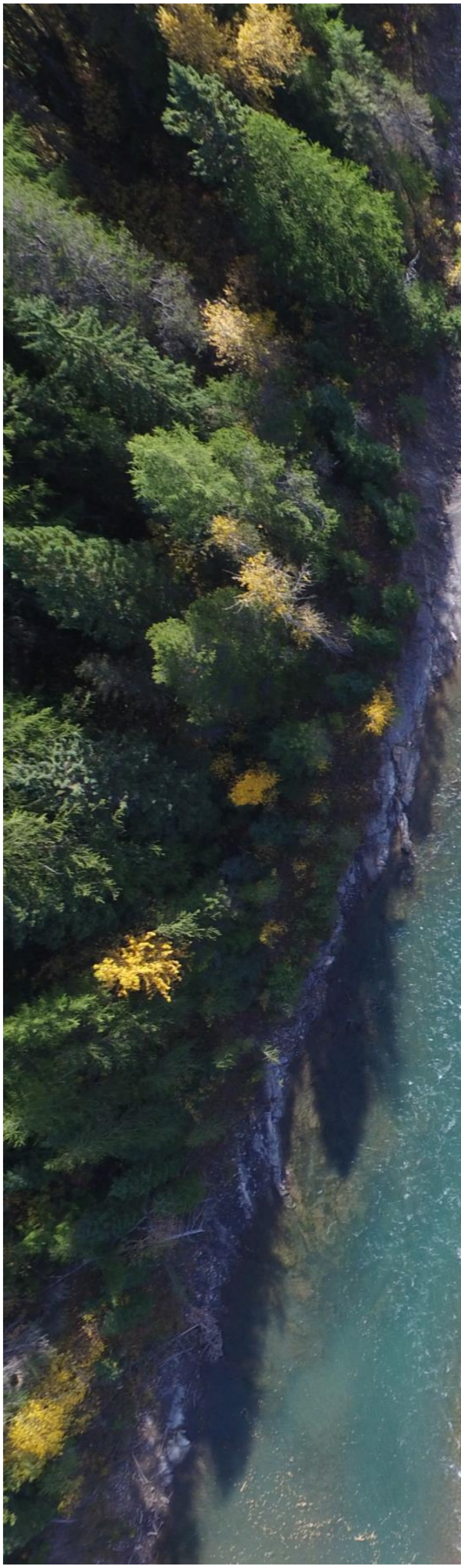

Year 2 Report – Upper Columbia Wetland Vulnerability Assessment

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1 Executive Summary

The goal of the Upper Columbia Wetland Vulnerability Assessment project is to determine the various types of wetlands in the upper Columbia Wetlands based on their hydrologic functions, determine which types of wetlands are more vulnerable to drought (and climate change), and to assess which wetlands may be amenable to conservation actions to prevent the loss of water. This work is classifying the wetlands based on their hydrologic and morphological characteristics. In May 2020, the team installed continuous water level loggers in 37 wetlands, 2 in the Columbia River, and 4 drive point piezometers to monitor shallow groundwater input in 4 sites. Precipitation and evaporation are also available from local data. Together, these data will be used to construct water balances of the monitored wetlands for extrapolation across all wetland types in the upper Columbia.

Analysis of the hydroperiod in 2020 (Yr1) using our monitoring data has indicated that there are 6 main types of wetlands based on their hydrologic responses to the rising and falling limbs of the seasonal flood as well as responsiveness to individual precipitation/inflow events. Hydroperiods in two types of wetlands appear to be determined by the peak flood and thus are unlikely to be amenable to conservation actions to mitigate the loss of water. Levees which isolate the wetlands from the Columbia River and differences in groundwater sources modify the hydrologic inflows and outflows in 4 types of wetlands. These are likely the wetlands which may be more amenable to mitigation actions by local conservation groups. This work will continue in 2021 and will direct where mitigation actions should be taken.

2 Introduction

This project is building on previous work conducted by the Columbia Wetland Stewardship Partners (CWSP) and Dr. Suzanne Bayley to evaluate wetland vulnerability as well as determine priority wetlands where management actions like conservation or mitigation should be implemented. The work is being conducted leveraging local expertise of Dr. Bayley and Dr. Ryan MacDonald as well as interactions with the University of Waterloo (Dr. Rebecca Rooney) and the University of Lethbridge (Dr. Chris Hopkinson). Collaboratively, we are applying a range of approaches to fully characterize the hydrologic regime of this important area. This study consists of 4 key activities:

1) Field investigation
    a. The field study uses automated level loggers to evaluate vertical hydraulic gradients, wetland water level response, and relationships with nearby creeks, shallow groundwater, and the Columbia River.
    b. This study uses HOBO U-20 level loggers, monitoring water level at 4-hour intervals for 37 wetlands.

c. This study also uses drive-point piezometers with Solinst Micro Diver loggers to measure water level at four shallow groundwater sites at 4-hour intervals. These loggers were damaged and data are being retrieved by Solinst.

2) Stable isotope analysis
   a. This study is evaluating the relative contributions of shallow (young) and deep (old) water to each wetland with a level logger as well as nearby creeks, the Columbia River, and groundwater wells.
   b. Isotopic signature analysis will allow source waters to be determined.
3) A remote sensing analysis
   a. This study uses time-series satellite imagery to determine temporal changes in wetland hydroperiod using frequency of open water as a proxy.
   b. Hydraulic modelling will be used to determine interactions between wetlands and the Columbia River/tributaries using information from water level loggers and a simple 1-D hydraulic model.
4) Mapping, and reporting
   a. A series of maps will be developed, outlining vulnerable wetlands based on their hydrologic characteristics and wetlands where conservation/mitigation can be implemented.
   b. A summary report of the findings from each of these investigations and how they collectively have identified wetland vulnerability will be provided.
   c. A peer-reviewed research article will be prepared based on the findings of all three study components.

This interim report provides an update on identifying wetlands and wetland types that are most (or least) vulnerable to hydrologic change based on an evaluation of water level response (i.e. principle component analysis), which was also supplemented with stable water isotope data and remote sensing information to develop conceptual understanding of the predominant water sources and fluxes to the wetlands. Data analysis and interpretation is ongoing.

3 Study Area and Methods

The study area is the Upper Columbia Watershed between Columbia Lake and Golden, with field investigation focused on the northern portion of this area (Figure 1). The study area encompasses high elevation mountain ranges including the Rocky Mountains to the east and the Columbia and Purcell Mountains in the west, separated by a deep post-glacial valley known as the Rocky Mountain Trench. The region extends from under 800 m above sea level (a.s.l.) in the Rocky Mountain Trench, to over 3,500 m a.s.l. at the highest mountain peaks in the Rocky Mountains. The region predominantly consists of coniferous forests below 2,200 m a.s.l. and alpine grasslands and talus above. Within the Rocky Mountain Trench, the Columbia River flows slowly, creating a braided system of wetlands within the wide valley. This unique wetland system is the focus of this study.

3.1 Water Level Monitoring

Hobo U-20 level loggers were used to measure wetland water level (m) at 37 individual wetlands and at two sites along the Columbia River (Figure 1). Monitoring began on May 6, 2020 and continued to October 10, 2020. Water levels were collected at 4-hour intervals. An example of field installation is presented in the Appendix (Figure 14). In addition, four drive-point piezometers with Solinst Micro Diver loggers measured shallow groundwater level at 4-hour intervals. Water level data from the piezometers and one wetland have not yet been collected and processed.

3.2 Wetland Grouping

Wetland groupings were used to assist in identifying wetland types that are most (or least) vulnerable to hydrologic change based on an evaluation of water level response (i.e. principle component analysis), which was supplemented with an isotopic signature analyses and remote sensing (satellite imagery) information. All these data were then used to develop a conceptual understanding of wetland water balances to infer the predominant water sources and fluxes to assist in identifying vulnerable wetlands.

3.2.1 Principle Component Analysis

To assist in wetland grouping, a principle component analysis (PCA) based on hydrograph characteristics was completed to reduce the number of variables of a large data set into a smaller data set that preserves as much information as possible to explore and visualize wetland grouping. Hydrograph characteristics were calculated for each wetland water level, which included: 1) the response to the low elevation snowmelt (“June 6 Peak”), 2) recession of the June 6 Peak (“Decline after First Peak”), 3) response to the high elevation snowmelt that produced the maximum annual peak flow (“Max Amplitude”), 4) percent maximum annual peak water level loss, 5) recession rate of the maximum annual peak flow (“Loss (cm/day)”).

3.2.2 Supplementary Data

The predominant water sources to the wetlands were inferred from stable water isotope data collected in 2019 and an isotope mixing model (Remer et al., *in prep*). The isotope mixing model estimated the percentage of groundwater in the wetland in the summer period, which was used to infer the predominant water source during the maximum annual peak runoff. For example, a high percentage of groundwater in a wetland inferred hydrologic connectivity was predominantly via subsurface pathways. In contrast, a low percentage of groundwater suggested hydrologic connectivity predominantly occured via surface pathways. In addition, an isotopic evapotranspiration/inflow (E/I) ratio was used to infer between isolated (subsurface connectivity) and drained (surface connectivity). For example, a high E/I ratio may indicate an isolated system, while a low E/I ratio could indicate a drained system. To corroborate these data, remote sensing information collected in a 2004 orthophotograph was used to determine an isolated versus drained system (Carli & Bayley, 2015), where a drained system was connected to the stream network via a channel. These supplementary data were used to develop a conceptual understanding of the water balance in each wetland group.

3.2.3 Conceptual Wetland Water Balances

The vulnerability of wetlands to changes in climate depend on their position within the hydrologic landscape and requires an understanding of the relative role of the wetland's hydrologic connectivity to the stream network and their predominant hydrologic fluxes. Therefore, a framework of first-order controls on wetland characteristics was used to develop a conceptual understanding of the water balance in each wetland group. The first-order controls include topography, topology and typology (Buttle, 2006). Topography refers to the topographic location of the wetland within the drainage basin and the relative role of hydraulic gradients in driving water fluxes from slopes to wetlands. Topology reflects the relative role of the wetlands in modulating water inputs from contributing slopes and a measure of the degree of hydrologic connectivity with the stream network. Topology also deals with whether a wetland shows continuous or discontinuous (both in time and space) hydrologic connectivity and whether the connectively is predominantly via surface or subsurface pathways. Lastly, typology refers to the predominant hydrologic fluxes (vertical versus lateral) and characterizes the relative residence time of water held within wetlands before making its way to the stream channel.

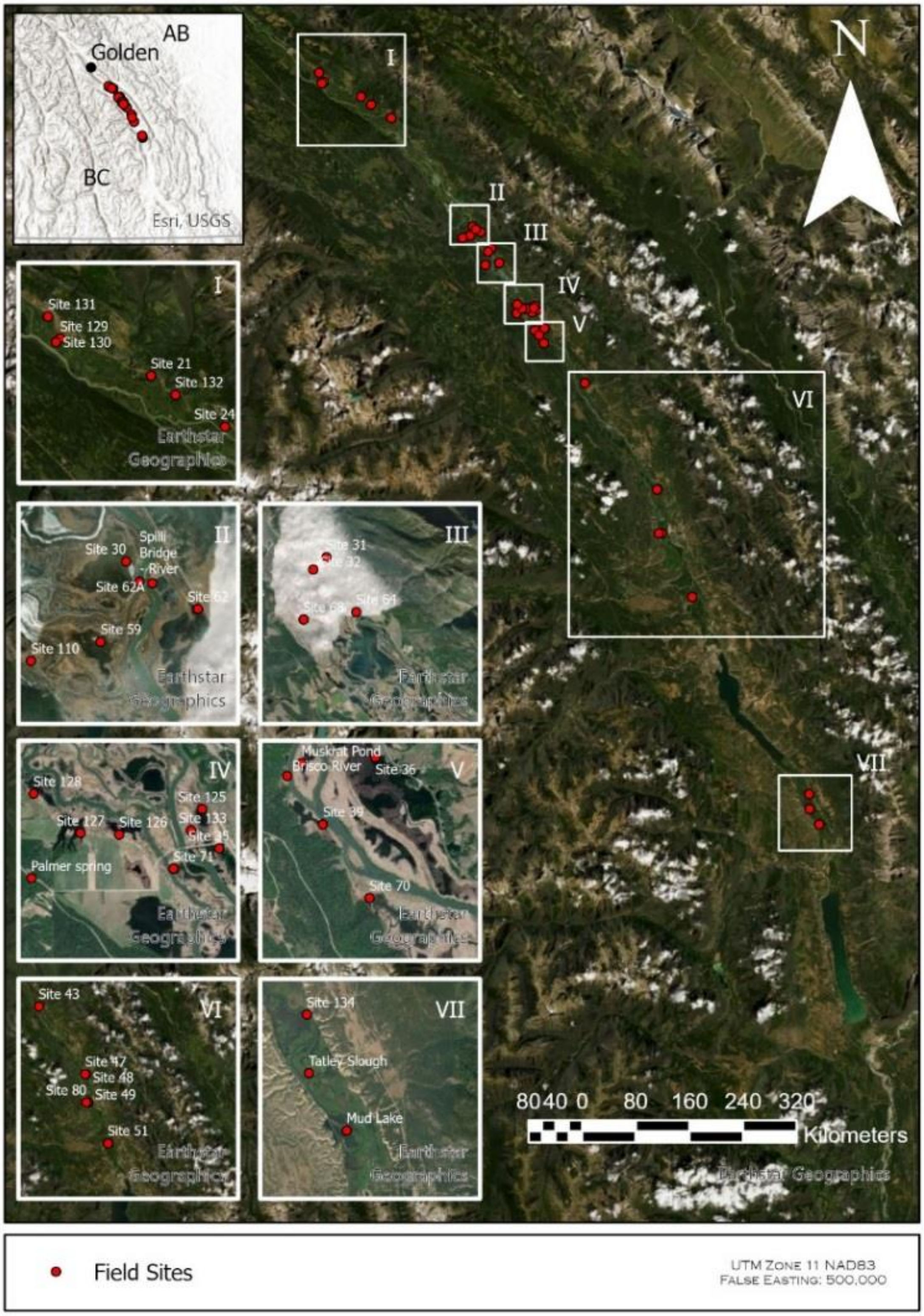

Figure 1 Study area showing water level monitoring locations (detailed maps are provided in the Appendix).

4 Results and Discussion

4.1 Principle Component Analysis

The PCA of wetland hydrograph characteristics found PC1 and PC2 carry 74% and 12% of the variance (i.e. information) of the data, respectively (Figure 2). In addition, the variance of the data is explained in PC1 similarly between all hydrograph characteristics (Table 1). However, the variance of the data is best explained in PC2 by the Decline of the First Peak, which is indicated by the higher value (Table 1). When wetlands are plotted along the PC1 and PC2 axes, the information is used to explore and visualize wetland grouping using hydrograph characteristics (Figure 3). Based on the PCA, wetlands seem to fall in several different groupings based on their water level response.

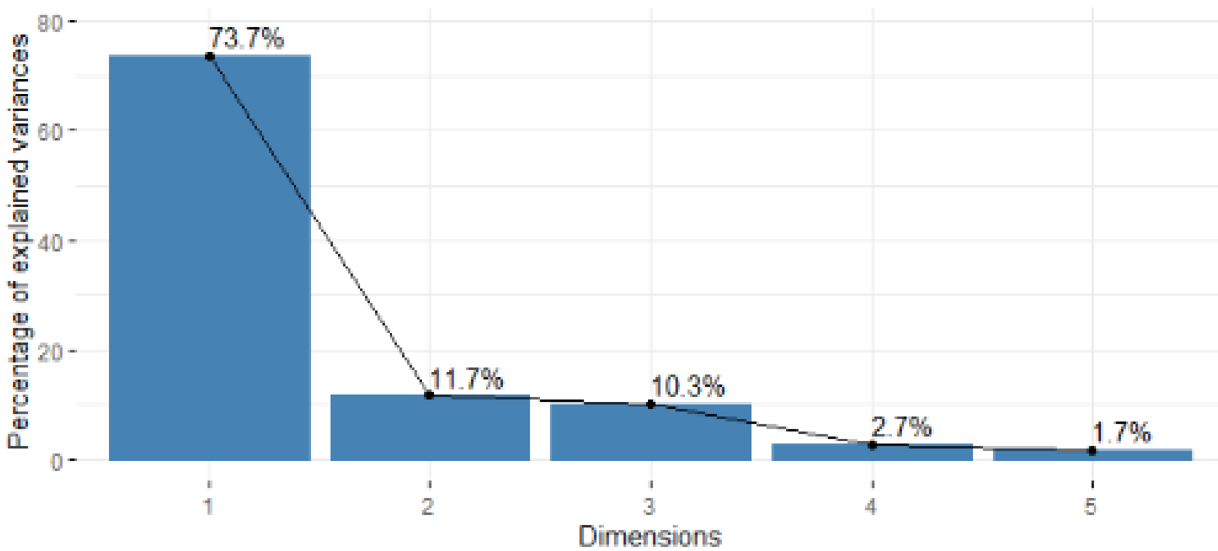

Figure 2 Percentage of explained variances in the principle components 1 – 5 based on eigenvectors and eigenvalues, which are algebra concepts that are needed in order to determine the principal components of the data. Principle components are new variables that are constructed as linear combinations of the initial variables. Therefore, the PCA tries to include the maximum possible information in the first component, then second and so on.

Table 1 Principle component analysis on hydrograph characteristic variables.

Principle Component	1	2	3	4	5
Max Amplitude	0.475	-0.151	0.443	0.389	-0.635
June 6 Peak	0.496	0.064	0.221	0.382	0.745
Decline after First Peak	0.380	0.866	-0.209	-0.175	-0.175
Percent Peak Water Level Loss	0.395	-0.352	-0.824	0.185	-0.083
Loss	0.477	-0.314	0.177	-0.799	0.067
Eigenvalues	3.68	0.585	0.513	0.136	0.083
Proportion (%)	73.7	11.7	10.3	2.7	1.7

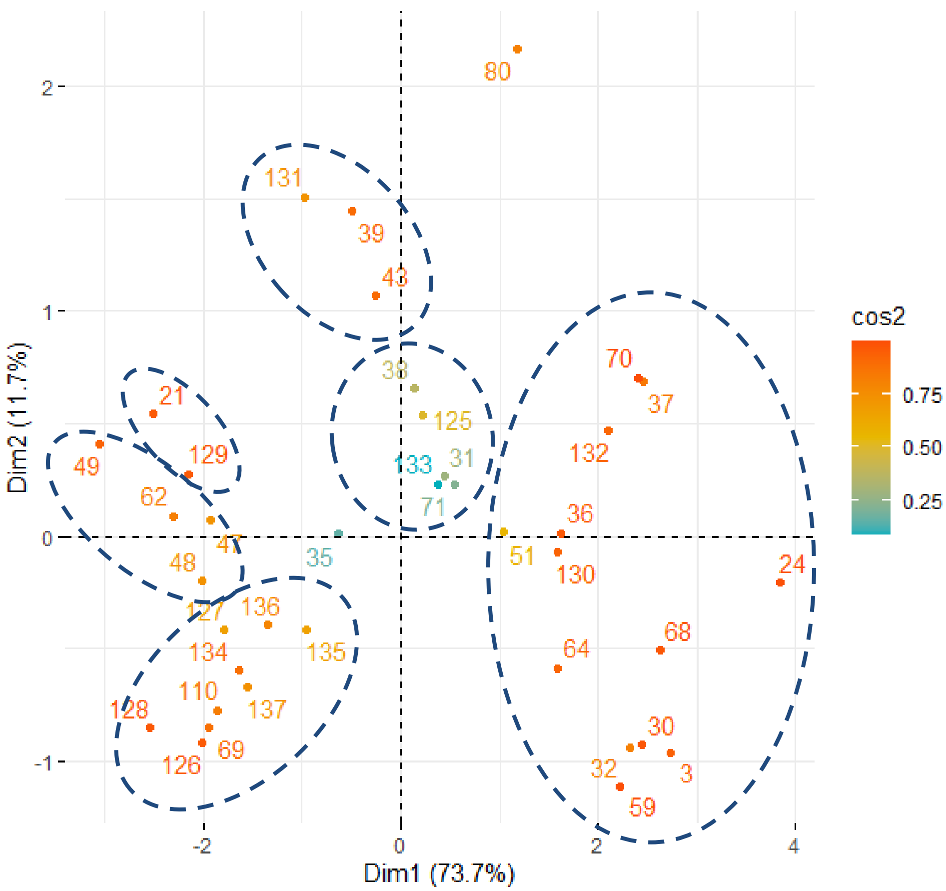

Figure 3 Wetlands plotted along the PC 1 (i.e. Dim1) and PC2 (i.e. Dim2) axes. The value "cos2" indicates the percentage of contribution of the variable to PC1 and PC2. The higher the cos2 value, the more the variable contributes to the principle components. Blue dotted lines indicate preliminary grouping of wetlands with similar hydrograph characteristics.

4.2 Conceptual Wetland Water Balances

The framework of first-order controls and the wetland's water level response were used to group the wetlands into six categories: A) river-dominated; B) river-dominated with outflow; C) fan wetland; D) groundwater-dominated (high gradient); E) groundwater-dominated (low gradient); and, F) terrace wetland (Figures 4 and 5).

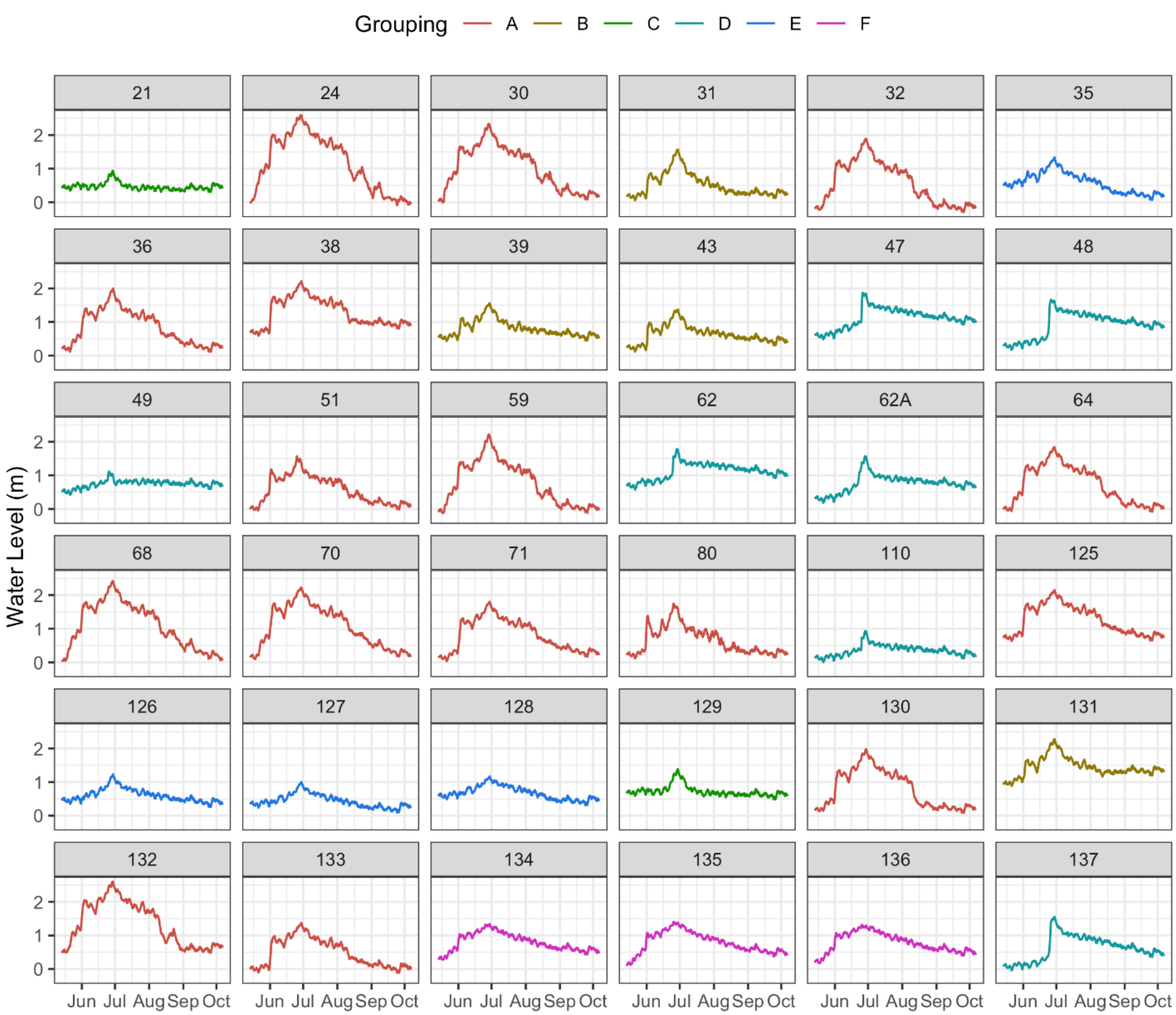

Figure 4 Wetland water levels measured in 2020 at 36 sites within the upper Columbia floodplain. Wetlands were grouped into six categories.

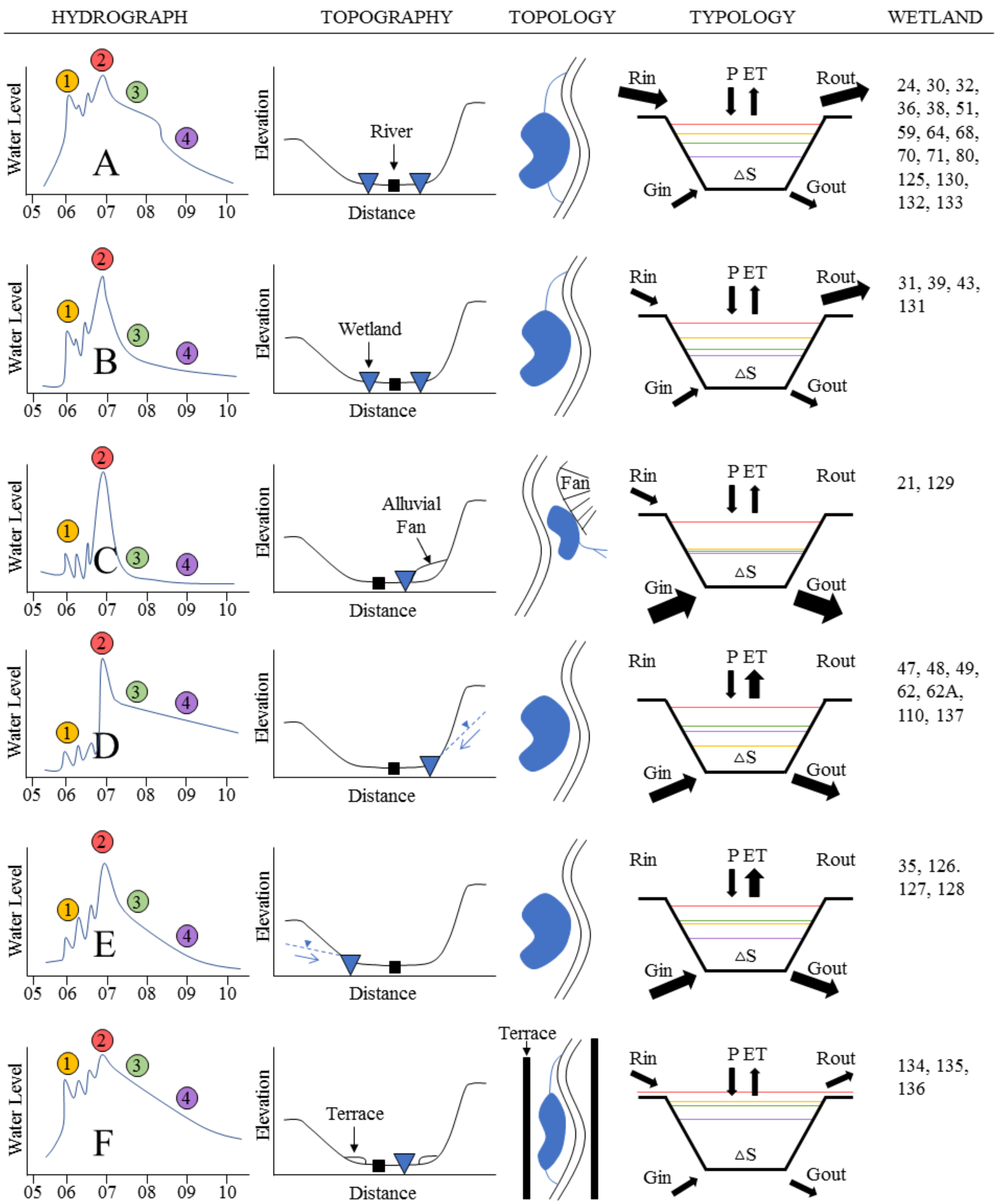

Figure 5 Conceptual diagram of wetland groups' water level response, topographic location, hydrologic connectivity (topology), and predominant water balance fluxes (typology). Wetlands were categorized based on water level response to: 1) low elevation

snowmelt (~June 6 peak); 2) high elevation snowmelt (~June 28 peak); 3) recession limb of max annual peak; and, 4) baseflow recession. Rin, surface inflow; Rout, surface outflow; P, precipitation; ET, evapotranspiration; ΔS, change in water storage; Gin, groundwater inflow; Gout, groundwater outflow. The temporal change in wetland storage corresponds to the coloured numbers in the wetland hydrograph.

4.2.1 Category A

Wetlands in category A have a higher degree of hydrologic connectivity with a stream network (Figure 5). Water levels in these wetlands have a similar hydrograph response to water levels measured in the Columbia River at Spilli Bridge and Brisco (Figure 6). Category A wetlands are connected primarily through surface pathways with inflow and outflow channels (i.e. drained wetland) to the Columbia River. However, some wetlands may have surface inflow from a tributary stream (e.g. wetland 132). Differences in wetland hydrographs may be the result of less stream connectivity with time. The percentage of groundwater in the summer and the E/I ratio is low, which also suggests surface pathways predominate in these wetlands with hydrologic connection to a stream network.

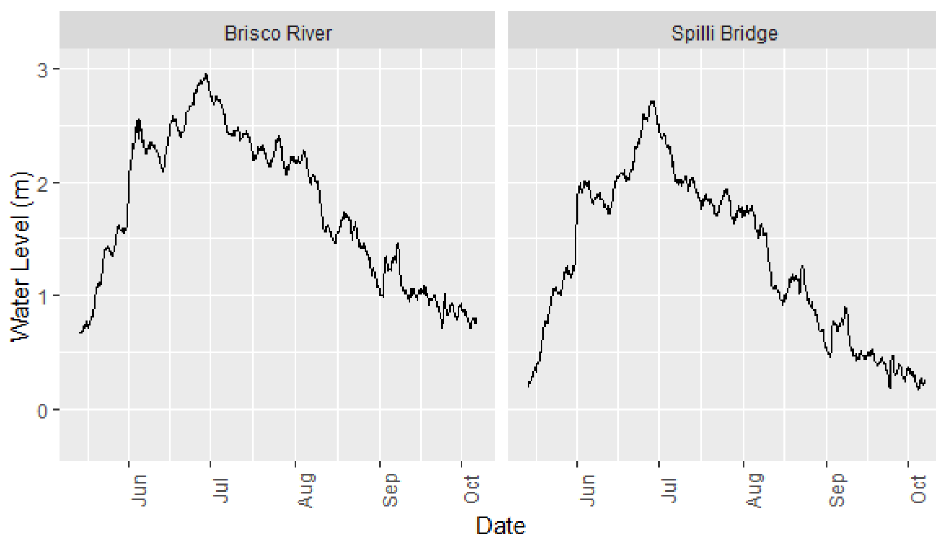

Figure 6 Water levels in the Columbia River at Brisco and Columbia River at the Spillimacheen Bridge in 2020.

4.2.2 Category B

Wetlands in category B have a similar water level response as those in category A, but with a faster maximum annual peak flow recession and baseflow recession rate (Figures 4 and 5). These wetlands did not appear to have surface inflow channels, but rather only an outflow channel. Greater surface outflow could explain the faster recession rate in the wetland hydrographs as there was little or no surface inflow to sustain the recession rate. Available water isotope data suggest the percentage of groundwater measured in the summer was low.

4.2.3 Category C

Only two wetlands were grouped into category C, which were located at the toe slope of an alluvial fan (Figure 5; Appendix Figure 7). The wetland hydrograph showed a very small response to the low elevation snowmelt compared to others (June 6^{th} peak). The rising limb of the maximum annual peak flow was slower (~9 days), while the peak flow recession and baseflow recession rates were quicker relative to other wetlands. These wetlands were isolated from the Columbia River, but surface inflow from mountain tributary streams may provide inflow. However, water isotope data indicate the percentage of groundwater in the summer was high with a low E/I ratio, which would support predominantly subsurface connectivity with fast residence times (i.e. duration of time groundwater remains in subsurface). Alluvial fans typically have highly permeable soil, which means there could be a large potential for substantial lateral subsurface flow to the wetlands.

4.2.4 Category D

Wetlands in category D had no distinct response to the low elevation snowmelt (June 6^{th} peak), but the rising limb of the maximum annual peak was quicker (~3 days) with a slower peak flow and baseflow recession relative to other wetlands. Category D wetlands are located at a break in slope with high gradient elevation (Figure 5), which suggests the higher hydraulic gradient would drive more shallow subsurface flow from the slope to the wetland. The wetlands are also isolated from the Columbia River and do not appear to have surface inflow from a mountain tributary stream from satellite imagery. The higher E/I ratio corroborates this assumption and would also suggest that evapotranspiration is a predominant hydrologic flux in these wetlands, especially during the recession period. However, the quick rising limb of the maximum annual peak flow suggests a threshold response, where either surface inflow or shallow subsurface flow has reached the wetland to rapidly increase the water level. For example, increased soil drainage with snowmelt may reach a point that couples the water tables in the upland and riparian zone and result in substantial rapid lateral shallow subsurface flow. Further ground truthing of these wetlands should be explored.

4.2.5 Category E

The wetlands in category E are similar to those in category D, but are located at a break in slope with lower gradient elevation (Figure 5). The lower hydraulic gradient would drive less shallow subsurface flow from the slope to the wetland. These wetlands are isolated from the Columbia River and have no surface channel, which means subsurface pathways are likely important to maintain wetland water levels (i.e. storage) and evapotranspiration is a predominant flux. There is no water isotope data available for this group.

4.2.6 Category F

Wetlands in category F are in a part of the riverine valley that is constricted by terraces (Figure 5; Appendix Figure 13). The wetlands are hydrologically connected to the Columbia River via surface inflow and outflow channels. The water level response in the wetlands reflects that of the Columbia River; however, category F differs from category A in that the maximum annual peak flow is not as distinct and its peak flow recession and baseflow recession is much slower. The hydrograph characteristics of category F could be attributed to rising river levels that overtop the levees and inundate the wetlands. Further ground truthing of these wetlands should be explored.

5 Conclusion

This interim report has presented further analyses to group monitored wetlands and provided a preliminary conceptual understanding of predominant water sources and fluxes within each wetland group. This information will be used to assist in calculating wetland-scale water balances and identify wetland groups that are most (or least) vulnerable to hydrologic change.

Wetlands in the lowlands of mountain landscapes receive their water primarily from groundwater discharge and from streams. Given that the wetlands are in the upper Columbia River floodplain, near the headwaters of both streams and groundwater flow systems, the upgradient watersheds of either water source are relatively small, which makes the region more vulnerable to changes in climate. However, at the wetland-scale, further evaluation is needed to determine whether a wetland is more (or less) vulnerable depending on whether it is predominantly connected via surface or subsurface pathways. All wetlands in the upper Columbia River floodplain will likely be vulnerable to hydrologic change, but at different time scales given that both streams and groundwater flow systems are snowmelt-dominated.

Recommendations for future work:

- Site investigation of select wetlands to better understand water sources and predominate pathways (decreasing the number of river-dominated wetlands being monitored).
- Analyses of shallow groundwater levels to support conceptual understanding.
- Calculate wetland-scale water balances by incorporating additional morphologic and meteorological data.
- Refine wetland groupings and statistical analyses.
- Develop a series of maps that outline vulnerable wetlands based on their hydrologic characteristics.

It is anticipated that these components of the project will be complete by the end of December 2021.

6 References

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Remer, C.R., Rooney, R., Bolding, M., Leven, C., & Bayley, S. (in prep). Hydrological processes of wetlands in the Columbia River floodplain.

7 Appendix

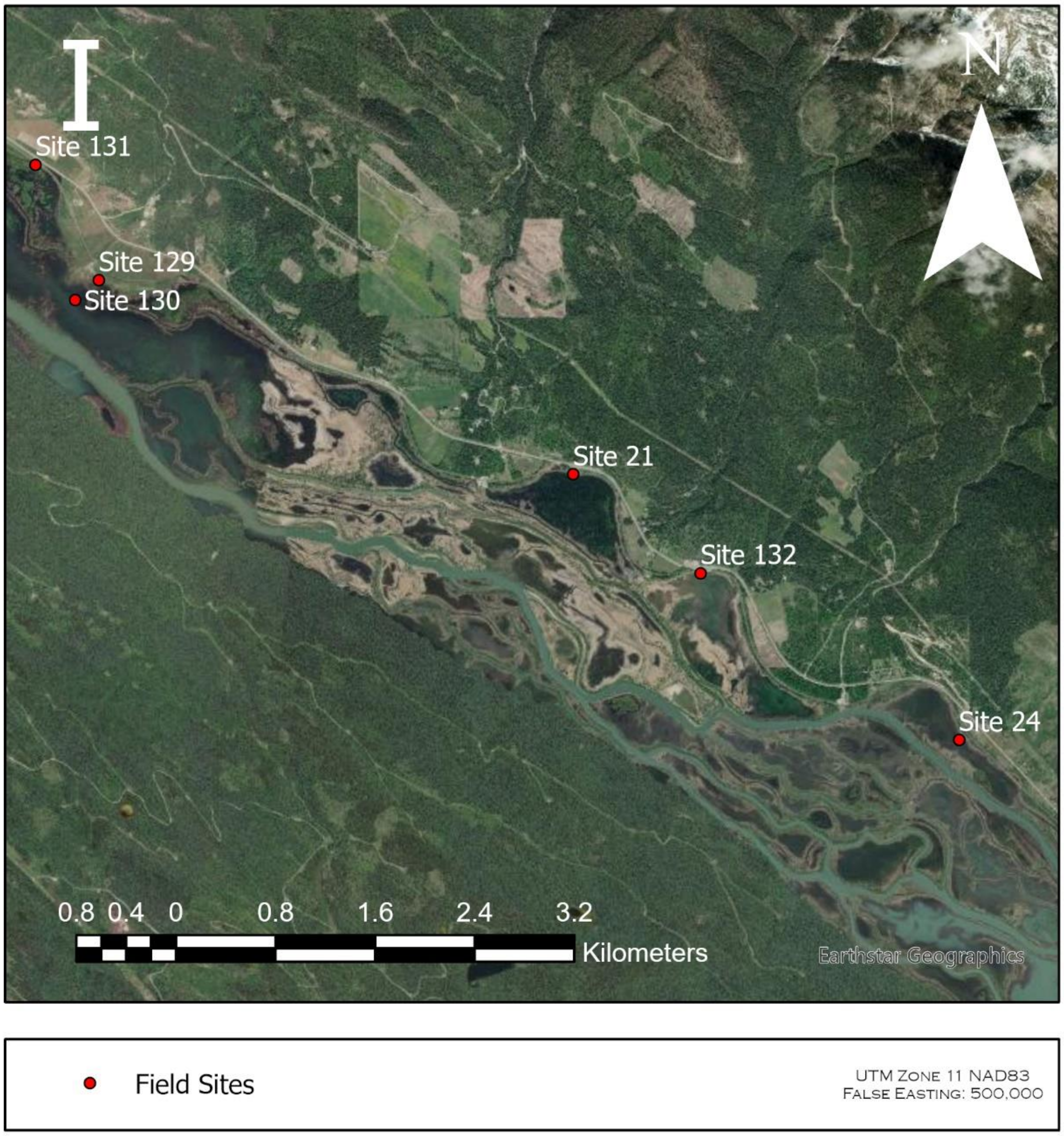

Figure 7 Detailed map of the field sites from panel I in Figure 1.

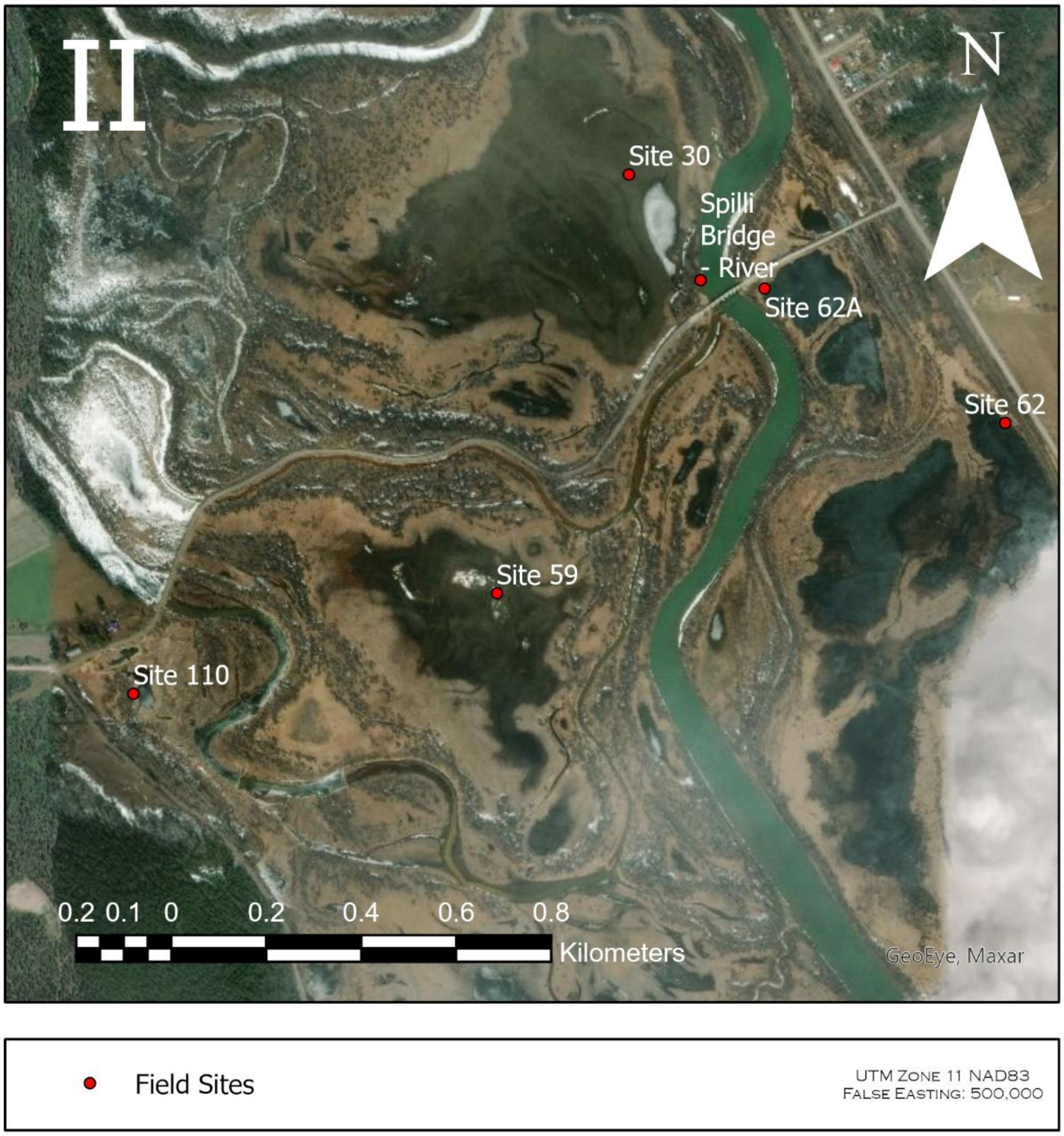

Figure 8 Detailed map of the field sites from panel II in Figure 1.

Figure 9 Detailed map of the field sites from panel III in Figure 1.

Figure 10 Detailed map of the field sites from panel IV in Figure 1.

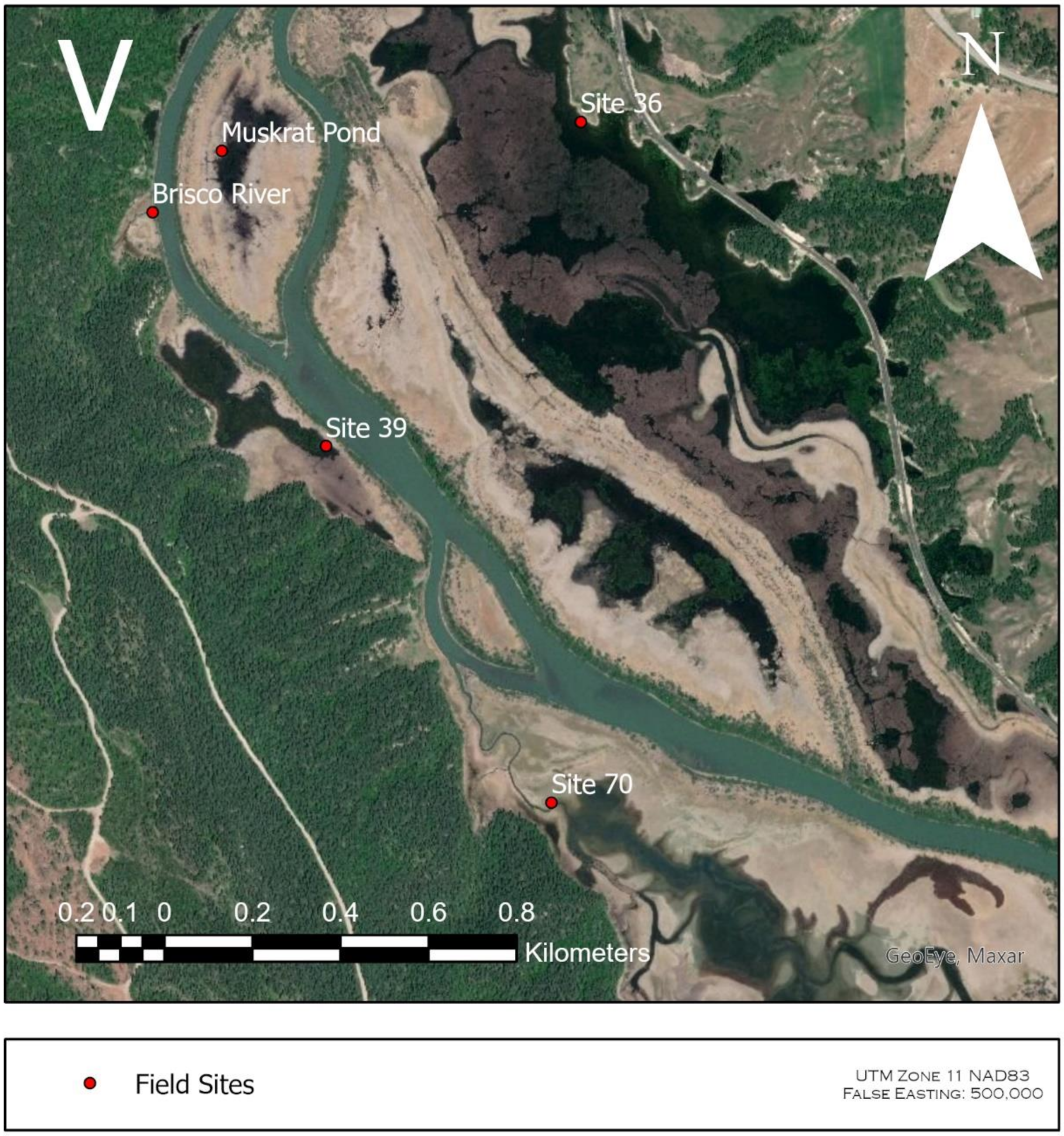

Figure 11 Detailed map of the field sites from panel V in Figure 1.

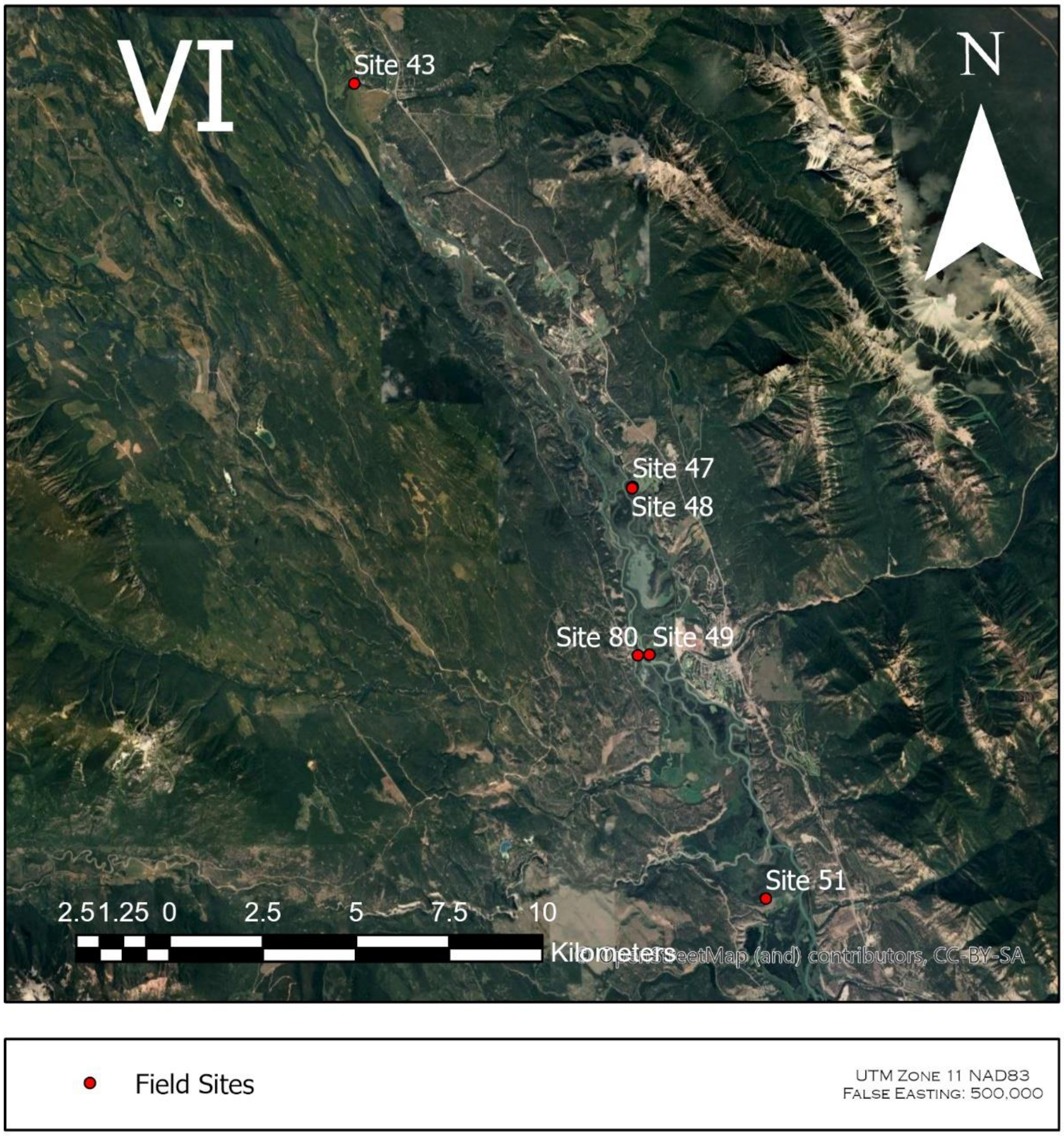

Figure 12 Detailed map of the field sites from panel VI in Figure 1.

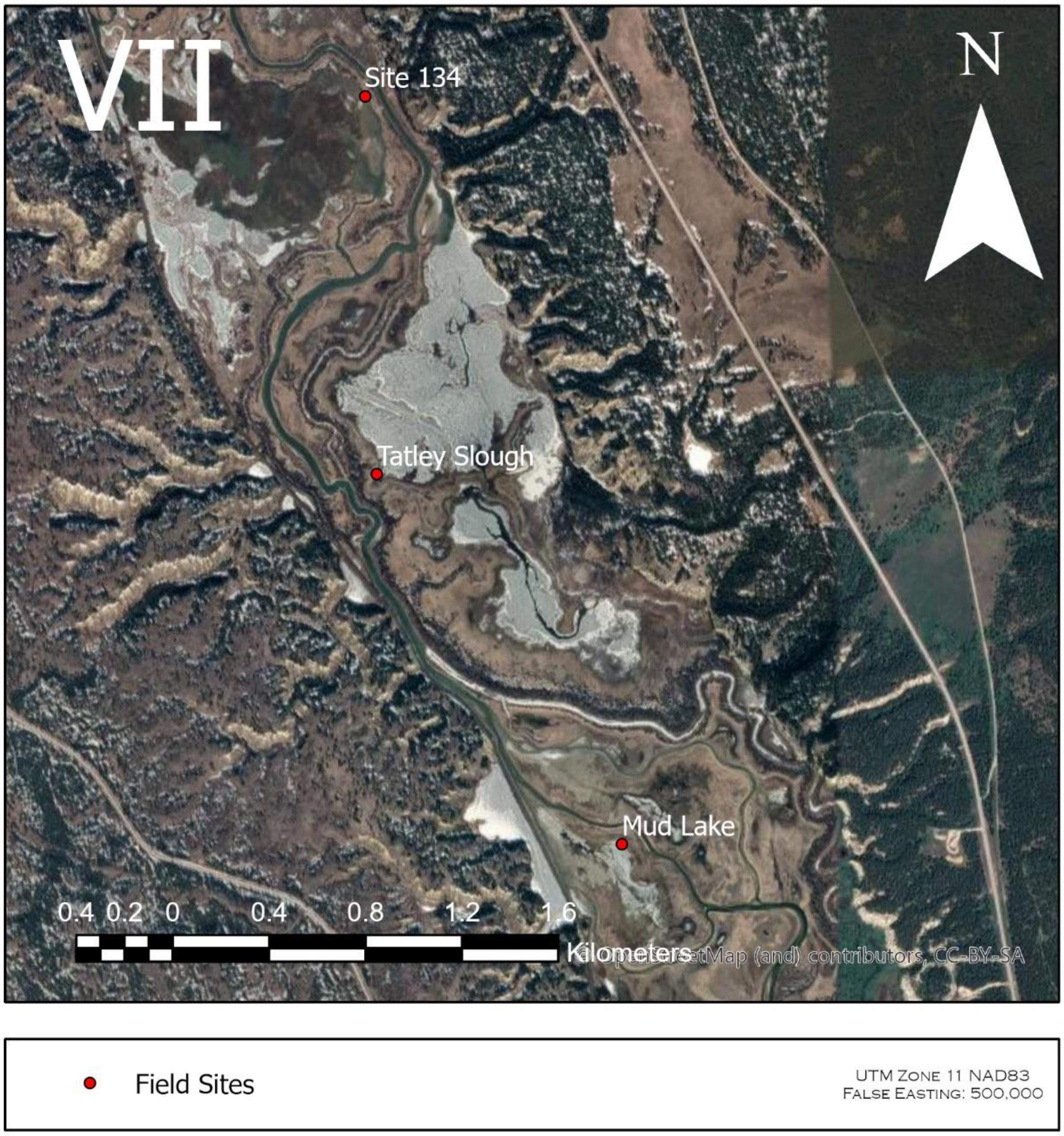

Figure 13 Detailed map of the field sites from panel VII in Figure 1.

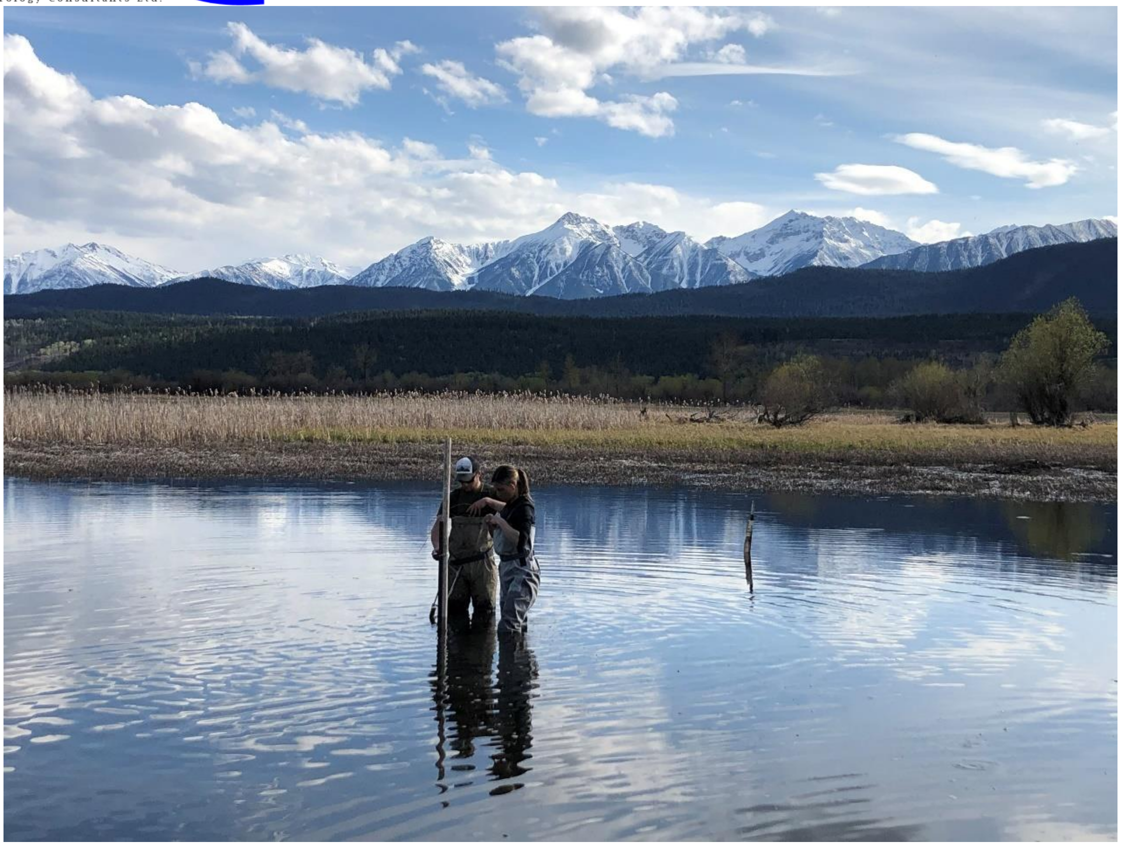

Figure 14 Logger installation at Site 31 Galbraith Lake.

Table 2 Wetland Site Water Level Seasonal Summary Statistics

Site	Seasonal Mean (m)	Seasonal Max (m)	Seasonal Min (m)	Post Peak Min (m)	Seasonal Range (m)	Wetland Group
24 Nabel Road	1.162	2.597	-0.105	-0.105	2.702	A
30 DS of Spilli Bridge	1.006	2.336	-0.006	0.078	2.342	A
32 Perrys Lake	0.574	1.892	-0.297	-0.297	2.189	A
36 Brisco Mill South	0.843	1.997	0.112	0.112	1.885	A
38 Threshers Pond	1.289	2.217	0.589	0.801	1.628	A
51 Wilmer Marsh	0.576	1.571	-0.046	-0.019	1.617	A
59 Iron Oxide	0.776	2.212	-0.122	-0.118	2.334	A
64 N of HWY95 Rest Area	0.717	1.841	-0.084	-0.084	1.925	A
68 Feldmans Drained	1.096	2.421	0.016	0.067	2.405	A
70 Halversons Slough	1.053	2.227	0.089	0.167	2.138	A
71 Elk Pond	0.811	1.807	0.035	0.159	1.772	A
80 S of 2nd Radium Bridge	0.651	1.745	0.113	0.145	1.632	A
125	1.258	2.154	0.631	0.646	1.523	A
130	0.794	1.979	0.079	0.079	1.9	A
132	1.347	2.604	0.479	0.48	2.125	A
133	0.49	1.375	-0.117	-0.117	1.492	A
31 Galbraiths Lake	0.521	1.569	0.058	0.125	1.511	B
39 Frog Lake	0.806	1.564	0.432	0.447	1.132	B
43 Luxor	0.636	1.372	0.115	0.305	1.257	B
131	1.445	2.283	0.887	1.159	1.396	B
21 Castledale	0.469	0.934	0.301	0.301	0.633	C
129	0.728	1.383	0.485	0.485	0.898	C
47 Taggert E of RR	1.117	1.872	0.483	0.923	1.389	D
48 Taggert W of RR	0.918	1.667	0.171	0.773	1.496	D
49 Radium Mill Pond	0.747	1.114	0.418	0.586	0.696	D
62 US of Spilli Turn Off	1.12	1.782	0.574	0.916	1.208	D
62A US of Spilli Turn Off	0.762	1.573	0.182	0.574	1.391	D
110 Blue Roof	0.357	0.931	0.004	0.111	0.927	D
137 Muskrat Pond	0.625	1.557	-0.042	0.355	1.599	D
35 Loon Pond	0.58	1.335	0.066	0.066	1.269	E
126	0.606	1.233	0.26	0.26	0.973	E
127	0.436	1.005	0.089	0.089	0.916	E
128	0.673	1.171	0.309	0.309	0.862	E
134	0.892	1.341	0.273	0.413	1.068	F
135 Mud Lake	0.792	1.406	0.09	0.352	1.316	F
136 Tatley Slough	0.788	1.318	0.171	0.375	1.147	F