



MacHydro

**Wetland
Restoration
Feasibility Index
for Bench
Wetlands in the
Upper Columbia
Valley – 2026
Update**

Prepared For:

Columbia Wetlands Stewardship Partners
P.O. Box 81
Brisco, BC
V0A 1B0

Prepared By:

MacDonald Hydrology Consultants Ltd.
4262 Hilltop Cres.
Cranbrook, BC V1C 6W3



MacHydro

Restoration Feasibility Index for Bench Wetlands in the Upper Columbia Valley – 2026 Update

March 19, 2026

Report Prepared By:

Spencer Spannier, B.A.Sc., EIT.
Hydrometeorological Technician
MacDonald Hydrology Consultants Ltd.

Report Reviewed By:

Ryan MacDonald, Ph.D., P.Ag.
Senior Hydrologist
MacDonald Hydrology Consultants Ltd.
P.Ag ID #2695

Suggested Citation:

Spannier, S., Millions, E.L., Plews, R., and MacDonald, R.J. (2026) Wetland Restoration Feasibility Index for Bench Wetlands in the Upper Columbia Valley – 2026 Update. Prepared for the Columbia Wetlands Stewardship Partners. (March 2026).

Contents

1 Executive Summary	2
2 Introduction	3
3 Study Area	5
4 Methods	8
4.1 Data Sources-----	8
4.2 Wetness Index-----	8
4.3 Flow Accumulation Index-----	8
4.4 P – ET Index-----	9
4.5 Wetland Restoration Feasibility Index-----	9
4.6 Wetland Field Assessments-----	10
4.7 Restoration Index Verification and Optimization-----	10
5 Results and Discussion	11
5.1 Field Assessment Results-----	11
5.2 Restoration Feasibility Index Results-----	17
5.3 Modified Restoration Feasibility Index-----	18
5.4 Flow Accumulation Index-----	21
5.5 Wetness Index and P-ET Score-----	22
5.6 Wetland Restoration Feasibility Index-----	23
6 Discussion and Recommendations	30
6.1 Discussion-----	30
6.2 Study Limitations-----	31
6.3 Recommendations-----	32
7 Closing	33
8 References	34

List of Figures

Figure 1. BEC zones within the study area, including IDFdk5 (Columbia Dry Cool Interior Douglas-fir), IDFdm2 (Kootenay Dry Mild).....	7
Figure 2 Distribution of field restoration potential results	11
Figure 3 Wetland restoration feasibility from field assessment for the entire study area showing low feasibility (red), moderate feasibility (orange), high feasibility (light blue), and very high restoration feasibility (dark blue). ...	12
Figure 4 Proportion of wetland cover for each field assessed wetland	16
Figure 5 Proportion of surrounding habitat types for each field assessed wetland.....	16
Figure 6 Restoration feasibility index comparison to field assessed restoration feasibility.....	17
Figure 7 The difference between the original restoration feasibility index and field assessed restoration feasibility	18
Figure 8 Comparison of unmodified restoration feasibility index to modified restoration feasibility index for all non-lake sites.....	20
Figure 9 The difference between the modified restoration feasibility index and field assessed restoration feasibility	21
Figure 10 Distribution of Flow Accumulation Index Scores.....	22
Figure 11 Distribution of wetland P-ET (left) and Wetness Index (right) scores.....	23
Figure 12 distribution of Wetland Restoration Feasibility Index values for the bench wetlands.....	24
Figure 13. Restoration Feasibility Index values for wetlands in the northern region of the study area showing low feasibility (red), moderate feasibility (orange), high feasibility (light blue), and very high restoration feasibility (dark blue).....	25
Figure 14. Restoration Feasibility Index values for wetlands in the southern region of the study area showing low feasibility (red), moderate feasibility (orange), high feasibility (light blue), and very high restoration feasibility (dark blue).....	26
Figure 15. Heat map showing P-ET values for the northern region of the study area from the lowest values (0-100; red) to the highest values (>500-600; blue).....	27
Figure 16. Heat map showing P-ET values for the southern region of the study area from the lowest values (0-100; red) to the highest values (>500-600; blue).....	28
Figure 17 Classification and Regression Tree (CART) with Wetland Feasibility Index as a response variable	29

List of Tables

Table 1 Restoration feasibility based on cumulative index score.	9
Table 2 Wetland Conditions During July/August 2025 Field Visits	13
Table 3 Unmodified Restoration Feasibility Index Component Scores	19
Table 4 Modified Restoration Feasibility Index Component Scores.....	19

1 Executive Summary

Wetlands provide critical ecosystem services, including helping mitigate the effects of climate change by sequestering (taking up) carbon and buffering the impacts of climate change on water resources. Wetland numbers are decreasing globally and are expected to decline further due to climate change. Within the Upper Columbia River Valley, an area that is internationally recognized for its important wetland ecosystems, wetlands have been drying out. The Columbia Wetland Stewardship Partners (CWSP) are working to restore these wetlands and improve their ability to hold water with the use of beaver dam analogues (BDAs). As little is known about the hydrology of these wetlands, prioritization of wetland restoration is a challenge, but is an important first step. As wetlands are ecosystems that are highly susceptible to the effects of climate change due to their reliance on local hydrology, not all wetlands can survive the impacts of climate change. Given limited resources, it is important to prioritize wetland restoration efforts.

Here we develop a simple restoration feasibility index to help score wetlands based on their likelihood of long-term restoration success. We use publicly available data to develop an approach that can be adapted for other areas. Geospatial analyses were used to calculate watershed-scale measures from digital elevation models (DEMs). Additionally, measures for how dry a region might be, taken from climate data to simulate precipitation minus evapotranspiration (P-ET) were used. In total a flow accumulation index, a wetness index and a P-ET index were combined to provide the restoration feasibility index, which ranks wetlands as having low, moderate, high, or very high potential to be successfully restored. The index was verified against field data during the summer of 2025 and was updated to improve its predictive powers. The index assessed various combinations of optimization and validation on the categories of low, moderate, high and very high restoration potential. When all 4 categories were considered, the index compared to the field validation was 31/51 (60.8%). Simplifying the index to consider it as a go/no-go assessment where low rated wetlands should not be considered for restoration and moderate, high, and very high should be considered for restoration, the wetland restoration index correctly predicts the field results for 37/51 wetlands (72.5%). The index can provide a reasonable desktop approach to help select wetlands where the restoration activities will be more likely to be successful.

A web mapping tool was developed for this project and is available at the following url: <https://cwsp.machydro.ca/>

2 Introduction

Due to the numerous services that wetlands provide, conserving and restoring wetlands is often seen as a nature-based approach to climate change mitigation (Taillardat et al., 2020). Hydrologically, wetlands can help buffer the impacts of climate change on river systems by mitigating peak flows (Ferreira et al., 2020; Phillips, 2017), increasing low flows (Kadykalo and Findlay, 2016), and reducing the risk of droughts (Wu et al., 2023). Further, wetlands are amongst the most productive ecosystems and through the sequestration of carbon can help mitigate climate change (Taillardat et al., 2020; Kayranli et al., 2010). However, despite the importance of wetlands in the fight against climate change, global wetland area has been reduced by more than half since 1900 (Davidson, 2015), and in North America, changes in climate may cause a further reduction in wetlands by 10% (Xu et al., 2024).

Within the Upper Columbia River Valley, the open water area has decreased by 16% between 1984 and 2019 (Hopkins et al., 2020), as wetlands dry out and are replaced by woody shrubs (Rodrigues et al., 2024). Increases in air temperature and evapotranspiration and precipitation shifts have occurred in the region, influencing the local hydrology (Utzig 2021; Rood et al. 2016). Within the benchlands of the Columbia Valley, wetlands have experienced a number of stressors that have reduced their historic extent, including forestry and draining for agriculture, ranching, and development (Personal Communication, Suzanne Bayley). Further, beavers have historically been active within the area, but many dams within the benchlands have been damaged and are incomplete, reducing the wetted area of wetlands from their historic extents (Leven et al., 2024).

Wetland restoration within the benchlands is underway in several capacities. BCWF has recently completed wetland restoration earth works along Sun Creek, a heavily cattle-impacted watershed near Canal Flats and CWSP has installed four beaver dam analogues on bench wetlands to increase the wetted area (Leven et al., 2024). However, as climate change will continue to impact wetlands in this region, it is important to assess how climate change might influence the success of future wetland restoration. Wetlands are intrinsically linked to the surrounding hydrology, so changes in the local climate can have large impacts on wetland form and function. Mountainous wetlands are often more sensitive to climatic variations, particularly when their water budgets rely heavily on precipitation for water inputs, or if they are groundwater driven within relatively small watersheds (Winter, 2000). In general, the smaller the contributing watershed or the smaller the wetlands surfaces, the more vulnerable the wetland is to the potential effects of climate change on surface water, groundwater, or precipitation pathways (Winter, 2000; Kim and Park, 2020).

To maximize the benefit of wetland restorations, it's important to understand the potential impacts of climate change on water bodies in the region to ensure that wetlands undergoing restoration efforts will be resilient in future climatic conditions. As previous work in the benchland region has shown, surface water connectivity and climatic conditions may be primary drivers of the vulnerability of the bench wetlands (Millions et al., 2024), these factors should be considered in the development of a wetland restoration index in the region. As wetland restoration work has been employed across North America in recent years, attempts have been made to prioritize potential restoration areas using available datasets to identify characteristics with the potential to support wetland ecosystems (Horvath et al., 2018). However, these previous attempts have focused on the suitability for locations to form and sustain a functional wetland by reconstruction of wetland areas where they have historically existed and have since dried, rather than the applicability of wetland improvement methods to increase

wetland function for an existing, semi-functional wetland (Johnson et al., 2024, Medland et al., 2020, Tang et al., 2012).

The purpose of this study is to develop a wetland restoration index for the benchlands in the Upper Columbia Valley using publicly available data sources; this index will guide further work to restore wetlands in the region, primarily by using beaver dam analogues (BDAs). The quality and health of wetlands is complicated and reliant on many site-specific factors including wetland area, upslope land use, landscape microtopography, surrounding habitat, and hydrological sources, connectivity, and disturbance (Hohn et al., 2017, Fletcher et al., 2024). Many of these factors are not available without field investigation and may not be applicable for understanding restoration potential using BDAs. The development of a restoration feasibility index is an attempt to simplify these factors using only physical characteristics of the landscape and climactic conditions that drive wetland hydrology in the region. The restoration index will integrate several indices and data sources to represent water source security, functional locations for wetland development, and climate sensitivity. The development of a restoration feasibility index builds on previous works to understand hydrological and landscape conditions that are conducive to wetland improvement and the applicability of beaver dam analogues for restoration (Mackey, 2025).

This report constitutes an update to the wetland restoration index developed in Millions et al. (2025), incorporating a validation of the index using field data recorded in 2025 and seeks to improve the accuracy of wetland restoration potential prediction.

3 Study Area

The study area includes the bench wetlands on the eastern slopes of the Purcell Mountains between Canal Flats and Spillimacheen, BC, within the Rocky Mountain trench. The study area is defined as an upland area between approximately 785 m and 1871 m with a median elevation of 1063 m. The study area was delineated using elevation and topographic features in GIS and is approximately 668 km² and 100 linear km from N to S.

The study area is 88.8% forested with 50.2% falling in the IDFdk5 BEC zone (Columbia Dry Cool Interior Douglas-fir; Figure 1), 26.8% as MSdk (Dry Cool Montane Spruce), 13.2% IDfxk (Very Dry Cool Interior Douglas-fir), 5.6% as ICHmk5 (Interior Cedar – Hemlock Moist Cool), 4.0% as IDFdm2 (Kootenay Dry Mild Interior Douglas-fir), 0.2% ESSFdk2 (Columbia Dry Cool Engelmann Spruce – Subalpine Fir), and 0.01% MSdw (Dry Warm Montane Spruce).

The study area aspect is primarily northeast (29.2%) while the remaining study area is split into the other aspects relatively evenly (between 5.95% to 16.1% for each aspect). The area is not particularly steep, with 35.7% of the area having a slope of less than 10%, and 31.3% of the area with a slope of 11-20% however, almost none of the study area is considered truly flat (0.25%).

Many 5th and 6th order streams originate in the Purcell Mountains and travel through the study area, including Spillimacheen River, Bugaboo Creek, Horsethief Creek, and Toby Creek, though these do not intersect any of the wetlands in the area; Templeton River and Dunbar, Goldie, Driftwood, Salter, Marion, Wilmer, Hurst, Castor, Brady, Neave, and Rand Creeks are all smaller tributaries that intersect with wetlands in the study area.

Within the study area, there are several wetlands that are being explored for restoration efforts, as well as a few which have already been restored with the use of beaver dam analogues to improve water retention (Leven et al., 2024).

The soils within the study area are predominantly comprised of loam and silty loam, with a minor amount of sandy loam and loamy sand and are well or rapidly draining. Depositional modes include glacial tills, glaciofluvial, and, to a lesser degree, fluvial and colluvial processes (BC Ministry of Environment, 1990). The study area is made up primarily of sedimentary rocks from the Proterozoic to Paleozoic Eras, including:

- Coarse clastic sedimentary rocks from the Neoproterozoic associated with the Horsethief Creek Group
- Conglomerate coarse clastic sedimentary rocks from the Neoproterozoic associated with the Toby Formation
- Quartzite, quartz, and arenite sedimentary rocks are found throughout the study area from the Mesoproterozoic associated with the Mount Nelson Formation and in small slivers in the north from the Neoproterozoic to Lower Cambrian associated with the Cranbrook Formation
- Undivided sedimentary rocks containing siltstone, argillite, quartzite, and dolomite from the Mesoproterozoic associated with the Dutch Creek Formation
- Dolomitic carbonate rocks from the Mesoproterozoic associated with the Kitchener Formation in the south, from the Middle Silurian to Upper Ordovician associated with the Beaverfoot Formation in the north, and from the Upper Ordovician to Middle Silurian associated with the Beaverfoot and Mount Wilson Formations

- Limestone, marble, calcareous sedimentary rocks Middle to Upper Cambrian associated with the Lyell, Sullivan or Jubilee Formations
- Mudstone, siltstone, shale fine clastic sedimentary rocks from the Cambrian to Ordovician associated with the McKay group

Soil and geology data layers were provided by BC Data Catalogue.

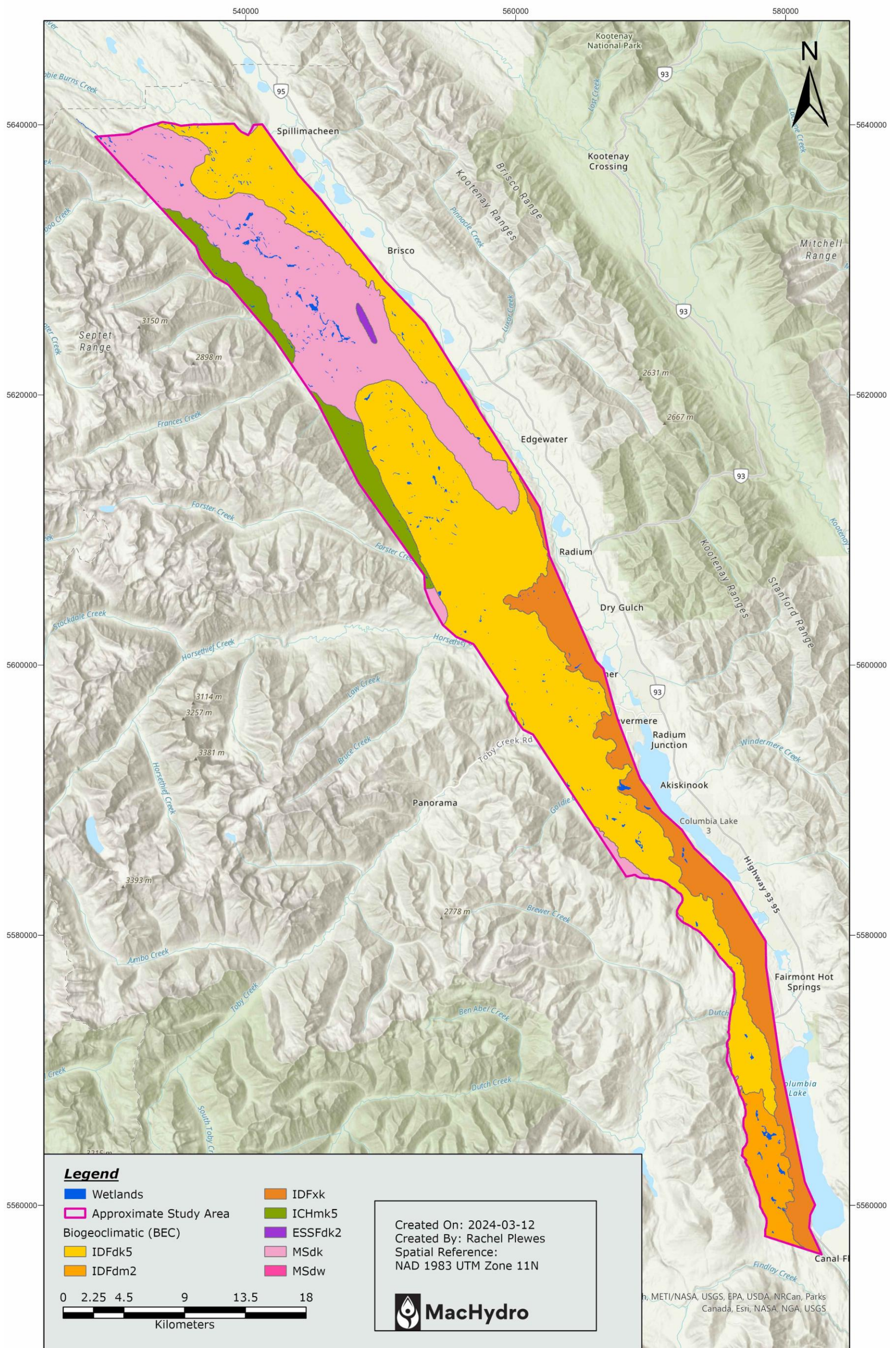


Figure 1. BEC zones within the study area, including IDFdk5 (Columbia Dry Cool Interior Douglas-fir), IDFdm2 (Kootenay Dry Mild Interior Douglas-fir), IDFfk (Very Dry Cool Interior Douglas-fir), ICHmk5 (Interior Cedar -- Hemlock Moist Cool), ESSFdk2 (Columbia Dry Cool Engelmann Spruce – Subalpine Fir), MSdk (Dry Cool Montane Spruce), and MSdw (Dry Warm Montane Spruce).

4 Methods

4.1 Data Sources

In order to build the flow accumulation and wetness indices, a digital elevation model (DEM) was downloaded using the `elevatr` R package (Hollister, 2023). Stream, lake, and wetland data were taken from Freshwater Atlas using the BC Data Catalogue; 443 bench wetlands were selected. Distinguishing classification of small lakes and wetlands are challenging and dependent on depth in British Columbia, whereby lakes with a depth of less than two meters would be considered a wetland (Warner, and Rubec, 1997). Freshwater Atlas originally defined 349 lakes, the vast majority of which were under a hectare in area. In the absence of depth information, lakes with a surface area less than the mean wetland area within the study region (<1.75 ha) were considered to be shallow enough to act similarly to other wetlands in the study. For these shallow lakes the wetland restoration index was also applied. After limiting the lake size and removing lakes that overlapped mapped wetlands, 126 lakes remained for restoration indexing.

Climate data was downloaded from Daymet, which provides 1 km² gridded daily weather estimates, and evapotranspiration was downloaded from Land Surface Evapotranspiration for Canada's Landmass (Wang, 2024) in 5 km² grids.

4.2 Wetness Index

The Topographic Wetness Index (TWI; Beven and Kirkby, 1979) is an estimate of where water will accumulate in an area based on slope and the upstream contributing area. This measure provides a relatively simplified understanding of where water is likely to accumulate, as it does not account for local geology, soil texture or permeability, or contributing sources, and assumes that surface and subsurface flows are primarily governed by topography. Typically, areas with a lower slope and greater contributing area will be more inclined to be wet, or have a greater wetness index, and will create conditions that are more conducive to support proper wetland form and function. Horvath et al. (2017) used TWI in their development of a potential wetland area indicator, and it has been used in other studies to identify wetlands (Lang et al., 2013; Curie et al., 2007).

The DEM was pre-processed using the breach depressions least cost method from Whitebox. The pre-processed DEM was used to calculate the mean wetness index for each bench wetland. The wetness index was calculated by determining the contributing area in m² and the average slope (radians) and inputting into the following equation:

$$WI = \ln(As/\tan(\text{Slope}))$$

Where As is the catchment area per unit contour length, estimated using a flow accumulation algorithm in the Hydrological Analysis toolbox and slope is measured in degrees and derived using the slope tool. In order to standardize values, scores were assigned to the first quartile (< 5.337), the second/third quartiles, and the fourth quartile (> 6.482).

4.3 Flow Accumulation Index

Water availability for wetland formation relies on the region's climate driven factors as well as transport of water from upland areas to the wetlands of interest. Without costly groundwater investigation there

is little inference that can be made to where groundwater is moving and its contribution to each wetland. Indexing is therefore reliant on surface water inflows to each wetland. As a proxy for streamflow, GIS derived flow accumulation provides an approximation of upstream contributions where runoff generates streamflow and is represented as a value of the number of cells contributing to each wetland. To obtain flow accumulation values the DEM was pre-processed using the breach depressions least cost method followed by the D8 flow accumulation method, both from Whitebox. The flow accumulation for each wetland was found by taking the maximum flow accumulation cell from the output raster that intersected with the wetland. To standardize values, scores were assigned to the first quartile (< 166), the second/third quartiles, and the fourth quartile (> 5722).

The flow accumulation index replaces the inflow index used in the original iteration of the restoration index framework. Inflow index evaluated the source connection using DEM derived wetland inflow and Freshwater Atlas Stream Network data to categorize source typing into isolated, intermittent stream, minor stream, lake, or major stream. Flow accumulation replaced inflow as an index because they provided redundant information and the inflow index may overvalue certain inflow sources without accounting for flow produced from the source.

4.4 P – ET Index

Water demands on a wetland vary across the region, as was illustrated in Millions et al. (2024). In order to incorporate climate-driven water availability and demands, a dryness index was developed subtracting evapotranspiration (ET) from precipitation (P). Annual precipitation data acquired through DayMet (Thornton et al., 2025) using the Single Pixel Extraction Tool to obtain observations from 2003-2022 for 1 km² grid cells. Evapotranspiration was acquired from Land Surface Evapotranspiration for Canada's Landmass (Wang, 2024) observations from 2003-2022 at a 5 km² resolution. In order to characterize the water demands on the wetlands, precipitation (P) minus evapotranspiration (ET) was used to create a dryness index for each of the bench wetlands. To standardize values, scores were assigned to the first quartile (< 144.5 mm), the second/third quartiles, and the fourth quartile (> 241 mm).

4.5 Wetland Restoration Feasibility Index

In order to develop an index of the relative ability of each wetland to succeed at collecting and holding water and provide adequate wetland form and function, the Wetness Index, Flow Accumulation Index, and P - ET Index were summed. Scores were then categorized as having very high, high, moderate, or low restoration feasibility (Table 1).

Table 1 Restoration feasibility based on cumulative index score.

Index Score	Restoration Feasibility
3-5	Low
<5-7	Moderate
<7-9	High
>9	Very High

4.6 Wetland Field Assessments

During July and August 2025 field teams from CWSP visited and recorded necessary information for 51 randomly selected bench wetlands to assess current wetland conditions and restoration potential using BDAs. The field teams recorded topographic conditions, the water inflow source, visually estimated streamflow, presence of water, water quality, estimated maximum water depth, evidence of drying, evidence of beaver presence/absence, wetland habitat and surrounding habitat including vegetation classification, wetland disturbance and surrounding disturbance including disturbance types, site accessibility, restoration potential using BDAs, and restoration potential using other methods. Field sites were accessed by foot and assessed through on the ground investigation and camera drone flights where applicable. Restoration potential was assessed on the same scale as index scores (Low, Moderate, High, Very High). Choice of restoration potential was based on qualitative assessment of the wetland conditions, site requirements for BDA installation, and field team judgement.

4.7 Restoration Index Verification and Optimization

To verify the efficacy of the wetland restoration feasibility index, field assessment results were compared to those of the feasibility index. Field results and those from the feasibility index were compared for each assessment site to obtain a correct or incorrect rating. When comparing field and index results, “High” and “Very High” restoration feasibilities were considered equivalent as achieving these results constitutes a wetland that should be considered for restoration.

To further improve the accuracy of the indexing approach, various weightings of the flow accumulation index, P-ET index, and wetness index were tested to determine the weighting that resulted in the greatest correct predictions of restoration feasibility. Each index kept a three-score system where a score was assigned to each of the first quartile, the second/third quartiles, and the fourth quartile. Scores were specified to be ascending (QRT1 score \leq QRT2/3 score \leq QRT4 score), ranged from 1-5, and the sum of the three QRT4 scores was greater than 10. All potential combinations where these conditions were met were generated for testing. Ten field sites were chosen at random, using a random sampling function in R and kept out of optimization testing. Each of the score combinations was applied to the remaining 41 of 51 field assessed wetlands. The restoration index results were compared against the field results to determine the number of correctly predicted results. The score combination with the highest success rate was chosen and applied to the ten verification sites to confirm if the verification sites had a similar proportionally correct result.

5 Results and Discussion

5.1 Field Assessment Results

Fifty-one field sites were randomly selected and assessed during summer of 2025. Most of these sites were in the northern portion of the study area (Figure 3). Of the field assessment sites, the majority of the sites (28/51) had low restoration potential (Figure 2). The primary driver of low rated field sites was the absence of flowing water during the site visit. Table 2 shows the wetland conditions during the 2025 field visits where higher rated wetlands generally had moderate to high streamflows and current or historic beaver activity.

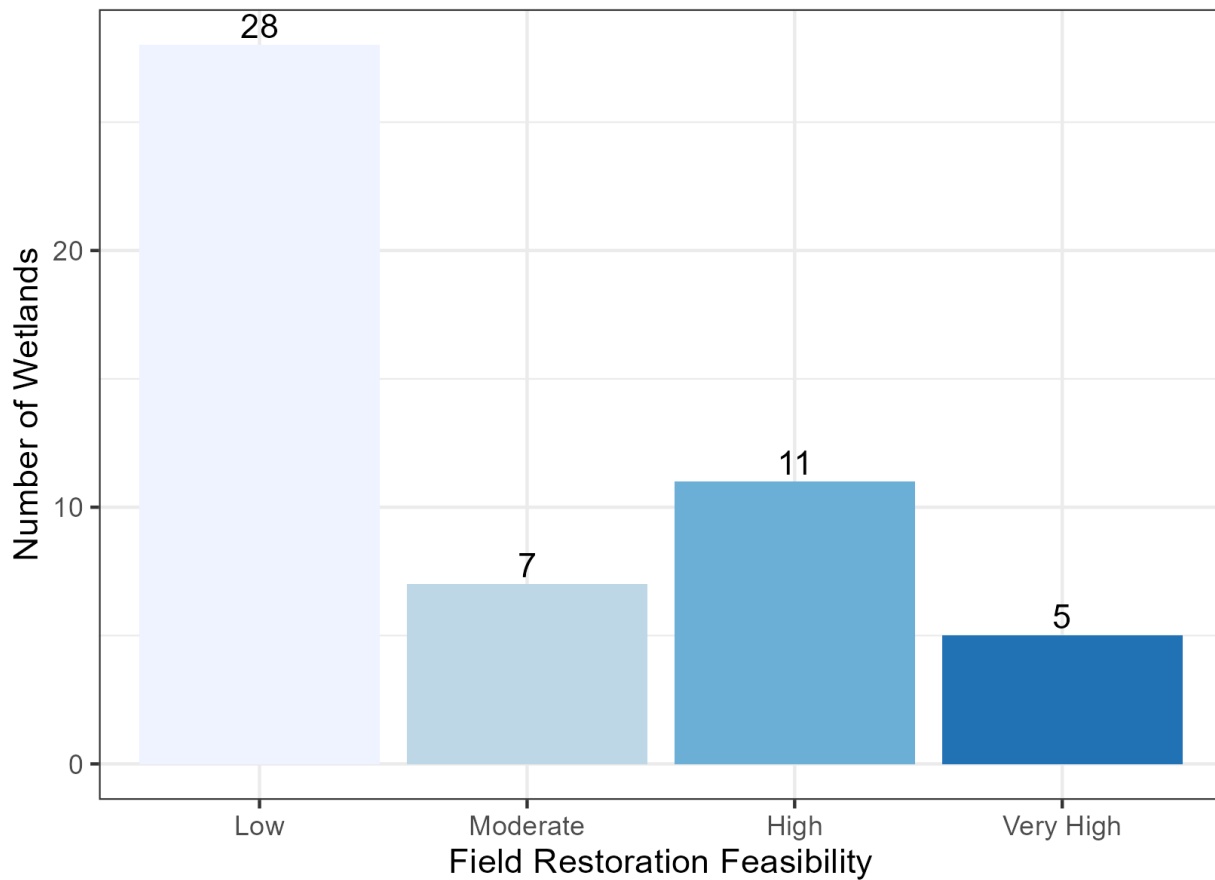


Figure 2 Distribution of field restoration potential results

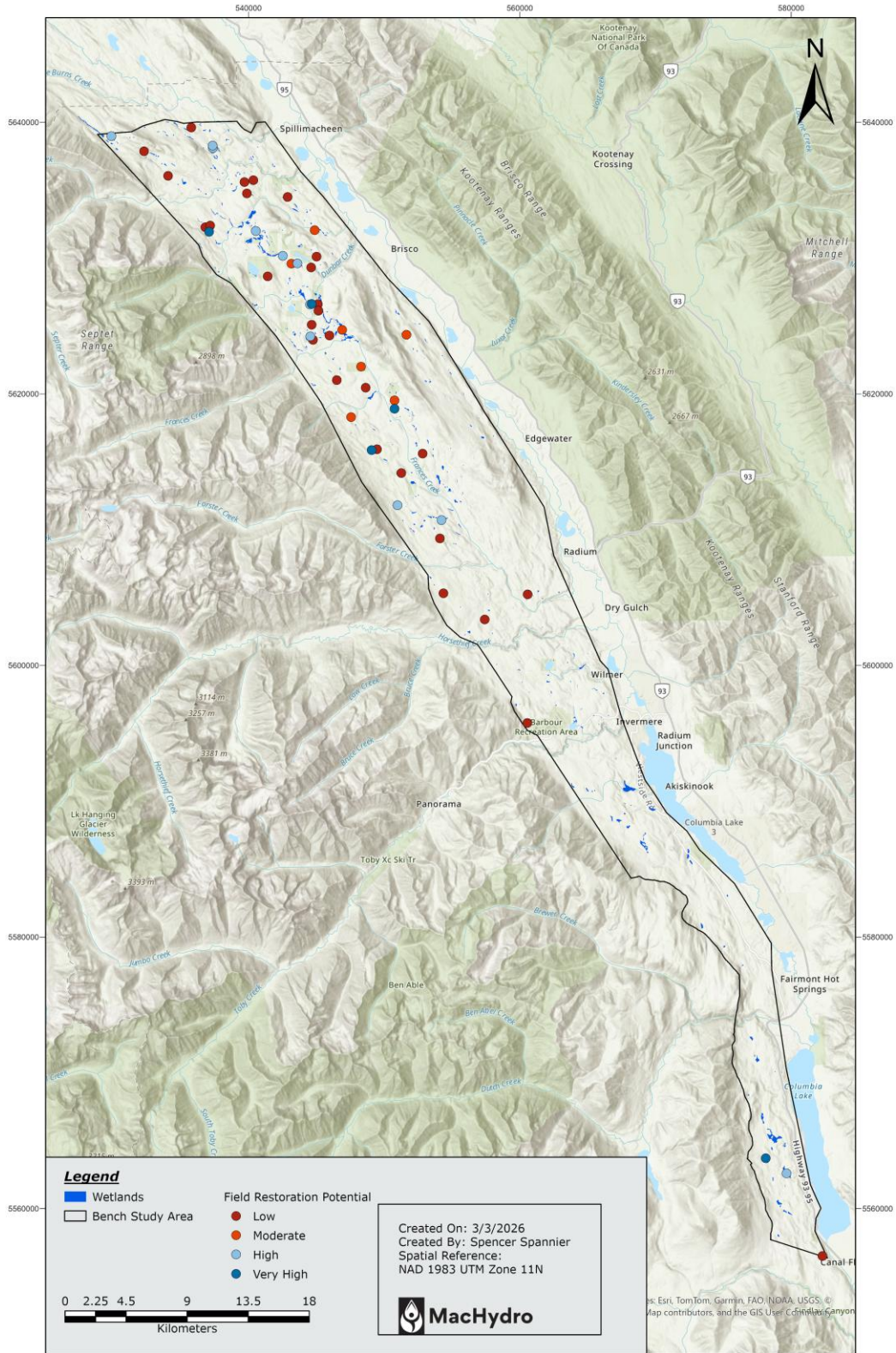


Figure 3 Wetland restoration feasibility from field assessment for the entire study area showing low feasibility (red), moderate feasibility (orange), high feasibility (light blue), and very high restoration feasibility (dark blue).

Table 2 Wetland Conditions During July/August 2025 Field Visits

FWA ID	Water Source	Estimated Streamflow (cubic feet per second)	Evidence of Wetness	Estimated Maximum Water Depth	Beaver Presence	Restoration Potential
705006637	None and no water present	0	None	0cm	None	Low
705006907	Unclear and no water present	0	Saturated ground	0cm	None	Low
705007019	Stream	0	Small open water, Saturated ground	<50cm	None	Low
705005656	Stream	>5 cfs	Stream running through, Saturated ground	>100cm	None	Low
705006186	Stream	~0.5 cfs	Small open water, Stream running through, Saturated ground	<50cm	None	Low
705006218	Unclear but water present	0	Large open water	<50cm	None	Low
705006472	Unclear and no water present	0	Small open water, saturated ground	>50cm	None	Low
705006572	Unclear but water present	0	Saturated ground	<50cm	None	Low
705006632	Lake	0	Large open water	>50cm	None	Low
705006797	None and no water present	0	Saturated ground	0cm	None	Low
705007136	None and no water present	0	None	0cm	None	Low
705005900	Unclear and water present	0	Small open water	<50cm	None	Low
705006713	None and no water present	0	None	0cm	None	Low
705006875	None and water present	0	Saturated ground	<50cm	None	Low
705007057	None and water present	0	Saturated ground	0cm	None	Low
705005938	Stream, Groundwater	0.25-2 cfs	Small open water, Saturated ground	<50cm	None	Low
705006493	None and no water present	0	None	0cm	Old dams	Low
705006743	Unclear and water present	0	Saturated ground	<50cm	None	Low
705006370	Unclear and water present	0	Saturated ground	<50cm	None	Low

705006475	Unclear and water present	0	Saturated ground	<50cm	None	Low
705006812	Stream, Groundwater	0	Small open water, Saturated ground	<50cm	Old dams	Low
705006461	Stream	0	Stream running through	>100cm	None	Low
705006920	Groundwater	0	Saturated ground	<50cm	None	Low
705015529	None and no water present	0	None	0cm	None	Low
705005798	Unclear and water present	0	Small open water	<50cm	None	Low
705006866	Groundwater	0	Small open water, Saturated ground	<50cm	None	Low
705006597	Unclear and water present	0	Small open water, Saturated ground	<50cm	None	Low
705006532	Lake	0	Large open water	>50cm	None	Low
705005819	Stream	>5 cfs	Stream running through, Saturated ground	>50cm	Old dams	Moderate
705005836	Unclear and water present	0	Large open water	>100cm	Active dams, active lodges, fresh beaver chews	Moderate
705006087	Lake	0	Small open water, Saturated ground	<50cm	None	Moderate
705006429	Lake	~0.5 cfs	Large open water	>50cm	Old dams	Moderate
705006717	Stream	2-5 cfs	Small open water, Stream running through, Saturated ground	<50cm	None	Moderate
705005836	Unclear and water present	<0.25 cfs	Large open water	>100cm	Active dams, Active lodges, Fresh beaver chews.	Moderate
705005990	Stream	~0.5 cfs	Stream running through	<50cm	None	Moderate
705005679	Stream	~2 cfs	Large open water, Stream running through, Saturated ground	>100cm	Old dams, old beaver chews	Moderate/High
705005706	Stream	2-5 cfs	Small open water, Stream running through, Saturated ground	>50cm	Active dams	High

705005982	Stream	~0.5 cfs	Stream running through, Saturated ground	<50cm	Old dams	High
705000242	Groundwater	0.25-2 cfs	Small open water, Stream running though, Saturated ground	<50cm	Old dams	High
705005936	Stream	~0.5 cfs	Small open water, Stream running though, Saturated ground	>50cm	Old dams	High
705006931	Lake	~0.5 cfs	Small open water, Stream running though	>50cm	Old dams	High
705005825	Stream	~0.5 cfs	Small open water, Saturated ground	>50cm	Active dams	High
705006018	Stream	~2 cfs	Stream running through	>50cm	Old dams	High
705015047	Stream	~0.5 cfs	Stream running through, saturated ground	<50cm	Old dams	High
705015530	Stream, Lake	~0.5 cfs	Small open water, Stream running through, Saturated ground	<50cm	Old dams	High
705006077	Stream	>5 cfs	Stream running through	>100cm	Old beaver chews	High
705006045	Stream	~0.5 cfs	Stream running through, Saturated ground	<50cm	Old dams	High
705000184	Stream, Groundwater	2-5 cfs	Large open water, stream running through	>100cm	Active dams, active lodges, fresh beaver chews	Very high
705006345	Stream	~0.5 cfs	Small open water, Stream running through	>50cm	Old dams and old beaver chews	Very high
705006322	Stream	~2 cfs	Stream running though	>50cm	Old dams	Very high
705006048	Stream	2-5 cfs	Stream running through	>50cm	Old dams	Very high
705006799	Stream	~2 cfs	Small open water, Stream running though, Saturated ground	>50cm	Old dams	Very high

Field teams assessed the type of wetland cover showing that the wetlands in the study region are dominated by vegetation, followed by open water (Figure 4). These wetlands are primarily surrounded by coniferous forests, and some are impacted by forestry activities; either adjacent to clear-cutting or in a period of young regeneration after clear-cutting (Figure 5).

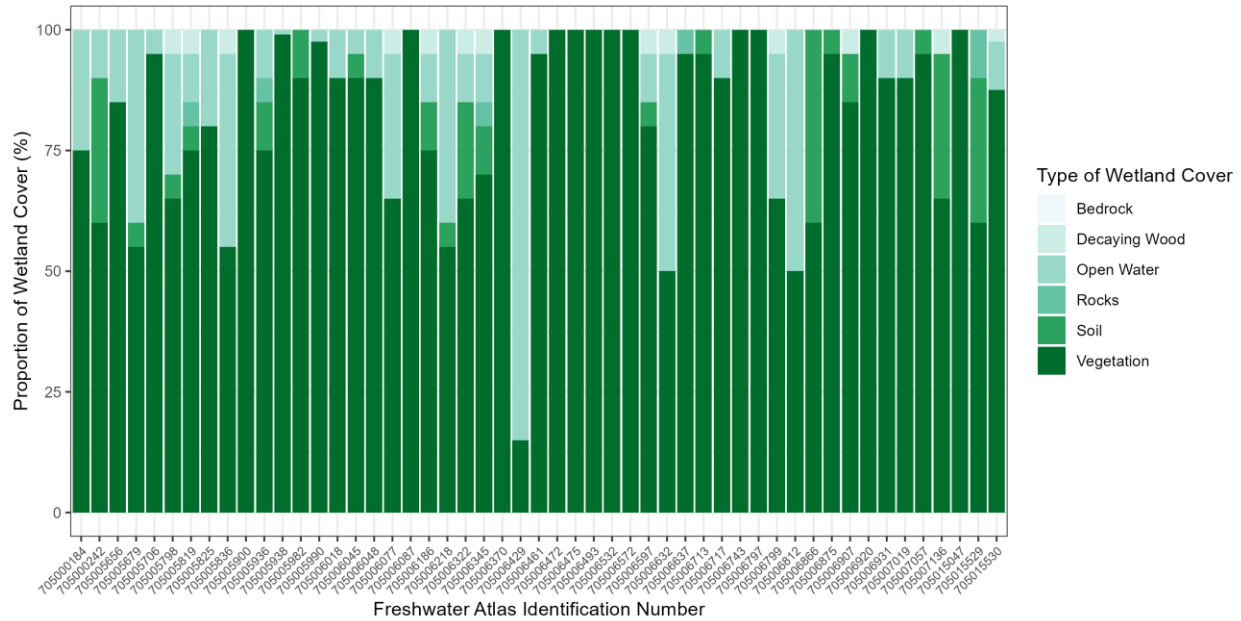


Figure 4 Proportion of wetland cover for each field assessed wetland

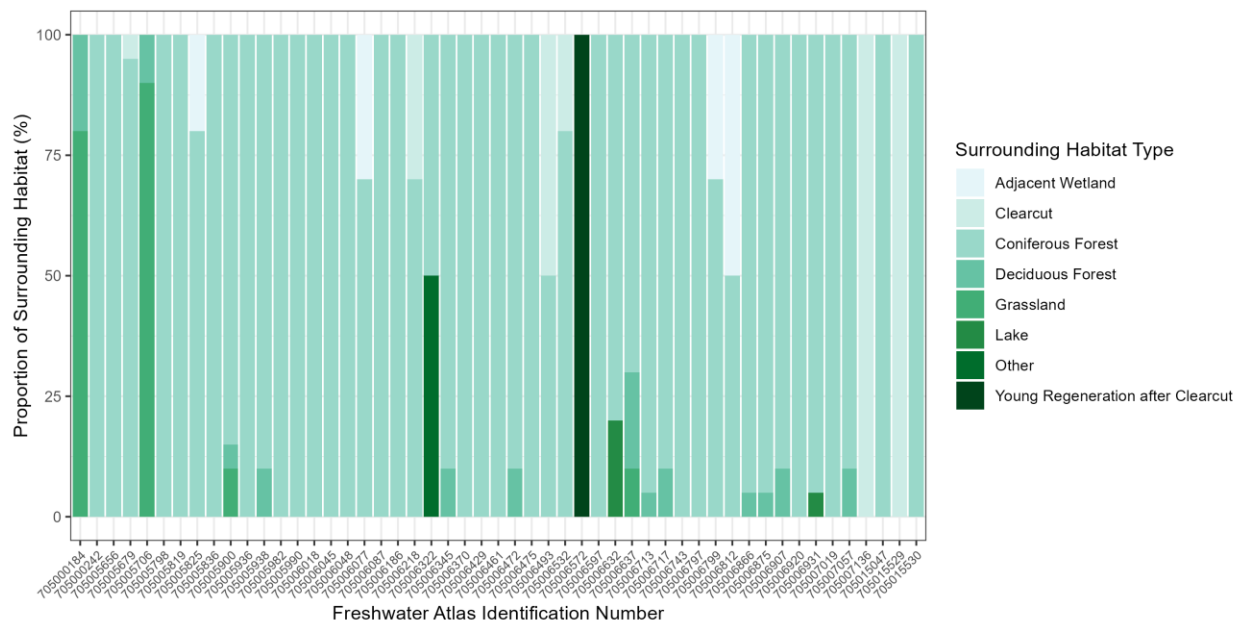


Figure 5 Proportion of surrounding habitat types for each field assessed wetland

5.2 Restoration Feasibility Index Results

The original, unmodified wetland restoration index correctly predicted 25 of 51 field results (49.0%). The results from the comparison of restoration index to the field results are shown in Figure 6. The restoration feasibility index results in similar proportions of low, moderate, high, and very high restoration potential for the 51 field assessed sites. Field assessment reveals that there is a much higher proportion of low rated sites. In general, the original wetland restoration index overestimated restoration potential compared to the field data. Figure 7 reveals that the restoration feasibility index underestimated restoration feasibility for only three wetlands, whereas 23 wetlands had restoration feasibility overestimated. The overestimation occurred for 18 low rated wetlands and 5 moderate rated wetlands by field assessment. The overestimates ranged from 1-6 index score points.

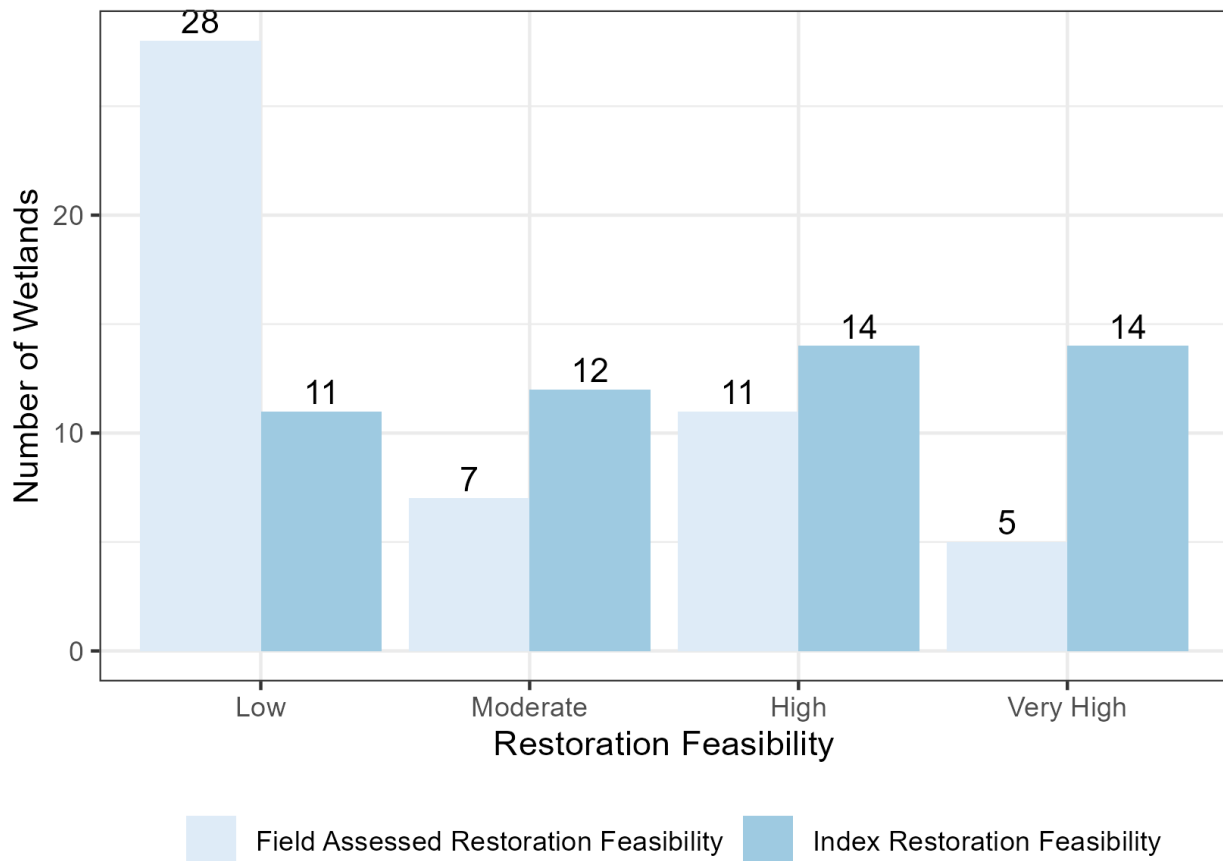


Figure 6 Restoration feasibility index comparison to field assessed restoration feasibility.

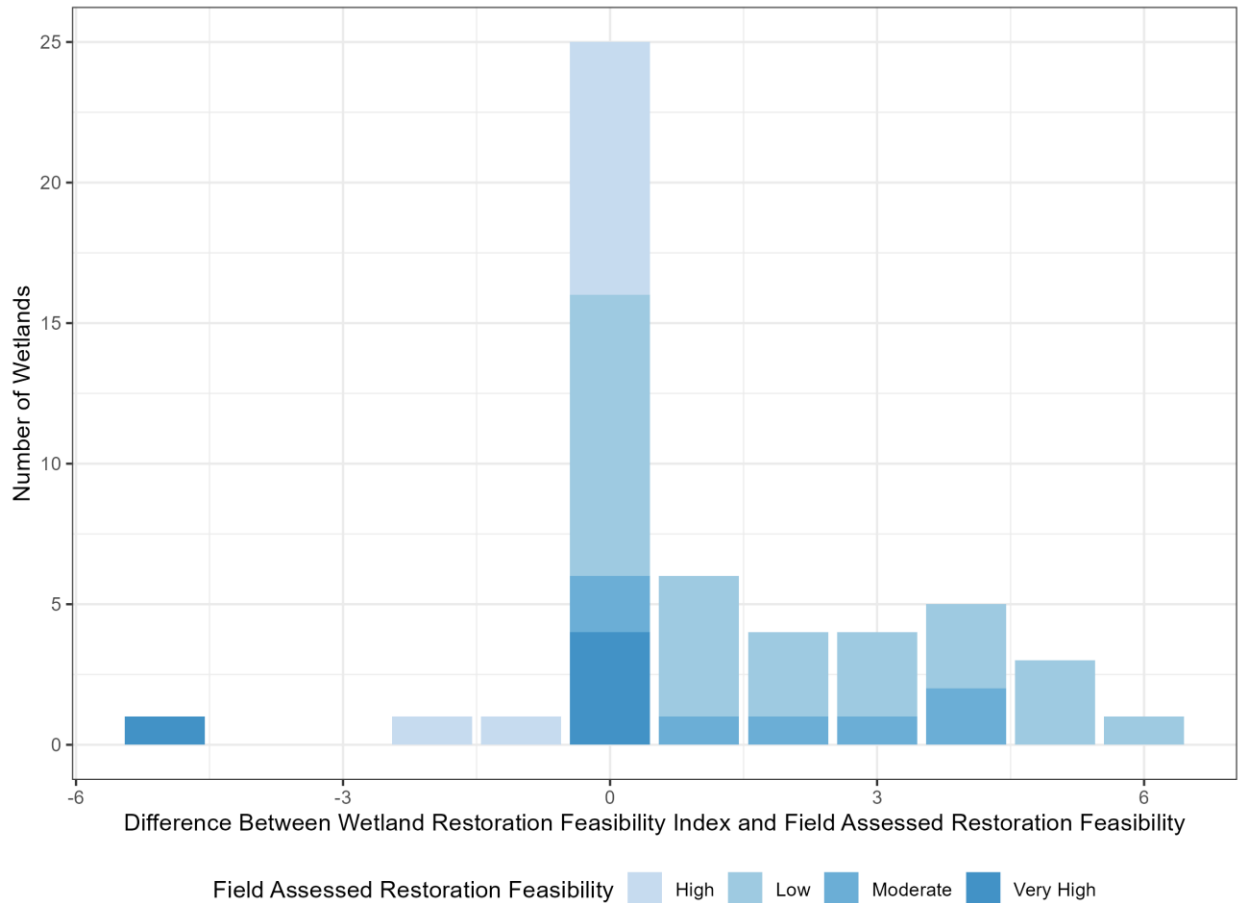


Figure 7 The difference between the original restoration feasibility index and field assessed restoration feasibility

5.3 Modified Restoration Feasibility Index

Table 3 and Table 4 show the original and modified restoration feasibility index component scores. The primary change in the restoration feasibility index is the replacement of inflow index with the flow accumulation index. The P – ET index remains the same for the unmodified and modified restoration feasibility index. The wetness index reduced to only 2 unique scores resulting in the index only providing additional sway to the overall feasibility index if the wetland is in the fourth quartile. The change in each component’s weighting is a shift towards lower overall restoration feasibility ratings. For a wetland to achieve a rating above low (Restoration feasibility score > 5) at least one index component must be in the fourth quartile. Figure 8 shows the change in distribution of restoration feasibility results by comparing the original restoration feasibility index to the modified restoration feasibility index. The modified restoration feasibility index shifts to a greater frequency of low, high, and very high rated wetlands with a reduction in frequency of moderate rated wetlands.

Table 3 Unmodified Restoration Feasibility Index Component Scores

Inflow Source	Inflow Index Score	Quartile	Wetness (TWI) Index Score	P – ET Index Score
Isolated	1	QRT 1	1	1
Intermittent Stream	2			
Minor Stream (Stream Order ≤ 1)	3	QRT2/3	2	2
Lake	4	QRT 4	3	3
Major Stream (Stream Order > 1)	5			

Table 4 Modified Restoration Feasibility Index Component Scores

Quartile	Flow Accumulation Index Score	Wetness (TWI) Index Score	P – ET Index Score
QRT 1	1	1	1
QRT2/3	2	1	2
QRT4	5	5	3

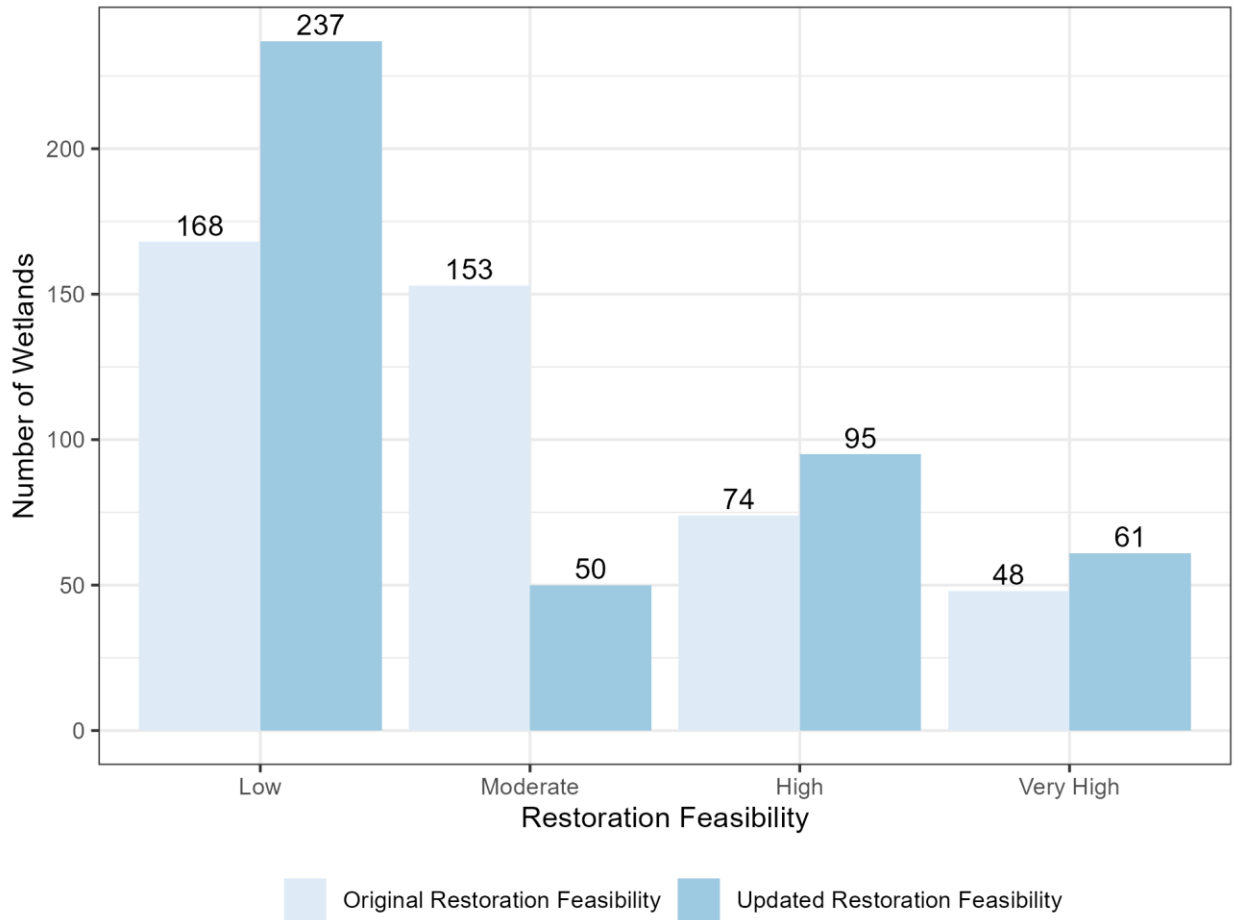


Figure 8 Comparison of unmodified restoration feasibility index to modified restoration feasibility index for all non-lake sites

Figure 9 shows that the modified restoration feasibility results in an improvement of correct predictions of field results from an original 25/51 (49.0%) to 31/51 (60.8%). The incorrect predictions are distributed between 7 underestimated wetland restoration feasibilities and 13 overestimated wetland restoration feasibilities. Simplifying the index to consider it as a go/no-go assessment where low rated wetlands should not be considered for restoration and moderate, high, and very high should be considered for restoration, the wetland restoration index correctly predicts the field results for 37/51 wetlands (72.5%).

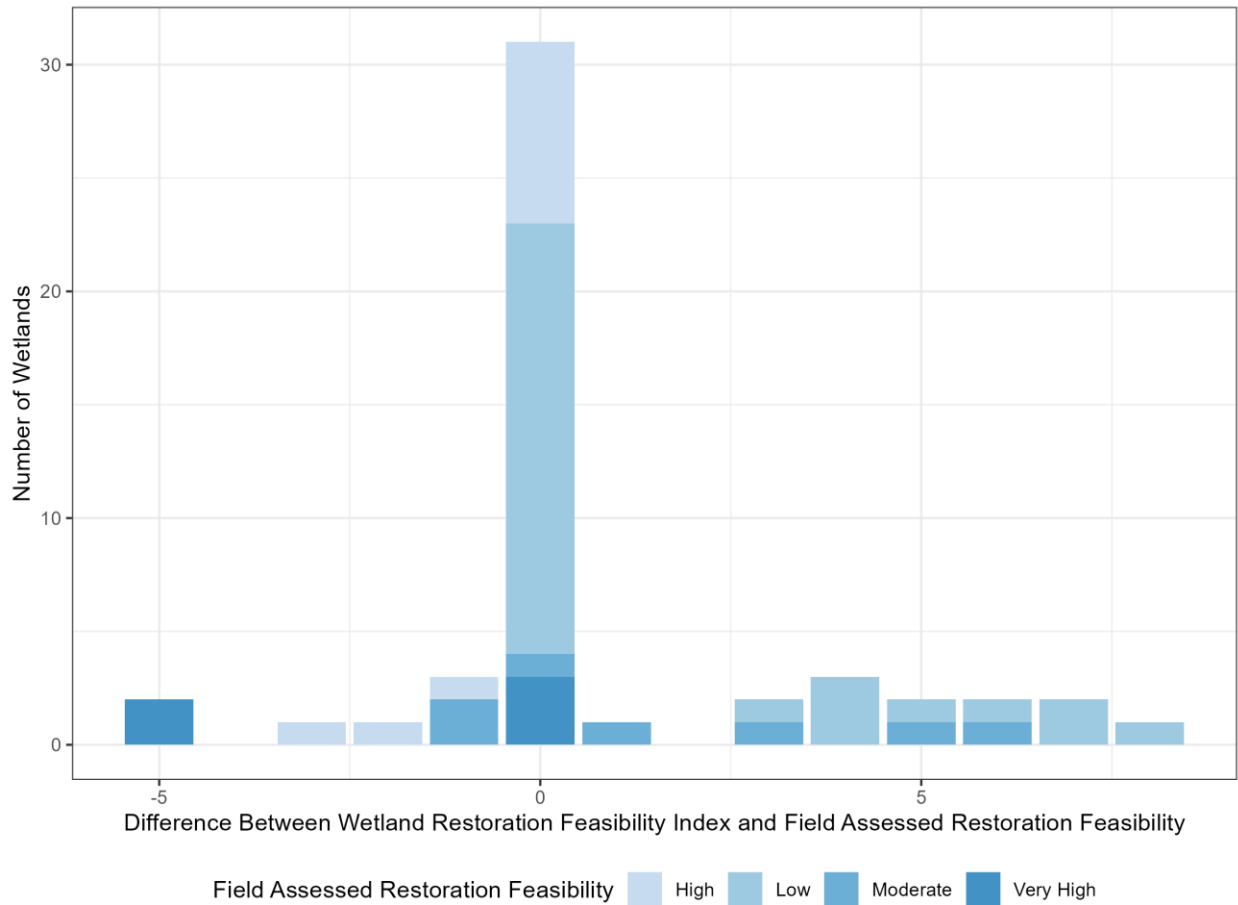


Figure 9 The difference between the modified restoration feasibility index and field assessed restoration feasibility

5.4 Flow Accumulation Index

Figure 10 shows the distribution of flow accumulation index scores for all wetland and shallow lake sites. One hundred sixty-one (161) wetlands had a flow accumulation index score of one out of five (<166 flow accumulation units), 282 had a flow accumulation index score of two out of five, and 126 had the highest wetness score of five out of five (>5722 flow accumulation units).

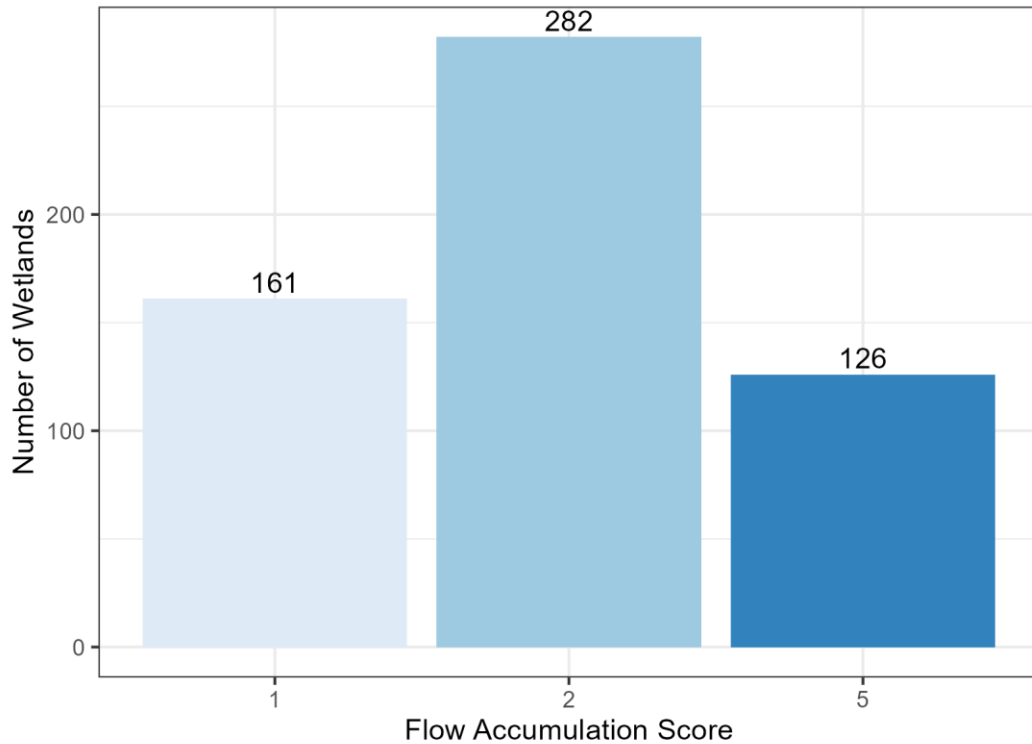


Figure 10 Distribution of Flow Accumulation Index Scores

5.5 Wetness Index and P-ET Score

Figure 11 shows the distribution of flow accumulation index scores for all wetland and shallow lake sites. Three hundred forty-four (344) wetlands had a wetness index of one out of five, while 221 had the highest wetness score of five out of five. One hundred forty-three (143) wetlands had a P-ET score of one out of three, 291 had a P-ET score of two out of three, and 135 had the highest P-ET score of three out of three.

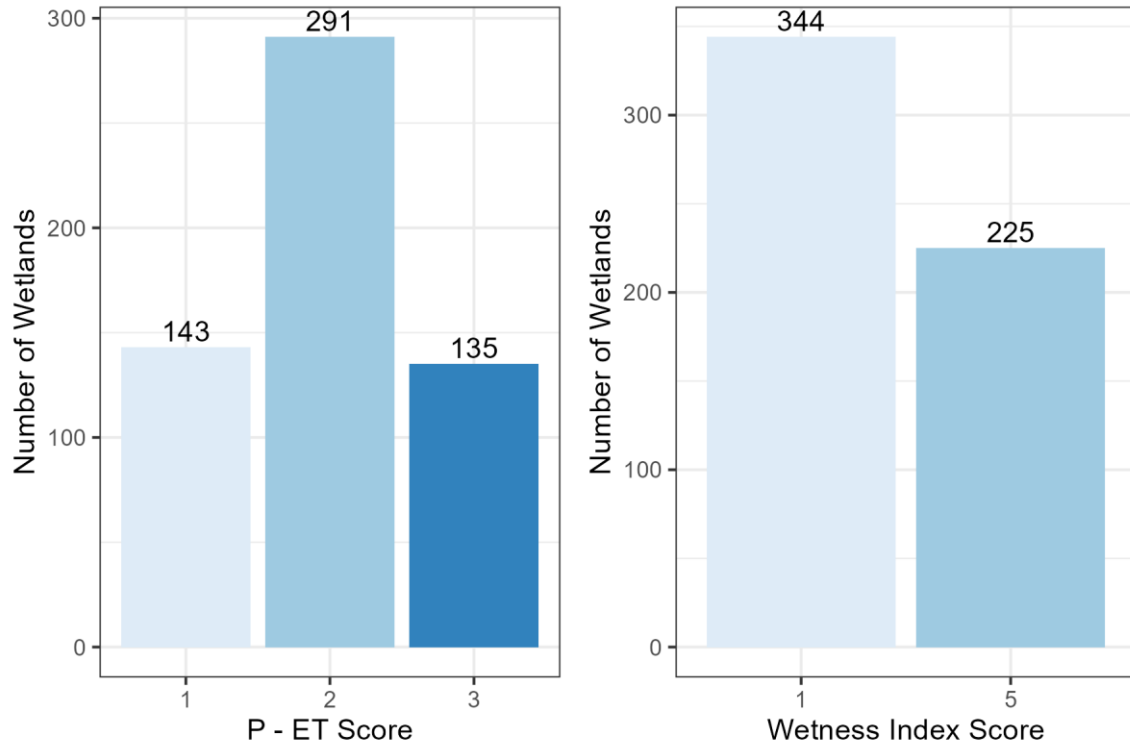


Figure 11 Distribution of wetland P-ET (left) and Wetness Index (right) scores.

5.6 Wetland Restoration Feasibility Index

A total of 569 wetlands or shallow lakes were assessed using the wetland restoration feasibility index. 248 wetlands had a low wetland restoration feasibility index, 59 had a moderate wetland restoration feasibility index, 175 had a high wetland restoration feasibility index, and 87 had a very high wetland restoration feasibility index (Figure 12).

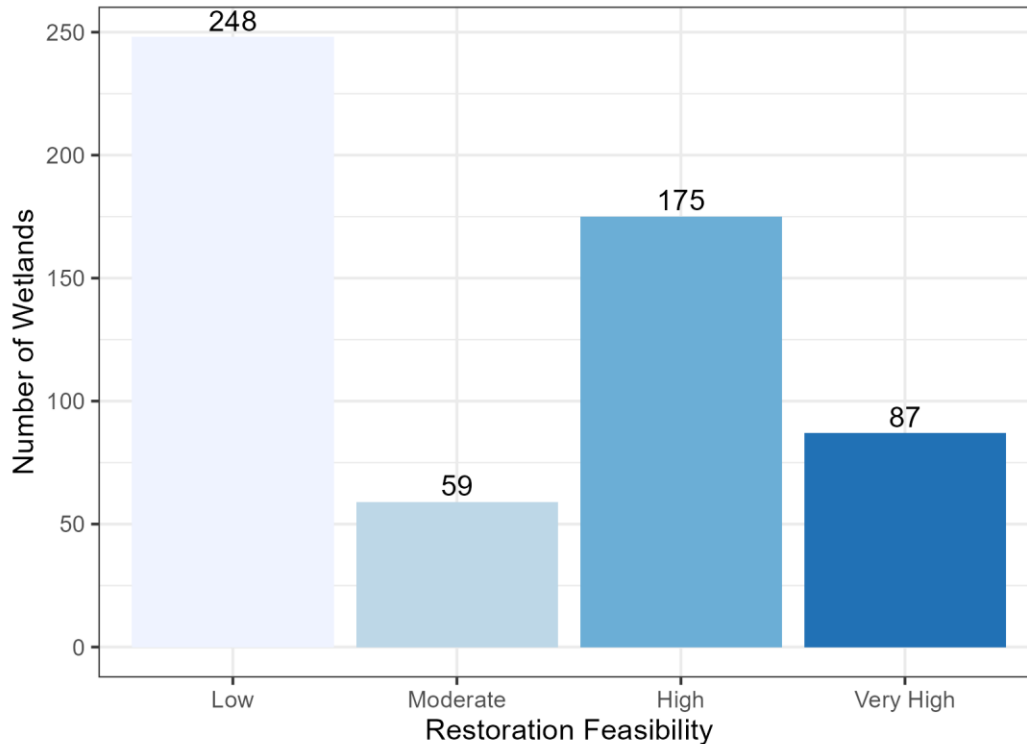


Figure 12 distribution of Wetland Restoration Feasibility Index values for the bench wetlands.

Wetlands with very high restoration values are primarily found in the northern regions of the study area, with increasing frequency with increasing latitude (Figure 13), and there is only one wetland with very high restoration feasibility south of Invermere BC (Figure 14). This appears to be largely driven by P-ET, as the further north regions are wetter (Figure 15) whereas the southern extent of the study area is drier (Figure 16). This may also explain the greater number of wetlands in general in the northern reach, as the further southern areas are no longer wet enough to support wetlands.

Wetlands with very high wetland restoration scores have high values in all the contributing scores, where they have a large contributing area and topology to support pond formation that holds water throughout the dry season, and have higher precipitation. The opposite is true of wetlands with low restoration feasibility scores, which are isolated, have small contributing areas, and are relatively dry. Of the wetlands in the moderate and high restoration feasibility categories, the wetness (TWI) score and flow accumulation scores are the primary drivers of the score; generally, these scores require opposing results to create moderate or high feasibility. Either wetness score is low and flow accumulation is high or wetness score is high and flow accumulation score is low (Figure 17). This is likely due to all the factors being linked to a certain degree, with topography linked to flow accumulation.

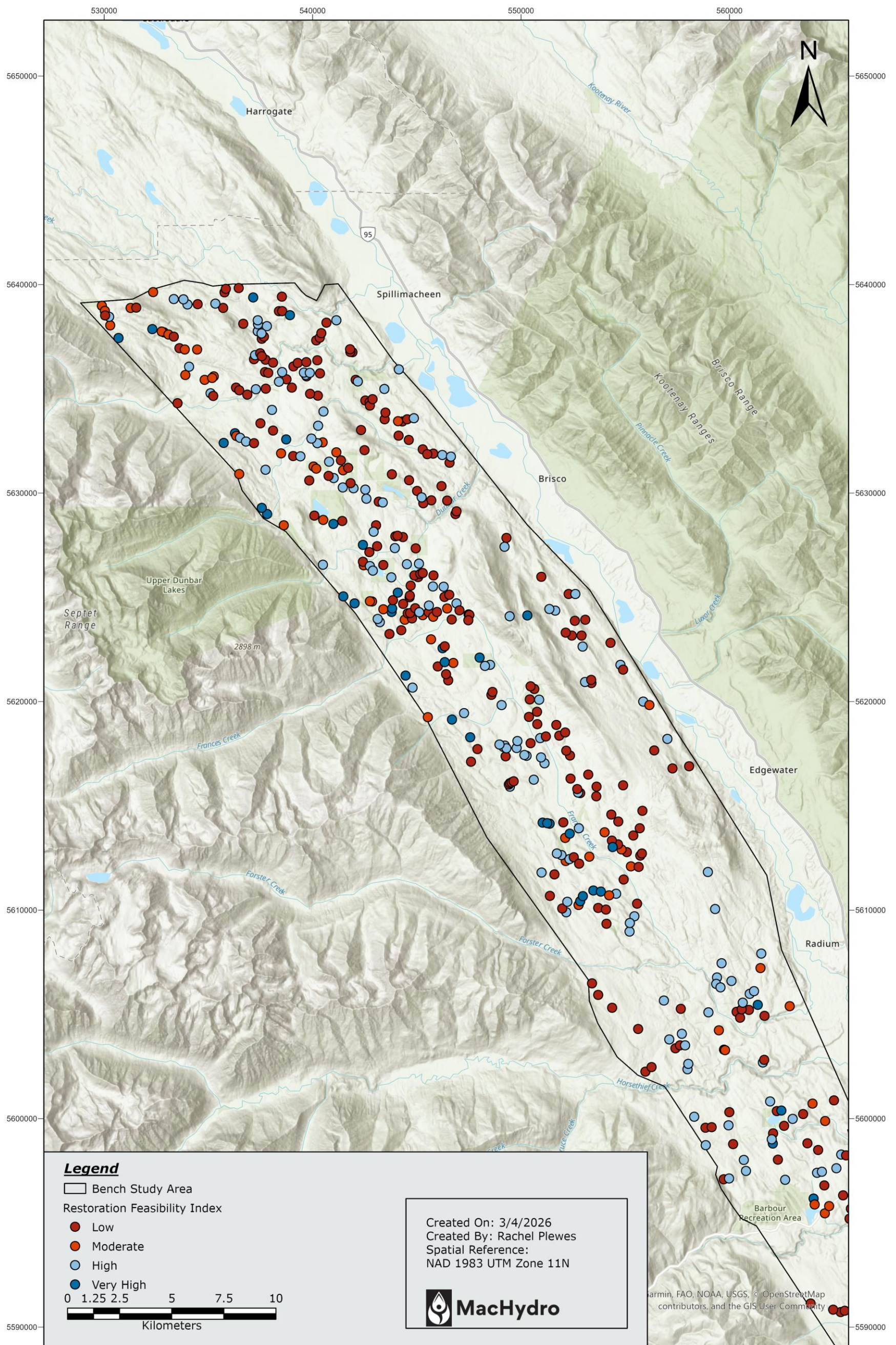


Figure 13. Restoration Feasibility Index values for wetlands in the northern region of the study area showing low feasibility (red), moderate feasibility (orange), high feasibility (light blue), and very high restoration feasibility (dark blue).

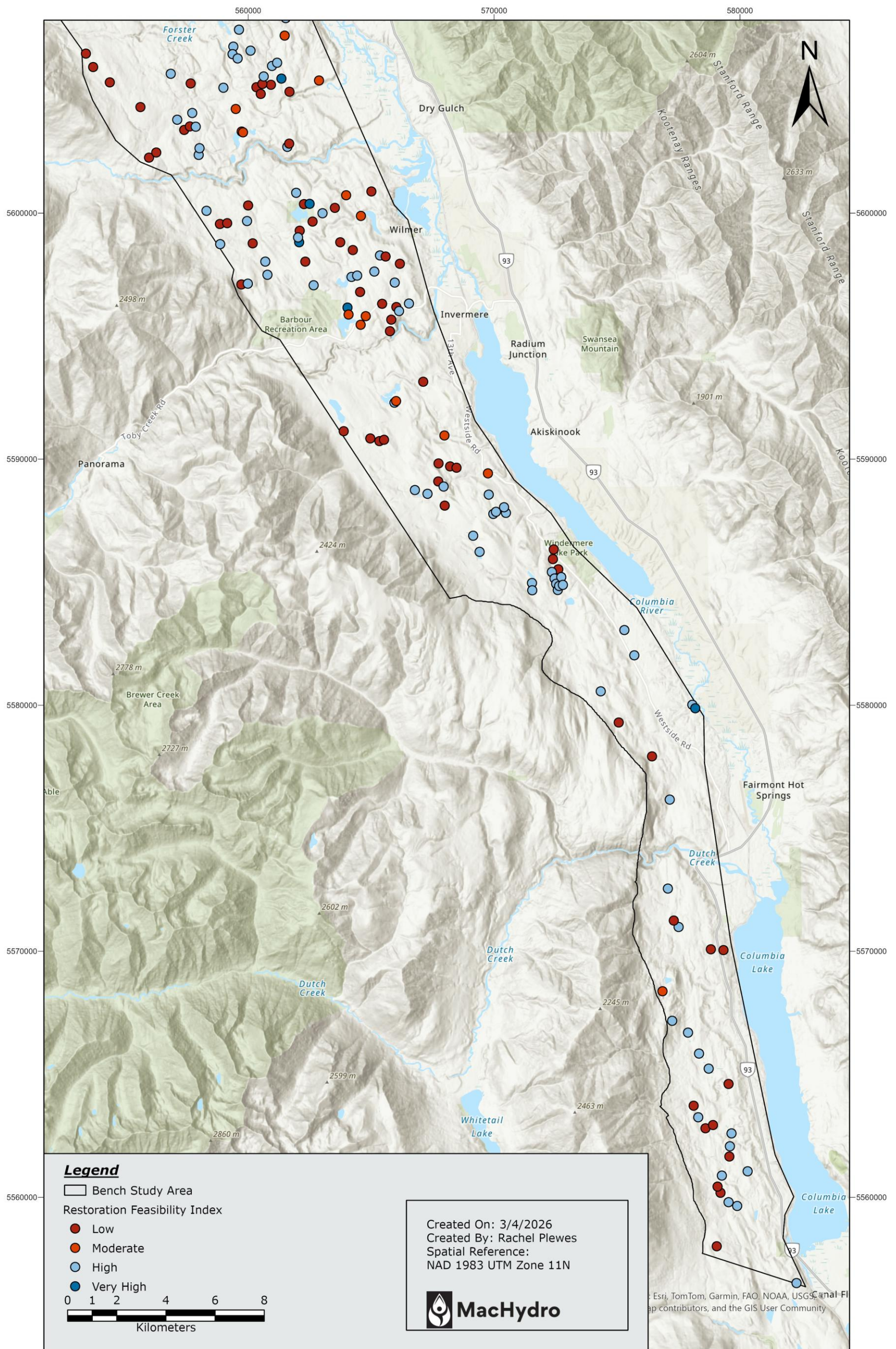


Figure 14. Restoration Feasibility Index values for wetlands in the southern region of the study area showing low feasibility (red), moderate feasibility (orange), high feasibility (light blue), and very high restoration feasibility (dark blue).

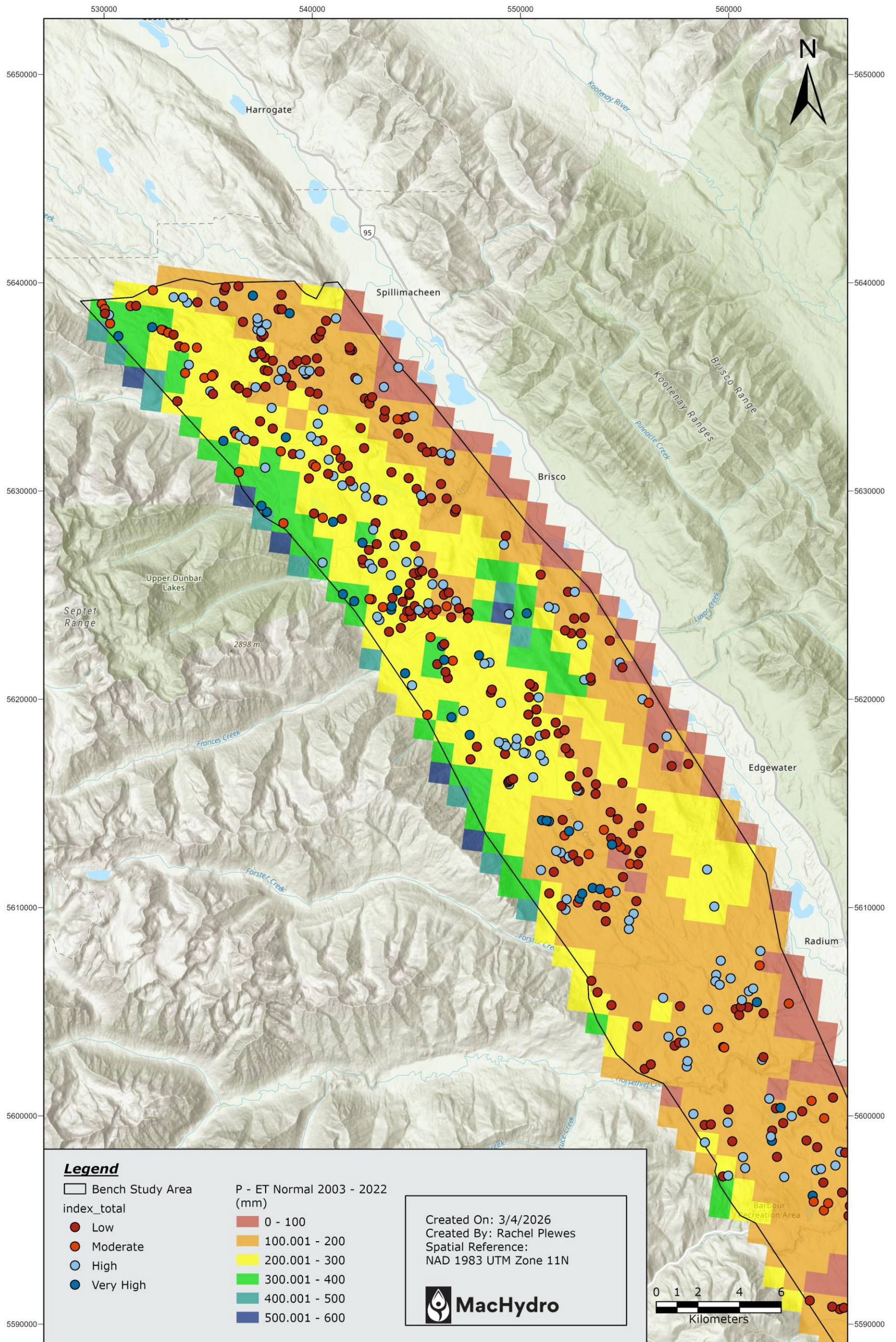


Figure 15. Heat map showing P-ET values for the northern region of the study area from the lowest values (0-100; red) to the highest values (>500-600; blue).

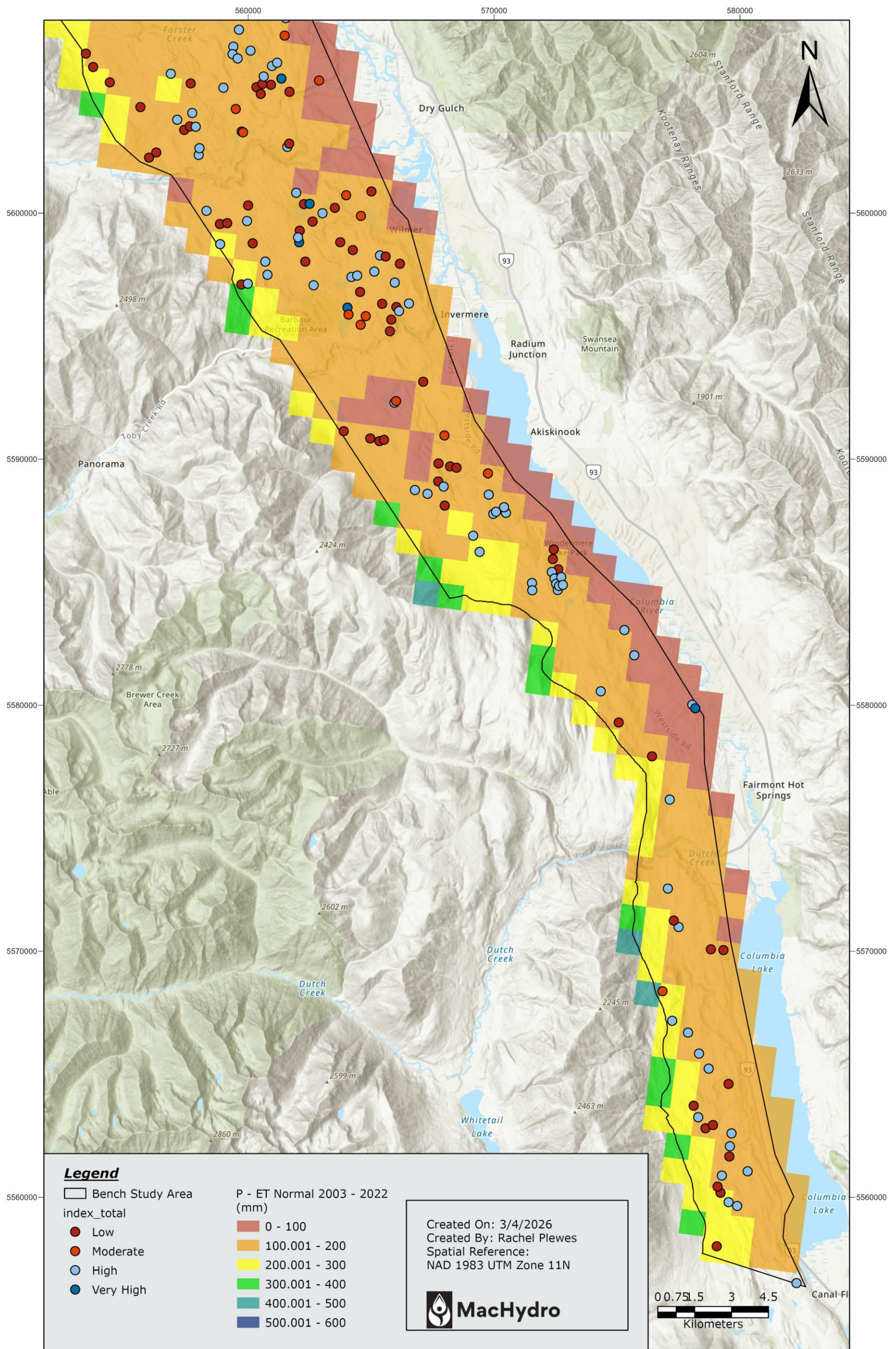


Figure 16. Heat map showing P-ET values for the southern region of the study area from the lowest values (0-100; red) to the highest values (>500-600; blue).

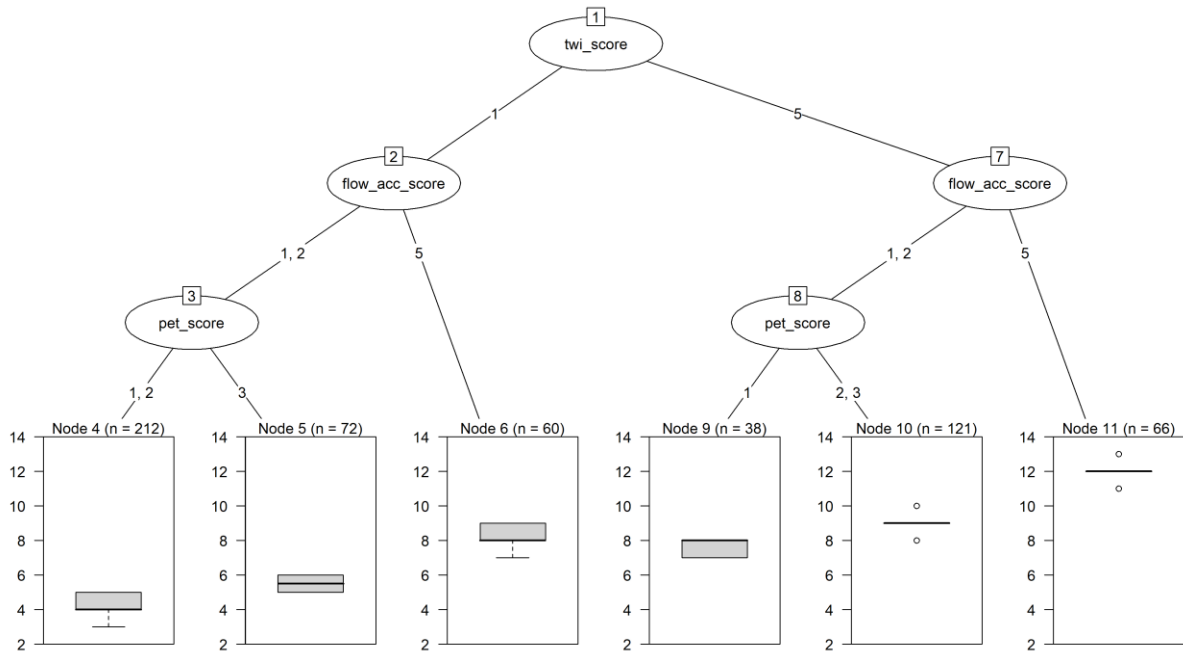


Figure 17 Classification and Regression Tree (CART) with Wetland Feasibility Index as a response variable

6 Discussion and Recommendations

6.1 Discussion

We updated the restoration feasibility index for wetlands within the Benchlands of the Upper Columbia River Valley. The index values are derived from publicly available data and can help practitioners prioritize wetland restoration efforts. Results from the wetland restoration index can be viewed at the link below:

<https://cwsp.machydro.ca/>

The 2026 updated Upper Columbia Bench Wetlands restoration feasibility index was calibrated and verified using field data recorded Summer 2025. The updated index improved the correct prediction of restoration potential from 49% to 61%. Fifty-one field sites were used in the verification approach, just under one tenth of the 569 total wetlands assessed using the restoration feasibility index. A notable outcome from field assessments was the abundance of sites with low restoration feasibility judged to have low feasibility due to the wetlands and outflows being dry during the site visits. These sites require reintroduction of water prior to beaver dam analogue installation through improved drainage, site modification, groundwater pumping, or other restoration methods outside the scope of current restoration activities in the area. The updated restoration feasibility index accounts for the abundance of low feasibility sites by requiring at least one index component score (flow accumulation score, wetness score, or P – ET score) to come from values in the fourth quartile to achieve a restoration feasibility above “Low”. A wetland must excel in at least one component to be considered for restoration using BDAs.

Wetland restoration is guided by site specific conditions obtained from a desktop review of wetland extent, local or traditional knowledge, and field assessment of current wetland conditions (Khan et al. 2021). Field assessment can be costly, time consuming, and may not target optimal sites for restoration. Standardized wetland restoration index approaches have been applied in various regions in attempts to identify areas with high suitability for wetland restoration potential, guiding further on-site feasibility assessments for restoration activities. Medland et al. (2020) investigated a wetland suitability index for restoration in Ontario’s Mixedwood Plains that incorporated weighted criterion of agriculture, build-up area, soil drainage type, groundwater level, slope, stream proximity, and if the area is a major waterbody. Johnson et al. (2024) created a restorable wetland index for Minnesota using the predictive variables of distance to nearest wetland, distance to nearest stream, ecological classification, elevation, topographic position indices for various radii, hydrologic position index, compound topographic index, slope, normalized difference vegetation index, normalized difference water index, and hydric soil status. Training and verification of the Minnesota model using 6000 field-verified points and 300 remote-verified points resulted in a restorable wetland classification error rate of 15%. Tang et al. (2012) developed a restorable wetland index for the Rainwater Basin in Nebraska incorporating vegetation characteristics, soil characteristics, water volume, topographic depression status, and habitat conditions (wetland area and functional wetland conditions). Horvath et al. (2017) and Uuemaa et al. (2018) used similar processes based on topological datasets to develop indicators for wetland restoration potential based on a topographic wetland index for the United States and New Zealand respectively. These restoration index and feasibility approaches do not assess the efficacy of certain restoration activities and instead primarily focus on the suitability for locations to form and sustain a functional wetland by reconstruction of wetland areas or development of novel wetlands.

Previous wetland restoration prioritization work guided the development of the restoration feasibility index used for the Upper Columbia Bench Wetlands. Prioritization approaches had varying dataset requirements but generally used information in the categories of hydrological and open water conditions (nearest streams, nearest wetland, wetland water volume, normalized difference water index), surrounding habitat and land use (ecological classification, normalized difference vegetation index, proximity to agriculture), soil and groundwater conditions (soil drainage, groundwater level), and topological conditions (topographic wetland index, topographic depressions, slope). Weighting of each index component varied across documented approaches; a quartile approach was used for the Upper Columbia Bench Wetlands restoration feasibility index as a similar approach to Tang et al. (2012).

A difference in the Upper Columbia Bench Wetlands restoration feasibility index compared to previous restoration indexing approaches is the focus on the efficacy of a particular restoration activity, beaver dam analogues, rather than identification of quality areas for wetland redevelopment. The goal of the beaver dam analogues is the improvement of currently flowing wetlands that are semi-functional rather than full restoration of non-functioning wetlands. This difference puts greater focus on the hydrologic conditions of restoration sites rather than the ecological conditions necessary for wetland health restoration. Flow accumulation was chosen to represent the conditions conducive to providing the required water quantity to support beaver dam analogue success (Mackey, 2025). Topographic wetland index (TWI) was chosen as a prediction index as this metric was used in two prioritization works (Horvath et al. 2017, Uuemaa et al. 2018) and the constituent parts, particularly slope and depression formation were used in all the reviewed restoration index works (Johnson et al. 2024, Medland et al. 2020, Tang et al. 2012). Previous restoration prioritization approaches did not consider local climate as a driver of wetland restoration potential but was considered important for the Upper Columbia Bench Wetlands and was included as the P – ET score.

The Upper Columbia Bench Wetlands restoration feasibility index is a simplified approach to assess restoration feasibility using three prediction components compared to previous works using five to fifteen predictor variables (Johnson et al. 2024, Medland et al. 2020, Tang et al. 2012). This difference was due to the differing purpose of the Upper Columbia Bench Wetlands restoration feasibility index and the limitations of using available open-source data for the area. Previous approaches were more data intensive, particularly Johnson et al. (2024) requiring eleven standardized geospatial datasets for index development. Fine scale soil and groundwater conditions were not available to assess site specific surface-groundwater connectivity in the Upper Columbia benchlands. The mapped Freshwater Atlas stream layer also differs substantially from DEM derived flow accumulation and stream formation. This is particularly challenging in this flat study region and limits the inferences that can be made for stream connectivity and the existence or absence of flowing streams. Concerns with accuracy of the Freshwater Atlas stream layer led to replacing the inflow index used in the original wetland restoration feasibility index with the DEM derived flow accumulation index.

6.2 Study Limitations

There are several limitations to this approach which must be considered. The index scores are intended to provide a desktop review of wetland restoration potential but should not be used in lieu of site visits. Ground truthing the index scores is critical as results from 2025 field investigations showed that there are site specific conditions that limit the accuracy of predictions for restoration potential. Certain conditions are difficult to account for using broad datasets particularly wetlands being dry during visits, wetland water exchange being primarily groundwater driven, or active beavers restoring the stream. In

the absence of understanding underlying geology and underground flows, inflow potential is reliant on overland flow and stream connectivity derived from DEMs. As such, the index does not appropriately account for groundwater sources and is also reliant on the accuracy of the Freshwater Atlas and topological datasets, which are not always up to date due to landscape and hydrologic changes. These limitations result in index scoring inaccurately predicting restoration potential for ~40% of wetlands.

While this approach can be modified to suit other regions, it is currently designed to represent the Benchland region of the Upper Columbia River Valley and scores are all relative to each other. As many wetlands have already been lost in the region, the values exist relative to each other at the current time and do not represent historic values. In addition to inaccuracies in FWA data, there are other data limitations. The climate evapotranspiration data exists in 5 km cells, which is quite large relative to the study area. Applying this index approach to other regions would ideally be paired with additional field visits to re-optimize the wetland restoration index to varied environments.

6.3 Recommendations

Due to the strong links in flow accumulation, topography, and climate condition on the success of bench wetlands in the Upper Columbia Valley, our recommendations are to:

- Use the wetland restoration feasibility scores provided in this study to prioritize wetland restoration efforts, particularly by prioritizing areas with several high or very-high feasibility restoration wetlands together.
- Continue documenting restoration feasibility at any wetlands visited during restoration efforts to provide a larger data source for continual restoration feasibility index improvement and validation.
- Do not attempt to restore isolated wetlands where there is limited waterbody connection or small flow accumulation areas, unless ground truthing or local knowledge shows a notable groundwater source, particularly in the southern region;
- When possible, use isotope analysis to determine wetland water balance and groundwater influence.

7 Closing

The Upper Columbia River bench wetlands are experiencing number of pressures and are decreasing both in surface area and number. As such, there are a number of restoration efforts being aimed at improving water retention in these wetlands. The current study develops a wetland restoration feasibility index to help guide restoration efforts and make prioritization possible.

We trust the above satisfies your requirements. Please contact us should you have any questions or comments.

8 References

- BC Ministry of Environment (1990). Soils of the East Kootenay Area. https://sis.agr.gc.ca/cansis/publications/surveys/bc/bc20/bc20_report.pdf
- Curie, F., Gaillard, S., Ducharme, A., and Bendjoudi, H. (2007). Geomorphological methods to characterise wetlands at the scale of the Seine watershed. *Science of the Total Environment*, 375(1), 59–68.
- Davidson, N. (2014). How much wetland has the world lost? Long-term and recent trends in global wetland area. *Marine and Freshwater Research*, 65(10), 934 – 941.
- Ferreira, C., Mourato, S., Ksanin-Grubin, M., Ferreira, A.J.D., Destouni, G., and Kalantari, Z. (2020). Effectiveness of nature-based solutions in mitigating flood hazard in a mediterranean peri-urban catchment *Water*, 12(10), 2893.
- Fletcher, N.F., Tripp, D.B., Hansen, P.L., Nordin, L.J., Porter, M., and Morgan, D. (2024). Protocol for the Wetland Health Management Routine Effectiveness Evaluation. Forest and Range Evaluation Program, B.C. Ministry of Forests, Victoria, B.C.
- Hohn, C., Lapierre, L., Heath, T., Courage, Z., Owczarski, D. (2017). Vermont Rapid Assessment Method for Wetlands v.2.1 User’s Manual and Scoring Form. Vermont Department of Environmental Conservation. https://dec.vermont.gov/sites/dec/files/wsm/wetlands/docs/wl_VRAM_Protocol.pdf
- Hollister, J.W. (2023). elevatr: Access Elevation Data from Various APIs. R package version 0.99.0. <https://CRAN.R-project.org/package=elevatr/>
- Hopkinson, C., B. Fuoco, T. Grant, S. E. Bayley, B. Brisco, and R. MacDonald. (2020). Wetland Hydroperiod Change along the Upper Columbia River Floodplain, Canada, 1984 to 2019. *Remote Sensing*, 12(24), 4084. <https://doi.org/10.3390/rs12244084>.
- Horvath, E.K., Christensen, J.R., Mehaffey, M.H., and Neale, A.C. (2018). Building a potential wetland restoration indicator for the contiguous United States. *Ecol Indic.* Author manuscript; available in PMC 2018 April 26.
- Johnson, L., Bartsch, W., Kovalenko, K., Kloiber, S., Nixon, K. (2024). Minnesota Restorable Wetland Index. Retrieved from the Data Repository for the University of Minnesota (DRUM), <https://doi.org/10.13020/vmmd-rs84>.
- Kadykalo, A.N., and Findlay, S.C. (2016). The flow regulation services of wetlands *Ecosystem Services*, 20, 91-103.
- Kayranli, B., Scholz, M., Mustafa, A. and Hedmark, Å. (2010). Carbon storage and fluxes within freshwater Wetlands: a critical review. *Wetlands*, 30, 111–124.
- Khan, A., Annschild, R., Herkes, J., and Rapai, S. (2021). Identifying Wetlands for Restoration and Enhancement: PEA-F21-W-3179. Chu Cho Environmnetal LLP, Prince George, BC.
- Kim, B. and Park, J. (2020). Random ecological networks that depend on ephemeral wetland complexes. *Ecological Engineering*, 156, 105972.
- Lang, M., McCarty, G., Oesterling, R., and Yeo, I.Y. (2013). Topographic metrics for improved mapping of forested wetlands. *Wetlands*, 33(1), 141–155.
- Leven, C., Haubrich, R., Holden, J., and Bayley, S. (2024). Kootenay Connect: 5CW Columbia Wetlands: Upland Wetlands Restoration Sites. Interim Report: Year 6, November 30, 2024.
- Mackey, T. (2025). Beaver Dam Analogues: A Review of Structure Installation and Analysis of Geomorphic and Biological Response in an Intermittent, Headwater Stream. University of Idaho.
- Medland, S. J., Shaker, R. R., Forsythe, K. W., Mackay, B. R., & Rybarczyk, G. (2020). A multi-criteria wetland suitability index for restoration across Ontario’s mixedwood plains. *Sustainability*, 12(23), 9953.
- Millions, E.L., MacDonald, R.J., Chernos, M., Plews, R., Braaten, M. (2024) Vulnerability Assessment of the Bench Wetlands in the Upper Columbia River Basin. Prepared for the Columbia Wetlands Stewardship Partners. (March 2024).
- Warner, B.G. and Rubec, C.D.A. (Eds). (1997). *The Canadian Wetland Classification System (2nd Ed.)*. University of Waterloo, Ontario.
- Phillips, J. (2017). Wetland buffers and runoff hydrology. In *Wetlands*. (CRC Press, 2017).
- Taillardat, P., Thopson, B.S., Garneau, M., and Friess, D.A. (2020). Climate change mitigation potential of wetlands and the cost-effectiveness of their restoration. *Interface Focus*. 1020190129.

- Xu D, Bisht G, Tan Z, Sinha E, Di Vittorio AV, Zhou T, Ivanov VY, Leung LR. Climate change will reduce North American inland wetland areas and disrupt their seasonal regimes. *Nat Commun.* 2024 Mar 18;15(1):2438. doi: 10.1038/s41467-024-45286-z. PMID: 38499547; PMCID: PMC10948824.
- Rodrigues, I.S., Hopkinson, C., Chasmer, L., MacDonald, R., Bayley, S., and Brisco, B. (2023). Multi-decadal Floodplain Classification and Trend Analysis in the Upper Columbia River Valley, British Columbia, *Hydrology Earth Systems Science*, 28(10), 2203-2221.
- Rood, S.B., Foster, S.G., Hillman, E.J., Luek, A., and Zanewich, K.P. (2016). Flood Moderation: Declining Peak Flows along Some Rocky Mountain Rivers and the Underlying Mechanism. *Journal of Hydrology*, 536, 174– 182, <https://doi.org/10.1016/j.jhydrolo.2016.02.043>
- Tang, Z., Li, X., Zhao, N., Li, R., Harvey, E.F. (2012). Developing a Restorable Wetland Index for Rainwater Basin Wetlands in South-Central Nebraska: A Multi-Criteria Spatial Analysis. *Community and Regional Planning Program: Faculty Scholarly and Creative Activity*. 15.
- Thornton, M.M., R. Shrestha, Y. Wei, P.E. Thornton, S. Kao, and B.E. Wilson. (2025). Daymet: Daily Surface Weather Data on a 1-km Grid for North America, Version 4. ORNL DAAC, Oak Ridge, Tennessee, USA. <https://doi.org/10.3334/ORNLDAAC/1840>
- Utzig, G. (2021). The Columbia Wetlands and Climate Disruption. Nature Investigations Ltd. Nelson, BC. <https://kootenayconservation.ca/wp-content/uploads/2021/06/Kootenay-Connect-Y2-Final-Report-09June2021.pdf>
- Uuemaa, E., Hughes, A. O., & Tanner, C. C. (2018). Identifying feasible locations for wetland creation or restoration in catchments by suitability modelling using light detection and ranging (LiDAR) digital elevation model (DEM). *Water*, 10(4), 464.
- Wang, S. (2024). Land Surface Evapotranspiration for Canada's Landmass. Natural Resources Canada, <https://open.canada.ca/data/en/dataset/0005301b-624e-4000-8dad-a1a1ac6b46c2>
- Winter, T.C. (2000). The Vulnerability of Wetlands to Climate Change: Hydrologic Landscape Perspective. *Journal of the American Water Resources Association*, 36(2), 305–311.