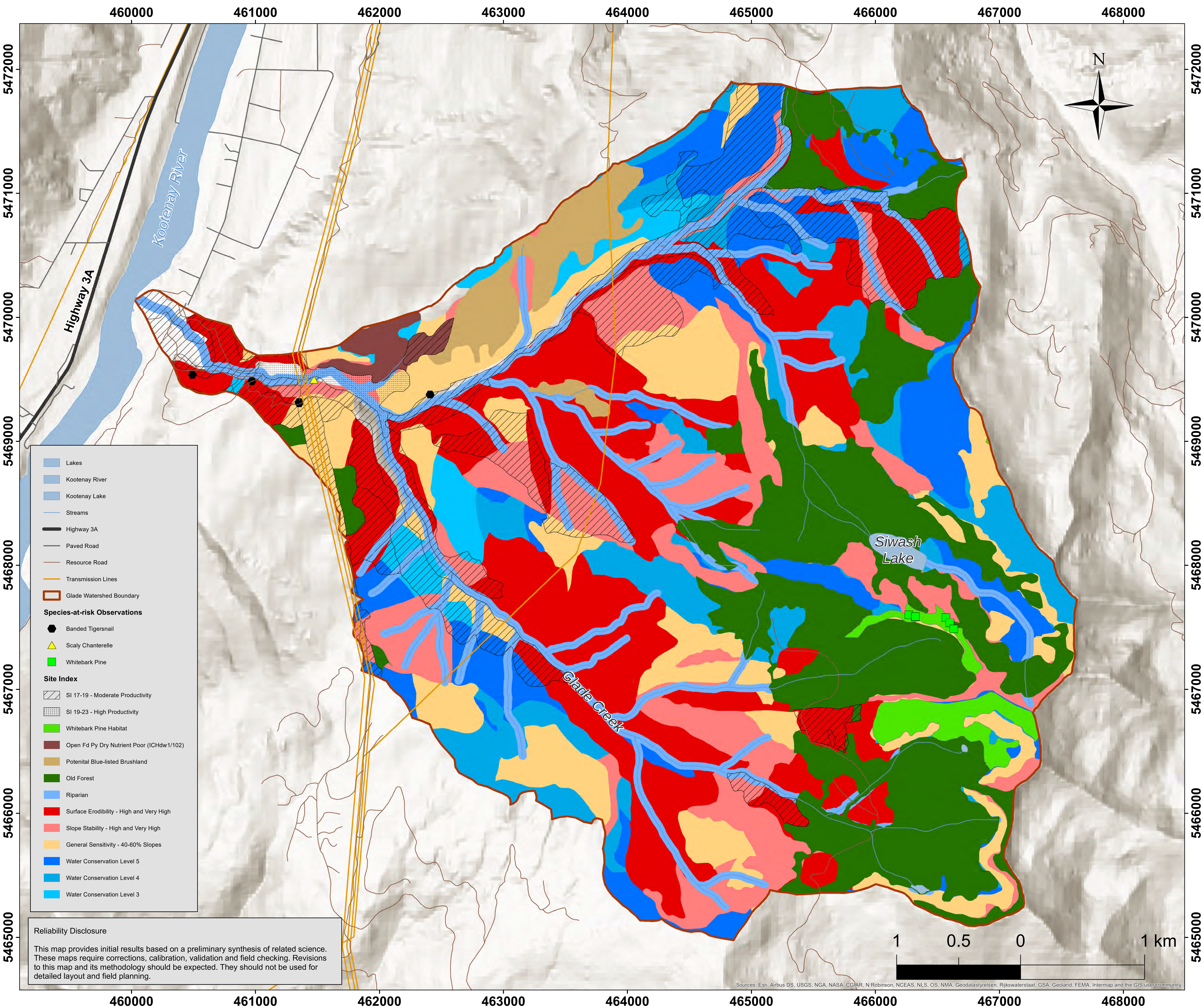


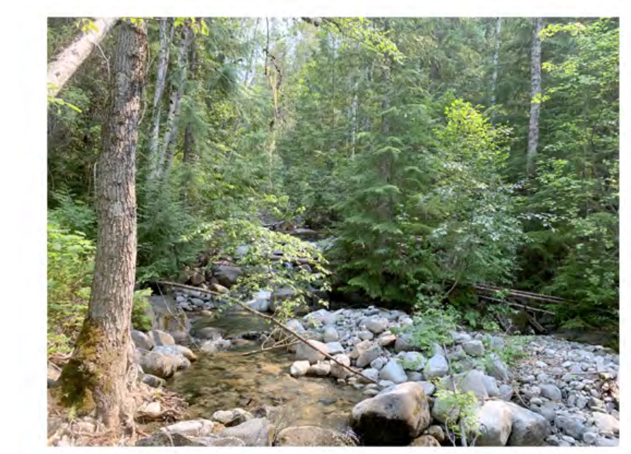
Map 13 - Preliminary Glade Watershed Protected Landscape Network (PLN)

The PLN provides the ecological framework necessary to protect water and biodiversity, moderate climate, and maintain connectivity. The PLN encompasses the range of natural ecosystems in the watershed. Ecologically sensitive and ecologically limited areas are important parts of the PLN. Protection is reciprocity with nature.

Photo 1. Old forests—centres for water conservation, carbon sequestration, & biodiversity

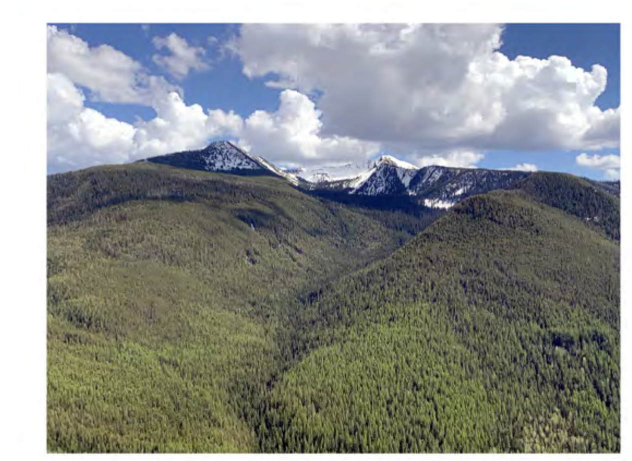
Old forests are complex ecosystems that are characterized by the prevalence of old and large trees (for a particular site's character), a wide range of tree species and ages, canopy gaps, multi-layered canopies, and a high occurrence of large snags and decayed wood from fallen trees. These forests are resilient to most natural disturbances from wind and fire to insects and disease. Old forests sequester and store carbon, and moderate climate better than other forest phases. Old forests have the highest level of biodiversity and of specialized species. For example old forests harbour carnivorous insects that prey on herbivorous insects, like bark beetles. The large crown masses and multi-layered crowns, coupled with large volumes of decayed wood and soil organic matter create an effective means of water interception, distribution, storage, and filtration. Old forests conserve and manage water better than any other forest phase.

Photo 2. Riparian zone within riparian ecosystems—important linkages in the watershed



Riparian ecosystems are directly associated with water bodies, including creeks, wetlands and lakes, and consist of two parts: riparian zone and riparian zone of influence. The riparian zone of influence is the upland area immediately adjacent to the riparian zone. What happens in the riparian zone of influence directly affects the riparian zone and water body. Riparian zones of influence end when the slope decreases enough so that down slope movement of water and nutrients in the soil slows significantly. In deeply incised valleys the riparian zone of influence can run all the way to the top of the ridge that bounds a watershed. Riparian ecosystems typically have abundant moisture throughout the growing season, and rich soils, resulting in productive ecosystems and often the largest trees in the watershed. Riparian zones are linkages within a watershed and are essential for maintaining water quality, providing shade that cools the water in creeks, and contributing food and nutrients to the aquatic ecosystems.

Photo 3. Ecological sensitivity/ecological limits: H & VH slope stability hazard



All areas of ecological sensitivity and ecological limits are part of the PLN. In many cases these classes overlay other parts of the PLN, including old forests, high productivity sites, and representative ecosystem types for the watershed. Concentrated drainage below resource roads are common landslide initiation points. Under natural conditions, runoff and shallow groundwater flow are dispersed through the soil mantle and in the forest floor. Road construction typically concentrates drainage either into ditchlines or along road surfaces leading to high levels of runoff immediately downslope. Where this concentration coincides with unstable terrain, typically on steep and moist slopes, slope failures can occur. These can form open-slope failures or debris flows where they enter steep streams and possess sufficient momentum.

Photo 4. Moderate productivity sites/representative sites of good tree growth

Inclusion of areas of moderate and high productivity tree growth sites captures areas of high biological productivity in the PLN. In Glade watershed, moderate productivity areas occupy nearly one-quarter of the watershed area and reflect ecosystem types that are representative of ecosystems found throughout much of the watershed.

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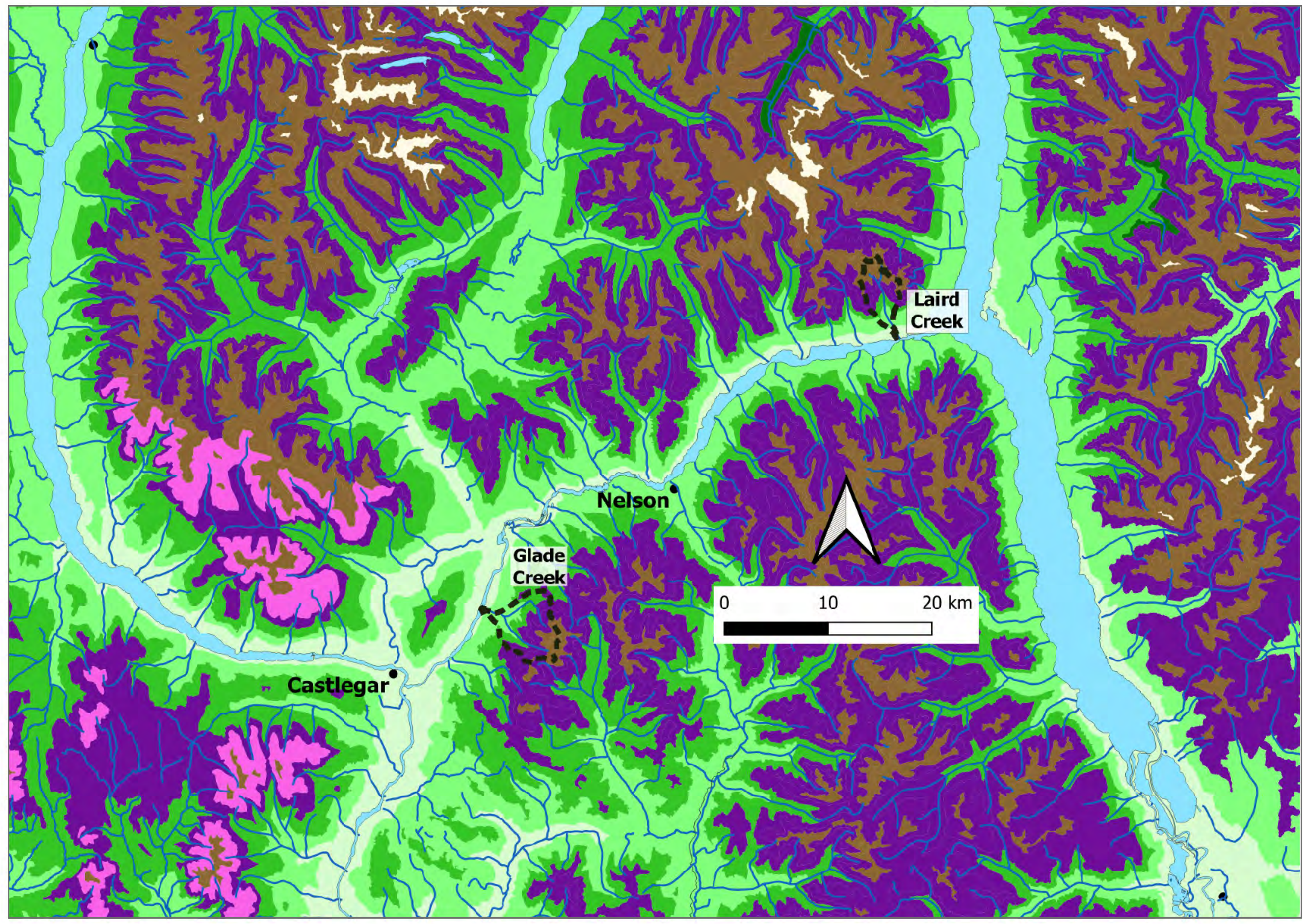
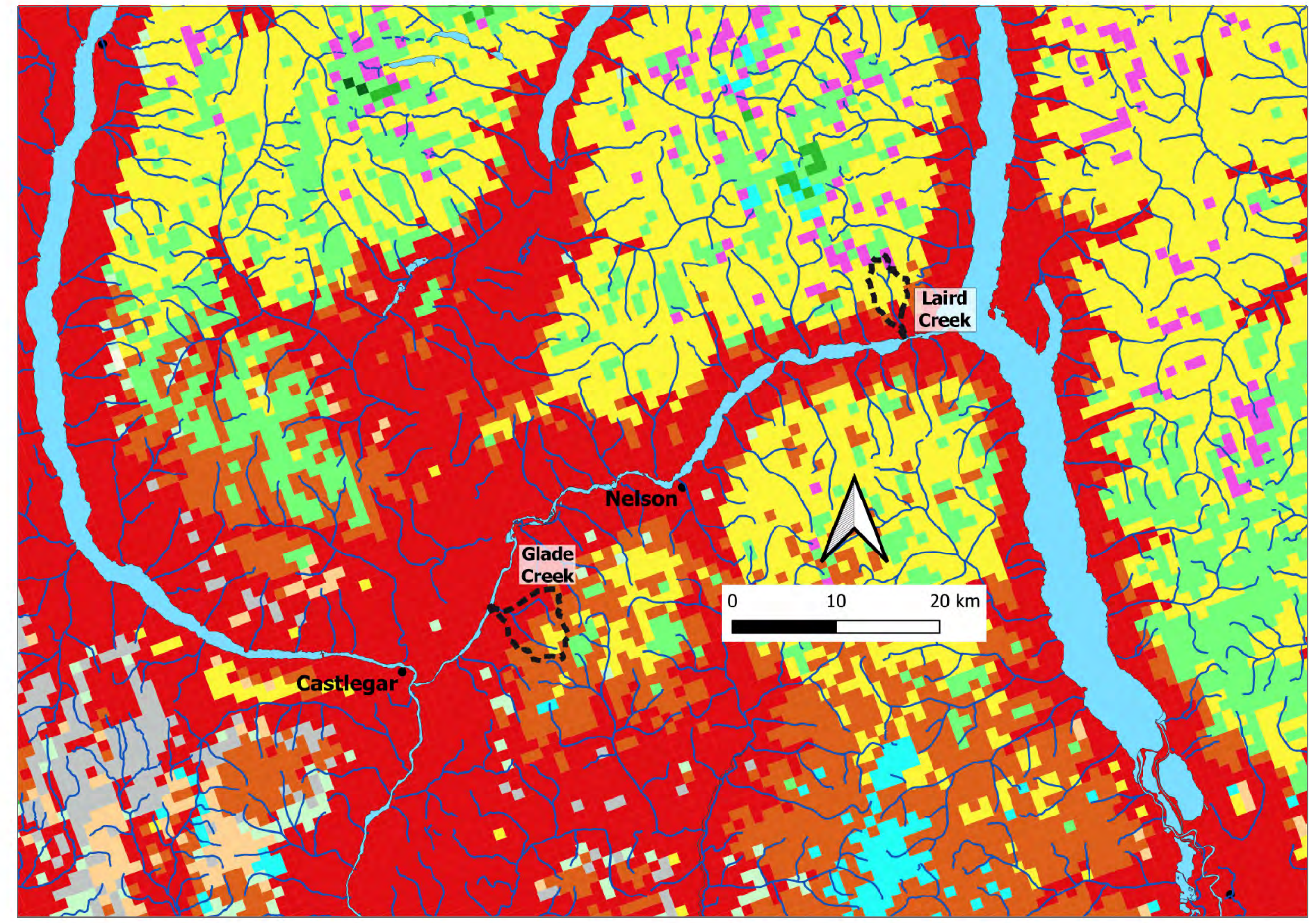
Map 14
Glade Watershed
Projected Bioclimates for the 2080s

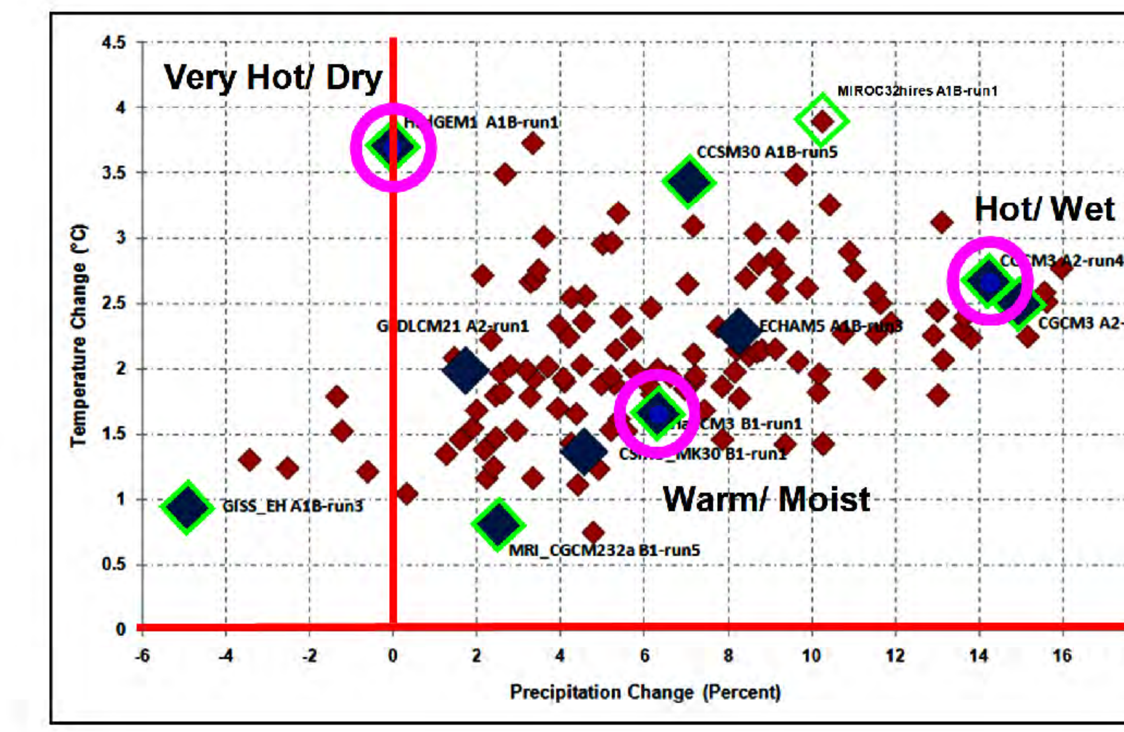
The changing climate is projected to lead to significant alterations to ecosystems through the twenty-first century and beyond. Changes are likely to lead to ecological regime shifts that results in extirpation of species and loss of benefits to human beings, like high quality water in moderate flows throughout the year, and climate moderation.

Current Mapping

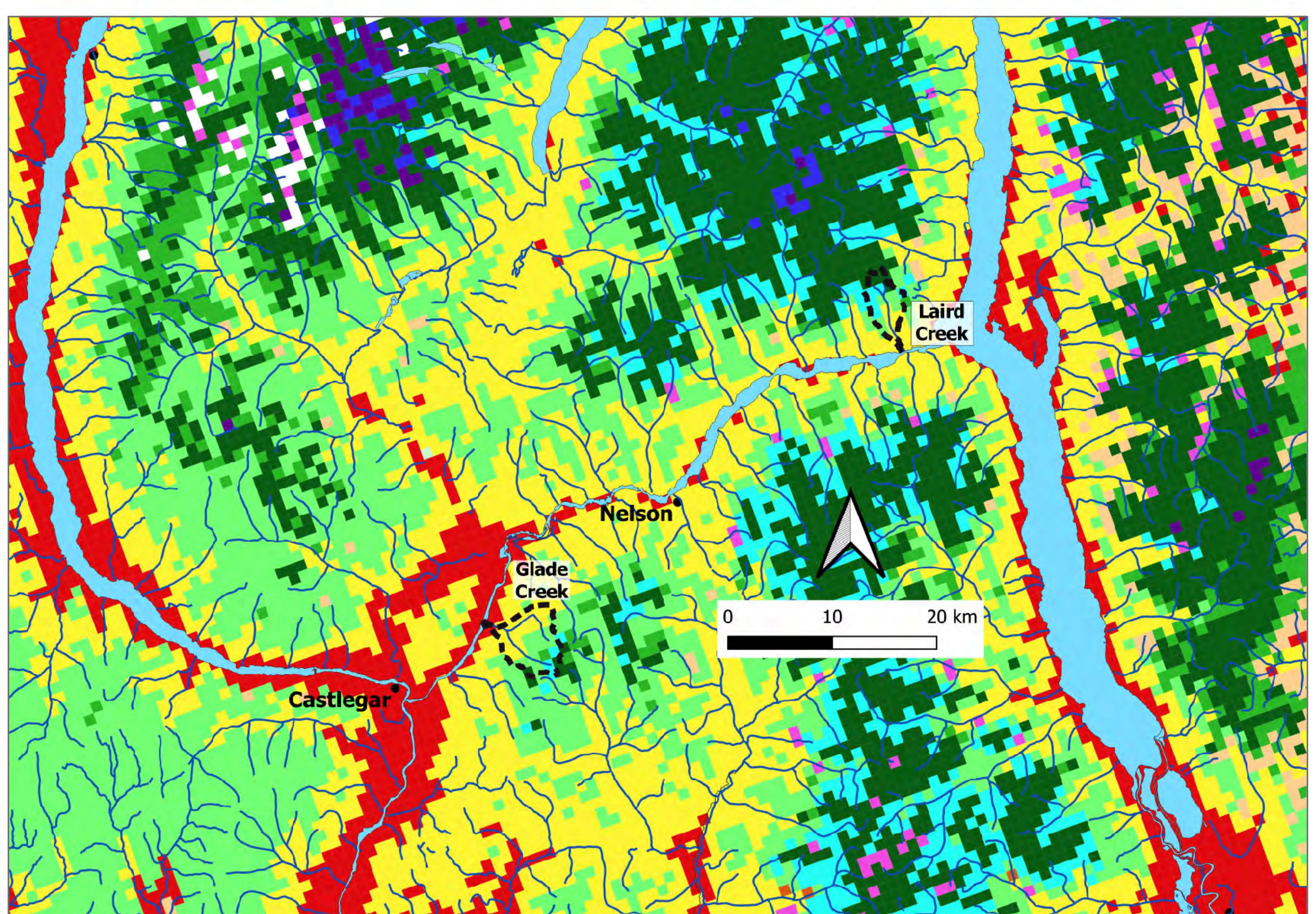


Very Hot / Dry 2080s

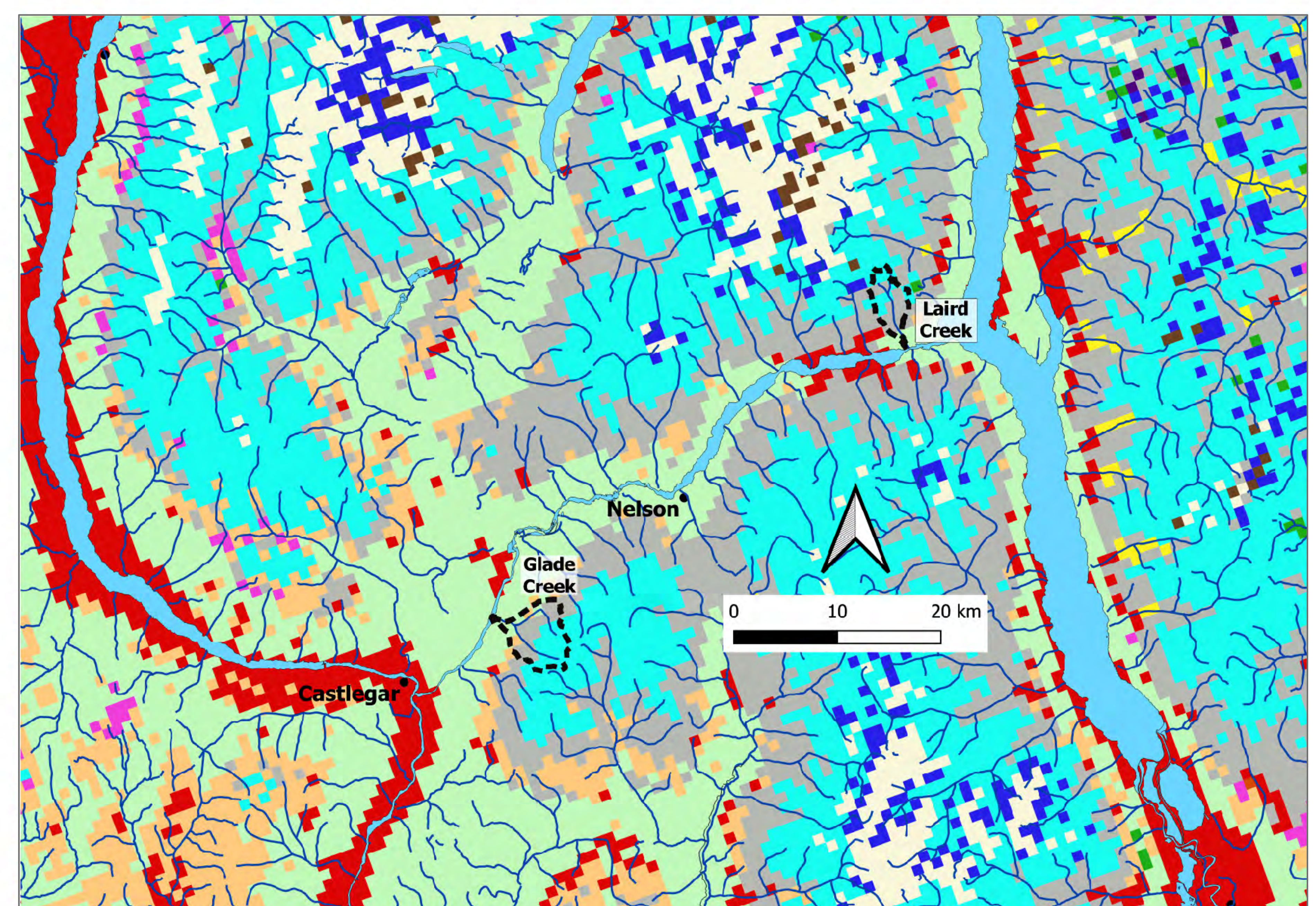




Warm / Moist 2080s



Hot / Wet 2080s



G. Utzig; original data from: Roberts and Hamann, U of A; HadCM3_B1, CGCM3_A3, HadGEM_A1B

Legend

- Alpine
- Alpine parkland
- Wet subalpine forest
- Dry subalpine forest
- Coastal hemlock
- Transitional coast/ interior hemlock
- Montane/sub-boreal spruce forest
- Wet interior cedar/ hemlock
- Moist interior cedar/ hemlock
- Dry interior cedar hemlock
- Grand fir/ Douglas-fir
- Wet Douglas-fir
- Dry Douglas-fir
- Ponderosa pine savanah
- Grassland/ steppe

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6. LAIRD WATERSHED MAPS

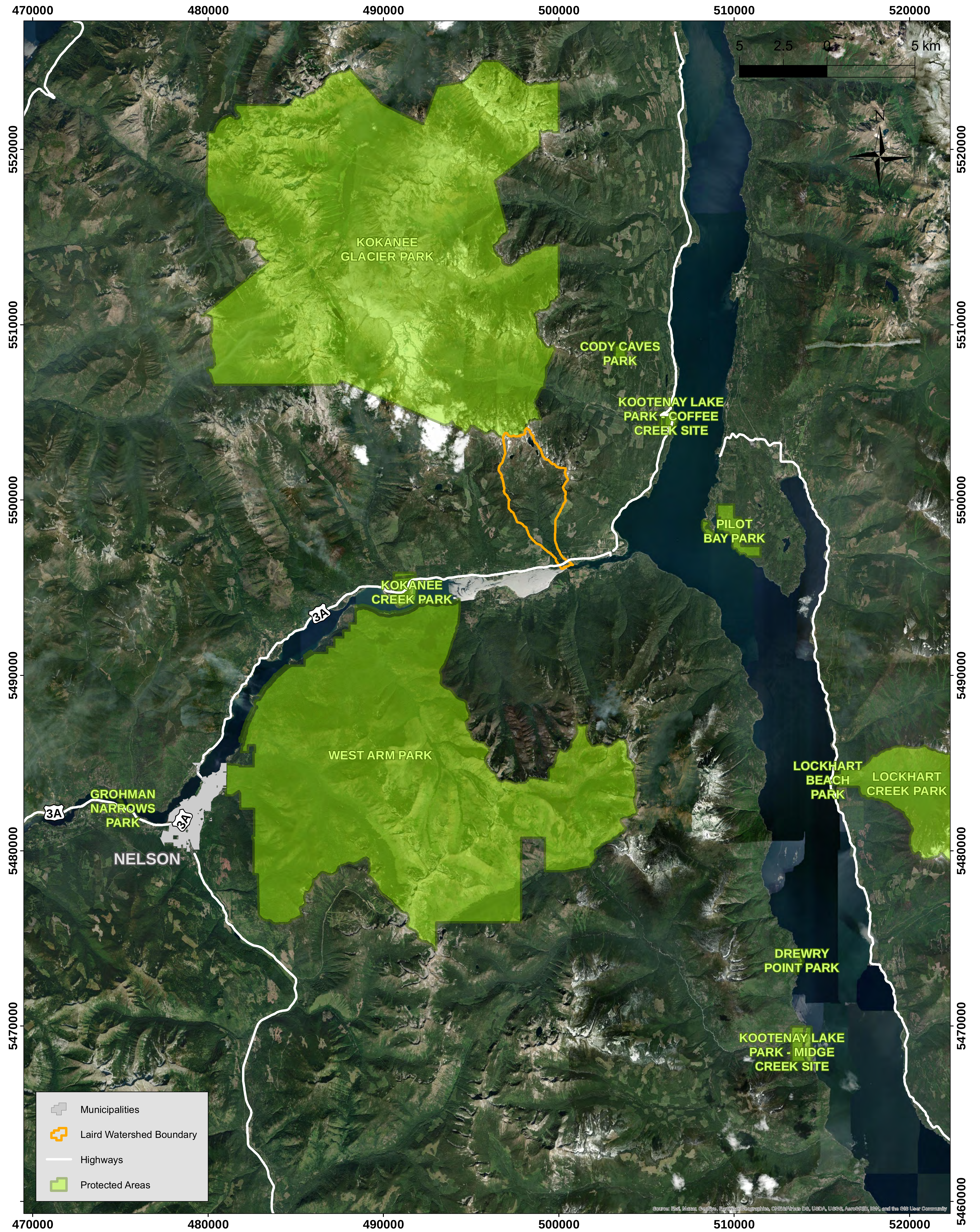

Photo 1. Intact older forests

The Glade watershed contains large areas of relatively intact forests, including older forests and old veterans. Contiguous forest stands and intact watersheds are essential for providing habitat to a wide range of flora and fauna, along with the plethora of ecosystem benefits they provide, including pure water in moderate flows throughout the year; and carbon sequestration and storage.

Photo 2. Clear-cuts and tree plantations within watersheds

The landscape around the watershed is highly fragmented by logging, roads, transmission lines and other human developments. A large portion of the regional landscape's forest cover includes historic logged areas that naturally regenerated, and more recent clearcuts that were converted to tree plantations, which have a significantly different composition and structure than natural forests.

Photo 3. Intact forests and habitat

Intact, natural forests are also referred to as primary forests. All forests that have not been significantly altered by industrialized society's activities are primary forests. Intact natural forests provide high quality water in moderate amounts throughout the year. Water management by intact, natural forests improves as the forest ages. Thus, old-growth primary forests provide the best water.

Photo 4. Creeks and water quality

Intact watersheds are essential for pure and abundant water supplies. Natural ecosystem processes help to regulate water flow, capturing early season snow melt and slowly releasing it through the watershed in summer and fall. Intact systems also provide high quality water, buy naturally filtering it through decayed fallen trees and natural soil profiles.

Map 1
Laird Watershed Landscape Context

Relatively intact watershed in a fragmented landscape provides opportunity for landscape level protected area and climate change refugia.Part of the red-listed Interior Wetbelt ecosystem encourages full protection of watershed.

Map 1: Landscape Context
Map 2: Topography and General Sensitivity
Map 3: Natural Character
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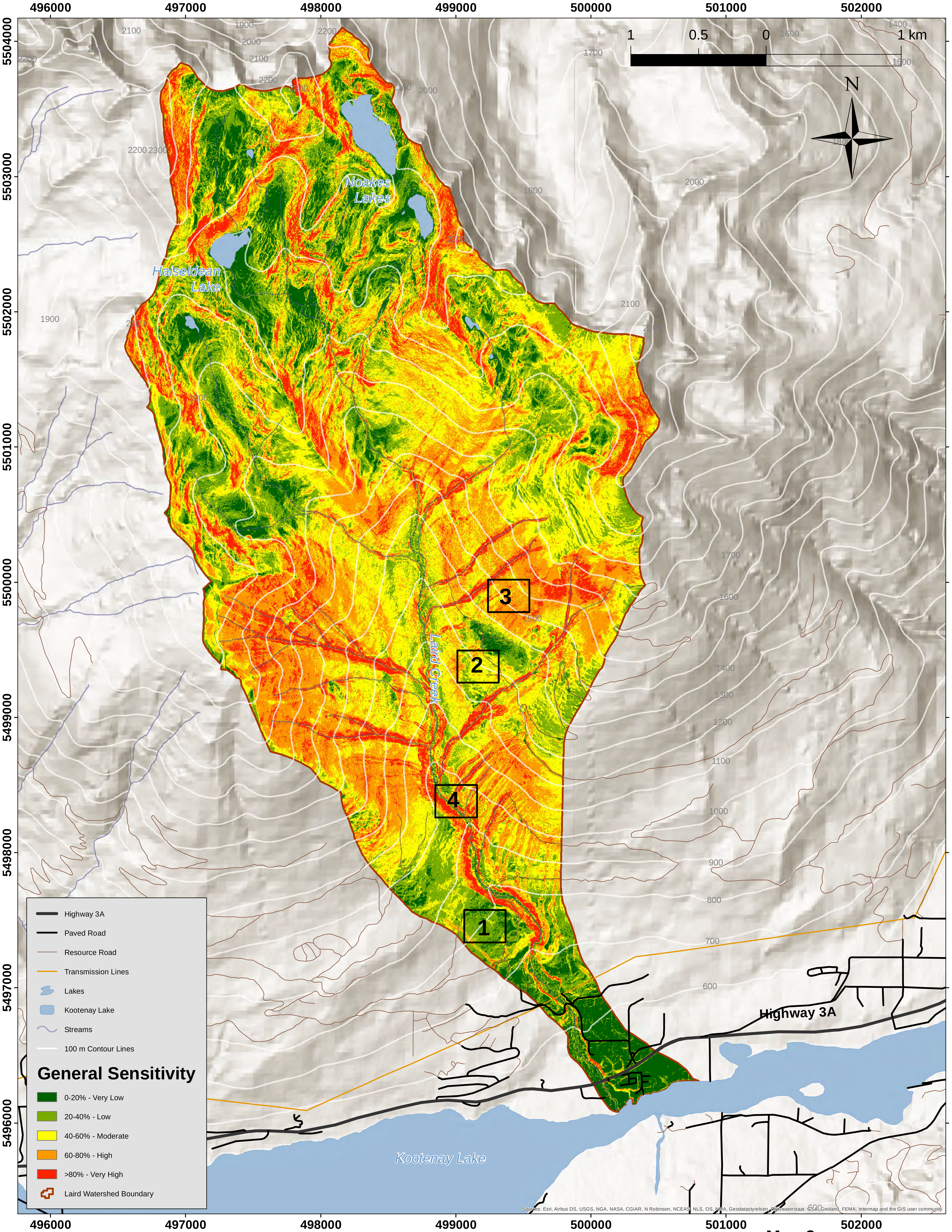


Map 2
Laird Watershed
Topography and General Sensitivity

As slope gradient increases, the need for caution in decision making increases. Factors additional to slope gradient need to considered to assess terrain sensitivity - landform, soil characteristics, moisture, etc.

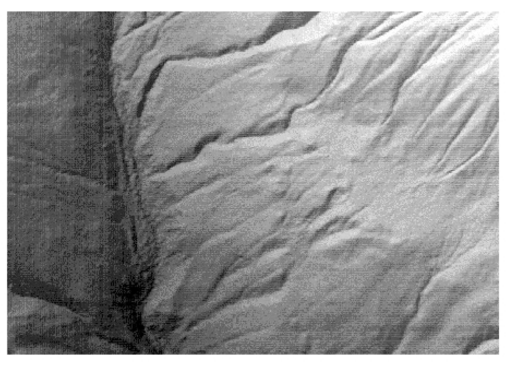
Photo 1. Low sensitivity

Low slope gradient, unbroken slopes that are mesic, or medium moisture are generally stable and offer the most options for Nature-directed activities. However, if these slopes are either wet or dry they display ecological limits that preclude many activities.

Photo 2. Moderate sensitivity

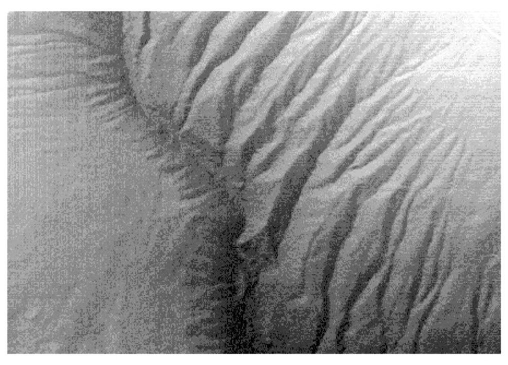
Moderate slopes, with slope gradients that range from 40-60% are on the edge between stable areas and unstable areas within a precautionary Nature-directed framework. On terrain within the lower end of this class, careful design, layout, and operations that protect the soil surface and avoid cutting into the slope are possible within ecological limits. However, terrain at the upper end of this class or gullied terrain generally preclude activities, like roads and logging.

Photo 3. High sensitivity: lower slope gullied terrain



When disturbed, these very steep slopes (60-80%) are prone to surface erosion that delivers sediment to lower slopes and water courses below. This tendency is magnified when the slope is dissected by gullies, creating a broken, steep slope condition. Depending upon landform and soil types, and site moisture conditions these slopes may be the source of landslides.

Photo 4. Extreme sensitivity: deeply incised gullies



Extreme slopes (>80%) are beyond reasonable ecological limits for development activities, and precluded from such activities. This extreme ecological and physical sensitivity is heightened when the terrain is broken by gullies with steep side slopes. In forested landscapes, full tree cover is important to maintain on these slopes to insure their integrity.

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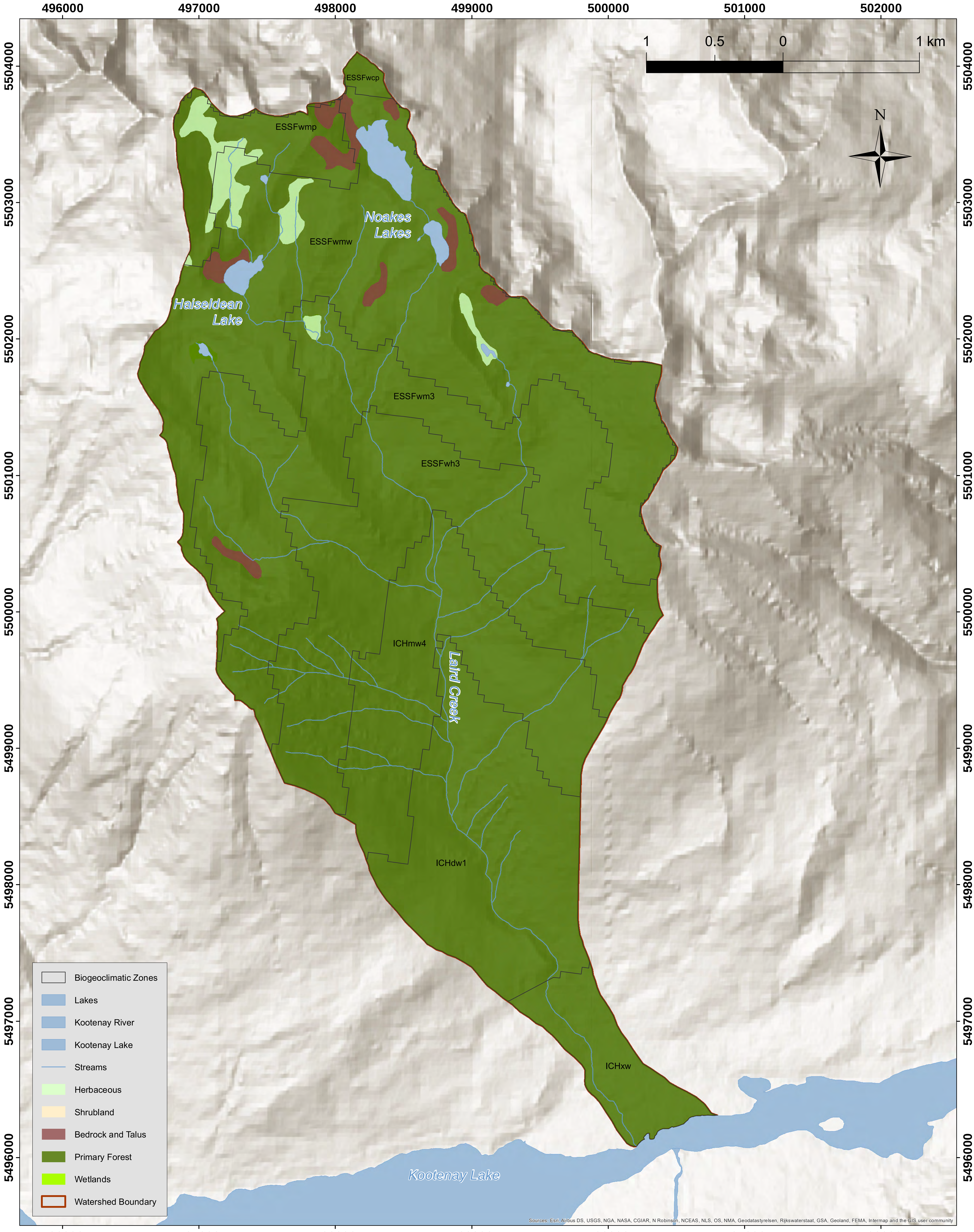

Photo 1. Younger forests

Without human intervention, younger forests would be expected to occupy small portions of most of the watershed. Natural disturbances such as fire, landslides, and insect outbreaks in a healthy natural ecosystem typically result in small areas of disturbance that enhance and maintain bodiversity. The large even age young to mature stands that dominant a large portion of the landscape are a reflection of the massive modification and interruption to natural process that have occurred since the advent of industrial forestry.

Photo 2. Mature forests with old vets

Early industrial era logging was limited by the available technology and restricted by difficult terrain. As a result, much of the 100+ year old forestry was focused on high-grading, i.e. removal of the largest and best quality trees. Since this work was mainly done by hand, a large portion of the smaller trees and saplings were not cut and were free to grow into the mature forests we have today. These older logged areas frequently have large old trees, termed veterans or vets, that were not cut and now have a significant ecological value.

Photo 3. Old subalpine forests

The remnant older high elevation forests in the Laird watershed represent the natural character, or expected pre-industrial condition of the watershed. Aside from large stand replacing fires and other natural events, the majority of the higher elevations of the watershed would look similar to these remnant stands before modern forestry and other resource development occurred.

Photo 4. Sparsely vegetated ridges, talus slopes and rock outcrops

In a natural watershed, there are areas where forests do not become established, or forests are limited to small stunted trees due to site conditions. Rocky ridges, steep slopes with coarse rocky material or thin soils, and areas with high wind exposure or cold air drainage, limit the ability of forests to develop. These non-forested areas contain important habitat for many species that are adapted to those specific conditions.

Map 3
Laird Watershed
Natural Character

Primary forests, particularly old-growth forests, conserve and manage water far better than second-growth forests. Plantation "forests" from logging are ineffective in water conservation. These forests need to be grown well past their rotation age in order to adequately conserve water, particularly in the climate crisis.

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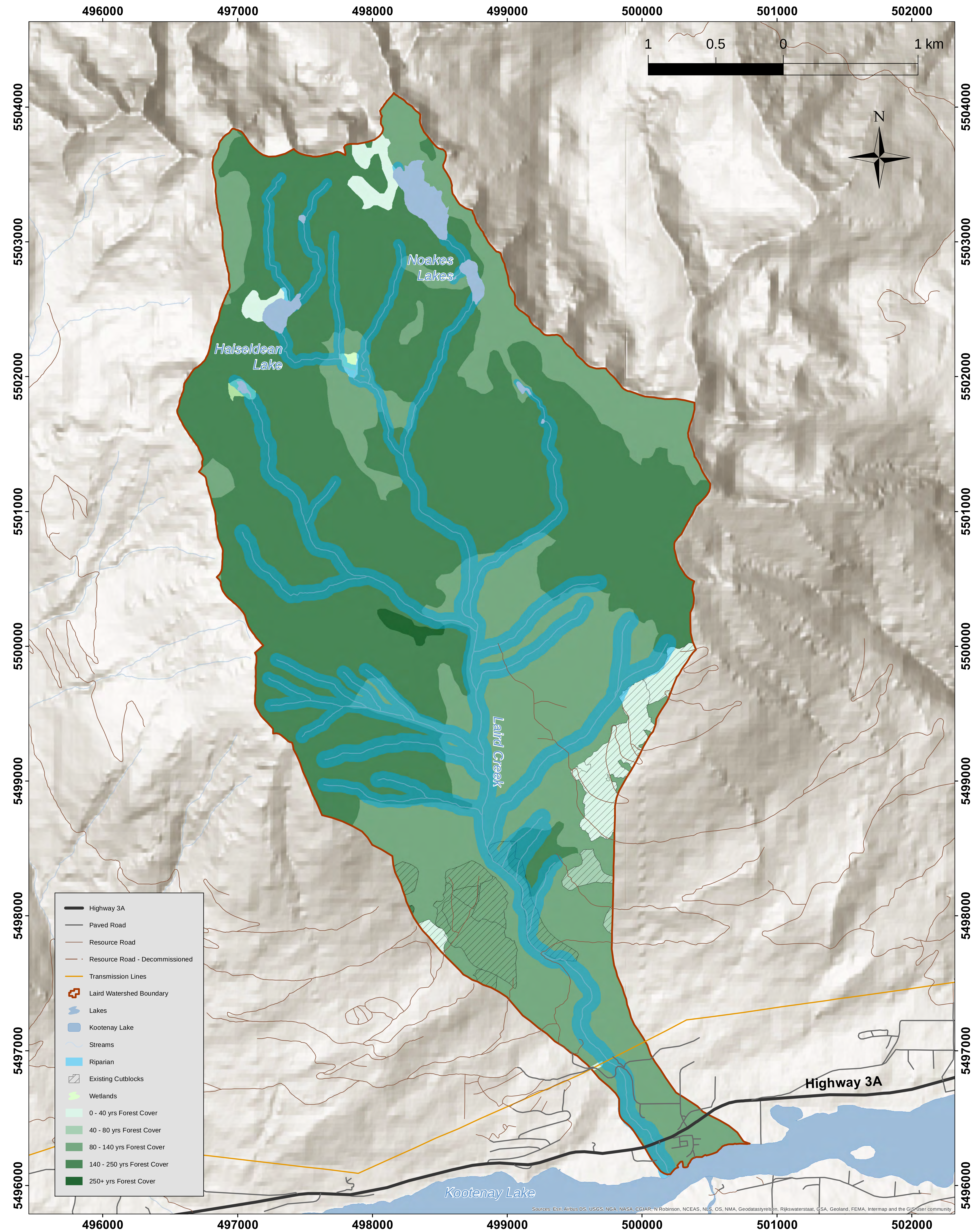

Map 4
Laird Watershed
Old Forest, Non-Forest, and Logged Areas

Over half (58%) of the watershed is old/old-growth forests that need protection for water, biodiversity, and ecological resilience. A substantial portion (36%) of the watershed contains mid-age forests. With increased age, these forests will improve in their effectiveness as water managers, biodiversity sources, and climate regulators. Many of these forests are found on steep, gullied slopes that are ecologically sensitive and prone to surface erosion and landslides. Recent logging is encroaching on these mid-age forests, heightening the need to conserve them as they move towards becoming future old forests.

Photo 1. Old forests

In the Laird Watershed, older forests are fairly common on mid to higher elevations that did not historically burn and were not logged. As these areas represent some of the last remaining old, high quality trees in the watershed, they are now being targeted for logging. High elevation forests are essential for maintaining summer and fall water flows, as their dense canopy cover and complex structure are effective at capturing and slowly releasing water from a melting snowpack. One logged, these areas lose most of their water retention functions, resulting in higher freshet flows and reduced summer low flows in the watershed.

Photo 2. Nid-aged forests

Maturing forests are the future old forests for a watershed. Justifiably, much attention is given to protecting the older forests in a watershed. However, protection of mature forests is equality important to ensure that mature forests are allowed to naturally age. As this process takes hundreds of years, proper planning is required to ensure that the old growth of the future has the opportunity to develop, and that the many different types of forested ecosystems are represented, including the full range of tree species, and site conditions (wet, dry, poor rich, etc.).

Photo 3. Riparian ecosystems—riparian zones & riparian zone of influence

Riparian ecosystems are directly associated with water, including creeks, wetlands and lakes, and consist of two parts: riparian zone and riparian zone of influence. The riparian zone of influence is the upland area immediately adjacent to the riparian zone. What happens in the riparian zone of influence directly affects the riparian zone and water body. Riparian zones of influence end when the slope decreases enough so that down slope movement of water and nutrients in the soil slows significantly. Riparian ecosystems typically have abundant moisture throughout the growing season, and rich soils, resulting in productive ecosystems and often the larger trees in the watershed. Riparian zones are linkages within a watershed and are essential for maintaining water quality.

Photo 4. Logged areas

Logged areas effectively re-set the ecological development of an ecosystem. Current industrial logging strips all trees from a site, creates extensive soil disturbance, and removes or burns the majority of the carbon from a site. Given the inhospitable conditions that follow logging, forest regeneration is slow. Management of logged areas attempts to exclude non-tree plants that heal the disturbed sits and usually plant the area with a limited number of commercially desirable tree species, often with limited genetic diversity and not from local genetic material. The future tree plantations that grow on these sites are very different from natural forests, and typically lack the diversity and complexity that is inherent in a natural system, making them much less resilient.

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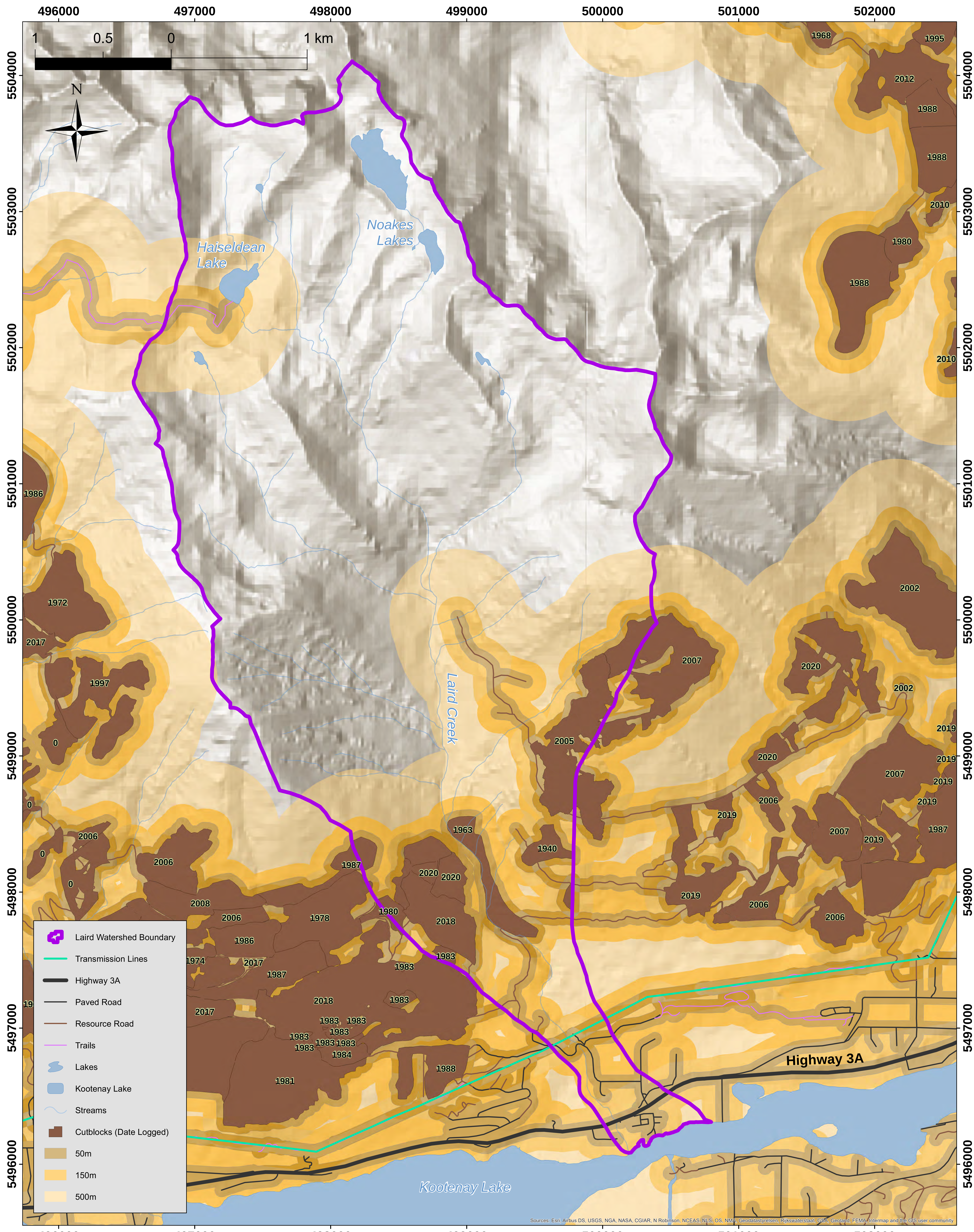


Map 5
Laird Watershed Industrial Disturbance

Industrial disturbances fragment forest landscapes, cause loss of habitat and connectivity, degrade water and soil, and exacerbate climate change. With cautious zones of influence, the actual footprint of roads, transmission lines and clearcuts is significantly larger than the actual opening created by each type of disturbance. In the Laird watershed 12 kilometres of road cover about 20 hectares of land, with zones of influence roads cover up to 615 hectares of land. Existing clearcuts cover 98 hectares of land, with zones of influence clearcuts cover about 386 hectares of land. The 0.5 kilometre of maintained transmission line right of ways, affect about 50 hectares of land.

Photo 1. Roads

The construction of roads throughout a watershed often results in many long-lasting impacts. The physical disturbance caused by the road is significant, particularly as slope gradient increases. Roads result in modifications to surface water flow via interception and concentration of water in ditches and culverts, create increased potential for erosion and landslides, and provide a pathway for the introduction of invasive species. Where roads modify topography, the original natural ecosystems, cannot be restored to its original condition after resource development is done. Partially restored roads are used for years after for recreation, hunting and other purposes, effective extends the disturbance of the road to degradation of wildlife populations.

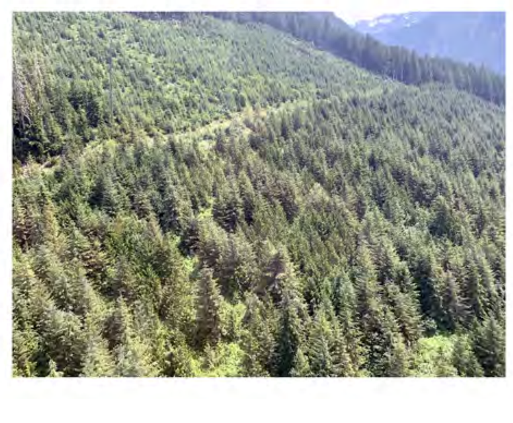
Photo 2. Clear cut logged blocks

Timber management activities affect ecological processes and population dynamics well beyond the apparent physical boundaries of access roads and clearcut blocks. The zone of influence, or "edge effect," created by roads, logging, and other disturbances extends much farther into the surrounding landscape than is often realized. Impacts within these zones of influence include habitat loss, fragmentation, increased air and soil temperature, increased wind and drying influences, and much more.

Photo 3. Motorized recreation

Off-road vehicles, such as ATVs, snowmobiles and other types of motorized recreation often cause damage in sensitive areas. In the Laird watershed, an information subalpine trail to Haiseldean Lake has extensive rutting in wet areas, resulting in erosion and sedimentation to streams. Old ATV use in the subalpine fens has created disturbances that will be long lasting, as alpine systems recover very slowly. Winter use of snowmobiles may not cause physical disturbances, but the activity is well known to have negative effect on wildlife. Glading runs from snowcat or helicopter ski operations, and clearing for helicopter pads, can impact sensitive

Photo 4. Clearcuts With Moderate Height Regeneration



The forest canopies of tree plantations are very simple and lack the biological diversity and physical complexity needed for intact, healthy forests. This is part of the reason that tree plantations are more flammable and less resilient to climate change than intact natural forests. Moderate height trees in a plantation, also lack the structure to effectively conserve and manage water

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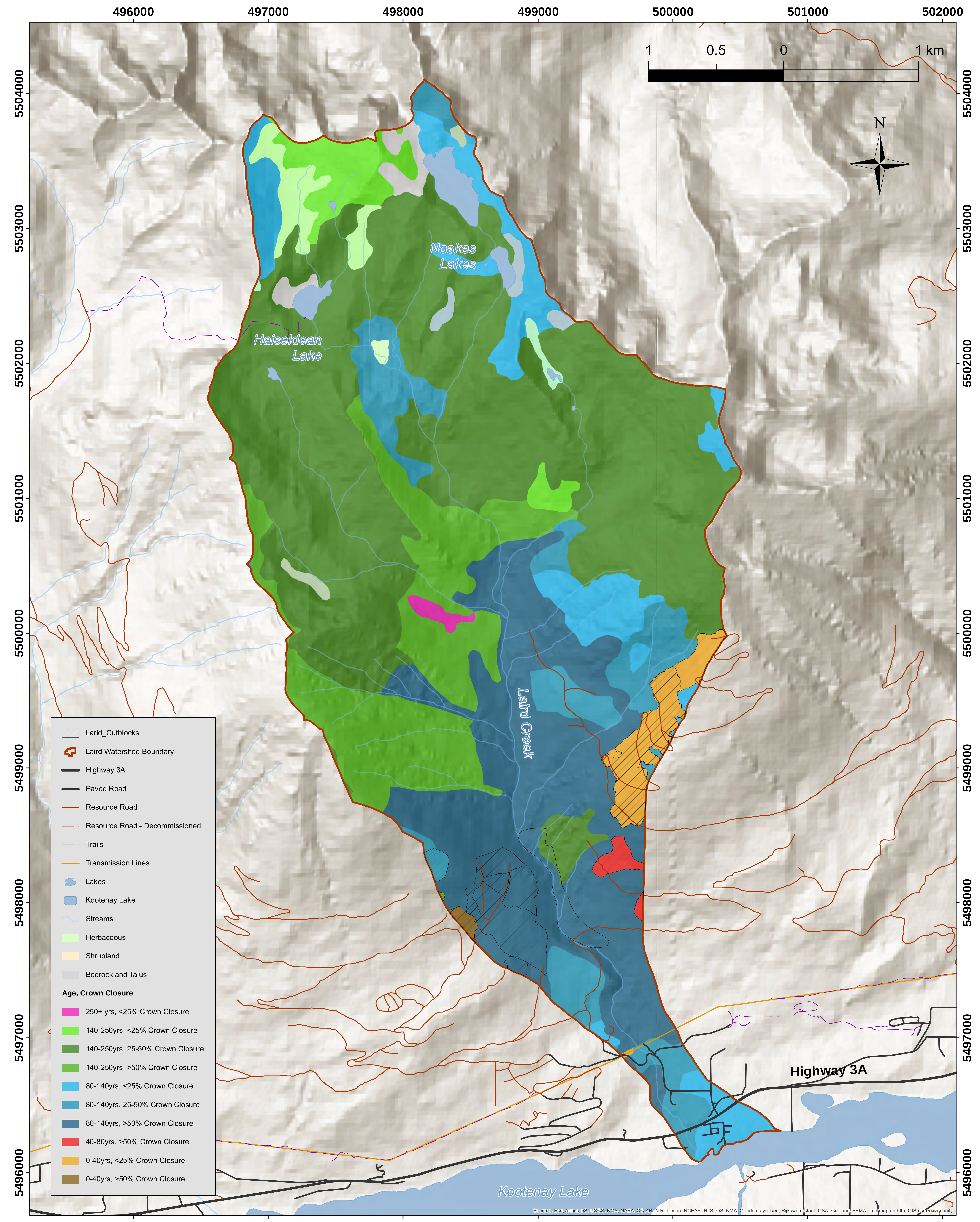
- Map 13: Protected Landscape Network (PLN)
- Map 14: Projected Bioclimates for the 2080s

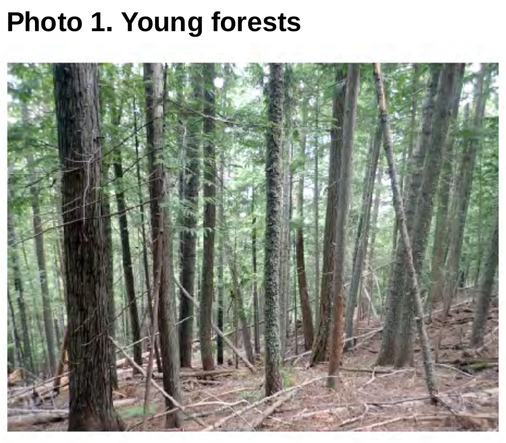
Projection: NAD 83 UTM 11N
Scale: 1:15,000
Date: March 2022
Base Data: Province of BC; BC Data Catalogue & LidarBC



Map 6
Laird Watershed Forest Crown Cover

Crown cover reflects the crown mass of living leaves, which intercept, redistribute, store, and conserve water, both rain and snow. Older trees with dense crown cover provide the best water conservation benefits.

Photo 1. Young forests



Young forests are often even-aged, tightly spaced trees with small crowns. These forests have limited diversity in composition and structure, especially on the forest floor which is often missing decayed wood and deep organic layers. Only a small number of plant and lichen species are found in these conditions. These forests have yet to undergo natural self thinning that reduces density, creates openings, and gradually increases structural diversity and complexity as the forest ages.

Photo 2. Mature forests

Mature forests, in the 80-140 yr range, are starting to develop the vertical and horizontal complexity that is so important for biodiversity and habitat. They often have multiple layers of tree canopies, with shade intolerant trees occurring as a subdominant canopy. Mature forests generally lack the old trees, snags, and large fallen trees of an old forest.

Photo 3. Old forests

Old forests are complex ecosystems that are characterized by the prevalence of old and (typically) large trees, a wide range of tree species and ages, canopy gaps, multi-layered canopies, and a high occurrence of large snags and decayed wood from fallen trees. These forests are naturally resilient to many natural disturbances from wind and fire to insects and disease. Young trees and sapling become established in openings created by canopy gaps. Species diversity is high, and specialised habitat for many old-growth dependant specialists occurs. The large crown masses and multi-layered, coupled with decayed wood and soil organic matter create an effective method of water interception, distribution, storage, and filtration.

Photo 4. Tree plantations

Logged areas are replanted with a variety commercially desirable conifer species at a high density. As the plantation establishes, a very dense canopy cover of closely spaced trees forms, and encroachment of natural regeneration increases both crown and stem density. Plantations conserve and manage water poorly, and have also been described as "biological deserts," owing to their lack of species and ecosystem processes. Without careful management, tree plantains often result unhealthy, poor quality stands of trees. This poor quality extends to the wood products generated from plantation trees, because the trees largely consist of juvenile wood that is a poorly suited for both structural lumber and pulp.

Map 1: Landscape Context	Map 8: Slope Stability Hazard
Map 2: Topography and General Sensitivity	Map 9: Peak-Flow Augmentation
Map 3: Natural Character	Map 10: Low-Flow Moderation
Map 4: Old Forest, Non-Forest, and Logged Areas	Map 11: Unique and Rare Habitats
Map 5: Industrial Disturbances	Map 12: Hydrologic Sensitivity
Map 6: Forest Crown Cover	Map 13: Protected Landscape Network (PLN)
Map 7: Surface Erosion Yield Potential	Map 14: Projected Bioclimates for the 2080s

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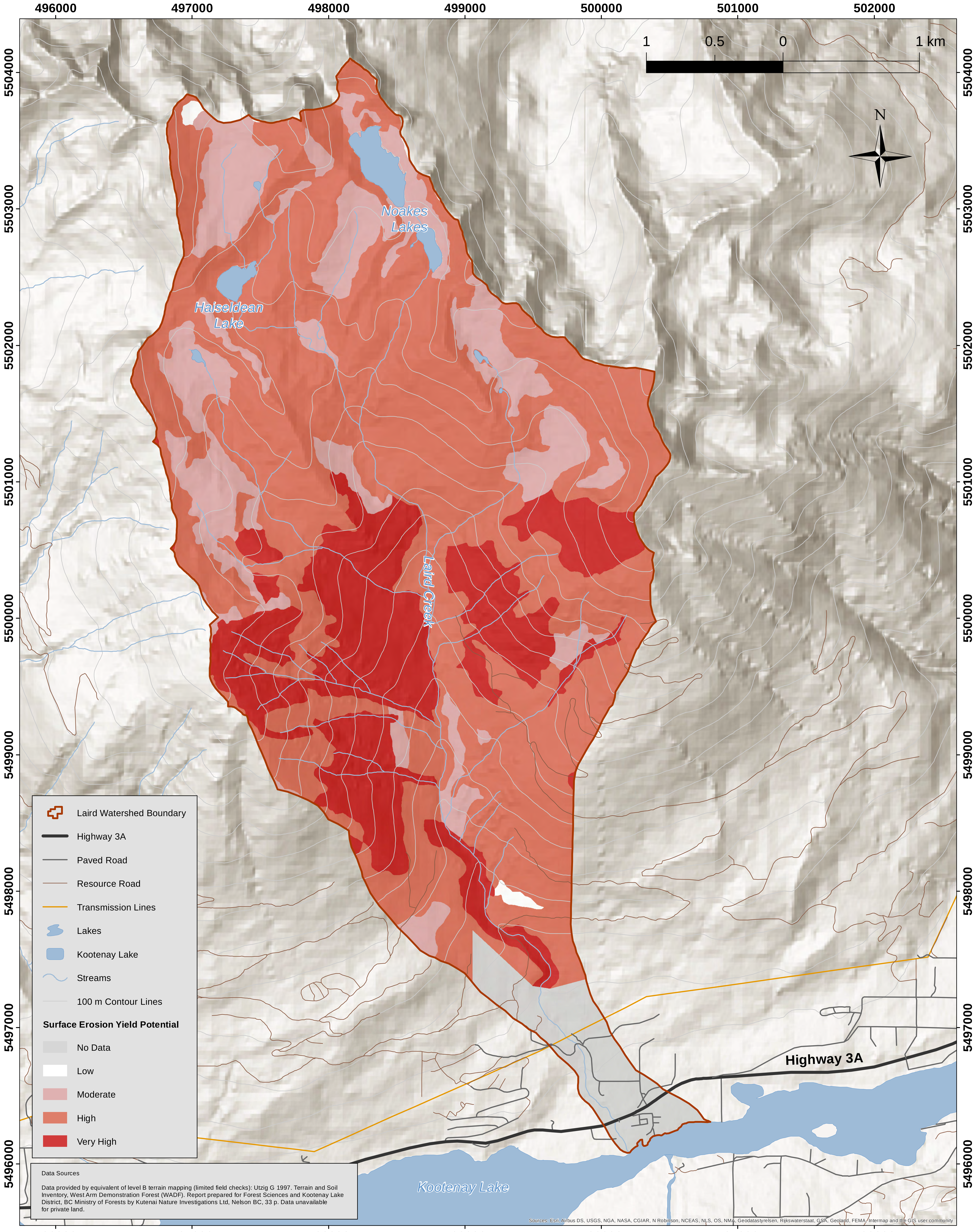

Map 7
Laird Watershed Surface Erosion Yield Potential

Surface disturbance on erodible soils can cause increased turbidity in waterbodies and potentially impair drinking water sources and aquatic habitats.

Photo 1. Road cutbanks as sediment sources

Roads on sloping ground create cutbanks which may erode because they are oversteepened, poorly vegetated, or intercept seepage from the subsurface. As a result, mineral soils are exposed to surface erosion processes. Eroded materials make their way to ditchlines and can be readily conveyed to the stream network, polluting aquatic habitats with suspended sediment and damaging drinking water supplies.

Photo 2. Erosion from road surfaces

The surface of logging roads is continually disturbed by industrial use and by the traffic from recreational vehicles. If local materials used in road surfacing are coarse and if road gradients are modest, surface erosion can be tolerable. Commonly, roads climb steep slopes and erodible material types are used in surfacing. In these cases, runoff from these impermeable road surfaces can generate significant erosion, thereby impairing water quality of streams and other receiving waterbodies. Common erosion processes include sheetwash and rilling.

Photo 3. Surface disturbance from forest-harvest activities

Ground-based forest-harvest activities create surface disturbances from large machinery and other activities such as dragging logs. These disturbances degrade soils and expose them to surface erosion processes.
Skidding operations are commonly undertaken on slopes up to 40% and steeper, leading to soil erosion and declines in water quality.

Photo 4. Water quality deterioration

Suspended sediment causes deterioration of water quality in receiving waterbodies. Aquatic habitats and community drinking water supplies are common values that can be threatened by elevated levels of suspended sediment. Where landslides and channel instability are also involved, coarse sediment may also be introduced to streams potentially leading to inundation and burial, bank instability, and safety hazards. In persistent or extreme cases of sedimentation, streams may be dewatered particularly during the low-flow period when the remaining streamflow goes subsurface in the excessive bed sediment.

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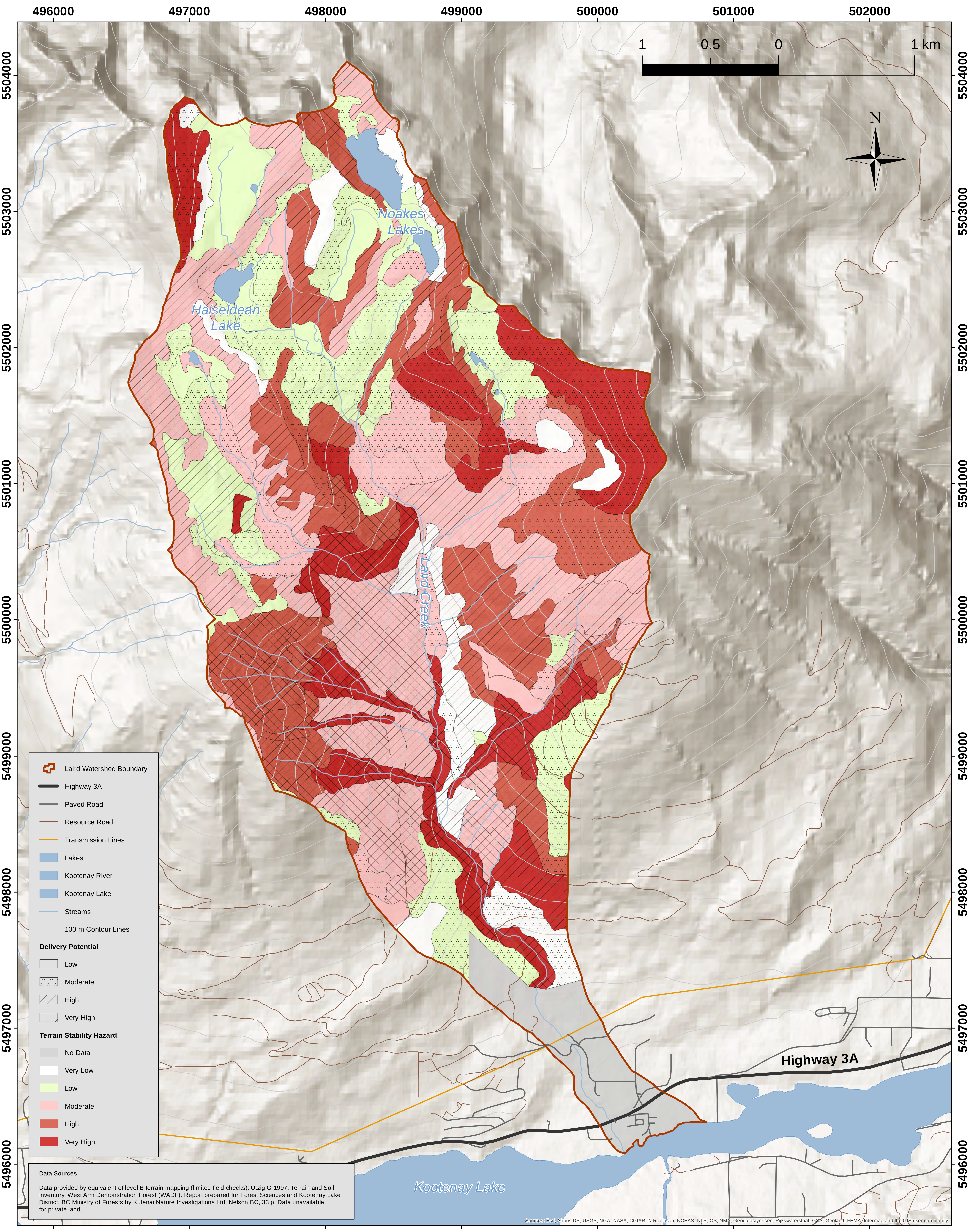
Watersheds BC
WEST KOOTENAY ECOSOCIETY



Map 8
Laird Watershed
Slope Stability Hazard

Many watershed locations are vulnerable to slope instability, which can lead to downslope ecological harm and hazards to human values due to landslides.

Photo 1. Drainage from roads on steep ground

Concentrated drainage below resource roads are common landslide initiation points. Under natural conditions, runoff and shallow groundwater flow are dispersed through the soil mantle and in the forest floor. Road construction typically concentrates drainage either into ditchlines or along road surfaces leading to high levels of runoff immediately downslope. Where this concentration coincides with unstable terrain, typically on steep and moist slopes, slope failures can occur. These can form open-slope failures or debris flows where they enter steep streams and possess sufficient momentum.

Photo 2. Landslide paths below resource roads

Forestry and other resource activities carried out in steep terrain may require road construction on unstable or potentially unstable slopes. Depending on the quality of construction, the approach to drainage management and long-term maintenance efforts, drainage pathways can be readily altered leading to downslope instability and, potentially, landslides. Landslide paths bring degradation and damage to downslope and downstream values.

Photo 3. Slope failures from concentrated drainage

Roads on steep slopes typically dispose of excavated material as sidecast, forming fillslopes. Often oversteepened, these are typical initiation sites of slope failure. Culverts receive drainage concentrated from upslope areas and ditchlines and provide discharge points that present hazards to downslope stability. Routine drainage management from resources roads on steep ground can lead to debris slides.

Photo 4. Disrupted drainage from resource roads

Resource roads are generally built wide enough to sustain large industrial trucks and promote safety for those travelling along the road. However, wide roads on steep terrain require careful drainage systems including cutbanks shedding into ditchlines which in turn may carry the runoff long distances to the next suitable discharge point. Cutbank erosion may quickly lead to blocked ditchlines involving random discharge of concentrated drainage down potentially unstable slopes. Once initiated, landslides can travel long distances and potentially reach important aquatic habitats, and human infrastructure.

Projection: NAD 83 UTM 11N
Scale: 1:15,000
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Map 9 - Preliminary Laird Watershed Peak-Flow Augmentation

Calibration, Validation & Revision Required

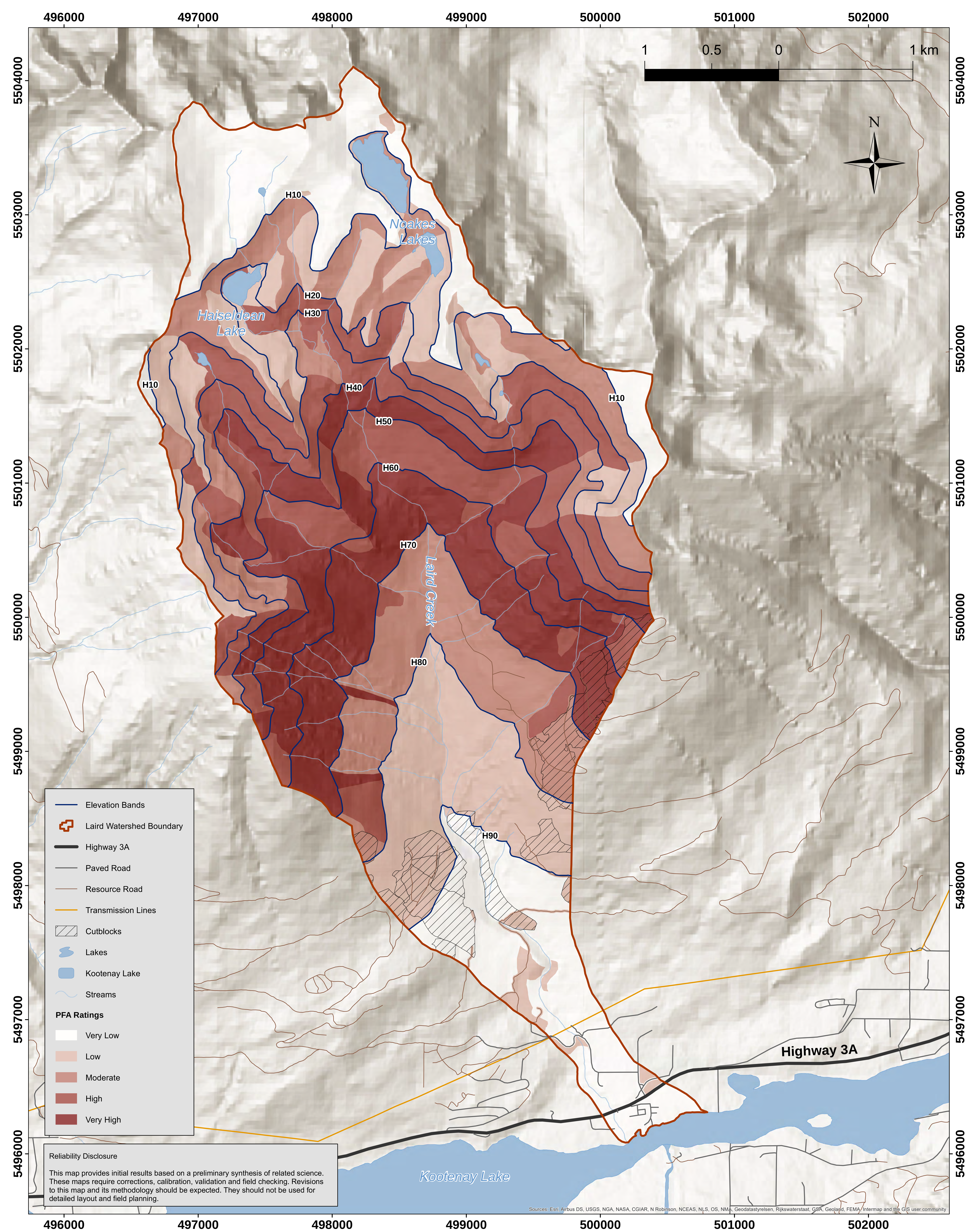


Photo 1. Forests moderate snow dynamics

In the Interior Wet Belt, forest cover intercepts falling snow, preventing it from reaching the ground surface. While suspended in the forest canopy, a large proportion (30-40%) of the total snowfall at a site is evaporated back into the air ("sublimated") before it ever reaches the ground surface. Forests also limit snowpack melt rates thereby reducing the pace at which runoff is formed during periods of heating.

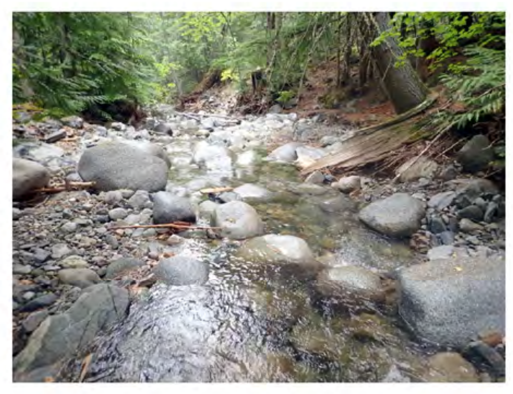
Photo 2. Clearcuts affect snow accumulation and melt

In snow-dominated watersheds, clearcuts increase snow accumulation and enhance melt rates. In clearcuts, sunny aspects (orientation to the sun) and steeper ground promote rapid melt whereas north aspects reduce melt both in clearcuts and under the forest canopy. Precipitation (including snowfall) rises with elevation in the Interior Wet Belt. As a result, the consequences for runoff of removing forests may be amplified with elevation.

Photo 3. Roads and ditchlines accelerate runoff

Roads and ditchlines concentrate drainage and modify runoff dynamics. Active road surfaces are impermeable and prevent infiltration, leading to enhanced runoff in adjacent areas. Ditchlines transport water, often long distances, across hillslopes to discharge points that, depending on the stability of downslope areas, may or may not be suitable to receive the concentrated drainage.

Photo 4. Peak flow integrates melt and runoff processes across watershed



During the spring freshet and other periods of heating, watershed snowmelt concentrates in complex ways to form a hydrograph typically with a peak flow and/or a period of very high flow. The magnitude and timing of the peak flow is greatly influenced by snow accumulation and melt across the watershed. Melt dynamics are greatly influenced by forest removal and road construction which modify snow accumulation/melt and patterns of runoff. A lot is at stake for downstream regions where aquatic ecosystems, stream channels and human values are sensitive to runoff magnitude.

Certain watershed locations have a higher effect on the freshet's peak flow due to changes in snow accumulation and melt. Disturbances in these locations may lead to higher peak flows and damaging floods and channel instability.

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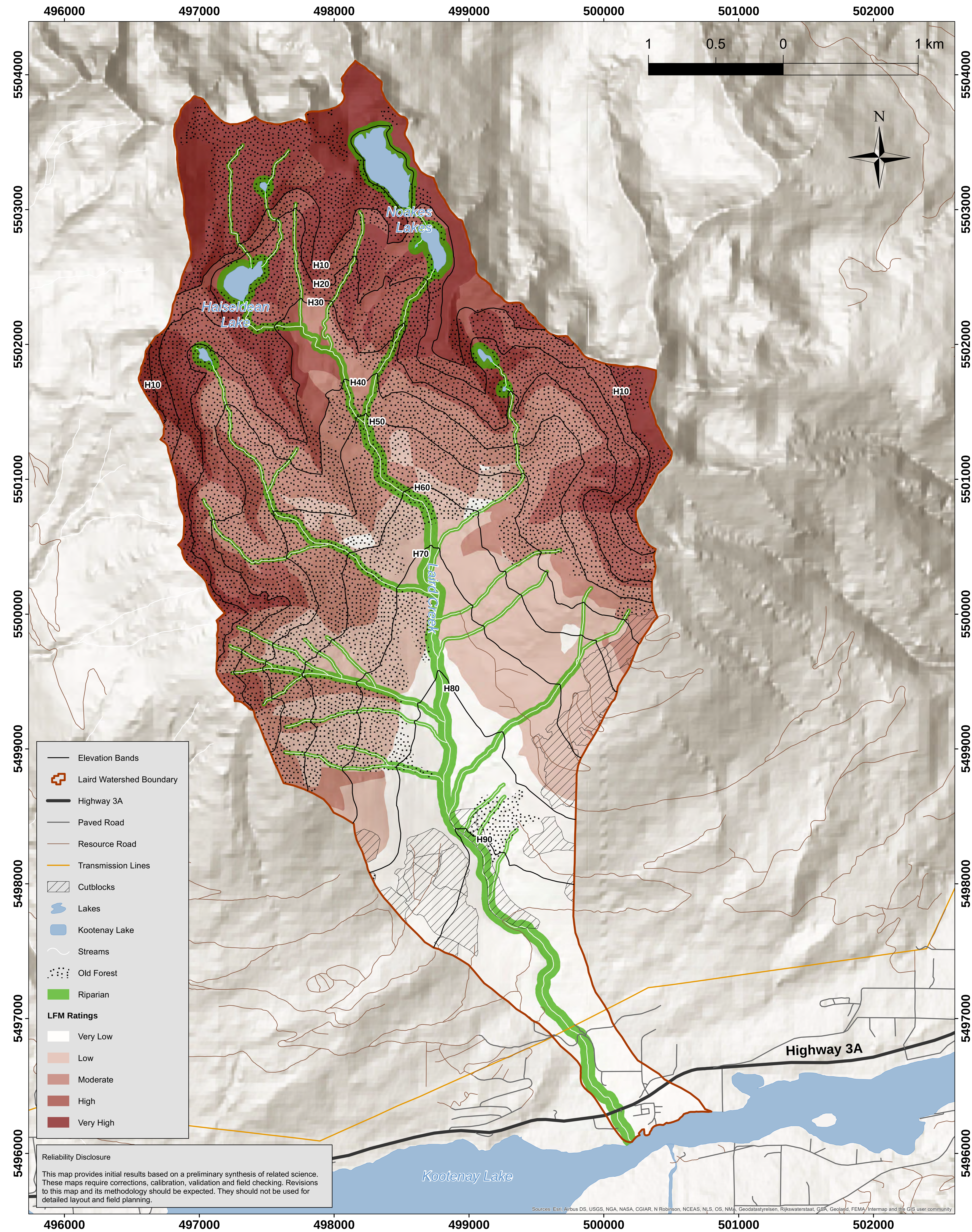

Photo 1. Forest Wetlands

Forested wetlands provide direct support to baseflows especially during periods of sustained summer heating. They represent locations where water is typically found year-round. They are associated with a slow release of drainage and often support rare and unusual species. Forest cover may also provide shading to the wetland to protect its moisture regime during periods of summer heating. This is expected to be of particular importance given the heating and heat waves associated with climate change projections.

Photo 2. Road cutbanks intercept shallow groundwater flow

Road cutbanks intercept shallow groundwater flow which may otherwise have been available to support late-season baseflow. Once in the ditchline, this water is routed to drainage structures which are frequently connected to the stream network. As the number of cuts increases into the soil surfaces of a watershed, the extent of potential interception grows thereby contributing to the decline in late-summer low flow. Minimising blading and reducing road widths provide strategies to reduce the impact of roads on baseflow.

Photo 3. Resource roads modify watershed runoff

Resource roads are built within mountain watersheds to provide access for many purposes. They extend the stream network enabling faster runoff from hillslopes to watershed outlet. Accelerated runoff patterns modify the annual hydrograph both during freshet - by speeding up and helping advance the timing of runoff and potentially increasing peak flows – and during baseflow period by reducing groundwater recharge through interception of shallow subsurface flows through the year. Roads also act as impermeable surfaces, preventing infiltration and further speeding up runoff processes.

Photo 4. Snow in small openings is not like in clearcuts

Small forest openings alter snow accumulation and melt in ways quite different than that of larger clearcuts. Depending on the size of the opening, snow accumulation can increase relative to forested sites while melt rates may remain unchanged or change only slightly (depending on the topography). If forest openings are designed carefully and respect the site's energy dynamics, it should be possible to use them to improve groundwater recharge thereby potentially providing opportunities to improve baseflow.

Map 10 - Preliminary Laird Watershed Low-Flow Moderation

Calibration, Validation & Revision Required

Certain locations and components in the watershed are more effective than others in raising and maintaining baseflows, especially in the face of prolonged summer heating. Disturbances in these locations may undermine reliability of baseflows for ecosystems and water supplies.

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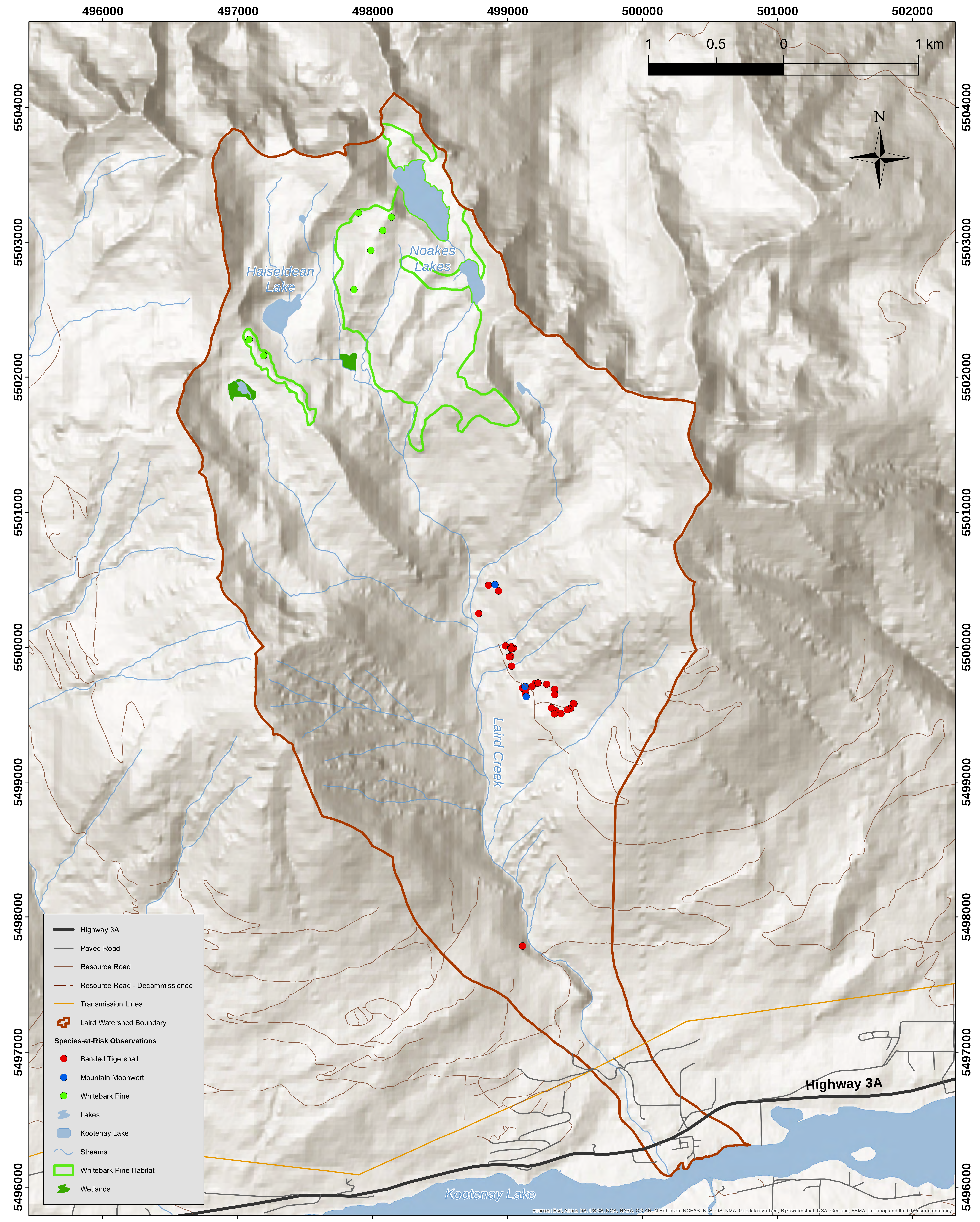

Map 11
Laird Watershed
Unique and Rare Habitats

Unique/rare habitats are small portions of the watershed but are essential to protect, because they are infrequent and critical to the persistence of key species. Habitats for threatened and endangered species are considered unique/rare habitats.

Photo 1. Banded Tigersnail

The banded tigersnail (Anguispira kochi ssp. occidentalis) is a blue-listed snail that only occurs in the Columbia and Kootenay River watersheds. While it is a threatened species, it is locally abundant in areas along Kootenay Lake. The banded tigersnail lives in a variety of forested habitats, most commonly occurring in moist areas with high canopy cover and generally adjacent to riparian areas. As with most gastropods, it is very susceptible to forestry and other activities that reduce the forest cover and disturb litter, woody debris or soil. It is likely abundant in the lower elevations of the Laird watershed.

Photo 2. Mountain Moonwort

Mountain moonwort (Botrychium montanum) is a blue-listed fern that occurs sporadically in Western North America. It is only known from about 20 locations in British Columbia, with the majority of the observations in the West Kootenays. It is an old-growth dependant species that is almost exclusively found in moist old western redcedar stands. Moonworts are perennial ferns that spend most of their lives below-ground, forming form mycorrhizal connections with subterranean fungi. As they are dependant on intact soil mycorrhizal network for survival, any disturbance to the forest stands they occur within will have a

Photo 3. Whitebark Pine habitat

Whitebark pine (Pinus albicaulis) is blue-listed in British Columbia and Endangered species nationally. It is restricted to upper elevation subalpine forests, typically along rocky ridges and slopes. Whitebark pine populations are decreasing due to the white pine blister rust, a very damaging non-native fungi that is widespread in the province. Whitebark pine seeds are critical food source for grizzly bears, particularly as a late season pre-hibernation energy source.

Photo 4. Subalpine wetlands

Subalpine wetlands, such as this Wf09 Few-flowered spike-rush – Hook-moss fen, are uncommon in the region and restricted to small, high elevation depressions. These high elevation fens are the only wetlands in the watershed occurring around the Haiseldean Lake basin. Wetlands are important for late season water flows, as they absorb a snow melt and rain and slowly release it over the growing season. Wetlands are very susceptible to disturbance, with recreation and off road vehicles damaging their sensitive organic soils.

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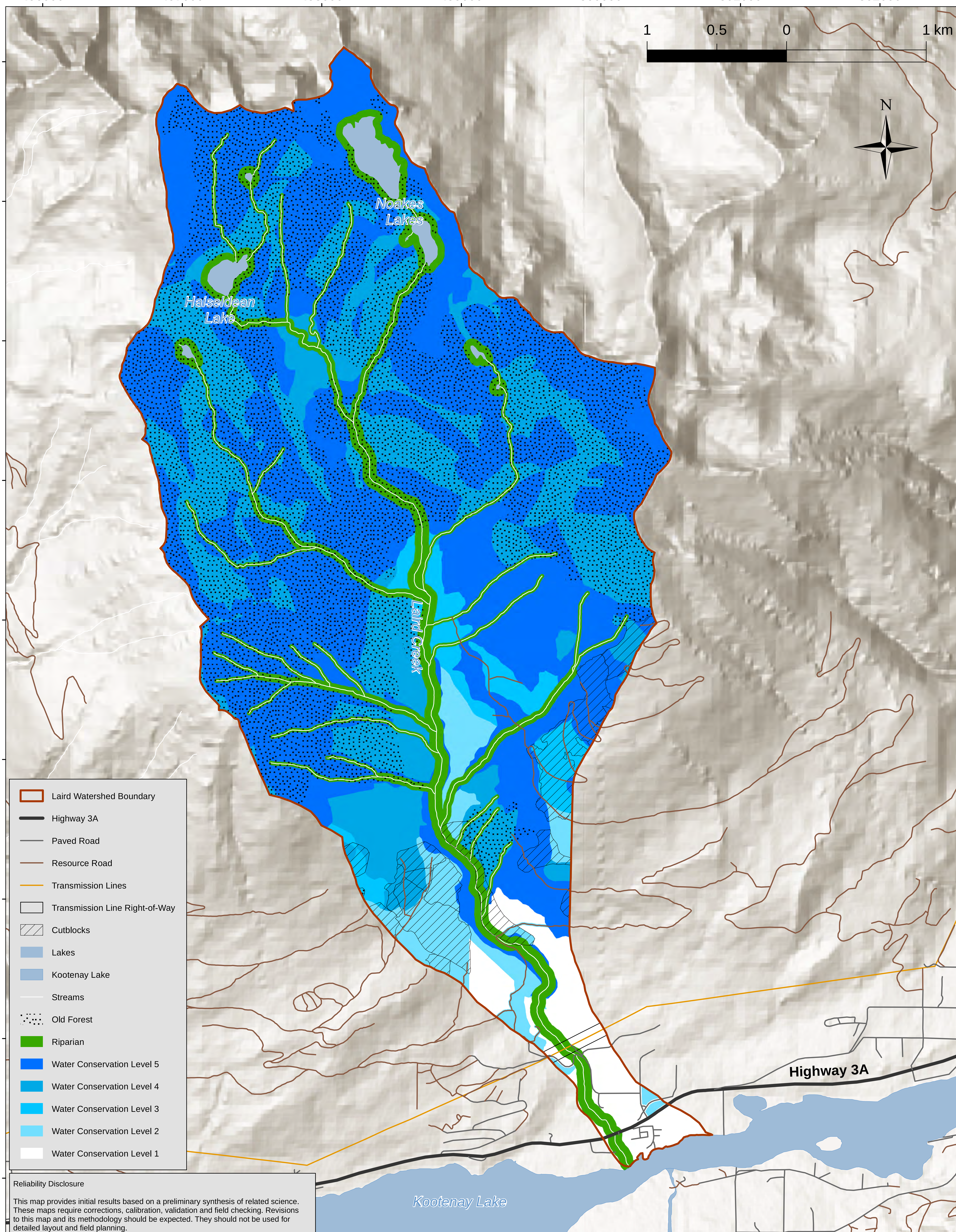


Photo 1. Old forests support positive water outcomes

Old forests provide a range of positive benefits to hydrologic function at both site and watershed levels. Rainfall and snow interception due to the forest canopy and tree trunks reduce the amount and/or pace at which incoming precipitation moves toward the watershed outlet. Old forests typically promote groundwater recharge. Deadfall and other decaying materials associated with old forest types store water, releasing it slowly and support baseflows. A multi-layered forest canopy provides valuable shade to ground-level forest ecosystems which is particularly valuable during periods of intense heating associated with climate disruption.

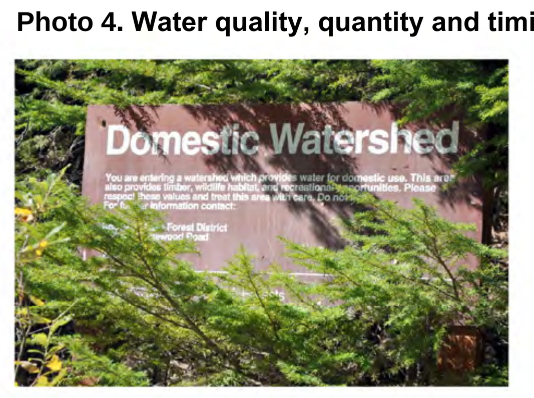
Photo 2. Wetlands

Wetlands provide a range of positive benefits to watershed hydrology as well as providing rich points of ecological diversity. Wetland typically support late-season baseflow by releasing water slowly to shallow groundwater and to streams. Wetlands also store water both from the freshet period and from rainfall events, making it available later. Depending on their location in the watershed, they also serve as important storage sites for sediment thus contributing to improvements in downstream water quality. Where they are able to survive future increases in temperature, wetlands of any size provide critical watershed elements to sustain beneficial function during periods of

Photo 3. The water benefits of riparian vegetation

The riparian zone is the strip of land adjacent to a waterbody with different characteristics due to its proximity to water. Riparian vegetation plays a large role in maintaining proper hydrologic function in a watershed across scales. Undisturbed riparian vegetation protects banks thereby promoting channel stability. In addition to its many essential habitats, riparian areas shade streams reducing summer water temperatures. This protection of aquatic habitats from temperature extremes is expected to be of growing importance as disruption escalated due to climate change. Whereas riparian vegetation transpires, it limits evaporation and reduces

Photo 4. Water quality, quantity and timing of flow



High quality water in the right amount and at the right timing is a foundation to watershed hydrology supportive of species, habitats, ecosystems and human uses. Within the smaller catchments that drain toward the West Arm of Kootenay Lake and to the downstream Kootenay River, every location within these watersheds contributes in some way to the water quality, quantity and timing of flow at the outlet. Some areas play an oversized role in comparison with others. Both the flow and sediment regimes should be moderated to maintain resilience in aquatic habitats and for human water uses, particularly during this ongoing period of climate disruption.

Map 12 - Preliminary Laird Watershed Hydrologic Sensitivity

Calibration, Validation & Revision Required

Clean water, healthy aquatic ecosystems, and stable channels require forest and soil protection widely distributed across the watershed to maintain the natural flow regime and minimize stream sedimentation. Few locations in the watershed are not involved in some capacity in maintaining a positive

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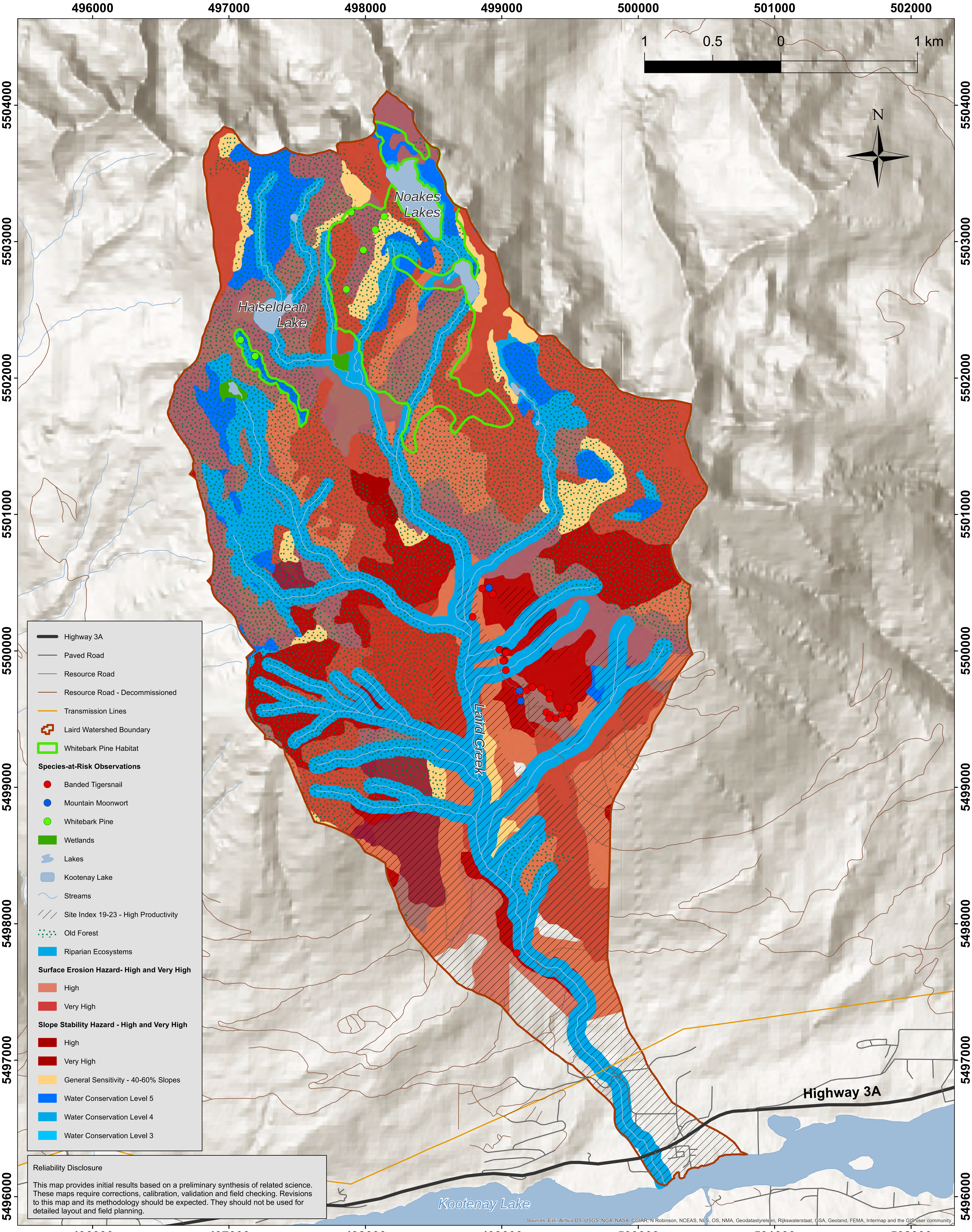

Map 13 - Preliminary Laird Watershed Protected Landscape Network (PLN)

Photo 1: Old forests—centres for water conservation, carbon sequestration, & biodiversity

Old forests are complex ecosystems that are characterized by the prevalence of old and large trees (for a particular site's character), a wide range of tree species and ages, canopy gaps, multi-layered canopies, and a high occurrence of large snags and decayed wood from fallen trees. These forests are resilient to most natural disturbances from wind and fire to insects and disease. Old forests sequester and store carbon, and moderate climate better than other forest phases. Old forests have the highest level of biodiversity and of specialized species. For example old forests harbour carnivorous insects that prey on herbivorous insects, like bark beetles. The large crown masses and multi-layered crowns, coupled with large volumes of decayed wood and soil organic matter create an effective means of water interception, distribution, storage, and filtration.

Photo 2. Riparian zone within riparian ecosystems—important linkages in the watershed

Riparian ecosystems are directly associated with water bodies, including creeks, wetlands and lakes, and consist of two parts: riparian zone and riparian zone of influence. The riparian zone of influence is the upland area immediately adjacent to the riparian zone. What happens in the riparian zone of influence directly affects the riparian zone and water body. Riparian zones of influence end when the slope decreases enough so that down slope movement of water and nutrients in the soil slows significantly. Riparian ecosystems typically have abundant moisture throughout the growing season, and rich soils, resulting in productive ecosystems and often the largest trees in the watershed. Riparian zones are linkages within a watershed and are essential for maintaining water quality.

Photo 3. Ecological sensitivity/ecological limits: H & VH slope stability hazard

All areas of ecological sensitivity and ecological limits are part of the PLN. In many cases these classes overlay other parts of the PLN, including old forests, high productivity sites, and representative ecosystem types for the watershed. Concentrated drainage below resource roads are common landslide initiation points. Under natural conditions, runoff and shallow groundwater flow are dispersed through the soil mantle and in the forest floor. Road construction typically concentrates drainage either into ditchlines or along road surfaces leading to high levels of runoff immediately downslope. Where this concentration coincides with unstable terrain, typically on steep and moist slopes, slope failures can occur.

Photo 4. High productivity sites/representative sites of good tree growth

Inclusion of areas of high productivity tree growth sites captures areas of high biological productivity in the PLN. In the Laird watershed, high productivity areas occupy over one-quarter of the watershed area and reflect ecosystem types that are representative of ecosystems found throughout the lower elevations of the watershed.

The PLN provides the ecological framework necessary to protect water and biodiversity, moderate climate, and maintain connectivity. The PLN encompasses the range of natural ecosystems in the watershed. Ecologically sensitive and ecologically limited areas are important parts of the PLN. Protection is reciprocity with nature.

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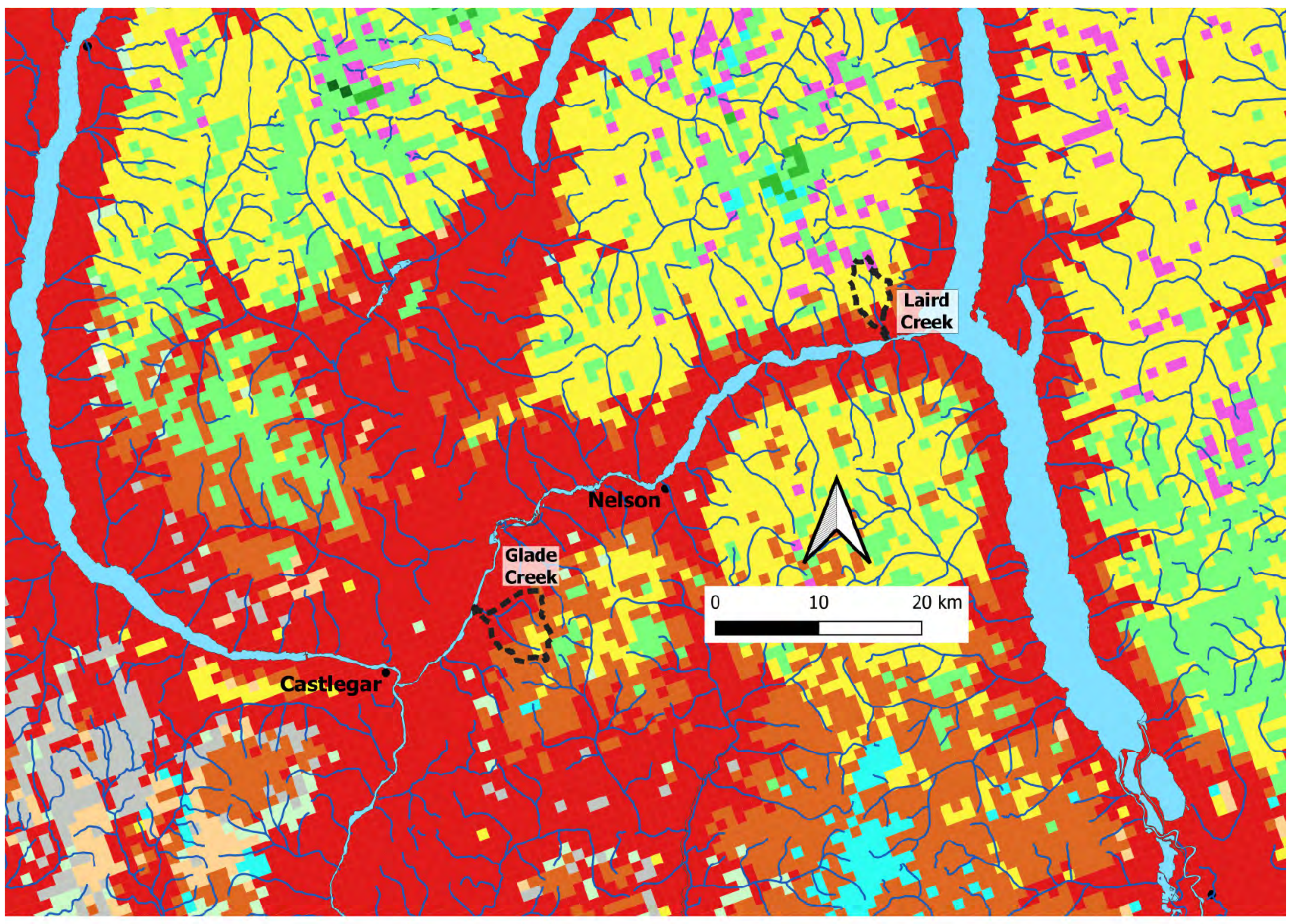
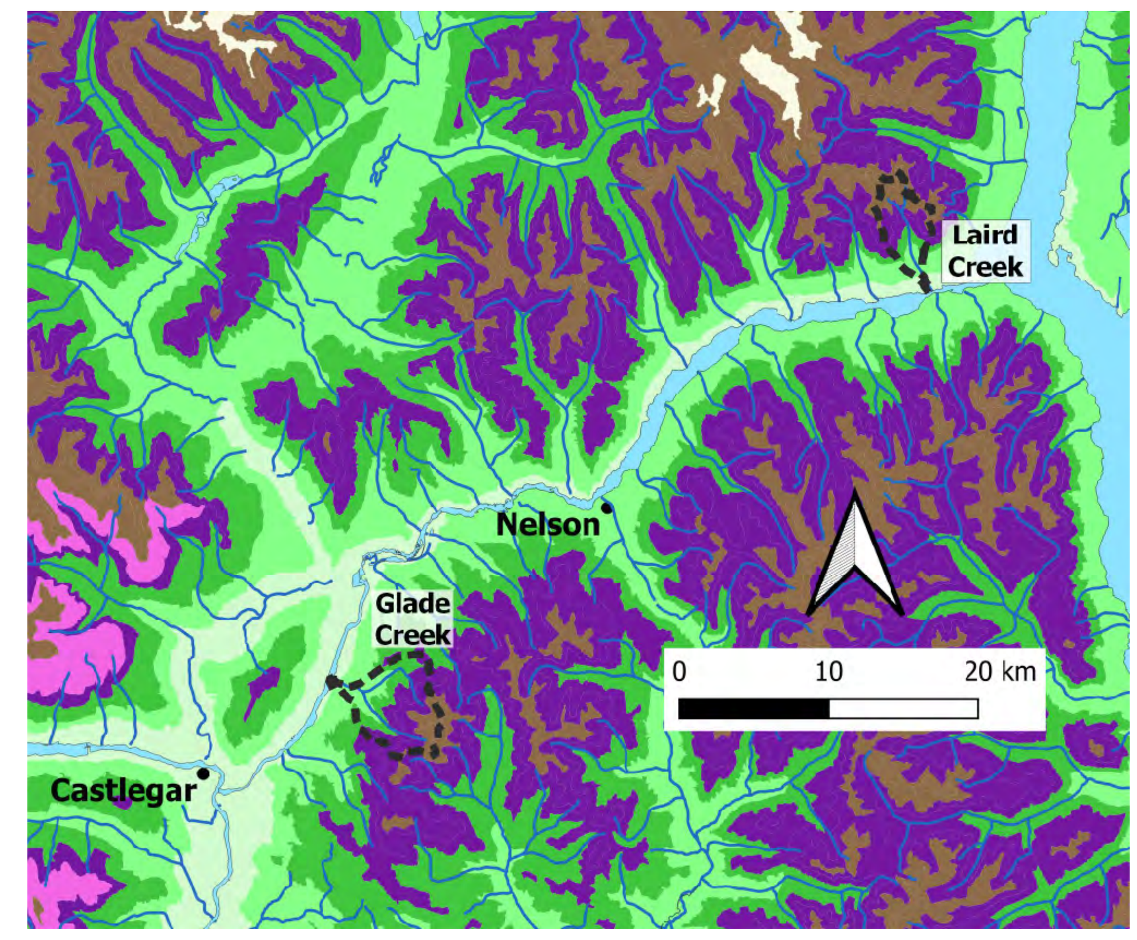
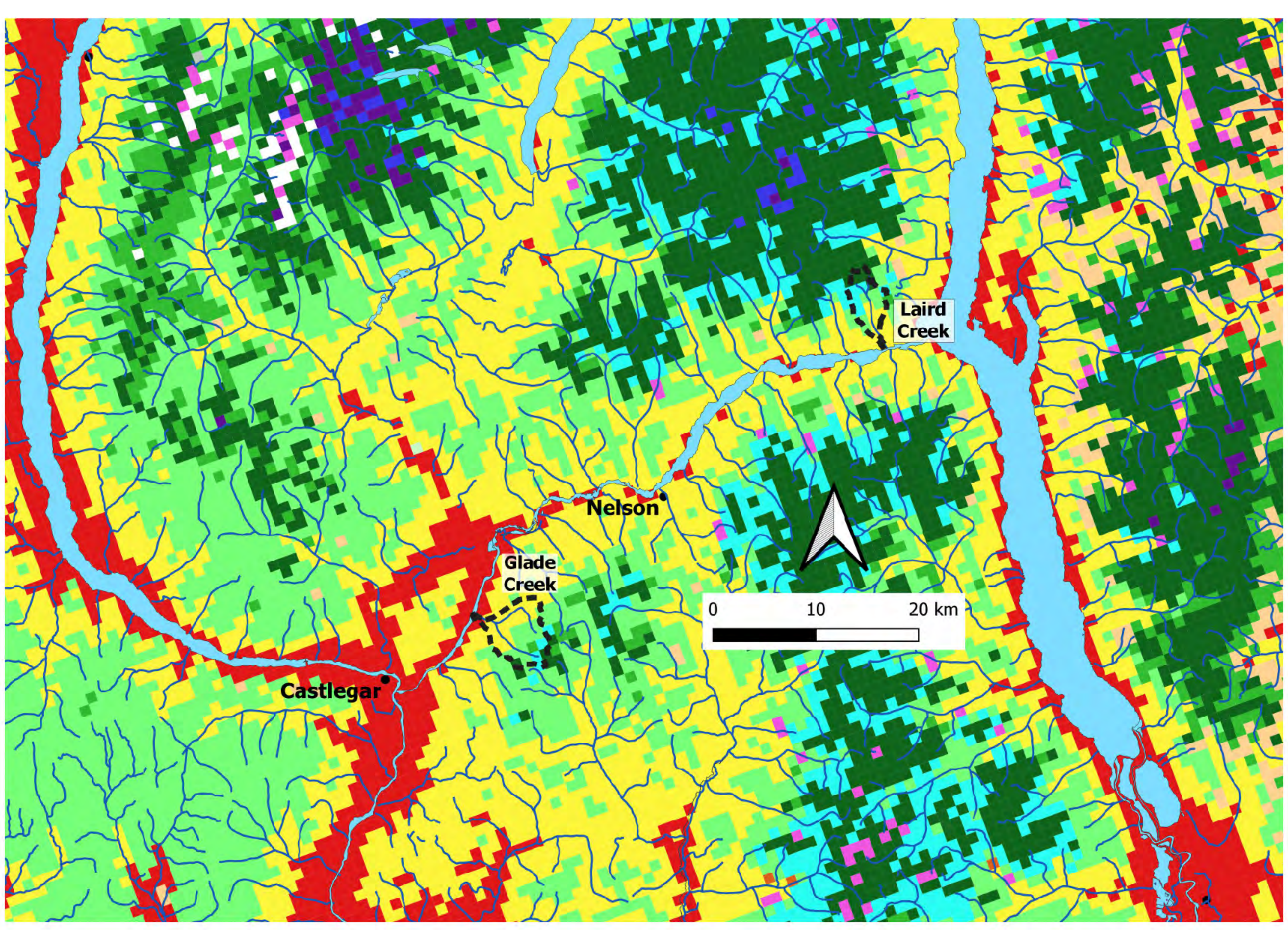
Very Hot / Dry 2080s

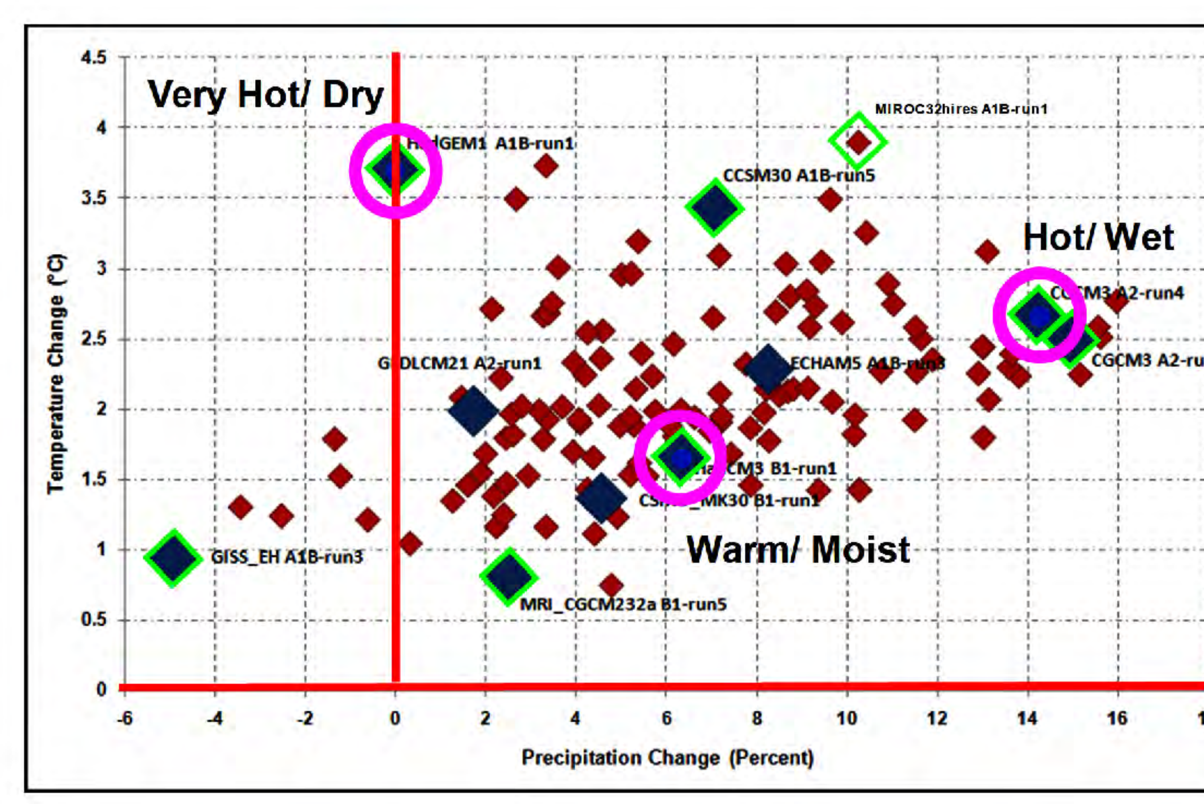


Current Mapping



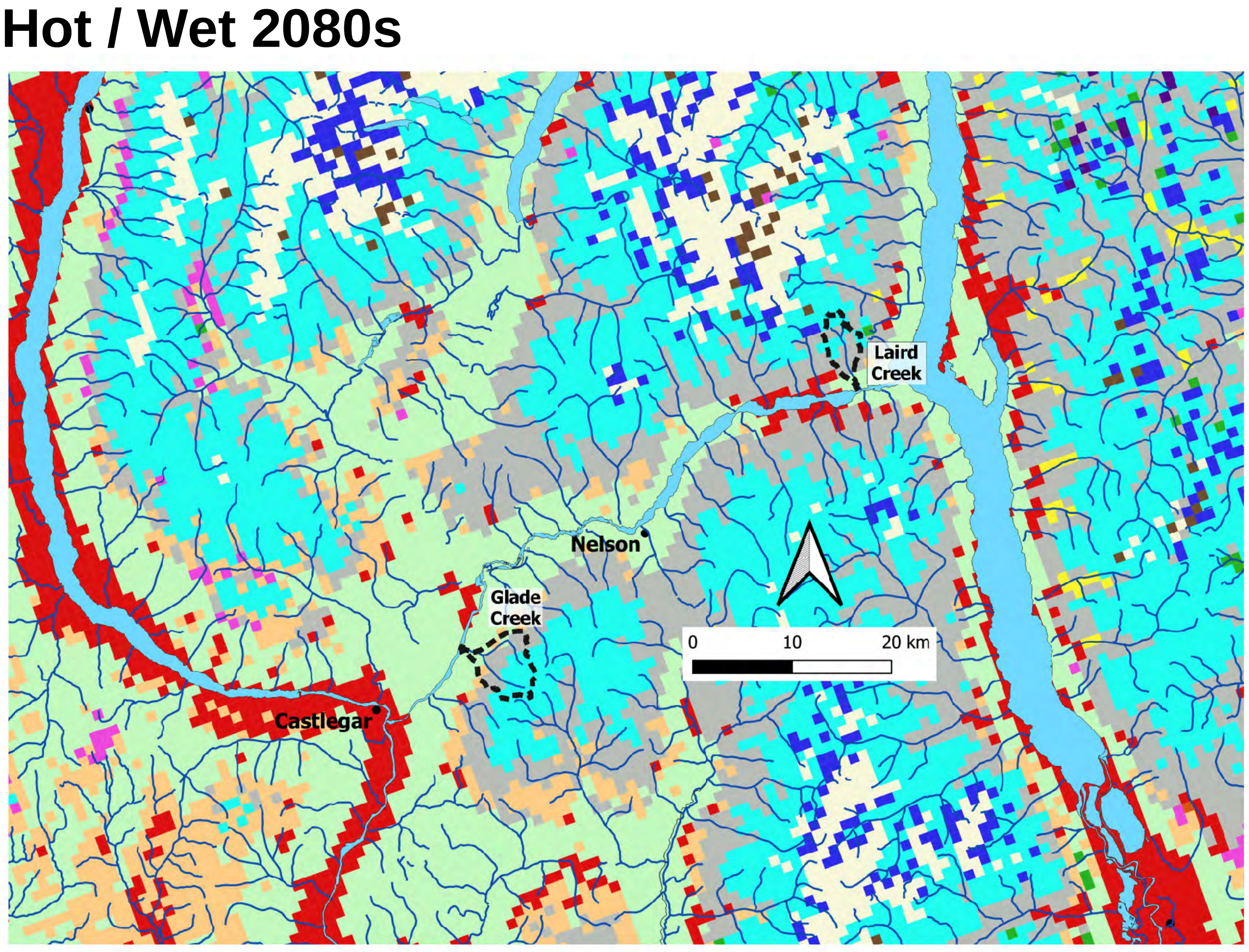
Warm / Moist 2080s





- Alpine
- Alpine parkland
- Wet subalpine forest
- Dry subalpine forest
- Coastal hemlock
- Transitional coast/ interior hemlock
- Montane/sub-boreal spruce forest
- Wet interior cedar/ hemlock
- Moist interior cedar/ hemlock
- Dry interior cedar hemlock
- Grand fir/ Douglas-fir
- Wet Douglas-fir
- Dry Douglas-fir
- Ponderosa pine savanah
- Grassland/ steppe

Hot / Wet 2080s



Map 14
Laird Watershed
Projected Bioclimates
for the 2080s

The changing climate is projected to lead to significant alterations to ecosystems through the twenty-first century and beyond. Changes are likely to lead to ecological regime shifts that results in extirpation of species and loss of benefits to human beings, like high quality water in moderate flows throughout the year, and climate moderation.

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7. NEXT STEPS AND CONCLUSION

7.1 NEXT STEPS

Following the steps outlined below (Table 7.1-1), the complete Nature-Directed Stewardship plans for Glade and Laird watersheds can be developed from the preliminary versions provided in this report. Completion of these plans would provide the Indigenous and settler communities associated with the Glade and Laird watersheds with reliable, clear plans for water and watershed protection.

Table 7.1-1. Next Steps to Complete the Nature-Directed Stewardship Plans

	Step	Details
1	Community meetings	Meet with Indigenous and settler communities to review preliminary plans and seek community guidance for clarifying and completing the NDS plans in ways that best meet community needs.
2	Map revisions	Review and revise interpretive maps, including underlying assumptions and analyses to be sure that they are consistent with best knowledge, both Indigenous and western science, and NDS principles. Identify representative areas for field assessment to provide data to check, and revise, as required, analyses and interpretations that form the basis for the interpretive maps and their underlying methodology.
3	Field review	Collect required field data including watershed photographs pertaining to the theme of each map and hydrologic data to test and revise preliminary methodologies used in the preliminary flow regime maps. Include areas of cultural and ecological importance identified by the communities. Invite Indigenous and settler community representatives to accompany the field assessment team as a means of incorporating community knowledge and of building community understanding and ownership of the plans.
4	Integration of field data	Summarize field assessment data and integrate into previous analyses. Compare data summaries with preliminary interpretations. Revise methodologies and interpretive maps, as required.
5	Summary of knowledge	Prepare summary of knowledge document describing the key findings from both western science and Indigenous knowledge on which the NDS plans are based. Produce the summary of knowledge in both detailed and summary formats, to be included with the complete NDS plans.
6	Community-driven plan revisions	Meet with Indigenous and settler communities to review and discuss field assessment results as the basis for revision of the plans. Engage the communities in a process to identify human-use areas to occur within the ecological and hydrologic limits defined by the plans and to facilitate the development of conservation-based steady-state community economies.
7	Socio-economic analyses	Prepare socio-economic analyses incorporating human-use areas as primary ways of facilitating a community-based economy. Identify meaningful work (i.e., jobs) provided primarily through protection and restoration of water and overall watershed function, both ecologically and hydrologically.
8	Completed revised set of interpretive	Design and produce improved interpretive maps with a focus on clear, attractive cartography and a well-synthesized story in photographs and captions specific to each watershed and describing the meaning and importance of each map. In the revised map set, include a new map depicting proposed human-use areas and describing ways to

	Step	Details
	maps	protect hydrologic and ecological functions while carrying out human uses.
9	Completed revised report	Revise and edit the reports for the NDS plans, incorporating any new information from the field assessments, revised interpretive maps, summary of knowledge and any changes in conclusions that result from revisions to the information and interpretations on which the plans are based. Develop a new report section on designation of human-use areas and the facilitation of community-based economies. Include plain-language community summaries to assist in development of a wide understanding of the plans within Indigenous communities and the Glade and Laird settler communities.
10	Interactive implementation workshops	Carry out interactive workshops with Indigenous and settler communities to convey and discuss the revised plan and interpretive maps for the Glade and Laird watersheds. In the workshops, discuss options in asserting and implementing the plans following approaches led by Indigenous and settler participants from both watersheds.
11	Community assistance	Provide assistance to each of the Glade and Laird communities and Indigenous communities in their efforts to assert and implement the NDS plans.

7.2 CONCLUSION

From timber and mining to residential development and large-scale tourism, watersheds function best in a state undisturbed by these activities of industrial society. As soon as these activities start to alter the composition, structure, and function of a watershed, the processes responsible for natural levels of water quality, quantity, and timing of flow begin to degrade.

Unfortunately, the natural integrity and resilience of primary forests often mask early impacts of water degradation and create a false sense of security that logging and other developments in watersheds do not negatively affect water. This false sense of security is augmented by the reality that linear scientific research is unable to detect significant problems associated with watershed development until it is too late for restoration in a reasonable timeframe. As development activities proceed, this false security and the low level of assistance from scientific knowledge leads to small problems becoming large problems that are long lasting and degrade overall watershed function.

The moral of the story is protection of water means protection of the watershed from industrial society's development activities. Under precautionary NDS that gives first priority to protection of water some low impact activities that maintain natural composition, structure, and function may safely occur on very stable terrain.

Past and proposed forestry development in the Glade and Laird watersheds does not meet the test of precautionary nature-directed planning. Forestry development in these watersheds has, and continues to follow, a timber-biased approach with few meaningful concessions to the protection of water. For example, proposed developments in Laird and Glade do not provide networks of ecological reserves, both use clearcutting or modifications of clearcutting to remove trees, and cutting rates are based on short rotations for regrowth of trees.

Currently, most decisions about development activities in watersheds are based upon flawed *assumptions of convenience* about logging, forestry, and water put forth by the timber industry and to government. These simplistic decisions are flawed, dangerous to watershed health and pose a threat to all life that depends upon healthy, intact watersheds. A critical review of these decisions, through the lenses of Indigenous knowledge, western scientific knowledge, or common sense reveals them to be flawed. The protection and use of watersheds needs to quickly move to decisions based upon a precautionary approach, rooted in factual understanding of how forested watersheds function, and how forestry negatively impacts watershed function. Without this change we face a future with increased uncertainty about the reliability of adequate, healthy water supplies.

That future depends in no small way on an important principle: *Water may either transmit the essence of life or magnify and transmit our mistakes*. The choice is ours.

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APPENDIX A. GEOLOGY, SURFICIAL MATERIAL, AND SOILS

Bedrock Geology in the South Selkirk Mountains

Coarse-grained, igneous intrusive rocks including granodiorite and granites are the most common bedrock types in the south Selkirk Mountains. Other common rock types occur mainly south of the West Arm and lower Kootenay River where they are interspersed with the intrusive rocks. Finer-grained sedimentary rocks including mudstone, siltstone, shale, argillite, and limestone occur throughout the area south of the arm and river to the U.S. border. Fine-grained volcanic rock (basalt) is very common in the Cottonwood Creek and Salmo River valleys (Highway 6 corridor) and to the west in the Bonnington Range and the area between the Beaver Creek and Pend d'Oreille River valleys. Medium- to coarse-grained sedimentary rocks including quartz sandstones (quartzite, quartz arenite), lithic sandstones (greywacke, wacke), and conglomerates are widely distributed in the Nelson Range between Highway 6 and the south arm of Kootenay Lake and the Creston Valley. Less common bedrock types include slate, a fine-grained metamorphic sedimentary (metasedimentary) rock scattered throughout the area, and fine-grained greenstone and greenschist metamorphic volcanic rocks that occur on the east side of the Nelson Range.

Surficial Materials in the South Selkirk Mountains

The types of surficial materials that occur in the south Selkirk Mountains include morainal (or glacial till), colluvial, fluvial (or alluvial), glaciofluvial, lacustrine, glaciolacustrine, eolian, bedrock, weathered bedrock, organic and anthropogenic. The materials and associated landforms are briefly described in Table 1.

Table 1: Surficial Materials and Landforms in the South Selkirk Mountains

Surficial Material	Definition	Landforms
morainal (glacial till)	materials deposited directly by glaciers	deep deposits in valley bottoms; morainal blankets (> 1m thick) and veneers (< 1m) overlying bedrock on gentle to moderately steep (<60%) slopes; morainal (till) deposits can include ablation till (deposited by ice melting in situ), deformation till (reworked from previous glaciation events), and basal till (deposited at the bottom of glaciers); basal tills tend to be heterogeneous mixtures of particle sizes with sub-angular to subrounded coarse fragments, and are compact, unsorted and unstratified
colluvial	materials deposited by mass wasting and movement by gravity	blankets and veneers overlying bedrock or other materials on moderately steep (>50%) and steep slopes; rockfalls (talus, scree), landslides, mudslides, debris flows, and slumps have formed colluvial aprons, cones, fans, and hummocky or undulating deposits at the base of cliffs, bluffs, and steep and/or unstable slopes; colluvial deposits often have angular coarse fragments
fluvial (alluvial)	recent (post-glacial) river and creek deposits	floodplains and terraces along rivers and major creeks and fans where larger creeks enter the main valleys (Kootenay, Slocan, Lower Arrow-Columbia); fluvial deposits are generally well sorted

Surficial Material	Definition	Landforms
		by particle size and well stratified
glaciofluvial	fluvial materials deposited from melting glaciers	outwash plains and terraces in the bottoms of large valleys, kame (ice-contact) deposits along river and creek valley walls, and steep scarp slopes; glaciofluvial deposits are generally coarse-textured (gravels and sands) with rounded coarse fragments; they can be poorly to well sorted and stratified
lacustrine	recent lake deposits	blankets and veneers of fine sediments (clays, silts and fine sands) that lack coarse fragments; deposits are most common along the margins of lakes and floodplain backwaters
glaciolacustrine	lacustrine materials deposited during glaciation	thick deposits, blankets and veneers of fine particles deposited in glacial lakes formed by valley ice dams; deposits may have massive to laminated bedding, and slumps and gullies are common
eolian	materials deposited by wind	veneers of fine sands and silts with few or no coarse fragments that commonly overlie other materials in the bottoms of large valleys; also includes deposits of fine ash from the Mount Mazama and Mount St. Helens volcanic eruptions
bedrock	outcrops and rock covered by <10 cm of soil	bedrock at or near the surface is common at higher elevations on steep slopes, ridges and summits; also occurs in areas of shallow soils at all elevations, and on steep valley walls particularly along the sides of large valleys
weathered bedrock	rock decomposed in situ	usually thin veneers of weathered rock material overlying the parent bedrock
organic	accumulations of decaying and decomposed vegetative matter	thick deposits, blankets and veneers occurring on poorly- to very poorly-drained sites in basins and wet depressions
anthropogenic	human-modified materials	areas disturbed by human activities including settlements, road corridors, agricultural fields, mines and quarries, and hydroelectric dams

a – Modified from Appendix 3.5 in MacKillop and Ehman (2016)

Surficial Geology

Surficial materials include the unconsolidated mineral and organic deposits that overlie bedrock. They form the parent materials of soils and thus influence the physical, chemical, and biological nature of ecosystems. The materials can be closely related to the underlying bedrock, or they can have properties that don't reflect the local bedrock geology when they've been transported long distances by glaciers, gravity, water and wind. Surficial materials can be highly modified during transport and also after deposition by living organisms and natural or anthropogenic disturbances (MacKillop et al, 2018).

Colluvial and morainal (till) materials are the most common surficial materials in the project area. Colluvial deposits typically occur on moderately steep to steep (>50%) slopes while morainal deposits are dominant on gentle to moderately steep (<60%) slopes. Colluvial veneers occur at all elevations from the steep sidewalls above valley floors to the mountain summits. Colluvial blankets are very common on lower to mid slopes in the main West Arm-Kootenay River Valley and in tributary valleys from low to subalpine elevations. Blocky talus deposits occur at the base of cliffs and bluffs. Morainal blankets and veneers are also very common on less steep terrain in the main valley and on mountain slopes from low to high elevations. Colluvial and morainal deposits derived from coarse-grained granodiorite bedrock have coarse textures and those derived from finer-grained sedimentary and volcanic rocks are medium to fine textured.

Coarse-textured glaciofluvial materials are also common in the main valley and in most of the larger tributary valleys. Both glacial river terraces and kame (ice-contact) deposits occur in the valley bottom along the West Arm and lower Kootenay River, particularly at the confluences of the main valley and the Slocan River and major creek valleys. The kame deposits include hills, mounds and terraces of sands and gravels laid down by glacial meltwaters along the margins of glaciers. Narrow kame terraces formed when meltwater streams deposited sediments between the ice and the valley walls. Ice-contact deposits also occur at low elevations along the main arm of Kootenay Lake north of Queens Bay and in the bottoms of the larger creek valleys from low to subalpine elevations.

Fluvial fans occur along the West Arm and lower Kootenay River where the larger creeks enter the main valley and deposit materials on the more gentle gradients. A narrow band of fluvial fan deposits also occurs at the base of steep slopes along the east side of Glade. Other fluvial deposits occur along Cottonwood Creek from south of Cottonwood Lake to the creek mouth in Nelson.

Extensive areas of exposed bedrock occur on the ridges and summits of Gray's Peak and Outlook Mountain in the upper Kokanee Creek drainage. Smaller areas of exposed rock occur at all elevations throughout the project area but are more common on upper slopes and crests at high elevations.

Other surficial materials that occur in the project area include lacustrine, eolian, ash, organic and anthropogenic. Areas of lacustrine beach sands and other finer-textured deposits in shallow bays and on floodplains occur along the West Arm. Eolian materials (fine sands and silts) are incorporated into the surface layers of glaciofluvial terraces and morainal deposits in the valley bottom along the West Arm and lower Kootenay River. Deposits of volcanic ash occur in upper soil horizons throughout the Selkirk Mountains. They consist of materials from the eruptions of Mount Mazama 7700 years ago and Mount St. Helens mainly in the 1400s. Mount Mazama Ash is usually deeper in the soil profile and has an orange-brown color, while Mount St. Helens ash often forms a thin (< 2 cm), discontinuous, white-colored layer at the top of the mineral soil (MacKillop et al, 2018). Organic deposits are uncommon and are restricted to small basins and wet depressions. Anthropogenic materials are common in the main valley where surficial deposits have been disturbed by settlements, roads, agriculture activities, and hydroelectric dams. Human-modified materials also include forestry roads and landings in many of the larger creek valleys as well as mine pits and tailings.

Soils in the South Selkirk Mountains

The soil orders that are represented in the south Selkirk Mountains include Brunisolic, Podzolic, Luvisolic, Regosolic, Gleysolic and in minor amounts, Organic. Brief descriptions of the soil orders and associated great groups, including diagnostic soil horizons and key features, are provided in Table 2. Modifier names for common soil subgroups that occur in the region are also identified in Table 2 and key features of the subgroups are described in Table 3.

Table 2: Soil Orders, Great Groups, and Common Subgroups in the South Selkirk Mountains [a]

Soil Order	Description	Diagnostic Horizon Criteria	Soil Great Group	Key Features	Common Soil Subgroup Modifier Names
Podzolic	soil typically associated with coniferous forests in moist-wet climates on parent materials derived from coarse-grained acid bedrock; iron, aluminum and/or organic matter are leached from the Ae surface horizon and accumulate in the Bf, Bhf or Bh horizon	Bf, Bhf, Bh horizon = or > 10 cm	Humo-Ferric Podzol	accumulation of mainly iron (Fe) and aluminum (Al); Bf = or > 10 cm	Luvisolic, Sombric, Gleyed, Gleyed Sombric
			Ferro-Humic Podzol	accumulation of Fe, Al and organic matter; Bhf = or > 10 cm	Sombric, Gleyed, Gleyed Sombric
			Humic Podzol	accumulation of mainly organic matter; Bh = or > 10 cm	* great group is uncommon in the area
Luvisolic	forest soil often associated with parent materials derived from finer-grained sedimentary rocks; clay particles are leached from the Ae horizon and accumulate in the Bt horizon	clay-enriched Bt horizon = or > 5 cm	Gray Luvisol	thin, organic-enriched (Ah) surface horizon < 5 cm thick	Brunisolic, Gleyed, Gleyed Brunisolic
Brunisolic	forest soil with weak to moderate development due to climate and/or soil moisture limitations that restrict the process of soil weathering; diagnostic horizons (Bm, Bfj, Btj) not well enough developed to meet the criteria for the Podzolic or Luvisolic Orders	Bm, Bfj, or Btj horizon = or > 5 cm; Bf < 10 cm	Dystric Brunisol	low base status (pH < 5.5) and thin Ah horizon < 10 cm	Eluviated, Gleyed, Gleyed Eluviated
			Eutric Brunisol	high base status (pH > 5.5) and thin Ah horizon < 10 cm	
			Sombric Brunisol	low base status (pH < 5.5) and thick Ah horizon = or > 10 cm	
			Melanic Brunisol	high base status (pH > 5.5) and	* great group is uncommon in

Soil Order	Description	Diagnostic Horizon Criteria	Soil Great Group	Key Features	Common Soil Subgroup Modifier Names
				thick Ah horizon = or > 10 cm	the area
Regosolic	very weakly developed soil with thin or no B horizon; occurs on very young surficial deposits (e.g., floodplains, fluvial fans), unstable slopes, and in areas with harsh climates	B horizon < 5 cm or absent	Regosol	thin Ah horizon < 10 cm	Cumulic, Gleyed, Gleyed Cumulic
			Humic Regosol	thick Ah horizon = or > 10 cm	
Gleysolic	soil that develops under conditions of excessive moisture due to poor drainage; long periods of saturation result in permanent or periodic reducing conditions (caused by a lack of oxygen) as indicated by gleying (bluish-grey colors) or prominent mottles (reddish-brown colors with grey colors) in the Bg or Btg horizon	Bg or Btg horizon within 50 cm of the mineral soil surface	Gleysol	Bg horizon and thin Ah horizon < 10 cm	
			Humic Gleysol	Bg horizon and thick Ah horizon = or > 10 cm	
			Luvic Gleysol	leaching of clay from the Ae into the gleyed (Bg) layer to form a Btg horizon	
Organic	soil formed by the buildup of partially decomposed plant material (peat) accumulating in depressional areas under saturated conditions	organic (O) horizon is > 40 cm thick	Fibrisol	middle tier of soil control section (between 40-120 cm) dominated by poorly-decomposed (fibric) organic materials (Of horizon)	
			Mesisol	middle tier dominated by moderately-decomposed (mesic) organic materials (Om horizon)	
			Humisol	middle tier dominated by well-decomposed (humic) organic materials (Om horizon)	

a – Modified from Appendix 3.4.1 in MacKillop et al (2018)

Table 3: Key Features of Some Common Soil Subgroups in the South Selkirk Mountains [a]

Soil Subgroups		
Soil Subgroup Modifier Name	**Applicable Soil Great Groups**	**Key Features**
Luvisolic	Humo-Ferric Podzol	soil includes a clay-enriched Bt horizon > 50 cm below the mineral soil surface
Sombric	Humo-Ferric Podzol, Ferro-Humic Podzol	soils have a thick, organic-enriched (Ah) surface horizon = or > 10 cm
Gleyed	Podzol, Luvisol, Brunisol, Regosol Great Groups	imperfectly- or poorly-drained soils that have faint to distinct mottles within 50 cm of the mineral soil surface (e.g., Bfgj horizon in a Gleyed Humo-Ferric Podzol) or distinct to prominent mottles at 50-100 cm (mottles indicate alternating reducing and oxidizing conditions in soils that are saturated for a part of the year)
Gleyed Sombric	Humo-Ferric Podzol, Ferro-Humic Podzol	Sombric Podzol soils with distinct or prominent mottling with 1m of the surface
Brunisolic	Gray Luvisol	soil has a Bm horizon = or > 5 cm or a Bf horizon < 10 cm in the upper profile
Gleyed Brunisolic	Gray Luvisol	Brunisolic Gray Luvisol soil with distinct mottles at depths of < 50 cm or prominent mottles at 50-100 cm
Eluviated	Dystric, Eutric, Sombric Brunisols	soils have a leached Ae or Aej horizon = or > 2 cm at the mineral soil surface
Gleyed Eluviated	Dystric, Eutric, Sombric Brunisols	Eluviated Brunisol soils with mottles indicating gleying
Cumulic	Regosol, Humic Regosol	soils with organically-enriched mineral layers (Ahb horizons) buried beneath more recent mineral deposits, usually due to intermittent flooding
Gleyed Cumulic	Regosol, Humic Regosol	Cumulic Regosol soils with faint to distinct mottles within 50 cm of the mineral surface
Orthic	Podzol, Luvisol, Brunisol, Regosol, Gleysol Great Groups	soils with the properties specific to the great groups and no other modifying features
lithic	Podzol, Brunisol, Regosol Great Groups	shallow soils < 50 cm in depth to a lithic contact (bedrock)

a – Modified from Appendix 3.4.2 in MacKillop et al (2018)

Soil Mapping

Soils with similar characteristics are also grouped into **soil associations** for the purpose of mapping. Soil associations are sequences of soils that are derived from similar parent materials and have developed under similar climatic conditions. The associations are developed by incorporating physiography, topography (landscape position), climate, vegetation (biogeoclimatic) zones, bedrock and surficial materials, soil profile development (soil orders, great groups and subgroups) and drainage features. The names, codes and characteristics of soil associations mapped in the south Selkirk Mountains are described in the historic soil survey report *Soil Resources of the Nelson Map Area* (Jungen, 1980). The report also includes four 1:100,000 scale soil maps that cover the 1:250,000 Nelson 82F topographic map area. For the purposes of this project, soil associations mapped within the project area are not described.

Soil Classification:

Soil is classified according to its development as described in *The Canadian System of Soil Classification* (Soil Classification Working Group, 1998). Within the classification, the **soil order** is the highest level of organization. All of the soils classified within one soil order have one or more basic soil profile characteristics in common. Each soil order within the classification system is subdivided into two to four **soil great groups** having certain features in common that reflect a similar environment for soil development. Each great group can be further subdivided into several **soil subgroups** that are based on the arrangement of horizons (layers) in the soil profile (Jungen, 1980).

Dystric Brunisols are the dominant soil type at lower to mid elevations (ICHxw, dw, mw) and also occur in the lower subalpine (ESSFwh) and on dry, warm sites at upper elevations (ESSFwm). They are most common in colluvial and morainal parent materials derived from coarse-grained, acidic, intrusive bedrock (mainly granodiorite) and typically have sandy loam to loamy sand textures and low nutrient status. The soils also occur in colluvial and till materials derived from medium- to fine-grained sedimentary and basaltic volcanic rocks and those soils tend to have medium textures ranging from loam to sandy loam and better nutrient availability for plant growth. Dystric Brunisols are the dominant soil type in the coarse-textured glacio-fluvial and fluvial fan deposits at lower elevations and also occur in colluvium and till derived from medium and coarse-grained sedimentary rocks (sandstones, conglomerates). Eluviated Dystric Brunisols with leached (Ae) surface horizons are locally common on glaciofluvial terraces along the lower Kootenay River. **Sombric Brunisols** with thick (= or > 10 cm) organic-enriched (Ah) surface horizons also occur in pockets on the terraces along the river.

Eutric Brunisols with higher base status (ph > 5.5) are uncommon and limited to drier, warmer sites at mainly lower elevations (ICHxw, dw) underlain by morainal or colluvial parent materials derived from calcareous (e.g., limestone) or basic (e.g., basalt) rock types. The drier site conditions limit soil development (including leaching of carbonates) due to a lack of moisture. **Gray Luvisols** with weakly-developed, clay-enriched (Bt) subsurface horizons are locally common at lower elevations on both sides of the West Arm between Harrop and Queens Bay. The soils developed under slightly moister conditions (compared to the Eutric Brunisol soil environment) in morainal parent materials derived from finer-grained bedrock types including limestone, slate, siltstone, mudstone and argillite. Surface textures are silt loam to sandy loam grading to silty clay loam in the Bt horizon. The Gray Luvisols in the project area also have Bm or Bfj horizons characteristic of the Brunisols and are classified as Brunisolic Gray Luvisols.

At mid to upper elevations (ESSFwh, wm, wmw, wmp), **Humo-Ferric Podzols** are the dominant soils. They also occur in the ICHmw biogeoclimatic unit on cool, moist sites. As for the Dystric Brunisols, the soils most commonly occur in coarse-textured colluvial and morainal parent materials derived from coarse-grained granodiorite bedrock. They have also developed in medium-textured colluvium and till derived from finer-grained sedimentary and volcanic rocks and in coarse-textured glaciofluvial kame deposits mainly at mid elevations (ICHmw, ESSFwh). Cooler temperatures and increased precipitation at higher elevations favor podzolic soil development. The higher precipitation in combination with well-drained, medium- to coarse-textured parent materials result in strong leaching of iron, aluminum and minor organic matter from the surface Ae layer into the Bf horizon. At lower mid elevations (ICHmw), Humo-Ferric Podzol soils that developed in basal till derived from finer-grained sedimentary rocks can also have clay-enriched (Bt) horizons > 50 cm below the soil surface. Those soils are classified as Luvisolic Humo-Ferric Podzols.

Sombric Humo-Ferric Podzols with well-developed Ah surface horizons can occur in cooler, moisture-receiving areas at mid to upper elevations (ESSFwh, wm, wmw). They also develop in avalanche tracks under shrub and forb vegetation and on cool, moist sites at high elevations (ESSFwmw, wmp). The soils are moderately well- to imperfectly-drained. **Ferro-Humic Podzols** also develop on cool, moisture-receiving sites in the lower and upper subalpine areas. They differ from the Humo-Ferro Podzols by having considerable amounts of organic matter in addition to iron and aluminum accumulate in darker-colored (Bhf) subsurface horizons. Sombric Ferro-Humic Podzols, that also have thick Ah surface horizons, are uncommon in the project area and only occur in scattered areas under stunted forests in the upper woodland and parkland (ESSFwmw, wmp).

Regosolic soils are very weakly developed due to disrupting factors, insufficient time for development, and climate constraints. They occur in young geological deposits on floodplains, fluvial fans and recent landslides, on unstable eroding slopes, and at high elevations where harsh climatic conditions (cold temperatures, short growing seasons) limit soil processes. The soil order has two great groups including **Regosols** that have a thin or no organic-enriched (Ah) surface horizon overlying the unaltered parent material (C layer) and **Humic Regosols** with a thick (= or > 10 cm) Ah horizon above the C layer. Regosols occur on talus deposits and very steep, unstable colluvial slopes (e.g., scree) at all elevations but are most common at high elevations. They also occur at lower elevations on fluvial fan and plain deposits that are subject to flooding. Cumulic Regosols and Cumulic Humic Regosols have buried organic-enriched (Ahb) surface horizons below more recent deposits due to periodic flooding on floodplains and fans.

Gleysolic soils develop under the presence of excess moisture resulting in permanent or periodic reducing conditions indicated by gleying and mottling in the soil profile. The soils are characterized by a gleyed (Bg or Btg) subsurface horizon within 50 cm of the mineral surface. They occur in depressions and on floodplains, fluvial fans and gentle to flat sites with poor to very poor drainage. Gleysolic soils include three great groups. **Gleysols** have a thin or no Ah surface horizon while **Humic Gleysols** have a thick Ah layer. In **Luvic Gleysols**, clay has also accumulated in the gleyed horizon resulting in a Btg layer. In the project area, Gleysolic soils are limited to poorly-drained gentle toe slopes, flats and depressional areas with permanent seepage or high water tables usually associated with riparian areas along creeks and around wetlands and lakes in small wet depressions and basins.

Organic soils consist mainly of decomposing organic matter. They develop in depressional areas under highly saturated conditions where decaying vegetation accumulates faster than it is decomposed. There are three great groups of organic soils subdivided by the degree of decomposition in the middle portion of the soil control section. **Fibrisols** have poorly-decomposed organic materials, **Mesisols** are characterized by moderately-decomposed materials, and **Humisols** have well-decomposed organic materials in the middle tier. Organic soils are uncommon in the project area and are associated with wetlands in small wet depressions and basins. They are not separated by great group in this project.

Gleyed soils have faint to distinct mottles within 50 cm of the soil surface or distinct to prominent mottles at 50-100 cm indicating periodic reducing conditions due to excess moisture. The soils are not saturated for long enough periods during the year to develop Bg horizons as in Gleysols but develop gleyed layers (e.g., Bfgj, Bmgj) as indicated by the mottles. They occur on gentle seepage slopes, on fluvial fans and plains, and in areas with fluctuating water tables and have imperfect to poor drainage. The Gleyed subgroup modifier is used with the Podzol, Gray Luvisol, Brunisol and Regosol great groups (e.g., Gleyed Humo-Ferric Podzol) as well as with some of the soil subgroups (e.g., Gleyed Sombric Humo-Ferric Podzol).

The Orthic subgroup modifier identifies soils within a great group that has no other modifying features. The modifier applies to all mineral soil great groups found in the project area but not to organic soils. In the following watershed sections, the Orthic modifier was not used with the great group names when referencing soils that are not modified by other features.

Lithic soils occur on shallow surficial deposits where the depth to the lithic contact (bedrock) is < 50 cm. They are common in colluvial and morainal veneers, and especially in colluvial deposits at upper elevations (ESSFwm, wmw, wmp). The lithic modifier applies to the Podzol, Brunisol and Regosol great groups (e.g., lithic Dystric Brunisol) and the Sombric Podzol subgroups (e.g., lithic Sombric Humo-Ferric Podzol) in the project area.

In the **Laird Creek Watershed**, Dystric Brunisols are dominant from low to mid elevations in the ICHxw, dw and mw biogeoclimatic subzones while Humo-Ferric Podzols are the dominant soils at higher elevations (ESSFwh, wm, wmw). Dystric Brunisols also occur in the ESSFwh and on dry, warm sites in the ESSFwm and Humo-Ferric Podzols occur in the ICHmw on cooler, moister sites. Both soil types have developed mainly in colluvial and morainal parent materials derived from coarse-grained, acidic, intrusive bedrock (granodiorite). As a result, the soils typically have sandy loam to loamy sand surface textures that often become coarser at depth, and poor nutrient status.

In the main valley bottom (ICHxw), Dystric Brunisols occur on the gently sloping kame terrace located where Laird Creek enters the West Arm. The soils developed in well to poorly sorted glaciofluvial deposits and are gravelly and cobbly with sandy loam surface textures that grade into loamy sands and sands at depth. The small fluvial fan at the mouth of Laird Creek also has Dystric Brunisols that formed in poorly sorted fluvial materials. The soils have sandy loam to loamy sand and sand textures and are stony at the fan apex and stone free in part on the fan apron. There may be inclusions of weakly-developed Regosol soils in area of recent deposition and gleyed soils due to poor drainage in the channels and on the lower fan apron.

The morainal (basal till) deposits at lower elevations (ICHdw) in the watershed are mainly blankets with some veneers. The Dystric Brunisols that developed in the stony deposits have sandy loam surface textures grading to loamy sand or sand at depth in the blankets and sandy loam or loamy sand textures in the veneers. The veneers, that may include some colluvial materials, have inclusions of lithic soils (e.g., lithic Dystric Brunisols) that are < 50 cm deep and rock outcrops are common. Site productivity of the soils for tree growth is low to moderate. It is limited by coarse-textured soils with low nutrient status and moisture deficits in the latter part of the growing seasons.

At mid elevations (ICHmw, ESSFwh), colluvial blanket and veneer deposits in the central part of the drainage are the most common parent materials for Dystric Brunisols and Humo-Ferric Podzols. Soils in the rubbly colluvium with typically high coarse fragment content have sandy loam or loamy sand surface textures and are well- to rapidly-drained. The colluvial blankets on lower and mid slopes include moisture-receiving (seepage) areas where soils are often imperfectly drained and gleyed (e.g., Gleyed Dystric Brunisols). The colluvial veneers have significant inclusions of lithic soils.

Productivity of the colluvial soils for tree growth is low to moderate in the shallow veneers and moderate in the deeper deposits, but seepage areas may have increased nutrient availability and higher site productivity. The seepage sites also have a higher sensitivity to disturbance as gleyed soils are susceptible to compaction and rutting when saturated. Potentially unstable soils on steep colluvial slopes are also sensitive to disturbance by road building and logging that can increase the risk of surface erosion, slope failures and landslides.

Morainal deposits at mid elevations in the watershed are less common and occur on the lower valley walls with colluvial blankets and along the west side of the drainage. The deposits are moderately to very stony and the soils have gravelly, loamy sand or sandy loam textures at the surface. As for the colluvial deposits, the dominant soils are Dystric Brunisols and Humo-Ferric Podzols. In the moist and wet climates of the ICHmw and lower subalpine (ESSFwh) subzones, the productivity of the till soils for tree growth is considered high (Jungen, 1980).

At upper elevations in the upper subalpine (ESSFwm) and woodland (ESSFwmw) subzones, colluvial veneers are the most common parent materials. Colluvial blankets are common on mid slopes on the east side of the valley and also occur in pockets among the veneers. Morainal deposits occur in the bottom of the west fork drainage located south of Haiseldean Lake.

Humo-Ferric Podzols are the most common soils that developed in the rubbly colluvial deposits on well- to rapidly-drained sites. The soils have sandy loam to loamy sand surface textures that often become coarser at depth. Lithic Humo-Ferric Podzols on shallow (< 50 cm) deposits are also common in the colluvial veneers, especially at higher elevations (ESSFwmw). Site productivity of soils for tree growth is low to very low in the colluvial veneers and slightly higher in the deeper colluvial blankets. The low productivities are mainly due to harsh climatic conditions including cold temperatures, deep snowpacks and short growing seasons. Weakly- developed Regosol soils in blocky talus deposits and areas of exposed bedrock are common at the highest elevations in the vicinity of Noakes Lake and Balfour Knob.

The morainal deposits in the upper west fork of Laird Creek are moderately to very stony and commonly have gravelly sandy loam surface textures. Humo-Ferric Podzols are the most common soils on moderately well- to well-drained sites. As for the colluvial soils, productivity for tree growth is low due to the harsh climatic conditions in upper subalpine areas.

In both the colluvial and morainal deposits, moisture-receiving areas and seepage sites are common on mid to lower slopes and in valley bottoms. Sombric Humo-Ferric Podzols with thick Ah layers and Ferro-Humic Podzols with Bhf subsurface horizons often develop in the concave, moisture-receiving areas. The moister areas usually have cooler site conditions as well due to cool-aspect slopes or cold air ponding. Sombric Humo-Ferric Podzols also occur on colluvial materials in avalanche tracks. The soil types are moderately-well to imperfectly drained.

Gleyed Podzolic soils often occur on seepage sites. The imperfectly- to poorly-drained soils have faint to distinct mottles in subsurface layers indicating that the soils are saturated for part of the year. Gleyed soils generally have higher productivity for tree growth than drier soils due to the nutrient inputs from seepage waters. The soils, when saturated, are also very sensitive to disturbance by road building and logging. Gleysolic soils with gleyed (Bg) subsurface horizons (Gleysols, Humic Gleysols) occur on saturated sites that include gentle toe slopes with permanent seepage, level sites with high water tables, and wet depressional areas. The poorly- drained soils are associated with wet forests and wet meadows in riparian areas around creeks, lakes and wetlands in the upper basins of the watershed. Small areas of organic soils may occur with wetlands in wet depressions and in the upper basins.

In the **Glade Creek watershed**, Dystric Brunisols and Humo-Ferric Podzols are the most common soils on the landscape. Dystric Brunisols are the dominant soils at low to mid elevations (ICHxw, dw, mw) and the Podzols are dominant at mid to high elevations (ESSFwh, wm, wmw, wmp). Dystric Brunisols also occur in the ESSFwh and on dry, warm sites in the ESSFwm, and Humo-Ferric Podzols occur in the ICHmw on cooler, moister sites. The soils have developed in colluvial, morainal, glaciofluvial, and to a minor extent, fluvial deposits in lower to mid elevation areas and mostly in colluvial veneers at higher elevations above the ICH-ESSF transition zone (ESSFwh). The colluvial and morainal parent materials in the project area are mainly derived from coarse-grained intrusive rocks (granodiorite) and associated soils have sandy loam to sandy textures and poor nutrient status. In the north part of the watershed (north of the north fork of Glade Creek), colluvial and morainal deposits are derived from finer-grained bedrock (limestone, slate, siltstone, argillite) and the associated soils have loamy to sandy loam textures and higher nutrient availability.

At lower elevations (ICHxw, dw) in the drainage, Dystric Brunisols occur on sloping, glaciofluvial kame deposits. The materials are gravelly and cobbly and the soils have sandy loam surface textures that grade to loamy sand and sand at depth. A small fluvial fan overlies the glacio-fluvial deposits at the mouth of Glade Creek. The Dystric Brunisol soils associated with the fan have sandy loam to sand textures and range from being stony at the fan apex to stone free on parts of the apron. Weakly-developed Regosols may be associated with recent deposits and gleyed soils can occur in channels and on the lower fan apron.

Kame deposits with moderate to moderately-steep (30-60%) slopes also occur on the valley sides above Glade Creek from lower to mid elevations (ICHdw, mw, ESSFwh). The deposits are in the lower part of the south fork and extend well into the lower subalpine subzone (ESSFwh) in the north fork. Associated soils include Dystric Brunisols at lower elevations (ICHdw, mw) and Humo-Ferric Podzols in the lower subalpine. The soils are very gravelly and cobbly and surface textures include sandy loams and loamy sands. Situated on lower valley slopes at lower to mid elevations, the well-drained soils are considered to have high productivity for tree growth (Jungen, 1980).

Colluvial and morainal deposits are both very common at lower and mid elevations in the watershed. On the north side of the north fork of Glade Creek, steep slopes are underlain by finer-grained sedimentary rocks. The colluvial and morainal veneers in that area are very stony and have sandy loam textures. The dominant associated soils are lithic Dystric Brunisols and lithic Humo-Ferric Podzols on shallow deposits < 50 cm in depth and rock outcrops are common. Other colluvial veneers and blankets at mainly mid elevations in the watershed are derived from coarse-grained granodiorite, and loamy sand or sandy loam are common surface textures in the rubbly deposits. Dystric Brunisols and Humo-Ferric Podzols are the dominant soils, but there are also significant areas of lithic soils and numerous rock outcrops in the shallow deposits. The soils associated with the colluvial and shallow till deposits have low to moderate productivity for tree growth and forestry is limited by the steep slopes and shallow soils that are very sensitive to disturbance.

Deeper morainal deposits occur on lower and mid slopes at mainly mid elevations (ICHmw, ESSFwh) in the south fork of Glade Creek, on the northwest-facing slopes between the north and south forks, and in the area between the big bend of the north fork and the north watershed boundary. The till deposits located in areas south of the north fork include some colluvial blankets on steeper terrain. The morainal and colluvial materials are derived from granodiorite and are moderately to very stony with gravelly, loamy sand or sandy loam surface textures. Among the dominant soils (Dystric Brunisols, Humo-Ferric Podzols), there are significant inclusions of gleyed soils on seepage sites in the morainal deposits. The till soils occurring at mid elevations in these areas have high productivity for tree growth.

The morainal deposits located north of the north fork are derived from finer-grained bedrock. The associated soils have loam or sandy loam surface textures with moderate to high amounts of coarse fragments, and higher nutrient status compared to soils associated with basal tills derived from granodiorite. This area also includes some coarse-textured kame deposits in the upper valley bottoms. As for the other mid elevation areas, both Dystric Brunisols and Humo-Ferric Podzols are common and some gleyed till soils occur in seepage areas. The soils that developed in the basal till in this area also have high site productivity.

The gleyed soils (Gleyed Humo-Ferric Podzols, Gleyed Dystric Brunisols) associated with wet forests on seepage sites usually have higher productivities than the drier unmodified soils and they are also more sensitive to disturbance. Roads can disrupt and redirect subsurface water flow in seepage areas and saturated soils are susceptible to compaction and rutting by logging activities.

At upper elevations (ESSFwm), soil parent materials are predominantly colluvial veneers with some morainal blankets on less steep terrain. The materials are derived from coarse-grained granodiorite. Soils that developed in the rubbly colluvial deposits have sandy loam textures at the surface that become coarser at depth. Humo-Ferric Podzols are the most common soils, but there are significant inclusions of lithic Humo-Ferric Podzols on shallow (< 50 cm) veneers with numerous rock outcrops. There are also inclusions of Gleyed Humo-Ferric Podzols in seepage areas and other Podzol subgroups that develop in cooler, moisture-receiving areas.

Cool, moist sites occur in the upper valley of the north fork on gentle terrain adjacent to Siwash Lake and on gentle to moderate, cool-aspect slopes below the lake. The area is mapped as having significant inclusions of Sombric Humo-Ferric Podzols (with thick Ah surface horizons) and Ferro-Humic Podzols (with Bhf subsurface horizons) with the more dominant Humo-Ferric Podzols. The soil types develop on moisture-receiving sites that are moderately-well drained and have cooler site conditions due to cool-aspect slopes or cold air ponding. Seepage sites with gleyed Podzols may also occur in this area.

The morainal deposits at higher elevations occur in the bottoms and along the sides of the upper valleys. The materials are moderately to very stony and sandy loam is the most common surface texture. Humo-Ferric Podzols are the dominant soils with Gleyed Humo-Ferric Podzols being common in seepage areas. The gleyed soils in both morainal and colluvial deposits usually have improved productivity compared to the soils on drier sites, but overall, the productivity of soils for forestry in the upper subalpine subzone is low due to the cold climate and short growing seasons.

Gleysols and Humic Gleysols (with thick Ah horizons) are saturated soils that develop on gentle toe slopes with prolonged or permanent seepage, on level sites with high water tables, and in depressional areas. The soils are associated with wet forests and meadows in riparian areas around creeks, lakes, tarns and wetlands in the upper valley bottoms and basins. Small areas of organic soils associated with wetlands may also occur in wet depressions and in the small subalpine basins.

At the highest elevations in the watershed (ESSFwmw, wmp), colluvial veneers are the dominant landforms and lithic Humo-Ferric Podzols on shallow veneers are the most common soils. There are also significant inclusions of Humo-Ferric Podzols and gleyed soils on seepage sites in areas where the veneers are deeper. Weakly-developed Regosols in blocky talus deposits and exposed bedrock are both common on the steep terrain around Siwash Mountain and the other high summits and ridges.

APPENDIX B. AT-RISK ECOLOGICAL COMMUNITIES AND ASSESSMENT OF THEIR POTENTIAL TO OCCUR IN THE LAIRD CREEK AND GLADE CREEK WATERSHEDS

English Name	Scientific Name	Biogeoclimatic Units	BC List[a]	Potential to Occur in Watersheds
slender sedge / common hook-moss (fen wetland)	*Carex lasiocarpa / Drepanocladus aduncus*	ICHxw/Wf05; ICHdw1/Wf05; ICHmw2/Wf05; ICHmw4/Wf05	Blue	unlikely; very few organic wetlands at low to mid elevations in the watersheds
timber oatgrass - grouseberry - thread-leaved sandwort - compact selaginella (alpine grassland)	*Danthonia intermedia - Vaccinium scoparium - Eremogone capillaris - Selaginella densa*	ESSFwmw/Ag01; ESSFwmp/Ag01; IMAun/Ag01	Red	possible; the alpine grassland occurs very infrequently at high elevations in the south Columbia Mountains on neutral to warm, moderate to steep upper slopes or in gentle depressions with cold air accumulation
rough fescue - sulphur buckwheat - thread-leaved sandwort (grassland)	*Festuca campestris - Eriogonum umbellatum - Eremogone capillaris*	ESSFwm3/Gg16; ESSFwmw/Gg16; ESSFwmp/Gg16	Red	unlikely; could occur on dry warm, moderately steep to steep, shedding slopes at high elevations, but typically associated with nutrient-rich soils
Idaho fescue - sulphur buckwheat - thread-leaved sandwort (grassland)	*Festuca idahoensis - Eriogonum umbellatum - Eremogone capillaris*	ESSFwm3/Gg14; ESSFwm3/Vh12; ESSFwmw/Vh12	Red	unlikely; could occur on windswept, dry warm, moderately steep to steep, mid slopes, or gentle upper slopes and crests at mid to high elevations, but typically occurs on soils with medium to rich nutrient regimes; can also occur in the mid-track and run-out zones of avalanche paths (Vh)
Idaho fescue - bluebunch wheatgrass - silky lupine - junegrass (grassland)	*Festuca idahoensis - Pseudoroegneria spicata - Lupinus sericeus - Koeleria macrantha*	ICHxw/Gg11; ICHdw1/Gb11; ICHmw2/Gb11; ICHmw4/Gb11	Red	possible; the grassland could occur on exposed, very dry, warm-aspect slopes in a mosaic with the dry ICHdw1/02 forests, Gb03 brushlands and exposed bedrock located above the lower north fork of Glade Creek

English Name	Scientific Name	Biogeoclimatic Units	BC List[a]	Potential to Occur in Watersheds
black cottonwood / common snowberry - roses (mid bench flood)	*Populus trichocarpa* / *Symphoricarpos albus* - *Rosa spp.*	ICHxw/Fm01; ICHdw1/Fm01	Red	no; no active floodplains in the very minor portions of the watersheds adjacent to the West Arm and lower Kootenay River
Douglas-fir / tall Oregon-grape / parsley fern (very dry forest)	*Pseudotsuga menziesii / Mahonia aquifolium / Cryptogramma acrostichoides*	ICHdw1/02	Red	yes; occurs on very dry, steep, warm-aspect slopes with exposed bedrock and very shallow soils in the Glade Creek watershed; could also occur on similar sites in the Laird Creek watershed; correlates to the *102 FdPy - Pinegrass - Rock-moss* site series (MacKillop and Ehman, 2016)
western redcedar - western hemlock / common horsetail (very wet forest)	*Thuja plicata - Tsuga heterophylla / Equisetum arvense*	ICHmw2/113	Blue	no; ICHmw2 only occurs in the project area north of the Laird Creek watershed
tufted clubrush / golden star-moss (fen wetland)	*Trichophorum cespitosum / Campylium stellatum*	ESSFwh3/Wf11; ESSFwm3/Wf11	Blue	unlikely; the fen ecosystem develop on sites with nutrient-rich parent materials
western hemlock / common snowberry (mesic forest)	*Tsuga heterophylla / Symphoricarpos albus*	ICHxw/01	Red	unlikely; very minor areas of ICHxw in the watersheds
ninebark – oceanspray – bluebunch wheatgrass (Gb03 brushland)	*Physocarpus malvaceus – Holodiscus discolor – Pseudoroegneria spicata*	ICHxw/Gb03; ICHdw1/Gb03; ICHmw2/Gb03; ICHmw4/Gb03	Ranking by CDC in progress [b]	likely; the shrub-dominated brushland community appears to occur (on air photography) on the dry, warm-aspect slopes with shallow soils located above the lower north fork of Glade Creek
[a] BC List Status: Red = considered to be Extirpated, Endangered, or Threatened in B. C.; Blue = considered to be of Special Concern (formerly Vulnerable) in B. C.				
[b] Ranking of this Gb community by the CDC is in progress and CDC mapping of occurrences is not yet available.				

APPENDIX C. AT-RISK VASCULAR PLANT SPECIES THAT COULD OCCUR IN THE LAIRD CREEK AND GLADE CREEK WATERSHEDS

English Name	Scientific Name	Biogeoclimatic Units	BC List[a]	COSEWIC [b] (Reviewed)	Habitat Subtype
alkali-marsh butterweed	*Senecio hydrophilus*	ICHdw; ICHxw	Red		Marsh; Riparian Herbaceous
American sweet-flag	*Acorus americanus*	ICHdw; ICHxw	Blue		Swamp; Marsh; Riparian Shrub; Lake; Pond/Open Water; Riparian Herbaceous
beardless wildrye	*Elymus curvatus*	ICHxw	Blue		Riparian Forest; Conifer Forest - Dry; Mixed Forest (deciduous/ coniferous mix); Gravel Bar
brown beak-rush	*Rhynchospora capillacea*	ICHmw	Blue		Bog; Fen; Marsh; Swamp
California Jacob's ladder	*Polemonium californicum*	ICHdw	Red		
Columbia quillwort	*Isoetes minima*	ICHdw	Red	E (2019)	Vernal Pools/Seasonal Seeps
common clarkia	*Clarkia rhomboidea*	ICHxw	Blue		Conifer Forest - Dry
dwarf hesperochiron	*Hesperochiron pumilus*	ICHdw	Red	E (2019)	Vernal Pools/Seasonal Seeps; Grassland
hairy paintbrush	*Castilleja tenuis*	ICHdw	Red	E (2019)	Vernal Pools/Seasonal Seeps
heart-leaved springbeauty	*Claytonia cordifolia*	ICHmw	Blue		Conifer Forest - Moist/wet; Deciduous/Broadleaf Forest; Mixed Forest (deciduous/ coniferous mix); Splash Zone; Riparian Forest; Cliff; Rock/ Sparsely Vegetated Rock; Talus
lance-leaved figwort	*Scrophularia lanceolata*	ICHmw	Blue		Conifer Forest - Mesic (average); Grassland; Meadow; Shrub - Natural
least bladdery milk-vetch	*Astragalus microcystis*	ICHdw	Blue		Grassland; Conifer Forest - Dry
linear-leaf moonwort	*Botrychium campestre* var. *lineare*	ESSFwm	Blue		Pasture/Old Field; Mixed Forest (deciduous/coniferous mix); Riparian Herbaceous; Cliff; Rock/Sparsely Vegetated Rock
Michigan moonwort	*Botrychium michiganense*	ICHdw	Blue		Conifer Forest - Dry; Grassland

English Name	Scientific Name	Biogeoclimatic Units	BC List[a]	COSEWIC [b] (Reviewed)	Habitat Subtype
mountain moonwort	*Botrychium montanum*	ICHmw	Blue		Conifer Forest - Mesic (average)
pale bulrush	*Scirpus pallidus*	ICHdw	Red		Marsh; Riparian Herbaceous
peduncled sedge	*Carex pedunculata*	ICHmw	Blue		Deciduous/Broadleaf Forest; Mixed Forest (deciduous/coniferous mix)
purple meadowrue	*Thalictrum dasycarpum*	ICHdw; ICHxw	Blue		Riparian Forest; Riparian Shrub; Meadow; Riparian Herbaceous
purple spike-rush	*Eleocharis atropurpurea*	ICHmw	Red		Lake
Pursh's wallflower	*Erysimum capitatum var. purshii*	ICHxw	Blue		Roadside/Ditch; Rock/Sparsely Vegetated Rock / Cliff; Shrub-Natural
satinflower	*Olsynium douglasii* var. *inflatum*	ICHdw	Red		Grassland; Conifer Forest - Dry
smooth goldenrod	*Solidago gigantea* var. *shinnersii*	ICHxw	Blue		Meadow; Riparian Herbaceous
sweet-marsh butterweed	*Senecio hydrophiloides*	ICHdw	Blue		Marsh; Vernal Pools/Seasonal Seeps; Riparian Forest; Meadow; Riparian Herbaceous
whitebark pine	*Pinus albicaulis*	ESSFwm; ESSFwmp; ESSFwmw; ICHmw; IMAun	Blue	E (2010)	Conifer Forest - Dry; Conifer Forest - Mesic (average); Cliff; Rock/Sparsely Vegetated Rock; Talus
wild licorice	*Glycyrrhiza lepidota*	ICHdw	Blue		Riparian Forest; Grassland; Riparian Herbaceous
woolly blue violet	*Viola sororia*	ICHdw	Blue		Conifer Forest - Mesic, Moist/ Wet
yellow widelip orchid	*Liparis loeselii*	ICHmw	Blue		Riparian Herbaceous; Riparian Shrub; Bog; Fen

[a]BC List Status: Red = Extirpated, Endangered, or Threatened in B. C.; Blue = Special Concern (formerly Vulnerable) in B. C.

[b] COSEWIC (Committee On the Status of Endangered Species In Canada) ranking: E = ENDANGERED: A species facing imminent extirpation or extinction