Environment and Climate Change Canada

Canada Nature Fund: Community-Nominated Priority Places for Species at Risk

Kootenay Connect: 5CW Columbia Wetlands:

Hydrology and Beavers: Columbia Wetlands Floodplain Hydrology and the Role of Beaver Dams

March 31, 2024. Final Report: Year 5

By Catriona Leven, Dr. Suzanne Bayley, and Jessica Holden (Columbia Wetlands Stewardship Partners)

Table of Contents

Table of Figures

Table of Tables

1. Executive Summary

The Columbia Wetlands are a complex system shaped by many different processes. They provide habitat for many species and ecosystem services for people including a source of water and a place for recreation. They face several threats including that of climate change. Better understanding the Columbia Wetlands will allow us to make more informed decisions about conservation and restoration strategies for the area. Thus, the Columbia Wetland Stewardship Partners aim to do both research and conservation actions to best protect this magnificent ecosystem.

Our research has found three groups of wetlands within the Columbia Wetlands complex, which can be characterised by their connectivity to the Columbia River as Most Connected, Partially Connected, and Least Connected. In some years, the Partially Connected group can be further separated into Partially Connected – Bigger Gaps and Partially Connected – Smaller Gaps. These wetlands differ hydrologically, particularly in their response to the Columbia River flood pulse, which is a major driving force of the Columbia Wetlands complex due to the undammed nature of this part of the river.

Most Connected wetlands respond rapidly to the rise and fall of the Columbia River and increase on average 2m with the flood pulse. They do not maintain water depth as the Columbia River recedes, thus resulting in them being very shallow or completely dry in the late fall and early spring. Least Connected wetlands respond less rapidly and retain water all year round, having on average 1m of water still present in the wetlands in the late fall and early spring, and increasing only 1m in response to the flood pulse. Partially Connected wetlands are midway between these two groups, and are the most variable between years due to the complexity of interactions between the flood pulse and the size, location, and condition of beaver dams present in these wetlands.

There is variation between years due to the variability in size, timing, and duration of the Columbia River flood pulse. Despite variation between years, we were able to assign Modal Wetland Groups to 35 wetlands, which are the group a wetland was in for at least two of three years of our study, thus indicating that our groups are persistent across year and are a meaningful way to categorise these wetlands.

2023 was a low water year with a very early flood pulse, which is reflected in our data. The flood pulse was a month early, with water depths being highest on May 24th 2023 (Day 144), whereas in 2020, 2021, and 2022 it was highest on June 29th (Day 180) or later. Mean maximum depth reached across our study wetlands was only just over 2m as opposed to over 2.5m in the other three years.

Despite the Partially Connected group containing the most wetlands (16 of 35, or 46%), the Most Connected group contains the biggest area of wetland, with 11.92km^2 or 51% of the studied wetland area being in this group. The Least Connected group has the smallest amount of wetlands both by count (8 of 36, or 23%) and by area (3.12km^2 or only 13%). While our study wetlands comprise just over 10% of the entire Columbia Wetlands complex (our study wetlands are 23.32km^2 of the total 200km^2), we believe they are a good representation of the whole area. This suggests that approximately 50% of the Columbia Wetlands are Most Connected wetlands, rising and falling rapidly as the river does, and not holding water when the river is low.

We identified 205 beaver dams within 30m of our study wetlands. 26 dams were directly impacting one of the wetlands, and 21 wetlands were directly impacted by one or more dams. Of the remaining 17 wetlands, 10 had levee gaps that were undammed by beavers and seven were entirely

enclosed by natural levees without any gaps. The longest dam was recorded in Site 49 at 150m long, and the shortest dam was in Site 39 and was only 1.7m long. Five wetlands had dams over 100m long, and eight wetlands had dams that were less than 10m long. The maximum number of dams in a wetland was three, however four wetlands had natural levees that were reinforced by beaver activity, with small low patches in the levee showing signs of the addition of mud and sticks. We didn't count these as full dams, but we did measure how much of the wetland perimeter was beaver reinforced in this way. The tallest dam we found was at Site 21 and was 1.83m high. The widest dam was in Site 62 and was 6.68m wide. We found active dams in 16 wetlands, with signs of recent beaver maintenance such as new sticks or new mud being added to the structure.

60% of the variation between these groups can be explained by gaps in the natural levees and beaver dams. Most Connected wetlands have open levee gaps, while Partially and Least Connected wetlands have beaver dams built across these levee gaps or levees without gaps, thus allowing for water to be retained within the wetlands. The remaining 40% of variation is likely due to variables that our analysis has not included, such as groundwater and precipitation. In 2019, isotopic analysis of our sites indicated the varying but important role of groundwater in the Columbia Wetlands (Remmer *et al.*, 2023).

However, the fact that we can predict 60% of group variation despite these other factors and the complex interactions between the Columbia River and the levee gaps and beaver dams, and considering how variable the Columbia Wetlands are between years, is indicative of how important beaver dams are to this system. As in many other wetland and riverine systems, beavers are having an outsize impact for their size, greatly affecting the Columbia Wetlands complex. Beaver dams are present in 21 of our 38 study wetlands, all of which are Partially or Least Connected wetlands. Without these beaver dams, these wetlands would be Most Connected, with nothing preventing the free flow of river water in and out of the wetland. Without beaver dams, there would be less diversity in wetland types and therefore less habitat diversity and less biodiversity within the Columbia Wetlands. Beaver dams are essential for the complex, beautiful, and biodiverse wetlands that we see today in the Columbia Valley.

26 dams were directly impacting one of the wetlands, and 21 wetlands were directly impacted by one or more dams. Of the remaining 17 wetlands, 10 had levee gaps that were undammed by beavers and seven were entirely enclosed by natural levees without any gaps. These dams varied greatly in size. The longest dam was recorded in Site 49 at 150m long, and the shortest dam was in Site 39 and was only 1.7m long. Five wetlands had dams over 100m long, and eight wetlands had dams that were less than 10m long. The maximum number of dams in a wetland was three, however four wetlands had natural levees that were reinforced by beaver activity, with small low patches in the levee showing signs of the addition of mud and sticks. We didn't count these as full dams, but we did measure how much of the wetland perimeter was beaver reinforced in this way. The tallest dam we found was at Site 21 and was 1.83m high. The widest dam was in Site 62 and was 6.68m wide. We found active dams in 16 wetlands, with signs of recent beaver maintenance such as new sticks or new mud being added to the structure.

As well as differing hydrologically and morphologically, these wetland groups differ ecologically. There are different communities of submerged aquatic vegetation in the different wetland groups, with the Partially and Least Connected wetlands providing more stable habitat, with less scour and without the challenge of drying due to water draw down post flood pulse. *Nymphaea tetragona*, a Blue-Listed species in BC, was only found in Partially or Least Connected wetlands.

We have recorded 142 species in and around our study wetlands either during dedicated waterbird counts or incidentally while working in the wetlands. 13 of these are Species at Risk. The use of wetlands by these species varies widely, from ducks using open water to rest and feed, swallows and other insect eating birds catching food over the wetlands, small passerines such as warblers nesting in wetland

vegetation, and shorebirds using exposed mud and short vegetation around the edges of wetlands to feed. During spring and fall migratory waterbird counts at 20 sites we recorded 82 species of birds, of which four are SAR, and 17,291 individual birds. Of these, Mallard was the most commonly observed species, being observed on 172 occasions and totaling 3232 individuals.

We are particularly interested in the use of wetlands by migratory waterbirds in the spring, as these species migrate through before the flood pulse when the wetlands are at their lowest. During our spring 2023 migratory waterbird counts, we recorded 33 species of waterbird, four species of raptor, and 4817 individual birds. This was slightly lower but similar in magnitude to spring 2022 when we recorded 34 species of waterbird, five species of raptor, and 5049 individual birds.

While mean number of individual birds does not differ across wetland groups, mean number of species do. In 2023 we observed an average of 10 and 15 species in Partially and Least Connected wetlands respectively and only six in Most Connected wetlands. The difference in what kind of birds use each wetland group is striking, with only four species that feed by diving underwater (such as Bufflehead) recorded in Most Connected Wetlands, while we observed 14 in Partially Connected Wetlands and 15 in least Connected wetlands.

Partially and Least Connected wetlands are clearly essential for many species, with species such as Pied-billed Grebes and Ring-necked Ducks simply not being found in Most Connected wetlands during spring migration due to the low water levels in these wetlands. Without them, these species would be unable to feed successfully, and their migration through the Columbia Wetlands would likely be negatively impacted.

As the Partially and Least Connected wetlands are a smaller percentage of the overall Columbia Wetlands but provide such important habitat, conservation actions to maintain these wetlands on the landscape are justified. In 2021, we built a beaver dam analogue in Site 38, where an old beaver dam had just blown out. This restored 38 hectares of wetland, raising the water levels by approximately m0.6m which increased the volume of water held within the wetland by 324,000m^3. In 2023, a new beaver dam in Site 71 showed immediate results, with an increase of 0.25m in water depth despite 2023 being a low water year. Over the whole wetland area, this is an estimated increase of 27,500m^3.

Going forward, we will build beaver dam analogues in Site 145 and Site 24, and monitor pre- and post-restoration for both these sites. In Site 145, we aim to increase water levels by 1.35m, which will result in an increase of 175, 500m^3 of water being held in the wetland, and will additionally allow more water to be retained in Site 144, thus restoring the capability for water retention and increasing water on the landscape in 32 ha of wetland, which will result in an additional of 432,000m^3 of water being retained.

We have communicated with the public in various ways, including with a CBC interview broadcast on television and radio in January 2024, and with presentations to community groups. We are also involved in advising BC Parks and Ducks Unlimited on wetland restoration at Burgess James Gadsden Provincial Park, and are a part of the Columbia Valley Recreational Planning Initiative, Recreational Plan for Forester Watershed group. Dr. Suzanne Bayley and Catriona Leven were also co-authors on the paper “The Importance of Groundwater to the Upper Columbia River Floodplain Wetlands”, along with Dr. Casey Remmer and Dr. Rebecca Rooney, published in the Canadian Water Resources Journal in July 2023.

2. Introduction

2.1 The Columbia Wetlands

The Columbia Wetlands, stretching from Columbia Lake in the south to just north of Golden in the north, are floodplain wetlands along the only undammed portion of the Columbia River, and are one of the longest contiguous wetlands in North America (Zimmerman, 2004). The elevation gradient of the Columbia River between Columbia Lake and Golden is very low, at about 19 cm/km, meaning that the river meanders substantially through the valley bottom, with multiple side channels and many wetlands created by erosion and deposition across the floodplain (Environmental Stewardship Division Kootenay Region, 2004) (Figure 1).

Figure 1: Aerial photo of a section of the Columbia Wetlands just upstream of Spillimacheen in May 2022.

As floodplain wetlands in an undammed system, they are maintained by the natural flood pulse of water flowing over the natural river levees and advancing and retreating across the valley, a process that has major effects on all aspects of the wetlands (MacDonald Hydrology Consultants Ltd., 2021; Makaske *et al.,* 2009). The flood pulse – the overbank flow of water across the landscape during a high water period (Junk *et al.*, 1989) – is an essential driver that determines floodplain connectivity and transport of both organic and inorganic material, from organisms to sediment, but other sources of water such as local rainfall or rising groundwater also contribute to the hydrological and ecological dynamics of floodplain wetlands (Amoros and Bornette, 2002; Junk *et al.,* 1989; Tockner *et al.*, 2000). Like all floodplain wetlands, the Columbia Wetlands are a complex system, with many processes operating at different temporal and spatial scales, and while many rivers and their floodplains systems around the world have been heavily modified by humans, the complexity of floodplain hydrological and ecological dynamics have been seen in both heavily and less modified temperate and tropical systems (Amoros and Bornette, 2002).

The Columbia Wetlands show anastomosing morphology, with multiple interconnected channels enclosing flood basins, and with stable channels and frequent crevassing of the natural levees to form gaps (Makaske *et al.,* 2009). The wetland system is approximately 180 km long and over 26,000 ha in area (Environment and Climate Change Canada, 2018), and provides important wildlife habitat and ecosystem services such as groundwater recharge, water for agriculture and residential use, flooding mitigation, and recreational use. The wetlands are important culturally to both First Nations and settlers in the Columbia Valley, and are located on the traditional territories of the Ktunaxa Nation, Secwepemc First Nation, Shuswap First Nations Band, and Metis Nation Columbia River.

Among the many ecosystem services they provide, the Columbia Wetlands are habitat for a tremendous diversity of organisms. A 2004 survey found 4 species of fungi, 268 species of plants, 34 species of invertebrates, 2 species of amphibians, 1 species of reptile, 112 species of birds, and 17 species of mammals within the Columbia National Wildlife Area, which at 1,001 ha comprises 3.9% of the entire Columbia Wetlands complex (Environment and Climate Change Canada, 2018). The Columbia Wetlands provide habitat for many wetland-dependent mammals such as North American river otter (*Lontra canadensis*, American beaver (*Castor canadensis*), and muskrat (*Ondatra zibethicus),* as well as important habitat for species that use wetlands for at least part of the year such as elk (*Cervus canadensis*) and American black bear (*Ursus americanus*), and provide corridors to traverse the valley for upland animals such as grizzly bear (*Ursus arctos*).

The Columbia Wetlands are a particularly vital habitat for migrating birds (Figure 2). They comprise an important part of the Pacific Flyway; one of North America's four major migratory routes (Environment and Climate Change Canada, 2018). They provide a stopover site for migratory birds, including provincially listed species such as tundra swan (*Cygnus columbianus*) which is on the BC Blue List 'of special concern' with a Provincial Conservation Status of S3N (special concern, non-breeding population). The Columbia Wetlands Waterbird Survey, which covered approximately 39% of the total Columbia Wetlands area, found that in 2019, across three dates, 41,095 birds of 90 different species were present in the wetlands, and across the five years of the survey 163 bird species were documented, with a maximum single day count of 20,822 individuals on 15th October 2016 (Darvill, 2020).

Figure 2: Three bird species found in the Columbia Wetlands. Top left: Trumpeter Swan, Bottom left: Ruddy duck, Right: Bald Eagle.

This importance is recognized provincially, federally, and globally: the Columbia Wetlands have been designated a RAMSAR site since 2004, qualifying under all eight RAMSAR criteria (Zimmerman, 2004), are being proposed as an Important Bird Area (Darvill, 2020), and are protected variously as the Columbia Wetlands Wildlife Management Area under the British Columbia (BC) Wildlife Management Act, the Columbia National Wildlife Area under the Canada Wildlife Act, and as Nature Trust of Canada and Nature Conservancy of Canada properties.

2.2 Climate Change and the Columbia Wetlands

The Columbia Wetlands face many threats, despite these protections and recognitions, and we do not have a good understanding of how these threats will affect wildlife and ecosystem services, particularly in combination. Although the Columbia Wetlands remain undammed, there is nonetheless rapid residential, agricultural, and recreational growth in the Columbia Valley (Environment and Climate Change Canada, 2018) which threatens the wetlands – and the organisms living within them – from disturbances due to boat or ATV users, to water being removed from the wetlands for agricultural irrigation or residential use. While these wetlands are critical habitat for birds and other organisms, we do not have a good understanding of how these varied threats will affects wildlife.

One of the main threats facing the Columbia Wetlands, and the subject of recent research (e.g., Hopkinson *et al.,* 2020; Utzig, 2021), is climate change. The Columbia Wetlands are particularly sensitive to climate change for several reasons. It has been suggested that mountainous regions are more sensitive to climate change because they are experiencing faster temperature increases and changes to precipitation than the global land average. While results globally are inconclusive (Rangwala and Miller, 2013), in western North America glaciers are shrinking due to increasing temperatures, with some having retreated up to 2 km since 1900; corresponding decreases in streamflow have been recorded, including in the Canadian Rocky Mountains (Moore *et al.,* 2009). Across the Rocky Mountains, particularly in the Northern Rockies and Upper Columbia River, the observed late 20th century snowpack declines resulting from springtime warming are almost unprecedented in magnitude, with corresponding impacts on streamflow and water supply (Pederson *et al.,* 2011).

Annual temperatures in the Columbia Wetlands have already increased by 1˚C and further increases of 2 ˚C to 4 ˚C are projected. Changes to precipitation amounts, timing, and form are also predicted by models, with less snow and more rain falling in the valley (Utzig, 2021). As the Columbia Wetlands are dependent on the natural flood pulse, which is primarily driven by snowmelt and rainfall depending on season (Makaske *et al.,* 2009), the decreasing snowpack of the Canadian Rockies and changes in precipitation are a direct and urgent threat to the hydrology of the Columbia River and its floodplain wetlands. There is less water in the Columbia Wetlands today than historically (Hopkinson *et al.*, 2020), and projections indicate that there will be increasingly less water in the future (Utzig, 2021).

2.3 Beavers and the Columbia Wetlands

Beavers may provide some natural mitigation of the effects of climate change on the Columbia Wetlands by increasing wetland resilience and complexity, and specifically by increasing open water area (Hood and Bayley, 2008). Beavers have profound effects on wetlands and are often termed ecosystem engineers for the extensive changes they provoke, providing both direct ecosystem services and economic benefits to people (Thompson *et al.*, 2021). They shape the wetland systems that they occur in by changing the hydrology and associated processes such as sediment transport and increasing habitat complexity and

biodiversity across all taxonomic groups, from invertebrates to mammals (Larsen *et al.*, 2021; Nummi and Holopainen, 2020).

Due to the large impacts that beavers have they have been widely studied in both Europe and in North America (while North American beaver (*Castor canadensi*s) and European beaver (*Castor castor*) are different species, as ecosystem engineers they function very similarly), in both river and floodplain contexts (Larsen *et al.*, 2021). However, most of the research undertaken on beavers has not been in a floodplain system the size of the Columbia Wetlands, where the river is large and undammed and the floodplain is up to 2 km across. Beavers in the Columbia Wetlands are not damming the Columbia River itself, they are damming small side channels and wetlands within the floodplain, and the impacts of this type of dam-building activity are very different from the impacts of dam-building activity in incised streams or even in river floodplains of around 500 m in width.

Crucially, while in an incised stream system water flow is unidirectional, only flowing over the beaver dams one way, in a floodplain system the water flows over beaver dams in both directions. In the spring, as the flood pulse rises, water flows over the beaver dams from the Columbia River into the wetlands; once the flood pulse has receded, the water flows out of the wetlands (either over, through, or under the dams, if they are present) into the Columbia River (Figure 3). Thus, the influences of beaver dams on the morphology, hydrology, and vegetative characteristics of these wetlands are likely profound, and as yet not well understood.

Figure 3: Beaver dam found within the Columbia Wetlands. The Columbia River is behind the photographer.

Many of the individual wetlands within the Columbia Wetlands complex have one or more gaps in the natural levees that enclose them, that allow for greater connectivity to the Columbia River, as water is able to flow through these gaps before the river floods enough to overtop the levees. The Columbia River does not flood enough every year to overtop the levees, only doing so approximately half the time

(Suzanne Bayley, pers. comm.) meaning that these levee gaps are the only way that water is able to enter the wetlands in years when the river does not flood over the levees.

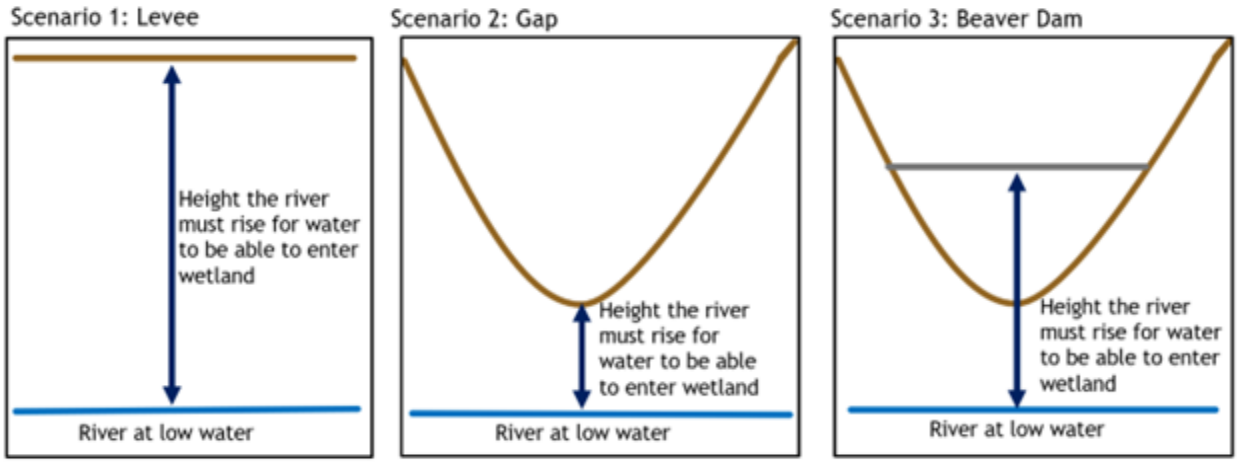


Figure 4: Schematic of the role of levee gaps and beaver dams in influencing the flood pulse entering wetlands.

In Scenario 1 in Figure 4, the natural levee surrounding a wetland, built by the gradual deposition of sediment over many years, is unbroken, without any gaps in it. Thus, the river must rise several metres from its pre-flood pulse depth so it can overtop the levee and enter the wetland. However, while it is harder for water to enter the wetland, it is also harder for water to leave the wetland, and so these wetlands will hold more water as the flood pulse recedes. In scenario 2, the natural levees have a gap in them, and so the water has to rise much less and will be able to easily flow into and out of this wetland. In scenario 3, beavers have built a dam across the gap in the levee and so have created an intermediate scenario, with water not having to rise as high to enter the wetland, but also being retained within the wetland by the beaver dam as the flood pulse recedes.

2.4 Beaver dam analogues (BDAs)

Beaver dam analogues are human-built structures that mimic or reinforce natural beaver dams. They try to replicate the features of natural beaver dams, and so are semi-porous, temporary features, built with natural local materials including sediment, wooden posts, and branches. They are constructed either in a location where there used to be a beaver dam (these are the locations CWSP is targeting in our work) or locations where it would be plausible that a beaver would build a dam. They aim to mimic the effects of natural beaver dams as well, by retaining water within a system, slowing down its progress across the landscape, and thus hopefully resulting in positive impacts to habitat complexity, biodiversity, and the other myriad impacts of beaver dams discussed above.

While there is extensive research on the impacts of beaver dams on wetlands (see above), there is far less research available on the impacts of Beaver Dam Analogues (BDAs), particularly on longer term impacts on biodiversity. As a small-scale, low-tech way to restore streams and wetlands they are currently very popular as a restoration technique; however, we are not certain if they will mimic natural beaver dams (Lautz *et al*., 2019). Munir and Westbrook (2021) found that in small mountains streams they did

mimic the impacts of natural beaver dams in raising the water table and retaining water on the landscape, but Wolf and Hammill (2023) found that BDAs did not support the same diversity of amphibians as natural beaver dams, perhaps because the natural dams were far older than the BDAs and biodiversity does not respond instantly. Thus, monitoring wetlands before and after the installation of BDAs is clearly essential to study their short- and long-term effects.

We hope that BDAs will, much like natural beaver dams, increase the amount of water retained in wetlands, particularly over the winter, so that open water habitat is available for migratory waterbirds when they migrate through the Columbia Valley before the Columbia River flood pulse begins. In order to determine whether BDAs are a feasible and effective way to increase wetland water retention and thus make different habitats available, we are trialing BDA installation in wetlands within the Columbia Wetlands complex (Figure 5).

Figure 5: Beaver dam analogue built by CWSP in Site 38 in fall 2021. Photograph from early May 2023.

3. Findings and Analyses

We have been studying 38 individual wetlands within the Columbia Wetlands complex between Invermere and Parson since 2020 (Figure 6; Appendix 1). Each year we collect a variety of data from these wetlands using both fieldwork and remote sensing methods. We use water level loggers to collect water level data between May and October and measure water quality several times during that same period and have collected sediment samples from all the wetlands. We have surveyed levee gaps and beaver dams across all the wetlands. In 16 of the wetlands, we have conducted more intense monitoring, including migratory waterbird surveys in spring and fall 2021, 2022, and 2023, and submerged aquatic vegetation (SAV) surveys in August 2021 and 2023. A more detailed description of our fieldwork methods and a full list of site coordinates can be found in Appendix 1 and 2.

Collecting data over multiple years allows us to build a better understanding of this complex system, as it means we can compare between years with different conditions, look at the differences in wetlands pre- and post- restoration, and perhaps even begin to predict and document the impacts of climate change.

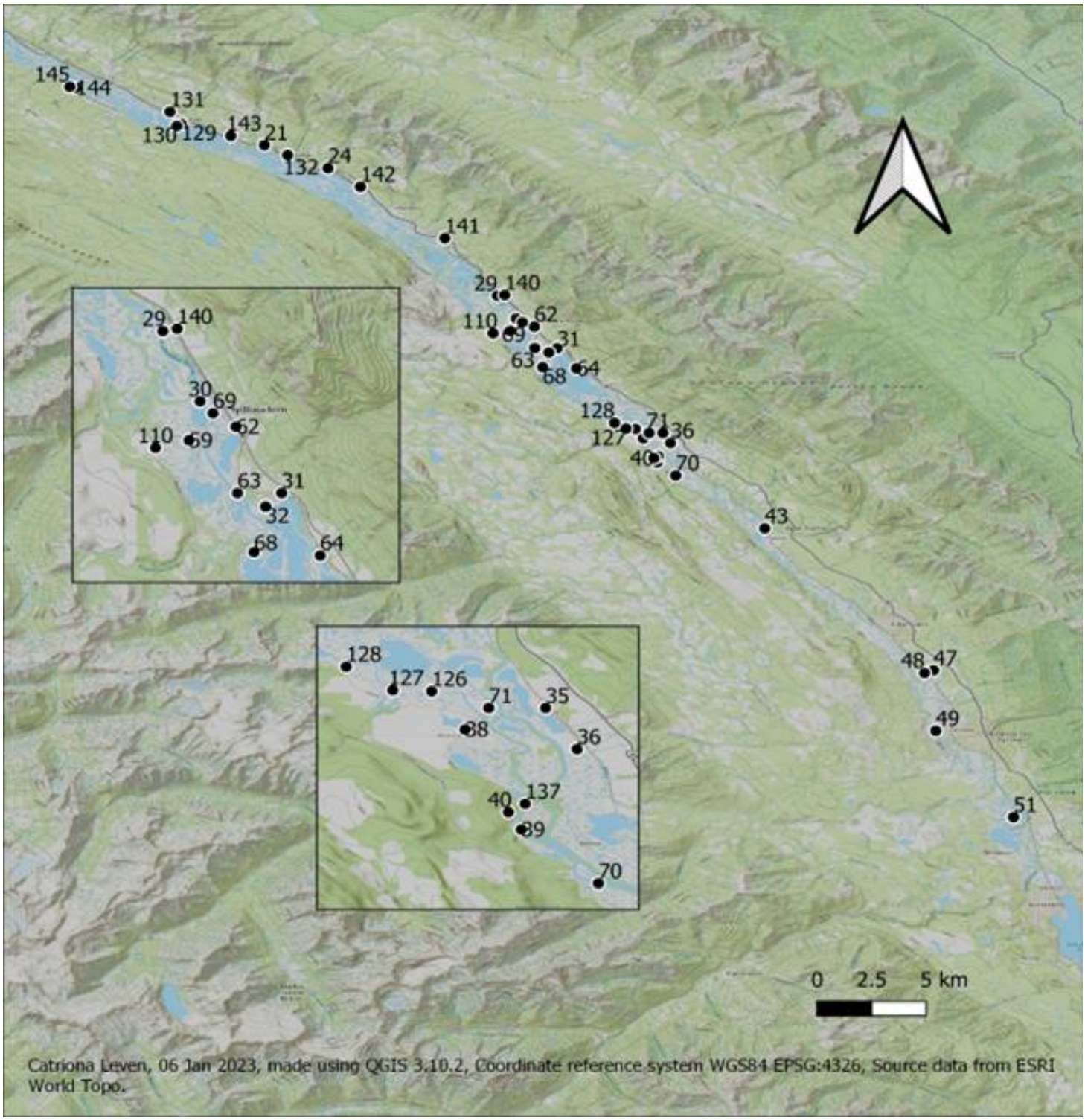


Figure 6: Map of study sites in the Columbia Wetlands.

3.1 Hydrologic classification of the Columbia Wetlands

Our first goal in understanding the Columbia Wetlands better is to identify and describe the different types of wetlands we find in the Columbia Wetlands complex. Just visually looking at the wetlands (Figure 7) there are areas of deep water, shallow water, and different vegetation types, and we are studying the hydrology and morphology of these wetlands to understand why we see these differences. We are also studying the role of beaver dams in these wetlands, as they are an important shaper of many North American wetlands, and we want to better understand their role in shaping the Columbia Wetlands and their contributions to the different wetlands that we see.

Figure 7: A view of the Columbia Wetlands looking north from Brisco in May 2022. Two channels of the Columbia River can be seen, as well as different wetlands.

3.1.1 Hydrological classification of the Columbia Wetland

Using a variety of analysis methods (see Appendix 2 for a detailed description of methods), we have determined that there are three main groups of wetlands within the Columbia Wetlands complex, which can be described along a gradient of connectivity to the Columbia River. These groups are Most Connected, Partially Connected, and Least Connected. In some years, there is high variation within the Partially Connected group, allowing for two sub-groups of Partially Connected – Bigger Gaps and Partially Connected – Smaller Gaps to be distinguished (Figure 8). These analyses are based on 2020, 2021, and 2022 data, as 2023 data were not received in time to do the complete hydrological analyses. 2023 data are discussed in Section 3.1.2.

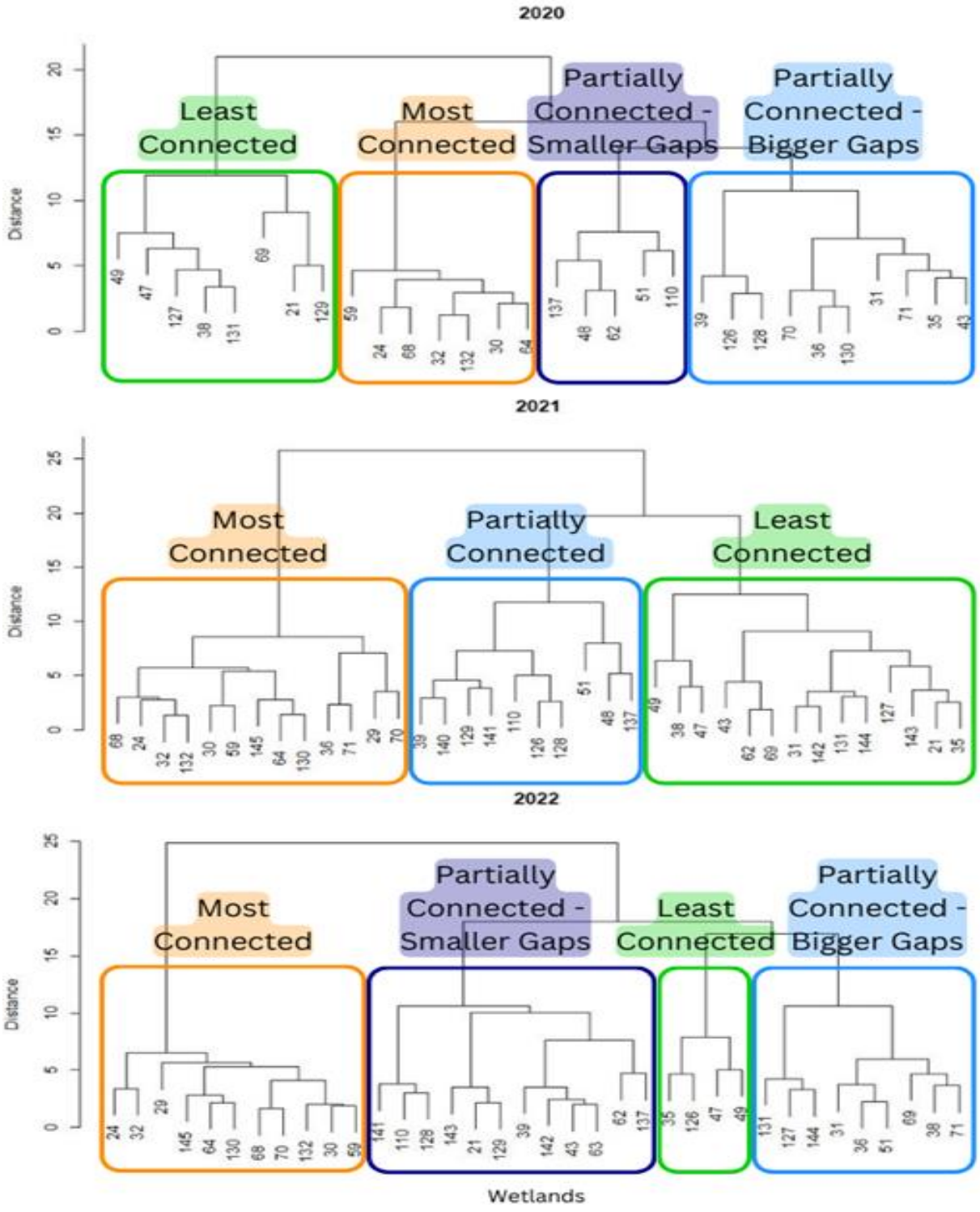


Figure 8: Hierarchical cluster analysis using Euclidean Distance and Ward D2 linkage; boxes indicate most parsimonious number of clusters as indicated by nbclust package, group characteristics are described in Table 9. In 2020, n = 30; 2021, n = 37; and 2022, n = 36.

These wetland groups are determined based on hydrological characteristics and can be partly explained by morphological characteristics such as gaps in the natural levees and the presence or absence of beaver dams, which is further discussed in section 3.2. Table 1 summarises these hydrological and morphological characteristics for each wetland group. The full hydrological variables data can be found in Appendices 3 and 4.

Table 1: Wetland groups and their associated hydrological and morphological (levee gap and beaver dam) characteristics.

Group		**Hydrological Characteristics**	**Morphological Characteristics**
Most Connected		Shallow in May and October; large increase in water depth with flood pulse; immediate response to river rise and fall, including during early peak	Gaps in natural levee present, beaver dams not present in all gaps; often large wetlands with large gaps
Partially Connected	**Bigger Gaps**	Less shallow in May and October; response to flood pulse less immediate and less amplitude than Most Connected	Gaps in natural levee present but beaver dams present in most gaps; beaver dams not as high as the levee; beaver dams more porous; gaps smaller than Most Connected
	Smaller Gaps	Less water in May and October than Bigger Gaps or Least Connected, but more than Most Connected. Slower rise than Bigger Gaps group; less water in May and October than Bigger Gaps or Least Connected, but more than Most Connected	Gaps in natural levee present but beaver dams present in all gaps or no gaps in levee present; beaver dams equal to or higher than the levee; beaver dams less porous
Least Connected		Deep in May and October; delayed rise in water depth; less response to early increase in river	No gaps in natural levee or beaver dams present in all gaps that are equal to or higher than the levee; beaver dams less porous

These wetlands are visibly different hydrologically, as can be seen in Figure 9. In these hydrographs, we can see that the Most Connected wetlands have low water depths in the spring and the fall, pre- and post- flood pulse, and are clearly not holding much water when the river is low. They rise very quickly and show a 2m increase in water with the flood pulse. The Least Connected group, in contrast, has the most stable water levels of all the groups, consistently begins and ends the season at a depth of 1.5m, and increases only 1m with the flood pulse.

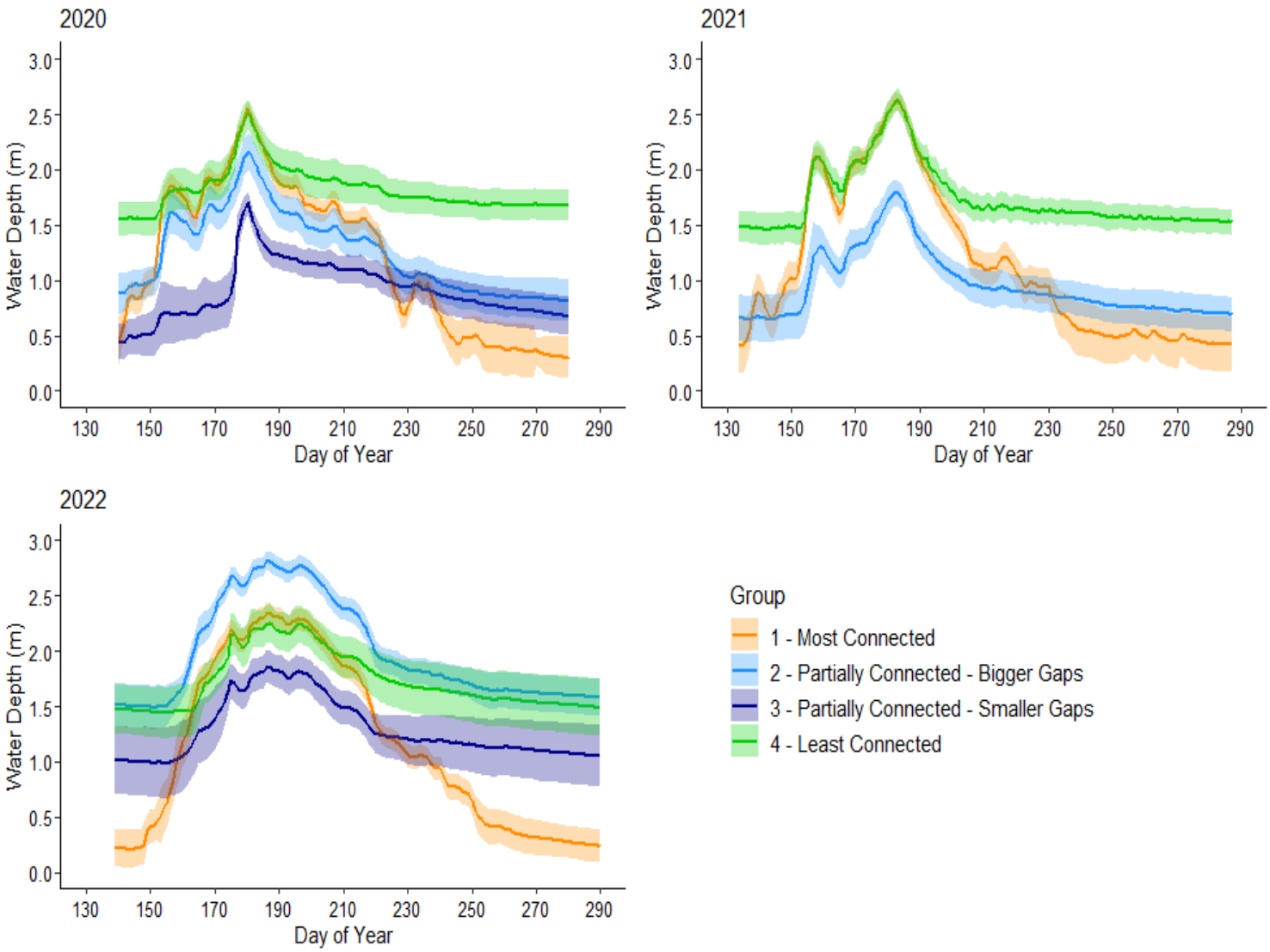


Figure 9: Mean hydrographs of each wetland group in each year. Error bars are standard error; in 2020, n = 30; in 2021, n = 37; and in 2022, n = 36. In 2021, only three groups were identified so light blue represents all Partially Connected wetlands.

The Partially Connected group, as its name suggests, is midway between these two groups, with deeper water in spring and fall than the Most Connected group and a more delayed rise in response to the flood pulse. The Partially Connected – Smaller Gaps shows a later rise than the Partially Connected – Bigger Gaps, due to large beaver dams and smaller (or no) gaps slowing the entry of water to these wetlands, resulting in the river having to overtop the levee to enter the wetlands within this group (further discussed in section 3.1). The Partially Connected groups show the most variation between years, as these groups have the most going on, with the interaction between the flood pulse and the beaver dams across the are affected by the most variables. As well as timing and magnitude of flood pulse, which affects all the wetlands, the Partially Connected wetlands are also affected by the interactions between the flood pulse and the size, condition, and location of beaver dams.

This variability in the wetlands reflects the variability in the Columbia River and its flood pulse. Every year, both the amount and timing of water entering the river varies. This section of the Columbia River is primarily driven by snowmelt and rainfall (Makaske *et al.,* 2009), so winter snowpack and spring temperatures have a large impact on these two factors. As can be seen in Figure 10, the variation in the Columbia River is reflected in the variation in the wetlands. In 2022, we saw a long period of high water in our wetlands, and we also saw a long period of high water in the Columbia River, with a slow decline of water.

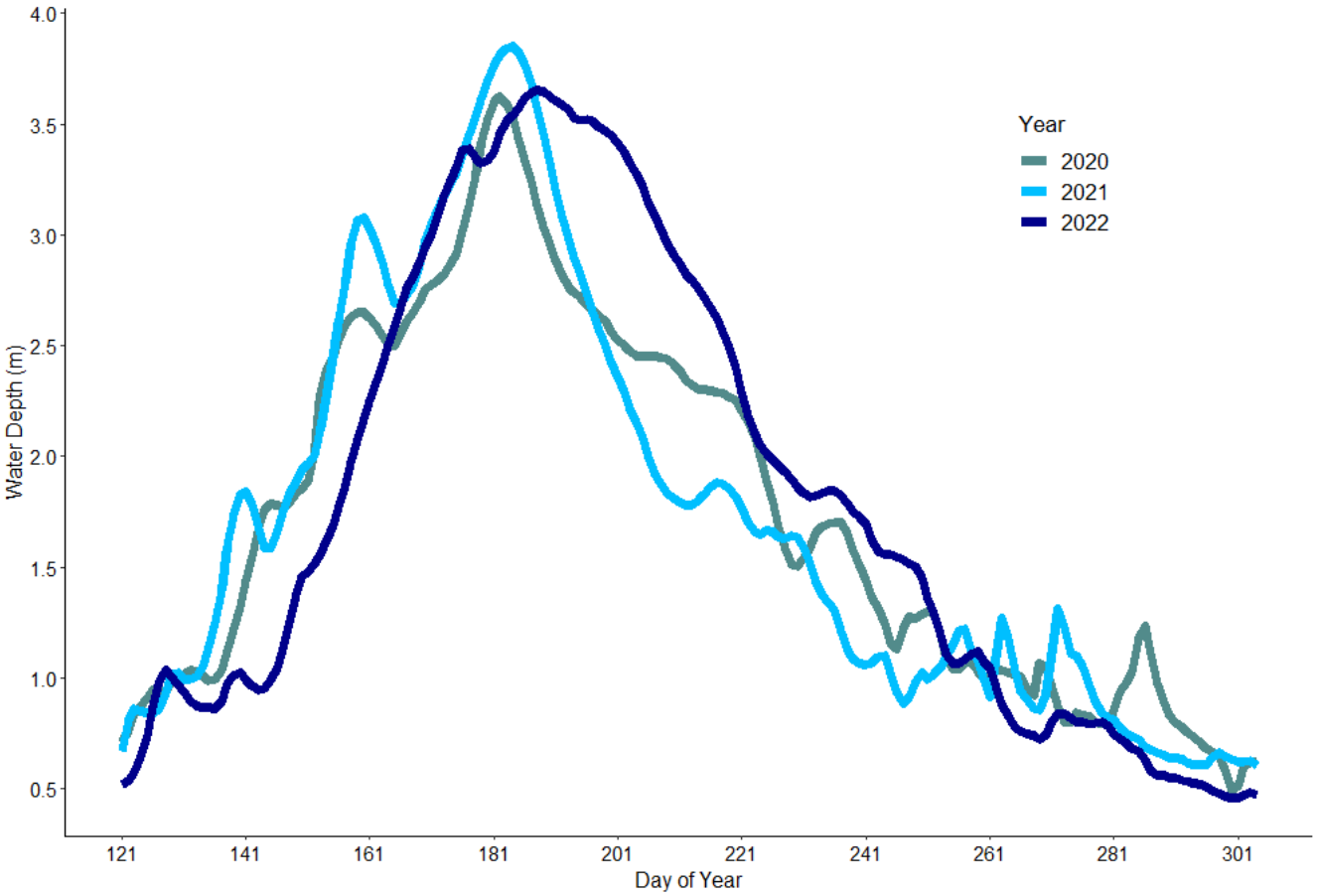


Figure 10: Water depth in the Columbia River at Nicholson from Day 121 (May 1st) to Day 304 (October 31st) in 2020, 2021, and 2022. 2023 data are not available yet.

While we have recorded the water depth in the Columbia River at Brisco using our water level loggers, we find that the pattern of the flood pulse is very similar to that seen at the ECCC station in Nicholson, downriver of our study area (Figure 11). Thus, we are using that data as the Nicholson dataset is much longer, with water depth data available from 1984 and discharge data available from 1903, which allows us to look at longer term trends in the Columbia River than if we just used the data we have collected ourselves.

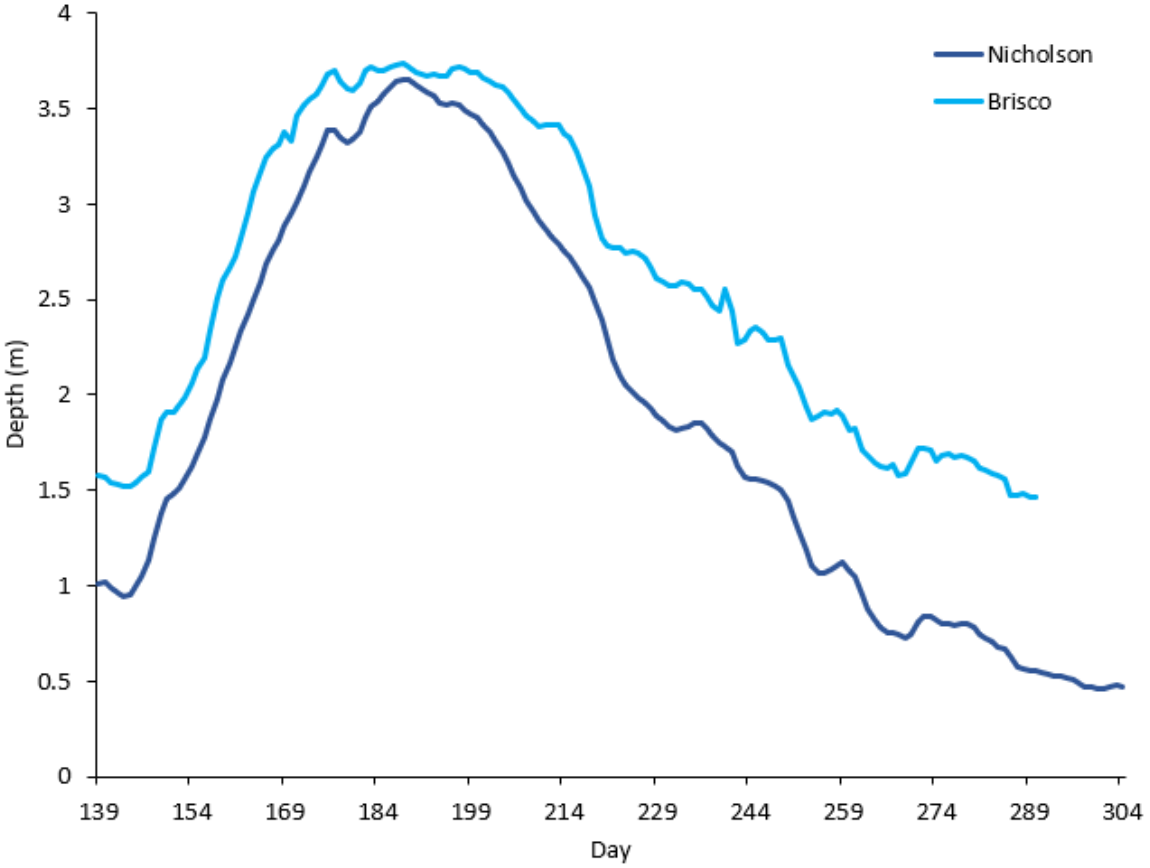


Figure 11: Water depth in the Columbia River at the ECCC Station in Nicholson and our recorded data from Brisco between Day 139 (May 19th) and Day 304 (October 31st) in 2022.

The wetland groups in 2022 are quite different from those in 2020 and 2021, due to the large difference in the Columbia River flood pulse in 2022. In 2022, the Least Connected group was the smallest group, containing only four wetlands (11%), as compared to 8 (27%) in 2020 and 14 (38% in 2021). We believe this is because 2022 was a year with a long flood pulse (as can be seen both in the hydrographs for the wetlands (Figure 9) and the hydrographs for the Columbia River (Figure 10)). The declining limb of the hydrograph began later and declined slower than in other years, and so less wetlands behaved in a Least Connected fashion, and more wetlands displayed Partially Connected characteristics. Thus, less of the wetlands displayed the characteristics of Least Connected wetlands due to this long flood pulse allowing for all the wetlands to be fully connected to the Columbia River for a relatively long period of time, even those without open levee gaps.

In 2022, the Partially Connected - Bigger Gaps showed the deepest mean depths overall, due to the deep points in these wetlands being emphasised by the long flood pulse. The deepest single depth

recorded across all wetlands in 2022 was 3.27m in Site 38, a Partially Connected - Bigger Gaps wetland, on July 7th 2022 (Day 188), while the deepest depth recorded in a Most Connected Wetland was 2.80m in Site 21. This suggests that Partially Connected and Least Connected wetlands are more topographically variable, with a mix of shallow and deep sections, due to the lack of the high scour experienced in the Most Connected Wetlands.

Four groups can be identified in 2020 and 2022, with the Partially Connected group showing variation within it. However, in 2021 only one more encompassing Partially Connected group can be detected. In our dataset, 2020 is the year with the lowest and shortest flood pulse, while 2022 is the year with the highest and longest flood pulse; 2021, is somewhere in the middle. We therefore hypothesise that in more average years such as 2021, only three groups can be distinguished, however in years where the flood pulse is larger, or smaller, or longer, or perhaps earlier or later, then the differences within the Partially Connected group become apparent.

It will be very interesting to repeat these analyses on the 2023 data (unfortunately this data was not ready in time to fully analyse for this report), as 2023 was a very dry year, with a low, short, and very early flood pulse. Based on this hypothesis, in 2023 we should also be able to detect four groups.

With only four years of data available – and only three fully analyses for this report – it is difficult to comment on long term trends. While we can look at the water depths recorded at Nicholson by ECCC as an indication of long term trends, we do not have that same data available for the wetlands themselves. There is clear evidence of much variability between years, with each of our four years being distinct from the others. Thus, while we can begin to predict how our identified wetland groups will behave in wetter or drier years and years with shorter or longer flood pulses, more years of data are needed to establish and predict trends. However, with the knowledge that the Columbia Wetlands are predicted to become warmer and drier going forward (Utzig, 2021), perhaps 2023 is an indication of what more future years will look like.

However, despite this dynamic system, we can still see consistency in our identified wetland groups between years. Between 2020 and 2021, 70% of wetlands remained in the same group, while between 2021 and 2022, 64% of wetlands remained in the same group, despite 2022 being unusual hydrologically due to the prolonged flood pulse and with only four wetlands showing Least Connected characteristics, as opposed to 14 in 2021. In a direct comparison between wetland groups in 2020 and 2022, 57% of wetlands remained in the same groups (Table 2).

This consistency allows for Modal Groups to be determined, with 35 wetlands either not changing groups between years or being in the same group for two of three years (modal groups were assigned based on 2020 to 2022 data, as 2023 data were not received in time to include in this analysis). These groups are an average group for each wetland, and using these modal groups for further analysis reduces the variability caused by variation across years. For consistency in identifying these Modal Groups we used the broader category of Partially Connected rather than Partially Connected – Smaller Gaps or Partially Connected – Bigger Gaps.

Table 2: Wetland groups for each wetland for 2020, 2021, and 2022, and the Modal Group where possible.

Wetland	2020 Group	2021 Group	2022 Group	Modal Group
21	4 - Least Connected	3 - Least Connected	3 - Partially Connected - Smaller Gaps	3 - Least Connected
24	1 - Most Connected	1 - Most Connected	1 - Most Connected	1 - Most Connected
29	ND	1 - Most Connected	1 - Most Connected	1 - Most Connected
30	1 - Most Connected	1 - Most Connected	1 - Most Connected	1 - Most Connected
31	2 - Partially Connected - Bigger Gaps	3 - Least Connected	2 - Partially Connected - Bigger Gaps	2 - Partially Connected
32	1 - Most Connected	1 - Most Connected	1 - Most Connected	1 - Most Connected
35	2 - Partially Connected - Bigger Gaps	3 - Least Connected	4 - Least Connected	3 - Least Connected
36	2 - Partially Connected - Bigger Gaps	1 - Most Connected	2 - Partially Connected - Bigger Gaps	2 - Partially Connected
38	4 - Least Connected	3 - Least Connected	2 - Partially Connected - Bigger Gaps	3 - Least Connected
39	2 - Partially Connected - Bigger Gaps	2 - Partially Connected	3 - Partially Connected - Smaller Gaps	2 - Partially Connected
43	2 - Partially Connected - Bigger Gaps	3 - Least Connected	3 - Partially Connected - Smaller Gaps	2 - Partially Connected
47	4 - Least Connected	3 - Least Connected	4 - Least Connected	3 - Least Connected
48	3 - Partially Connected - Smaller Gaps	2 - Partially Connected	ND	2 - Partially Connected
49	4 - Least Connected	3 - Least Connected	4 - Least Connected	3 - Least Connected
51	3 - Partially Connected - Smaller Gaps	2 - Partially Connected	2 - Partially Connected - Bigger Gaps	2 - Partially Connected
59	1 - Most Connected	1 - Most Connected	1 - Most Connected	1 - Most Connected
62	3 - Partially Connected - Smaller Gaps	3 - Least Connected	3 - Partially Connected - Smaller Gaps	2 - Partially Connected
63	ND	ND	3 - Partially Connected - Smaller Gaps	2 - Partially Connected
64	1 - Most Connected	1 - Most Connected	1 - Most Connected	1 - Most Connected
68	1 - Most Connected	1 - Most Connected	1 - Most Connected	1 - Most Connected
69	4 - Least Connected	3 - Least Connected	2 - Partially Connected - Bigger Gaps	3 - Least Connected
70	2 - Partially Connected - Bigger Gaps	1 - Most Connected	1 - Most Connected	1 - Most Connected
71	2 - Partially Connected - Bigger Gaps	1 - Most Connected	2 - Partially Connected - Bigger Gaps	2 - Partially Connected
110	3 - Partially Connected - Smaller Gaps	2 - Partially Connected	3 - Partially Connected - Smaller Gaps	2 - Partially Connected
126	2 - Partially Connected - Bigger Gaps	2 - Partially Connected	4 - Least Connected	2 - Partially Connected
127	4 - Least Connected	3 - Least Connected	2 - Partially Connected - Bigger Gaps	3 - Least Connected
128	2 - Partially Connected - Bigger Gaps	2 - Partially Connected	3 - Partially Connected - Smaller Gaps	2 - Partially Connected
129	4 - Least Connected	2 - Partially Connected	3 - Partially Connected - Smaller Gaps	2 - Partially Connected
130	2 - Partially Connected - Bigger Gaps	1 - Most Connected	1 - Most Connected	1 - Most Connected

Wetland	2020 Group	2021 Group	2022 Group	Modal Group
131	4 - Least Connected	3 - Least Connected	2 - Partially Connected - Bigger Gaps	3 - Least Connected
132	1 - Most Connected	1 - Most Connected	1 - Most Connected	1 - Most Connected
137	3 - Partially Connected - Smaller Gaps	2 - Partially Connected	3 - Partially Connected - Smaller Gaps	2 - Partially Connected
140	ND	2 - Partially Connected	ND	2 - Partially Connected
141	ND	2 - Partially Connected	3 - Partially Connected - Smaller Gaps	2 - Partially Connected
142	ND	3 - Least Connected	3 - Partially Connected - Smaller Gaps	NA
143	ND	3 - Least Connected	3 - Partially Connected - Smaller Gaps	NA
144	ND	3 - Least Connected	2 - Partially Connected - Bigger Gaps	NA
145	ND	1 - Most Connected	1 - Most Connected	1 - Most Connected

It is also interesting to consider the distribution of wetlands among the groups. Figure 12 compares the number of wetlands and the area of wetlands in each of the modal groups. Despite the Partially Connected group containing the most wetlands (16 of 35, or 46%), the Most Connected group contains the biggest area of wetland, with 11.92km^2 or 51% of the studied wetland area being in this group. The Least Connected group has the smallest amount of wetlands both by count (8 of 36, or 23%) and by area (3.12km^2 or only 13%).

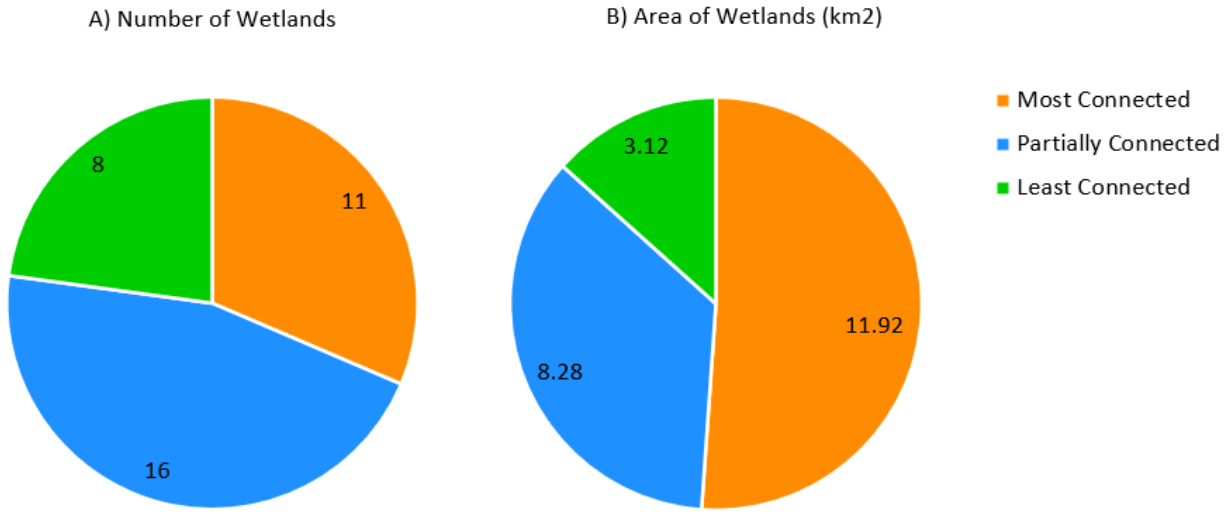


Figure 12: A) Number of Wetlands, and B) Area of Wetlands (km2) in each of the modal wetland groups (Most Connected, Partially Connected, and Least Connected).

While our study wetlands comprise just over 10% of the entire Columbia Wetlands complex (our study wetlands are 23.32km^2 of the total 200km^2), we believe they are a good representation of the whole area. This suggests that approximately 50% of the Columbia Wetlands are Most Connected wetlands, rising and falling rapidly as the river does, and not holding water when the river is low.

3.1.2 2023 hydrological data

We continued to collect hydrology data in 2023 - our fourth year of data - and can use our previous work to look at it. We are working in a complicated system, with a suite of study sites that are all unique, as can be seen in Figure 13, where the water depth throughout the year is shown for each individual wetland, grouped by the Modal Group. Within each wetland group there is much variation, with the difference between the maximum and minimum depth (or the total change in amplitude through the season) in the Least Connected group ranging from a difference of only 0.22m in Site 49 to a difference of 1.15m in Site 38.

However, we can also see clear differences between the groups even with this variation. The Most Connected wetlands begin and end the season at low water depths, some of them having no water in them at all, while the Least and Partially Connected groups are deeper in both the spring and the fall. We can also see how quickly water in the Most Connected wetlands rises and falls, with all the Most Connected wetlands rapidly increasing in water depth immediately after we started logging water depths in the first week of May and decreasing rapidly from Day 170 onwards.

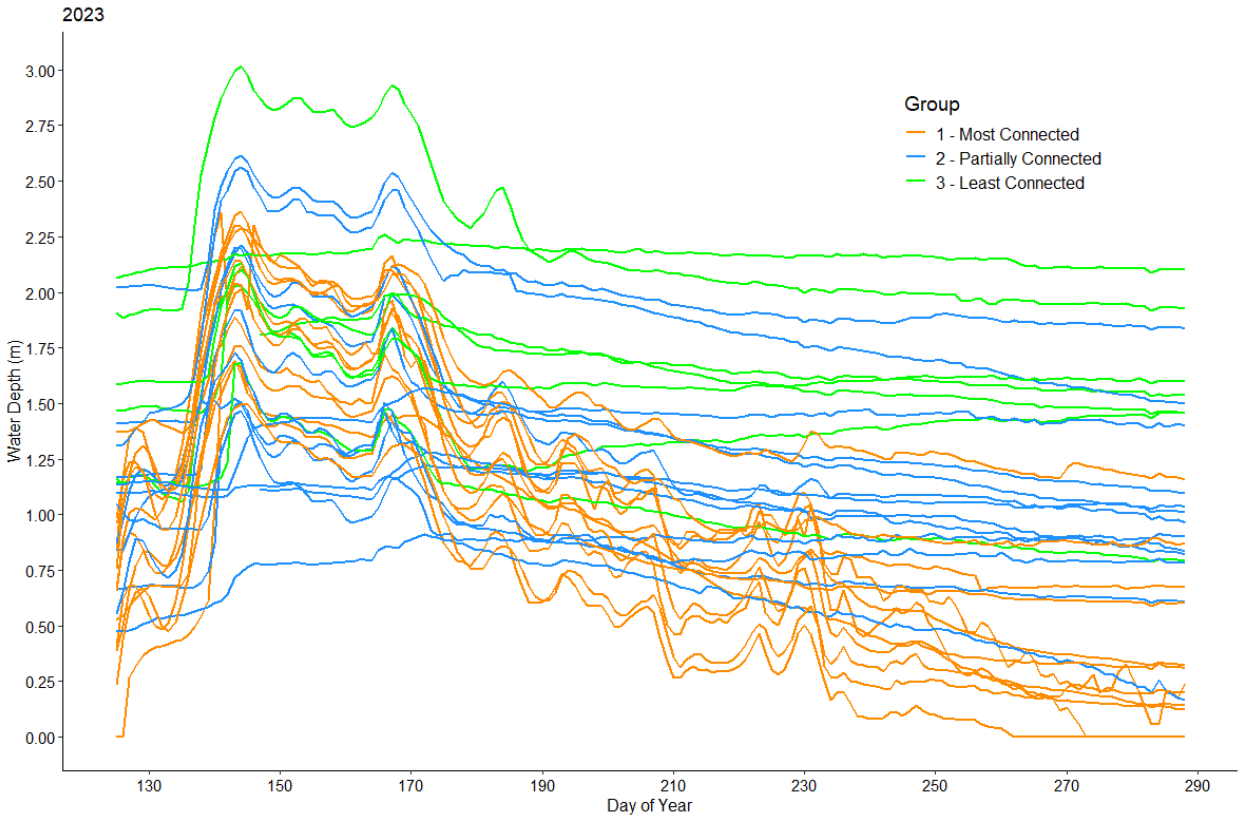


Figure 13: Individual hydrographs for all wetlands in 2023 (n = 35), coloured by Modal Group.

Looking at the mean depths of each wetland group through the year (Figure 14), we can see that the three groups are distinct, particularly towards the latter half of the data collection period. The Least Connected wetlands are consistently deeper than the other two groups, beginning and ending at approximately 1.5m deep, and show the smallest amplitude. The Partially Connected wetlands begin and end at a mean of 1m in depth and have a similar amplitude to the Least Connected group. The Most Connected wetlands show the greatest amplitude, and begin and end at the lowest depth, ending at a mean of 0.5m.

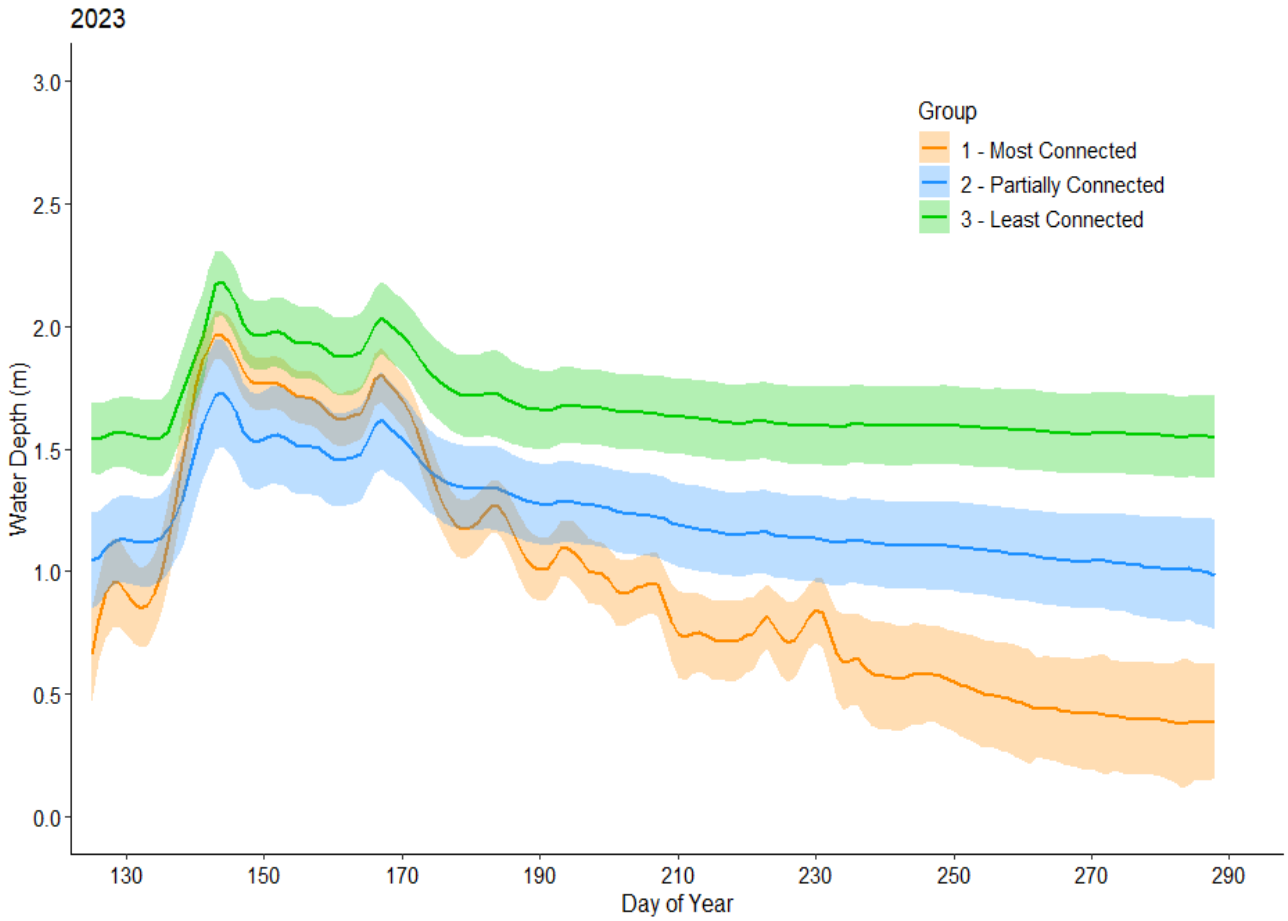


Figure 14: Mean hydrographs from May to October 2023 of Modal Groups of all wetlands (n = 35). Error bars are standard error.

2023 was a low water year compared to our previous three study years, as can be seen in Figure 15. In all three other years, the mean maximum depth is over 2.5m whereas in 2023, the mean maximum depth is between 2m and 2.5m. The flood pulse was also a month earlier in 2023 than the other three years, with the deepest day in 2023 being day 144 (or May 24th), whereas in all other years it is Day 180 or later (Day 180 in 2020, Day 183 in 2021 and Day 188 in 2022). Interestingly, this also suggests a link between size of flood pulse and timing of flood pulse, with later flood pulses also being larger.

With the low water levels, it is interesting that the Least Connected wetlands begin and end at a very similar depth (around 1.5m) as they do in all the other years, thus showing the least variation between years. This reinforces their classification as Least Connected wetlands, showing that they are in fact the least impacted by the Columbia River. While they do still show a response to the flood pulse, it is very likely that the Least Connected wetlands are strongly influenced by other sources of water, such as springs arising directly in the wetland, groundwater flow underground, or creeks flowing into the wetland.

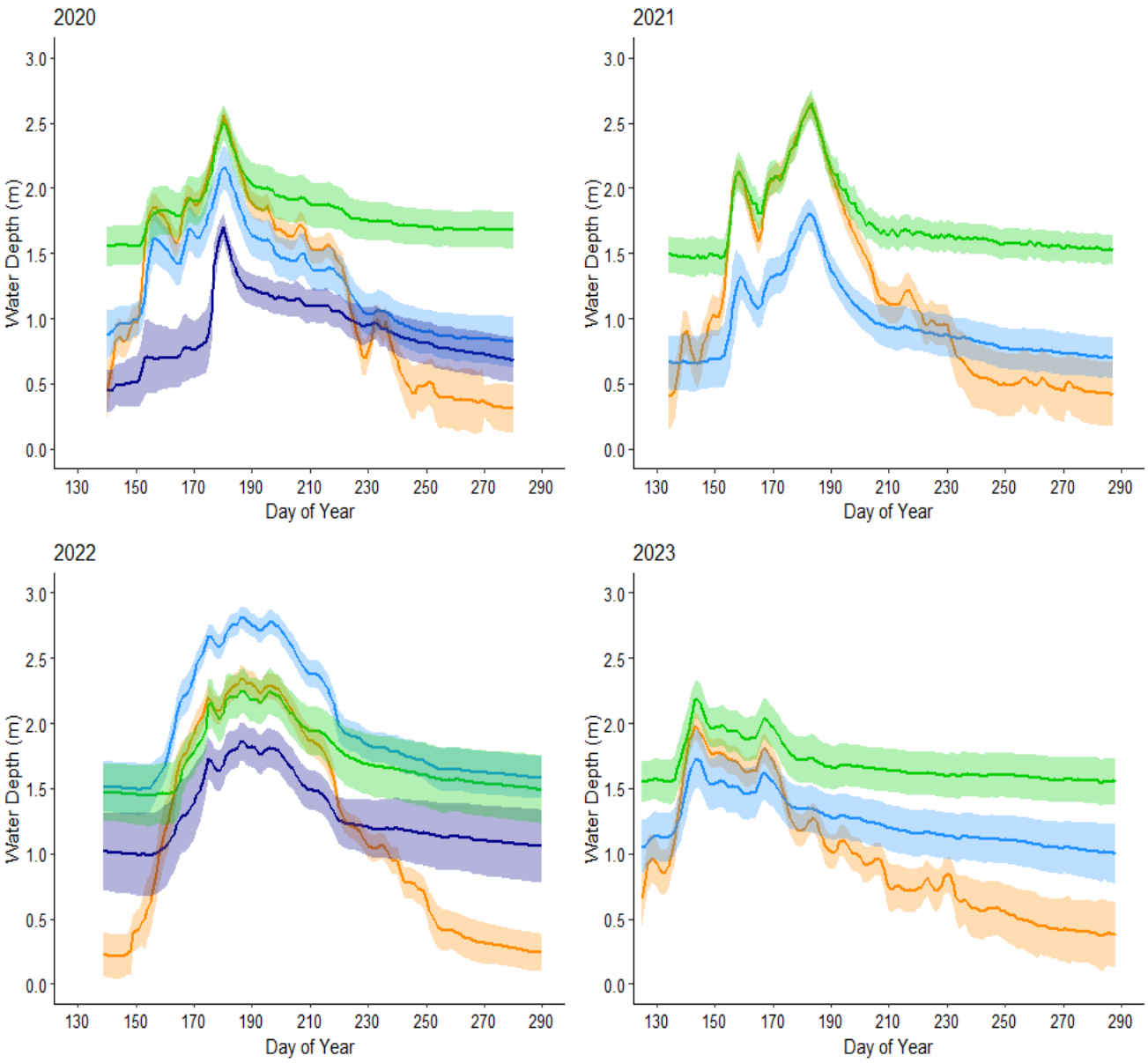


Figure 15: Mean hydrographs of all wetlands in all four study years, with standard error error bars. Groups in 2023 are Modal Groups as data were not ready in time to separately analyse this year.

3.2 The role of beavers in different wetland groups

We located 205 dams within 30m of our 38 study wetland using aerial imagery (Appendix 5 and 6). On visiting the wetlands and inspecting these dams, many of them were not directly impacting the study wetlands (but were impacting other wetlands nearby) or were old dams that were no longer holding water but were still visible both on site and on imagery. For a dam to be considered to have been directly impacting a wetland it had to be holding water within the wetland perimeter. Some of the dams directly impacting a wetland were not within the wetland itself, but had been built by beavers across back channels of the Columbia River and were sometimes holding water into multiple wetlands, including those we are not studying.

26 dams were directly impacting one of the wetlands, and 21 wetlands were directly impacted by one or more dams (Appendix 6 and 7). Of the remaining 17 wetlands, 10 had levee gaps that were undammed by beavers and seven were entirely enclosed by natural levees without any gaps. These dams varied greatly in size. The longest dam was recorded in Site 49 at 150m long, and the shortest dam was in Site 39 and was only 1.7m long. Five wetlands had dams over 100m long, and eight wetlands had dams that were less than 10m long. The maximum number of dams in a wetland was three, however four wetlands had natural levees that were reinforced by beaver activity, with small low patches in the levee showing signs of the addition of mud and sticks. We didn't count these as full dams, but we did measure how much of the wetland perimeter was beaver reinforced in this way. The tallest dam we found was at Site 21 and was 1.83m high. The widest dam was in Site 62 and was 6.68m wide. We found active dams in 16 wetlands, with signs of recent beaver maintenance such as new sticks or new mud being added to the structure (Figure 16).

Figure 16: Two beaver dams encountered in the field. On the left, the 1.83m tall beaver dam at Site 21, and on the right a beaver dam with evidence of fresh mud and sticks having been recently added.

Using Random Forest Modeling (See appendix 2 for full analysis details), we determined that the presence of natural levee gaps and beaver dams predict on average 60% of the variation in hydrological groups, with the presence of levee gaps and beaver dams being strongly correlated with the different wetland groups (Figure 17 A). Ten of 11 Most Connected wetlands have levees with open gaps, allowing water to easily flow in and out of these wetlands, responding rapidly to the river as it rises and falls. Of the 16 Partially Connected wetlands, nine have levee gaps that are dammed by beavers while four have levees without gaps in them at all, thus resulting in water being retained within these wetlands even as the river falls. Three wetlands in the Partially Connected group do have open levee gaps, which indicates that there are other sources of water to these wetlands, perhaps springs or creeks. Of the eight Least Connected wetlands, six have beaver dams and two have no levee gaps.

While the number of wetlands with beaver dams in them is high, the area of wetlands impacted by beaver dams is smaller (Figure 17 B), due to Most Connected wetlands often being larger. Almost 12km^2 of our total 23.32km^2 study area is Most Connected, with all but 0.08km^2 of that being undammed wetlands with large levee gaps. Our two biggest wetlands (Site 70 and 130) are both Most Connected wetlands with open levee gaps and comprise 6km^2 of our study area. Meanwhile, our biggest wetland that has beaver dams in it is Site 43, which is only 0.75km^2.

Beaver cannot impact the big wetlands within the Columbia Wetlands complex, the gaps are too large and the volume and force of water that passes through those gaps is too much for the beavers to contend with. They can successfully dam smaller gaps in smaller wetlands, or back channels where the flow is not strong, but they cannot dam either the main channels of the Columbia River or large levee gaps. Thus, while the impact of beavers is large, it is also restricted; there are some places where beavers will never be able to build dams, and so these wetlands will always be Most Connected. This is not a bad thing, as Most Connected wetlands are an important part of the Columbia Wetlands system, and their conservation is important. In our work, we focus on the Partially and Least connected wetlands as these are the smaller proportion of the Columbia Wetlands and the wetland groups that require active work (either by beavers or by humans) to maintain).

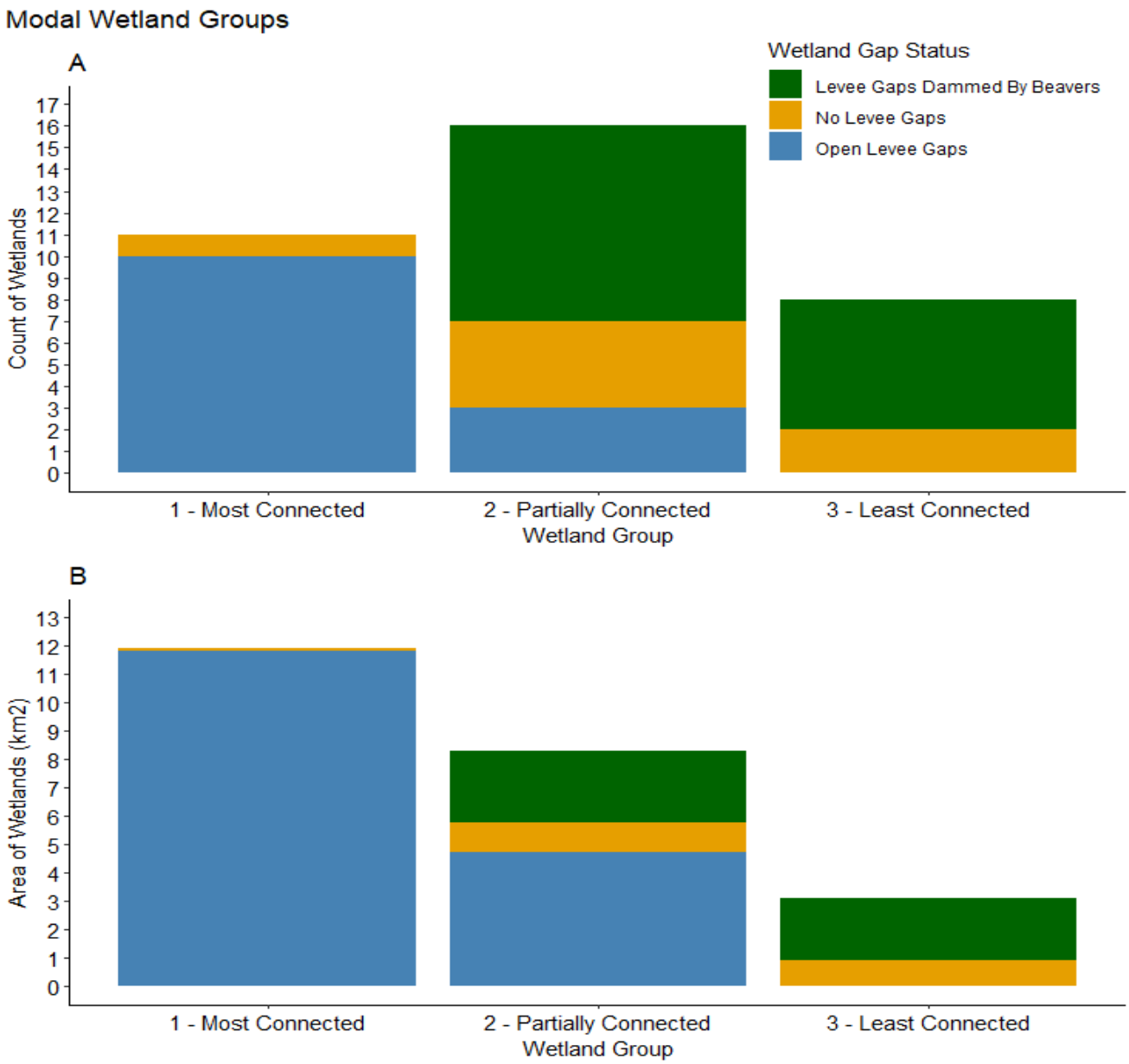


Figure 17: A) Wetlands in each of the three Modal wetland groups, and whether they have levee gaps with beaver dams, no levee gaps at all, or open levee gaps. B) The area of wetlands in each of the three modal groups and whether they have levee gaps with beaver dams, no levee gaps at all, or open levee gaps.

While we found five wetlands with beaver dams greater than 100m in length, these dams were not built directly across levee gaps or back channels of the river, but within the wetlands, often with multiple dams built in succession to withstand the force of the water. Site 49 is one such example (Figure 18). During initial fieldwork in fall 2021, we found a short actively maintained beaver dam directly across a gap adjacent to the river, and then three long (also active) beaver dams built within the wetland itself. In spring 2022 the short dam across the gap was removed by CP Rail, and the north section of this wetland drained. However, most of the wetland showed no change in water levels at all, due to the three other dams indicated in the photograph, with the northernmost long dam holding 0.95m inside the wetland. During subsequent visits to this wetland, we have not yet found the short dam rebuilt, instead the beavers seem to be relying on the other, long dams within the wetland to maintain water levels.

Figure 18: Location of three long beaver dams within Site 149, and one smaller dam built directly across a gap. As of fall 2023, the small dam is no longer present.

The size of levee gaps and beaver dams is also important. Wetlands in the Most Connected group have significantly bigger gaps and smaller dams, while those in the Partially Connected group and Least Connected group have significantly bigger dams (Figure 19).

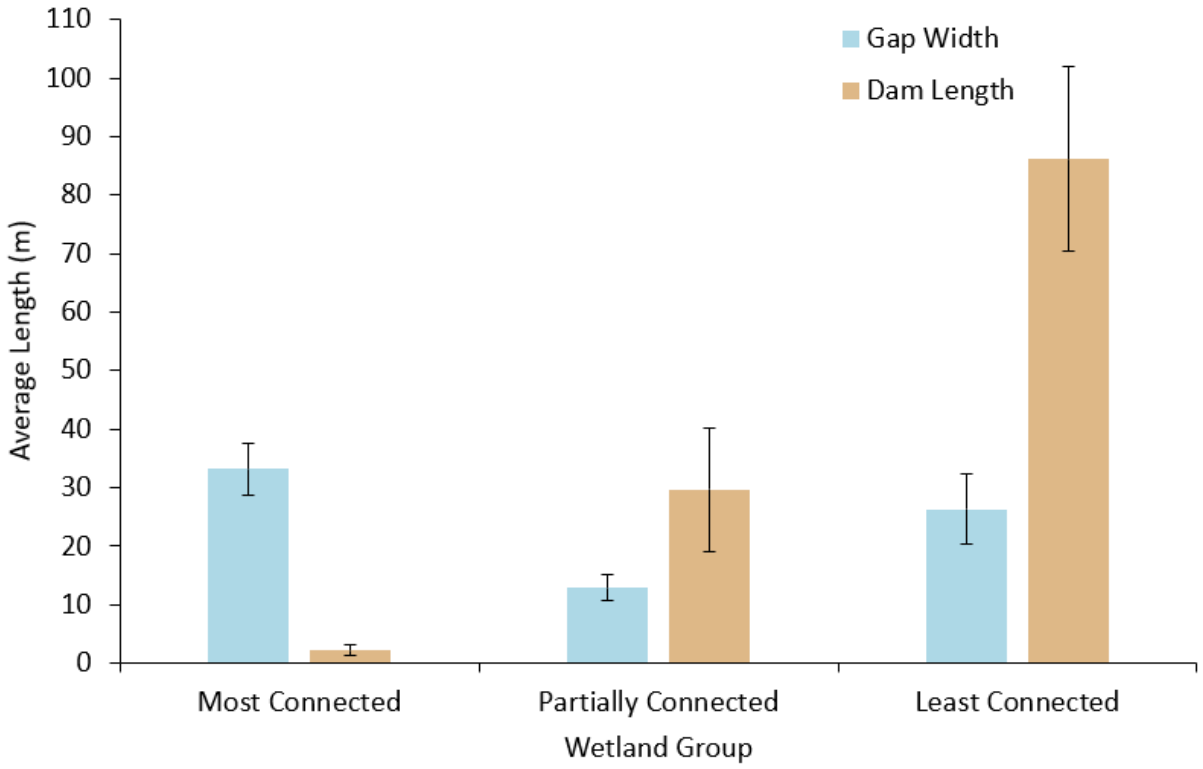


Figure 19: Mean gap width and dam length in the three Modal wetland groups. Error bars are standard error.

The remaining 40% of variation is likely due to factors that our analysis has not considered. Figure 20 is a visual schematic of the Columbia Wetlands system, with the aspects considered in the hydrological and levee gap/beaver dam analyses highlighted with black borders. Aspects that are not included in these analyses are the influence of groundwater, entering the wetlands via creeks or springs, and also precipitation, which will all impact the wetlands. In 2019, isotopic analysis showed that the relative input of river water and groundwater varied widely, ranging from 50% groundwater in Site 51 to only 5.5% groundwater in Site 70 in spring 2019. The percentage of wetland water that could be attributed to groundwater was generally higher in the fall (Remmer *et al.,* 2023), but groundwater is clearly an important input to many of these wetlands.

However, the fact that we can predict 60% of group variation despite these other factors and the complex interactions between the Columbia River and the levee gaps and beaver dams, and considering how variable the Columbia Wetlands are between years, is indicative of how important beaver dams are to this system. As in many other wetland and riverine systems, beavers are having an outsize impact for their size, greatly affecting the Columbia Wetlands complex. Beaver dams are present in 21 of our 38 study wetlands, all of which are Partially or Least Connected wetlands. Without these beaver dams, these wetlands would be Most Connected, with nothing preventing the free flow of river water in and out of the wetland. Without beaver dams, there would be less diversity in wetland types and therefore less habitat diversity and less biodiversity within the Columbia Wetlands. Beaver dams are essential for the complex, beautiful, and biodiverse wetlands that we see today in the Columbia Valley.

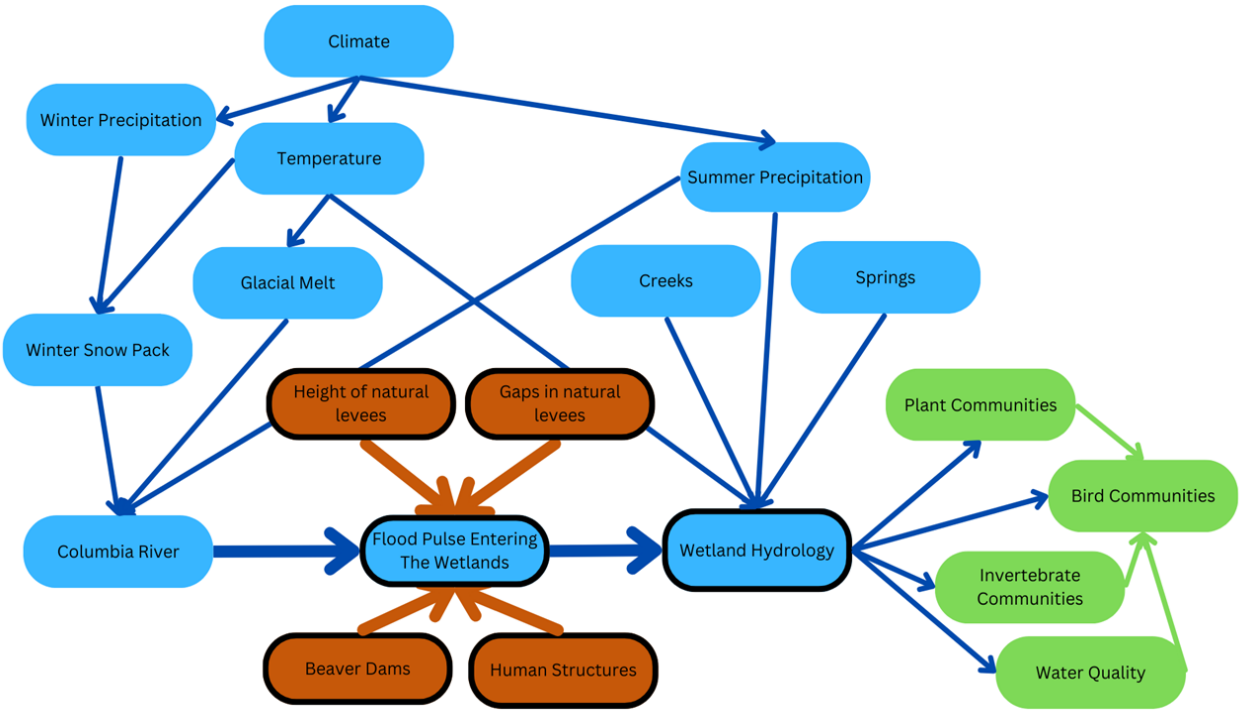


Figure 20: A visual schematic of the Columbia Wetlands complex, with hydrological input factors in blue and morphological input factors in brown and arrows showing impacts on each other. The thicker lines and black borders of boxes indicate what our hydrological and levee gap/beaver dam analysis focused on. The green boxes represent ecological outputs, and are discussed further in Section 3.3.

3.3 Ecological differences between wetland groups

As well as determining wetland groups based on hydrology and how wetland morphology and beaver dams are influencing those wetland groups, we are also studying the ecological differences between wetland groups (the green boxes in Figure 20). We want to understand how these groups differ in terms of water quality, plants, and birds in order to better understand the rich diversity of the Columbia Wetlands complex. We also want to better understand how to protect and conserve this diversity, and understanding how different wetland groups contributes to that will allow us to make better informed conservation decisions.

3.3.1 Water quality

We measured different aspects of water quality throughout the year (Appendix 9). We found the most useful measures to be specific conductance and turbidity. Specific conductance is conductivity standardised to temperature and is a measure of the capability of the water to pass an electric charge, which is a result of the ionic concentration of the water. Conductivity is an indication of water source, with water of a higher conductivity tending to be groundwater, as the passage through the earth increases the ions present in the water, while water of a lower conductivity tends to be river water which has less ions in it. Turbidity is a measure of the cloudiness of the water and indicates the amount of particles present in the water. The Columbia River is most turbid during high flow, as this is when it is carrying the most sediment.

These three variables vary through the year and by individual wetland, with some wetlands always having unusually high or low measurements. Site 35, for example, always has very high conductivity (between 700 and 1000 uS/cm), due to receiving a lot of water from high conductivity springs.

River conductivity remains similar throughout the year (Figure 21), whilst wetland conductivity varies through the year. The Most Connected wetlands are clustered around the River connectivity measurement in late May 2023, when the river was at its peak, and was flowing freely into these wetlands. In contrast, in early May, prior to the flood pulse and the river reconnecting with the wetlands, conductivity in the Most Connected wetlands is higher than the River value, indicating that at this time of year a higher proportion of water in these wetlands comes from ground water. Similarly, in the fall, when the river had dropped and is no longer fully connected to even the Most Connected wetlands, conductivity varies greatly, and we see the largest conductivity values in the fall.

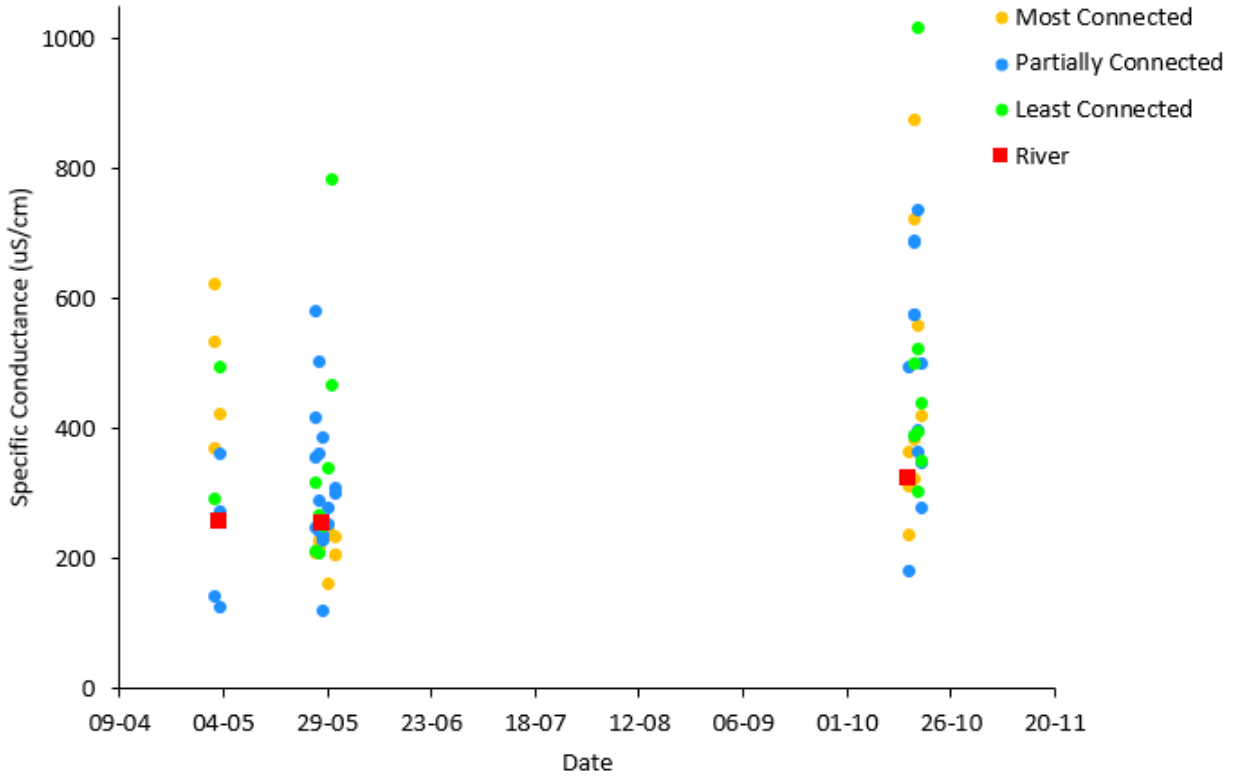


Figure 21: Specific conductance (uS/cm) of different wetland groups and of the Columbia River at the three sampling periods.

River turbidity varies greatly through the year, with the highest turbidity early in the season and during high flow, and very low turbidity in the fall (Figure 22 A). River turbidity is in fact so high in the River and Site 30 in May that it makes looking at the other data difficult, so Figure 22 B removes those two very high values. In this second figure we can see that the Most Connected wetlands have higher turbidity, particularly at the end of May during peak high water, when these wetlands were fully connected to the Columbia River, with turbidity ranging between 3 and 13 FNU. Turbidity in Partially and Least Connected wetlands is generally much lower, averaging about 1 FNU in May and 3 FNU in October.

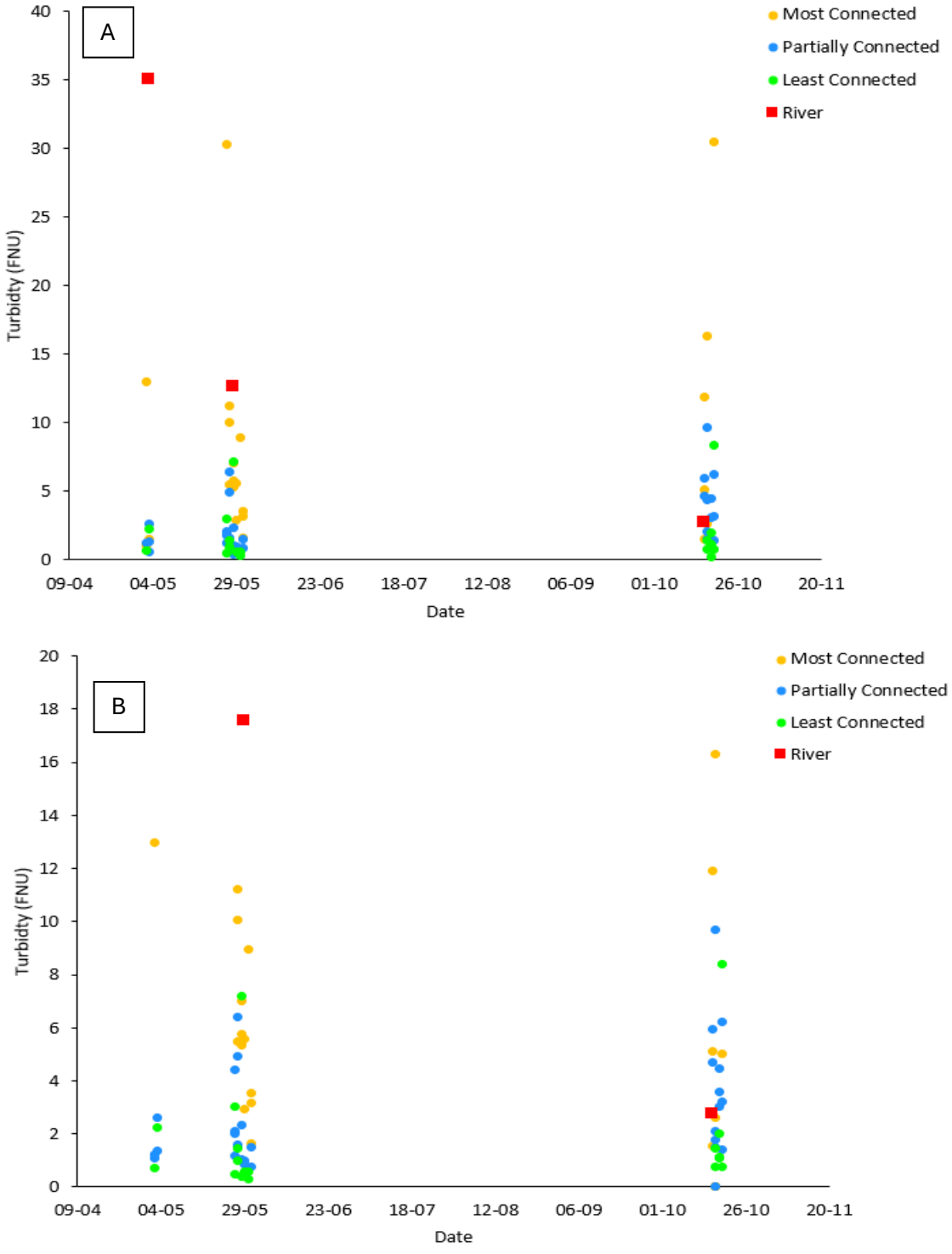


Figure 22: A) All turbidity measurements from all wetlands between May and October 2023. B) Turbidity measurements with the three largest data points removed so as to better see the differences in the other data points.

3.3.2 Submerged aquatic vegetation

We conducted submerged aquatic vegetation surveys in August 2023 in 16 wetlands (Appendix 3), identifying specimens found to species where possible, or higher taxonomic groups when in-field identification to lower levels was impossible. We found 27 species of vascular plant, two genera of algae, one species of cyanobacteria, one species of moss, one species of liverwort, and one freshwater sponge (identified to family; freshwater sponges are in fact animals, but due to their sedentary nature are often grouped with plants) (Table 3). One of these species, *Nymphaea tetragona*, or Pygmy Waterlily, is a Blue-Listed Species in BC (B.C. Conservation Data Centre, 1994); we found it in four wetlands.

Table 3: List of SAV species found during our surveys, with the wetland groups they were found in identified. Species at Risk indicated with an *.

Species	Most Connected	Partially Connected	Least Connected
Vascular Plant			
Bidens beckii	Yes	Yes	Yes
Callitriche palustris	Yes	No	No
Ceratophyllum demersum	No	Yes	Yes
Elodea canadensis	Yes	Yes	Yes
Hippurus vulgaris	Yes	Yes	No
Lemna minor	No	No	Yes
Myriophyllum sibiricum	Yes	Yes	Yes
Najas flexilis	Yes	Yes	Yes
Nuphar variagata	Yes	Yes	Yes
Nymphaea tetragona *	No	Yes	Yes
Potamogeton foliosus	Yes	Yes	Yes
Potamogeton gramineus	Yes	Yes	Yes
Potamogeton illoinensis	No	Yes	Yes
Potamogeton natans	Yes	Yes	Yes
Potamogeton praelongus	No	Yes	Yes
Potamogeton richardsonii	Yes	Yes	Yes
Potamogeton zosteriformis	Yes	Yes	Yes
Ranunculus aquaticus	Yes	Yes	Yes
Ranunculus gmelinni	Yes	No	No
Saggitaria cuneata	No	Yes	Yes
Sparganium angustifolium	Yes	Yes	Yes
Sparganium eurycarpum	Yes	No	Yes
Stuckenia filiformis	No	No	Yes
Stuckenia pectinata	Yes	Yes	Yes
Utricularia intermedia	Yes	Yes	Yes
Utricularia machoriza	Yes	Yes	Yes
Utricularia minor	No	Yes	Yes
Algae			
Chara sp.	Yes	Yes	Yes
Nitella sp.	Yes	Yes	Yes
Cyanobacteria			

Species	Most Connected	Partially Connected	Least Connected
Nostoc kihlmani	No	Yes	Yes
Moss			
Fontinalis antipyretica	No	Yes	Yes
Freshwater Sponge			
Spongillidae	No	Yes	Yes
Liverwort			
Ricciocarpos natans	No	Yes	No

We found more species in the Partially Connected and Least Connected wetlands than the Most Connected Wetlands (Figure 23), with 14 species not found in the Most Connected group. However species diversity was high across all wetland groups, and we found unique species in each group as can be seen in Table 3, demonstrating that all three wetland types provide important habitat and are necessary for an intact, complex, and resilient ecosystem.

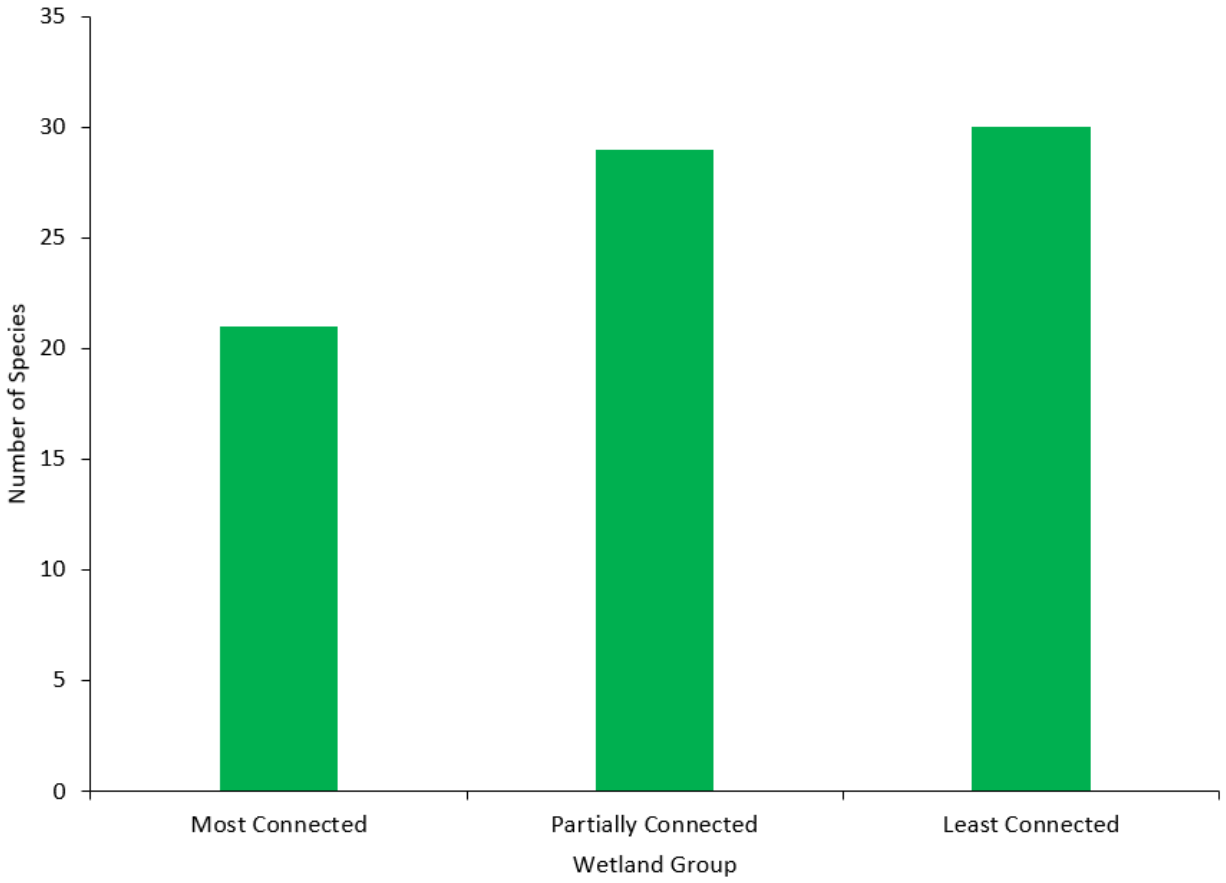


Figure 23: Number of species of SAV found in each wetland group.

It is clear that the different wetland groups have different aquatic vegetation communities, with the Most Connected wetlands containing species that are tolerant of the conditions found in these wetlands such as large changes in water depth, drying out when water levels drop in the wetland, and of the increased scour that is found in the Most Connected wetlands, due to the large gaps present in the levees allowing for a large volume of water to enter and leave quickly with a lot of force behind it, thus

scouring the wetlands out. We can conclude that the 14 species found only in Partially and Least connected wetlands are not tolerant of these conditions.

In Partially and Least Connected wetlands, water levels will be more stable, plants will not risk drying out as water levels do not drop as much, and scour will be much reduced, as levee gaps are either blocked by beaver dams or they are not present. However, water levels will be deeper overall, and there may be more competition, due to the less harsh conditions. Some species such as *R. gmelini* are only found in Most Connected wetlands so presumably cannot survive conditions in the other two wetland groups.

Nymphaea tetragona is Blue-listed in BC, and requires clear water with low flow and a rich organic substrate (B.C. Conservation Data Centre, 1994). As we only found it in Partially and Least Connected wetland, we surmise it also requires water year round and will not tolerate the conditions in Most Connected wetlands. The four wetlands we found it in are all beaver dammed wetlands, suggesting that it prefers conditions from beaver dammed wetlands to wetlands with complete levees.

Freshwater sponges are not a well-studied group, though they are found in a wide variety of habitats across the world, and identification of sponges is difficult both due to lack of knowledge about what species exist and because identification often relies on microscopic features or DNA analysis (Manconi and Pronzanto, 2008). It is therefore impossible to say if we are finding one species or several in our wetlands, or to draw any conclusions about habitat preference, however as we are only finding freshwater sponges in Partially and Least Connected wetlands we can surmise that they do not tolerate conditions in Most Connected wetlands.

3.3.3 Birds

General Bird Observations

We have recorded 142 species in and around our study wetlands either during dedicated waterbird counts or incidentally while working in the wetlands (full list of species in Appendix 12). 13 of these are Species at Risk (Appendix 13). The use of wetlands by these species varies widely, from ducks using open water to rest and feed, swallows and other insect eating birds catching food over the wetlands, small passerines such as warblers nesting in wetland vegetation, and shorebirds using exposed mud and short vegetation around the edges of wetlands to feed.

During spring and fall migratory waterbird counts at 20 sites (full methods in Appendix 2), we recorded 82 species of birds, of which four are SAR (full list of observations in Appendix 11), and 17,291 individual birds. Of these, Mallard was the most commonly observed species, being observed on 172 occasions and totaling 3232 individuals. Nine species have only been observed once, including American Bittern, Canvasback, and Eared Grebe.

Our target species for these counts are waterbirds and raptors, as these times of year are when these birds are migrating through the Columbia Wetlands, and we are interested in seeing how these species are using the wetlands. We also use a count strategy most appropriate for large birds like these, observing the wetlands from a distance, so as to not scare away any of the birds present.

Spring Migratory Waterbird Counts

We are particularly interested in wetland use by waterbirds during spring migration, as this is when water levels are at their lowest. Most waterbirds migrate through the Columbia Valley in April, which is prior to the Columbia River flood pulse, and so the water present in the wetlands at this time is a combination of water retained from the previous year, local snow and ice melt, and groundwater input. Water retained from the previous year is partly due to the presence of beaver dams, as wetlands with beaver dams or with unbroken levees retain water over the winter (as discussed above).

During our spring 2023 migratory waterbird counts, we recorded 33 species of waterbird, four species of raptor, and 4817 individual birds. This was slightly lower but similar in magnitude to spring 2022 when we recorded 34 species of waterbird, five species of raptor, and 5049 individual birds. The species observed in 2022 but not 2023 were Bonaparte's Gull, Cackling Goose, Canvasback, Eared Grebe, Eurasian Wigeon, Redhead, and Tundra Swan. The species observed in 2023 but not 2022 were American Bittern, Blue-winged Teal, Ruddy Duck, Snow Goose, Solitary Sandpiper, and Virginia Rail.

The ten most common species recorded in both years were the same (Table 4), however, the counts of each species differ. In general, 2022 has slightly higher counts of most species, however more American Wigeon were observed in 2022 (839 in 2022 and 438 in 2023 across the survey period), and more American Coots were observed in 2023 (565 in 2023 and 185 in 2022 across the survey period).

Table 4: The ten most common waterbird species observed in 2022 and 2023, and aggregate counts of individuals in each year.

Species	**2022**	**2023**
Mallard	873	957
American Wigeon	839	438
Canada Goose	607	525
Ring-necked Duck	569	359
Northern Pintail	525	477
Green-winged Teal	391	351
Common Goldeneye	298	306
Bufflehead	232	253
American Coot	185	565
Hooded Merganser	160	116

The different wetland groups differ in the migratory waterbirds that use them. Mean number of individual birds does not differ significantly across wetland groups (Figure 24) due to large variation within wetland groups. For example, in 2022 within the Most Connected group, 1302 individual birds were counted in Site 132 while 50 individual birds were counted in Site 30.

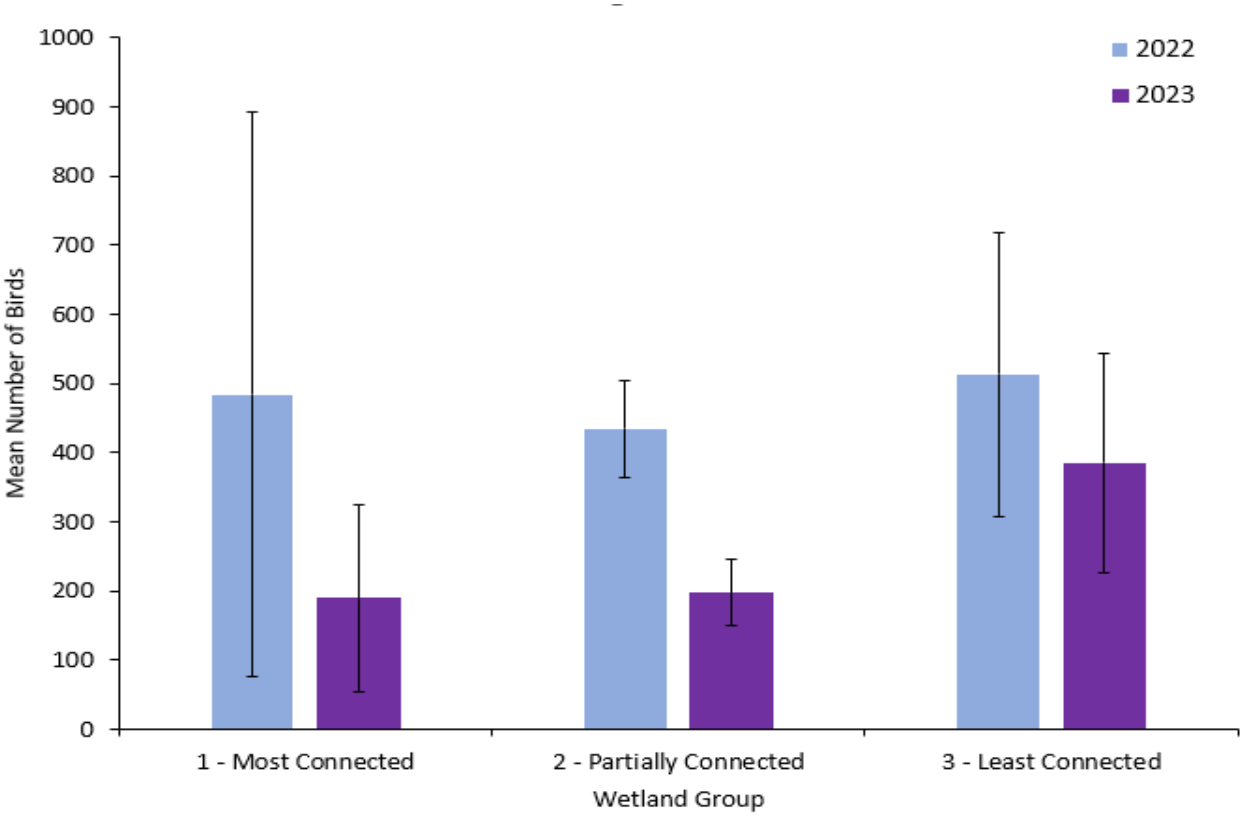


Figure 24: Mean number of individual birds in each wetland group in 2022 (blue) and 2023 (Purple). Error bars are standard error. Total n = 20, Most Connected n = 5, Partially Connected n = 10, and Least Connected n = 5.

The number of species in each wetland group, however, does differ (Figure 25). In 2022 the Most Connected group had significantly less bird species than the Partially and Least Connected groups, while in 2023, the Least Connected group had significantly more species than the Most Connected group. This indicates that more bird species are using the Partially and Least Connected wetlands, likely due to the fact that at this point in the year, water levels are very low in the Most Connected groups. Thus, species of waterbird that require there to be deeper water in the wetlands, such as Bufflehead, a duck species that prefers to feed in water 1 - 3m deep (Sandilands, 2005), will not be present in Most Connected wetlands as the conditions are unsuitable for them.

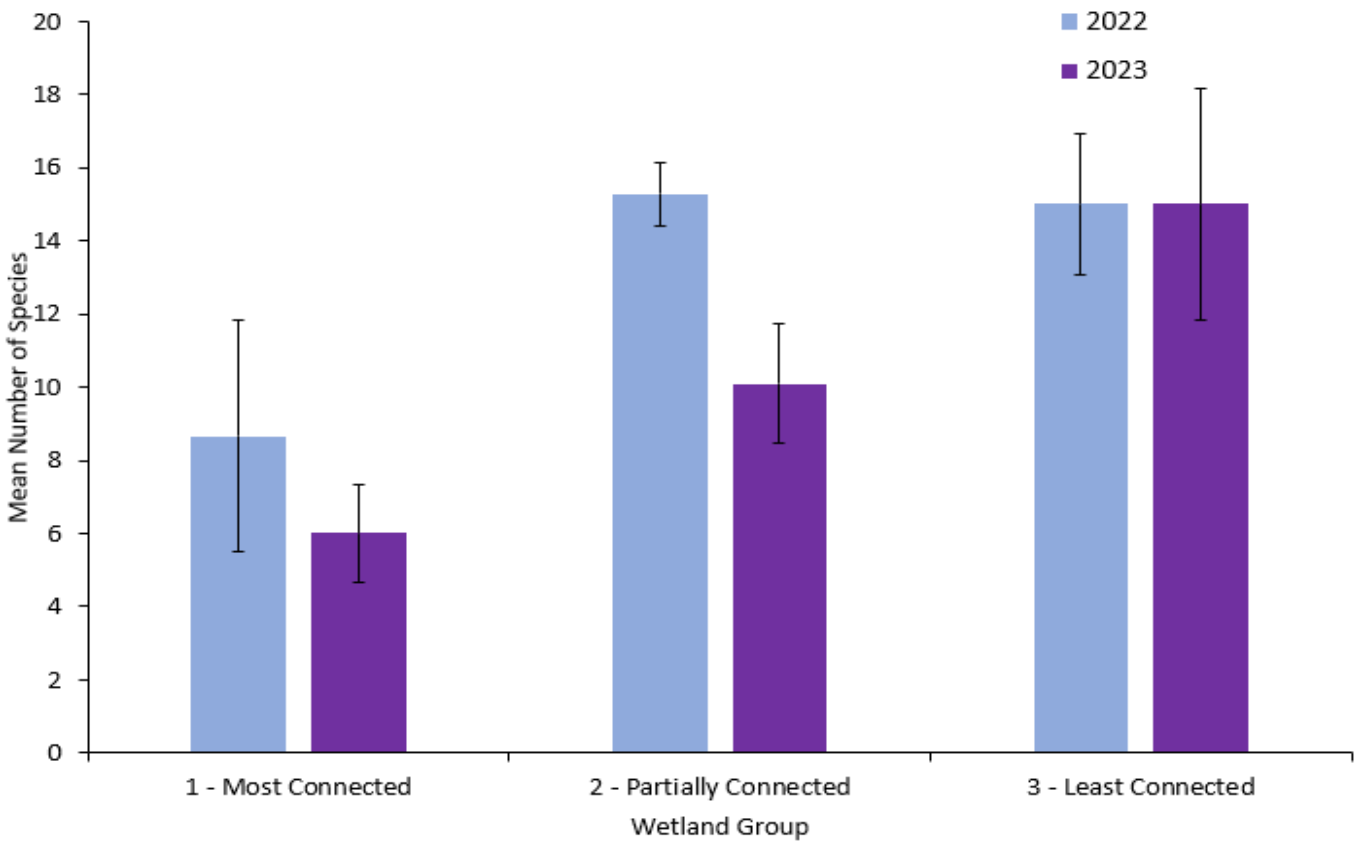


Figure 25: Mean number of species in each wetland group in 2022 (blue) and 2023 (Purple). Error bars are standard error. Total n = 20, Most Connected n = 5, Partially Connected n = 10, and Least Connected n = 5.

While some species are found across all wetland groups, such as American Wigeon, other species are more selective, leading to the differences seen in figure 25. Table 5 shows which species were found in each group, and the requirements of those different bird species are crucial to understanding which wetland groups we find them in. Foraging strategy is often used as a way to group bird species, as foraging strategy varies greatly between species and foraging successfully is obviously essential for survival. The foraging strategies we find in our species are Dabbling, Diving, Ground Foraging, and Soaring/Aerial Diving (Table 5).

Dabbling species feed on the surface of the water and sometimes on land, placing just their heads under the water to access food near the surface. Mallards are an example of a dabbling species. Diving species fully immerse themselves under the surface, diving down and swimming using their feet and wings to access food that is deeper in the water. Bufflehead are an example of a diving species. Ground foraging covers a variety of different feeding strategies that have here been combined for simplicity of analysis, but which all include birds finding food by walking on either the ground or vegetation rather than swimming. Great blue herons are an example of a ground foraging species. Soaring/Aerial diving were also combined for simplicity of analysis, and include foraging techniques such as hovering and then diving through the air to catch prey. Ospreys are an example of an aerial diving species.

Table 5: Species found in each wetland group (data from both spring 2022 and 2023 used), with foraging strategy indicated.

Species	Foraging Strategy	Most Connected	Partially Connected	Least Connected
Belted Kingfisher	Aerial Diving	No	Yes	Yes
Northern Harrier	Aerial Diving	No	Yes	Yes
Osprey	Aerial Diving	Yes	No	Yes
American Wigeon	Dabbling	Yes	Yes	Yes
Bonaparte's Gull	Dabbling	No	No	Yes
Blue-winged Teal	Dabbling	No	No	Yes
Cackling Goose	Dabbling	No	Yes	No
Cinnamon Teal	Dabbling	No	Yes	Yes
Eurasian Wigeon	Dabbling	No	No	Yes
Green-winged Teal	Dabbling	Yes	Yes	Yes
Mallard	Dabbling	Yes	Yes	Yes
Northern Pintail	Dabbling	Yes	Yes	Yes
Northern Shoveler	Dabbling	Yes	Yes	Yes
Trumpeter Swan	Dabbling	Yes	Yes	Yes
Tundra Swan	Dabbling	No	No	No
Wood Duck	Dabbling	Yes	Yes	Yes
American Coot	Diving	Yes	Yes	Yes
Barrow's Goldeneye	Diving	No	Yes	Yes
Bufflehead	Diving	No	Yes	Yes
Canvasback	Diving	No	Yes	No
Common Goldeneye	Diving	Yes	Yes	Yes
Common Loon	Diving	No	Yes	Yes
Common Merganser	Diving	Yes	Yes	Yes
Eared Grebe	Diving	No	Yes	No
Greater Scaup	Diving	No	No	Yes
Horned Grebe	Diving	No	Yes	Yes
Hooded Merganser	Diving	Yes	Yes	Yes
Lesser Scaup	Diving	No	Yes	Yes
Pied-billed Grebe	Diving	No	Yes	Yes
Redhead	Diving	No	No	Yes
Ring-necked Duck	Diving	No	Yes	Yes
Red-necked Grebe	Diving	No	Yes	Yes
Ruddy Duck	Diving	No	No	Yes
American Bittern	Ground Foraging	No	Yes	No
Canada Goose	Ground Foraging	Yes	Yes	Yes
Great Blue Heron	Ground Foraging	Yes	Yes	Yes
Killdeer	Ground Foraging	Yes	Yes	Yes
Sandhill Crane	Ground Foraging	Yes	Yes	Yes
Snow Goose	Ground Foraging	No	No	Yes
Sora	Ground Foraging	No	Yes	Yes

Species	Foraging Strategy	Most Connected	Partially Connected	Least Connected
Solitary Sandpiper	Ground Foraging	No	No	Yes
Virginia Rail	Ground Foraging	No	No	Yes
Bald Eagle	Soaring	Yes	Yes	Yes
Golden Eagle	Soaring	No	Yes	Yes
Red-tailed Hawk	Soaring	No	Yes	Yes

The differences in foraging strategies between wetland groups are apparent (Figure 26), with the biggest difference visible in Diving species. Few Diving species are found in the Most Connected wetlands, due to their shallow water making this foraging strategy unsuccessful or even impossible. Partially and Least Connected wetlands, however, provide suitable conditions for these species, with 14 Diving species found in Partially Connected wetlands and 15 Diving species in Least Connected wetlands. Dabbling species are found in all wetlands, as they can successfully feed in both shallow and deeper water. In deeper water, dabbling species simply feed by accessing vegetation or invertebrates near the surface.

Ground Foraging species are also found across all wetlands, with species such as Canada Goose and Killdeer present in all wetland types. This is because in the Partially and Least connected wetlands, there are still shallow areas and exposed edges where ground foraging species can feed. There are less Soaring/Aerial Diving species in Most Connected wetlands, which could be for several reasons. Soaring/Aerial diving species include fish specialists such as Osprey and Belted Kingfisher, and there are more likely to be fish in the deeper water found in Least and Partially Connected wetlands. Kingfishers, in particular, may also be reluctant to hunt in very shallow water as they often fully immerse themselves when they dive, and presumably cannot dive in very shallow water without risking harming themselves.

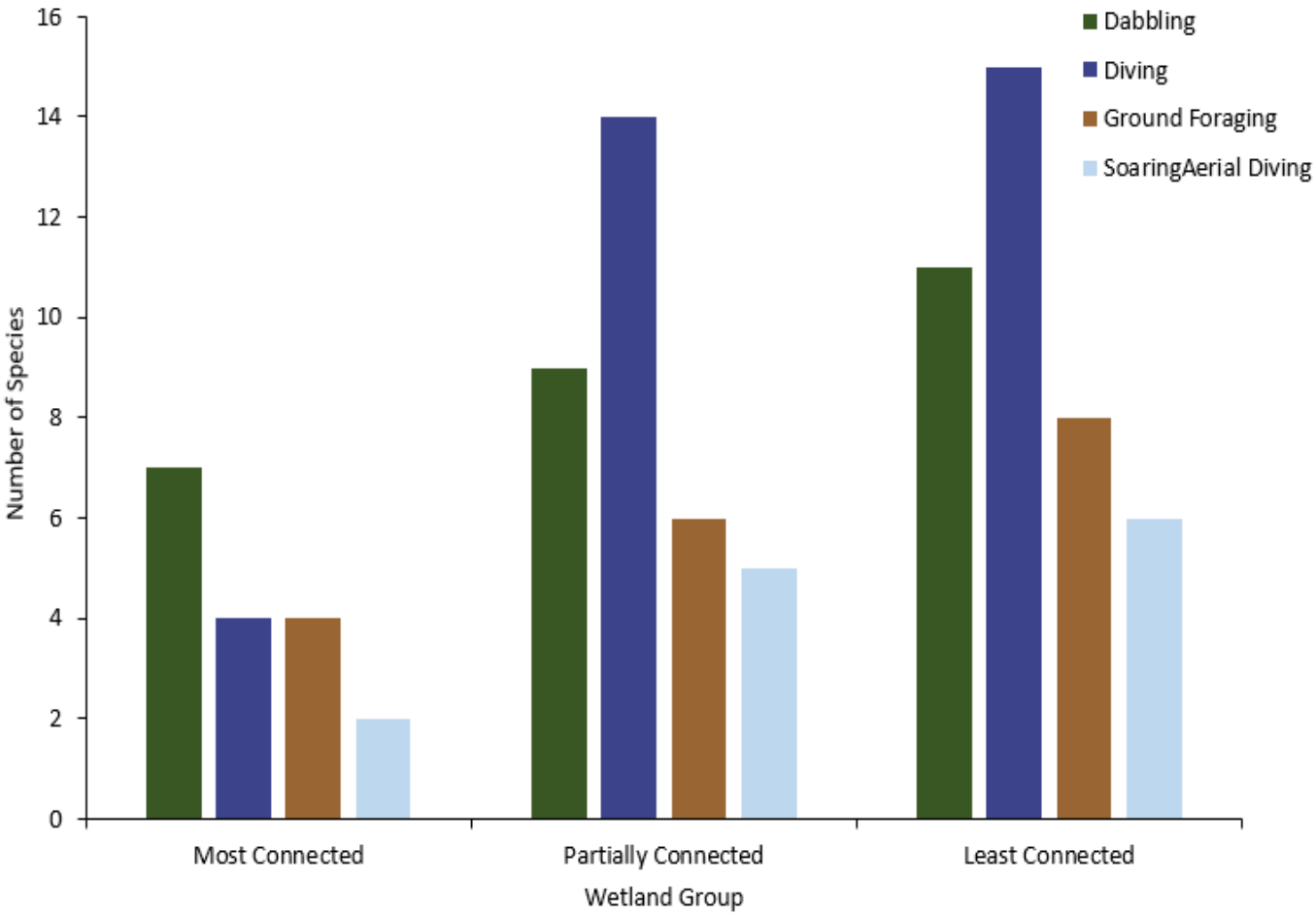


Figure 26: Total number of species of different foraging strategies found in each wetland group. Data combined from both 2022 and 2023, with n = 20.

Partially and Least Connected wetlands are clearly essential for many species, with species such as Pied-billed Grebes and Ring-necked Ducks simply not being found in Most Connected wetlands during spring migration due to the low water levels in these wetlands. Without them, these species would be unable to feed successfully, and their migration through the Columbia Wetlands would likely be negatively impacted.

3.4 Restoration using beaver dam analogues

There are clear ecological differences between the different wetland groups, and in order for the Columbia Wetlands to be an intact and diverse ecosystem, all these different wetland groups must be present. Most Connected wetlands comprise a greater area of the Columbia Wetlands, and are the wetland group that will dominate without the actions of beaver or conservation actions by people. As the Partially and Least Connected wetlands are particularly important for waterbirds during spring migration, where due to their high water levels, they provide habitat for a greater variety of species than the Most Connected wetlands, maintaining Partially and Least Connected wetlands is essential. They also provide habitat for plant species such as *Nymphaea tetragona*, which require year-round immersion in water and will not tolerate the high scour or potential for drying out found in Most Connected wetlands.

One way to do that is by building Beaver Dam Analogues. With these, we can retain water in wetlands, thus providing this less common habitat type, and increasing diversity across the wetland complex.

3.4.1 Site 38 – Restored in 2021

In the fall of 2021 we built a beaver dam analogue in Site 38, and have subsequently repaired it in the fall of 2022 and 2023. The natural beaver dam blew out in the spring of 2020, and as can be seen in Figure 27, the restoration of the dam has increased water levels by approximately 0.6m. The restoration of the dam increased water levels to more than the 2020 (when the natural dam was still in place) level. This is likely because the dam was old and inactive (not being maintained by beavers) and so the installation of a new dam with yearly maintenance is retaining more water than the previous old dam, While 0.6m seems like a small increase, across the whole area of the wetland this is an increase of 324,000m^3, which is a substantial increase in the amount of water being stored in this wetland.

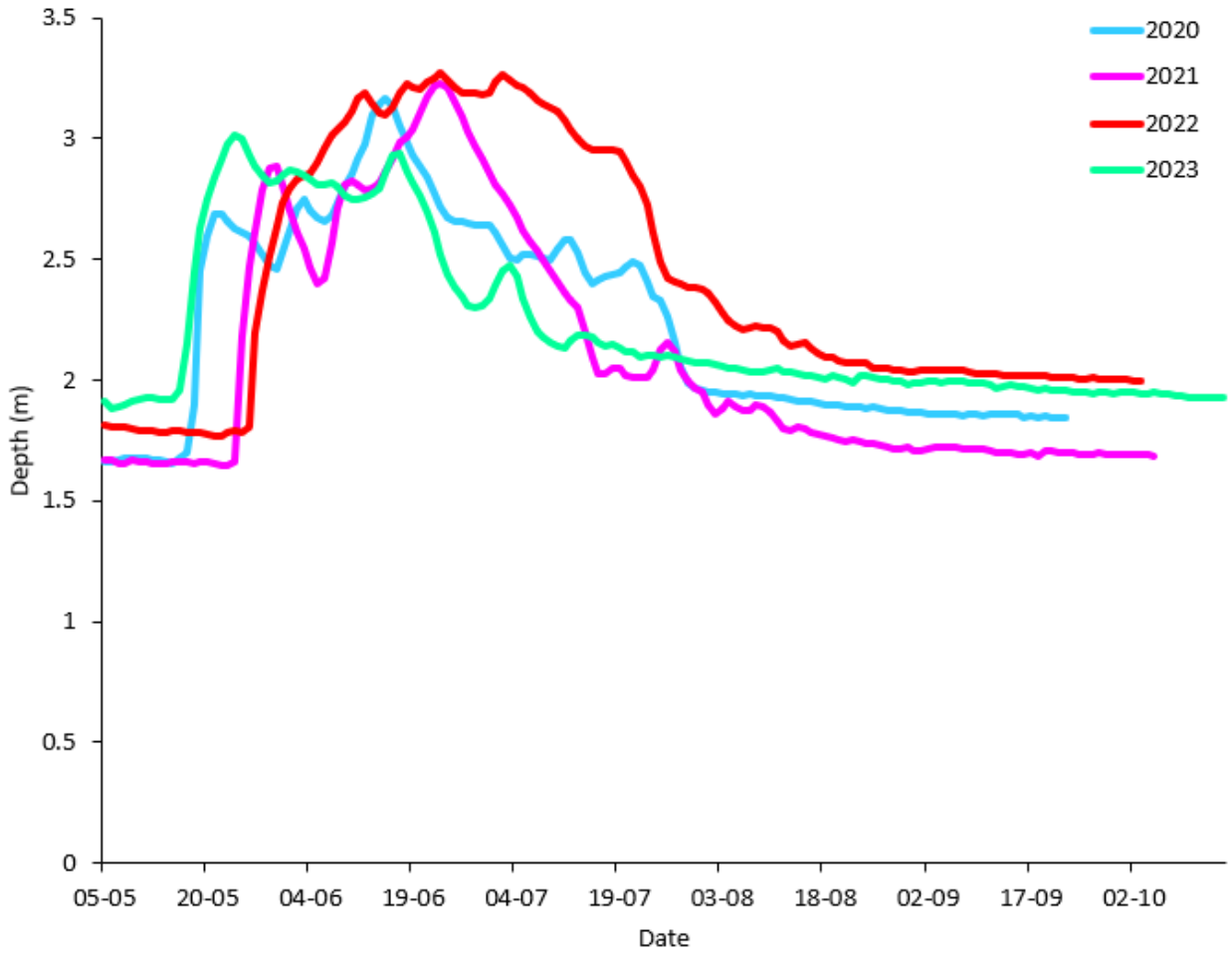


Figure 27: Water depth in Site 38 in 2020 (blue), 2021 (pink), 2022 (red), and 2023 (green).

While we do not have pre-restoration data for Site 38, the data we do have demonstrates that it is an ecologically valuable site, with 26 species of bird being recorded during spring migratory bird counts and 22 species of SAV, including the Species At Risk *Nymphaea tetragona*. As migratory waterbird species diversity is greater in Partially and Least Connected wetlands than in Most Connected wetlands, by restoring the beaver dam and retaining this wetland's status as a Least Connected wetland has very likely

allowed for a greater diversity of species to be present than if it had become a Most Connected wetland. Similarly, *N. tetragona* is only found in Partially and Least Connected wetlands, so this species would likely have been lost from this wetland if water levels were not being maintained by the restoration of this beaver dam.

3.4.2 Site 71 – Restored in 2023

Site 71 was identified as a restoration project due to the relatively small size of the levee gap that needed to be dammed and the relatively large area restored as a result. This wetland provided the opportunity to restore 22 ha (0.22 km2) of wetland by repairing an old beaver dam. Work was planned (permits permitting) for fall 2023, however in early 2023 a group of beavers built a dam on the remnants of the old beaver dam, exactly as we had been planning to do. The impacts of this dam hydrologically were immediate, as can be seen in Figure 28. Despite 2023 being a low water year, with a high water peak in Site 71 of just over 2.5m as opposed to almost 3m, due to the presence of the beaver dam, more water was retained into the fall, with an increase of 0.25m of water. Over the whole wetland area, this is an estimated increase of 27,500m^3.

Given projections that the Columbia Wetlands will be becoming drier, with less water input from the flood pulse of the Columbia River, the fact that a single beaver dam can make such a difference in a dry year is very important. Retaining water with both beaver-built and human-built beaver dams is clearly an effective way to retain water on the landscape, maintain the habitat diversity of the Columbia Wetlands by maintaining different wetland types, and mitigate the impacts of climate change.

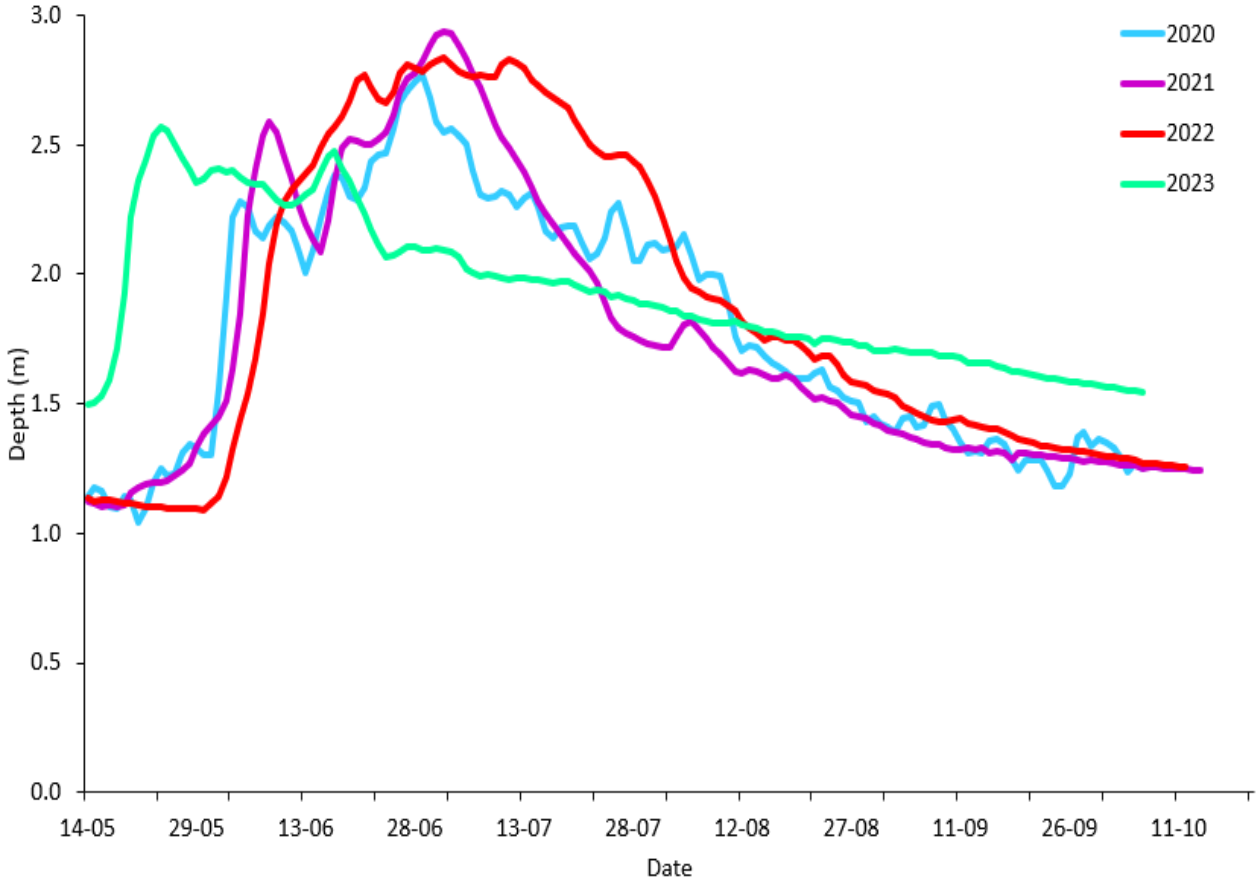


Figure 28: Water depth in Site 71 in 2020 (blue), 2021 (pink), 2022 (red), and 2023 (green).

We will continue to monitor this site into the future so that we can compare it pre- and post-beaver dam, by collecting both hydrological and ecological data. In previous years, 71 has been used by many waterbird species, with 13 species of migratory waterbird recorded in spring 2022 and 2023; spring bird surveys will be repeated in 2024 and following years, and it will be interesting to see if more species are now supported in this wetland.

3.4.3 Site 145 – Future Restoration Project

We have identified our third Columbia Wetlands restoration project as Site 145, located near Parson (Figure 29). In January 2024 we applied for a permit to build a beaver dam analogue at the indicated location in this site, with support for our application from the two landowners who own areas of the wetland. The actual BDA will be built on crown land. The dam will be approximately 10.5m long, 3m wide, and 1.35m tall, and we will build it as per the guidelines in The Beaver Restoration Guide (Pollock *et al.,* 2023) using local materials as much as possible.

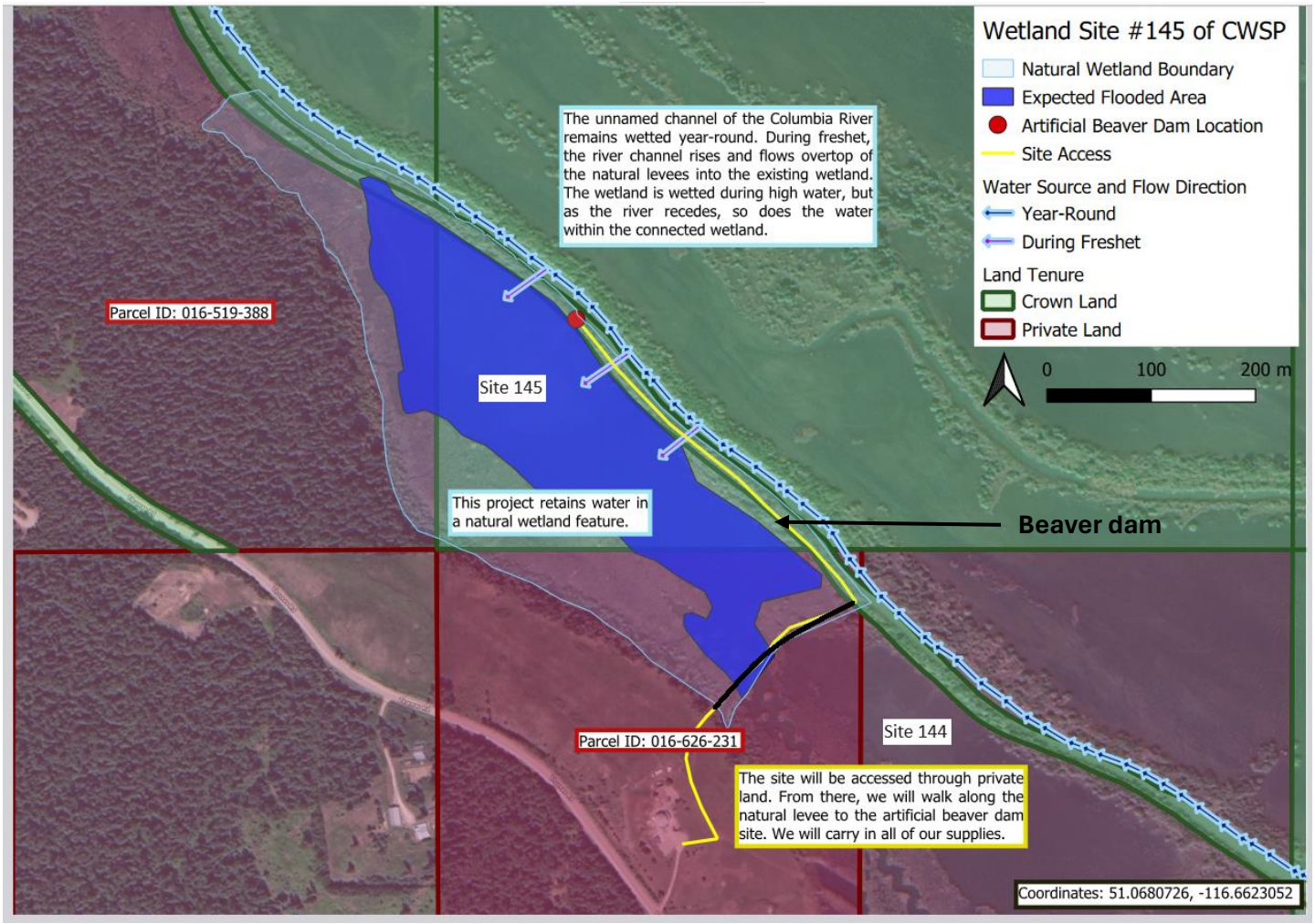


Figure 29: Diagram of Sites 144 and 145. Beaver dam separating the wetlands indicated with black line.

Site 145 is a Most Connected wetland, and with the building of this BDA we hope to turn it into a Partially Connected wetland, thus retaining more water throughout the year, providing a greater diversity of habitat, and increasing available open water habitat. At present, Site 145 drains out and is very low in the spring and fall (Figure 30). By building a dam in the above indicated position, we hope to increase

water levels across the wetland by approximately 1.35m, which will result in an increase of 175, 500m^3 of water being held in the wetland.

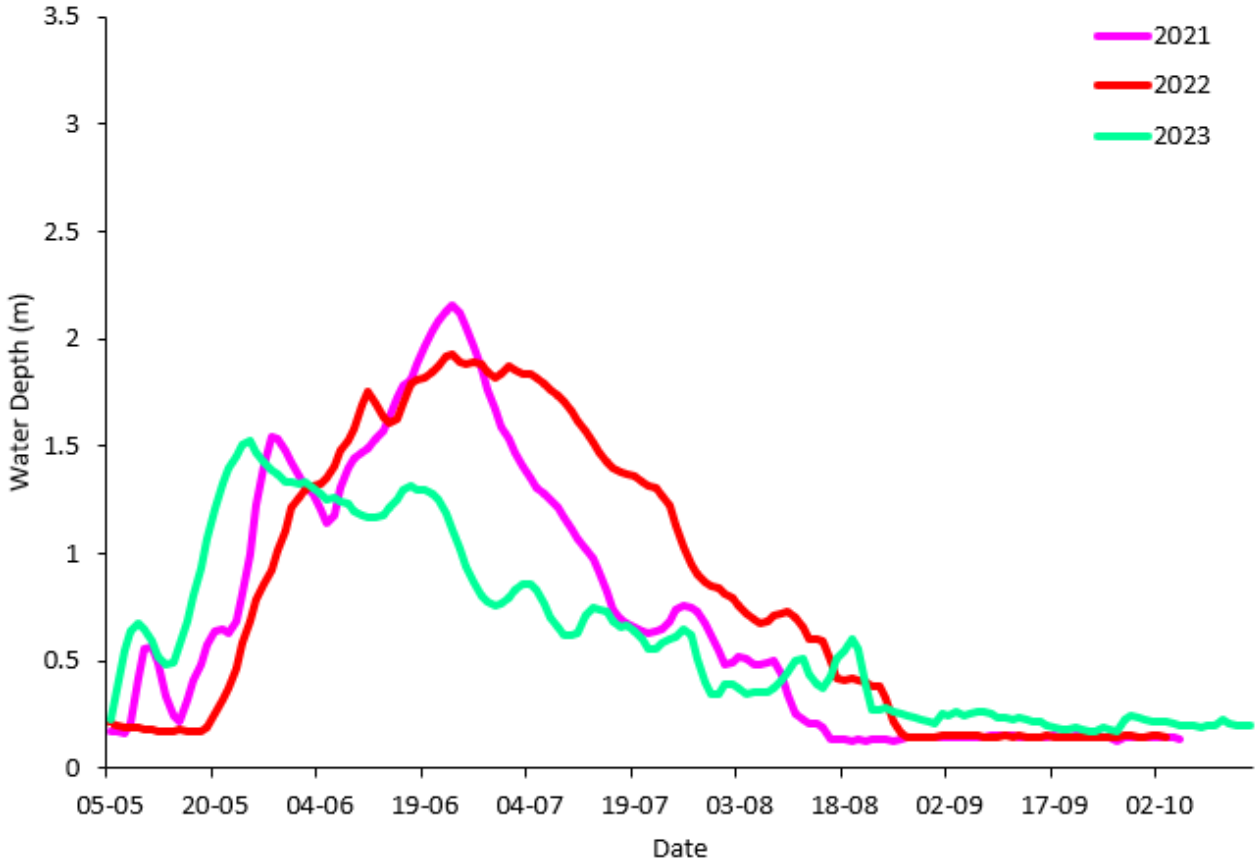


Figure 30: Water depth in Site 145 in 2021 (pink), 2022 (red), and 2023 (green).

Interestingly, during fieldwork in 2023 we found that Site 144, directly to the south of 145 and previously separated from 145 by a beaver dam (as indicated in Figure 29), had very low water levels compared to previous years (Figure 31). Upon further investigation we concluded that the beaver dam had blown out, with an undercut gap wider than 1m present in the beaver dam. Thus, 144 no longer displayed hydrological characteristics of a Partially Connected wetland, but of a Most Connected wetland, where in 2023 the water depth dropped rapidly and by the fall there was very little water remaining in the wetland. By building a beaver dam as indicated above, we will also be able to restore water levels in Site 144, thus restoring the capability for water retention and increasing water on the landscape in 0.32 km^2 or 32 ha of wetland, which will result in an additional of 432,000m^3 of water being retained in the wetland.

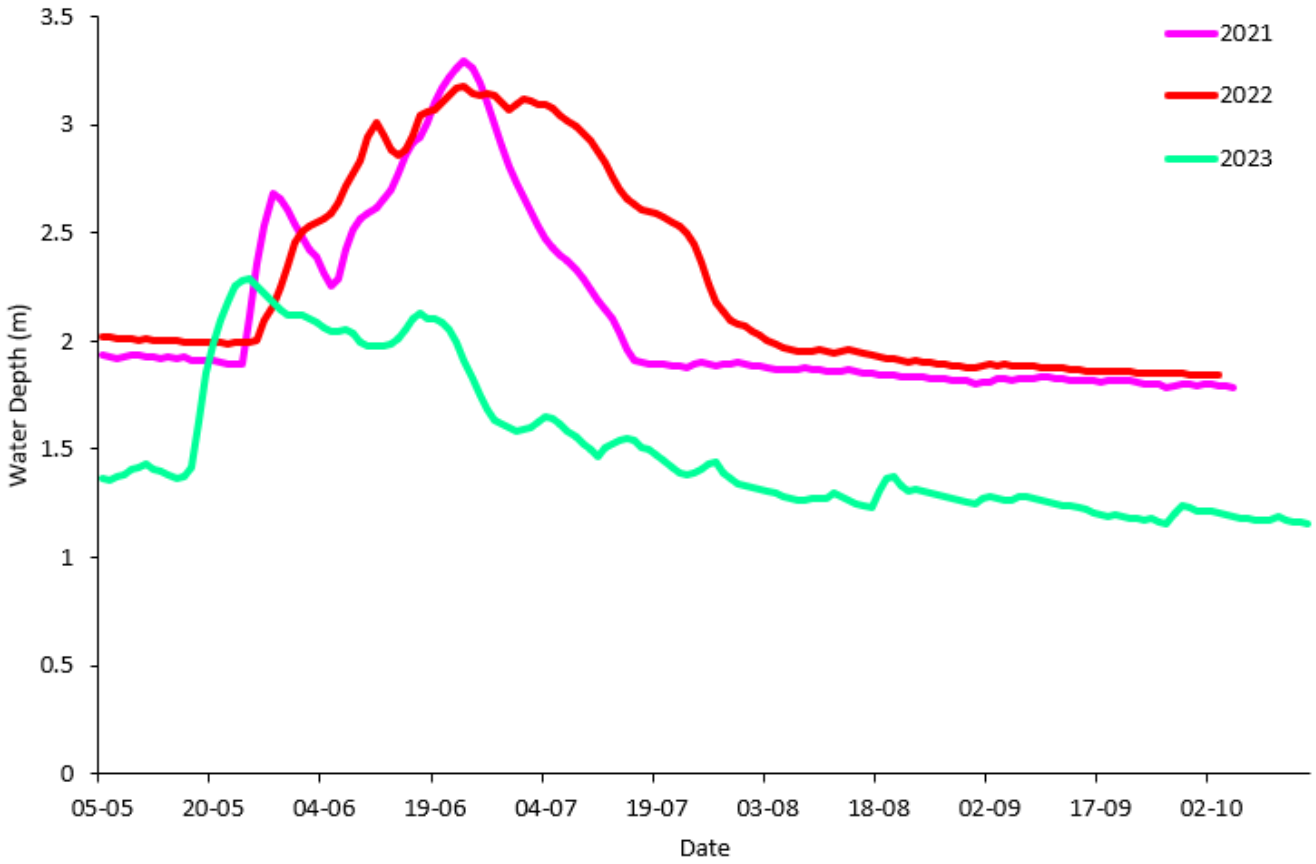


Figure 31: Water depth in Site 144 in 2021 (pink), 2022 (red), and 2023 (green).

This will be particularly important for Site 144, as this was one of the four wetlands in which we found *Nymphaea tetragona*. As noted above, the conditions required for this species are not found in Most Connected wetlands, so by restoring Site 144 through the building of this beaver dam we will hopefully be able to restore habitat for *N. tetragona*, a Blue-listed Species in BC. We will continue to survey birds and SAV in both Site 144 and 145 in order to determine impacts of this restoration.

3.4.4 Site 24 – Future Restoration Project

We have also identified Site 24 as a future restoration site, though currently our plans are less concrete than for Site 145. We are collaborating with the Nature Trust who manage the land that Site 24 is on. Site 24 is a Most Connected wetland that is 0.46km^2 in area, which retains very little water in it as the river recedes, as can be seen in Figure 32. We can compare Site 24 to a nearby Least Connected site, Site 21 (see Figure 1 for site locations), and the difference in water depth between the two sites is striking, with Site 24 draining out almost entirely while Site 21 maintains at least 1m of water throughout the year.

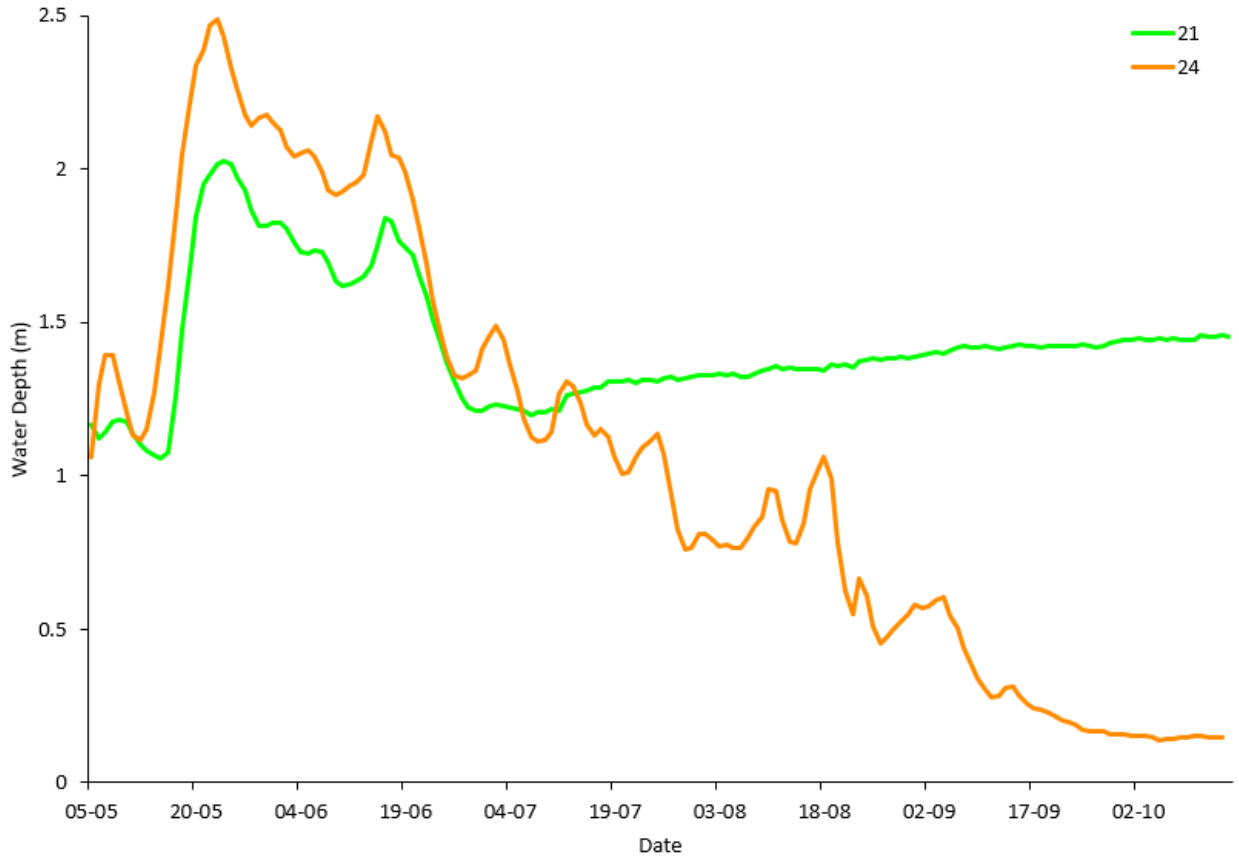


Figure 32: Water depths in Site 21 (Least Connected) and Site 24 (Most Connected) between May and October 2023.

The bird species found during migratory waterbird counts in spring 2022 and 2023 also differ, with 21 species of bird observed in Site 21 and only nine observed in Site 24 (Table 6). Our intent in building a beaver dam in Site 24 would be to make it more similar to Site 21, and thus increase both water depths and bird diversity in Site 24.

Table 6: Migratory waterbird and raptor species observed in Sites 21 and 24 in spring 2022 and spring 2023.

Site 21	**Site 24**
American Coot	American Wigeon
American Wigeon	Canada Goose
Bald Eagle	Green-winged Teal
Bufflehead	Hooded Merganser
Canada Goose	Mallard
Common Goldeneye	Osprey
Common Loon	Killdeer
Common Merganser	Wood Duck
Greater Scaup	
Green-winged Teal	
Hooded Merganser	
Horned Grebe	
Lesser Scaup	
Mallard	
Northern Pintail	
Osprey	
Pied-billed Grebe	
Red-necked Grebe	
Ring-necked Duck	
Sandhill Crane	

4. Communications

As well as conducting research and restoring wetlands, we also endeavour to communicate with both the general public and with other conservation and research organisations in various ways. We have given several presentations to different groups of people (Table 7).

Table 7: List of presentations given by CWSP personnel between April 2023 and March 2024.

Date	Presenter(s)	Occasion	Presentation Title
May 2023	Suzanne Bayley	CWSP AGM	Recreation proposals, local planning initiatives, and Cottonwood conservation in the Columbia Valley
May 2023	Catriona Leven	CWSP AGM	Hydrology and Beavers in the Columbia Wetlands
May 2023	Suzanne Bayley	Wings Over The Rockies Festival	Threats to Water and Wildlife in the Columbia Valley
May 2023	Suzanne Bayley, Catriona Leven	Wings Over The Rockies Festival	Birding walk and talk at Radium Mill Pond
June 2023	Catriona Leven	Wildsight Youth Columbia River Field School	An introduction to the Columbia Wetlands and Beaver Dams
October 2023	Suzanne Bayley	Kootenay Connect Fall Gathering	Conservation of biodiversity in the Columbia Valley
March 2024	Suzanne Bayley	Lake Windermere Rod and Gun Club Meeting	Biodiversity, Wildlife, and Access Management in the Columbia Valley

We are also collaborating with and sharing information with organisations such as Living Lakes Canada, the British Columbia Wildlife Federation, and Ducks Unlimited. Specifically, we are advising Ducks Unlimited and BC Parks on their restoration of wetlands at Burgess James Gadsden Provincial Park, and have attended site visits and meetings to discuss restoration options and provide data and advice from our work. In May 2023 we showed representatives from both organisations some of our sites in the Columbia Wetlands and shared data on wetland groups and the different ecology of different groups. In May and October 2023 we visited Burgess James Gadsden Provincial Park with other involved groups and discussed restoration options. This work is still ongoing.

We also work closely with and share accommodation with the Columbia Headwaters Aquatic Restoration Secwépemc Strategy team. Dr. Suzanne Bayley is also a part of the Columbia Valley Recreational Planning Initiative, Recreational Plan for Forester Watershed, an ongoing project to better manage recreation in the Forester Watershed in the Columbia Valley.

In January 2024, in collaboration with Living Lakes Canada, we did an interview with Corey Bullock from CBC News (Figure 33), which was broadcast as a television segment on CBC News Vancouver on January 26th 2024 (Figure 33), and as a radio segment on Daybreak South on January 29th 2024. There was also a written article available online from 2nd February 2024.

Figure 33: Corey Bullock interviewing Dr. Suzanne Bayley overlooking the Columbia Wetlands. Also in photo are Kat Hartwig (Living Lakes Canada) and Jessica Holden (CWSP).

We also had a scientific paper published in July 2023 in collaboration with Dr. Casey Remmer and Dr. Rebecca Rooney of the University of Waterloo in the Canadian Water Resources Journal titled “The Importance of Groundwater to the Upper Columbia River Floodplain Wetlands”. Both Dr. Suzanne Bayley and Catriona Leven are co-authors on this paper.

We are also increasing our profile on social media, and are aiming for twice weekly posts on Facebook and Instagram, where we can be found as Columbia Wetlands Stewardship Partners and @columbiawetlands, respectively.

5. Acknowledgments

We are very grateful to the funders of this project, Kootenay Connect, Environment and Climate Change Canada, Columbia Basin Trust, the RDEK's Columbia Valley Local Conservation Fund, and Living Lakes Canada. We are also very appreciative of the numerous landowners in the Columbia Valley who have allowed us access to our sites.

Many thanks are also due to Jessica Holden, Darcie Quamme, Braeden Toikka, Brody Kuntz, Annie Pankovitch, Jenn Bouwes, Spencer Cairns, Tomba Paagman, and Kalista Pruden for hours of fieldwork and literal blood, sweat, and tears to collect all these data – without you, none of this would be possible! And further thanks to Jessica Holden and Annie Pankovitch for invaluable help with GIS and remote sensing data collection and analysis. Thanks also to everyone at MacHydro Consulants – particularly Dr. Ryan MacDonald and Beth Millions – for help in the field, with data analysis, and with project direction. And thank you to Living Lakes Canada for all your support with fieldwork, equipment loans, reporting, and public outreach.

Thanks of course to all of the CWSP partners for supporting this work, the CWSP directors for both support and guidance, and particularly to Dr. Suzanne Bayley for bringing her years of experience, dedication, and drive to get things done to this work.

6. References

Airborne Imagery, Columbia Valley Existing Data Project Number 15712. Reigl Q1560. Calgary, Alberta: Airborne Imagery. 11 September – 02 October 2015.

Amoros, C., and G. Bornette. 2002. "Connectivity and Biocomplexity in Waterbodies of Riverine Floodplains." *Freshwater Biology* 47 (4): 761–76. https://doi.org/10.1046/j.1365-2427.2002.00905.x.

B.C. Conservation Data Centre. 1994. Species Summary: *Nymphaea tetragona*. B.C. Minist. of Environment. Available: https://a100.gov.bc.ca/pub/eswp/ (accessed Mar 16, 2024).

Birds Canada. n.d. "Prairie and Parkland Marsh Monitoring Program." Birds Canada. https://www.birdscanada.org/download/PPMMPmanual.pdf.

Collen, P., and R.J. Gibson. 2000. "The General Ecology of Beavers (Castor Spp.), as Related to Their Influence on Stream Ecosystems and Riparian Habitats, and the Subsequent Effects on Fish – a Review." *Reviews in Fish Biology and Fisheries* 10 (4): 439–61. https://doi.org/10.1023/A:1012262217012.

Darvill, Rachel. 2020. "Columbia Wetlands Waterbird Survey." Prepared for: Wildsight Golden.

Darvill, Rachel, and Ashleigh Westphal. 2020. "Columbia Wetlands Marsh Bird Monitoring Project (CWMBMP) Final Report." Goldeneye Ecological Services, Prepared for Fish and Wildlife Compensation Program.

Environment and Climate Change Canada. 2018. "Columbia National Wildlife Area Management Plan." Environment and Climate Change Canada.

Environmental Stewardship Division Kootenay Region. 2004. "Columbia Wetlands Wildlife Area Management Plan." Government of British Columbia: Ministry of Water, Land and Air Protection: Environmental Stewardship Division, Kootenay Region.

Forest, Lands, and Natural Resource Operations and Rural Development, Geo BC. NDMP Kootenay, 2018. Optech Galaxy. 06 June – 26 July 2018.

Hood, Glynnis A., and Suzanne E. Bayley. 2008. "Beaver (Castor Canadensis) Mitigate the Effects of Climate on the Area of Open Water in Boreal Wetlands in Western Canada." *Biological Conservation* 141 (2): 556–67. https://doi.org/10.1016/j.biocon.2007.12.003.

Hopkinson, Chris, Brendon Fuoco, Travis Grant, Suzanne E. Bayley, Brian Brisco, and Ryan 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.

Junk, Wolfgang, Peter Bayley, and Richard Sparks. 1989. "The Flood Pulse Concept in River-Floodplain Systems." In . Vol. 106.

Larsen, Annegret, Joshua R. Larsen, and Stuart N. Lane. 2021. "Dam Builders and Their Works: Beaver Influences on the Structure and Function of River Corridor Hydrology, Geomorphology, Biogeochemistry and Ecosystems." *Earth-Science Reviews* 218 (July): 103623. https://doi.org/10.1016/j.earscirev.2021.103623.

MacDonald Hydrology Consultants Ltd. 2021. “Year 2 Report - Upper Columbia Wetland Vulnerability Assessment.” Prepared for: Columbia Wetland Stewardship Partners. Prepared for: Columbia Wetland Stewardship Partners.

MacKenzie, W.H., and J.R. Moran. 2004. *Wetlands of British Columbia: A Guide to Identification*. Land Manage. Handb. No. 52. Res. Br., B.C. Min. For., Victoria, B.C. https://www.for.gov.bc.ca/hfd/pubs/Docs/Lmh/Lmh52.htm.

Makaske, Bart, Derald G. Smith, Henk J. A. Berendsen, Arjan G. de Boer, Marinka F. van Nielen-Kiezebrink, and Tracey Locking. 2009. “Hydraulic and Sedimentary Processes Causing Anastomosing Morphology of the Upper Columbia River, British Columbia, Canada.” *Geomorphology* 111 (3): 194–205. https://doi.org/10.1016/j.geomorph.2009.04.019.

Manconi, R., and R. Pronzato. “Global Diversity of Sponges (Porifera: Spongillina) in Freshwater.” *Hydrobiologia* 595, no. 1 (January 1, 2008): 27–33. https://doi.org/10.1007/s10750-007-9000-x.

Moore, R. D., S. W. Fleming, B. Menounos, R. Wheate, A. Fountain, K. Stahl, K. Holm, and M. Jakob. 2009. “Glacier Change in Western North America: Influences on Hydrology, Geomorphic Hazards and Water Quality.” *Hydrological Processes* 23 (1): 42–61. https://doi.org/10.1002/hyp.7162.

Munir, Tariq M., and Cherie J. Westbrook. “Beaver Dam Analogue Configurations Influence Stream and Riparian Water Table Dynamics of a Degraded Spring-Fed Creek in the Canadian Rockies.” *River Research and Applications* 37, no. 3 (2021): 330–42. https://doi.org/10.1002/rra.3753.

Nummi, Petri, and Sari Holopainen. 2020. “Restoring Wetland Biodiversity Using Research: Whole-Community Facilitation by Beaver as Framework.” *Aquatic Conservation: Marine and Freshwater Ecosystems* 30 (9): 1798–1802. https://doi.org/10.1002/aqc.3341.

Pederson, Gregory T., Stephen T. Gray, Connie A. Woodhouse, Julio L. Betancourt, Daniel B. Fagre, Jeremy S. Littell, Emma Watson, Brian H. Luckman, and Lisa J. Graumlich. 2011. “The Unusual Nature of Recent Snowpack Declines in the North American Cordillera.” *Science* 333 (6040): 332–35. https://doi.org/10.1126/science.1201570.

Rangwala, Imtiaz, and James R. Miller. 2012. “Climate Change in Mountains: A Review of Elevation-Dependent Warming and Its Possible Causes.” *Climatic Change* 114 (3–4): 527–47. http://dx.doi.org/10.1007/s10584-012-0419-3.

Remmer, Casey R., Rebecca Rooney, Suzanne Bayley, and Catriona Leven. “The Importance of Groundwater to the Upper Columbia River Floodplain Wetlands.” Canadian Water Resources Journal / Revue Canadienne Des Ressources Hydriques 0, no. 0 (2023): 1–15. https://doi.org/10.1080/07011784.2023.2234869.

Sandilands, A.P. 2005. *Nonpasserines: Waterfowl Through Cranes.* Birds of Ontario: Habitat Requirements, Limiting Factors, and Status. UBC Press. https://books-scholarsportal-info.proxy.lib.uwaterloo.ca/en/read?id=/ebooks/ebooks0/gibson_crkn/2009-12-01/3/406803#page=114.

Thompson, Stella, Mia Vehkaoja, Jani Pellikka, and Petri Nummi. 2021. “Ecosystem Services Provided by Beavers Castor Spp.” *Mammal Review* 51 (1): 25–39. https://doi.org/10.1111/mam.12220.

Tockner, K., F. Malard, and J. V. Ward. 2000. “An Extension of the Flood Pulse Concept.” *Hydrological Processes* 14 (16–17): 2861–83. https://doi.org/10.1002/1099-1085(200011/12)14:16/17<2861::AID-HYP124>3.0.CO;2-F.

Utzig, Greg. 2021. “The Columbia Wetlands and Climate Disruption: A Preliminary Assessment.”

Westbrook, Cherie J., David J. Cooper, and Bruce W. Baker. 2006. “Beaver Dams and Overbank Floods Influence Groundwater–Surface Water Interactions of a Rocky Mountain Riparian Area.” *Water Resources Research* 42 (6). https://doi.org/10.1029/2005WR004560.

Zimmerman, Ellen. 2004. “Columbia Wetlands Ramsar Information Sheet.” The East Kootenay Environmental Society.

7 Appendices

7.1 Appendix 1: List of sites

Including easting and northing, 2020, 2021, 2022, and modal group, and whether bird surveys were conducted at each site.

Site	Easting	Northing	2020 Wetland Group	2021 Wetland Group	2022 Wetland Group	Modal Group	Bird Surveys
21	532535	5652873	4 - Least Connected	3 - Least Connected	3 - Partially Connected - Smaller Gaps	Least Connected	Yes
24	535422	5651111	1 - Most Connected	1 - Most Connected	1 - Most Connected	1 - Most Connected	Yes
29	543167	5641399	ND	1 - Most Connected	1 - Most Connected	1 - Most Connected	No
30	544030	5639666	1 - Most Connected	1 - Most Connected	1 - Most Connected	1 - Most Connected	Yes
31	545913	5637403	2 - Partially Connected - Bigger Gaps	3 - Least Connected	2 - Partially Connected - Bigger Gaps	Partially Connected	Yes
32	545543	5637069	1 - Most Connected	1 - Most Connected	1 - Most Connected	1 - Most Connected	No
35	550776	5630949	2 - Partially Connected - Bigger Gaps	3 - Least Connected	4 - Least Connected	Least Connected	Yes
36	551130	5630189	2 - Partially Connected - Bigger Gaps	1 - Most Connected	2 - Partially Connected - Bigger Gaps	Partially Connected	No
38	549892	5630542	4 - Least Connected	3 - Least Connected	2 - Partially Connected - Bigger Gaps	Least Connected	Yes
39	550531	5628689	2 - Partially Connected - Bigger Gaps	Partially Connected	3 - Partially Connected - Smaller Gaps	Partially Connected	No
43	555476	5623684	2 - Partially Connected - Bigger Gaps	3 - Least Connected	3 - Partially Connected - Smaller Gaps	Partially Connected	No
47	563287	5612893	4 - Least Connected	3 - Least Connected	4 - Least Connected	Least Connected	No
48	562874	5612685	3 - Partially Connected - Smaller Gaps	Partially Connected	ND	Partially Connected	No
49	563443	5608264	4 - Least Connected	3 - Least Connected	4 - Least Connected	Least Connected	Yes
51	567072	5601686	3 - Partially Connected - Smaller Gaps	Partially Connected	2 - Partially Connected - Bigger Gaps	Partially Connected	No
59	543772	5638706	1 - Most Connected	1 - Most Connected	1 - Most Connected	1 - Most Connected	No
62	544859	5639039	3 - Partially Connected - Smaller Gaps	3 - Least Connected	3 - Partially Connected - Smaller Gaps	Partially Connected	Yes
64	546804	5635861	1 - Most Connected	1 - Most Connected	1 - Most Connected	1 - Most Connected	No
68	545273	5635944	1 - Most Connected	1 - Most Connected	1 - Most Connected	1 - Most Connected	No

Site	Easting	Northing	2020 Wetland Group	2021 Wetland Group	2022 Wetland Group	Modal Group	Bird Surveys
69	544325	5639373	4 - Least Connected	3 - Least Connected	2 - Partially Connected - Bigger Gaps	Least Connected	Yes
70	551389	5627697	2 - Partially Connected - Bigger Gaps	1 - Most Connected	1 - Most Connected	1 - Most Connected	No
71	550149	5630945	2 - Partially Connected - Bigger Gaps	1 - Most Connected	2 - Partially Connected - Bigger Gaps	Partially Connected	Yes
110	542996	5638520	3 - Partially Connected - Smaller Gaps	Partially Connected	3 - Partially Connected - Smaller Gaps	Partially Connected	No
126	549517	5631250	2 - Partially Connected - Bigger Gaps	Partially Connected	4 - Least Connected	Partially Connected	No
127	549090	5631267	4 - Least Connected	3 - Least Connected	2 - Partially Connected - Bigger Gaps	Least Connected	Yes
128	548571	5631699	2 - Partially Connected - Bigger Gaps	Partially Connected	3 - Partially Connected - Smaller Gaps	Partially Connected	No
129	528755	5654469	4 - Least Connected	Partially Connected	3 - Partially Connected - Smaller Gaps	Partially Connected	No
130	528565	5654310	2 - Partially Connected - Bigger Gaps	1 - Most Connected	1 - Most Connected	1 - Most Connected	No
131	528247	5655396	4 - Least Connected	3 - Least Connected	2 - Partially Connected - Bigger Gaps	Least Connected	Yes
132	533588	5652117	1 - Most Connected	1 - Most Connected	1 - Most Connected	1 - Most Connected	Yes
137	550568	5629167	3 - Partially Connected - Smaller Gaps	Partially Connected	3 - Partially Connected - Smaller Gaps	Partially Connected	No
140	543498	5641456	ND	Partially Connected	ND	NA	No
141	540750	5645785	ND	Partially Connected	3 - Partially Connected - Smaller Gaps	Partially Connected	Yes
142	536898	5649710	ND	3 - Least Connected	3 - Partially Connected - Smaller Gaps	NA	Yes
143	531008	5653564	ND	3 - Least Connected	3 - Partially Connected - Smaller Gaps	NA	Yes
144	523973	5657202	ND	3 - Least Connected	2 - Partially Connected - Bigger Gaps	NA	Yes
145	523706	5657294	ND	1 - Most Connected	1 - Most Connected	1 - Most Connected	Yes

7.2 Appendix 2: Detailed methods of fieldwork and analysis

2 Methods

We conducted research in a total of 38 wetlands (Figure 6), working over three years from 2020 to 2022, with the majority of fieldwork completed in 2021 and 2022. In 2020, only 30 wetlands were studied and eight new wetlands were picked in 2021 to better represent the different types of wetland present in the Columbia Wetlands ecosystem. Wetlands were chosen for inclusion in this study based on local expert knowledge and previous work conducted in the Columbia Wetlands.

2.1 Fieldwork

2.1.1 Wetland Hydrology

We measured water levels (m) and water temperature at individual wetlands using HOBO U-20 (HOBO by Onset, Cape Cod, Massachusetts, USA) water level loggers, installed each year in May and removed in October, with pressure (later converted to water depth) and temperature being recorded every four hours. All measurements were corrected with a barometric pressure sensor located at Brisco. In 2021 and 2022 there were equipment failures, resulting in data from 37 and 36 wetlands respectively. Similarly, one or both of the two water level loggers in the Columbia River were lost in all three years, so for Columbia River water depth we instead used a publicly available dataset from the Environment and Climate Change Canada hydrometric station on the Columbia River at Nicholson (cite this!).

2.1.2 Levee Gaps and Beaver Dams

We identified potential locations of beaver dams, beaver lodges, and levee gaps within the wetland, and within 10m, 20m, and 30m of the 38 study wetlands using ArcGIS Pro 2.8.0 and a combination of orthophotos, satellite imagery, LiDAR imagery, and digital elevation models (Airborne Imagery, 2015; Forest, Lands, and Natural Resource Operations and Rural Development, Geo BC, 2018). These buffer distances were included as in several instances we found that the dam(s) responsible for holding water into the wetland were not within the boundaries of the wetland itself. From the imagery, using ArcGIS Pro 2.8.0 tools, we measured the length of beaver dams, the perimeter length (m) and area (m^2) of each wetland and levee gaps. All gaps were included to determine the total gap width (m) in each wetland, regardless of whether these gaps were influencing water levels in the wetlands. Gaps that did not influence wetland water levels were then excluded from further analysis and 'Inflow Gaps' were summarized to determine the width of gaps influencing water levels within each wetland. Inflow gaps were determined based on characteristics visible on ArcGIS and then confirmed via in person fieldwork (Appendix 5).

Once we determined the locations of beaver dams and gaps through remote sensing, we conducted in-person fieldwork at each wetland site. In-person fieldwork was essential, as not all dams and gaps were visible from remote sensing sources, and measuring all the required dam dimensions, as well as determining how the dams or gaps affected the hydrology of the wetland itself, was not possible otherwise. All dams and gaps were visited and measured between August 2021 and May 2022, within the same flood year. This timing was important because dams and gaps could not be measured during high water. We walked and/or kayaked the perimeter of each wetland to identify beaver dams and gaps, using the remote sensing derived information as a guide for where there were likely to be dams or gaps; in some instances we located dams on the ground that were not visible through remote sensing. Once at a dam or gap location, we measured the dimensions of the feature (Appendix 6), took notes on building material, beaver activity (active, where there were signs of fresh mud or new sticks; inactive, where there were no such signs but the dam was still in good repair; and old, where the dam was no longer in good repair), water flow, and its influence on the wetland, as well as drawing a rough sketch of the feature. Preliminary digital measurements were then amended based on this ground-truthing in the field.

2.1.3 Migratory bird surveys

We conducted migratory bird surveys in 20 wetlands (Appendix 1). We found that time of day did not have a consistent or large impact on the numbers of species and birds present at a site, after which point we surveyed sites for as long as possible on a single day. In case diurnal patterns are significant, however, with some sites maybe being chosen as roost sites and some as feeding sites, we made sure to vary the times of day at which we surveyed each site, and will take time of survey into account in my analysis. We did not survey in inclement weather (e.g., heavy snow and rain, fog), but on days when such weather was inconsistent we did conduct surveys in the periods of suitable weather. We surveyed each site using binoculars and a spotting scope, and took photographs of birds present, for a minimum of 15 minutes up to however long it took to count and identify to species (if possible) all waterfowl and raptors using the wetland. We also recorded weather conditions, human disturbances, and other factors that might have affected the presence of waterfowl. I also entered count data on eBird.

We did six spring migratory waterfowl counts at each of the site in April 2022 and five in April 2023. Larson *et al.* (2020) concluded that due to the variability of waterfowl count data, three surveys were the minimum required for data analysis.

2.1.4 Submersed Aquatic Vegetation

We classified submersed aquatic vegetation in 16 study wetlands in August 2023. We placed ten 1 m^2 quadrats across each wetland to capture a representative sample of the open water area. In each quadrat, we

estimated total infestation of all vegetation. We then identified all submersed aquatic vegetation to the lowest taxonomic group possible and estimated percent infestation of each individual species using the system developed by Rooney *et al*. (2013) which is usable as a proxy for biovolume to quantify relative abundance of submersed plants. We used a rake to rake up vegetation within the quadrat to identify and to determine relative biovolumes if necessary. For species where we were unsure of identification in the field, we took photographs, notes, and samples for later identification. In some wetlands we did not do 10 quadrats due to the small area (or no area) of open water. We also recorded water depth in each quadrat.

2.2 Statistical Analysis

2.2.1 Hydrograph Variables

All analyses unless otherwise specified were performed using R Statistical Software (v4.3.2; R Core Team, 2021) and plotted using the ggplot2 package (v3.5.0; Wickham, 2016). We first visually observed the differences in wetland patterns using hydrographs of each wetland in the three study years. We then calculated hydrograph variables from the 2020, 2021, and 2022 water level data (Appendix 3). We used Goodbrand and MacDonald (2022) and Neary *et.al.* (2021) as guidance for what variables would be suitable for classifying wetland types based on hydrograph data.

2.2.2 Wetland characterisation of floodplain wetland basins

Using these hydrograph variables, we conducted a Principal Component Analysis (PCA) to visualise hydrologic differences between wetlands using the factoextra package (v1.0.7; Kassambara, 2020). We then assessed the importance of each Principle Component (PC) axis and variable contributing to that axis. We followed Kaiser's Rule in determining which of the PC axes should be retained, where all components with eigenvalues greater than 1 should be kept for statistical inference. For all three years, We retained 6 Principal Components (Table 1). In 2022, PC 6 only had an eigenvalue of 0.99; I retained six components in this year to maintain consistency over the three years. For all three years, this resulted in more than 90% of the total variance being explained. I then took the PCA axis values and performed a Hierarchical Cluster Analysis on these to further explore and visualise differences in wetland groups, and to reduce overemphasising certain aspects of wetland hydrology due to repetition in the collected hydrologic variables (e.g. slope of flood pulse rise and length of flood pulse rise). I used the stats package (v3.6.2; R Core Team, 2021). I specified Euclidean linkage method and Ward D2 distance measure. Group selection from the resulting dendrogram was informed by the NbClust package (v3.1.0; Charrad, 2022), which determined the most parsimonious number of groups.

To determine if there were significant differences in hydrology among wetland groups, we performed one-way ANOVAs using the stats package (v3.6.2; R Core Team, 2021), testing whether each hydrologic metric was effected by wetland group (e.g. Did wetland group have an effect on amplitude of the rising limb of the hydrograph?). We repeated this for all hydrologic metrics that explained greater than 5% of the variance of each PCA axis.

Based on analysis of the wetland hydrographs, the hydrological variables and associated PCA and Hierarchical Cluster Analysis, and the levee and beaver dam variables, wetland groups were described by their connectivity to the Columbia River. In 2020 and 2022 the following four groups were identified: 1) Most Connected, 2) Partially Connected – Bigger Gaps, 3) Partially Connected – Smaller Gaps, and 4) Least Connected. In 2021, only three groups were identified: 1) Most Connected, 2) Partially Connected, and 3) Least Connected. A modal group for each wetland was assigned based on which group each wetland was assigned in the majority of the study years (i.e. 2 out of 3). As only three groups were identified in 2021, the modal group was assigned from one of those three groups, with wetlands in Partially Connected – Bigger Gaps and Partially Connected – Smaller Gaps being described as Partially Connected for consistency. Characteristics associated with these groups are discussed further in section 3.1.

2.2.3. Prediction of wetland groups by levee gap and beaver dam data

We then performed a Random Forest Analysis using identified wetland groups and collected levee gap and beaver dam data (Appendix 7) to determine if these variables can predict wetland group membership in each year. We used the randomForest package (v4.7-1.1; Llaw, 2022). We standardised all the numeric input variables using Z-score standardisation:

$$\frac{(\chi - \mu)}{\sigma}$$

Where X = data point value, μ = variable mean, and σ = variable standard deviation, to reduce over-dominance by variables with larger values. We then ran Random Forest models with and without area and perimeter included in the input variables and with different numbers of variables used at each split to determine the model with the lowest estimated out-of-box error.

To determine if there was statistical significance in gap and dam metrics between the wetland groups, We also visualised the gap and dam metrics and performed one-way ANOVAs using the stats package (v3.6.2; R Core Team, 2021).

7.3 Appendix 3: Hydrological variables

All hydrological variables used to determine wetland groups (see Appendix 2 for detailed methods). See Appendix 4 for explanations of variables.

Site	Year	Mean Depth (m)	Initial Depth (m)	Final Depth (m)	Max Depth (m)	Min Depth (m)	Change (m)	Early Peak Depth (m)	Day deepest	Day shallowest	Depth 2 weeks after deepest date	Depth 4 weeks after deepest date	Day 2 weeks	Day 4 weeks	Day rise started	Day fall started	Day fall ended	Depth rise started	Depth fall started	Depth fall ended	Length of rise
21	2020	1.62	1.64	1.59	2.13	1.52	0.61	1.65	180	243	1.63	1.58	194.00	208.00	172	181	200	1.64	2.12	1.55	8.00
24	2020	1.37	0.53	0.12	2.82	0.11	2.72	2.09	180	278	2.17	2.01	194.00	208.00	140	182	268	0.53	2.73	0.19	40.00
30	2020	1.11	0.41	0.25	2.48	0.24	2.24	1.67	180	280	1.77	1.57	194.00	208.00	140	181	246	0.41	2.44	0.32	40.00
31	2020	1.51	1.19	1.21	2.59	1.18	1.41	1.79	180	141	1.82	1.65	194.00	208.00	152	181	228	1.20	2.58	1.28	28.00
32	2020	1.41	0.70	0.49	2.77	0.49	2.28	2.01	180	280	2.02	1.87	194.00	208.00	141	181	245	0.69	2.75	0.69	39.00
35	2020	1.52	1.50	1.12	2.30	1.12	1.18	1.81	181	280	1.80	1.69	195.00	209.00	152	181	252	1.53	2.27	1.17	29.00
36	2020	1.41	0.80	0.79	2.57	0.77	1.80	1.89	181	267	1.88	1.76	195.00	209.00	141	182	249	0.79	2.52	0.85	40.00
38	2020	2.24	1.66	1.84	3.17	1.65	1.52	2.66	181	149	2.64	2.58	195.00	209.00	152	182	226	1.70	3.12	1.95	29.00
39	2020	0.92	0.68	0.64	1.69	0.64	1.05	1.12	181	280	1.11	1.02	195.00	209.00	152	182	221	0.68	1.66	0.87	29.00
43	2020	1.37	1.00	1.12	2.13	0.98	1.15	1.54	181	151	1.54	1.43	195.00	209.00	152	181	280	1.00	2.10	1.12	29.00
47	2020	2.15	1.65	2.02	2.91	1.62	1.30	1.85	180	151	2.45	2.37	194.00	208.00	151	181	280	1.62	2.89	2.01	29.00
48	2020	1.02	0.41	0.94	1.79	0.39	1.40	0.53	180	151	1.39	1.31	194.00	208.00	151	181	280	0.39	1.76	0.92	29.00
49	2020	2.01	1.82	1.95	2.38	1.81	0.57	1.97	180	140	2.07	2.07	194.00	208.00	152	180	186	1.86	2.34	2.06	28.00
51	2020	0.96	0.42	0.44	1.93	0.42	1.51	1.31	179	141	1.32	1.27	193.00	207.00	142	180	255	0.44	1.86	0.49	37.00
59	2020	0.80	0.00	0.00	2.28	0.00	2.28	1.34	180	270	1.43	1.23	194.00	208.00	140	181	254	0.00	2.24	0.02	40.00
62	2020	1.20	0.80	1.05	1.90	0.78	1.13	0.91	180	141	1.41	1.38	194.00	208.00	143	181	280	0.80	1.87	1.04	37.00
64	2020	1.14	0.43	0.42	2.28	0.42	1.87	1.68	180	280	1.68	1.59	194.00	208.00	141	181	255	0.44	2.23	0.48	39.00
69	2020	1.40	0.97	1.27	2.27	0.94	1.33	1.15	180	151	1.60	1.52	194.00	208.00	152	181	189	0.95	2.23	1.62	28.00
68	2020	1.23	0.36	0.18	2.57	0.17	2.39	1.84	180	280	1.88	1.73	194.00	208.00	140	181	280	0.36	2.55	0.17	40.00
70	2020	1.18	0.30	0.28	2.36	0.27	2.09	1.76	181	280	1.76	1.61	195.00	209.00	140	181	280	0.30	2.33	0.27	41.00
71	2020	1.76	1.10	1.17	2.76	1.10	1.66	2.20	181	141	2.22	2.10	195.00	209.00	140	182	280	1.10	2.71	1.17	41.00
110	2020	0.64	0.44	0.46	1.27	0.41	0.86	0.53	180	150	0.80	0.72	194.00	208.00	152	181	208	0.43	1.24	0.71	28.00
126	2020	1.07	0.96	0.81	1.71	0.81	0.90	1.15	181	280	1.27	1.16	195.00	209.00	152	182	280	0.94	1.68	0.81	29.00
127	2020	2.19	2.14	2.00	2.78	1.92	0.86	2.28	181	263	2.40	2.26	195.00	209.00	152	182	221	2.13	2.73	2.18	29.00
128	2020	0.75	0.70	0.53	1.26	0.47	0.79	0.86	181	255	0.98	0.85	195.00	209.00	152	182	247	0.70	1.24	0.51	29.00
129	2020	1.21	1.22	1.07	1.89	1.06	0.83	1.23	181	261	1.27	1.16	195.00	209.00	172	182	194	1.24	1.84	1.24	9.00
130	2020	1.13	0.55	0.51	2.33	0.49	1.83	1.63	181	253	1.72	1.55	195.00	209.00	140	182	231	0.55	2.27	0.56	41.00

Site	Year	Mean Depth (m)	Initial Depth (m)	Final Depth (m)	Max Depth (m)	Min Depth (m)	Change (m)	Early Peak Depth (m)	Day deepest	Day shallowest	Depth 2 weeks after deepest date	Depth 4 weeks after deepest date	Day 2 weeks	Day 4 weeks	Day rise started	Day fall started	Day fall ended	Depth rise started	Depth fall started	Depth fall ended	Length of rise
131	2020	1.79	1.35	1.65	2.64	1.34	1.30	1.95	181	140	2.03	1.87	195.00	209.00	152	181	222	1.43	2.62	1.60	29.00
132	2020	1.41	0.64	0.69	2.67	0.57	2.11	2.00	180	261	2.06	1.95	194.00	208.00	140	181	244	0.64	2.64	0.61	40.00
137	2020	0.72	0.19	0.50	1.67	0.17	1.50	0.26	181	151	1.11	1.02	195.00	209.00	157	181	280	0.22	1.64	0.49	24.00
Briver	2020	1.95	1.11	0.94	3.13	0.86	2.27	2.58	181	273	2.57	2.40	195.00	209.00	140	182	267	1.14	3.10	0.97	41.00
21	2021	1.76	1.75	1.70	2.40	1.59	0.82	1.94	183	207	1.64	1.61	197.00	211.00	167	184	198	1.73	2.34	1.61	16.00
24	2021	1.21	0.25	0.15	2.95	0.13	2.82	2.50	183	207	1.96	1.18	197.00	211.00	167	184	198	0.26	2.91	0.14	49.00
29	2021	0.97	0.24	0.19	2.29	0.18	2.11	1.76	182	285	1.43	1.19	196.00	210.00	138	184	287	0.25	2.25	0.20	44.00
30	2021	1.01	0.02	0.25	2.62	0.01	2.60	2.02	183	135	1.56	0.98	197.00	211.00	136	184	239	0.02	2.58	0.31	47.00
31	2021	1.53	1.22	1.24	2.76	1.20	1.56	2.17	183	143	1.69	1.33	197.00	211.00	153	184	208	1.24	2.72	1.33	30.00
32	2021	1.32	0.70	0.69	2.88	0.69	2.19	2.33	183	236	1.85	1.23	197.00	211.00	137	184	237	0.69	2.84	0.69	46.00
35	2021	1.72	1.57	1.42	2.67	1.41	1.26	2.30	183	278	1.99	1.63	197.00	211.00	155	184	208	1.56	2.63	1.65	28.00
36	2021	1.42	0.87	0.90	2.77	0.83	1.94	2.34	183	137	1.91	1.37	197.00	211.00	138	184	239	0.86	2.73	0.97	45.00
38	2021	2.10	1.68	1.69	3.24	1.64	1.60	2.90	182	152	2.59	2.03	196.00	210.00	152	184	231	1.64	3.21	1.87	30.00
39	2021	1.02	0.76	0.78	1.89	0.71	1.18	1.60	182	154	1.18	0.95	196.00	210.00	155	184	200	0.73	1.86	0.99	27.00
43	2021	1.47	1.03	1.26	2.29	0.99	1.30	2.06	183	153	1.56	1.43	197.00	211.00	154	184	212	1.00	2.27	1.40	29.00
47	2021	2.18	1.89	1.96	2.96	1.80	1.16	2.59	181	154	2.44	2.23	195.00	209.00	156	184	206	1.84	2.91	2.23	25.00
48	2021	1.26	0.78	1.03	1.97	0.70	1.26	1.68	181	154	1.54	1.34	195.00	209.00	155	184	210	0.71	1.93	1.33	26.00
49	2021	2.03	1.89	1.94	2.43	1.87	0.56	2.16	181	137	2.07	2.03	195.00	209.00	174	184	189	2.08	2.38	2.08	7.00
51	2021	1.26	0.81	0.87	2.41	0.78	1.63	1.99	181	137	1.66	1.28	195.00	209.00	137	182	255	0.78	2.39	0.89	44.00
59	2021	0.77	0.04	0.04	2.49	0.03	2.46	1.78	183	135	1.24	0.69	197.00	211.00	136	184	239	0.04	2.44	0.09	47.00
62	2021	1.45	1.06	1.29	2.31	1.02	1.29	1.27	183	142	1.64	1.57	197.00	211.00	156	184	193	1.04	2.29	1.66	27.00
64	2021	0.98	0.34	0.33	2.38	0.31	2.07	1.93	183	282	1.54	0.95	197.00	211.00	137	184	241	0.34	2.36	0.37	46.00
68	2021	1.22	0.29	0.23	2.81	0.23	2.58	2.27	183	287	1.83	1.23	197.00	211.00	134	184	284	0.30	2.79	0.25	49.00
69	2021	1.62	1.09	1.43	2.56	1.02	1.54	1.86	183	153	1.66	1.65	197.00	211.00	153	184	197	1.02	2.51	1.66	30.00
70	2021	1.20	0.30	0.47	2.51	0.29	2.22	2.25	182	134	1.88	1.24	196.00	210.00	135	185	270	0.30	2.46	0.54	47.00
71	2021	1.75	1.12	1.25	2.94	1.10	1.84	2.59	183	137	2.23	1.74	197.00	211.00	139	184	252	1.11	2.91	1.33	44.00
110	2021	0.73	0.31	0.56	1.48	0.28	1.20	0.59	183	141	0.90	0.83	197.00	211.00	143	184	213	0.29	1.46	0.79	40.00
126	2021	0.77	0.58	0.56	1.53	0.52	1.01	1.10	183	155	0.94	0.75	197.00	211.00	156	184	212	0.54	1.51	0.74	27.00
127	2021	2.24	2.09	2.00	3.00	1.99	1.01	2.65	183	287	2.39	2.19	197.00	211.00	166	185	200	2.26	2.95	2.30	17.00
128	2021	0.48	0.28	0.24	1.33	0.19	1.14	1.04	183	268	0.77	0.32	197.00	211.00	153	184	209	0.23	1.29	0.33	30.00
129	2021	1.06	0.97	0.92	1.90	0.89	1.01	1.42	183	252	1.02	0.93	197.00	211.00	167	184	201	1.03	1.89	0.95	16.00

Site	Year	Mean Depth (m)	Initial Depth (m)	Final Depth (m)	Max Depth (m)	Min Depth (m)	Change (m)	Early Peak Depth (m)	Day deepest	Day shallowest	Depth 2 weeks after deepest date	Depth 4 weeks after deepest date	Day 2 weeks	Day 4 weeks	Day rise started	Day fall started	Day fall ended	Depth rise started	Depth fall started	Depth fall ended	Length of rise
130	2021	1.02	0.47	0.44	2.50	0.42	2.08	2.01	183	285	1.60	0.81	197.00	211.00	145	184	239	0.53	2.45	0.44	38.00
131	2021	1.59	1.43	1.40	2.55	1.39	1.17	2.09	183	278	1.65	1.42	197.00	211.00	166	184	201	1.52	2.52	1.44	17.00
132	2021	1.25	0.39	0.38	2.86	0.37	2.49	2.38	183	283	1.95	1.19	197.00	211.00	135	184	240	0.40	2.80	0.48	48.00
137	2021	0.84	0.22	0.52	1.77	0.16	1.61	1.09	182	156	1.17	1.03	196.00	210.00	157	184	287	0.17	1.74	0.51	25.00
140	2021	1.01	0.96	0.87	1.69	0.84	0.85	1.18	182	278	1.07	0.97	196.00	210.00	154	184	213	0.90	1.67	0.94	28.00
141	2021	1.10	1.02	0.64	2.08	0.64	1.44	1.76	183	286	1.33	0.94	197.00	211.00	152	184	213	0.97	2.05	0.91	31.00
142	2021	1.72	1.45	1.36	2.87	1.35	1.52	2.42	183	287	1.94	1.56	197.00	211.00	153	184	207	1.41	2.83	1.59	30.00
143	2021	1.54	1.51	1.51	2.00	1.46	0.54	1.61	183	202	1.49	1.49	197.00	211.00	167	184	194	1.51	1.97	1.49	16.00
144	2021	1.46	1.29	1.14	2.64	1.13	1.52	2.04	183	278	1.82	1.24	197.00	211.00	154	185	207	1.25	2.60	1.24	29.00
145	2021	0.71	0.18	0.14	2.16	0.12	2.04	1.55	183	247	1.28	0.64	197.00	211.00	137	185	237	0.17	2.12	0.14	46.00
21	2022	1.57	1.52	1.48	1.98	1.37	0.61	1.56	187	219	1.83	1.56	201.00	215.00	169	200	220	1.59	1.85	1.37	18.00
24	2022	1.36	0.23	0.08	2.80	0.07	2.74	1.50	187	286	2.64	2.21	201.00	215.00	144	200	270	0.15	2.67	0.12	43.00
29	2022	1.01	0.00	0.42	1.88	0.00	1.88	0.20	186	152	1.71	1.32	200.00	214.00	153	198	260	0.01	1.75	0.41	33.00
30	2022	1.14	0.00	0.21	2.43	0.00	2.43	1.21	186	148	2.28	1.81	200.00	214.00	148	200	256	0.00	2.28	0.34	38.00
31	2022	1.91	1.50	1.53	2.85	1.47	1.38	1.52	187	149	2.71	2.15	201.00	215.00	157	198	231	1.51	2.76	1.57	30.00
32	2022	1.48	0.69	0.39	2.76	0.39	2.37	1.46	187	290	2.62	2.08	201.00	215.00	151	198	252	0.71	2.68	0.76	36.00
35	2022	1.72	1.44	1.32	2.42	1.30	1.12	1.43	197	288	2.11	1.67	211.00	225.00	163	198	252	1.44	2.37	1.40	34.00
36	2022	1.59	0.88	1.01	2.66	0.85	1.82	1.31	188	151	2.50	2.03	202.00	216.00	153	198	255	0.87	2.62	0.99	35.00
38	2022	2.41	1.81	1.99	3.27	1.76	1.51	1.79	188	155	3.17	2.80	202.00	216.00	160	198	254	1.81	3.23	2.03	28.00
39	2022	1.15	0.82	0.83	1.80	0.75	1.05	0.78	188	155	1.69	1.24	202.00	216.00	163	197	219	0.77	1.77	1.09	25.00
43	2022	1.60	1.17	1.33	2.23	1.09	1.15	1.12	188	153	2.13	1.67	202.00	216.00	162	197	219	1.13	2.21	1.53	26.00
47	2022	2.11	1.77	1.89	2.74	1.67	1.06	1.71	196	155	2.34	2.18	210.00	224.00	164	200	239	1.72	2.64	2.11	32.00
49	2022	2.08	1.93	2.02	2.38	1.91	0.48	1.97	196	146	2.13	2.10	210.00	224.00	161	197	206	1.97	2.33	2.11	35.00
51	2022	1.61	1.02	1.11	2.50	0.98	1.52	1.44	186	146	2.32	1.86	200.00	214.00	154	196	253	1.02	2.42	1.21	32.00
59	2022	0.93	0.00	0.09	2.30	0.00	2.30	0.94	186	148	2.14	1.53	200.00	214.00	148	199	256	0.00	2.17	0.10	38.00
62	2022	1.08	0.70	0.87	1.66	0.64	1.03	0.67	186	155	1.48	1.25	200.00	214.00	164	199	235	0.67	1.52	1.15	22.00
63	2022	1.66	1.31	1.36	2.32	1.21	1.11	1.36	187	155	2.14	1.80	201.00	215.00	157	199	225	1.23	2.20	1.60	30.00
64	2022	1.12	0.34	0.36	2.20	0.31	1.89	0.97	187	148	2.08	1.67	201.00	215.00	149	199	262	0.32	2.13	0.44	38.00
68	2022	1.22	0.07	0.14	2.48	0.07	2.42	1.22	187	139	2.34	1.86	201.00	215.00	148	199	290	0.12	2.42	0.14	39.00
69	2022	1.95	1.46	1.77	2.65	1.37	1.28	1.40	186	161	2.48	2.07	200.00	214.00	162	200	221	1.38	2.47	1.93	24.00
70	2022	1.22	0.28	0.34	2.33	0.24	2.10	0.95	188	148	2.24	1.88	202.00	216.00	148	198	290	0.24	2.29	0.33	40.00

Site	Year	Mean Depth (m)	Initial Depth (m)	Final Depth (m)	Max Depth (m)	Min Depth (m)	Change (m)	Early Peak Depth (m)	Day deepest	Day shallowest	Depth 2 weeks after deepest date	Depth 4 weeks after deepest date	Day 2 weeks	Day 4 weeks	Day rise started	Day fall started	Day fall ended	Depth rise started	Depth fall started	Depth fall ended	Length of rise
71	2022	1.86	1.14	1.25	2.84	1.08	1.76	1.30	188	151	2.70	2.36	202.00	216.00	155	200	255	1.09	2.74	1.43	33.00
110	2022	0.64	0.39	0.38	1.22	0.29	0.93	0.33	186	155	1.06	0.80	200.00	214.00	156	199	235	0.30	1.10	0.66	30.00
126	2022	1.00	0.81	0.73	1.57	0.71	0.86	0.76	197	290	1.24	0.96	211.00	225.00	165	198	239	0.76	1.53	0.89	32.00
127	2022	2.47	2.34	2.17	3.04	2.15	0.89	2.32	188	290	2.95	2.65	202.00	216.00	163	201	221	2.31	2.97	2.39	25.00
128	2022	0.51	0.22	0.17	1.15	0.15	1.00	0.21	187	278	1.10	0.89	201.00	215.00	160	200	254	0.22	1.12	0.17	27.00
129	2022	1.38	1.27	1.21	1.94	1.19	0.74	1.29	187	288	1.79	1.38	201.00	215.00	164	200	219	1.29	1.81	1.23	23.00
130	2022	1.15	0.46	0.43	2.29	0.41	1.88	0.99	187	289	2.16	1.75	201.00	215.00	155	199	255	0.56	2.20	0.46	32.00
131	2022	1.79	1.56	1.56	2.47	1.54	0.93	1.58	187	289	2.33	1.93	201.00	215.00	162	201	220	1.58	2.33	1.56	25.00
132	2022	1.25	0.26	0.28	2.55	0.21	2.34	1.34	187	144	2.37	2.00	201.00	215.00	147	199	256	0.24	2.41	0.36	40.00
137	2022	0.86	0.24	0.54	1.62	0.15	1.47	0.18	188	161	1.50	1.21	202.00	216.00	169	199	210	0.22	1.58	1.20	19.00
142	2022	1.46	1.06	1.03	2.33	1.00	1.34	1.02	187	155	2.19	1.74	201.00	215.00	160	199	223	1.04	2.24	1.32	27.00
143	2022	1.45	1.42	1.42	1.67	1.38	0.30	1.43	187	212	1.57	1.41	201.00	215.00	170	199	210	1.43	1.58	1.40	17.00
144	2022	2.28	2.02	1.84	3.18	1.83	1.35	2.00	187	288	3.05	2.57	201.00	215.00	160	201	232	2.00	3.05	1.94	27.00
145	2022	0.82	0.21	0.15	1.92	0.13	1.79	0.56	188	265	1.76	1.32	202.00	216.00	152	200	252	0.17	1.80	0.15	36.00
Briver	2022	2.59	1.58	1.46	3.74	1.44	2.30	2.58	188	288	3.64	3.28	NA	NA	NA	NA	NA	NA	NA	NA	NA
141	2022	0.95	0.57	0.51	1.73	0.49	1.25	0.80	187	271	1.61	1.31	201.00	215.00	156	200	257	0.59	1.64	0.54	31.00

Site	Year	Length of fall	Amplitude of rise	Amplitude of fall	2 week slope	4 week slope	Slope of rise	Slope of fall	Max Depth - Early Peak	Fall end depth - lowest depth	Final depth - Initial depth	Fall End Depth - Rise Start Depth
21	2020	19.00	0.48	0.57	0.04	0.02	0.06	0.03	0.48	0.03	-0.06	-0.57
24	2020	86.00	2.29	2.54	0.05	0.03	0.06	0.03	0.74	0.08	-0.41	-2.54
30	2020	65.00	2.07	2.12	0.05	0.03	0.05	0.03	0.81	0.08	-0.16	-2.12
31	2020	47.00	1.39	1.30	0.06	0.03	0.05	0.03	0.80	0.10	0.02	-1.30
32	2020	64.00	2.08	2.06	0.05	0.03	0.05	0.03	0.76	0.20	-0.21	-2.06
35	2020	71.00	0.77	1.10	0.04	0.02	0.03	0.02	0.49	0.05	-0.38	-1.10
36	2020	67.00	1.78	1.68	0.05	0.03	0.04	0.03	0.68	0.08	-0.01	-1.68
38	2020	44.00	1.47	1.17	0.04	0.02	0.05	0.03	0.51	0.30	0.18	-1.17
39	2020	39.00	1.01	0.79	0.04	0.02	0.03	0.02	0.57	0.23	-0.04	-0.79
43	2020	99.00	1.13	0.99	0.04	0.02	0.04	0.01	0.58	0.14	0.13	-0.99
47	2020	99.00	1.30	0.88	0.03	0.02	0.04	0.01	1.06	0.39	0.37	-0.88
48	2020	99.00	1.40	0.84	0.03	0.02	0.05	0.01	1.26	0.53	0.53	-0.84

49	2020	6.00	0.52	0.29	0.02	0.01	0.02	0.05	0.41	0.25	0.13	-0.29
51	2020	75.00	1.49	1.37	0.04	0.02	0.04	0.02	0.62	0.07	0.02	-1.37
59	2020	73.00	2.28	2.22	0.06	0.04	0.06	0.03	0.94	0.02	0.00	-2.22
62	2020	99.00	1.10	0.82	0.04	0.02	0.03	0.01	1.00	0.26	0.26	-0.82
64	2020	74.00	1.84	1.76	0.04	0.02	0.05	0.02	0.61	0.06	-0.01	-1.76
69	2020	8.00	1.32	0.61	0.05	0.03	0.05	0.08	1.12	0.68	0.31	-0.61
68	2020	99.00	2.20	2.38	0.05	0.03	0.06	0.02	0.73	0.00	-0.19	-2.38
70	2020	99.00	2.06	2.05	0.04	0.03	0.05	0.02	0.60	0.00	-0.02	-2.05
71	2020	98.00	1.65	1.54	0.04	0.02	0.04	0.02	0.55	0.07	0.07	-1.54
110	2020	27.00	0.84	0.54	0.03	0.02	0.03	0.02	0.74	0.29	0.02	-0.54
126	2020	98.00	0.77	0.87	0.03	0.02	0.03	0.01	0.56	0.00	-0.15	-0.87
127	2020	39.00	0.65	0.56	0.03	0.02	0.02	0.01	0.50	0.26	-0.14	-0.56
128	2020	65.00	0.56	0.73	0.02	0.01	0.02	0.01	0.40	0.04	-0.18	-0.73
129	2020	12.00	0.65	0.60	0.04	0.03	0.07	0.05	0.67	0.18	-0.15	-0.60
130	2020	49.00	1.78	1.71	0.04	0.03	0.04	0.03	0.70	0.07	-0.04	-1.71
131	2020	41.00	1.21	1.02	0.04	0.03	0.04	0.02	0.69	0.25	0.30	-1.02
132	2020	63.00	2.04	2.03	0.04	0.03	0.05	0.03	0.68	0.04	0.05	-2.03
137	2020	99.00	1.44	1.15	0.04	0.02	0.06	0.01	1.41	0.32	0.30	-1.15
Briver	2020	85.00	2.00	2.13	0.04	0.03	0.05	0.03	0.55	0.11	-0.17	-2.13
21	2021	14.00	0.68	0.73	0.05	0.03	0.04	0.05	0.46	0.02	-0.06	-0.73
24	2021	64.00	2.69	2.77	0.07	0.06	0.05	0.04	0.44	0.01	-0.11	-2.77
29	2021	103.00	2.04	2.06	0.06	0.04	0.05	0.02	0.53	0.01	-0.05	-2.06
30	2021	55.00	2.60	2.27	0.08	0.06	0.06	0.04	0.59	0.30	0.23	-2.27
31	2021	24.00	1.52	1.40	0.08	0.05	0.05	0.06	0.59	0.12	0.02	-1.40
32	2021	53.00	2.19	2.15	0.07	0.06	0.05	0.04	0.55	0.00	-0.01	-2.15
35	2021	24.00	1.11	0.99	0.05	0.04	0.04	0.04	0.37	0.23	-0.14	-0.99
36	2021	55.00	1.91	1.77	0.06	0.05	0.04	0.03	0.43	0.14	0.03	-1.77
38	2021	47.00	1.60	1.35	0.05	0.04	0.05	0.03	0.34	0.23	0.01	-1.35
39	2021	16.00	1.16	0.87	0.05	0.03	0.04	0.05	0.29	0.28	0.02	-0.87
43	2021	28.00	1.29	0.87	0.05	0.03	0.04	0.03	0.23	0.42	0.23	-0.87
47	2021	22.00	1.11	0.68	0.04	0.03	0.04	0.03	0.37	0.43	0.07	-0.68
48	2021	26.00	1.25	0.60	0.03	0.02	0.05	0.02	0.29	0.63	0.25	-0.60
49	2021	5.00	0.35	0.30	0.03	0.01	0.05	0.06	0.27	0.21	0.04	-0.30
51	2021	73.00	1.63	1.50	0.05	0.04	0.04	0.02	0.42	0.11	0.06	-1.50

59	2021	55.00	2.45	2.34	0.09	0.06	0.05	0.04	0.71	0.06	0.00	-2.34
62	2021	9.00	1.28	0.63	0.05	0.03	0.05	0.07	1.04	0.64	0.23	-0.63
64	2021	57.00	2.05	1.99	0.06	0.05	0.04	0.03	0.45	0.06	-0.01	-1.99
68	2021	100.00	2.52	2.50	0.07	0.06	0.05	0.02	0.54	0.02	-0.06	-2.54
69	2021	13.00	1.54	0.85	0.06	0.03	0.05	0.07	0.70	0.64	0.34	-0.85
70	2021	85.00	2.21	1.92	0.04	0.05	0.05	0.02	0.25	0.25	0.17	-1.92
71	2021	68.00	1.83	1.58	0.05	0.04	0.04	0.02	0.35	0.23	0.13	-1.58
110	2021	29.00	1.19	0.67	0.04	0.02	0.03	0.02	0.89	0.51	0.26	-0.67
126	2021	28.00	0.99	0.77	0.02	0.03	0.04	0.03	0.43	0.22	-0.02	-0.77
127	2021	15.00	0.75	0.66	0.04	0.03	0.04	0.04	0.35	0.31	-0.09	-0.66
128	2021	25.00	1.10	0.96	0.04	0.04	0.04	0.04	0.28	0.14	-0.05	-0.96
129	2021	17.00	0.87	0.94	0.06	0.03	0.05	0.06	0.48	0.06	-0.05	-0.94
130	2021	55.00	1.97	2.01	0.06	0.06	0.05	0.04	0.49	0.01	-0.03	-2.01
131	2021	17.00	1.03	1.08	0.06	0.04	0.06	0.06	0.46	0.05	-0.03	-1.08
132	2021	56.00	2.47	2.32	0.07	0.06	0.05	0.04	0.48	0.11	-0.01	-2.32
137	2021	103.00	1.60	1.23	0.04	0.03	0.06	0.01	0.68	0.35	0.30	-1.23
140	2021	29.00	0.79	0.73	0.04	0.03	0.03	0.03	0.51	0.10	-0.09	-0.73
141	2021	29.00	1.11	1.14	0.05	0.04	0.04	0.04	0.33	0.27	-0.38	-1.14
142	2021	23.00	1.46	1.25	0.07	0.05	0.05	0.05	0.45	0.23	-0.10	-1.25
143	2021	10.00	0.49	0.48	0.04	0.02	0.03	0.05	0.39	0.03	-0.01	-0.48
144	2021	22.00	1.39	1.36	0.03	0.05	0.05	0.06	0.61	0.12	-0.15	-1.36
145	2021	52.00	1.99	1.98	0.06	0.05	0.04	0.04	0.61	0.02	-0.04	-1.98
21	2022	20.00	0.39	0.48	0.01	0.02	0.02	0.02	0.43	0.00	-0.04	-0.48
24	2022	70.00	2.65	2.55	0.01	0.02	0.06	0.04	1.30	0.06	-0.15	-2.55
29	2022	62.00	1.88	1.35	0.01	0.02	0.06	0.02	1.68	0.41	0.42	-1.35
30	2022	56.00	2.43	1.94	0.01	0.02	0.06	0.03	1.22	0.34	0.21	-1.94
31	2022	33.00	1.34	1.19	0.01	0.03	0.04	0.04	1.33	0.10	0.03	-1.19
32	2022	54.00	2.05	1.91	0.01	0.02	0.06	0.04	1.30	0.37	-0.30	-1.91
35	2022	54.00	0.98	0.97	0.02	0.03	0.03	0.02	0.99	0.11	-0.13	-0.97
36	2022	57.00	1.79	1.63	0.01	0.02	0.05	0.03	1.36	0.14	0.12	-1.63
38	2022	56.00	1.47	1.21	0.01	0.02	0.05	0.02	1.48	0.27	0.18	-1.21
39	2022	22.00	1.03	0.67	0.01	0.02	0.04	0.03	1.02	0.34	0.01	-0.67
43	2022	22.00	1.11	0.68	0.01	0.02	0.04	0.03	1.11	0.44	0.16	-0.68
47	2022	39.00	1.02	0.52	0.03	0.02	0.03	0.00	1.03	0.44	0.12	-0.52

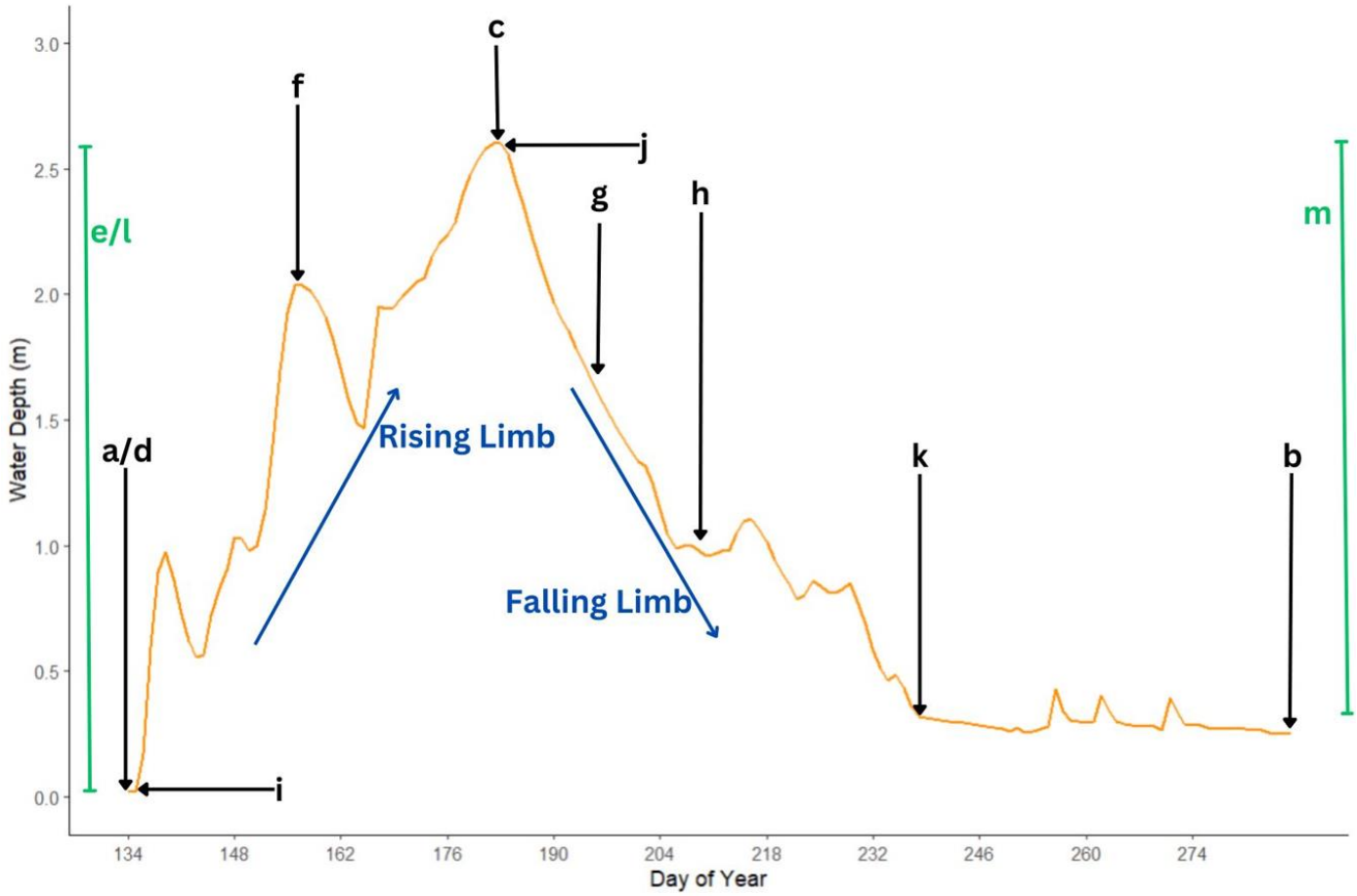
49	2022	9.00	0.41	0.21	0.02	0.01	0.01	0.02	0.42	0.20	0.09	-0.21
51	2022	57.00	1.48	1.21	0.01	0.02	0.05	0.02	1.06	0.23	0.09	-1.21
59	2022	57.00	2.30	2.07	0.01	0.03	0.06	0.04	1.36	0.10	0.09	-2.07
62	2022	36.00	1.00	0.37	0.01	0.01	0.05	0.01	1.00	0.51	0.18	-0.37
63	2022	26.00	1.09	0.60	0.01	0.02	0.04	0.02	0.96	0.39	0.05	-0.60
64	2022	63.00	1.88	1.69	0.01	0.02	0.05	0.03	1.22	0.13	0.03	-1.69
68	2022	91.00	2.37	2.28	0.01	0.02	0.06	0.03	1.27	0.08	0.08	-2.28
69	2022	21.00	1.27	0.53	0.01	0.02	0.05	0.03	1.25	0.57	0.31	-0.53
70	2022	92.00	2.10	1.97	0.01	0.02	0.05	0.02	1.38	0.09	0.06	-1.97
71	2022	55.00	1.75	1.32	0.01	0.02	0.05	0.02	1.53	0.35	0.12	-1.32
110	2022	36.00	0.92	0.44	0.01	0.01	0.03	0.01	0.89	0.37	-0.01	-0.44
126	2022	41.00	0.81	0.64	0.02	0.02	0.03	0.02	0.82	0.18	-0.08	-0.64
127	2022	20.00	0.73	0.58	0.01	0.01	0.03	0.03	0.73	0.24	-0.17	-0.58
128	2022	54.00	0.93	0.95	0.00	0.01	0.03	0.02	0.94	0.02	-0.05	-0.95
129	2022	19.00	0.65	0.58	0.01	0.02	0.03	0.03	0.65	0.04	-0.06	-0.58
130	2022	56.00	1.73	1.74	0.01	0.02	0.05	0.03	1.30	0.05	-0.04	-1.74
131	2022	19.00	0.89	0.77	0.01	0.02	0.04	0.04	0.90	0.02	-0.01	-0.77
132	2022	57.00	2.31	2.05	0.01	0.02	0.06	0.04	1.21	0.15	0.02	-2.05
137	2022	11.00	1.40	0.38	0.01	0.01	0.07	0.03	1.44	1.04	0.30	-0.38
142	2022	24.00	1.30	0.92	0.01	0.02	0.05	0.04	1.31	0.32	-0.03	-0.92
143	2022	11.00	0.24	0.19	0.01	0.01	0.01	0.02	0.25	0.02	-0.01	-0.19
144	2022	31.00	1.18	1.10	0.01	0.02	0.04	0.04	1.18	0.12	-0.18	-1.10
145	2022	52.00	1.75	1.65	0.01	0.02	0.05	0.03	1.37	0.02	-0.06	-1.65
Briver	2022	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
141	2022	57.00	1.15	1.10	0.01	0.02	0.04	0.02	0.93	0.05	-0.06	-1.10

7.4 Appendix 4: Description of hydrological variables

Hydrological variables are derived from the hydrograph for each wetland in each year; Appendix Figure 1 also illustrates some variables.

Variable	Spreadsheet Abbreviation	Description
Wetland	Wetland	Wetland ID number
Year	Year	Year of data collection
Mean Depth (m)	Mean Depth (m)	Mean depth calculated from all water depth data points from May to October
Initial Depth (m)	Initial Depth (m)	Depth when water logger was installed in wetland and data collection started (in May for all three years); a in Appendix Figure 1
Final Depth (m)	Final Depth (m)	Depth when water logger was removed from wetland and data collection ended (in October for all three years); b in Appendix Figure 1
Maximum Depth (m)	Maximum Depth (m)	Maximum depth during the data collection period; c in Appendix Figure 1
Minimum Depth (m)	Minimum Depth (m)	Minimum depth during the data collection period; d in Appendix Figure 1
Change in Depth (m)	Change (m)	The difference between the maximum and minimum depths (maximum depth minus minimum depth); e in Appendix Figure 1
Early Peak Depth (m)	Early Peak Depth (m)	In many years the river has a two-part flood pulse with a small increase in water earlier in the season before the main flood-pulse. In 2020 this was June 7th and in 2021 it was Jun 8th; there was no such early peak in 2022, but for comparative purposes I used the depth on June 7th. f in Appendix Figure 1
Day of Maximum Depth	Day deepest	The Day of Year/Julian Day on which the Maximum Depth was recorded; this was the variable used for analysis instead of date.
Day of Minimum Depth	Day shallowest	The Day of Year/Julian Day on which the Minimum Depth was recorded; this was the variable used for analysis instead of date.
Depth 2 Weeks After Maximum Depth	Depth 2 weeks after deepest date	The depth recorded two weeks (14 days) after the Maximum Depth was recorded, as a measure of the falling limb of the hydrograph; g in Appendix Figure 1
Depth 4 Weeks After Maximum Depth	Depth 4 weeks after deepest date	The depth recorded four weeks (28 days) after the Maximum Depth was recorded, as a measure of the falling limb of the hydrograph; h in Appendix Figure 1
Day 2 Weeks After Maximum Depth	Day 2 weeks	The Day of Year/Julian Day two weeks (14 days) after the Maximum Depth was recorded
Day 4 Weeks After Maximum Depth	Day 4 weeks	The Day of Year/Julian Day four weeks (28 days) after the Maximum Depth was recorded
Beginning Depth of Rising Limb of Hydrograph	Day rise started	The depth at which the rising limb of the hydrograph began; i in Appendix Figure 1
Beginning Depth of Falling Limb of Hydrograph	Day fall started	The depth at which the falling limb of the hydrograph began; j in Appendix Figure 1

End Depth of Falling Limb of Hydrograph	Day fall ended	The depth at which the falling limb of the hydrograph ended; k in Appendix Figure 1
Day Rise Started	Depth rise started	The Day of Year/Julian Day on which the rising limb of the hydrograph began; the date on which the Beginning Depth of Rising Limb of Hydrograph was recorded
Day Fall Started	Depth fall started	The Day of Year/Julian Day on which the falling limb of the hydrograph began; the date on which the Beginning Depth of Falling Limb of Hydrograph was recorded
Day Fall Ended	Depth fall ended	The Day of Year/Julian Day on which the falling limb of the hydrograph ended; the date on which the End Depth of Falling Limb of Hydrograph was recorded
Length of Rise	Length of rise	The number of days between the Day Rise Started and the Day of Maximum Depth
Length of Fall	Length of fall	The number of days between the Day Fall Started and the Day Fall Ended
Amplitude of Rising Limb	Amplitude of rise	The difference between the Beginning Depth of Rising Limb and the Maximum Depth; the amplitude of the rising limb of the hydrograph; i in Appendix Figure 1. In Appendix Figure 1 this is the same as Change in Depth (e) but this is not always the case (e.g. some wetlands have their shallowest depth in October not May).
Amplitude of Falling Limb	Amplitude of fall	The difference between the Maximum Depth and the End Depth of Falling Limb; the amplitude of the falling limb of the hydrograph; m in Appendix Figure 1
2-week Slope	2 week slope	The slope of the falling limb between Maximum Depth and Depth Two Weeks After Maximum Depth; (Maximum Depth – Depth Two Weeks After Maximum Depth) ÷ (Two Weeks)
4-week Slope	4 week slope	The slope of the falling limb between Maximum Depth and Depth Four Weeks After Maximum Depth; (Maximum Depth – Depth Four Weeks After Maximum Depth) ÷ (Four Weeks)
Slope of Rise	Slope of rise	The slope of the rising limb between Beginning Depth of Rising Limb and Maximum Depth; (Beginning Depth of Rising Limb – Maximum Depth) ÷ (Beginning Depth of Rising Limb – Day of Maximum Depth)
Slope of Fall	Slope of fall	The slope of the falling limb between Maximum Depth and Depth Fall Ended; (Maximum Depth – Depth Fall Ended) ÷ (Day of Maximum Depth – Day Fall Ended)
Max Depth - Early Peak	Max Depth - Early Peak	Maximum Depth minus Early Peak Depth
Fall end depth - Minimum Depth	Fall end depth - lowest depth	End Depth of Falling Limb minus Minimum Depth
Final depth - Initial depth	Final depth - Initial depth	Final Depth minus Initial Depth
Fall End Depth - Rise Start Depth	Fall End Depth - Rise Start Depth	End Depth of Falling Limb minus Beginning Depth of Rising Limb



Appendix Figure 1: Hydrograph with various hydrological variables indicated in it.

7.5 Appendix 5: List of all gaps

All 76 gaps in the 38 wetlands located during this project, including their length (m), coordinates, the type of flow they allow (from a creek, from the Columbia River, or between different wetlands), the wetland they are associated with, and an estimate of how much flow they allow.

Site	Length (m)	Easting	Northing	Flow Type	Wetland	Flow
71	6.141517	533161.2565	5652049.257	Creek	21	Partial
15	24.893359	534921.5953	5651029.603	River	24	Yes
16	25.458515	535083.1347	5650985.545	River	24	Yes
17	6.376966	536163.5906	5650166.597	River	24	Yes
24	6.901693	535748.6244	5650446.176	River	24	Yes
25	9.590938	535778.3825	5650426.466	River	24	Yes
26	7.612752	535843.7784	5650368.078	River	24	Yes
27	2.548828	536219.5641	5650128.851	River	24	Yes
60	35.005776	536553.798	5649934.089	Between	24	Partial
29	5.92368	543007.8592	5639809.519	Creek	30	Partial
55	25.460025	544233.2534	5639644.455	River	30	Yes
31	6.712468	545243.1177	5637345.398	River	31	Yes
30	22.286735	545364.125	5637022.36	River	32	Yes
65	90.932422	546563.0816	5634839.68	Between	32	Yes
66	11.090475	545807.7941	5636503.909	Between	32	Yes
67	10.915157	545886.1436	5636462.485	Between	32	Yes
53	13.81519	550362.9299	5631117.131	Between	35	Partial
40	6.372885	550496.387	5628803.98	River	36	Partial
44	9.932595	552486.9529	5627571.369	River	36	Partial
45	13.764772	552882.7755	5627313.8	River	36	Partial
46	9.175271	550792.1145	5629304.904	River	36	No
68	3.448838	550938.0983	5629906.766	River	36	Yes
38	6.180095	550328.1779	5630502.364	River	38	Partial
39	5.682428	550426.4626	5629776.155	River	38	Partial
43	10.395809	550941.2605	5630123.205	River	43	Yes
47	8.422075	555290.5646	5623790.791	Between	43	Partial
74	12.408544	555846.0435	5622058.364	River	43	Yes
48	5.038287	564090.6818	5609438.731	River	49	Partial
49	15.135733	566874.8332	5603116.979	River	51	Yes
50	11.169073	567431.2574	5601792.353	River	51	Yes
51	9.42228	566951.0646	5601236.576	Between	51	Partial
52	17.65629	566628.6165	5601069.848	Between	51	Partial
56	14.508731	544030.7112	5638909.891	River	59	Yes
61	18.565673	543815.6679	5638138.925	Between	59	No
62	9.017384	543940.6325	5638161.662	Between	59	No
57	9.321968	544283.8698	5638429.969	River	62	No
63	19.773274	544647.267	5639259.107	River	62	No

Site	Length (m)	Easting	Northing	Flow Type	Wetland	Flow
64	25.447703	544727.0034	5637161.61	Between	63	Partial
34	4.95868	546774.903	5635830.832	River	64	Partial
32	32.859154	545496.9046	5636754.946	River	68	Yes
33	24.892575	545622.712	5634678.128	Between	68	Partial
73	30.805878	545434.7426	5636060.411	River	68	Yes
22	8.435164	544508.4034	5639453.13	River	69	No
41	13.579639	551086.4541	5628003.038	River	70	Yes
42	15.196324	553932.9556	5624641.712	Between	70	Partial
36	3.19426	550147.9652	5631070.201	River	71	Yes
37	1.699973	550166.2158	5631075.159	Partial	71	Partial
35	4.966876	549376.9647	5631479.321	River	127	Partial
70	66.068981	528665.9996	5654545.691	Creek	129	Yes
2	10.272638	527262.3422	5655875.896	River	130	Yes
3	3.195472	527616.9515	5655757.668	River	130	Partial
4	4.431353	527674.8569	5655710.678	River	130	Partial
5	11.556243	527814.753	5655586.71	River	130	Partial
8	10.122296	531115.3832	5652772.752	River	130	Partial
9	12.429047	529844.7854	5653178.558	River	130	Partial
10	26.648345	529539.1244	5653655.251	River	130	Yes
23	10.111973	529186.4756	5653585.359	River	130	Yes
69	14.077658	528631.501	5654545.482	Creek	130	Yes
7	9.093137	528604.1391	5654472.792	Between	130	Partial
11	8.191307	528703.558	5654367.217	Between	130	Partial
6	2.510863	528325.2174	5654688.984	Between	130	Partial
59	6.942217	528473.9195	5654653.568	Between	130	Partial
12	9.707181	531033.2481	5653404.33	Between	130	Partial
58	18.746356	527837.3383	5655567.668	River	131	Partial
13	24.523959	533369.6824	5651651.661	River	132	Yes
14	8.567115	533162.634	5652045.141	Creek	132	Partial
54	3.363489	533069.5823	5651968.738	River	132	Yes
20	13.946944	543150.5186	5641657.533	River	140	Partial
21	14.440718	543647.7704	5640911.673	River	140	Partial
28	6.947139	543589.7137	5640935.59	River	140	No
19	10.277599	540555.085	5645966.617	River	141	Partial
72	16.271294	541065.888	5644627.837	River	141	Partial
18	23.926546	536517.5835	5649725.708	River	142	Partial
0	10.579563	523410.1608	5657727.71	None	145	No
1	10.782324	523617.572	5657580.718	River	145	Yes

7.6 Appendix 6: List of all beaver dams

All 205 beaver dams located within 30m of the 38 study wetlands, with dam length, coordinates of the dam, and the wetland site each dam is associated with.

Dam Number	Dam Length (m)	Easting	Northing	Associated Site
20	20.8219584	531883.763	5652677.912	21
21	11.39934415	531978.9127	5652660.135	21
22	20.31248109	532851.3925	5652160.366	21
27	33.19528593	536501.8172	5649965.472	24
174	33.66709333	536554.0442	5649934.658	24
176	17.02980097	543189.4583	5641619.852	29
178	14.92235967	543196.4549	5641518.565	29
180	9.276479187	543287.2168	5641269.487	29
48	11.15434956	543873.456	5639170.111	30
49	10.40400206	543690.7206	5639187.546	30
50	16.81915898	543164.106	5639339.055	30
51	8.015539931	543074.206	5639329.597	30
52	5.89055246	543217.3644	5639535.729	30
53	13.00617205	543243.6689	5639551.691	30
54	9.107756952	543266.6029	5639551.674	30
61	12.14082268	543667.3552	5639023.156	30
62	11.03226342	543525.3371	5638998.476	30
63	6.86692438	543442.8365	5639017.687	30
64	10.42536672	543366.6392	5639014.366	30
116	5.686822136	543773.9585	5639012.369	30
121	8.512432109	543199.7454	5638928.689	30
77	4.81703026	550898.9843	5629291.457	36
78	54.51498142	551344.1479	5629675.399	36
102	65.77696483	551281.9703	5628600.907	36
103	43.67775788	551259.5096	5628663.639	36
104	19.41177395	551281.0703	5628651.242	36
141	6.6073602	551082.6947	5630128.154	36
142	5.993427486	551020.0212	5630143	36
75	7.924097346	550321.1071	5630444.188	38
76	7.417059888	550382.5851	5629757.37	38
86	36.78732812	555312.0122	5623770.693	43
87	14.54871336	555362.2538	5623790.679	43
88	16.71290972	555447.464	5623861.632	43
89	11.64297555	554923.2589	5623014.049	43
90	11.33253435	555557.9768	5622395.689	43
91	7.848812175	555639.9451	5622188.972	43
92	8.529403068	555684.0803	5622196.326	43
93	9.358097658	555694.3948	5622159.458	43
94	15.88105345	567469.8721	5602066.744	51
95	11.09950639	567407.2258	5602415.197	51
96	2.894392402	567127.1647	5603019.04	51

Dam Number	Dam Length (m)	Easting	Northing	Associated Site
97	4.098537607	567116.4702	5603032.042	51
98	6.414713671	567105.6035	5603039.289	51
99	3.468287799	567079.4919	5603049.383	51
100	3.183615736	567053.3735	5603043.13	51
101	2.413332695	567038.4292	5603035.78	51
60	23.63264852	544045.1273	5638933.77	59
65	5.989028575	543244.3873	5638768.674	59
66	57.51260437	543219.1668	5638345.196	59
68	40.1929364	543434.6751	5638342.349	59
69	44.4268921	543990.5852	5638152.667	59
114	14.21757911	543966.5013	5638575.959	59
115	10.76350855	544029.4582	5638661.38	59
117	15.28150443	544030.4311	5638683.173	59
118	12.48353632	544033.6107	5638712.062	59
119	12.71246471	544037.2764	5638737.524	59
120	16.70067332	544060.2815	5638853.157	59
122	8.512432109	543199.7454	5638928.689	59
153	15.86880136	543214.4561	5638358.738	59
154	3.678419304	543925.4048	5638181.04	59
155	21.75688029	543832.4946	5638157.112	59
184	57.51260437	543219.1668	5638345.196	59
188	228.0726982	543119.9831	5638566.982	59
204	15.86880136	543214.4561	5638358.738	59
182	17.21511562	544648.1146	5639260.023	62
190	27.24707926	544687.3913	5639144.577	62
192	10.747736	544355.0377	5638693.968	62
194	11.59548056	544631.993	5639044.945	62
196	6.19959464	544657.8396	5639068.016	62
70	24.87238694	544728.1912	5637160.225	63
71	5.289120051	544702.1047	5636965.053	63
72	6.894809305	544885.8892	5636806.865	63
124	14.0621532	544594.2665	5637403.192	63
125	8.787594013	544542.9251	5637385.145	63
126	46.71025985	544375.4659	5637396.877	63
127	38.01554249	544384.0746	5637349.99	63
128	53.48549909	544379.8144	5637282.288	63
129	26.60420881	544227.0492	5637125.653	63
130	15.61112965	544099.6712	5637044.168	63
131	34.0255288	544508.612	5636869.505	63
132	38.50734726	544552.9115	5636899.399	63
133	11.26289945	544578.4121	5636968.023	63
134	10.08308518	544592.924	5636914.852	63
135	22.12927304	544589.1667	5637036.304	63
136	38.18154177	544599.1273	5637259.571	63
137	24.98998627	544414.9181	5637468.998	63
138	14.57267652	544570.2991	5637539.647	63

Dam Number	Dam Length (m)	Easting	Northing	Associated Site
139	14.24518645	544583.5215	5637546.482	63
140	4.473474703	546779.6422	5635830.403	64
73	6.340880715	544909.851	5635599.701	68
55	16.97718033	544519.2008	5639457.443	69
56	10.90865858	544499.9303	5639445.723	69
57	12.20493873	544560.4434	5639394.434	69
58	12.95008525	544568.8819	5639380.114	69
59	14.14523678	544606.6882	5639315.849	69
123	7.832788083	544282.0306	5638428.913	69
183	17.21511562	544648.1146	5639260.023	69
191	27.24707926	544687.3913	5639144.577	69
193	10.747736	544355.0377	5638693.968	69
195	11.59548056	544631.993	5639044.945	69
197	6.19959464	544657.8396	5639068.016	69
79	13.99893496	551584.4135	5627175.14	70
80	22.48690522	552638.8535	5626629.738	70
81	53.95107034	552539.646	5626463.067	70
82	11.47830653	553316.3602	5625483.918	70
83	12.48836419	553782.5229	5624999.733	70
84	13.54537929	553926.9103	5624745.101	70
85	15.74406838	553934.473	5624698.005	70
74	3.330902528	550146.6603	5631065.013	71
67	57.51260437	543219.1668	5638345.196	110
109	20.47997569	543152.4891	5638343.28	110
110	17.56620542	543122.8712	5638370.972	110
111	228.0726982	543119.9831	5638566.982	110
185	57.51260437	543219.1668	5638345.196	110
189	228.0726982	543119.9831	5638566.982	110
205	15.86880136	543214.4561	5638358.738	110
112	24.87036762	548769.4795	5631059.356	127
168	12.83011272	529487.6035	5654136.267	129
198	43.78199591	528884.9565	5654251.95	129
200	8.738730114	528702.7816	5654348.923	129
5	10.10116967	527884.3246	5654915.972	130
9	28.65643836	528666.2969	5654121.042	130
14	23.57765208	529766.6774	5653296.042	130
15	15.7996017	529789.3579	5653245.808	130
16	26.28240642	529807.5457	5653215.552	130
17	4.572128889	529855.9868	5653182.994	130
18	15.33885402	529847.8522	5653153.562	130
143	8.738730114	528702.7816	5654348.923	130
158	15.90090027	527741.5506	5655680.16	130
160	18.67018682	527781.3418	5655648.374	130
162	18.74633477	527837.3383	5655567.668	130
164	251.3677277	527912.9961	5655487.06	130
166	21.1253051	528267.4843	5654710.863	130

Dam Number	Dam Length (m)	Easting	Northing	Associated Site
169	12.83011272	529487.6035	5654136.267	130
170	9.150838712	530389.5757	5653779.563	130
172	23.7791923	530992.0868	5653454.664	130
186	12.00875519	530479.7264	5653715.657	130
199	43.78199591	528884.9565	5654251.95	130
201	8.738730114	528702.7816	5654348.923	130
202	6.586676318	527724.1915	5655697.445	130
4	251.3677277	527912.9961	5655487.06	131
6	14.9139232	528440.1466	5654698.844	131
7	20.32910335	528468.0097	5654676.731	131
8	4.818749721	528568.8012	5654610.742	131
159	15.90090027	527741.5506	5655680.16	131
161	18.67018682	527781.3418	5655648.374	131
163	18.74633477	527837.3383	5655567.668	131
165	251.3677277	527912.9961	5655487.06	131
167	21.1253051	528267.4843	5654710.863	131
203	6.586676318	527724.1915	5655697.445	131
23	5.313056809	533125.585	5652019.866	132
24	17.13777724	533274.031	5651746.406	132
25	24.01796335	533354.626	5651649.852	132
26	28.16099841	533449.8432	5651388.251	132
106	215.6242279	533946.5331	5651342.992	132
107	175.773267	533995.5524	5651297.784	132
145	57.35882699	533945.8429	5651443.138	132
146	17.19993713	533206.9348	5651792.798	132
147	49.5387546	533360.7547	5651627.191	132
148	33.28321147	533493.9661	5651330.871	132
43	12.70015057	543034.1416	5641994.525	140
44	17.02980097	543189.4583	5641619.852	140
45	14.92235967	543196.4549	5641518.565	140
46	9.276479187	543287.2168	5641269.487	140
47	16.65995123	543625.8396	5641015.326	140
177	17.02980097	543189.4583	5641619.852	140
179	14.92235967	543196.4549	5641518.565	140
181	9.276479187	543287.2168	5641269.487	140
33	16.31483538	540533.3744	5645922.75	141
34	3.39630924	540601.6183	5645961.002	141
35	2.0494965	540639.7599	5645933.78	141
36	27.55144629	540577.2071	5645591.607	141
37	16.69144489	540594.1131	5645549.42	141
38	10.16396624	540769.9248	5644896.073	141
39	26.79618316	540819.0963	5644890.378	141
40	97.34567222	540846.2159	5644812.51	141
41	40.70090355	540987.2972	5644724.055	141
42	42.43482589	541085.2463	5644652.003	141
108	3.425558988	540949.4942	5644698.483	141

Dam Number	Dam Length (m)	Easting	Northing	Associated Site
113	24.60953576	541186.1162	5644590.285	141
151	3.583882357	541073.2268	5644645.278	141
152	8.236681881	540555.1939	5645967.634	141
28	12.64490827	536694.6906	5649848.495	142
29	15.96209287	536730.5913	5649820.146	142
30	7.311350338	536625.7875	5649711.798	142
31	14.61444303	536705.5768	5649668.956	142
32	19.31345963	536787.3652	5649665.789	142
149	8.683565062	536963.1865	5649259.246	142
150	1.828127316	536940.5027	5649246.233	142
175	33.66709333	536554.0442	5649934.658	142
10	9.150838712	530389.5757	5653779.563	143
11	17.9190107	530518.4906	5653638.865	143
12	48.75530072	530858.7329	5653628.088	143
13	23.7791923	530992.0868	5653454.664	143
19	15.75591314	531736.763	5652778.99	143
105	12.00875519	530479.7264	5653715.657	143
144	10.51319622	531411.3112	5652956.871	143
171	9.150838712	530389.5757	5653779.563	143
173	23.7791923	530992.0868	5653454.664	143
187	12.00875519	530479.7264	5653715.657	143
156	33.92988671	523785.8263	5657232.937	144
1	63.44243087	523415.3662	5657702.465	145
2	6.224595358	523599.3211	5657564.161	145
3	45.85672316	523270.1802	5657780.721	145
157	33.92988671	523785.8263	5657232.937	145

7.7 Appendix 7: Summary of dams and gaps directly influencing study sites

See Appendix 6 for explanation of variables

Wetland	Perimeter	Area	NoGap	GapW	GapD	PerGap	NoDam	DamL	PerDam	GapDepth	PerGapPerDam	GapStat	DamStat	DamHW	Levee	Water	GapV
43	6080.64	0.75	1	10.8	0.7	0.18	1	64.13	1.05	-0.65	-0.88	Dammed	Active	Yes	796.94	797.59	-7.02
21	3733.51	0.49	1	17.2	0.85	0.46	1	211.18	5.66	-0.65	-5.20	Dammed	Active	Yes	798.98	799.63	-11.18
129	4428.91	0.32	2	22.45	1.14	0.51	2	257.25	5.81	-0.49	-5.30	Dammed	Active	Yes	799.55	800.04	-11.00
110	1157.18	0.04	1	31.6	1.03	2.73	1	41.50	3.59	-0.25	-0.86	Dammed	Active	Yes	799.40	799.65	-7.90
132	4882.55	0.75	2	25.3	1.2	0.52	1	2.15	0.04	-0.22	0.47	Open	Old	Partly	798.20	798.42	-5.57
35	2030.47	0.16	1	23.5	0.57	1.16	1	19.00	0.94	-0.18	0.22	Dammed	Active	Yes	797.21	797.39	-4.23
141	3478.63	0.24	3	18.18	1.29	0.52	3	23.24	0.67	-0.16	-0.15	Dammed	Active	Partly	798.54	798.70	-2.85
126	2721.2	0.19	0	0	0	0.00	0	0.00	0.00	0.00	0.00	None	Levee	Levee	797.10	797.10	0.00
48	4950.26	0.53	0	0	0	0.00	0	0.00	0.00	0.00	0.00	None	Levee	Levee	796.00	796.00	0.00
137	1698.16	0.17	0	0	0	0.00	0	0.00	0.00	0.00	0.00	None	Levee	Levee	796.71	796.71	0.00
47	4932.59	0.78	0	0	0	0.00	0	0.00	0.00	0.00	0.00	None	Levee	Levee	796.97	796.97	0.00
127	2589.05	0.13	0	0	0	0.00	0	0.00	0.00	0.00	0.00	None	Levee	Levee	797.02	797.02	0.00
29	2053.61	0.08	0	0	0	0.00	0	0.00	0.00	0.00	0.00	None	Levee	Levee	797.75	797.75	0.00
63	1653.56	0.13	0	0	0	0.00	0	0.00	0.00	0.00	0.00	None	Levee	Levee	797.40	797.40	0.00
69	1655.1	0.12	2	29.5	1.035	1.78	2	54.30	3.28	0.00	-1.50	Dammed	Active	Yes	797.49	797.49	0.00
144	2352.94	0.19	1	57.3	0.92	2.44	1	57.30	2.44	0.00	0.00	Dammed	Old	Yes	798.87	798.87	0.00
143	2220.6	0.08	0	0	0	0.00	0	111.00	5.00	0.00	-5.00	Dammed	Active	Yes	799.50	799.50	0.00
131	2902.72	0.29	1	18.65	0.91	0.64	1	166.24	5.73	0.00	-5.08	Dammed	Active	Yes	799.31	799.31	0.00
49	4357.68	0.61	1	116	1.37	2.66	1	232.00	5.32	0.00	-2.66	Dammed	Active	Yes	796.28	796.28	0.00
62	4074.77	0.55	1	36.84	1.51	0.90	1	36.84	0.90	0.01	0.00	Dammed	Active	Yes	797.78	797.77	0.37
128	1767.28	0.12	1	1.1	0.74	0.06	1	2.10	0.12	0.03	-0.06	Dammed	Active	Partly	797.11	797.08	0.03
142	3619.67	0.39	2	5.95	0.64	0.16	2	4.23	0.12	0.14	0.05	Dammed	Old	Yes	798.03	797.89	0.83
39	2302.09	0.12	1	2.8	1	0.12	1	1.70	0.07	0.20	0.05	Dammed	Active	Yes	797.02	796.82	0.56
24	4720.58	0.46	2	17.9	2.68	0.38	1	3.50	0.07	0.33	0.31	Open	Old	Partly	797.78	797.45	5.91
71	2445.7	0.22	1	5.6	1.1	0.23	1	1.70	0.07	0.47	0.16	Dammed	Active	Partly	796.99	796.52	2.63
140	2256.5	0.17	2	39.59	1.475	1.75	2	45.29	2.01	0.56	-0.25	Dammed	Active	Yes	798.31	797.75	22.17
32	7600.45	1.35	2	50	1	0.66	0	0.00	0.00	1.00	0.66	Open	None	No	797.38	796.38	50.00
59	3546.51	0.56	2	31.4	1.09	0.89	1	18.70	0.53	1.09	0.36	Open	Old	Partly	798.61	797.52	34.23
36	10029.26	2.07	3	19.94	1.2	0.20	0	0.00	0.00	1.20	0.20	Open	None	No	797.15	795.95	23.93
51	10166.99	2.26	1	10.31	1.2	0.10	0	0.00	0.00	1.20	0.10	Open	None	No	797.77	796.57	12.37

30	5652.57	1.11	1	28.5	1.3	0.50	0	0.00	0.00	1.30	0.50	Open	None	No	797.60	796.30	37.05
31	4021.09	0.4	1	7.04	1.35	0.18	0	0.00	0.00	1.35	0.18	Open	Old	No	797.37	796.02	9.50
145	1910.78	0.13	1	10.5	1.35	0.55	0	0.00	0.00	1.35	0.55	Open	None	No	798.96	797.61	14.18
64	2431.48	0.14	1	2.2	1.4	0.09	0	0.00	0.00	1.40	0.09	Open	None	No	797.26	795.86	3.08
130	12695.03	2.72	4	88.33	1.4	0.70	0	0.00	0.00	1.40	0.70	Open	None	No	798.01	796.61	123.66
38	4225.03	0.54	1	5	2.8	0.12	1	6.10	0.14	1.70	-0.03	Dammed	Active	Yes	797.36	795.66	8.50
68	6495.4	1.35	3	66.98	1.82	1.03	0	0.00	0.00	1.82	1.03	Open	None	No	797.29	795.47	121.90
70	11961.62	3.27	2	43.55	2.05	0.36	0	0.00	0.00	2.05	0.36	Open	None	No	796.85	794.80	89.28

7.8 Appendix 8: Explanation of gap and beaver dam variables

Variable Name	Spreadsheet Abbreviation	Description	Units
Wetland Perimeter	Perimeter	Total length of wetland perimeter	m
Wetland Area	Area	Total wetland area	Km^2
Number of Gaps	NoGap	Count of number of gaps in the levees	Count
Total Gap Width	GapW	Total width of all gaps (including those with beaver dams across them) in the levees	m
Mean Gap Depth	GapD	Mean depth of open gaps (i.e. not gaps that have beaver dams across them)	m
Gap Percentage	PerGap	Percentage of wetland perimeter that is gap (i.e. (gap length / wetland perimeter)*100)	%
Number of Dams	NoDam	Count of number of dams in the levees	Count
Total Dam Length	DamL	Total length of all dams in the wetland	m
Dam Percentage	PerDam	Percentage of wetland perimeter that is dam (i.e. (dam width / wetland perimeter)*100)	m
Gap Depth Including Dams	GapDepth	Mean depth of all gaps within wetland, including those that have dams in them (i.e. gaps with dams will be less deep than gaps without dams; in this case gap depth would be the distance from the top of the levee to the top of the dam)	%
Difference Between Gap Percentage and Dam Percentage	PerGapPerDam	Percentage of wetland perimeter that is gap minus percentage of wetland perimeter that is dam (i.e. Gap percentage – dam percentage)	%
Gap Status	GapStat	Assessment of whether the wetlands gaps are Open (gaps present, no dams), Dammed (gaps are present but beaver dams have been built), or None (no gaps are present). If a wetland had one open gap and one dammed gap it was characterized as Open.	Categorical
Dam Status	DamStat	Assessment of dam status and activity, whether dams were Active (signs of beaver activity such as fresh mud or sticks observed), Old (no such signs were seen), None (no dams present), or Levee (no gaps present).	Categorical
Are Dams Holding Water?	DamHW	Yes, No, or Partly	Categorical
Levee Elevation	Levee	Estimated lowest levee elevation along the wetland perimeter	m above sea level
Elevation At Which Water Enters Wetland	Water	Estimated elevation at which water can enter the wetland, i.e. the levee elevation for wetlands without gaps, and the levee elevation minus Gap Depth Including Dams for wetlands with gaps	m above sea level
Gap volume	GapV	Gap Depth Including Dams multipled by Gap Width to give an estimate of gap volume, i.e. how much water can enter the wetland through the gaps. For wetlands without gaps, this is 0.	m^3

7.9 Appendix 9: Water quality data

Date	Time	Site	Round	Depth (m)	Secchi Depth (m)	Temperature (°C)	Pressure (mmHg)	Dissolved Oxygen (%)	Dissolved Oxygen (mg/L)	Specific Conductance (uS/cm)	Conductivity (uS/cm)	pH	Turbidity (FNU)
2023-05-26	1135	110	2	0.56	0.56	15.5	692.9	116.6	11.55	581	477.6	7.88	4.4
2023-05-26	1201	30	2	1.55	1.1	14.3	692.6	91.2	8.89	208.9	166.2	8.29	30.31
2023-05-26	1230	69	2	0.88	0.88	15.7	692.4	96.6	9.57	210.4	172.8	8.53	3.03
2023-05-26	1245	62	2	0.79	0.79	20.9	692.4	144.9	13.01	417.7	384.1	8.91	2
2023-05-26	1357	43	2	1.35	1.35	15.3	691.4	100.7	10.17	356.3	284.6	8.26	2.08
2023-05-26	1628	47	2	0.87	0.87	19.8	690.1	87.7	8	316.5	284.9	8.27	0.48
2023-05-26	1650	48	2	1	1	19.2	690.1	178.5	16.47	247.9	220.5	9.28	1.2
2023-05-27	1021	141	2	1.06	1.06	18.5	690.5	95	8.89	287.8	251.6	8.49	4.93
2023-05-27	1100	142	2	1.1	1	16.4	690.2	57.5	5.6	241.2	201.3	7.92	6.4
2023-05-27	1145	24	2	2.05	1	14.8	689.7	86.4	8.75	228.5	183.8	8.24	10.05
2023-05-27	1220	21	2	1.51	1.51	18.4	689.4	109.9	10.33	209.5	182.9	8.71	1.44
2023-05-27	1257	143	2	0.89	0.89	18.8	689.6	86.3	8.03	502	442.3	8.27	1.5
2023-05-27	1314	131	2	1.04	1.04	18.1	689	95.8	9.05	267.3	231.6	8.2	1
2023-05-27	1335	132	2	1.39	1.18	16.9	688.7	93.2	9.02	217.2	183.1	8.32	11.21
2023-05-27	1429	29	2	0.71	0.71	17.7	687.8	59	5.6	215.8	185.8	7.7	5.5
2023-05-27	1500	140	2	0.9	0.9	21.8	687.4	184.5	16.25	362.1	339.6	9.14	1.58
2023-05-28	1015	70	2	1.35	1.35	18.2	690.1	97.3	9.2	233.4	202.9	8.33	5.74
2023-05-28	1043	39	2	1.28	1.28	19.2	690	95	8.75	236	210	8.32	0.77
2023-05-28	1107	137	2	0.43	0.43	14.1	689.9	36.1	3.65	385.5	304.5	7.52	1.05
2023-05-28	1122	River	2	NA	NA	14.8	689.6	90.4	9.16	253	203.5	8.4	12.59
2023-05-28	1148	38	2	1.18	0.77	15.3	689.4	96.4	9.66	251.1	204.6	8.49	7.2
2023-05-28	1231	71	2	1.41	1.41	18.8	689	103.7	9.64	227.6	200.7	8.43	2.33
2023-05-28	1443	64	2	1.38	1.07	17.2	688	105.8	10.19	252.6	215.3	8.68	7.03
2023-05-28	1511	32	2	1.22	1.01	18	687.6	100.7	9.56	248	214.9	8.42	5.33
2023-05-28	1540	63	2	1.5	1.5	20.6	687.4	106.7	9.57	118.8	109	8.31	0.4
2023-05-29	1050	126	2	0.32	0.32	17.4	688.1	26.3	2.43	252.3	215.8	7.5	0.99
2023-05-29	1126	127	2	0.31	0.31	18.4	687.9	48.6	4.52	338.6	295.7	7.33	0.58
2023-05-29	1148	128	2	0.48	0.48	18.7	687.8	49.2	4.56	278.6	245.2	7.7	1
2023-05-29	1250	River	2	NA	NA	15	687.5	90.9	9.16	243	196.7	8.35	17.55
2023-05-29	1335	68	2	1.42	0.76	16.2	687.5	90.8	8.92	246.4	204.8	8.37	5.58

2023-05-29	1441	59	2	1.36	1.03	21	686.9	92.7	8.25	162.3	150	8.2	2.92
2023-05-30		35	2	1.93	1.93	21.5	686.1	120.1	10.59	783	731	8.53	0.32
2023-05-30		36	2	1.21	1.1	17.7	685.8	121.2	11.51	236.8	204.9	8.82	8.95
2023-05-30		49	2	1.2	1.2	21.6	684.9	88.2	7.75	466.9	436.9	8.04	0.56
2023-05-31	1050	31	2	0.5	0.5	18.8	688	104.6	9.57	306.9	270.1	8.43	1.5
2023-05-31	1158	145	2	0.78	0.78	18	687.9	77.2	7.3	206.6	179.1	8.03	3.53
2023-05-31		144	2	0.99	0.99	18.5	687.9	74.2	6.95	205.4	179.3	7.84	1.65
2023-05-31		129	2	0.88	0.88	19.4	687.3	101.9	9.3	298.9	268.1	8.16	0.86
2023-05-31		130	2	1.35	1.35	18.9	687.3	85.1	7.9	232.2	204.6	8.16	3.18
2023-10-16	1329	68	3	0.14	0.14	14.1	691.8	196.5	11.05	365	287.6	8.63	5.09
2023-10-16	1411	32	3	0.39	0.39	13.3	691.3	102.6	10.76	310.1	240.8	8.76	11.89
2023-10-16		River	3	0.28	0.28	10.1	691	90.6	10.2	321.4	230.1	8.69	2.77
2023-10-16	1439	63	3	0.51	0.51	13.9	690.7	94.5	9.76	180.7	142.3	8.8	4.7
2023-10-16	1546	31	3	0.61	0.61	15.3	689.8	105.1	105.1	494.8	403.4	8.65	5.94
2023-10-16	1652	59	3	0	0	ND	ND	ND	ND	ND	ND	ND	ND
2023-10-16	1711	110	3	0	0	ND	ND	ND	ND	ND	ND	ND	ND
2023-10-16	1630	30	3	0.25	0.25	14.8	698.7	133.1	15.53	236.7	190.8	9.87	1.56
2023-10-18	1437	69	3	0.32	0.32	11.4	695.3	61.1	6.5	301.9	223.1	8.37	2
2023-10-18	1537	62	3	0.4	0.4	11.6	695.1	89.7	9.7	736	549	8.49	3.58
2023-10-18	1600	36	3	0.16	0.16	11.5	695	95.4	10.38	559	414.5	8.7	1.51
2023-10-18	1700	35	3	0.31	0.31	11.6	695.1	111.9	12.19	1018	756	9.18	1.07
2023-10-19	1039	70	3	0.16	0.16	9.5	693.6	71.7	8.04	418.8	294.4	8.64	30.5
2023-10-19	1114	39	3	0.53	0.53	9.8	693.7	66.4	7.38	499.3	355	8.39	3.2
2023-10-19	1208	137	3	0	0	ND	ND	ND	ND	ND	ND	ND	ND
2023-10-19	1240	38	3	0.18	0.18	11.8	693.8	93.7	10.19	349.5	261	8.98	0.74
2023-10-19	1400	126	3	0.28	0.28	9.6	692.3	33.4	3.73	347.8	245.3	7.24	6.2
2023-10-19	1510	127	3	0.15	0.15	12.6	692.4	84.2	8.98	440	335.5	8.23	8.4
2023-10-19	1550	71	3	0.44	0.44	12	691.7	90.6	9.76	277.4	208.6	8.57	1.42
2023-10-17	1001	64	3	0.14	0.14	9.9	692.9	78.8	8.8	320.9	228.9	8.82	2.59
2023-10-17	1102	141	3	0.26	0.26	11.1	693.2	82.3	9.05	686	504	8.51	1.76
2023-10-17	1140	142	3	0.23	0.23	10.3	698.8	51	5.71	576	413.9	8.15	ND
2023-10-17	1200	24	3	0.03	0.03	13.7	694	147.9	15.3	722	567	9.11	ND
2023-10-17	1223	21	3	0.46	0.46	12.1	694.1	120	12.88	389.2	293.5	9.05	0.78
2023-10-17	1253	143	3	0.89	0.89	11.1	694.1	66.7	7.33	575	422.6	8.48	1.48

2023-10-17	1338	129	3	0.15	0.15	11.9	694.5	128.7	14.09	387.8	290.7	8.6	9.71
2023-10-17	1354	130	3	0.03	ND	ND	ND	ND	ND	ND	ND	ND	ND
2023-10-17	1450	144	3	0.16	0.16	12.5	694.8	72.8	7.65	1066	811	8.49	ND
2023-10-17	1450	145	3	0.14	0.14	15.2	694.8	ND	ND	875	711	9.67	ND
2023-10-17	1538	131	3	0.96	0.96	11.7	694.6	80.2	8.7	501	373.6	8.34	1.45
2023-10-17	1607	132	3	0.44	0.44	11.9	694.9	123.7	13.33	384.3	288.5	8.75	16.32
2023-10-17	1650	29	3	0	0	ND	ND	ND	ND	ND	ND	ND	ND
2023-10-17	1711	140	3	0.2	0.2	13.2	695.6	115.8	12.18	688	536	8.64	2.11
2023-10-18	1031	49	3	0.91	0.91	11	694.9	77	8.47	521	381.9	8.39	1.13
2023-10-18	1200	47	3	0.27	0.27	10.7	695.6	53.3	5.9	395.3	287.2	8.27	0.23
2023-10-18	1348	43	3	0.58	0.58	10.8	695.3	97.3	10.79	364.7	265.5	8.81	3.05
2023-10-18	1207	48	3	0.4	0.4	10	695.5	57.5	6.47	396.3	282.9	8.26	4.45
2023-05-02	0951	64	1	0.33	0.33	17	ND	ND	ND	533	451.7	ND	1.13
2023-05-02	1155	68	1	0.06	0.06	20.9	ND	ND	ND	623	574	ND	1.07
2023-05-02	1250	63	1	0.47	0.47	19.5	ND	ND	ND	142	127.4	ND	1.22
2023-05-02	1505	30	1	0.25	0.25	29.5	ND	ND	ND	368.8	405.8	ND	12.98
2023-05-02	1535	69	1	0.65	0.65	18.6	ND	ND	ND	290.6	254.4	ND	0.73
2023-05-03	1000	70	1	0.16	0.16	17.4	ND	ND	ND	423.5	361.4	ND	1.54
2023-05-03	1049	39	1	0.43	0.43	19.2	ND	ND	ND	361.6	322.2	ND	1.35
2023-05-03	1115	River	1	ND	ND	11.1	ND	ND	ND	256.7	188.6	ND	48.62
2023-05-03	1200	137	1	0.4	0.4	15.6	ND	ND	ND	126	103.3	ND	0.58
2023-05-03	1237	38	1	0.61	0.61	20.7	ND	ND	ND	495.7	455.4	ND	2.25
2023-05-03	1350	71	1	0.33	0.33	26.5	ND	ND	ND	272.6	279.1	ND	2.6

7.10 Appendix 10: Submerged Aquatic Vegetation survey data

See attached excel file

7.11 Appendix 11: Incidental bird observation data

See attached excel file

7.12 Appendix 12: Spring 2022 and 2023 migratory waterbird survey data

See attached excel file

7.13 Appendix 13: List of observed Species at Risk birds

Scientific Name	English Name	Biogeoclimatic Units	Provincial	BC List	Global	COSEWIC	SARA
Botaurus lentiginosus	American Bittern	BG; BWBS; CDF; CWH; ICH; IDF; MS; PP; SBPS; SBS	S3B,SNRN (2015)	Blue	G5 (2016)		
Hirundo rustica	Barn Swallow	BAFA; BG; BWBS; CDF; CWH; ESSF; ICH; IDF; IMA; MH; MS; PP; SBPS; SBS; SWB	S4B (2022)	Yellow	G5 (2016)	SC	1-T (2017)
Cypseloides niger	Black Swift	BAFA; BG; CDF; CMA; CWH; ESSF; ICH; IDF; IMA; MH; MS; PP; SBPS; SBS; SWB	S2S4B (2022)	Blue	G4 (2016)	E	1-E (2019)
Larus californicus	California Gull	BG; BWBS; CDF; CWH; ICH; IDF; MS; PP; SBS	S1B,SNRN (2022)	Red	G5 (2016)		
Chordeiles minor	Common Nighthawk	BG; BWBS; CDF; CWH; ESSF; ICH; IDF; MH; MS; PP; SBPS; SBS; SWB	S3S5B (2022)	Blue	G5 (2016)	SC	1-SC (2023)
Nannopterum auritum	Double-crested Cormorant	BWBS; CDF; CWH; ICH; IDF; PP; SBPS; SBS	S3S4 (2015)	Blue	G5 (2016)	NAR	
Podiceps nigricollis	Eared Grebe	BAFA; BG; BWBS; CMA; CWH; ESSF; ICH; IDF; IMA; MH; MS; PP; SBPS; SBS	S3B (2015)	Blue	G5 (2016)		
Chondestes grammacus	Lark Sparrow	BG; BWBS; CDF; CWH; ICH; IDF; MS; PP; SBPS; SBS	S2S4B (2022)	Blue	G5 (2016)		
Falco peregrinus	Peregrine Falcon	BG; BWBS; CDF; CWH; ESSF; ICH; IDF; MS; PP; SBS; SWB	S3 (2015)	No Status	G4 (2016)	SC	1-SC
Phalaropus lobatus	Red-necked Phalarope	BG; BWBS; CDF; CWH; ICH; IDF; MS; PP; SBPS; SBS; SWB	S3B,SNRM (2023)	Blue	G4G5 (2016)	SC	1-SC (2019)
Buteo lagopus	Rough-legged Hawk	BAFA; BG; BWBS; CDF; CWH; ESSF; ICH; IDF; IMA; MS; PP; SBPS; SBS; SWB	S3N (2015)	Blue	G5 (2016)	NAR	
Cygnus columbianus	Tundra Swan		S3N (2015)	Blue	G5 (2016)		
Aechmophorus occidentalis	Western Grebe	BG; BWBS; CDF; CWH; ICH; IDF; MS; PP; SBPS; SBS	S1S2B,S2N (2023)	Red	G5 (2016)	SC	1-SC (2017)