Kinbasket Reservoir Monitoring of the Valemount Peatland

Reference: CLBMON-08

Final Report

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Executive Summary

Kerr Wood Leidal Associates (KWL) was retained by BC Hydro to continue the existing CLBMON-08 monitoring program associated with the updated Columbia River Water Use Plan (BCH 2007). The purpose of the CLBMON-08 monitoring program is to assess the nature of the peatland erosion in the upper Kinbasket Reservoir and to determine the extent to which on-going reservoir operations influence the erosion processes which affect long-term viability of the wetland (BCH 2019).

The management questions specific to the CLBMON-08 monitoring program are provided in Table ES-1. This study is to be completed over a 5-year time frame. The MQs will be partially answered in this report. KWL understands that BC Hydro intends to have a second year of monitoring, in 2024, which will yield updated answers to the MQs.

Table ES-1: Management Question Summary

Management Question	2019 Status
1. What are the processes and associated rates leading to observed erosion of the wetland? Are erosion rates increasing or decreasing?	The loss of peatland vegetation through the deposition of wood debris, combined with prolonged inundation during the growing season, appear to be likely factors that have contributed to erosion of the peatland.
2. Are current reservoir operations creating or contributing to conditions that are leading to the observed erosion processes.	While the wood debris entering the reservoir may not be directly related to reservoir operations, higher pool elevations allow the migration of wood debris (via wind processes) to enter the Kinbasket Reservoir and deposit into the Valemount Peatland. Combined with prolonged inundation, the reservoir operations are creating the conditions leading to the observed erosion of the peatland.

A field program was conducted to guide the identification of geomorphic processes that may be occurring within the peatland as well as to assess the baseline plant community composition of the vegetated portion of the peatland. Imagery analysis was used to classify the 2019 terrain types coverage for future comparison in 2024, and to digitize specific geomorphic features. Lastly, an assessment of Kinbasket Reservoir duration of inundation in relation to Canoe River peak flows was also conducted.

The main results of this monitoring study showed that, given the current Canoe River position, it does not appear to have the potential to directly erode the current peatland (both vegetated and non-vegetated portions). The deposition of wood debris combined with prolonged inundation are likely the primary factors that have reduced the size of vegetated portion of the peatland and continue to prevent colonization of peatland flora in the non-vegetated area.

1. Introduction

Kerr Wood Leidal Associates (KWL) was retained by BC Hydro to continue the existing CLBMON-08 monitoring program. CLBMON-08 is one of the monitoring programs associated with the updated Columbia River Water Use Plan (BCH 2007). The purpose of the CLBMON-08 monitoring program is to assess the nature of the peatland erosion in the upper Kinbasket Reservoir and to determine the extent to which on-going reservoir operations influence the erosion processes which affect long-term viability of the wetland (BCH 2019).

Based on the updated Terms of Reference (BCH 2019), CLBMON-08 is intended to answer the following management questions (MQs):

1. *What are the processes and associated rates leading to observed erosion of the wetland? Are erosion rates increasing or decreasing?*
2. *Are current reservoir operations creating or contributing to conditions that are leading to the observed erosion processes?*

This study is to be completed over a 5-year time frame. The MQs will be partially answered in this report. KWL understands that BC Hydro intends to have a second year of monitoring, in 2024, which will yield updated answers to the MQs.

1.1 Project Location and Description

The Mica Dam, completed in 1973, impounds the Kinbasket Reservoir. The Mica Dam fulfilled the final requirement of the Columbia River Treaty, which ensured the best conditions for producing hydroelectricity downstream in the United States as well as providing flood control along the entire length of the Columbia River. The Kinbasket Reservoir is 216 km long and is fed by the Columbia, Kicking Horse, Canoe, and Wood Rivers (Ham 2010).

The Valemount Peatland (referred to herein as 'the peatland') is in the northern end of the Kinbasket Reservoir, also referred to as Canoe Reach. The 375 km^2 peatland is located approximately 13 km south-east of the town of Valemount (Figure 1-1).

The normal operational range of the Kinbasket reservoir, as dictated by the updated Water Use Plan (BCH 2007), is between 707.41 m and 754.38 m above sea level (ASL). The peatland occupies the mid- to upper drawdown zone elevations of the reservoir: from 738 m to 755 m ASL (Ham 2010). The peatland currently contains two distinct sections: a vegetated fen or wetland area and a non-vegetated section primarily comprised of exposed peat material (Ham 2010, BCH 2019).

Prior to inundation by Kinbasket Reservoir, the Valemount Peatland supported a dense vegetative cover consisting of mixed coniferous / deciduous riparian forest, a large wetland interior where imperfect drainage allowed the development of fen peat over time, a well drained swampy area to the south that supported some trees, and a dense coniferous forest along higher elevation margins (Ham 2010).

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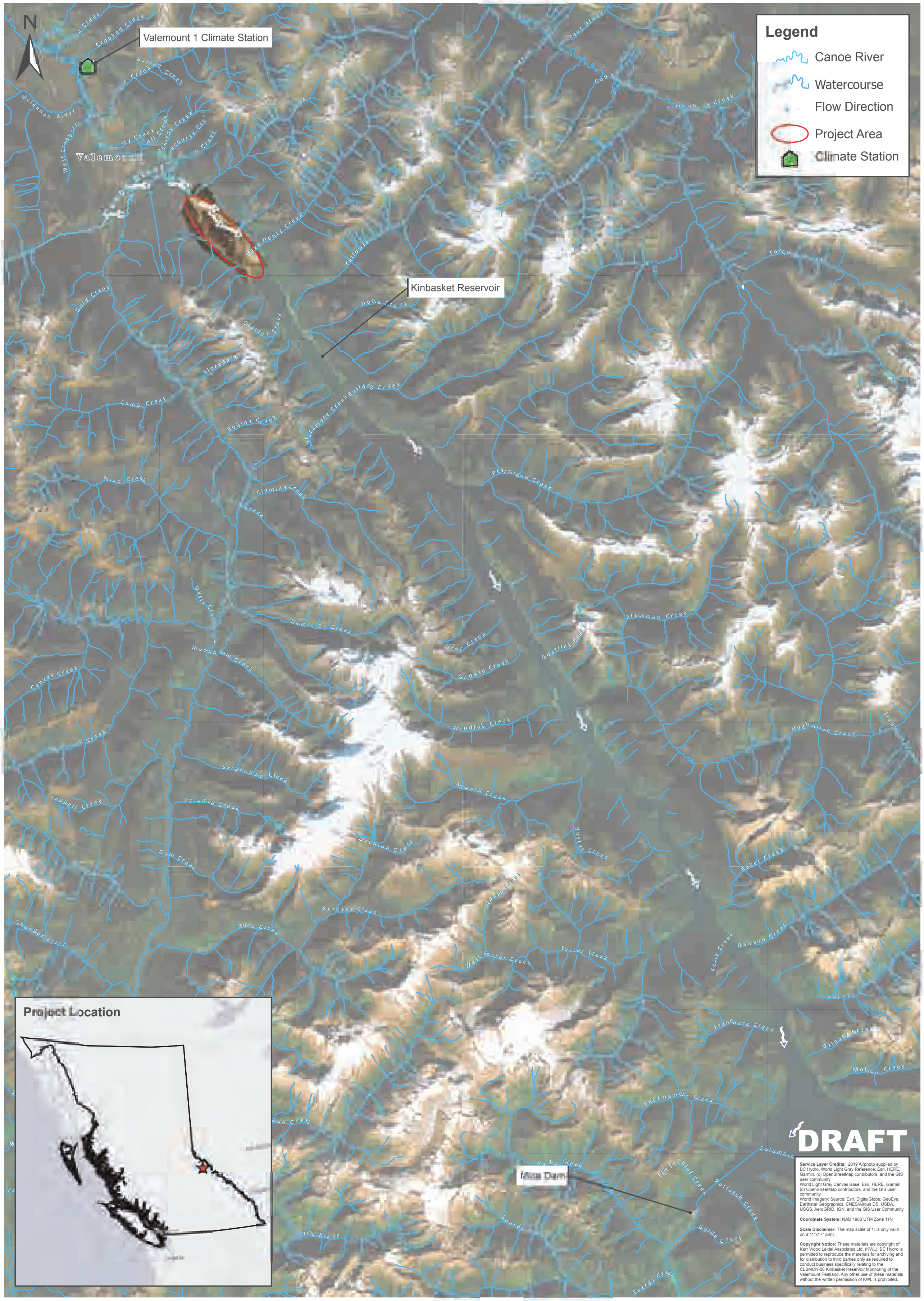

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Coordinate System: NAD 1983 UTM Zone 11N

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Date April 2020

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1:275,000

Project Area

Figure 1-1

1.2 Project Team

The KWL project team and roles for this study are as follows:

- Erica Ellis – Project Manager and Professional of Record (Fluvial Geomorphology);
- Patrick Lilley – Senior Technical Reviewer (Biology);
- Chad Davey – Project Biologist and Fluvial Geomorphologist; and
- Deanna Shrimpton – Junior Geomorphologist.

The biological study component was led by Estsék' Environmental Services, whose team included:

- Greg Sykes, Project Manager (Triton Environmental Consultants);
- Hazel Cameron-Inglis, Biologist (Triton Environmental Consultants); and
- Jay Curtis, Field Technician (Estsék').

The following BC Hydro staff provided input to the CMSMON8 MQ analysis:

- Mark Sherrington – BC Hydro Contract Manager; and
- Guy Martel – BC Hydro Fish and Aquatic issues (Subject Matter Expert).

1.3 Project Design

The study is designed to quantify erosion processes over a 5-year time frame (2019 to 2024). It is anticipated that field data and aerial imagery analysis conducted this year (2019) will be repeated in 2024 to monitor changes in the peatland terrain. The primary goals of this report are to:

- Identify geomorphic processes that appear to be associated with the current erosion of the Valemount Peatland and assess whether or not these are related to reservoir operations or from natural processes (e.g., Canoe River);
- Collect baseline plant community composition data from the vegetated section of the peatland for comparison purposes in 2024; and
- Collect terrain feature coverage data for entire project area for comparison purposes in 2024.

Two separate teams were assembled to address the MQs: a geomorphology team (KWL) and a biology team (Estsék' Environmental Services). The KWL team was responsible for the following tasks:

- Identification of geomorphic processes (erosion and deposition) in the project area;
- Digitizing terrain features (e.g., vegetation boundary, cobble terrace, etc.) for 2019 and other selected historical images;
- Focused assessment of terrain types (e.g., bare ground, woody debris, etc.) at specific locations to compare change (e.g., area, presence / absence) over time using other selected historical imagery;
- Classification of various terrain types (e.g., bare ground, vegetated peatland, unvegetated peatland, woody debris, etc.) along the project area using the 2019 imagery;
- Mapping of changes in the Canoe River channel position over time based on selected historical imagery and the 2019 imagery;
- Analysis of reservoir level data to determine the spatial extents of peatland inundation and duration of inundation during the growing season;

- Comparison of Canoe River peak flow timing with elevation of the Kinbasket Reservoir: and
- Valemount wind assessment to understand the direction, frequency, and magnitude of wind in the Kinbasket Reservoir.

The biological study component was led by Estsék' Environmental Services, who were responsible for the following tasks:

- Assessment of absolute ground cover, plant health, vegetation composition, and species richness/diversity at each plot along each transect; and
- Analysis of potential trends in ground cover, plant health, vegetation composition, and/or species richness/diversity with respect to peatland elevation.

2. Methodology

A field program was conducted to investigate the geomorphic processes that may be occurring within the peatland as well as to assess the baseline plant community composition of the vegetated portion of the peatland. Imagery analysis was used to classify the 2019 terrain types coverage and to digitize specific geomorphic features. An assessment of Kinbasket Reservoir duration of inundation in relation to Canoe River peak flows was conducted. Lastly, an assessment of the Valemount wind direction, frequency, and magnitude was conducted. The methodological details of the field program, imagery analyses, and the reservoir duration assessment are provided in the sections below.

2.1 Field Visit

The field staff mobilized to the Valemount Peatland on June 9, 2019 to complete the field component of the project. KWL staff (Chad Davey, Deanna Shrimpton) demobilized from the site on June 13, and the Estsék' team (Hazel Cameron-Inglis and Jay Curtis) demobilized on June 14. The reservoir elevation at the time of the site visit ranged from 728.5 m to 730.1 m ASL.

The field visit had two main purposes:

1. To document geomorphic features and associated processes occurring in the project area (KWL); and
2. To establish transects and conduct vegetation sampling (Estsék').

2.2 Geomorphic Field Investigation

Prior to conducting the field visit, KWL staff reviewed the 2017 orthophotos to identify specific areas to visit within the project area. Field sites were chosen to represent the various terrain types present within the project area (e.g., bare sediment, exposed peat, woody debris, peatland vegetation, etc.). An iPad with the ESRI Collector for ArcGIS app (Collector) was used to collect points, lines, and polygons of interest, along with photographs and notes. Polygons were mapped of the various terrain types for use in terrain mapping and classification of the 2019 orthophotos (see Section 2.4.2). In addition, the edge of the vegetation section of the peatland was mapped in the field using Collector. To safeguard the collected field data, data from Collector was uploaded to a cloud server at the end of each day and backup photos of field notes were taken.

2.3 Peatland Vegetation Assessment

To assess the plant composition of the vegetated (living) portion of the peatland, a vegetation field sampling program was conducted. Prior to the field assessment, reference maps were reviewed to aid in the vegetation plot selection. Inundation elevation contours (m) during the growing season were overlaid onto aerial imagery and three transects were randomly established within the visibly eroded peat zone (Figure 2-1). Four additional transects were added in the field by arbitrarily selecting and navigating to a parallel starting waypoint on a handheld Garmin GPSmap 64s Global Positioning System (GPS).

Final transects were a minimum of 180 m apart and extended from the NW edge of the reservoir (higher elevation range: 752–754 m ASL) toward the Canoe River (lower elevation range: 738–744 m ASL). Up to ten plots were randomly selected along each transect (49 plots total); in most cases vegetation sampling was stopped one plot past the end of the vegetated zone on each transect, as the ground was predominately saturated bare organic soil and hazardous to traverse. Although this modification resulted in a variable number of sampled plots per transect, it enabled the field crew to add additional replicates (i.e., transects).

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Field Sites for Geomorphic Investigations and Vegetation Assessment

Figure 2-1

Rectangular 0.5 m^2 plots, consisting of two adjacent 0.5 x 0.5 m quadrats, were established at each transect point (Photo A). Percent ground covers, species composition and species vigour were recorded for each plot. Percent ground covers were estimated to the closest 0.1% for live vegetation, litter, bare ground, water, coarse woody debris, and rocks within each plot. Soil decomposition, pH, and electrical conductivity (EC) were measured for plots with moist or wet peat. The degree of soil decomposition was evaluated using the von Post Scale of Humification (Ekono 1981). Soil pH and EC (mS/m) were measured using an Oakton Instruments digital pH meter.

Photo A: Example of 0.5 m x 0.5 m quadrats placed for vegetation sampling. Percent cover of each layer was estimated at ground level (i.e., below vegetation canopy).

Vegetation data were collected by a team of two vegetation specialists (Estsék' Environmental Services). To establish visual reference points and to document surrounding ground cover, a minimum of five photographs, facing North, South, East, West, and of the ground, were taken at plot centre for each point. GPS coordinates and elevation were taken at plot centre using a handheld Garmin GPSmap 64s unit with a GPS accuracy estimated to be ± 3 m. At the end of each field day, data were reviewed for accuracy and completeness and any collected specimens were identified or confirmed. All GPS and camera data were downloaded to a laptop for nightly backup and uploaded onto a secure server upon returning from the field.

All vegetation within the plots were identified to species and were determined to be native or non-native. Where plant specimens could not be identified to species, the genus or family name was recorded. Species richness was calculated as the mean number of native species per plot. Species from each plot were compared against a list of characteristic species based on wetland species assemblages (Mackenzie and Moran 2004). Weeds and invasive plants can reduce local-scale biodiversity (Amantangelo et al. 2018) and alter habitat structure (Zedler and Kercher 2004). Thus, each plot was also screened for provincially-regulated noxious weeds and invasive plants. Plant vigour for each species within a plot was ranked from 0 to 4 as described in Table 2-1.

Table 2-1: Plant Vigour Score Definitions

Vigour Score	Description
1	Dead. Plant has completely shed all leaves and/or all vegetative components are discoloured or dead, but plant has not yet merged with the litter layer.
2	Poor. Plant is not dead but greater than 50% of its vegetative components are shed, withered, discoloured or diseased. Fruits are absent, or if present, aborted.
3	Fair (Average). Plant has some (25-50%) signs of foliage discolouration/loss or discolouration/loss is localized. May have produced some fruits. Fruits appear to be developing normally or the fruits have matured.
4	Good. Plant has minimal (less than 25%) foliage discolouration or loss and growth, including of fruits and growth appears normal.
5	Excellent. Foliage is lush and there is almost no foliage discolouration/loss. Plants, and fruits if present, may be larger (taller or fuller) or vibrant than normal.

Statistical analysis was conducted to assess trends in ground cover, vegetation health, and vegetation community richness with respect to inundation elevation and was implemented by the glm function in the statistical computer program R version 3.5.3 (R Core Team 2018). Generalized linear models are an extension of linear regression models that accommodate dependent variables from non-normal distributions (McCullagh and Nedler 1989, Dobson and Barnett 2018). Generalized linear models (glm) were built with vegetation characteristics of individual plots as dependent variables and transect order (i.e., sequential position from west to east) and elevation (m above sea level) as continuous independent variables. Each analysis initially considered transect x elevation, which was subsequently excluded because it did not statistically influence variation in the dependent variables ($p > 0.6$) in all cases.

Analyses used sampling distributions and link functions appropriate for each dependent variable: the binomial distribution (with a logit link) for the proportion of plots with plants, the beta distribution (logit link) for the portion of the plot covered by vegetation, and the negative binomial distribution (ln link) for plot species richness.

2.4 Imagery Analysis

There were two objectives for the imagery analyses:

- To digitize and map specific geomorphic features within the peatland to assess how these features may spatially overlap with each other and change over time, and to assist in efforts to provide insight on the primary processes that may be responsible for the erosion of the peatland; and
- To classify terrain type and associated coverage area within the project area using the 2019 high-resolution imagery (including infrared band) for future comparison with the 2024 imagery.

To support the imagery analyses of the peatland, BC Hydro provided KWL with orthophotos and associated LiDAR of the Kinbasket Reservoir. The datasets that were provided, including date collected and resolution, are summarized in Table 2-2.

Table 2-2: Digital Orthophotos of Valemount Peatland Provided by BC Hydro

Orthophoto Year	Date of Collection	Resolution
1968	1968-06-24	NA
1993	1993-05-05	10 cm
2002a	2002-06-02	1 m
2002b	2002-05-15	10 cm
2007	2007-05-30	25 cm[1]
2008	2008-07-25	25 cm[1]
2016	NA	NA
2017	NA	NA
2019[2]	2019-05-09	2 cm

Notes:
[1] Partial coverage
[2] Dataset also includes infrared band and associated LiDAR
NA = Information not available

Feature Mapping

The following features were mapped using selected digital imagery from those datasets listed in Table 2-2. The features as well as the purpose of the mapping are provided below:

- Canoe River channel – to assess changes in channel position over time.
- The boundary between the vegetated (living) and non-vegetated (exposed peat) portions of the peatland – to assess change in position over time.
- The outer edge of a cobble terrace located within the unvegetated section of the peatland – to map the change in exposure of this feature over time.

While wood debris was not specifically mapped, a qualitative comparison of changes in wood debris coverage along the non-vegetated portion of the peatland was assessed.

The banks of the Canoe River were digitized in ArcGIS for a selection of orthophotos (1968, 2002b, 2007, 2017, and 2019) to assess how the planform position of the channel changed over time. Since the resolution of each orthophoto is different (Table 2-2), the banklines were digitized at a scale of 1:3,000 for consistency across differing photo qualities.

The boundaries of an exposed cobble terrace near the Canoe River were mapped in ArcGIS in 1993, 2002b, and 2019 orthophotos to assess the change in exposure over time. In addition, the edge of the vegetated section of the peatland was mapped in ArcGIS using 2016 and 2019 orthophotos (2019 was also partially mapped in field), and compared to the 1968 vegetated peatland boundary prior to the reservoir being in place (Ham 2010). To assess the peatland area changes from 1968 to 2019, polygons of the vegetation extents were drawn. For comparative purposes, the 1968 vegetation boundary was truncated at the northern and southernmost extents of the digitized 2019 vegetation boundary.

A qualitative assessment in changes to woody debris coverage was conducted using a side-by-side comparison of the 2002b, 2017, and 2019 imagery in a focused area.

Terrain Classification

Using the colour and infrared bands within the 2019 imagery, a classification analysis was conducted using ArcGIS to assess the amount or coverage (in km^2) of various terrain types that are present within the project area. Two approaches were used to classify the 2019 digital imagery: a supervised and an unsupervised classification.

For the supervised classification an object-based approach was used to group pixels based on similarity, a process known as segmentation. Segmentation takes into account color, shape and geographic information characteristics when deciding on how to group pixels.

The ISO-Cluster classification algorithm was used to perform the unsupervised classification on the segmented results from the supervised classification. This algorithm separates all the cells of the image into user-defined number of groupings, that will later be manually assigned to the land classes of the image (e.g., wood debris, vegetation, etc.). An iterative procedure is used to then calculate the means of the pixel values for each group, then move pixels between groups until the smallest possible gap between pixel value and group mean is achieved.

Based on the field observations and review of the digital imagery, the following terrain types (e.g., groups) were used in the classification analyses:

- wood debris;
- exposed peat;
- dry sediment;
- wet sediment;
- vegetation; and
- water.

2.5 Reservoir Elevation and Canoe River Flow Analysis

To better understand the duration of water inundation that occurs in the Valemount Peatland, an assessment of the reservoir water level data was conducted. In addition, this assessment considered the timing of the annual Canoe River peak flow events in relation to the reservoir elevation.

Reservoir water level data from June 1993 to June 2019 (e.g., daily maximum, daily minimum, and daily average) was provided by BC Hydro. The reservoir water level data were analysed to determine the duration of inundation in relation to peatland vegetation extent. The water level data was also used to examine the reservoir operating regime (i.e., inundation elevation) in relation to the timing of Canoe River peak flows. Peak flow data for Canoe River was obtained from a Water Survey of Canada real-time hydrometric gauge (08NC004, Canoe River Below Kimmel Creek), located about 17 km upstream of the reservoir.

The water level data was sorted by water years, which is the 12-month period starting October 1 through September 30 of the following year. The average daily water level (in m) was sorted in descending order (from highest elevation to lowest), then ranked. The percent of time during the yearly record that each elevation was underwater was then calculated. The inundation duration analysis was conducted for both the year as a whole, and for the growing season of each year. The growing season is defined here as April 1st to September 30th (Hawkes and Gibeau, 2017).

2.6 Valemount Wind Assessment

To better understand the mobilization of wood debris in Kinbasket Reservoir, an assessment of the frequency, magnitude and direction of wind for the Valemount area was conducted. Wind data was downloaded from a provincially managed climate station immediately north of Valemount BC (Valemount 1, FLNRO-WLB 1755). This climate station is currently active and has been recording wind data since 1989. The period of wind data that was assessed was from 1989 to 2019. The location of the climate station is shown in Figure 1-1.

3. Results

The following sections summarize the results of the geomorphic field investigation, peatland vegetation assessment, imagery analyses, and reservoir water elevation assessment. In addition, an assessment of the wind direction, magnitude and frequency was also assessed for the Valemount area.

3.1 Geomorphic Field Investigation

The field observations revealed two distinct features of the Valemount Peatland: a vegetated section and a non-vegetated section (these two sections are distinguished in Figure 3-3). These sections of the Valmount Peatland contain multiple terrain types. The locations, inferred processes, photos of the observed terrain types, and other related geomorphic features, are summarized in Table 3-1.

Terrain types that have extensive coverage in the project area include:

- wood debris deposits,
- lacustrine deposits,
- exposed peat, and
- vegetated peatland.

The vegetated section primarily contains peatland vegetation and water features (e.g., ponds), whereas the non-vegetated section primarily contains exposed peat and wood debris.

Wood debris deposits appear to be the most prominent terrain type in the non-vegetated section of the peatland. These deposits range in size from large immobile tree trunks to fine wood dust that is actively mobilized by wind and deposited in the form of dune-like structures. In some cases, the wood debris deposits were measured to be 0.5 m thick, before encountering peat material below. The arrangement, or imbrication, of the wood debris seemed to align with the direction of the receding waters (Table 3-1).

Another prominent terrain type in the project area is lacustrine deposits of silt and sand-sized material. This terrain type primarily covers the eastern and southern portions of the project area. It is suspected that fine-grained material entering from stream and river inlets during high reservoir levels are deposited along the reservoir bottom. When these sediments become dry and exposed to wind (at lower reservoir levels), they appear to be eroded by wind processes and blown northward forming dune structures (up to 0.3 m in height) in the northern portion of the project area.

Exposed peat is another terrain type that covers a wide expanse within the project area. Visually, exposed peat is identified by a wet, black surface. This terrain type was present primarily within the centre of the project area within the non-vegetated section of the peatland. The exposed peat was typically saturated with water, however, in certain areas the peat material was relatively dry.

The vegetated portion of the peatland ends abruptly and is in marked contrast to the non-vegetated section of the peatland where it transitions to wood debris deposits and, to a lesser extent, exposed peat. Numerous ponds of water were observed in the vegetated portion of the peatland. Drainage from these ponds was generally eastward towards the Canoe River. Detailed observations of the plant communities within the vegetated peatland area are provided in Section 3.2.

Table 3-1: Summary of Geomorphic Field Observations

	
Terrain Feature	Vegetated Peatland
Photo Location (Figure 2-1)	1 (left), 2 (right)
Inferred Process	Deposition
Occurrence/Coverage	Limited to western edge of project area
Comment on Process Mechanism	A healthy peatland environment is typically a depositional environment in which vegetation accumulates in layers on top of older, decaying vegetation to eventually form peat (Photo 1). Photo 2 (right) shows the edge of living vegetation on the peatland.
	
Terrain Feature	Wood Debris
Photo Location (Figure 2-1)	3 (left), 4 (right)
Inferred Process	Deposition
Occurrence/Coverage	Extensive coverage throughout non-vegetated section of peatland
Comment on Process Mechanism	When reservoir levels are high, floating wood debris is likely washed into this part of the reservoir. When reservoir water levels recede, wood debris is deposited onto the ground surface (Photo 3). Some fine wood debris may be windblown. In some areas, the woody debris deposits appeared to be imbricated: their position is aligned with the direction of receding water (Photo 4).

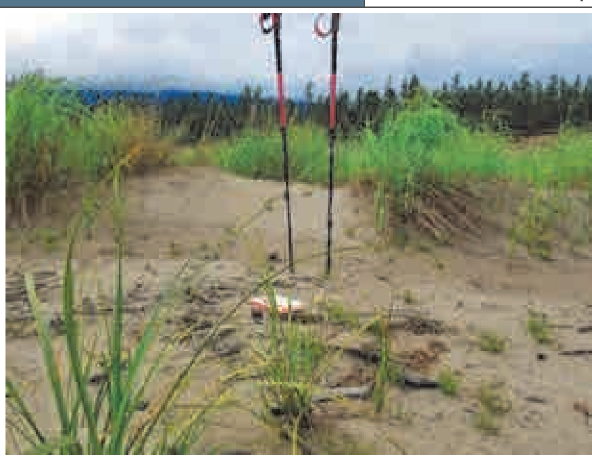
Terrain Feature	Exposed Peat
Photo Location (Figure 2-1)	5 (left), 6 (right)
Inferred Process	Erosion
Occurrence/Coverage	Extensive coverage throughout non-vegetated section of peatland
Comment on Process Mechanism	Exposed peat material is initiated by the loss of living peatland surface vegetation. This is likely occurring as a result of two concurrent processes: prolonged water inundation and deposition of wood debris on the peat surface. Once vegetation is absent from the peatland surface, desiccation, wind, and wave processes further expose and erode the peat material.

Terrain Feature	Cobble Terrace
Photo Location (Figure 2-1)	7 (left), 8 (right)
Inferred Process	Erosion (exposure of former fluvial depositional feature)
Occurrence/Coverage	A few isolated locations adjacent to the Canoe River
Comment on Process Mechanism	Originally formed by historic fluvial depositional processes, this terrace feature, which appears to underlay the peat material (Photo 8), is now being exposed by the erosion of the peat material via desiccation, wind, and wave processes (Photo 7).

Terrain Feature	Scarp
Photo Location (Figure 2-1)	9 (left), 10 (right)
Inferred Process	Erosion
Occurrence/Coverage	Minor occurrences along a few isolated areas along the peatland vegetation boundary (Photo 9), and along the eastern edge of exposed cobble terrace feature (Photo 10).
Comment on Process Mechanism	This type of erosion is likely occurring from wave-related processes.

Terrain Feature	Alluvial Fans
Photo Location (Figure 2-1)	11 (left), 12 (right)
Inferred Process	Deposition
Occurrence/Coverage	There are two large alluvial fans within the project area: one at the outlet of David Henry Creek (Photo 12) and a second at an unnamed creek near the southwest corner of project area (Photo 11).
Comment on Process Mechanism	These are large depositional features that introduce a significant amount of sediment into the reservoir. It is not known if they cover peat material.

Terrain Feature	Dunes Comprised of Wood Debris
Photo Location (Figure 2-1)	13 (left), 14 (right)
Inferred Process	Deposition
Occurrence/Coverage	Moderate coverage throughout the non-vegetated section of the peatland
Comment on Process Mechanism	Wind-blown deposits of fine-grained wood debris subject to renewed erosion and redeposition (Photos 13 and 14).



Terrain Feature	Dunes Comprised of Sand/silt
Photo Location (Figure 2-1)	15 (left), 16 (right)
Inferred Process	Deposition
Occurrence/Coverage	Concentrated occurrences in the north section of the project area.
Comment on Process Mechanism	Wind-blown deposits of sand/silt sized sediment (Photo 16) subject to ongoing erosion and redeposition (Photo 15).

Terrain Feature	Rills
Photo Location (Figure 2-1)	17 (left), 18 (right)
Inferred Process	Erosion
Occurrence/Coverage	There are many rill channels across the project area; flowing from west to east into the Canoe River
Comment on Process Mechanism	These rill structures are fed by small ponds and poorly-defined drainage channels in the vegetated portion of the wetland (Photo 17). These rills transition into well defined, and incised, channels within the exposed peat and wood debris terrain (Photo 18).

Terrain Feature	Lacustrine Deposits
Photo Location (Figure 2-1)	19 (left), 20 (right)

Inferred Process	Deposition
Occurrence/Coverage	Extensive coverage within the south and eastern portions of the project area
Comment on Process Mechanism	These deposits are primarily silt- and sand-sized sediments. Some of the lacustrine deposits appear darker in colour (Photo 20), which is a result of being moist compared to the lighter-coloured dry areas.

Terrain Feature	Canoe River
Photo Location (Figure 2-1)	21 (left)
Inferred Process	Primarily erosion, but also some deposition
Occurrence/Coverage	Meandering river channel flows from north to south within project area, and is situated quite far from vegetation portion of peatland (> 1 km)
Comment on Process Mechanism	Bank erosion and, to a lesser extent, depositional features (sediment bars) were observed along the Canoe River.

Terrain Feature	ATV Tracks
Photo Location (Figure 2-1)	22 (left), 23 (right)
Inferred Process	Erosion
Occurrence/Coverage	Minor coverage throughout the project area
Comment on Process Mechanism	ATV tracks were evident by the parallel depressions that resulted from the vehicle tires. Minor erosion and some compaction of the surface material from the tires depressions, where observed.

3.2 Peatland Vegetation Assessment

The peatland vegetation assessment found that only a portion of the Valemount Peatland exhibited a living vegetation cover. There was a distinctive transition from living vegetation to exposed peat material and/or wood debris around 749 m above sea level (ASL). Below this elevation, vegetation was largely absent or only present in trace amounts (Photo B, Photo C). On Transect 1, a single plot was sampled below the 744 m ASL contour line. Within this plot, vegetation was present in trace amounts (0.2%, Table 3-2).

Photo B: View from the end of the living vegetation zone on Transect 7 facing North showing the absence of visible living vegetation.

Photo C: View from the end of living vegetation zone on Transect 7 facing South showing the distinctive edge of living vegetation.

Table 3-2: Mean Percent Ground Cover (± SE[1]), Mean Plant Vigour (± SE) and Mean Species Richness (± SE) within Sampled Plots by Minimum Inundation Zone

Plot variable	Above 752 (m ASL)	751–752 (m ASL)	749–751 (m ASL)	Below 749 (m ASL)
Number of plots	14	12	13	10
Species richness	6.21 ± 0.76	5.17 ± 0.64	3.00 ± 0.85	0.90 ± 0.38
% live vegetation	36.72 ± 7.28	17.03 ± 4.88	11.27 ± 5.04	2.17 ± 2.11
% litter	38.31 ± 5.18	47.46 ± 8.37	6.93 ± 3.28	0
% water cover	20.91 ± 7.43	11.00 ± 7.17	0.15 ± 0.15	0
% CWD[2]	5.07 ± 3.46	7.79 ± 3.92	15.65 ± 7.43	16.24 ± 8.27
% rocks	0	0	0.04 ± 0.04	0
% bare soil	3.97 ± 1.43	15.89 ± 4.96	65.96 ± 9.12	81.59 ± 9.63

Notes:
[1] SE = standard error
[2] CWD = coarse woody debris

Within the vegetation assessment plots, 43 unique species were identified (Table 3-3). Due to the underdeveloped or incomplete state of some plants, five plant groups were identified only to genera. Likewise, one lichen, one liverwort and one moss specimen could not be identified to species or genera. All identified species are native to British Columbia and no noxious weeds were detected within the sampled area or along the transects. *Carex aquatilis, Equisetum fluvitale*, and *Comarum palustre* were the most common species surveyed (in 26, 22 and 17 plots, respectively). All other species were found in eight or fewer plots: only 12 species were observed in five or more plots and 27 species were found in only a single plot. The high number of sedges and brown mosses found within the sample plots is in alignment with fen site associations (Mackenzie and Moran, 2004). pH ranged from 5.3 to 6.9, which is most consistent with a circumneutral fen.

Table 3-3: Number of Plots and Range of Percent Cover for Each Species Found Within Sampled Plots

Scientific Name	Common Name	# of Plots	% Cover	Elevation Range
Alopecurus aequalis	water foxtail	8	0.1–6.4	744–749
Aulacomnium palustre	glow moss	5	1–47	749–752
Betula papyrifera	paper birch	1	1	752
Bryum spp.		3	0.1–18	749–752
Calamagrostis canadensis	bluejoint reed grass	1	8	752
Calligeron spp.		1	1	752
Campylium stellatum	yellow star-moss	3	1 - 2	751-752
Carex aquatilis	water sedge	26	0.1–25	744 -752
Carex bebbii	Bebb's sedge	2	0.1–3.5	751
Carex canescens	grey sedge	3	0.1– 2	751–752
Carex crawfordii	Crawford's sedge	3	0.1–20	751–752
Carex interior	inland sedge	2	0.1	752
Carex lasiocarpa	slender sedge	1	3	752
Carex limosa	shore sedge	2	8.5–9.25	751
Carex spp.		1	2	751
Carex tenuiflora	sparse-leaved sedge	2	0.25–3	751
Climacium dendroides	tree moss	2	0.5–12.5	751–752
Comarum palustre	marsh cinquefoil	17	0.1–4	744–752
Deschampsia cespitosa	tufted hairgrass	7	0.1–7	751–752
Drosera anglica	great sundew	1	0.5	751
Eleocharis palustris	common spike-sedge	5	0.1–2	749–752
Epilobium ciliatum	purple-leaved willowherb	2	0.1	752
Epilobium palustre	swamp willowherb	7	0.1–1	744–751
Equisetum fluvitale	swamp horsetail	22	0.1–6.5	744–752
Equisetum palustre	marsh horsetail	1	0.1	752

Scientific Name	Common Name	# of Plots	% Cover	Elevation Range
Galium trifidum	small bedstraw	2	0.1	749–751
Juncus alpinoarticulatus	alpine rush	4	0.1–5	749–751
Lemna minor	common duckweed	1	0.1	752
Menyanthes trifoliata	Buckbean	8	0.1–4	749–752
Mitella nuda	common miterwort	1	0.1	752
Myosotis laxa	small-flowered forget-me-not	1	0.1	751
Plagiomnium ellipticum	marsh leafy moss	1	0.5	752
Platanthera dilatata	fragrant white rein orchid	1	0.25	752
Potentilla norvegica	Norwegian cinquefoil	2	0.25–1	749–751
Rorippa palustris	marsh yellow cress	1	0.1	749
Salix pedicellaris	bog willow	2	0.1–0.5	752
Salix planifolia	plane-leaved willow	1	0.1	752
Salix spp.	unknown willow	1	0.1	752
Scorpidium aduncus	hook moss	2	0.5–18	752
Scorpidium revolvens	hook moss	5	0.1–14	752
Scorpidium spp.	unknown hook mosses	2	1	752
Sphagnum fuscum	common brown peat-moss	1	29	752
Sphagnum spp.		2	0.1–62	752
Sphagnum squarrosum	shaggy peat	1	0.1	752
Sphagnum warnstorfii	Warnstorf's peat-moss	2	0.1	751–752
Tomentypnum nitens	golden fuzzy fen moss	8	0.1–80	751–752
Triglochin maritima	seaside arrow-grass	1	0.1	752
Utricularia intermedia	flat-leaved bladderwort	7	0.1–4	751–752
Viola palustris	marsh violet	2	0.1–1	751–752
	unknown lichen	2	0.1–0.5	749
	unknown liverwort	2	0.1	749–752
	unknown moss	8	0.5–25	744–752

Species richness, the percentage of plots with plants, and percent cover of live vegetation varied statistically with elevation, but not with transect order (Table 3-4). The effects of elevation zone on these variables were positive. The percentage of plots with some vegetation increased from 40% to 100% between the 744 m and 752 m elevation zones (Figure 3-1A). The positive association was evident for many individual species, as illustrated in Figure 3-1B for the three most common species, *Carex aquatilis*, *Comarum palustre*, and *Equisetum fluvitale*. Likewise, the average percent cover of vegetation increased from 5% to 37% within plots (Figure 3-1C) and species richness increased from 1 to 7 species (Figure 3-1D).

Table 3-4: Results of Generalized Linear Models Assessing Effects of Transect Order and Elevation Zone on the Proportion of Plots With Live Vegetation, Relative Vegetation Cover of Plots, and Species Richness of Plots with Vegetation

Effect	% Plots with Vegetation	% Ground Cover of Vegetation	Species Richness
Transect order	$G_1 = 0.00002$	$G_1 = 0.37$	$G_1 = 0.03$
Elevation zone	$G_1 = 10.35$**	$G_1 = 10.96$***	$G_1 = 25.01$***
** $P < 0.01$, *** $P < 0.001$			

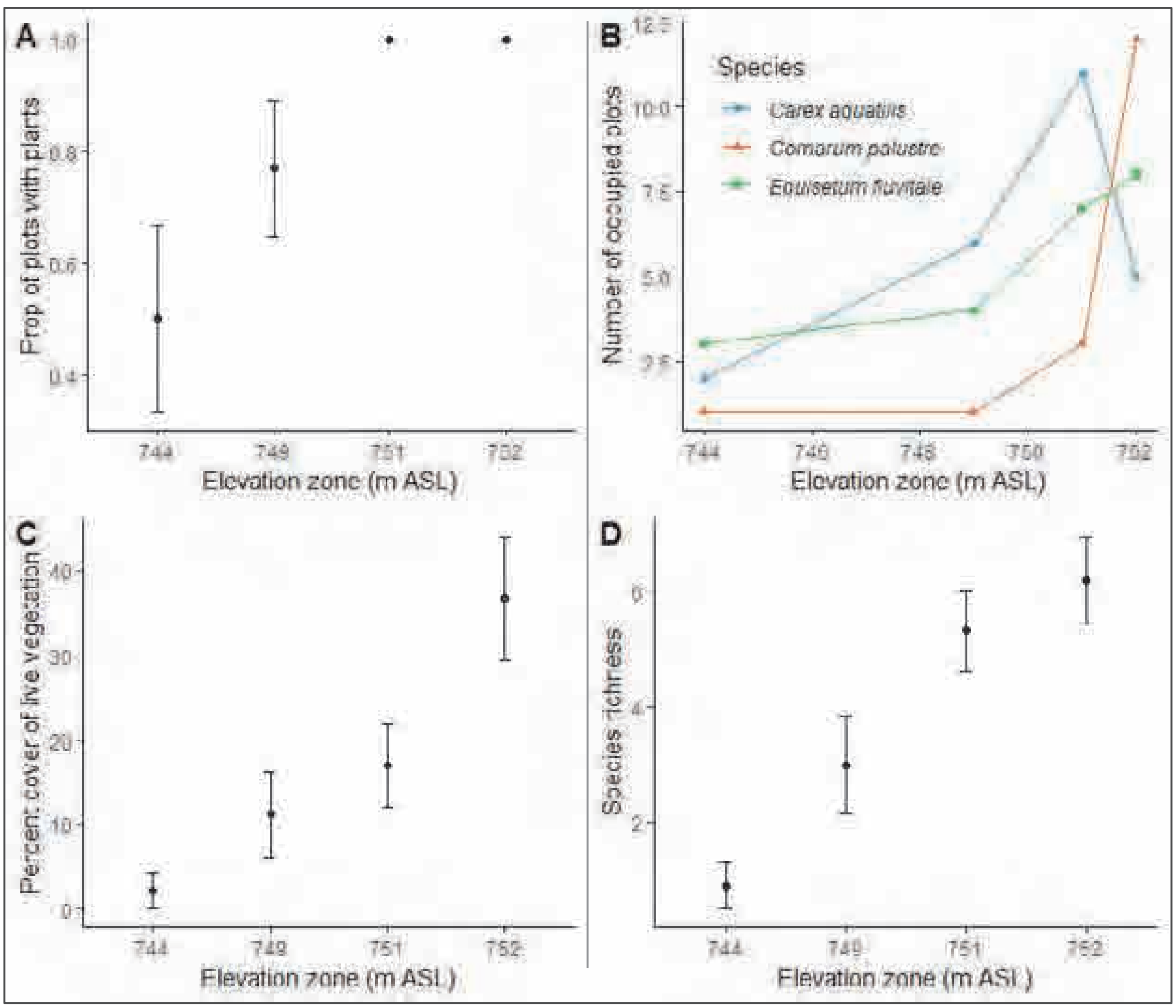


Figure 3-1: Effects of Elevation Zone on A) Mean (± SE) Proportion of Plots with Plants, B) Number of Plots Occupied by the Most Common Species, C) Mean (± SE) Live Vegetation Cover of Plots and D) Mean Species Richness in Plots with Plants

C. aquatilus, *C. palustre,* and *E. fluvitale* were found within plots at each elevation zone. While the number of occupied plots decreased with elevation (Figure 3-1B, Figure 3-2), the majority of plants exhibited Good to Excellent vigour in all elevation zones.

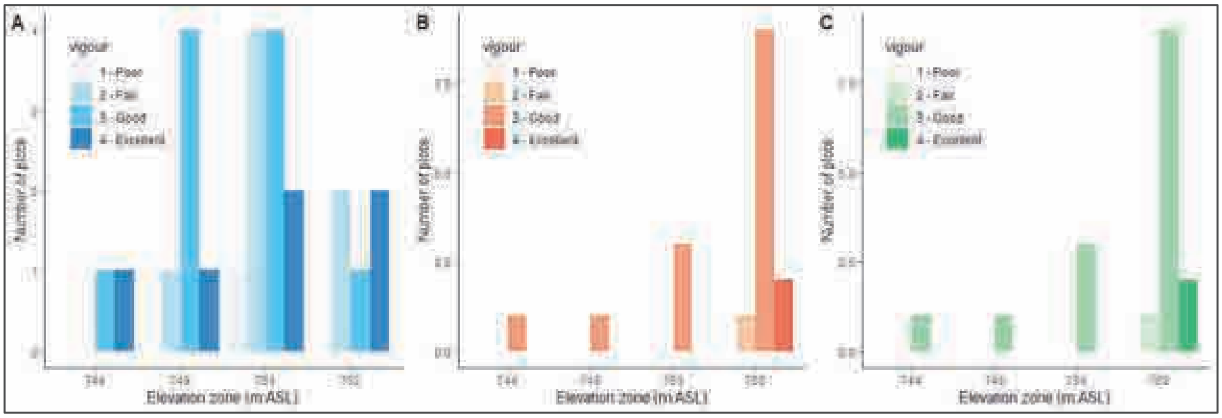


Figure 3-2: Vigour Exhibited by the Three Most Common and Widely Distributed Species (A = *Carex aquatilis*, B = *Comarum palustre*, C = *Equisetum fluvitale*) within surveyed Plots at Each Elevation Zone

3.3 Imagery Analysis

Feature Mapping

Canoe River Channel

The planform position of the Canoe River channel in relation to the vegetated boundary of the peatland in 1968, 2002, 2007, 2017, and 2019 is illustrated in Figure 3-3. The majority of changes in position took place between 1968 (pre-reservoir conditions) and 2002. However, the mapped Canoe River channel has not overlapped with the pre-reservoir (1968) vegetation boundary on any of the imagery datasets, implying that the river has not eroded into the historical peatland.

Vegetated Peatland Boundary

The position of the 1968 (pre-reservoir condition), 2016, and 2019 peatland vegetation boundaries are also shown in Figure 3-3. The position of the 2016 and 2019 boundaries are quite similar. Minor variations in their position are likely explained by differences in vegetation characteristics, potentially due to differences in the time within the growing season when the imagery was collected. By assuming consistent (arbitrary) north and south boundaries, and an identical western (forest edge) boundary, a comparison of the vegetated portions of peatland area in 1968 and 2019 is provided in Table 3-5. Within the area of analysis, the vegetated portion of the peatland has reduced by 76% from 1968 to 2019.

Table 3-5: Vegetated Peatland Area in 1968 and 2019

Year	Area (km^2)
2019	1.49
1968	6.42

Cobble Terrace

Figure 3-4 illustrates the change in exposure of the cobble terrace between 1993 and 2019. It appears that the cobble terrace has become progressively more exposed towards the western edge (Figure 3-4).

Table 3-6 summarizes the change in exposed area of this cobble terrace feature over time. Between 1993 and 2019, the exposed area of the cobble feature has more than quadrupled in size. The rate of exposure has increased since 2002 (Table 3-6).

Table 3-6: Exposed Area of a Cobble Terrace at Project Site

Year	Area of Cobble Terrace Feature (m^2)[1]
1993	12,600
2002	20,600
2019	58,000
Notes: [1] Area rounded to nearest 100 m^2	

Wood Debris Deposits and Exposed Peat

Figure 3-5 illustrates the change in wood debris coverage in 2002, 2017, and 2019 in an area located in the non-vegetated section of the peatland. The red triangles are sites that were visited in the field in 2019 and are included as points of reference. The coverage of exposed peat material (dark areas) appears to vary for each year shown in Figure 3-5. Even between 2017 and 2019 there appears to be a notable change in wood debris coverage, suggesting that wood debris is remobilised and deposited in different areas of the peatland annually during reservoir operations.

It is important to note however, that larger pieces of wood debris can be stationary over a longer period of time. The green circles in Figure 3-5 show a large piece of wood debris that is in the same position from 2002 to 2019. This same piece of wood debris is visible in the same location in the 1993 digital image as well (not shown).

Terrain Classification

The following image classifications were conducted on the 2019 digital imagery:

- An unsupervised classification using visible bands (red, blue, green);
- An unsupervised classification using a combination of visible and infrared bands; and
- A supervised classification using training sites of terrain type identified during the field visit.

Of the approaches used to classify the terrain with the 2019 digital imagery, the unsupervised classification using the infrared band and two visible bands (green and blue) seemed to represent the terrain types best. The supervised classification technique using training sites shows promise, however further refinement of this technique is likely needed to improve the classification results.

The following discussion focuses upon the results of the unsupervised classification using the infrared band and two visible bands (green and blue). The success of the classification for each terrain type are assessed qualitatively. A system for quantifying the success of the terrain classification (e.g., measurement of error) was beyond the scope of this project.

In general, the unsupervised classification technique seemed successful in identifying areas of bare sediment (e.g., terraces, lacustrine deposits, alluvial fans) in both wet and dry conditions. This technique appeared to be moderately successful in identifying exposed peat terrain, however: in certain areas, usually in close proximity to rill channels, exposed peat terrain was classified as wood debris. It is suspected that higher moisture content of the surface terrain near rill channels may have influenced this misclassification.

The unsupervised classification results for vegetated terrain seemed to produce mixed results. The area containing the peatland vegetation is confined to the western edge of the project area and its presence was quite evident during the field visit (Photos B and C). While a significant portion of this area was correctly classified as vegetation, this technique appeared to misclassify numerous smaller areas as wood debris and wet sediment terrain. It is possible that in mid-May when the imagery was collected, the living vegetation may not yet have fully leafed out, causing several of the misclassifications within the vegetated peatland area.

The classification of the wood debris terrain type appeared to produce poor results. The majority of the wood debris terrain observed in the field was classified as vegetated terrain. It is suspected that this may be related to wood debris and living vegetation having similar spectral (infrared) properties and thus the classification technique was largely unable to differentiate these two terrain types.

Table 3-7 summarizes the area of each terrain type resulting from the unsupervised classification using the 2019 digital imagery. The bare sediment terrain (combined wet and dry sediment) accounts for almost half of the total area within the project area. As identified above, the vegetation is assumed to be over-represented while the wood debris is underrepresented in the classification results.

Table 3-7: Terrain Type Classified Using 2019 Digital Imagery and Infrared Channel

Terrain Type	Total Area (km^2)[1]	% of Total Area[2]
Exposed Peat	32.7	16
Dry Sediment	39.0	19
Wet Sediment	60.6	30
Vegetation	31.4	16
Water	7.8	4
Wood Debris	30.0	15
Total	201.5	100

Notes:
[1] Rounded to nearest 100 m
[2] Rounded to nearest 1%

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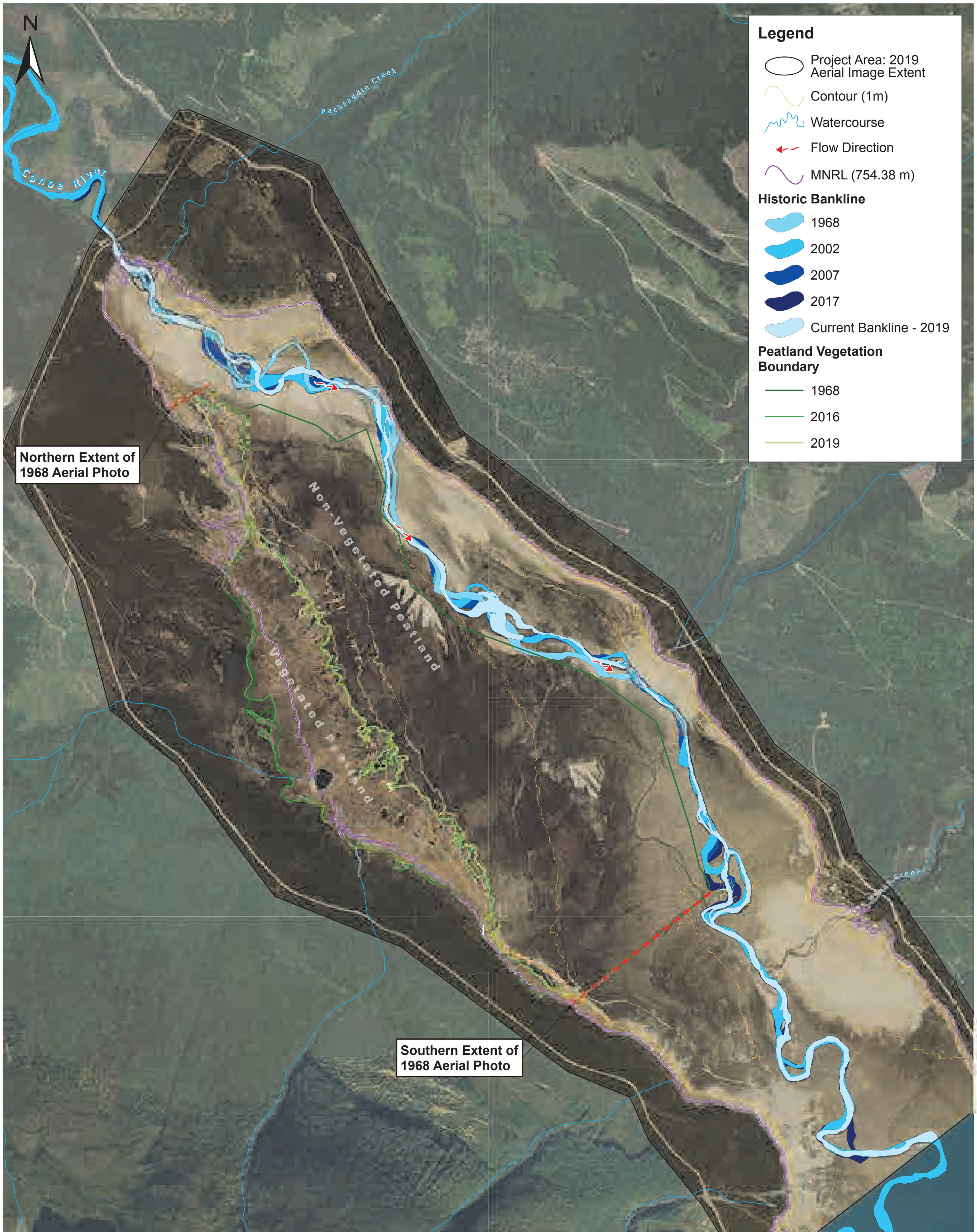
BC Hydro

CLBMON-08 Kinbasket Reservoir Monitoring of the Valemount Peatland

KERR WOOD LEIDAL consulting engineers



Service Layer Credits: 2019 Airphoto supplied by BC Hydro. World Imagery: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Coordinate System: NAD 1983 UTM Zone 11N

Scale Disclaimer: The map scale of 1:25,000 is only valid on a 11"x17" print.

Project No. 478-218

Date May 2020

Scale 1:25,000 — 0, 250, 500, 1,000 (m)

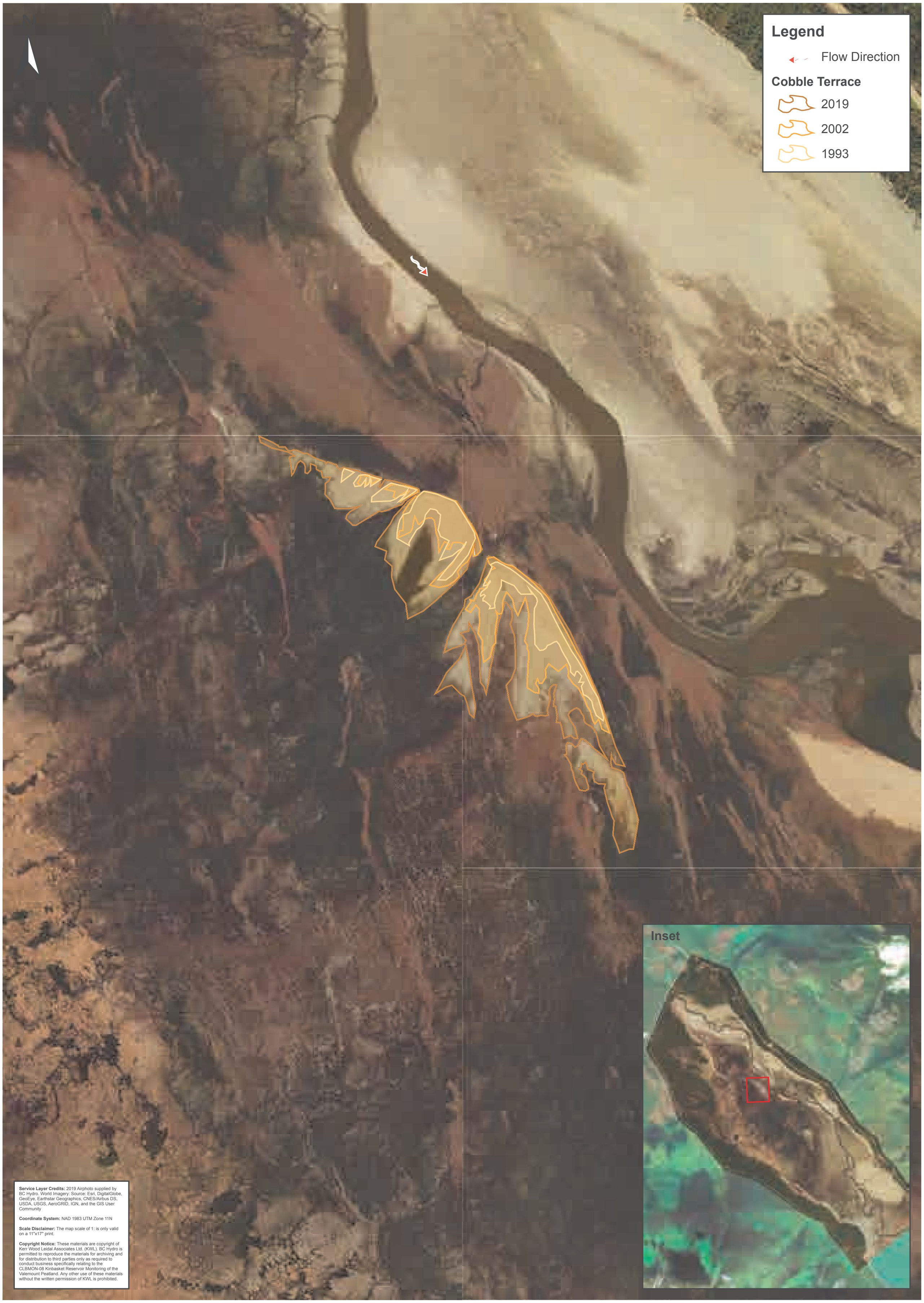
Changes in Canoe River Channel Position and Vegetated Peatland Boundary, 1968 to 2019

Figure 3-3

BC Hydro

CLBMON-08 Kinbasket Reservoir Monitoring of the Valemount Peatland

KERR WOOD LEIDAL consulting engineers



Service Layer Credits: 2019 Airphoto supplied by BC Hydro. World Imagery: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Coordinate System: NAD 1983 UTM Zone 11N

Scale Disclaimer: The map scale of 1: is only valid on a 11"x17" print.

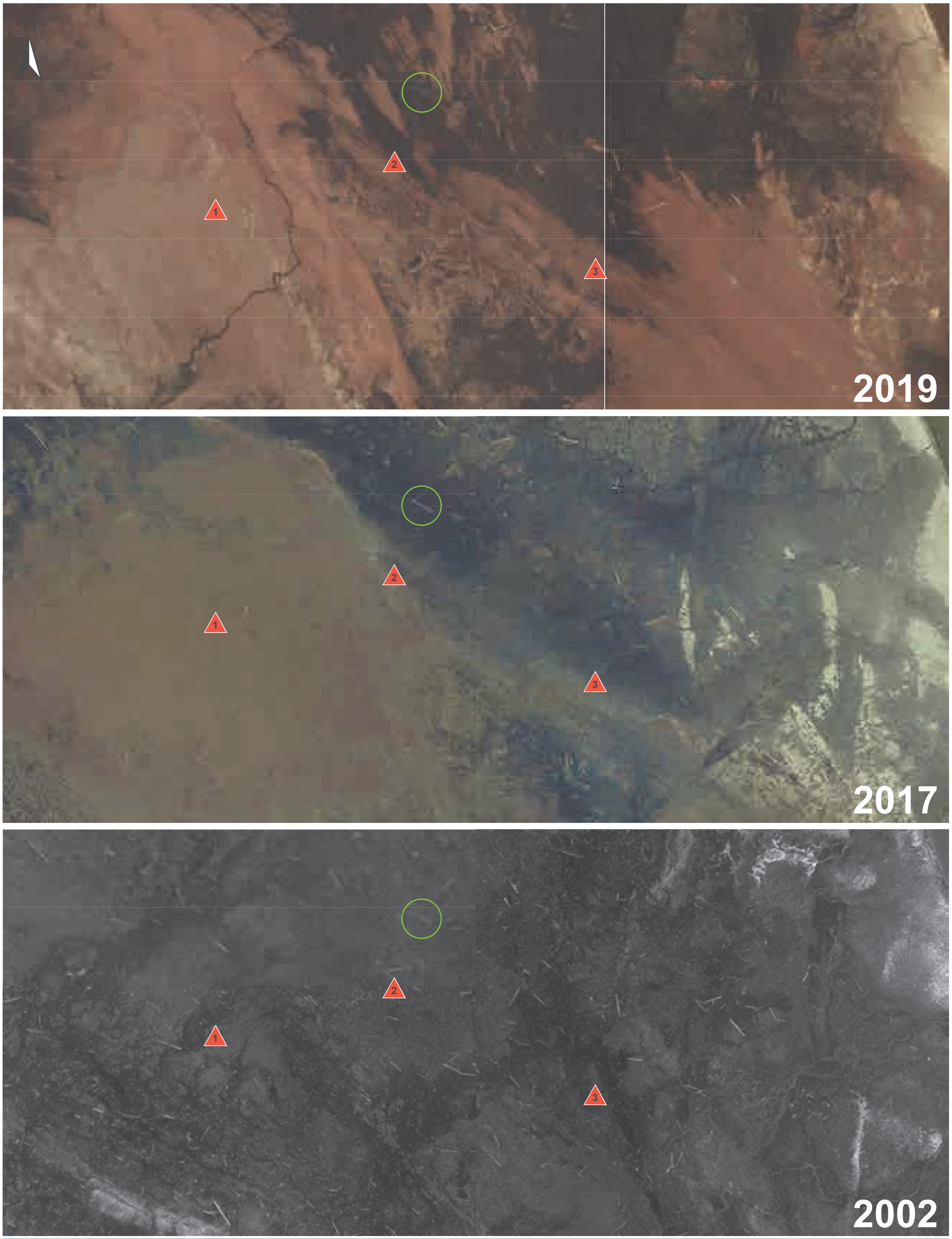
Project No. 478-218

Date April 2020

Scale 0 25 50 100 (m)
1:5,000

Changes in Cobble Terrace Exposure, 1993 to 2019

Figure 3-4



Field Visit Site
Stable Wood Debris

Service Layer Credits: 2019 Air photo supplied by BC Hydro.

Coordinate System: NAD 1983 UTM Zone 11N

Scale Disclaimer: The map scale of 1: is only valid on a 11"x17" print.

Project No. 478-218
Date April 2020
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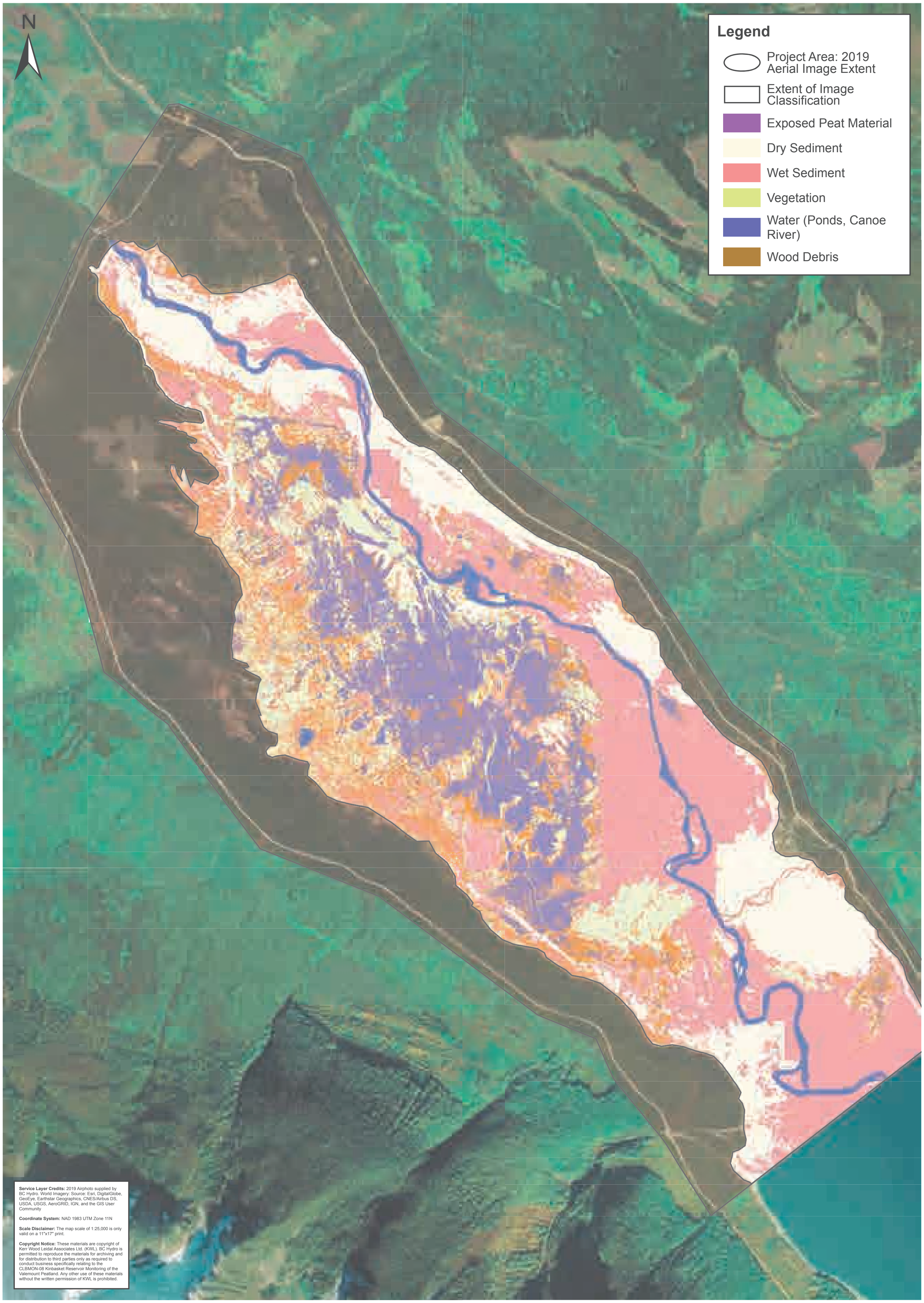
Changes in Location and Extent of Wood Debris Deposits, 2002 to 2019

Figure 3-5



Project No. 478-218

Date April 2020

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Unsupervised Terrain Classification of 2019 Imagery Using ArcGIS

Figure 3-6

3.4 Reservoir Elevation and Canoe River Flow Analysis

Figure 3-7 illustrates the annual maximum Kinbasket Reservoir elevation from 1993 to 2018. The red line represents the historic vegetation boundary in 1968 (pre-reservoir) and the purple line represents the mapped vegetation boundary in 2019 and 2016. In general, Figure 3-7 shows that inundation of the peatland occurs annually:

- the annual maximum reservoir elevation exceeded the lowest elevation of the historic peatland vegetation boundary every year; and
- in 22 of 26 years, the annual maximum reservoir level has exceeded the lowest elevation of the current vegetation boundary.

Figure 3-8 illustrates the average duration of reservoir inundation by elevation between 2007 and 2018 during the growing season (April 1st to September 31st). As shown, the current vegetated area of the peatland (elevation 749 m and higher) is inundated by water ~ 40% of the growing season.

Figure 3-9 illustrates the mean monthly reservoir elevation (between 2007 to 2019) for each month. The growing season is shown in green and the red line represents the mapped vegetation boundary in 2019. In general, the reservoir elevation is lowest from March through May and reaches its highest elevations in August through October. The reservoir levels are typically at and above the 2019 vegetation boundary from July to November.

Figure 3-10 illustrates the Kinbasket Reservoir elevation at the time of annual peak flow on the Canoe River. While there is no obvious trend in peak flow and reservoir level evident in Figure 3-10, it appears that the Canoe River annual peak flow occurs when reservoir levels are fairly high (742 m and higher) compared to the normal operational range of the Kinbasket Reservoir (707.41 m to 754.38 m). The effect of a relatively high reservoir level would be to backwater the Canoe River and reduce channel velocities.

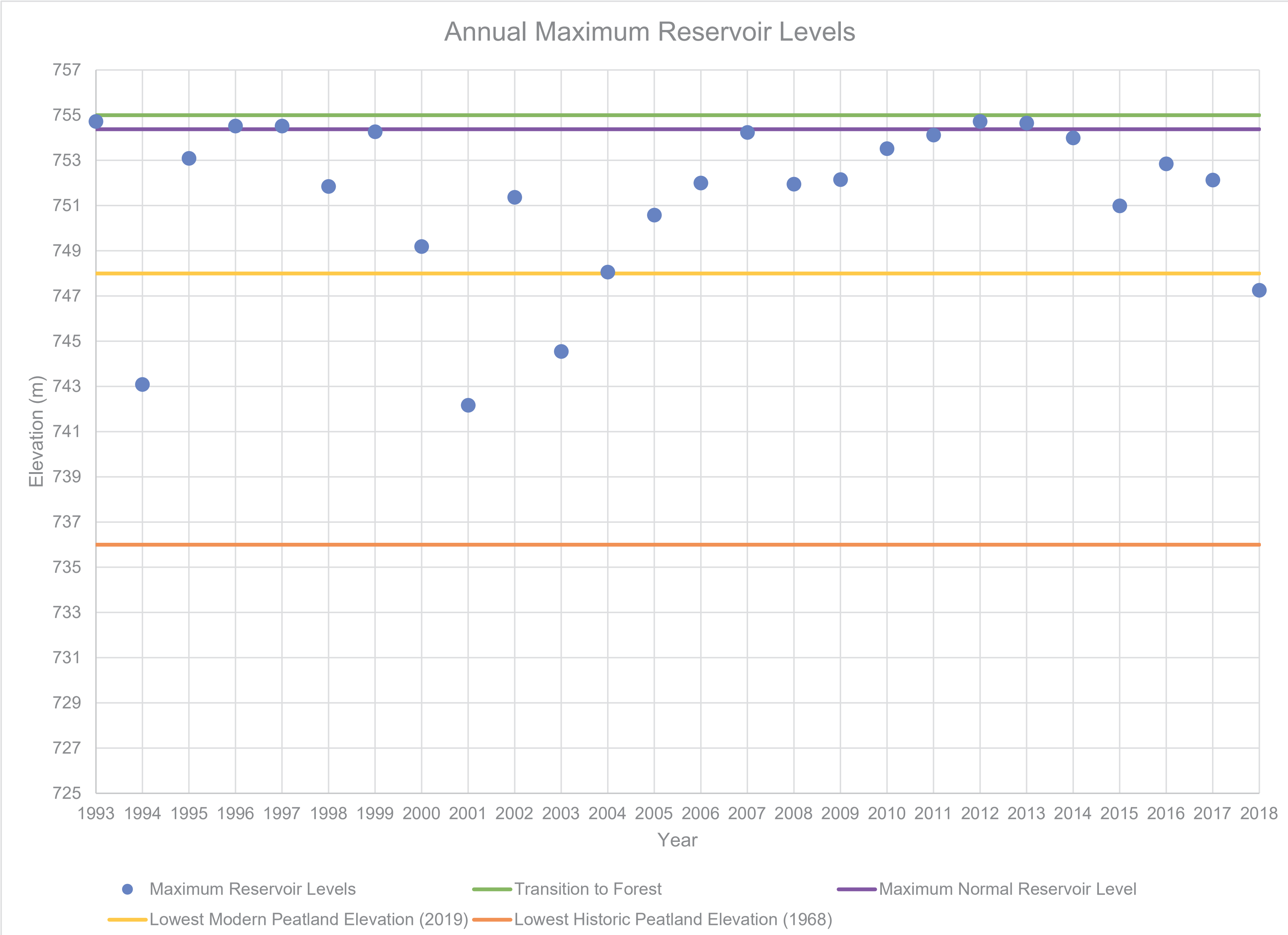

Figure 3-7: Annual Maximum Levels in the Kinbasket Reservoir, 1993 to 2018

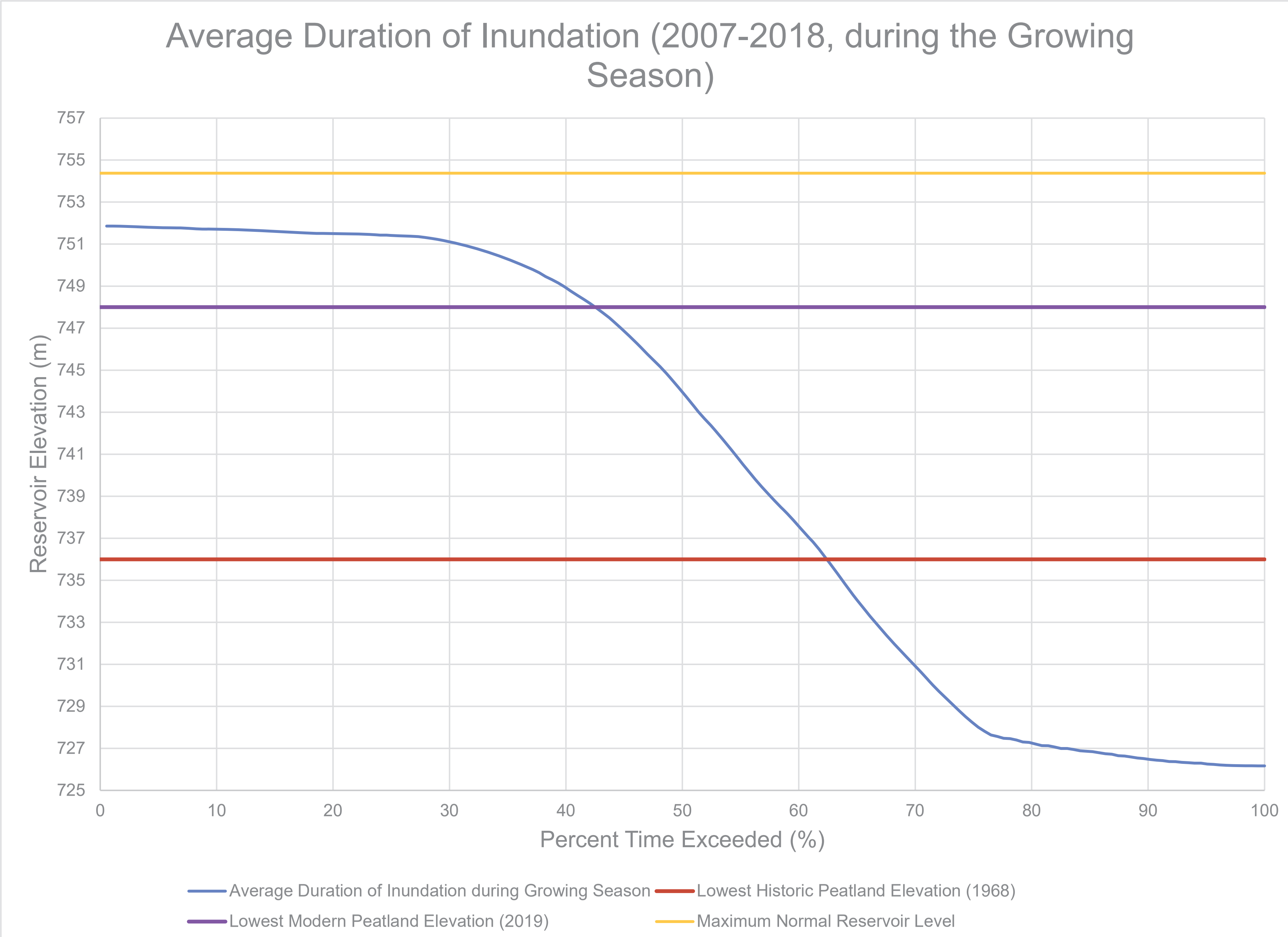

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Figure 3-8: Average Duration of Reservoir Inundation During the Growing Season, 2007 to 2018

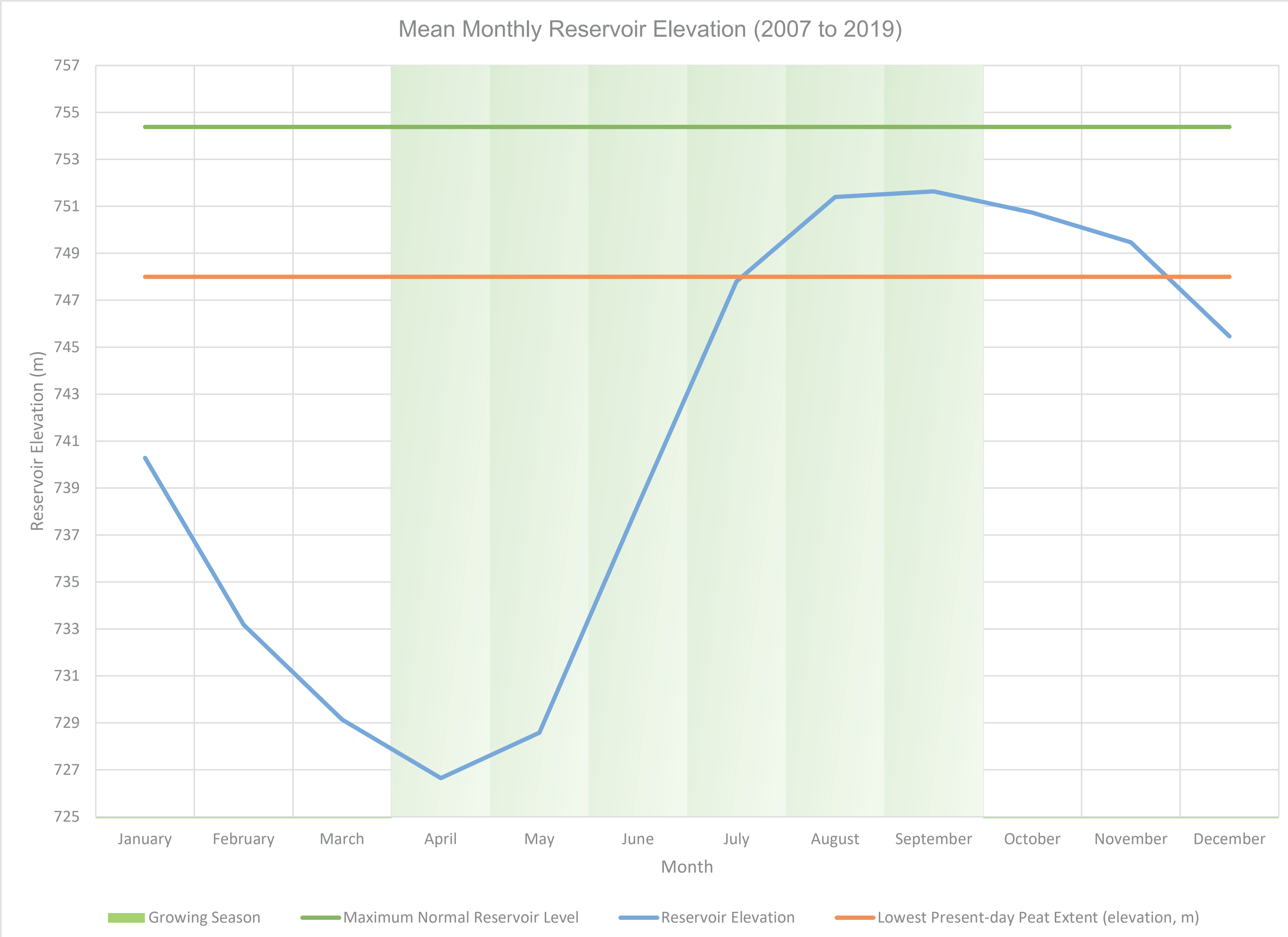

Figure 3-9: Mean Monthly Reservoir Elevation (2007 to 2019) throughout the Growing season

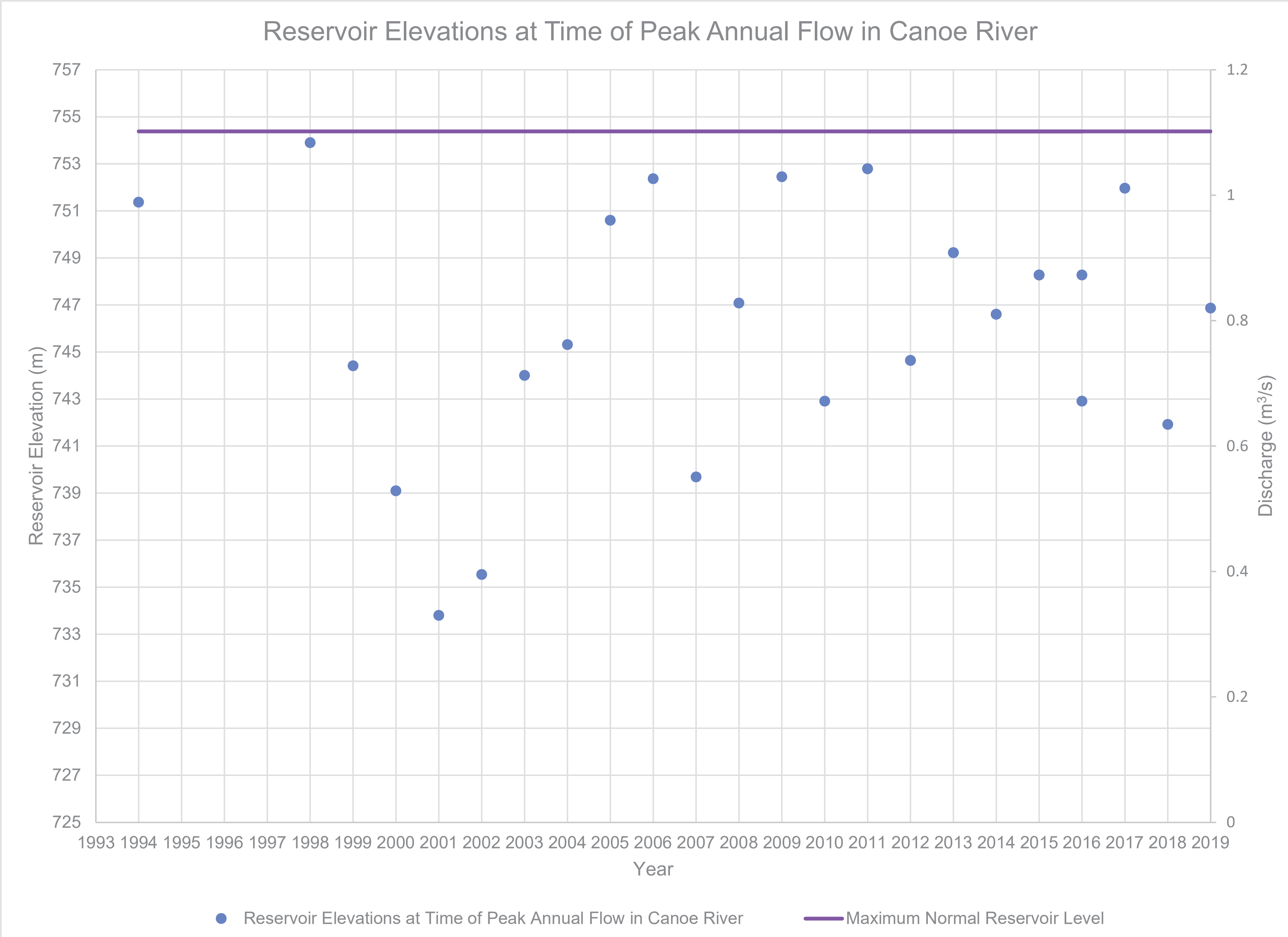

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Figure 3-10: Elevation of Kinbasket Reservoir During Annual Peak Flow in Canoe River, 1994 to 2016

3.5 Valemount Wind Assessment

Figure 3-11 shows the annual wind rose diagram for the Valemount 1 climate station. As shown, the highest frequency and largest magnitude winds are from the southeast direction (i.e. blowing towards the northwest). This wind direction is aligned with the reservoir itself. The implications for the movement of wood debris are discussed in Section 4.

The average wind speed from the SE direction for the Valemount area (not shown) tends to be highest during the winter months (November to March), while the lowest average wind speeds tend to occur in July through September.

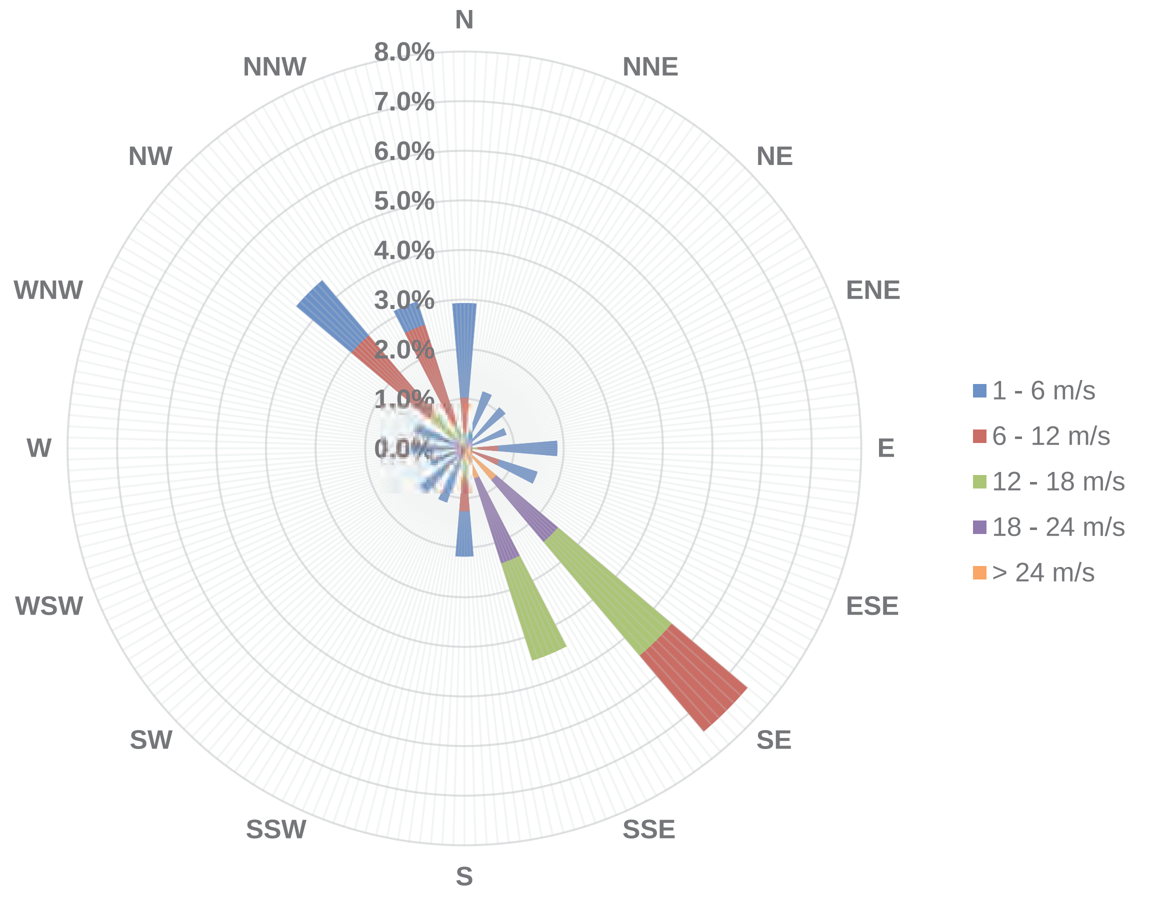

Figure 3-11: Wind Rose Diagram for Valemount 1 Station (FLNRO-WLB 1755)

4. Discussion

4.1 Processes and Features Associated with Observed Peatland Erosion

One of the goals of this report was to identify geomorphic processes and features that appear to be associated with the current erosion of the Valemount Peatland and assess whether or not these are related to reservoir operations or from natural processes. Although Management Questions 1 and 2 are focused on “erosion” of the wetland, it is important to understand that the loss of vegetation in large areas of the historic peatland may not be associated with an active ‘erosion’ process *per se* and that erosional processes acting on <u>unvegetated</u> peatland may be of secondary concern from an operational perspective. Below we discuss processes that we hypothesize have contributed to loss of vegetated peatland, as well as erosional processes.

A number of geomorphic features and associated processes were identified in the project area (Table 3-1). In particular, the Canoe River was previously identified as a potential natural source of peatland erosion (BCH 2019). The Canoe River channel continues to migrate laterally within the project area over time (Figure 3-3). However, these migrations are confined to a narrow corridor that does not overlap with the current peatland vegetation boundary, nor with the historical (1968) peatland boundary (Figure 3-3). In addition, the timing of peak flow events in the Canoe River, which is typically when erosion would occur, coincide with high reservoir levels (Figure 3-10). High reservoir levels during peak flows would attenuate the erosion potential of the Canoe River. Thus, it is unlikely that the Canoe River has contributed to the loss of the vegetated portion of the peatland.

It is suspected that prolonged inundation of the peatland (Figure 3-8) is generally responsible for the reduction in the size of the vegetation peatland compared to pre-reservoir conditions due to water stress on the vegetation community (LGL 2017). However, it is not clear why the boundary of the vegetated portion of the peatland appears to be situated at ~749 m ASL and has stayed in this position since at least 2016 (Figure 3-3). Reservoir levels routinely exceed an elevation of 749 m ASL (Figure 3-7). However, inundation of this elevation of the vegetated peatland area occurs for 40% or less of the growing season (Figure 3-8). It is hypothesized that the effects of inundation at this elevation (and above) reflect a threshold at which peatland flora can withstand inundation the reservoir operations impose.

It is hypothesized that wood debris deposits observed in the non-vegetated portion of the peatland are related to reservoir operations and have contributed to the observed vegetation loss. The wood debris floats along the water surface when reservoir levels are high and is likely blown into the northern part of the Kinbasket Reservoir. This hypothesis is substantiated by the prevailing wind direction in the Valemount area (Figure 3-11). When reservoir levels recede, the wood debris is deposited on the ground surface. The deposition of wood debris buries existing vegetation and limits future growth of wetland plant species. The location and extent of the wood debris ground coverage can change notably from year to year (Figure 3-5), further limiting the colonization of wetland flora. The impacts of wood debris on the recolonization of natural vegetation in the Kinbasket Reservoir drawdown zone has been identified previously (Hawkes 2016), and a management program (CLBWORKS-16) has been in place since 2008 to remove wood debris from the Kinbasket Reservoir (BCH 2018).

While the combined effects of wood debris deposition and reservoir inundation are likely continuing to prevent the growth of wetland flora in the non-vegetated portion of the peatland, it is suspected that the exposed peat in unvegetated areas is also actively eroding. The surface erosion of the exposed peat is inferred from the ongoing exposure of a cobble terrace (Figure 3-4). The cobble terrace underlies the peat material and, as the peat is eroded, likely by combined effects of desiccation (when reservoir waters are low) and wind, more of the cobble terrace is exposed. The exposure of this cobble terrace appears to be accelerating over time (Figure 3-4). Wave processes appear to be eroding the eastern edge of the cobble terrace (Photo 10 in Table 3-1), suggesting wave action may also be contributing to erosion of the exposed peat material.

While exposed sediment terrain (both wet and dry) has the most extensive coverage in the project area (Figure 3-6, Table 3-7), exposed sediment is largely confined to areas at the east and south of the project area, with very little coverage in the peatland area (vegetated and non-vegetated sections) itself. Other features and associated processes identified in the project area are considered secondary in that they are either related to larger terrain features (e.g., dunes of sediment and wood debris) or are fairly localized and unlikely to impact the peatland (e.g., ATV tracks).

Wave related processes appear to be a secondary source of erosion within the project area. Wave erosion features were observed in the form of two scarps (Table 3-1): one along the cobble terrace and another at the southern edge of the peatland vegetation boundary. It is assumed that if wave processes were notably impacting the vegetated peatland, or other terrain types, it would have been more evident during the field visit. Although the prevailing winds are from the SE direction (Figure 3-11), wave activity may be limited since the average wind speeds tend to be lowest when the reservoir elevation is at and above the vegetation boundary (Figure 3-9). Wave activity may also be limited within the Kinbasket Reservoir due to shallow gradients and low water depths that limit wave height formation. However, further analysis would be needed to confirm this assumption.

4.2 Current Conditions within Vegetated Peatland

Another goal of this report is to present the baseline plant community composition within the vegetated section of peatland, which will be used for comparison purposes in 2024.

The results of the vegetation analyses in the vegetated section of the peatland (> 749 m ASL) revealed a statistically significant increase in species richness and plant cover within the peatland plant community with increasing elevation (Table 3-2). Percent cover of bare soil and coarse woody debris significantly increases with decreasing elevation. While the vegetated portion of the peatland seems to tolerate the effects of the reservoir operations, plant abundance and diversity increased as they were less likely to be exposed to reservoir inundation (i.e., higher in elevation). It is reasonable to expect that gradients in plant communities may reflect ecological gradients such as availability of nutrients, or tolerance to changes in water levels. Future analysis on the current data set, such as linear discriminant functions analysis (DFA) could reveal the combination of cover classes (i.e., CWD, litter, vegetation and soil) that maximally distinguish between elevation zones.

4.3 Terrain Analysis

The final goal of this report is to present the 2019 terrain feature coverage data for the entire project, with the purpose of comparing terrain coverage in 2024 to assess the rate of peatland erosion.

The unsupervised classification using the infrared band and two visible bands (green and blue) seemed to represent the terrain types best. This technique seemed successful in identifying bare sediment (wet and dry surfaces) and exposed peat. However, this technique had difficulty in differentiating between vegetation and wood debris terrain types (Figure 3-6).

Results showed that bare sediment terrain (combined wet and dry sediment) accounts for almost half of the total area within the project area, followed by exposed peat, vegetation and wood debris (Table 3-5). However, the vegetation is assumed to be over-represented while the wood debris is underrepresented in the classification results.

It is possible to only assess changes in exposed peat and bare sediment terrain (between 2019 and 2024) to understand the rate at which the peatland may be eroding. However, it may be useful to also assess how the wood debris and vegetation terrain has changed over that same time period.

The spectral properties of vegetation and their reflectance is complex and can vary greatly with factors such as plant type, time of year, soil moisture levels, and plant health (Roy 1989). There is potential to improve the unsupervised classification technique with a more in-depth analysis of the infrared wavelengths capture by the imagery, such that woody debris and living vegetation can be differentiated.

Further refinement of the supervised classification technique may also markedly improve the terrain classification. Refinement of this technique may include, but is not limited to:

- Using the unsupervised classification analysis for identifying problematic areas (i.e., where spectral properties overlap);
- Developing high-quality training sample areas for the classification analysis, focusing on the identified problematic areas; and
- Focussing the classification analysis on mapped features of interest only (e.g., peatland, exclusion of surrounding forest, etc.).

In addition, setting up a practical structure to support the quantification of error would be useful for assessing the success of the terrain classification for both 2019 and 2024.

5. Summary and Conclusions

5.1 Summary

Findings of the analyses presented here include the following:

- The Canoe River channel has migrated laterally from 1968 to 2019. However, the channel changes observed are unlikely to have contributed to the reduction in the vegetated portion of the peatland. Given the current river position, it does not appear to have the potential to directly erode the current peatland (both vegetated and non-vegetated portions).
- High reservoir levels generally coincide with Canoe River peak flows, which would likely attenuate the potential for high Canoe River flows to erode the peatland.
- In general, the historic annual maximum reservoir water elevation exceeds the lowest elevation of the vegetated peatland boundary (> 749 m ASL) suggesting that the vegetation portion of the peatland is regularly inundated.
- The mean annual duration of inundation of the vegetated peatland boundary (i.e., water levels greater than 749 m ASL) during the growing season is ≤ 40%.
- Prolonged inundation combined with wood debris deposition are likely the primary factors that have reduced the size of vegetated portion of the peatland and continue to prevent colonization of peatland flora in the non-vegetated area.
- The historical peatland vegetation boundary (1968) is situated much further to the east (lower in elevation) compared to the current vegetation boundary. A 76% reduction in the vegetated peatland was found between 1968 to 2019. The current vegetation boundary appears to have remained approximately in the same location since at least 2016.
- The smaller-sized wood debris deposits are highly mobile and are redistributed along the non-vegetated portion of the peatland every year by wind processes.
- Surface erosion of the exposed peat is likely occurring as a result of desiccation, wind erosion, and possibly by wave-related processes. An example of this process is the continued increase in the area of the exposed cobble terrace from 2002 to 2019 that underlies the peat.
- The peatland vegetation assessment found that species richness and plant cover significantly increase with elevation. Whereas, percent cover of bare soil and coarse woody debris decreases significantly with elevation.
- Bare sediment terrain (combined wet and dry sediment) accounts for almost half of the total area within the project area, followed by exposed peat, vegetation, and wood debris. However, the vegetation is assumed to be over-represented while the wood debris is underrepresented in the classification results.

5.2 Conclusion

The CLBMON8 project is intended to answer the following management questions:

1. *What are the processes and associated rates leading to observed erosion of the wetland? Are erosion rates increasing or decreasing?*
2. *Are current reservoir operations creating or contributing to conditions that are leading to the observed erosion processes.*

Based on the work completed to date, the MQs are partially addressed below:

For MQ1:

- The loss of peatland vegetation through the deposition of wood debris, combined with prolonged inundation during the growing season, appear to be likely factors that have contributed to erosion of the peatland.

For MQ2:

- While it is not known whether the wood debris entering the reservoir is directly related to reservoir operations, higher reservoir elevations allow the migration of wood debris (via wind processes) to enter the Kinbasket Reservoir and deposit onto the peatland area. Combined with regular, sustained inundation, the reservoir operations are likely creating the conditions leading to the observed loss of the peatland.

It is anticipated that the 2024 monitoring program will provide further insight into some of the processes identified in the current work.

5.3 Recommendations for Future Work

Based on 2019 program results, the following are recommendations for the 2024 monitoring program:

- Further refinement of the supervised classification technique (e.g., analysis of infrared wavelength, enhanced training sites, etc.) to improve the terrain classification.
- Development of suitable quantification of error for assessing the success of the terrain classification for both 2019 and 2024 imagery.
- Additional analyses on the vegetation sampling data (e.g., linear discriminant functions, ordination, assessment of Valemount Peatland diversity compared to other wetlands, etc.) to enhance the assessment of elevation effects on vegetation cover classes.
- Examination of carbon dynamics and general 'health' of the Valemount Peatland (e.g., systematic measurement of peat depth, rate of decomposition, assessment of peat age, etc.).

Report Submission

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